European Commission

JRC SCIENCE AND POLICY REPORTS

Strategic Energy Technology Plan Study on Energy Education and Training in Europe

Assessment Reports of the Expert Working Groups

JRC Coordination: A.Georgakaki, U.von Estorff, S.D.Peteves,

2014

Report EUR 26725 EN

Joint Research Centre

European Commission
Joint Research Centre
Institute for Energy and Transport

Contact information
Aliki Georgakaki
Address: Joint Research Centre, Westerduinweg 3, 1755 LE, The Netherlands
E-mail: aliki.georgakaki@ec.europa.eu
Tel.: +31 224 565133

https://ec.europa.eu/jrc

JRC90300

EUR 26725 EN

ISBN 978-92-79-39145-3 (PDF)

ISSN 1831-9424 (online)

doi:10.2790/30422

Luxembourg: Publications Office of the European Union, 2014

Abstract

This document contains the collection of Assessment Reports from the Expert Working Groups of the Strategic Energy Technology Plan European Energy Education and Training Task Force. It provides background information supporting the findings and recommendations put forward in the Strategic Energy Technology (SET) Plan Roadmap on Education and Training, which addresses the human resource challenge for the energy research and innovation sector and constitutes an integral part of the SET Plan agenda. The findings put forward in the assessment reports are those of the experts involved in each working group, following a process of consultation on the current situation, ongoing activities in the education and training domain, needs and gaps and recommendations for specific actions regarding their respective technology field.

Strategic Energy Technology (SET) Plan
Initiative on Education and Training

Assessment Reports from the Expert Working Groups

Introductory note

This document contains the collection of Assessment Reports developed in 2012/2013 by the Expert Working Groups of the Strategic Energy Technology Plan European Energy Education and Training Task Force. It provides background information supporting the findings and recommendations put forward in the Strategic Energy Technology (SET) Plan Roadmap on Education and Training.

The assessments cover key low-carbon energy fields:

- bioenergy
- carbon capture and storage
- concentrated solar power
- electricity grids
- energy efficient buildings, thermal energy networks and smart cities integration aspects
- energy storage
- fuel cells and hydrogen
- geothermal energy
- nuclear energy
- photovoltaics
- wind and ocean energy

as well as some horizontal aspects:

- coordination of education and training systems
- system integration

The findings presented and recommendations put forward in the assessment reports are those of the experts involved in each working group. The working groups may differ in the process they have used to consult, reach consensus and compile the reports presented in this assessment.

Outline of the Assessment Reports

Each technology assessment report is organised along four main sections :

1. Current situation

This section describes the state of play today within the energy technology field covered. It includes key information about the market and its players, including also total employment figures. It gives a forecast for the market growth rate and the net increase in employment up to 2020/2030. The technology's value chains are described in terms of current workforces' profiles and core occupations. When it is adequate, the labour intensity in terms of jobs/MW is used as a reference. Finally, the workforces' profiles (researchers, engineers, technicians) required to achieve the SET Plan vision for the respective technology field are described, including both the type of positions needed and the scale of the required workforce.

2. Ongoing actions

This section lists the main ongoing activities at EU and Member State level relevant for the respective technology field in relation to undergraduate, graduate, post-graduate education, lifelong training, reconversion schemes, professional training, including also relevant major actions at international level.

3. Needs and gaps

The Needs and Gaps section describes the main barriers or bottlenecks in terms of workforce profiles that hinder the achievement of the technology goals within the SET Plan vision.

At academic and vocational training institution level, it covers key information such as curriculum capacities, faculty needs, research (laboratory) infrastructure, and interest of students/professionals in particular educational fields.

At industry/company level, it addresses, among others, missing knowledge, skills and competences for the industry and their customer services, difficulty in reconverting existing skills, need for experienced workers versus training time, difficulty in building programmes and bridges between industry/research centres and universities.

4. Recommendations at EU and Member State level

This last section outlines recommendations for key actions at EU and Member State level in relation to education and training schemes, required platforms and networks.

The actions proposed aim to depart from Business as Usual and have a key impact. They aim to address the needs and gaps outlined in the previous section.

The names of the authors and contributors are listed on the first page of each assessment. Coming from academia, the research community and industry, the authors represent major European organisations in the field of energy education and training[1], and field experts coming from the SET Plan European Industrial Initiatives and other relevant European industry groupings. We are grateful for their work and contribution to the initiative.

European Commission staff - Project coordination:

Miroslava NANEVA (RTD), Caroline THEVENOT (RTD)
Aliki GEORGAKAKI (JRC), Efstathios PETEVES (JRC)

[1] The European Platform of Universities engaged in Energy research, education and training (EPUE), European University Association; the SET Plan European Energy Research Alliance (EERA); KIC InnoEnergy, European Institute of Innovation & Technology; the European Strategic Partnership for Sustainable Energy Education, Innovation and Technology (SEEIT); the European Sustainable Energy Innovation Alliance (eseia); the European Strategy Forum on Research Infrastructures (ESFRI).

Table of Contents

Assessment Report on Horizontal issues: Coordination of Education and Training Systems

Horizontal issues: Coordination of Education and Training Systems

Working Group Contributors

Maarten J.	Arentsen
Hester	Bijl
Lidia	Borrell-Damian
Torbjørn	Digernes
Torsten	Fransson (Co-Rapporteur)
Vaclav	Havlicek
Peter D.	Lund (Co-Rapporteur)
Paola	Mazzucchelli
Kirsti	Miettinen
Juan	Pascual Martínez Pastor
Merete	Reuss
Ulrik	von Estorff

Executive Summary

Meeting Europe's future goals in energy and climate policy requires a skilled and adequate work-force. New competences, sufficient specialization, multi-disciplinary thinking, among others are key factors to be developed in the coming years within the SET-Plan of the EU. In this report, we address issues of common nature and interest in education and training in all sustainable energy technology fields. These so-called horizontal factors do not focus on the needs of a specific technology but relate to the challenges and improvements needed in the educational systems and processes as a whole to support the SET-Plan targets through education and training. Areas of interest in this context are for example transfer of research knowledge into education, dissemination of state-of-the art education widely in EU, the "knowledge triangle", coordination issues, mobilizing of capacities, and, accreditation, quality assurance and harmonization of educational systems. The report mainly deals with higher education and professional development and only to some extent with vocational training.

The recommendations are ample and backed up with background analyses and tacit knowledge of the working group. We recommend among others to develop world's first a fully on-line Masters programme in sustainable energy; to establish a working group on accreditation and quality assurance in energy education; to support monitoring and mapping of educational activities and needs; to foster dialogue among key stakeholders in education and training on different levels to share best practices and future plans, jointly develop energy curricula, improve university-business cooperation, and to enhance student mobility.

Financial support will be necessary to make these recommendations operational. We firmly believe that such an investment would well pay off. Through well-functioning horizontal processes and systems in place, positive impacts from vertical technology-specific efforts in education and training can then be expected.

Introduction

Europe must pave the way towards an independent and sustainable energy system enabling a climate-neutral world by 2050 achieved by successful commercialization of innovations, i.e. new products, services and business ideas. The European educational, research and innovation systems must work together and aspire to develop ideas and people, and to warrant a new industrial wave based on energy technologies and services in Europe and to become the global leader in sustainable energy innovation. Efforts in the fields of energy production, energy transport and energy usage must be coordinated and aligned. Such coordination has started to take place (for example through the InnoEnergy[1], EPUE[2], EERA[3]), but need to be strengthened in particular in the higher education sector where energy education and training schemes in Europe are very fragmented.

The EU's Strategic Energy Technology plan (SET-Plan) is the major pathway for Europe to reach these goals. As such the SET-Plan must not only comprise research and industrial implementations, but needs to include education and business creation as essential elements. To achieve the ambitious goals of the SET-Plan, the paradigm shift mentioned above must take place in all stakeholders (including educators, researchers, general public, industrialists, business creators and politicians). As such there will be a massive need for new talents and upgrade of the existing competencies in society, to create the so much needed change agents. At the moment, the lack of qualified and skilled human resources is actually one of the major obstacles that hinder the development of a sustainable energy system

The link between European research and education institutions and the business world (public private linkages) need to be further strengthened. Although higher education institutions are often integrated in existing EU alliances between research institutions and the business world, the full potential of such collaborations has not yet materialized and the relationships need to be improved to foster innovation. Interaction between technical progress, and the social and human reaction and acceptances is needed, together with an awareness of changed social behaviour. A higher degree of integration of the actors from higher education, research and industry (forming the knowledge triangle) as well as new and output-oriented organization mechanisms are needed.

The growing population, urbanization into mega-cities, and the urgency of climate change make energy to one of the grand challenges. This challenge incorporates, among others, (1) global recruiting of the best young talent for careers in the energy sector, (2) fast building significantly increased education and research capacity to meet this demand, (3) the creation of educational material based on the latest knowledge available in Europe and easily accessed (e.g. through world-wide web), (4) integration of the cutting edge knowledge triangle in sufficient large number of places in Europe, (5) multi-disciplinary and cross-border collaboration in the knowledge triangle. In this framework there will also be (6) a significant need for a paradigm shift towards cross national accreditation of universities, programs and courses all over Europe.

---

[1] EIT KIC InnoEnergy

[2] EUA-EPUE: European University Association – European Platform of Universities engaged in Energy research, education and training

[3] European Energy Research Alliance

This report presents the outcome of the Working Group of the Horizontal Field - Coordination of Education and Training Systems with the SET-Plan Education and Training Initiative. The focus is on Coordination related issues and not on technology-specific questions which are dealt with in the vertical working groups. Due to the short time frame available, the contents have been based on the WG's existing knowledge base and it was not possible to undertake neither major in-depth reviews nor profound analysis. Also, the main focus has been on higher education and to some extent to vocational training.

Objective of the SET Plan Energy Education and Training effort and related considerations

The objective of the education and training effort must be to produce a basis from which the main stakeholders can plan and prepare for education and training for the future energy markets, directly or indirectly. These stakeholders include: i) education institutions; ii) research institutions; iii) governmental bodies; iv) industry; v) young people seeking education; vi) current professionals seeking further education.

We are facing 30-40 years development of the energy systems in constant transformation, and the education concept must be adaptable in a timeframe of this duration. With rapidly evolving technologies and the related changes in the labour markets, professionals may require frequent knowledge update. Knowledge must be disseminated both through continuing education of the existing workforce, and from the initial stages of educational programmes for young generations in higher education institutions. Thus, to reach widely across Europe, this knowledge must be made available in a large number of educational programmes, easily running into 3-digit numbers, as well as through many continuing education channels.

A sufficiently large vocational workforce is also required. The need for specialisation based on recent research based knowledge is, however, considered less important here than in higher education. All the same, attracting the needed volume of manpower trained to an adequate level must be considered a challenge, and without it, production activities cannot take place in Europe.

Therefore the following horizontal factors should be considered when designing the education and training concept for the SET-Plan:

1. Competence base required

The competence profiles required for working with low carbon energy technologies come from a wide range of basic education profiles, in areas ranging from across all engineering disciplines to basic science disciplines, which are needed early on to create the basis for enabling technologies. In addition to technical subjects, significant capacity is required to work on the societal and economic aspects to achieve the objectives of the SET-Plan. Such basic knowledge and competence profiles must be "topped off" by specialised education on energy applications based on the latest research generated knowledge. This may be a relatively small, but important, part of the curriculum of each competence profile.

2. Recruitment of people by the industrial labour market

The labour market already experiences bottlenecks in the recruitment of young people into science and engineering professions. Europe has a grave disadvantage compared to the expanding BRIC economies, which educate growing numbers of people with competencies in these fields. Europe may attract people from these countries for education and employment, but hardly in numbers required to run our societies. To maximise Europe's competitiveness based on indigenous workforce, we need to search widely across Europe to attract the maximum of available motivated talent, making sure that this talent is utilised to its fullest potential, and being educated with relevant profiles. The solution should not be outsourcing to other economies to remain in business, thus leading to fewer jobs created in Europe.

3. Young candidates as agents of change

There is adequate evidence that the most efficient way to spearhead industrialisation of new knowledge is through educating candidates integrated with research and industrial innovation processes - i.e. embedded in the knowledge triangle. This is particularly important for the Master and Doctorate level. The candidates will then gain a deep insight in a new subject, and will be able to act as forceful change agents, both in the industry and society. They will be the most effective workforce that companies can recruit to deploy new technologies quickly.

Implications

Putting a lot of effort into long term forecasting of technical skill requirements and timing several decades ahead is not worthwhile, since such forecasts will not be precise enough for the stakeholders to take significant decisions, particularly for young people seeking education with good employment prospects in the labour market. The industry sector and public bodies are generating deployment forecasts for a range of low carbon energy technologies. There are several inherent weaknesses in such forecasts. Most of the technologies are immature and not commercially viable without subsidies at this point. It is clear that large scale deployment will happen only when they reach that maturity. In several cases that is uncertain.

The need for education and training in the dynamic situation that we will be facing at technology level can only be accomplished through an educational system that is able to respond flexibly to the market development. Thus the design of such a Europe wide educational system should be the foremost guideline for planning the SET-Plan Energy Education and Training contents.

General guiding principles recommended for the SET-Plan:

A) Addressing societal challenges through multidisciplinary and cross border collaboration. The ability to rapidly teach new knowledge generated through research into the existing workforce and into the curricula of a large number of education programmes across Europe. Therefore, cross border accreditation issues must be solved. For example, creating cross-border research schools could be one of the mechanisms to facilitate high quality doctorate education.

B) Leveraging public investment. All significant publicly funded research efforts should have an impact on educational syllabus and materials. An instrument/mechanism to generate Open Educational Resources from the research outputs should be created for specialization subjects on top of basic competence profiles. The subjects should include the knowledge required to effectively implement research results in industry and in society. When the research is basic science, the curriculum should be oriented to next step in the value chain of R&D leading to innovation based on the new knowledge. This work is best done by educational partners in the research projects.

C) Linking education to research. All significant research efforts integrate education of candidates at the master and Doctorate level, and industrial innovation actors. This is to enable the candidates to act as first tier disseminators and innovators in industry and society, applying new research based knowledge. Education institutions involved in the research will have a special responsibility to take initiative to develop and adapt curricula, subject courses, and to potentially establish programmes to disseminate the knowledge. Wide cross border cooperation should allow for good horizontal dissemination. Open and distant learning should be applied when deemed appropriate. Due consideration should be made to timing of the injection of the knowledge into the market.

D) Immediate implementation of education initiatives**.** For thematic areas where significant societal deployment of technology is expected within the next ten years, efforts should be initiated to develop short/medium term skill requirement forecasts, curricula and dissemination planning.

E) Doctorate education**.** Since most of the fields in question require significant R&D effort in the coming years, the need for researcher training in key scientific fields for energy related research should be assessed and acted upon.

Specific Recommendations

To achieve the goals of the SET-Plan through training and education, it is recommended that the SET-Plan incorporates as a minimum the following educational elements and actions as part of its consideration on horizontal coordination related activities:

1. *Launching of a three-year pilot-project towards establishing of the world's first fully on-line open source Master's program in sustainable energy* with engineering, financial, social, entrepreneurial and humanitarian content, by direct coupling with introduction of latest relevant research results from all the pilot project partner institutions into the program. (1 year preparation, 2 years running the first intake of students, tuition-free for the first two cohorts). The MSc program will cover a few different options. This pilot project is intended to show the European leadership related to higher education in the renewable energy sector, to be a show-case for universities, and is intended to lead to larger engagement of such initiatives;
2. *Establish a pilot action on accreditation and quality assurance of energy education.* Provide support through this pilot action to develop accreditation and certification structures in the member states in cooperation with national accreditation bodies to make high level cooperation amongst educational institutions possible. Provide support to establish structures which accelerate a communication (including regular organisations of workshops and seminars) process between universities to exchange and to plan for harmonized curricula;
3. *Start a pilot action to monitor:* (i) skills needed from the energy industry-side; (ii) new/ongoing research results in the energy field; (iii) educational programmes offered by universities in the energy area; as a separate effort *undertake a survey (similar to the EUA/EPUE for European Universities) on professional development activities* and establish a EU-wide expert database of researchers and top professional experts;

4. *Create a pilot action for updating/expanding/creating energy curricula*, also aiming at attracting students to a career in the energy sector. This action need to involve relevant European stakeholders both from the industrial and educational side; a sub-group on developing *professional (certified) programmes for energy business professionals and managers* is also recommended, to include professional organizations, industry and business employers and universities;
5. *Initiate a pilot action to establish a structured dialogue between the existing EU technology platforms and EU thematic university platforms* and other university initiatives to enhance university-business cooperation; this should also include support for sharing the best practices among knowledge institutes on curriculum design of sustainable energy. This could form a sort of clusters of excellence;
6. *Start a pilot-action to form a European-wide open and overarching platform for higher education* Masters and Doctoral programmes. As part of this pilot action establish a bi-annual high-level dialogue forum of major European networks to exchange information of on-going and planned activities in education and training in energy, to coordinate such efforts, to advice on necessary measures on European level to meet SET-Plan Education and Training goals. Provide more support for the mobility of master and Doctorate students across the countries. Create EU-wide programmes e.g.an 'Erasmus-Mundus'-type of joint-educational (MSc, Doctorate) programmes either within the existing EM-scheme or within the SET-Plan;
7. *Support a pilot action or study to apply an ECVET-type of a scheme for vocational education and training in sustainable energy* fields outgoing from experiences in the nuclear field. A few 2-3 year pilot projects in selected sustainable energy technology fields should be set up to establish, test and modify the model concept;

Nomenclature/Abbreviations

EUA- EPUE	European University Association – European Platform of Universities engaged in Energy research, education and training
EIT KIC	InnoEnergy
EERA	European Energy Research Arena
SEEIT	European Strategic Partnership for Sustainable Energy Education, Innovation and technology
EUREC	European Renewable Energy Research Centres Agency
CLUSTER	Universities Erasmus-Mundus
CE	Continuing Education
ECTS	European Credit Transfer System
ECVET	European Credit System for Vocational Education and Training
IEE	Intelligent Energy Europe (EU Programme)
EQF	European Qualifications Framework
NQF	National Qualifications Framework
RES	Renewable Energy Systems

1. Current situation – existing workforces (value chain), labour-intensity, future trends, and workforces required to achieve the SET-Plan vision

The challenge of training a growing and skilled workforce for energy sector

In order to ensure the appropriate training of a growing and skilled workforce for the energy sector[4], higher education organizations, universities and other training institutions are currently faced with two major challenges:

- To develop *adequate capacity* in terms of both manpower, and infrastructures. An increasing number of students studying successfully have to be supported by growing numbers of: programme planners; professorships and doctorates; research and educational laboratories; technicians; programme managers and secretaries;
- To integrate *new competences* in their educational programmes to respond to the emerging needs from the energy sector. An energy engineer of the future should be able to function in a multidisciplinary setting of the modern energy system and to be able to respond to new design and performance standards articulated by the societal and political agenda. At the same time the modern engineer should be able to function in a high tech environment with different advanced technologies requiring in-depth technological knowledge and skills. The modern energy system, therefore, is confronting the energy engineer of the future through a two dimensional knowledge space: one requiring specialized in-depth advanced technological knowledge and one requiring widening of focus beyond technology sector. As a result, there is a need for different types of technological programs, which combine pure science and technology with socio-economic knowledge and skills in the curriculum.

An in-depth analysis of the present status and future developments of the educational workforce for the energy sector is currently missing, in particular on the capacity and competence issues mentioned above. Appropriate resources at the EU level should be made available to ensure that such an analysis is carried out and linked to the SET-Plan energy education and training.

This chapter will briefly explore what are the needs in terms of capacity and competences development in general by educational institutions in order to face the challenge of training a growing and skilled workforce for the energy sector.

Capacity needs in terms of manpower and infrastructures

According to a survey recently carried out by the European University Association EUA[5] (February 2012), which involved a sample of 165 universities from 29 European countries, almost 21,000 persons are currently employed in research activities for the energy sector, including doctoral candidates. Concerning Master's education, these universities offer over 900 masters in the field of

[4] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2011:0031:FIN:EN:PDF

[5] "Presentation of the main results of the EPUE survey on the research and education capacity of European universities": http://www.eua.be/events/past/2012/epue-inaugural-event/presentations.aspx

energy6. A more complete survey that would involve the whole higher education sector in Europe would lead to much higher figures, and would also yield most probably a very fragmented picture of the landscape of energy education in Europe, as it is already apparent in the available data today.

Given the projected growing demand of workforce needed in the sustainable energy sector the number of both experienced staff, and high-quality infrastructures need to increase along improved coordination of resources and activities across the Europe. We foresee growing needs in particular in the following areas:

- *Number of professorships and doctorates*. Development of an adequate number of highly skilled teaching personnel for lectures, laboratories and seminars. Emphasis needs to be put on tutoring, mentoring and examination capacities to educate the rising number of students (e.g. considering research based oriented learning, international environment, intercultural diversity);
- *Number of programme planners*: The planning for new programmes is a process which typically involves personnel and creates costs of up to several €100,000 before launching the actual programme. The process takes several years from idea-launch to the first cohort of students graduating. This encompasses direct planning and coordination of involved partners, market analysis, accreditation process as well as development of a financial plan and curriculum development;
- *Number of Technicians*: The universities must be enabled to guarantee establishing operation and maintenance staff in a medium term perspective, in particular for laboratories and infrastructure necessary for high-level education and teaching;
- *Programme managers and secretariat:* In order to run international programmes and to establish new programmes as well as to foster international university cooperation management and support staff will be necessary;
- *Availability of high-quality educational training infrastructure*: Universities must be enabled to offer adequate number of seminar rooms, lab facilities, state-of the art technical equipment, library (divers media and licences) and other infrastructural equipment (e.g. IT service), an adaptable number of students working places and consequently master thesis working places;
- *Number of high-quality research laboratories*: The infrastructural development of state-of-the-art research laboratories is a pre-condition to run additional study programmes successfully.

Knowledge and expertise to face the future energy challenges of Europe

An increasing number of European universities offer Masters programs in the sustainable energy field. Some universities also offer Bachelor level and Vocational Training programs. At the Master level, the science and technology training is quite often added by transversal key competences. The focus of these transversal competences varies from general technological orientations to communication and social skills and competencies. The rationale of offering students additional transversal knowledge and skills is to prepare them better for the profession, which not only requires excellent disciplinary science/engineering knowledge and skills, but also a good adaptation

[6] "Presentation of the main results of the EPUE survey on the research and education capacity of European universities": http://www.eua.be/events/past/2012/epue-inaugural-event/presentations.aspx

to the international and complex environment of the energy industry. This combination of excellent science and technology training with vocational competences turns out to be very productive approach and should be continued in the SET-Plan education activities.

European universities often offer research oriented Doctorate programs to talented graduates. The Doctorate programs are highly specialized. This needs to be the case to develop further cutting edge knowledge in energy for Europe. It is important to continue such in-depth disciplinary research oriented Doctorate programs all across Europe, since they are crucial for the future energy knowledge base of Europe. Without cutting edge science/technology research, Europe will not be able to meet the SET-Plan goals.

Europe requires also an economically viable energy industry. One can identify knowledge and expertise needs across the energy production chain in Europe. Industry requires state of the art knowledge and expertise in conversion technologies in the whole range of energy resources, in handling and integration of new (renewable) energy resources, in logistics and transmission technologies and in smart energy management systems, among others. From the science and technology perspective, the knowledge requirements will become more and more specialized whereas the diversity of themes and aspects will increase. Industry therefore will need more specialized engineers to be able to respond to the frame conditions all over production chains.

But excellence in technological performance is not anymore the only parameter that the energy industry in Europe has to commit to. Companies should be financially viable, excellent in commerce and trading, able to communicate adequately with the outside world and with a legally legitimated license to operate. This requires an industrial engineer to be able to work in multidisciplinary settings together with professionals in trade and commerce, communication and law.

Europe's energy challenge of a sustainable, affordable and a secure energy supply also requires specific knowledge and expertise. Facing these challenges will need strategic planning, the organization and management of stakeholder engagement, political and societal engagement. The challenges will require high quality multidisciplinary knowledge.

Facing the Challenge

To keep educational institutions updated of the needs of a skilled workforce in energy sector, present and future educational workforce need to be firstly mapped in detail. Strategies for re-training and upgrading the teachers should also be pursued. Professional management competences should be further developed in the universities and other training institutions requested to develop new and innovative educational programmes.

Responding to the European energy challenges requires adequately trained new generations of engineers and professionals. The wide range of knowledge and skills required can hardly be integrated in one professional profile only. A more clear division of knowledge and skills is needed in combination with a stronger notion on multidisciplinary collaboration. One way to go ahead is to offer special energy programs with different profiles in parallel. The existing highly specialized science and engineering programs should continue but could be complemented by other more mixed programs responding a more multidisciplinary knowledge need in the energy sector, such as socio-economics, entrepreneurship, policy making, and European/international dimension, among others. The energy education challenge is to provide the future European workforce with strong expertise in a specific energy field/technology as well as with the necessary flexibility to respond to a rapidly changing energy environment. Mitigating these problems requires energy education and knowledge ranging from hard core science/technology to hard core social science/humanities. In this way energy educational programs could diversify and address different types of challenges in the energy scenery of the future. Diversification could also interest new student groups for enrolment in academic energy programs. For the benefit of the future energy supply we therefore recommend to develop several new energy programs with different knowledge and skills profiles.

2. Ongoing actions

The Higher Education Institutions (HEI) in Europe, and in particular the leading ones, are aware of the need for evolution of their educational programmes along the evolution of the labour markets. HEIs also strive for the update of their programmes with the most recent scientific and technological developments, especially in the more specialized Master and Doctorate degrees. The main mission of universities is to educate students that by earning a university degree can demonstrate good background knowledge of their field and a good capacity to learn quickly specific new knowledge required by their employers.

In the field of energy, a number of universities in Europe are already developing innovative Master and Doctorate programmes, frequently pooling resources from different universities and also involving businesses or other employers as core actors in their programmes. Many of these initiatives involve HEIs from different EU countries. Among many examples, we can mention the energy-related programmes from the KIC-InnoEnergy, SEEIT, EUREC, CLUSTER networks; or on a university level we find well-elaborated programmes e.g. at Delft University of Technology (part of a joint programme of 3 technical universities in the Netherlands), Lappeenranta University (Finland), Newcastle University (UK) and Technical University of Denmark (Denmark). The Erasmus Mundus programs are also good examples in this regard (the 5-years limit for sponsorship of these programs is too short and should be prolonged).

The European University Association (EUA), through its recently created European Platform of Universities Engaged in Energy Research (EUA-EPUE) is conducting since 2009 a survey open to EUA members (more than 800 individual institutions in Europe) to identify Master programmes, Doctorate programmes and research capacity of the European universities in the field of energy. To date, the EPUE survey has been completed voluntarily by 165 universities from 29 countries. The survey is still on-going and its uniqueness lies in the facts that are the largest and the only one aiming at covering the entire university sector in Europe. Several of the universities in the networks mentioned earlier are also covered by this survey. As the EPUE data set has the broadest coverage as far as we know, we have drawn in the next so generic conclusions from this study.

The EPUE survey data[7] has shown that there is a substantial research capacity in energy in the university sector with up to 1500 groups consisting of 21,000 people, with a multitude of educational programmes at all three cycles of education, including 900 Master Programmes, in

[7] Main outcomes; presentation given at the EUA-EPUE Inaugural Event, 23 February 2012, Delft University of Technology: http://www.eua.be/Libraries/EPUE_Event/Plenary_2_EPUE_DELFT_v3_LBD-JS.sflb.ashx

many areas of energy-related matters, both included and not included in the current SET Plan technology priorities. Research and education programmes also show extensive cooperation with external partners, particularly research institutes and industry. For example, 28% of the Master Programmes involved at least another academic partner and 21% involved collaborations with non-academic partners.

Normally Science, Engineering, Technology and Biotechnology are the traditional fields through which universities organise the study of energy related matters, but results of the survey show the development of energy studies in other disciplinary fields (e.g. economics, social sciences) and an incipient set of interdisciplinary Master and Doctorate courses (e.g. urban planning, energy policy development). The degree of specialization of the Master Programmes was found to be very diverse, from those general programmes named "Master in Renewable Energies" or "Master in Sustainable Energies" to others very specific such as "Master in energy efficient buildings".

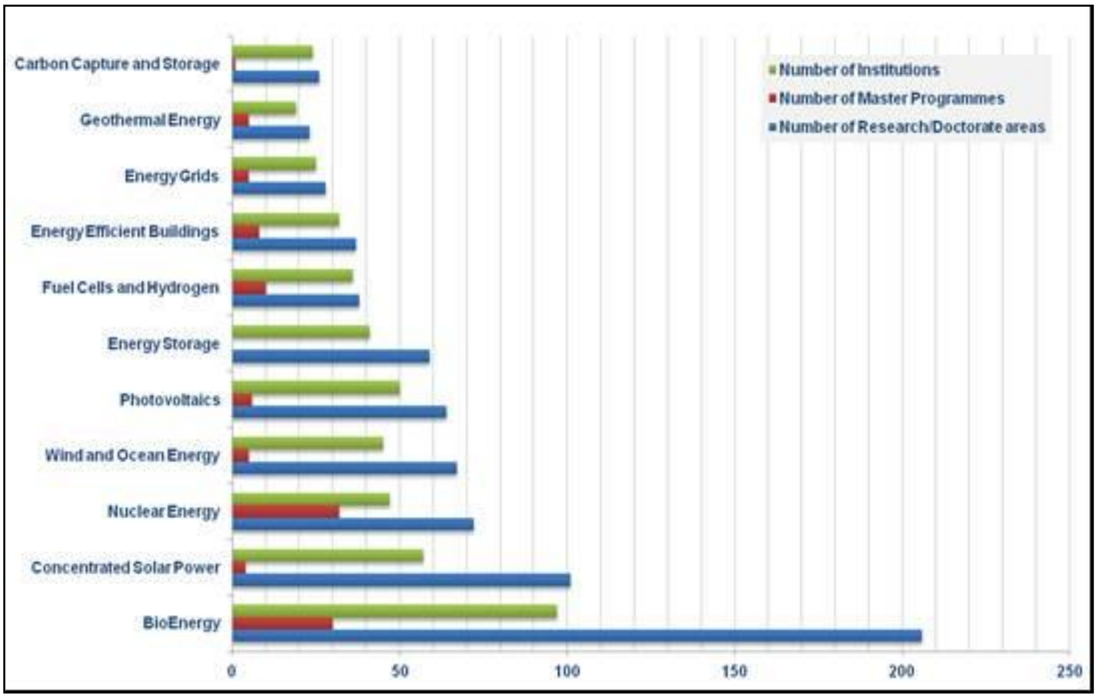


Figure 1. Number of i) institutions; ii) master programmes; iii) research/doctorate areas within each of the eleven SET-Plan Energy Research and Training Initiative vertical working groups. *Source: EUA - EPUE (February 2012 – 166 responses)*

Respondent universities provided their own titles of programmes and courses in the questionnaire responses. EUA extracted from them those that specifically made reference to the eleven technology areas prioritised in the SET Plan Education and Training Initiative. Fig. 1 shows the number of i) institutions; ii) master programmes; iii) research/doctorate areas within each of the eleven SET-Plan Energy Research and Training Initiative vertical working groups. A similar exercise could be done for other areas such as smart cities, smart grids and sustainable energy programs.

As a follow-up step, it would be most useful to continue mapping of on-going activities and in particular to update research capacity, research projects and education programmes in the universities. Aiming at broader coverage among European institutions would also be worthwhile in particular to support some other recommendations in this report. These would strongly support SET-Plan goals in education and in providing significant impacts from it.

Based on the survey of on-going activities in university Master and Doctorate and research, we can provide the following summarizing observations:

- There is well-documented coverage of education and research topics in all SET Plan technology priority areas within universities. A remaining open question is to what extent this provision is adequate, harmonized, and how will it satisfy the needs for the future. The reports of the eleven vertical working groups of this exercise will probably provide some indication on steps to follow in each energy technology field.
- There is large potential for developing cross-disciplinary research areas and courses at Doctorate and Master level. Several disciplines need to be involved here to address the societal challenge of energy. No clear concept for this is not available and need to be investigated further.
- There is an increasing involvement of businesses and other external partners in research and doctoral programmes. Many of those are individual businesses and research centres but regional clusters of companies and authorities are also involved. This indicates that there is a basis of collaboration that could be strengthened to better serve the objectives of the SET Plan Energy Education and Training Initiative in the frame of the so-called Knowledge Triangle.

Furthermore, the following recommendations can be put forward:

- Resources should be made available to ensure and facilitate coordination and information flow among higher education establishments and universities active in energy research and with other stakeholders of the SET-Plan. This could include organisation, management and follow up of meetings as well as setting up an internet based information system;
- Continued mapping of research and education capacities with respect to academic research and technical personnel, research projects, partnership with industry and Master and Doctorate programmes. An important additional element could be to seek for details on the extent and degree of interdisciplinary collaboration in research and education t, and how this could be improved and promoted;
- Development of clusters of excellence, based on areas of core competence of universities such as frontier research and education and training and design of common activities within these clusters;
- Develop structured dialogue between the existing EU technology platforms and EU thematic university platforms and other university initiatives to enhance university-business cooperation.

  This kind of dialogue could be extended to professional development and vocational training and education as well.

3. Needs and gaps, in particular main barriers or bottlenecks for the different sectors and their markets

The Working Group identified several horizontal-type of issues common to all technologies, which need to be addressed properly in order to meet the SET-Plan goals through educational efforts. These are listed in the following and described in detail below:

A. Transfer of latest generated knowledge into education;
B. Making available state-of-the-art education with latest knowledge widely in EU;
C. Integrating education, cutting edge research, and rich innovation environment;
D. Creating and coordinating EU wide education, training, doctoral programmes;
E. Mobilise the capacity of professional development agents (and universities) in Europe;
F. Accreditation and quality assurance of education and training;
G. Harmonization of educational systems.

A. Transfer of latest research generated knowledge into education

High-level education is not possible without integration of latest research outcomes into the educational programmes.

Present situation and best practices

Most of the contents in courses at undergraduate and Master levels are based on well-established knowledge. The research learning process is more important than research project findings in the case of undergraduate studies. Both types of knowledge are considered at Master and first year Doctorate levels, but this may not the case in all Universities and Research Centres. Interdisciplinary/ multidisciplinary approaches (needed for paradigm shifts) are often absent. Main barriers to the transfer are the following: lack of awareness, results not in the right format for education purposes, fragmented and lack of overall synthesis, and information overload.

Identification of needs and gaps

The lack of harmonization (different discipline backgrounds, different specializations and different geographical/country needs) may lead to critical knowledge gaps in certain fields. Latest Research/Technology advances are needed to shorten the pathways from problem definition to solutions and industry transfer (and hence commercialization). The latest research knowledge in a given scientific/technological field is crucial for the Doctorate formation at the top level across Europe (best students in cutting edge research groups, for example). Important solutions in the future will need of inputs to the problems from many points of view (interdisciplinary/multidisciplinary vision), especially critical in certain fields (smart grids and smart buildings and cities).

General recommendations

Transfer can be implemented in Doctorate and Master programmes, through the participation of appropriate researchers. Master and Doctorate programs can involve researchers identified as providing research advances in the different fields in their programs. External speakers from research and/or industry should be integrated parts of academic curricula through specific lectures (within a given Master/Doctorate program). Appropriate budget can be allocated in these programs (from different sources: university, national, EU).

In most EU research projects dissemination activities are programmed and developed (web pages of the project, technology/result assessment deliverables, press releases, specialized workshops and conference), but most of this material does not reach the wider society and especially the university community (students and professors). An effort should be done to compile these efforts and information in the Energy field and centralize it through different organizations (EPUE, EERA, KIC-Innoenergy, etc.) in order to identify main results achieved. This initiative is already carried out in some co-funded projects (for example in SOPHIA, a project related to Research Infrastructure for PV: http://www.eurec.be/en/Activities/Ongoing-Projects/SOPHIA/).

Press and Media are more and more interested to disseminate technology/science advances. An effort should be developed in the case of universities engaged in energy research and education (many universities have their own TV/radio/press media). It is important to transfer technology/science advances to undergraduate students (self-learning activities), as well as to vocational training, and hence as a motivation to choose future specialization (Postgraduate courses, Master and Doctorate).

Open-source-kind of tools may be powerful as well to disseminate research results into education and should be elaborated further.

B. Making available state-of-the-art education with latest knowledge widely in EU

The challenge here is knowledge management, in particular increasing the chance that new knowledge diffuses in the communities. Exploring the potential of new (social) communication media is of high importance. Not for sending around information, but for sending alerts guiding people to the new information. In general we should think of new unconventional mechanisms for the diffusion of new knowledge. A few examples include:

- The EU energy technology community could develop new layered interfaces for making new knowledge more easily accessible. The first layer of the interface displays the big news, with behind layers bringing the interested scholar to the academic information (written/image/video/animation);
- Another way of knowledge diffusion across Europe is making a lecture tour across Europe part of prestigious academic prices and awards. In this way excellent price and award winning scientists in energy can lecture to academic communities in different parts of the EU. This high prestige lecture tour might inspire the next generation price and award winners among the students in the audience of the lecturing laureates.

C. Integrating education, cutting edge research, and rich innovation environment

The complete integration of the knowledge triangle education, research and innovation is considered to be one of the keys towards creating, and re-launching, the innovation system in Europe. There is a need for a highly dedicated and skilled work-force in the energy area, a work-force with specialist knowledge but also with a capacity to change between energy fields. It is expected that this need will be more apparent over the coming decades as the different energy technologies progress in directions that today are difficult or impossible to predict. An in-depth analysis of the structure of the educational system in Europe in the field of energy is required to address this issue. This could be accomplished through e.g. EPUE and KIC-InnoEnergy which possess comprehensive know-how in these issues.

The European higher education system is very good in general. European graduates, as well as European researchers, are highly valued all over the world. The system would benefit, however, from more frequent and continuous syllabus updates and from more effective approaches to multidisciplinarity. It is widely recognized that the capacity of Graduates, Masters and Doctorates evolve along the needs of their employers to achieve the degree of specialization that their jobs require. This is due to the good and solid background knowledge that the students receive during their university education.

Importantly, knowledge and labour markets evolve presently at such a speed that it makes it virtually impossible to update constantly the educational programmes. A typical university Degree takes 3-4 years to achieve while new technological developments are being implemented every day in the more innovative business sectors, particularly in the field of energy. Therefore, there is a significant need for a much higher degree of innovation and creativity in the educational system. Many energy technologies could today be significantly more effective if there would be a public acceptance and a social awareness of the energy use. The energy market is a very complex interaction between many stakeholders, and involves both investments related to private persons on a small scale (for example windows in a building) up to very large internationally coupled systems. The word “subsidies” is continuously mentioned related to renewable energy technologies, whereas it is always forgotten that in principle all fossil fuels are subsidies as they do not bear their full cost towards environmental effects. There is thus a need for several special energy programs in which technology is mixed with various combinations of market analyses, social and public awareness. Special needs are also directly related to the innovation and entrepreneurship of the energy concept. A new kind of entrepreneurs, using the modern social media, needs to be educated and given the support to realize the ideas. Europe can, within the SET-Plan be the forerunner on this.

The research output needs to be significantly more coupled to education. Research results are often published in research journals and do eventually make their way into the higher education at the institution where the research was performed. But this process must be made much more efficient, and the “not invented here” syndrome must be reduced in higher education. Research results need to be disseminated into education at many different universities directly as they are made available. To enable this researchers/educators are required to work increasingly with educational material such as Open Resources and as Shareware. The SET-Plan can incorporate such Open Educational Resources (OER) to make Europe a world leader in energy education, first by offering the research and educational community the funding possibility to work together on OER and second by implementing a more pro-active dissemination policy into all energy research programs sponsored by the EC. We recommend considering to develop on-line open source Master's program in sustainable energy engineering with a financial, social, entrepreneurial and humanitarian content. The effort required here is estimated around €10 M for a 3-year project. Such a tool could reach broad geographical coverage, enable uniformity in quality, and a quick way to update contents.

D. Creating and coordinating EU wide higher education, training, doctoral programmes

Coordination of educational programmes is per se a broad theme and would contain e.g. undergraduate and graduate level activities. Coordination of energy education within a single university is in most cases non-existing and the same applies for coordination between university programmes within a single member state. We are aware that there are coordinations “ad-hoc” but they are often based on interests of single persons and good personal contacts.

We focus here mainly on the university-level programmes, but the observations presented are applicable to other levels as well.

Present situation and best practices

We have a several university networks that could serve as good examples and cases for coordination. For example, KIC-InnoEnergy, SEEIT, EUREC, “CLUSTER” universities, Erasmus-Mundus programme just to mention a few ones. Most of these networks work with a limited number of partners and universities, and often the scope includes research collaboration as well. Many of these have been created and supported through EU funding which seems to be one important factor for successful coordination.

The European Platform for Universities engaged in Energy Research (EPUE) of the European University Association (EUA) has collected information on master and doctorate provision and could assist in identifying European wide schemes and coordination needs based on their statistics and surveys on almost 200 universities, covering all SET-Plan technologies and beyond.

The Erasmus-Mundus scheme offers funding for partnership in higher education, e.g. joint doctoral programmes. In the energy fields, a few joint-doctorate programmes have been launched such as SETS - Erasmus Mundus Joint Doctorate in Sustainable Energy Technologies and Strategies, FUSION DC- International Doctoral College in Fusion Science and Engineering, and SELECT+ - Environomical Pathways for Sustainable Energy Services. Erasmus-Mundus is not energy-specific but open to other disciplines as well meaning that energy education is just one more component in the overall programme.

Identification of needs and gaps

As a general observation one may say that the education and training in energy at any level is not well coordinated in Europe albeit several coordination efforts. There are though some exceptions, in particular in the Nuclear Fission field. It should also be observed that there are several pan-

European networks among universities, but mainly on research collaboration, some also touch education. The number of different education programmes in Europe, e.g. on Masters or Doctoral level, is easily counted in many thousands, which makes any coordination effort not easy if geographical coverage are sought for. However, from the SET-Plan point of view being able to cover whole Europe is an important aspect. In addition to coordination, resources for special programmes such as pilot studies on EU-level are important, in particular to enhance good practices and establishing programmes with high quality and good reputation.

Limited coordination in energy education and training has resulted in major overlap in supply (though some is justified), little specialization and underutilization of modern educational tools. Mobility or networking as instruments seems to be underutilized as well. All in all, present situation leads to ineffectiveness and not being able to capture of the many benefits from doing things together. A better coordination would lead to economic savings and improving the quality of the programmes. In a rapidly growing and dynamic field such as sustainable energy, a better coordination would definitely support SET-Plan goals and industrial competitiveness. The challenge is to create European-wide flexible and strong coordination efforts, e.g. platforms that are inclusive for new entrants.

In highly interdisciplinary energy technology fields such as energy storage or energy systems, which may involve several science and engineering disciplines simultaneously, a single university or education provider may not be able to offer a wide-enough but in-depth teaching portfolio in all disciplines involved. In this case stronger coordination efforts would enable universities to specialize in a few topics only, but at the same time cover all relevant themes through the coordination and co-operation arrangements. For example, in case of energy storage, there are several storage technologies based on quite different physico-chemical principles requiring e.g. mechanical engineering, thermodynamics, physics, chemistry etc. which are not necessarily available at one university for energy storage specifically.

General recommendations

The demand of coordination of education and education, training, and doctoral programmes is considerable and here we put forward a few recommendations considered of highest importance:

- Supporting a European-wide neutral, open and one-voice overarching platform for coordination of higher education Masters and Doctoral programmes which could be organized under the present frames ; this will require an inherent capability to deal with a broad membership (inclusive by nature) and take neutral role. As part of such an effort, we propose establishing a bi-annual high-level dialogue forum of major European networks to exchange information of on-going and planned activities in education and training in energy, to coordinate such efforts, to advice on necessary measures on European level to meet SET-Plan Education and Training goals.
- Creating EU-wide programmes; for example an 'Erasmus-Mundus'-type of joint-educational (MSc, Doctorate) programmes for the SET-Plan energy technologies either within the existing EM-scheme or within the SET-Plan;
- Support creating an Open Access Educational and Training Tool based on modern educational instruments to enable wide-spread, up-to-date and effective education and training in Europe in

energy. This will necessitate establishing a coordination centre to serve as a supporting body. The EIT KIC-Innoenergy platform offers an inherent environment for this task, which could be complemented with the EPUE/EUA forum (see point 1) to ensure good information flow between suppliers and users of the information.

First steps forward

As a first step we suggest 3-4-year limited-scope pilot activities to test the coordination recommendations (point 1 and point 3). Once assessed and modified, these could be scaled-up to European wide practice. This effort could also be combined with the harmonization issues that follow. In addition, adequate funding should be available to test new ideas.

E. Mobilise the capacity of professional development agents (and universities) in Europe

Capacity mobilization across Europe will be necessary to provide the educational services needed. The approaches both for higher education and professional development may be quite similar. Here we have looked more in detail to the issue through the professional development side, but the findings can also be applied to higher-education side as well. The practices may though differ somewhat.

Present situation and best practices

The European Union has launched several actions to support development of education systems and to increase convergence of member states' educational policies and training systems, yet respecting national specifications. A few examples are The Lifelong Learning (LLL) Program, European Qualifications Framework (EQF) and European Credit Transfer System (ECTS).

The Lifelong Learning Program emphasizes, amongst several things, the need for quality lifelong learning for European competitiveness, transparent degree and qualifications systems and cooperation between national training systems. We need projects to support the LLL program objectives by creating flexible and creative continuing education and professional development provision, supporting cooperation between higher education institutions and working life as well as increasing the degree of transparency. These projects also need to create partnerships between different actors and thus promote one of the key lines of the Charter in Lifelong Learning of EUA.

To our knowledge there is no database or collected information about professional development training in the energy sector in EU universities or by "other agents" such as professional organizations, consultants, industries/companies in-house activities etc. The survey that EPUE has carried out in European universities could be extended to cover also universities' professional development activities.

To be able to utilize the full capacity of European University and Professional Development Agents we need the cooperation with all the players in the field. Below are some good practical examples of capacity mobilization through Professional Development:

- Example 1: The example from the nuclear sector EHRO-N/ECVET European Credit for Vocational Education and Training is a system that could be adjusted also for professional development ("ECPET");
- Example 2: EUREC Agency´s European Master in Renewable Energy. Master programme is a good example of European co-operation. We should develop similar concepts i.e. certified programmes at continuing education and professional development level;
- Example 3: One example of programmes that eventually aims at certification at European level is the UP-RES project funded by EU/ IEE – Intelligent Energy Europe. UP-RES – Urban Planning with Renewable Energy Systems aims at overcoming and eliminating non-technological barriers currently impeding the market penetration of renewable energy systems offering heating and cooling services (RES H/C). The particular focus is urban and regional planning, where energy has not traditionally been a key factor. In some countries planning guidance is already driven by energy efficiency and renewable energy systems, but there is nevertheless a lack of awareness among planners in local authorities of how to put this into practice. UP-RES project organizes training of urban and regional planners by means of *short* and *long* courses in 5 partner countries, specifically Finland, Germany, UK, Hungary and Spain during 2011-2013. The UP-RES training is designed and put together utilizing the best practices of each country. Industry, business and communities are strongly involved in the training steering groups. The delivery is country specific due to differences in energy systems. The tailoring of the training concept to all the participant countries means there will be various forms and approaches to assisting RES H/C market penetration, and this will also mean the training material will be relevant and useful to countries across the whole of Europe. The material will be compiled in the form of usable files and booklets in10 European languages.

Identification of needs and gaps

The demand of BSc and MSc graduates and professionals will exceed supply: turning the entire energy sector from fossil to RES base demands substantially improved engineering education at all levels. BSc, MSc graduates have a basic / generic knowledge in energy systems that give them a basis to add on any specific vertical competence. Continuing Education and Professional Development can provide for this need faster than basic education. University Professional Development can, as an example, have an important role in educating professionals with a background in declining industry fields to a new career in the energy field. This needs attention at EU level.

RES technologies develop so fast that basic knowledge becomes outdated in a decade. There will be a constant need for upgrading both basic and professional skills and knowledge. Energy professionals need cross-discipline thinking and horizontal work related skills and competences, such as management, systems thinking, project management, economics, multidisciplinary problem solving skills etc.

Energy efficiency, use of renewable energy sources and reducing CO_2 emissions are part of social responsibility and thus issues relevant to many professions and should be part of most CE programs in each field of human society in years to come. This will lead to a broader societal understanding and acceptance of the need of required SET Plan energy actions. Especially industry, urban planning, building and transportation sector need competent professionals that are capable of taking into account energy- and environmental aspects in their tasks when designing, planning and operating in their own field

Recommendations

A similar survey that the European University Association through EPUE has carried out in European Universities could be done to cover professional development activities. An EU-wide expert database of researchers and top professional experts would be highly beneficial for professional development training purposes. Such an action should be undertaken by relevant actors in the Vocational Training Field.

There are also several recommendations related to professional development and re-training offered by higher education institutions:

- We need EU supported collaborative projects to build networks of Universities and other players including business partners to pilot coordinated professional development programmes;
- Professional organizations, industry and business employers and universities need a platform to join together to develop master and professional (certified) programmes for energy business professionals and managers;
- Professional organizations and bodies need to be supported to encourage their members to include energy and emission related topics into their professional competence profile;
- Professional development has to foster professionals with a holistic understanding of the energy system and bring together professionals from different fields to tackle common energy challenges utilizing their best practices.

F. Accreditation and Quality Assurance of education and training

Current situation and present practices

The structure of regulations and practices for educational programmes in Europe is complex. Regulations and practices exist at three levels: European, national and institutional. Many regulations originate from old practices and cultural differences between higher education institutions and nations. The Bologna process in Europe has for the last 15 years slowly but steadily moved European universities and member states towards a higher degree of interconnectivity in terms of accepting grades, merit, courses and programs. But barriers still exist.

The external quality assurance normally is performed at two levels in European countries: Programme and institutional external quality assurance (whether it takes the form of accreditation, evaluation or audit). It is important to point out that not all EU countries practice accreditation (one of the types of Quality Assurance) but use evaluations and audits instead. Furthermore, the autonomy of the establishments may vary in the accreditation process. The Programme accreditation based on e.g. national accreditation committees for each study programme seems to be relatively stiff for innovation, but higher education providers such as universities are usually free to change the set of courses and their content, e.g. in the range 10 to 30%. The Institutional accreditation/evaluation/audit can give a possibility to create new study programmes in a general accredited area rather freely, but requires an internal quality assurance system. A majority of European countries have Programme accreditation but the university reforms in many countries show a trend towards the Institutional accreditation, evaluation or audit.

An increasing trend is also on Double degree or Joint degree that may improve quality and cost efficiency of education. Double degree programmes are simpler for the accreditation process, but Joint degree programmes would represent a more advanced form of co-operation.

Special programmes for certified professions are usually accredited in each country by the professional societies or chambers according to very different rules so the co-ordination or co-operation in the international area seems to be difficult.

Identification of needs and gaps

Although Ministers for higher education of the 47 countries that conforms the European Higher Education Area (EHEA) have, in the context of Bologna Process, adopted the Standards and Guidelines for Quality Assurance in the European Higher Education Area (ESG)[8], a common framework for quality assurance in Europe, national accreditation systems are most often not compatible. National accreditation systems therefore become a bottleneck for the development of trans-European educational programmes. Accreditation can be a necessary and useful tool for assessing and evaluating educational programmes. But as accreditation now works, it impedes the development of joint international programmes.

As an *example*, the Danish accreditation system aims to ensure and proving both the quality and relevance of higher education. Furthermore, the accreditation system is based on individual assessments of all higher education study programmes in contrast to other countries where institutional accreditation is to be used. The focus on proving of the *relevance* of a given new educational programme is a limiting factor for the development of new programmes and in particular for improved European collaboration. The relevance factor focuses on the regional/national labour market without having a broader/global perspective. Experience tells that the process of developing new programmes which can meet the needs of the labour market is slowed down by this procedure. To proof the relevance of joint European programmes in a national accreditation system is difficult, as the accreditation board will ask for evidence that the candidates are needed in a regional/national labour market. Another challenge is the fact that all new programmes may need to be accredited individually before start up. Altogether, both factors outlined contribute to a slow implementation of new educational programmes. An estimate is that it takes up even to 7 years in some countries from the creation of an idea to till the first student graduates.

[8] ENQA report on Standards and Guidelines for Quality Assurance in the European Higher Education Area; http://www.enqa.eu/pubs.lasso

There are many European HEIs offering joint Master programmes or joint course 'packages' but it is apparent that globalization and increasing mobility of students make joint international programmes more attractive and needed. Through joint programmes HEI can

- use complementary competences;
- pool resources and offer degree programs with increased depth and opportunity for specialization;
- facilitate a marketplace for Master programmes based on a European Master Programme platform to be created in specific engineering disciplines (e.g. as part of the vertical technology-specific recommendations);
- share expensive and highly specialized laboratory facilities with access to all partners;
- increase mobility of students between partners. This will be facilitated through clearly defined and visible study tracks (to students) so that it is easy for students to move between universities.

Accreditation systems should take the above mentioned measures and needs in the previous sections into account. Additionally, national accreditation should cohere with other European quality measurements. Therefore, there is a strong need for real compatibility between national accreditation systems, creating incentives for (large-scale) European joint programmes. Educational systems in Europe as a whole must in the future become more integrated. As such it is logical to also, further to the excellent national accreditation systems, in the future consider common accreditation possibilities.

An initial analysis of accreditation processes in European countries in necessary for the internationalization and harmonization of educational processes has already been conducted and it should serve as a basis for further efforts aiming at internationalisation and harmonisation of educational processes[9].

Recommendations

Improvement in Accreditation and Certification procedures are considered of outmost importance to recognise appropriately high-quality European-wide energy education and training in Europe. We acknowledge that such recognition requires the involvement of the Member States as they are legally responsible for the national accreditation procedures. However, this issue does not relate solely to the energy sector and the approach should be systemic. Therefore, the following recommendations are suggested:

- Provide an analysis of the accreditation processes in European countries in necessary for the internationalization and harmonization of educational processes in the field of energy;

[9] Eurydice Report: "The European Higher Education Area in 2012: Bologna Process Implementation Report"; http://eacea.ec.europa.eu/education/eurydice/documents/thematic_reports/138EN.pdf

- Accreditation procedures and criteria in EU member stated should evolve towards more flexible structures facilitating the accreditation of pan-European educational programmes;
- Encourage Member States through their national agencies to work towards such flexible accreditation systems and undertake necessary reforms, in particular for the energy field and SET-Plan purposes. The Commission should initiate such a process and also provide means to undertake the necessary background analysis and preparations. An example of a potential flexible approach that could be considered as a starting point for discussion, could be creating a two-step European accreditation system as follows:
    - I. National accreditation on an institutional level. Based on this accreditation, institutions are free to start new programmes (national and in a European framework);
    - II. Programme accreditation on a European level. Specialised European agencies perform the accreditation process within a specific area (for instance within the area of applied science, computing, engineering, and technology, like ABET in the US). The programme accreditation should be mandatory and achieved through a recognised peer review process, which provides assurance that a university program meets the quality standards established by the profession for which the program prepares its students. In this case it should be assured that relevant national competences recognise this accreditation as equivalent to their national processes, thus limiting the administrative burden of the HEIs.

G. Harmonization of educational systems

Harmonization in broad terms relates also to the Accreditation and Certification discussed in the previous chapters. Harmonization of educational systems means here setting some kind of uniform minimum requirements on the energy education and disciplines involved. Harmonization looks here more on contents side whereas accreditation more on the performer and organizational side.

Present situation and best practices

The European Credit Transfer and Accumulation System (ECTS) is a major effort in Europe to make higher educational programmes compatible. It is a learner-centred system for credit accumulation and transfer based on the transparency of learning outcomes and learning processes. It aims to facilitate planning, delivery, evaluation, recognition and validation of qualifications and units of learning as well as student mobility. ECTS is widely used in formal higher education and can be applied to other lifelong learning activities.[10] ECTS makes teaching and learning in higher education more transparent across Europe and facilitates the recognition of all studies. The system allows for the transfer of learning experiences between different institutions, greater student mobility and more flexible routes to gain degrees. It also aids curriculum design and quality assurance. The ECTS

[10] ECTS User's Guide: http://ec.europa.eu/education/lifelong-learning-policy/doc/ects/guide_en.pdf

concept also means that there must be more clear recommendations on both program and course levels related to the Intended Learning Outcomes at all different levels.

On the vocational education and training side, the European Credit system for Vocational Education and Training (ECVET) aims to facilitate validation, recognition and accumulation of work-related skills and knowledge acquired during a stay in another country or in different situations. It should ensure that these experiences contribute to vocational qualifications. This makes it more attractive to move between different countries and different learning environments.

The European Qualifications Framework (EQF)[11] is a step forward to link member states qualifications systems or national qualifications frameworks (NQF) to the EQF. Basically, the EQF is a common European reference framework acting as a translation device to make qualifications acquired within the different education and training systems in Europe more readable and understandable. It includes Higher Education and Vocational Education and Training which makes EQF particularly important for the life-long learning sector.

Within the life-long learning sector in particular, the European Qualifications Framework (EQF) is a step forward to link member states qualifications systems or national qualifications frameworks (NQF) to the EQF. Basically, the EQF is a common European reference framework acting as a translation device to make qualifications acquired within the different education and training systems in Europe more readable and understandable.

The Working Group is unaware of major specific harmonization efforts in the whole energy education field in Europe. However, there are several coordination initiatives that illustrate harmonization efforts which should be followed up closely for their potential applicability to other future harmonization efforts:

- Example 1: In Nuclear Energy (under the EURATOM-treaty), which can be viewed as a mature industry area, the educational system seems to be well underway to be harmonized in Europe. The need to share expensive and unique education infrastructure (e.g. research reactors), ageing workforce, lack of students, high quality standards, etc. are among the factors that have forced the nuclear educators to collaborate and plan for more uniform and effective educational systems. The collaboration among the universities, research organizations and companies in Europe have led to a kind of nuclear education platform and have enabled to provide uniformity in education, e.g. minimum requirements. The nuclear case serves also as an example, where a technology field itself, though with help and financial support from the Commission, has been able to provide adequate harmonization and also to implement the changes necessary on a national level.
- Example 2: The EUREC Agency's Renewable Energy Master's Programme aims to harmonize learning outcomes, leaving more free space to learning providers for their own teaching approaches and methods. Harmonization of learning outcomes ensures that students throughout Europe have similar basic knowledge in a specific technology field. Such

[11] The European Qualifications Framework (EQF); http://ec.europa.eu/education/lifelong-learning-policy/eqf_en.htm

uniformity seems to ease student and teacher exchange. When done e.g. on a semester basis, harmonization have also served to synchronize curricula.

Identification of needs and gaps

Traditionally energy education in Europe has been based on national approaches outgoing from the national needs and traditions in energy and education. However, educational systems have not evolved under complete isolation and have been subject to inherent benchmarking supported by visits and exchange of personnel of academia and educational institutions. Moreover the interaction with stakeholders such as companies having a more international profile has encouraged improving the contents of the education to toward the best-practice in the field. The interaction of national education provides with the surrounding society at large has led to a kind of natural harmonization of the educational system. For example in electrical engineering education, the differences in basic university education are small throughout Europe. In case of new energy technologies covered in the SET-Plan the situation is different as the tradition of education in this field is still short and the practices in the EU are very diverse. In these new fields harmonization would definitely provide a value, because without some kind of harmonization critical knowledge gaps in certain fields may result which in turn could lead to poor quality of education and training activities.

There are several perspectives on the harmonization of educational systems that need to be addressed such as

- Harmonization per technology, e.g. defining some kind of basic education requirements for the technologies in the SET-Plan. Basically this needs to be addressed within the vertical technology groups of this exercise;
- Implementation and creating a framework for harmonization efforts, i.e. how to implement such initiatives Europe wide;
- Educational systems are not organized by technologies but by disciplines meaning that harmonization may touch several science and engineering disciplines simultaneously even when discussing a single technology. Multidisciplinary energy education would be even more challenging;
- Harmonization involves definitively both a geographic and time dimension, i.e. harmonization should be European wide, or it may even go beyond Europe's boundaries, and should work on a continuous basis. A major challenge will be to cope with the huge number of universities and education providers involved throughout Europe.

General recommendations

From the few but successful examples, our recommendations on harmonization of the educational system within the SET-Plan Education and Training Initiative are the following:

- Harmonization should be focused on the Intended Learning Outcomes defining the level of knowledge and skills that students should acquire at different educational levels;
- A dialog is needed with stakeholders to create a framework for harmonization will be necessary to enable key education providers to define the contextual side of the education and the learning outcomes for SET-Plan technologies. Utilizing recently established organizational

structures of the SET-Plan would be advisable to provide such a framework. Two options can be identified: Energy Industry Initiatives (EII) and their technology platforms meaning establishing e.g. Energy Education Platforms within the EIIs, or, the European Platform for Universities engaged in Energy Research (EPUE) within the European Universities Association representing the university sector, and e.g. KIC-Innoenergy representing the knowledge triangle. Financial provisions will be necessary to run such an activity. The kind of European level coordination suggested here will be necessary to provide harmonization throughout Europe on a relatively short time notice;

- Outgoing from the initial positive experiences with the ECVET in the Nuclear Energy field, it is recommended that the Commission initiates a study to analyse these experiences in more detail and how these could be applied to less mature energy fields (most of sustainable technologies are still disruptive industries) than nuclear energy, and what kind of modification could be required. Following the study, a few 2-3 year pilot projects in selected sustainable energy technology fields could be set up to establish, test and modify the model concept. This should lead to a more generic frame applicable to all SET-Plan technologies simultaneously.

4 Recommendations at EU and Member State level within specific target dates

Europe must ensure a sufficiently specialized work force with competence to exploit technological opportunities. Recruiting sufficient numbers of young talent, providing them with sound basic scientific and engineering education in energy relevant disciplines is a key requirement. Multidisciplinary topics need increasingly be included in the competence portfolio of the students. This work force must be kept updated with latest research knowledge in specialized fields and include sufficient vocational training for the needs of energy sectors as a whole.

For this, we propose the following recommendations:

- Europe should <u>create a robust and responsive education system</u> that would be able to effectively and quickly disseminate new research-based knowledge required to implement the new technologies. This could be achieved, for example, through the creation of an Open Educational Resources repository from research results as they would appear. This “courseware” should be made available to education providers. A pilot project could be mounted to develop this approach;
- Since the dynamics of the market is hard to predict, and trends that will be created can change quickly, the key part of the responsiveness must be created through <u>continuously updating the competence in the existing work force</u>. This means incorporating Life Long Learning as an integral part of the SET Plan Energy Education and Training Initiative, since relying only on newly graduated candidates to disseminate the new knowledge would take too long. In addition, it is important to ensure the there are enough workforce available which addresses e.g. the higher education sector;
- One of the key bottlenecks in the whole energy education in Europe is its fragmentation on all levels from within a single entity through member states to EU-level. We think the SET-Plan could <u>benefit from stronger coordination of the energy education and training</u>, but been given

specified tasks, e.g. surveys and statistics, link between SET-Plan and grass-root level actors, i.e. “one voice”-provision, among others:

- The innovation system in the energy sector must be sharpened to the maximum possible level that integrates effectively research, education, and industrial innovation to create and sustain innovative knowledge triangles. The EPUE survey has revealed the existence of a considerable number of these knowledge triangles at a local/regional scale and they should receive proper funding to be sustained and improved where necessary. Education programmes at master and doctorate level are most important in this context because they can produce educated people that can act as “agents of change” in terms of energy technological development and its socio-economic and cultural context;
- A pilot project should be devoted to analyse the new types of energy systems and their relation with the system engineering competence profiles required. This is required because of the increasingly complex energy supply and end use systems that are being developed. This should be fostered in a research environment where analytical models of integrated energy systems are developed. This may need also other multi-disciplinary elements such as socio-economics;
- Pan-European studies to further identify current Masters and Doctorates and Life Long Learning courses should be conducted to map European educational provision in the field of energy. This could be performed at different scales and stages by the existing networks at European level (EUA-EPUE, KIC InnoEnergy, EUREC, ESEIA, SEEIT, etc.). These studies should enable the identification of educational needs and opportunities for harmonization and/or clustering of courses.

As concrete immediate (pilot) actions to support above statements, we recommend the following steps to be undertaken:

1. *Launching of a three-year pilot-project towards establishing of the world’s first fully on-line open source Master's program in sustainable energy* with engineering, financial, social, entrepreneurial and humanitarian content, by direct coupling with introduction of latest relevant research results from all the pilot project partner institutions into the program. (1 year preparation, 2 years running the first intake of students, tuition-free for the first two cohorts). The MSc program will cover a few different options. This pilot project is intended to show the European leadership related to higher education in the renewable energy sector, to be a show-case for universities, and is intended to lead to larger engagement of such initiatives;
2. *Establish a pilot action on accreditation and quality assurance of energy education***.** Provide support through this pilot action to develop accreditation and certification structures in the member states in cooperation with national accreditation bodies to make high level cooperation amongst educational institutions possible. Provide support to establish structures which accelerate a communication (including regular organisations of workshops and seminars) process between universities to exchange and to plan for harmonized curricula;
3. *Start a pilot action to monitor:* (i) skills needed from the energy industry-side; (ii) new/ongoing research results in the energy field; (iii) educational programmes offered by universities in the energy area; as a separate effort *undertake a survey (similar to the EUA/EPUE for European*

Universities) on professional development activities and establish a EU-wide expert database of researchers and top professional experts;

4. *Create a pilot action for updating/expanding/creating energy curricula*, also aiming at attracting students to a career in the energy sector. This action need to involve relevant European stakeholders both from the industrial and educational side; a sub-group on developing *professional (certified) programmes for energy business professionals and managers* is also recommended, to include professional organizations, industry and business employers and universities;

5. Initiate a pilot action to establish a structured dialogue between the existing EU technology platforms and EU thematic university platforms and other university initiatives to enhance university-business cooperation; this should also include support for sharing the best practices among knowledge institutes on curriculum design of sustainable energy. This could form a sort of clusters of excellence;

6. *Start a pilot-action to form a European-wide open and overarching platform for higher education* Masters and Doctoral programmes. As part of this pilot action establish a bi-annual high-level dialogue forum of major European networks to exchange information of on-going and planned activities in education and training in energy, to coordinate such efforts, to advice on necessary measures on European level to meet SET-Plan Education and Training goals. Provide more support for the mobility of master and Doctorate students across the countries. Create EU-wide programmes e.g.an 'Erasmus-Mundus'-type of joint-educational (MSc, Doctorate) programmes either within the existing EM-scheme or within the SET-Plan;

7. *Support a pilot action or study to apply an ECVET-type of a scheme for vocational education and training in sustainable energy* fields outgoing from experiences in the nuclear field. A few 2-3 year pilot projects in selected sustainable energy technology fields should be set up to establish, test and modify the model concept.

SET Plan Education & Training
Bioenergy

Bioenergy

Working Group Contributors

Edited by Nora Niemetz	Graz University of Technology, Austria

Based on the SET Plan Education for Bio-Energy Working Group consisting of:

Michael Narodoslawsky (Rapporteur)	Graz University of Technology, Austria
Ina Körner	Hamburg University of Technology, Germany
Outi Krause	Aalto University, Finland
Guido Saracco	Politecnico di Torino, Italy
Semida Silveira	Kungliga Tekniska Högskolan (KTH), Sweden
Han de Winde	Delft University of Technology, Netherlands
Tony Bridgwater	Aston University, United Kingdom
JJ Leahy	University of Limerick, Ireland
Markku Karlsson	Forest Industries, Finland

The authors would like to thank the following persons for their valuable input:

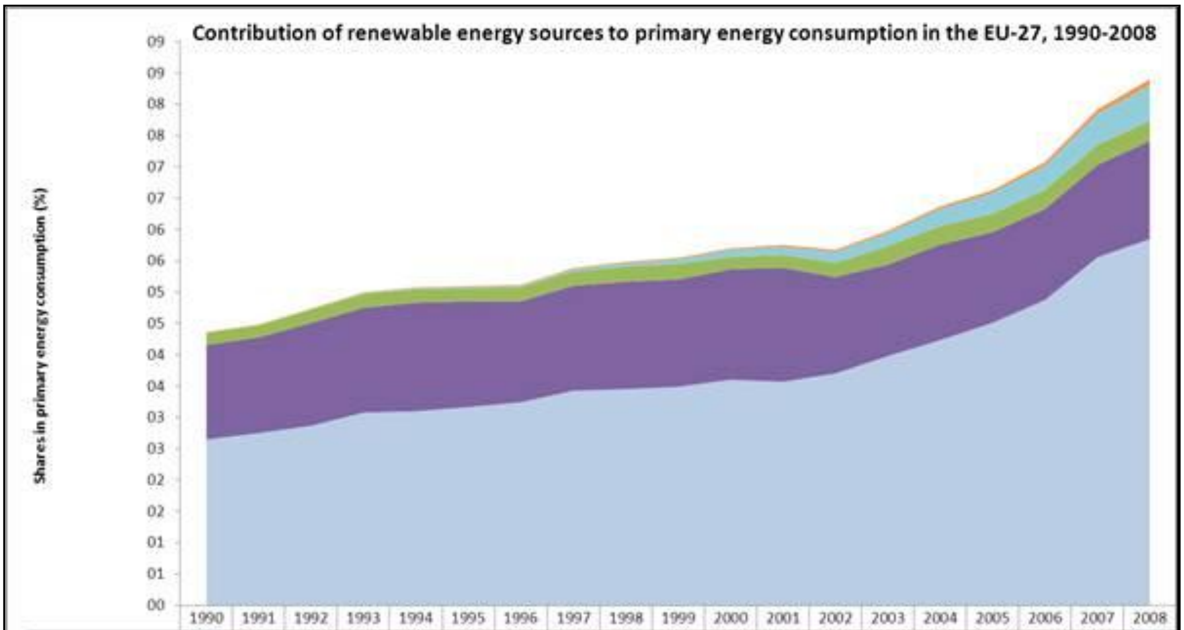
Dipl.-Ing. Dr. Horst Jauschnegg
Dr. Marco Ricci
Dr. Luis Oriani
Ing. Roberto Zocchi
Dr. Alessandra Fornaziero
Ing. Sara Rolandi
Ing. Massimiliano Antonini
Prof. Dr. Athanasios Konstandopoulos
Dipl.-Ing. Anna Deipser
Prof. Dr. habil. Bodo Saake

1 Current Situation

Bioenergy in Europe

Bioenergy is a traditional energy technology in Europe. Hundreds of years ago heat provision for domestic purposes via biomass combustion was the main energy source. Europe's industry to a great also extent relied on char coal as its main energy source for a long time. Both often resulted in catastrophic effects for the environment. Even with the ascent of fossil energy resources in the 19th century biomass retained an important if diminished position within Europe's energy system, mainly for heat production.

In the recent past, utilisation of biomass however has entered a decisive and dynamic phase in Europe (see fig 1).



	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Solar	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,1	0,1	0,1
Wind	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,1	0,1	0,1	0,1	0,2	0,2	0,3	0,3	0,4	0,5	0,6
Geothermal	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,3	0,2	0,2	0,2	0,3	0,3	0,3	0,3	0,3	0,3
Hydro	1,5	1,5	1,6	1,7	1,7	1,7	1,6	1,7	1,7	1,7	1,8	1,8	1,5	1,5	1,5	1,4	1,5	1,5	1,6
Biomass and waste	2,6	2,8	2,9	3,1	3,1	3,2	3,2	3,4	3,5	3,5	3,6	3,6	3,7	4,0	4,2	4,5	4,9	5,6	5,8

Figure 1 Contribution of renewable energy sources in the EU-27, 1990-2008

Primary Biomass, waste biomasses and biomass processed to biofuels provided a share of approx. 7.5 % to the end- energy use in Europe in 2009, as seen in table 1, making bioenergy a provider of more than 50% of all renewable energy in Europe. The dynamic development of bioenergy, both in terms of diversification of energy products and services (e.g. the generation and provision of bio-fuels, bio-heat and –cold, bio- electricity as well as Synthetic Natural Gas) and increasing demand has led to a considerable push into other sources than wood, particular crops like corn and rape. This has in turn put bioenergy in competition with the food sector for finite land resources and increasingly also with established material provision industries like pulp and paper and the wood processing industries. On top of that the chemical industry may also enter this competition if crude oil becomes scarcer.

Tab. 1 Final energy consumption and share of biomass in the year 2009 (Mtoe)

	Final Energy Consumption in Mtoe	**Final Energy Consumption Biomass Mtoe**	**Share of Biomass %**
EU 27	1113.6	83.68	7.51
Austria	26.2	4.15	15.84
Belgium	34.5	1.23	3.57
Bulgaria	8.6	0.69	8.02
Cyprus	1.9	0.03	1.58
Czech Republic	24.3	1.84	7.57
Denmark	14.7	2.43	16.53
Estonia	2.7	0.61	22.59
Finland	24.0	6.95	28.96
France	155.5	12.43	7.99
Germany	213.2	15.73	7.38
Greece	20.5	0.96	4.68
Hungary	16.4	1.03	6.28
Ireland	11.8	0.24	2.03
Italy	120.9	3.45	2.85
Latvia	3.9	1.05	26.29
Lithuania	4.4	0.76	17.27
Luxembourg	4.0	0.07	1.75
Malta	0.4	0.00	0
Netherlands	50.4	1.47	2.92
Poland	60.9	4.80	7.88
Portugal	18.2	2.87	15.77
Romania	22.1	3.91	17.69
Slovak Republic	10.6	0.58	5.47
Slovenia	4.6	0.46	10.00
Spain	88.9	4.63	5.21
Sweden	31.6	8.92	28.23
United Kingdom	137.5	2.38	1.73

Data Source: AEBIOM Annual Statistical Report 2011; www.aebiom.org

This has considerably diversified the supply chain of bioenergy, which now encompasses agriculture, forestry but also waste management. It will require new suppliers like aquaculture, land based algae producers and waste water management, with a great number of associated actors within the chain as shown in fig. 2.

It has to be stated that utilisation of biomass for energetic as well as other industrial purposes is not by itself sustainable and limitations in production due to the limited areas, but also decreasing soil fertility must be taken into consideration. In the public opinion biomass is often still assumed as unlimited, since it is renewable. Biomass is however limited by finite yields per acreage. This is why by increasing demand biomass imports transferred problems to the less developed world to a large extent.

Although bioenergy draws on renewable resources, the overall ecological impact along the whole supply chain shown in fig. 2 (even in terms of carbon emissions and soil fertility) may be considerable. The complexity of the supply chain means that sustainability of bioenergy is critically dependent on the sustainability of the sectors involved in the supply chain such as forestry, agriculture, waste management and transport as well as the sustainability of the competing sectors.

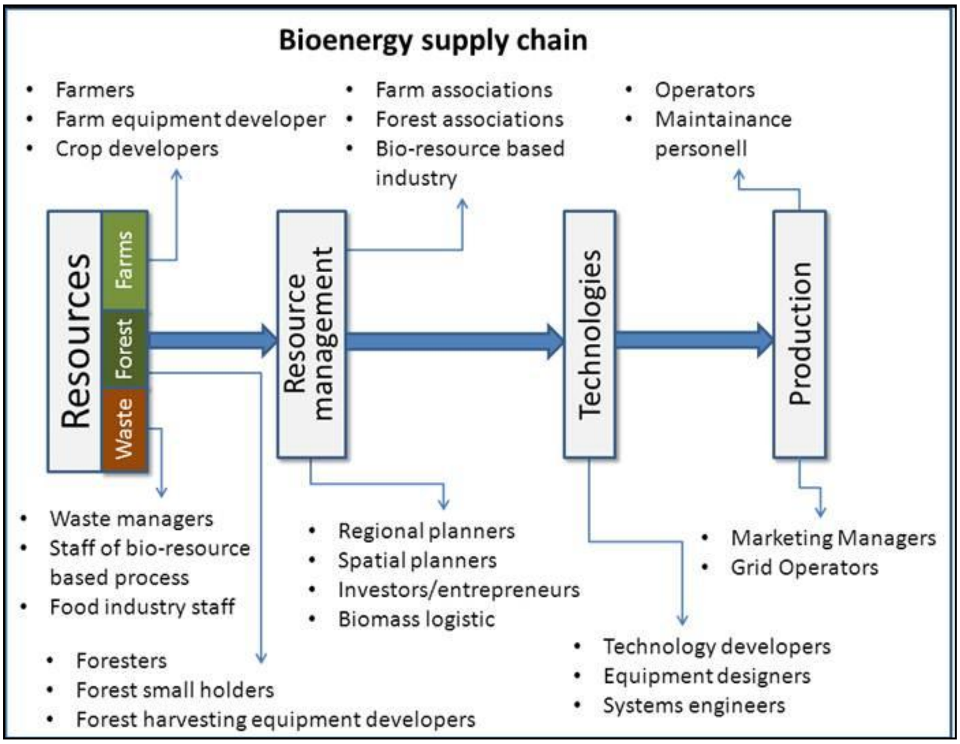


Fig 2: The bioenergy supply chain (simplified)

Another result of the complex supply chain is that the economic and social impact of the whole bioenergy sector is thoroughly interwoven with other strong economic sectors with their own dynamics. Estimates[1] are that bioenergy adds about 15 % to the economic value of agriculture. Cutting out the value added by bioenergy of e.g. agriculture or the transport sector is however almost impossible. Therefore the focus of the following data will be laid on direct bioenergy impacts, although this clearly underestimates the overall importance of this sector.

Table 1 shows that bioenergy consumption in the EU 27 varies considerably as share of total consumption in member states. The average across the Union of about 7,5 % is overshot by a factor 4 in northern countries like Finland and Sweden, whereas in countries like the UK, the Netherlands and Italy bioenergy is utilised far below the average in the Union.

Fig. 2a and b show that the bioenergy supply chain is considerably different throughout the EU member states. Municipal waste plays an important role for bioenergy (both heat and electricity) in Germany, Denmark, Netherlands and UK, whereas Finland and Austria rely heavily on solid biomass

[1] Frauenhofer ISI: Final report of EmployRES, 2009

as fuel for electricity and heat provision. Biogases (from digestion) are the main source for electricity in Germany and UK, with solid biomass a close runner-up. Although these differences are strongly influenced by the natural endowment of a country, they also mirror variations in factors like ownership structures, technological development paths and interaction with other sectors within a national economy.

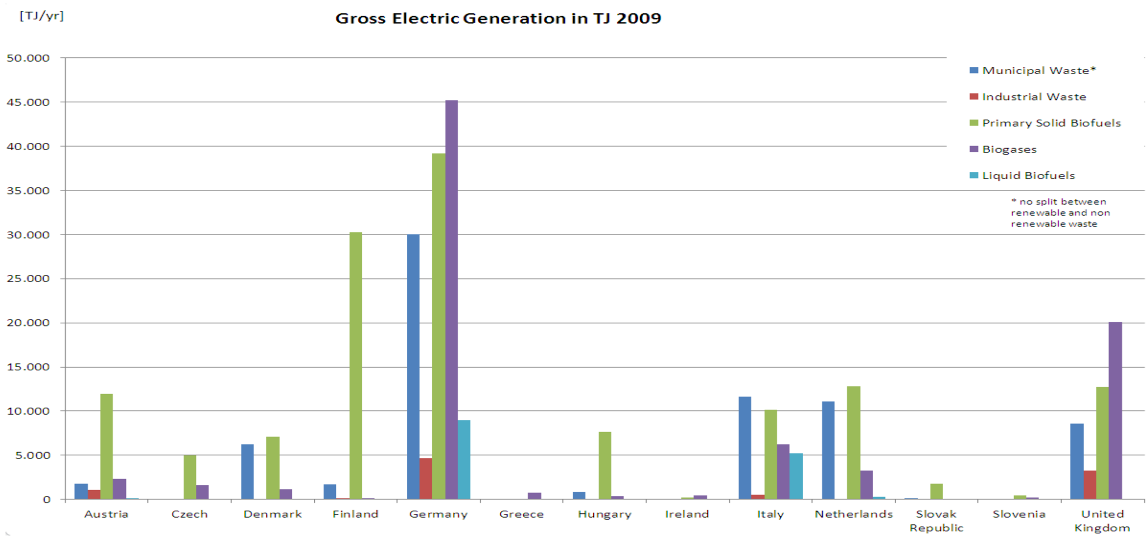


Fig 2a Gross Electric generation and heat production in TJ, 2009

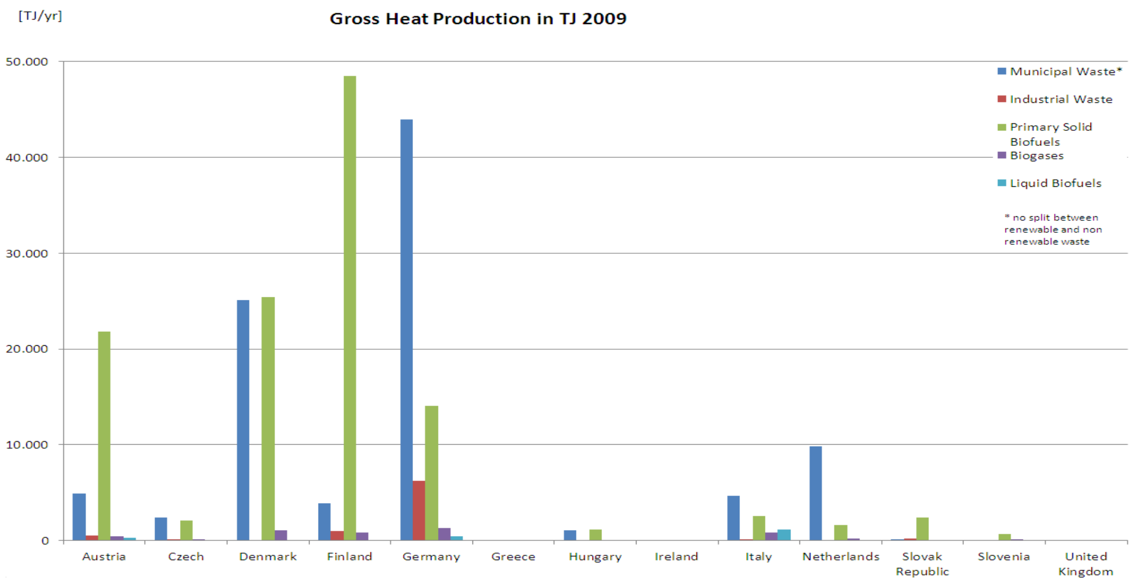


Fig 2b Gross heat production in TJ, 2009

Data Source: IEA http://www.iea.org/stats/

These variations translate into very different development pathways of bioenergy within the Union. It ranges from Greece, where the bioenergy sector is still mostly dormant to Italy with a vibrant development in the utilisation of waste flows including waste water sludge and organic municipal waste as well as generation of biofuels and bio-oils (for use in transport as additives to fossil fuel as well as in stationary cogeneration plants) produced via 2nd generation biofuel technologies. In Germany activities to utilise urban waste water fractions (black water) directly are currently under way. Austria shows a particularly well developed forestry based heat provision sector, with a wide range of innovative technology companies in this field as well as an important biogas sector. Finland features even more cutting edge development in the fields of biofuels (in particular by Neste Oil, a company that also drives BTL development, and UPM producing biodiesel from tall oil), forestry residues utilisation (e.g. gasification of bark by Metsä Fiber) and pyrolysis (Fortum). Finland already pursues a comprehensive approach to a Bio-Economy, driving the systemic development of bio-refinery technologies.

Germany has the highest overall bioenergy consumption within the EU 27 (Tab.1), and has further increased it (2010: 2496 TWh). Also the share of biomass increased (2010: 7.9 % of total energy consumption); biomass contributes around 70 % to the renewable energy share (BMU/AGEE-Stat March 2011 total) and is mainly used for heating. Wood is with 90% the most important source. However, electricity generation from biomass has drastically increased in the last years supported by the Renewable-Energy-Law (EEG). With about 7.000 (as of 2011) plants it has by far the highest number of biogas facilities in Europe, mainly operated with corn and manure. Most of these facilities use CHP however 52 facilities already provide bio-methane in natural gas quality, with increasing tendency. In the biofuel sector biodiesel is most important, but also first and second generation systems for the production of plant oil, bio ethanol, Bio-ETBE and biogas to liquid are in operation[2].

Regarding the overall impact of bioenergy in economic terms as well as in terms of employment, fig. 3 and 4 represent the situation in 2005. In these figures Biogas summarises all digestion plants using agricultural products, Biomass-grid represents all solid biomass utilisation efforts that produce grid-based energy services like district heat and/or electricity, Bio-waste stands for utilisation of biogenic wastes from society (e.g. waste water, municipal bio-waste, etc.) and biofuels represent all liquid bio-based energy carriers used in mobility (e.g. bio-ethanol, bio-diesel, etc.). The columns are segmented into the economic impact of investment for equipment and infra-structure, operation of the facilities and the impact created by providing the raw materials utilised in the installations.

A total induced value added of about 34 billion. €/a (of which 55 % are direct value added and 45 % indirect effects) may be attributed to bioenergy, representing about 0.34 % of total gross EU-GDP. In terms of employment roughly 0.875 Mio fulltime equivalent jobs can be attributed to the direct and indirect economic impact of bioenergy in 2005, representing 0.43 % of the European workforce[3].

---

[2] See http://mediathek.fnr.de/grafiken/daten-und-fakten/bioenergie/struktur-des-primarenergieverbrauchs-in-deutschland-primarenergie.html

[3] Frauenhofer ISI: Final report of EmployRES, 2009

64 % of total value added as well as of workforce is induced by solid biomass utilisation (grid &non-grid). Particularly interesting is the large fraction of economic impact of the supply chain, with 33 % of total value added and even 29 % of people employed in bio-energy. This indicates the strong position of solid biomass utilisation pathways and in particular forest product utilisation within bioenergy in Europe.

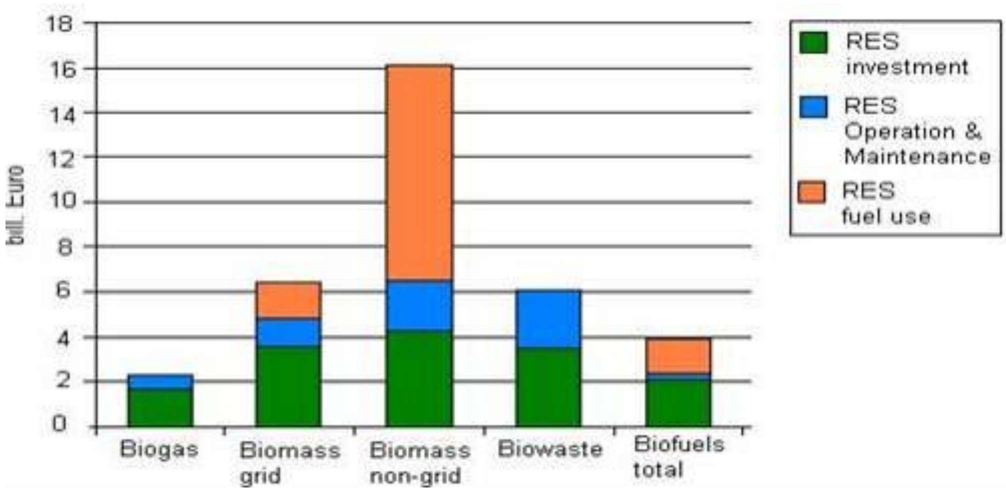


Fig. 3: total value added in the EU induced by bioenergy (2005)

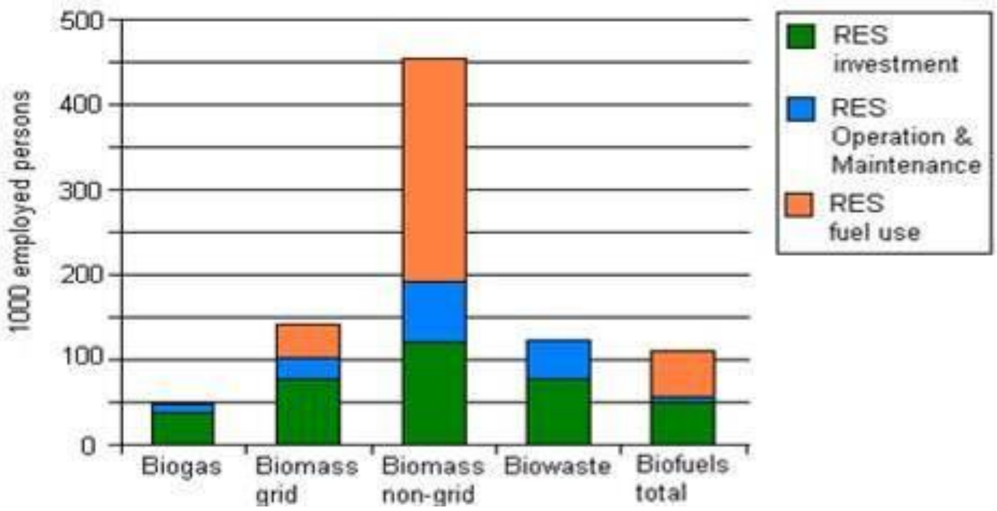


Fig. 4: Total employment induced in the EU by bioenergy (2005)

Future trends

Quantitative Trends

From the point of the European Commission bioenergy development is addressed in one of the seven SET Plan Roadmaps on Low Carbon Energy Technologies[4] (calling i.a. for a share of 14 % of sustainable, cost competitive bioenergy in the European energy mix) as well as in the SET Plan Materials Roadmap[5].

Table 2 shows estimates for the development of bioenergy until 2020 in the Union. In total biomass use for energetic purposes will, according to this estimate, rise by a factor 2.25 in the 15 years from 2005 to 2020. Combining these two datasets allows to roughly estimate the impact on employment. The increase of bioenergy will correspond to a necessary workforce by 2020 of almost 2 million. fulltime equivalent employees, requiring education of almost 1 million employees in the remaining time to 2020[6].

This table shows that the increase of bioenergy utilisation will be uneven in different applications. Whereas electricity from bio-resources will increase by a factor of 3.3, heat provision will only increase by 70 % (although with the highest increase in absolute numbers). The most dramatic increase will be seen in biofuels, with a factor of 10!

An increase in combined heat, power and cooling (CHPC) and biofuel provision will translate in a disproportionate increase in the jobs created in the supply chain, as these two bioenergy applications require particular strong efforts to provide resources. The jobs created in this field will predominantly require qualifications geared towards bioenergy in agriculture and logistics of bioresources especially at the level of vocational training and supply chain management. Watkinson[7] analysed that in comparison to fossil fuels in Europe, biofuels create 50 to 100 times the number of jobs; electricity from biomass creates 10 to 20 times the number of jobs; and heat from biomass creates double the number of jobs. The disproportionate increase in bio-electricity as well as in biofuels will require new jobs in research and technology development, as these bioenergy sectors are currently subject to especially dynamic innovation.

---

[4]See http://setis.ec.europa.eu/about-setis/technology-roadmap/the-set-plan-roadmap-on-low-carbon-energy-technologies [last consulted July 2012] for further details.

[5] See http://setis.ec.europa.eu/activities/materials-roadmap/ [last consulted July 2012] for further details.

[6] Estimated from Frauenhofer ISI: Final report of EmployRES, 2009

[7] Watkinson, I.I., Bridgwater, A.V., Luxmore, C., 2011: Advanced education and training in bioenergy in Europe, Biomass and Bioenergy 38 (2012), 128-143

Tab. 2 Estimation of total contribution expected from bioenergy (ktoe)

	Bioelectricity				**Biomass for heat and bio-heat**				**Biofuels**			
	2005	2010	2015	2020	2005	2010	2015	2020	2005	2010	2015	2020
EU 27	5936	9737	14344	19697	52522	61782	72880	89756	2821	13819	19460	28859
Austria	243	406	415	443	3033	3415	3463	3607	35	330	370	490
Belgium	154	259	512	949	477	682	1178	2034	0	329	497	789
Bulgaria	0	0	56	75	724	734	929	1073	0	30	115	196
Cyprus	0	3	7	12	4	18	24	30	0	16	22	38
Czech Republic	62	166	414	531	1374	1759	2248	2517	3	243	438	623
Denmark	279	324	519	761	1759	2245	2526	2643	0	31	247	261
Estonia	3	21	30	30	505	612	626	607	0	1	35	89
Finland	831	696	850	1110	5490	4990	5810	6610	0	220	420	560
France	328	378	902	1476	9153	9953	12760	16455	403	2715	2925	3500
Germany	1206	2818	3619	4253	7260	9092	10388	11355	1742	3429	3070	5300
Greece	8	22	43	108	951	1012	1128	1222	1	107	386	617
Hungary	0	168	193	286	0	812	829	1272	5	144	250	506
Ireland	10	30	76	87	183	198	388	486	1	134	299	481
Italy	402	743	1179	1615	1655	2239	3521	5670	179	1016	1748	2480
Latvia	4	6	57	105	1114	1020	1147	1392	3	39	39	46
Lithuania	1	13	65	105	686	663	879	1023	4	55	109	167
Luxembourg	4	6	17	29	19	23	50	83	1	42	81	216
Malta	0	1	12	12	0	1	2	2	0	0	0	0
Netherlands	433	514	1148	1431	609	684	778	878	0	307	567	834
Poland	125	518	851	1223	0	3911	4227	5089	43	966	1327	1902
Portugal	170	206	289	302	2507	2179	2339	2322	0	281	429	477
Romania	0	0	0	0	3166	2794	2931	3876	0	224	363	489
Slovakia	3	52	116	147	358	447	576	690	0	82	137	185
Slovenia	10	26	54	58	445	415	495	526	0	41	79	192
Spain	228	388	513	861	3477	3583	4060	4950	258	1703	2470	3500
Sweden	651	914	1177	1441	7013	7978	8622	9426	144	340	528	716
UK	783	1060	1229	2249	560	323	958	3914	nm	996	2510	4205

Data Source: AEBIOM Annual Statistical Report 2011; www.aebiom.org

This means increased need in academic education. According to the SET Plan about 200,000 new jobs in bioenergy equipment supply and operation will be created by the year 2020; 800,000 new jobs in agriculture and forestry. In the engineering field (supply and operation) 5 – 10 % of those jobs require an academic degree focussed on bioenergy while in the supply chain 3 -5% will require such a degree. In addition to academics the establishment of bioenergy value chain managers will be necessary and are also included in the following table:

	Foreseen needs 2020	Foreseen needs 2030	Foreseen needs 2050
Bioenergy total			
	2,000,000	3,000,000	4,000,000
Engineering: Equipment Supply & Operation			
Total	200,000	200,000	200,000
Academics graduated per year	1.075 – 2,150	850 - 1700	430 - 850
Academics PHD per year	175 - 350	150 - 300	70 - 150
Supply Chain: Agriculture and Forestry			
Total	800,000	800,000	800,000
Academics graduated per year	2,570 - 4,300	2,050 – 3,430	1,030 – 1,720
Academics PHD per year	430-700	350-570	170 - 280
Supply Chain Manager per year	1,000	1,000	400

Qualitative Trends

The main challenge for bioenergy in Europe will be to provide considerably more energy, in particular heat and storable energy (solid, liquid and gaseous energy carriers) as well as support for smart (electricity) grids by providing energy "just in time". Competition with the food sector for agricultural bio-resources as well as with pulp and paper industry and the construction timber sector for forest biomass and particle board production and chemical industry will on the one hand drive the bioenergy sector increasingly to the utilisation of lower quality biomass, agricultural by-products, wastes and non-conventional resources (e.g. algae). On the other hand it will require highest efficiency standards for the technologies employed. Overseas imports of biomass will probably increase drastically leading to a demand for political regulations of the imports to reduce problems by unsustainable utilization in the producing countries. Furthermore it can be expected, that biomass thefts will increase. They already occur actually with increasing tendency and partly have already commercial scale.

Bio-resources are highly dependent on spatial context, relying on land and its fertility as the basic resource. Many bio-resources have unfavourable transport properties (high water content and/or low transport densities) requiring a thorough optimisation of logistics and in many cases de-central utilisation. This is in particular true for low quality biomass, agricultural by-products and many wastes, which will contribute an increasing share to European bioenergy. This will give raise to new business models and require a high degree of resource management, calling for complex consortia of stake holders and actors to co-operate in order to bring the full potential of bioenergy to bear.

As the underlying resource for bioenergy, namely land, is limited and subject to competing claims from food, material industry and energy sectors management of land as well as material flows from (in terms of harvested biomass) and to land (in form of recycled waste flows) will become crucial for a sustainable bio-economy. Regional management of this limited resource and utilisation of bio-resources will become a major driver for integrated policy approaches as well as economic and political importance, making regional political entities a beneficiary of the increased role of bioenergy in the European energy mix.

Besides innovation in resource management and business models, the requirement for high efficiency in resource utilisation will give raise to technical innovation. Bio-refineries will become an option to utilise resources to their fullest extent by providing no single products but portfolios of products and services. This will intertwine bioenergy even more with other sectors, namely the chemical industry. This trend calls for a strong R&D capability in Europe, such as EERA, paired with sufficient engineering capacity to develop technologies, plan facilities and operate them.

This trend towards innovative technologies will even become stronger as the heat market, the mainstay of current bioenergy utilisation, will undergo a profound change. More efficient buildings will generally decrease the heat load to be covered and bioenergy will get competition from other technologies well geared to supply lower heat loads e.g. heat pumps. This will shift the market for bioenergy more towards provision of (just-in-time) electricity, SNG and liquid biofuels. Again, this calls for a forceful technological innovation, even for companies that are currently quite successfully providing biomass heating systems, with the necessity to provide sufficient research engineering capacity to support this innovation.

2 On-going Activities

Staff development strategies of business

Companies employ different enrolling and training strategies depending on their size and strategic goals:

- Large companies with fossil product portfolios (e.g. ENI in Italy) are heavily investing in R&D in the field of bioenergy but so far do not convert their research results into substantial industrial initiatives. These companies will surely come out with striking bioenergy initiatives in due time. Their hiring strategy is mainly based on excellent quality of traditional science and engineering curricula. They operate internal training programmes particularly on financial and environmental topics.
- However, some changes have already taken place. E.g. Neste Oil has hired several experts in bio-chemistry and biotechnology to support the development on fuels from renewable raw materials to join their multidisciplinary teams.
- Large engineering companies producing and selling know how are choosing employees with either science (biology, bio-chemistry, etc.) or engineering (chemical, environmental, energy…) degrees. Quality of the candidates' disciplinary knowledge and engineering as well as science skills are a prerequisite but know-how in the bio-sector is appreciated. These companies often lament lack of knowledge of university alumni of how an engineering work is done in practice, how an industrial project is carried out and managed. In addition they would appreciate if life cycle thinking would enter the intellectual DNA of more than it is now. They are covering these gaps with internal training.
- Medium-size companies (with 200-300 employees) follow different hiring approaches: either they bet on the solid scientific and technical knowledge (especially in civil-, environmental-, chemical engineering) and augment the skills of their employees with internal training on financial and economic issues or they hire preferentially industrial engineering and management which allow the best compromise between technical and managerial knowledge. In both cases employees from top quality master programs featuring renewable and/or green technologies courses (even if not specifically bioenergy related) are given priority.
- Small companies generally bet on the quality and independence of the persons they hire. The liberalisation of the market of energy has led to an explosion of small companies pretending to deliver high tech and risky plants (e.g. bio-waste pyro-gasifiers) which more often than not have a severe shortage of skilled personnel, especially in the light of their ambitions. This knowledge deficit can lead to bad industrial practices in the field which in turn severely affects the standing of the whole sector with business, the general public and political decision makers.

As a general rule bioenergy technology has so far not attained the standing of an engineering discipline in its own right. The workforce active in bioenergy as well as along the whole supply chain is therefore composed of employees with different educational backgrounds with companies often providing educational fine tuning to enhance the skill base of their workforce. The hiring strategy of business which is looking for excellence in traditional curricula is cementing this status quo.

On-going educational activities

Bioenergy is less seen as an educational discipline in its own right (such as e.g. electrical engineering or aerospace engineering) and more as an occupational field to apply different disciplines. Therefore the vast majority of curricula on all levels of education, from vocational training to bachelor to master courses and doctoral schools is defined by the need of generic fields like mechanical, chemical and electrical engineering and, if the supply chain is concerned, agriculture, forestry, wood management and economics. On the vocational level the same rational applies, with employees in bioenergy featuring backgrounds like electrician, plumber and mechanic or, again in the supply chain, farmer and forester.

The rising importance of the sector has however led to different education strategies in Europe to integrate necessary skills for bioenergy into traditional curricula and the development of special educational offers. [8]

A look on the bioenergy supply chain in Figure 1 point to the following main disciplines wherein specific bioenergy education plays a main role – agriculture, forestry, wood management, engineering, policy (including regional development) and sustainable development. An international review of bioenergy training and education showed that the first three are the dominant relevant sectors. [9]

A recent study[10] lists 65 English-language Masters Courses in the EU27 plus Norway and Switzerland that include at least some bioenergy content. Additional Masters Courses offered in native languages were not included since their international appeal is limited.

On the international level the EUREC European Master in renewable energy technology is offered by a consortium of European universities which features a specialization in biomass technologies.

Looking at some sample EU member countries a quite diverse picture emerges. In Italy numerous master curricula concerning bioenergy are either in panning or implemented however their economic sustainability (depending mostly on public funding) is often shaky. Bioenergy content on undergraduate and postgraduate levels is just a minor part of the main curricula in engineering disciplines.

Austria offers masters courses e.g. in natural resources management and ecological engineering at the University of Natural Resources and Life Sciences in Vienna. Some University of Applied Sciences put their focus on renewable energies and natural resources like the one in Wieselburg offering a master course in renewable energy systems and technical energy management with a strong bioenergy focus. In most engineering master courses in Austria bioenergy is usually just a minor and in many cases elective part of the curriculum.

---

[8] Müller, S., Brown, A., Ölz, S., 2011: Renewable Energy – Policy considerations for deploying renewables. An IEA information paper, November 2011; http://www.iea.org/publications

[9] Helaion, K., et al., 2005: Bioenergy Training and Education Needs, SEI; www.seai.ie

[10] Watkinson, I.I., Bridgwater, A.V., Luxmore, C., 2011: Advanced education and training in bioenergy in Europe, Biomass and Bioenergy 38 (2012), 128-143

Large Finnish universities have master and doctoral level programmes in which there is at least a major part related to bioenergy/bio-refining/bio-economy. Several universities join forces in national doctoral programmes. Bioenergy is included at least in the following programmes: Graduate School in Chemical Engineering (coordinated by Abo Akademy University with Aalto University, Lappeenranta University of Technology and Oulu University), Doctoral Programme for Biomass Refining (coordinated by University of Helsinki, with Aalto University, Abo Akademy University and VTT), International Doctoral Programme in bio-products Technology (coordinated by Aalto University with Abo Akademy University, Universities of Helsinki, Jyväskylä and Oulu, Lappeenranta University of Technology, Tampere University of Technology), Graduate School in Forest Sciences (coordinated by University of Eastern Finland, University of Helsinki, University of Oulu and METLA). The Aalto University is one of the partners of Erasmus Mundus Master Programme SELECT and of Erasmus Mundus Joint Doctorate SELECT+ with responsibility for bioenergy. Both the programmes are coordinated by KTH, Sweden.

For Germany bioenergy education is very complex integrated in manifold options. "Studium-Erneuerbare-Energien" gives an overview (http://www.studium-erneuerbare-energien.de/). Around 250 study courses and qualification possibilities for the field of renewable energies are listed there – ranging from bachelor, master, diploma courses, training activities and dual studies, extra-occupational studies and long distance studies. From the subject, bioenergy education may be included in study courses such as: renewable/ regenerative energies, energy management, energy systems, energy technology, building technique, mechanical engineering, electrical engineering, process engineering, chemical engineering and environmental technique/ management/ engineering. But this list is by far not complete.

Other important courses with bioenergy modules are e.g. not included in these list are e.g. forestry, wood science and agricultural disciplines. These studies are not only focused on the production and harvest of bio-resources but include different utilisation routes as well. Besides traditional utilisation pathways of bio-resources central to these disciplines bioenergy technologies or their utilisation in bio-refineries are taught intensively.

In case of vocational trainings and lifelong learning a steady growing offer in courses can be seen across EU member states. Case in point is the Austrian effort on this level. There is a vocational farming school (in Freistadt) that is particularly dedicated to providing know-how for bioenergy systems and their supply. The Austrian Biomass Association runs e.g. training programs on bioenergy ranging from one day seminars to advanced vocational training courses. The Austrian Biofuels Institute offers training courses to companies in the biofuels business as well as for those considering entering it and for financial institutions providing biofuel funding and governmental agencies.

Summarizing on-going activities in education for bioenergy the following general conclusions can be drawn:

- Bioenergy has not emerged as a professional educational discipline in its own right;
- The workforce in bioenergy is therefore educated in a variety of traditional curricula following the requirements of their more generic fields;

- Bioenergy content is in most cases an add-on to existing curricula, mostly in the form of elective modules;
- Business shoulders the burden of fine tuning more generic education of their employees to the requirements of bioenergy through in-house training;
- Vocational training initiatives for bioenergy emerge in many EU countries. Co-ordination as well as standardization of these initiatives on a European (and even national) level is still deficient.

3 Needs and Gaps

Although bioenergy has a long tradition in Europe and subsequently has an established base in the education system in EU Member States, recent development and future trends bring educational requirements that cannot be covered by the existing educational system. Transforming in a larger context present industry towards bio-economy is creating huge challenges, where traditional tools taught are not any more sufficient and a modernization of curricula on every level to include multidisciplinarity, entrepreneurship and teamwork skills in multicultural groups is needed. Bioenergy in particular will see four major future challenges that together herald a wave of innovation:

- A substantial broadening of the resource base, including waste and waste water flows, residues from industry, commerce, landscaping, gardening, agriculture and forestry as well as unconventional resources like algae;
- The advent of an encompassing Bio-Economy, linking bioenergy with a complex production system for manifold products combined with the introduction of utilization hierarchies and the need of evaluation systems
- The particular requirements of achieving the SET plan objectives such as provision of storable energy, bio-fuels and integration into smart grids.
- Design of the interfaces to other disciplines along the utilization chain and handling of competitions for bio-resources

These challenges will strain the educational base for the workforce in bioenergy. In particular gaps between existing education and future requirement of skills of the workforce in bioenergy exist in the following areas:

- Engineering, technology development and operation
- (Bio)-Resource management
- Business innovation and supply chain management
- Improving skills in existing industries utilising bio-resources
- R&D
- Public involvement and decision making

Within these topical areas success of bioenergy in Europe depends on innovation in educational approaches and organisation of learning. In particular, innovations are needed in

- Modernization of curricula to include multidisciplinarity, entrepreneurship and teamwork in multicultural groups
- Practice and problem orientation of education
- R & D as well as educational infra-structure
- New teaching methods, including virtual education
- Mobility of learners and teaching staff
- Life-long learning

It must be stated here that education for bioenergy does not have to start from scratch. Existing curricula and training courses offer a solid fundament on which to build new educational capacities. In the following paragraphs the gaps still arising in the fields summarised above will be discussed in detail as well as needs necessary to bridge these gaps and overcome educational bottlenecks.

Engineering, technology development and operation

Bottlenecks, gaps and barriers

The challenge here is to provide well educated engineers and technicians that will satisfy the increasing demand for technical personnel in the bioenergy sector. Most jobs here are fairly conventional in their requirements as technology providers as well as equipment operation and maintenance call for mechanical engineers, chemical engineers, electronics and control engineers and technicians as well as manufacturing technicians. Bioenergy is here in a fierce competition with other sectors outside the energy sector, e.g. the automotive sector, as well as all sectors that provide renewable and non-renewable resource based energy equipment. All technical sectors in Europe are confronted with increasing demand for a skilled workforce at a time of shrinking interest of people entering the workforce in technical jobs. This creates a **bottleneck** in terms of trained engineers, that bioenergy shares with other industries in general and other renewable energy sectors in particular. The **barrier** here is that bioenergy, although it has a generally positive public image, is not seen as the particularly dynamic sector generating interesting job chances it actually is.

The **gap** to be seen here is not so much a gap in the provision of particular skills than a quantitative gap between available employees and jobs to be filled. As competition with other sectors will remain important for the foreseeable future, besides measures to interest European youth in general for technical careers, making the bioenergy sector more attractive compared to other contenders is becoming critical for reaching the SET plan goals. There is a definite gap between the attractiveness of the bioenergy sector and other, more established and bigger competitors for young technical talent that has to be overcome in order to provide a sufficient base of skilled labour to shoulder the burden of the highly dynamic development in this sector.

Many alumni of academic as well as vocational (at least in countries that do not require dual or co-operative education) education in all disciplines touched by bioenergy face a **barrier** when entering the job market in the form of missing practical experience. The **gap** between employer's expectation and applicants experience diminishes chances for young job starters on all levels of qualification and may also reduce market penetration of ideas from academia to business.

Education provides the fundament of a flexible and mobile workforce. It is therefore necessary to integrate a mobility element in the education on all levels. Though that is already addressed on the higher education level via European Union exchange programs (with still some room for improvement), there is a **gap** on the level of vocational training. Main **barriers** here are different educational systems and quality standards in the member states.

Innovation Needs

- *Modernisation of curricula to include multidisciplinarity, entrepreneurship and teamwork in multicultural groups*

One particular way of attracting young people to technical training is by offering modern curricula that while providing sound scientific and engineering fundamentals feature interdisciplinary education and foster entrepreneurship. This is of particular importance for bioenergy with its complex supply chain as employees in this sector will inevitably be required to understand economic, social and environmental implications of their work. More than in other sustainable energy sectors, life cycle thinking as well as entrepreneurial skills is necessary in bioenergy. This makes the need for modernised engineering and vocational training curricula especially pressing from the point of view of reaching the SET plan goals in bioenergy.

- *Practice and problem orientation of education*

A major factor for improving both effectiveness and attractiveness of education is to link training with practice. The better this link will be developed between the bioenergy sector and education institutions the higher the attractiveness of this sector to engineers and technicians of all disciplines and the better the alumni are prepared to meet the challenges of their professional life. There is a definite need for programs that link bioenergy industry with institutions for education, ensuring on the one hand practice and problem oriented learning and on the other hand early contact to companies, allowing them to impress and attract them to careers in bioenergy. The development of a tight bond between bioenergy business and education has to cover all levels, from vocational training to bachelor to master to PhD and post-doc education. The link on the latter two levels has to be seen in terms of more efficient research co-operation besides its educational impact.

- *R & D as well as educational infra-structure*

Besides contact to business there is a need for engineering students to be exposed to research and development within their curricula. In particular training at sites that offer access to pilot scale installations will greatly improve the skill level of future bioenergy engineers. There is a need to establish such research and development centres across Europe, co-ordinate their activities and open them to educational purposes. This should happen jointly with industry and academia.

- *New teaching methods, including virtual education*

Virtual education offers a chance for many educational institutions to join forces in providing high quality courses online. This becomes particularly important if curricula have to be modernised which usually is a costly enterprise. There is a need for enhanced co-operation between institutions for tertiary education to improve their virtual education capacities and co-operate to make outstanding courses in relevant topics for bioenergy available to their students.

- *Mobility of learners and teaching staff*

Creating a truly European, highly skilled and motivated workforce requires exposing students to different cultural contexts by supporting and stimulating mobility. Mobility in this respect however must not be restricted to mobility between universities in different countries, but includes also mobility to business. The latter mobility is also crucial for teaching staff in order to stimulate the necessary close co-operation between education and business in general.

A major gap identified here is the lack in mobility programs for vocational education level. If the bioenergy sector pioneers filling this gap it would provide the sector with a considerable advantage over other contenders for technical talent on the vocational level, helping to alleviate the deficit in terms of skilled personnel on this level. On top of that it would increase the capabilities of alumni from such a program as they gain professional and cultural experience (and possibly language skills) within their education. This would also add to a mobile and flexible European workforce in this sector.

- *Lifelong learning*

Lifelong learning is a necessity in all disciplines and sectors and bioenergy is no exception to this rule. There is however a particular need here as many new employees in this expanding sector have a professional background in other fields. It is therefore an urgent need to provide lifelong learning opportunities to employees in bioengineering that specially focus on technological innovation as well as issues related to the complexity of the supply chain, life cycle thinking and the interaction between different actors from resource generation to grid operation. In order to meet this need all synergies resulting from modernising curricula and implementation of virtual learning tools have to be utilised.

Resource management

Bottlenecks, gaps and barriers

Competition for limited resource capacity requires careful management of bio-resources. This competition is already visible in the forestry based supply for bioenergy as increased energy demand puts bioenergy against more traditional utilisation pathways such as pulp & paper and timber. Additional forest resources must be mobilised risking over-exploitation and de-forestation in developing countries. The competition for bio-resources in general will become a particularly vexing problem as the resource base will be diversified in future and competing claims to resources will spread far beyond what is currently already visible in forestry and in the case competition of bio-fuels with the food sector. Here we encounter a number of **barriers** for bringing on the full potential of bioenergy:

- Lack of knowledge on mass and energy balances along the utilization chains; danger of introduction of inefficient technologies
- Lack of consistent management of resources on a regional scale leads to uncertain raw material provision and resource bottlenecks for bioenergy technologies.
- As bioenergy increasingly utilises agricultural by-products (e.g. straw, intercrops), uncertainty about possible impact on fertility of taking additional biomass from fields restrict a broader utilisation of these resources. This is a particularly sensitive topic as over-

exploitation can lead to lasting damage to fertility and hence diminish further utilisation of the basic resource of land.

- In some European countries (i.e. Austria, Finland) forest resources are not utilised to their fullest potential, partly because ownership structures (small holders, unclear ownership) pose restrictions. The same holds true for agricultural by-products where retrieving and handling these resources has still room for improvement.
- All waste, waste water and residue-based resources are by far not utilized to their full potential, there does not even a suitable, broad knowledge, documentations about their amount and potentials exist.
- Complete new infrastructures would be necessary for efficient utilization e.g. from kitchen waste or toilet waste; such changes are difficult in established systems.
- Uncertainty about the impact of re-integrating residues of bioenergy technologies (biogas manure, ashes, etc.) on fertility of fields restricts implementation of bioenergy systems on a broader scale.
- Consideration of material products from bio-resources as main product and bioenergy as side-product; that leads to bio-refinery systems and a highly efficient utilization of the original resource.
- There is a lack of European-wide regulations for biomass trade, product quality requirements and subsidies.
- Consideration of energy savings if old systems are exchanged to new systems (e.g. conventional waste water treatment is very energy intensive; new systems may even produce excess energy)

These barriers point to a number of **gaps** in the educational system that pertain to different levels of qualification and disciplines:

- Regional planning so far has concentrated on issues of spatial planning and in some cases regional economic development. Regional resource planning and long term resource management has been less developed so far, although some industry sectors (e.g. sugar as well as starch industry) have pioneered the way to some extent. There is a definite skill gap on the part of regional planners as well as regional authorities on the requirements of an encompassing "Bio-Economy", including methods of optimal resource allocation, taking bioenergy (and bio-refinery concepts) into account. Another skill gap exists with respect to other spatially relevant SET plan programs such as smart grids and smart settlements and the contribution bioenergy can bring to meet these objectives. On top of that knowledge of the societal processes and business models necessary to bring together the different actors along the bioenergy value chain has also not sufficiently penetrated the communities of these actors.
- Farmers are responsible for the fertility of their fields and are well educated to maintain it under current agricultural practice. Skills to handle utilisation of by-products in a sustainable way retaining fertility however are in short supply in many European countries, leading to an impediment of the development of innovative bioenergy systems.

- Skills (as well as equipment and appropriate technologies) to harvest additional bio-resources are missing in many fields. This holds e.g. for small holder forests, where neither the knowledge nor the equipment is available to the individual farmer in some countries. It also holds for agricultural by-products in some cases (e.g. sugar beet leafs, corn cobs, many intercrops, etc.) and forest residues.
- Reintegration of residues from bioenergy technologies is both a cost factor as well as a crucial factor for maintaining fertility of the land. Knowledge regarding sustainable reintegration as well as skills (and in some cases technologies) to apply them properly to the land is missing in many cases. Handling of residues could contribute to GHG, water pollution and soil degradation, if it is done wrongly.

Innovation Needs

Modernization of curricula

Modernisation of curricula in spatial planning, waste and waste water management as well as agriculture and forestry and wood management on all levels is needed. Spatial planners need to be exposed to knowledge about spatial requirements of a Bio-Economy as well as optimal site, size and logistical requirements for bioenergy and bio-refinery installations. E.g. Waste and waste water management curricula must be enriched by knowledge about new collection strategies, energetic and (combined) material utilisation of waste materials and waste water, quality requirements for different technologies and the subsequent utilisation of the residues from energy provision.

Curricula on all levels of agricultural, forestry education need to address challenges posed by a Bio-Economy in general and bioenergy in particular to production, harvest, transport, conversion and quality control. Sustainable harvest of residues from fields and forests, optimal handling of residues from bioenergy production (ashes, biogas manure, etc.), quality control for products utilised in energy provision and the combined energetic and material use in bio-refineries are among the most important topics for curricula modernisation. Basic knowledge in Life Cycle Assessment as well as material flow management must become compulsory elements of curricula. New courses for algae, marine biomass, handling of urban and rural residues etc. should be offered.

New teaching methods, including virtual education

Similar to the need stated for engineering modernisation of existing curricula require implementation of new teaching methods, in particular practice and problem oriented training as well as utilisation of all possibilities offered by virtual education. The latter is of special importance here as curricula modernisation is only feasible by close co-operation between educational institutions covering different disciplines. Also participation of industry should be included, especially in the development of process simulation and optimisation tools. Looking for co-operative approaches to make high quality courses available via IT channels and thereby pooling resources across Europe will decrease costs and increase quality of educational efforts to meet the SET plan challenges for bioenergy in this field.

Life-long learning

The same line of argument discussed in the section about engineering holds for resource management, too. As many employees currently employed in spatial planning and waste management did not have a direct link to bioenergy within their disciplinary education, knowledge about particular aspects of bioenergy and bio-resources must urgently be made available via lifelong learning channels, possibly utilising synergies with efforts in virtual education.

Existing lifelong learning courses in agriculture and forestry must be augmented by including topics relevant to the modernisation of curricula, providing practitioners with a possibility to up-date their knowledge about requirements for a Bio-Economy, again utilising synergies with virtual education efforts.

To boost bioenergy education one important source of human resources is experts with long experience either in academia or industry to act as mentors for younger ones.

Business innovation and supply chain management

Bottlenecks, gaps and barriers

As bioenergy demand increases, its resource base broadens considerably and new markets (just-in-time electricity, bio-refinery product portfolios, etc.) emerge, new business models are necessary to exploit the sector's potential. The challenges here are in particular to link the diverse stakeholders along the value chain economically, providing balanced profit within complex supply chains, integrate bioenergy and energy provision systems in the broader objective of a Bio-Economy. On top of that economic models to exploit the particular advantage of bioenergy over other energy forms based on renewable resources, namely the provision storable energy and support of distribution grid stability, have to be widely applied.

Besides these challenges an increase in trade of bio-resources and transportable intermediates produced from them will emerge as demand for bioenergy increases in areas that do not produce them (e.g. urban areas, densely populated regions, etc.). This international trade in bioenergy resources will also require skilled actors to operate. The main **barrier** here is that effective supply chain management (and the required business innovations) are still underdeveloped for bioenergy.

Knowledge **gaps** exist for many actors along the bioenergy value chain regarding the different already existing Bio-Economy business models, their particular requirements to transfer them into different contexts and their legal, technical and organisational requirements. Supply chain management becomes critically important as limited resources have to be managed, with diverse and numerous stakeholders involved, to provide stable input to bioenergy systems. As alternative resources (e.g. wastes, agricultural by-products, etc.) gain more importance, new supply systems have to build up, involving stakeholders that have limited previous experience of co-operation with each other. The job profile of a special "bioenergy supply chain manager", who combines knowledge about the actors and technologies involved along the whole supply chain with knowledge about appropriate business models but also about conflict resolution, creative win-win situations within a supply chain and a basic understanding of psychology and communication may have to be developed and the necessary education has to be initiated.

Innovation Needs

- *Development of curricula focussed on bioenergy supply chain management*

There is an urgent need to develop education for experts capable of managing the supply chain as well as marketing of services of bioenergy within the larger context of an encompassing Bio-Economy and SET plan objectives. These curricula must be developed in close co-operation between educational institutions covering spatial planning, agriculture, waste management, business administration and technology as the topic is cross-cutting and requires interdisciplinary education. These new curricula have to be developed for all levels of tertiary education, from bachelor to master to PhD level.

- *Virtual education*

The curricula development is only feasible by close co-operation between educational institutions covering different disciplines. The argument made for resource management, namely that looking for co-operative approaches to make high quality courses available via IT channels and thereby pooling resources across Europe will decrease costs and increase quality of education, is particularly true in this case of implementing a new educational track that requires highly interdisciplinary co-operation.

- *Life-long learning*

Supply chain management for bioenergy is an urgent need for reaching the SET plan objectives. Waiting for alumni of new curricula to start managing supply chains is therefore not an option. It is therefore particularly needed to jump start improvement of supply chain management for bioenergy by providing targeted lifelong learning modules to practitioners with backgrounds in agriculture, forestry, regional development, engineering and business, possibly utilising synergies with efforts in virtual education in the parallel development of comprehensive curricula for bioenergy supply chain managers.

Improving skills and knowledge in existing industries utilising bio-resources

Bottlenecks, gaps and barriers

There exist a number of business sectors that have utilised bio-resources for a long time. They naturally concentrate on their main products (e.g. pulp & paper, animal feed, sugar, food & beverage etc.). In many cases they do not fully realise the chances offered by bioenergy technologies, either for utilising by-products or wastes or providing additional business chances. Even if they become aware of these chances, implementation of these technologies often runs against the **barrier** of technological path-dependency within the given sector. A case in point is the sugar sector, which has reacted slowly to the chances of utilising sugar in different ways than as a food product, even in the face of severe global competition (and ensuing capacity reductions) on this market.

In this area the main **gap** is thorough knowledge of technological and market opportunities offered by as well as of requirements for implementing bioenergy systems within the particular sector. In many cases adoption of bioenergy technologies requires re-education of the workforce currently employed and/or integration of employees with a different background as usually employed by the sector in question. For adopting innovative bio-refinery technologies these sectors have to undergo a considerable re-orientation of the skill profile and training of their workforce when entering to the era of Bio-Economy.

Innovation Needs

- *Modernisation of curricula to include multidisciplinarity and entrepreneurship*

Existing bio-resource based industries build on traditional educational tracks, such as chemical and mechanical engineering or food technology, in many cases even with highly specialised curricula. Bringing the potential of these sectors in terms of bioenergy to bear requires substantial modernisation of these traditional educational tracks, in particular the highly specialised curricula, by integrating key know-how on bioenergy technologies as well as related business chances and models. This calls for using synergies with the modernisation of engineering curricula as discussed in the section about engineering and development in order to improve on the one hand the quality of the education for traditional bio-resource based industries in the face of an encompassing Bio-Economy and on the other hand helping to meet the objectives of the SET plans by mobilising the bioenergy potential of these industrial sectors that have already mastered their logistic challenges.

- *Lifelong learning*

Again, waiting for alumni from reformed curricula is not an option for reaching SET plan goals. It is therefore important to reach decision makers and employees in industries like pulp & paper, sugar industry but also industries based on fossil resources, in particular refining. The need here is to develop attractive lifelong learning modules focussed on the need of these sectors and their actors. Using synergies with curricula development and modernisation as well as with virtual learning tools is necessary, but main emphasise must be laid on effectively targeting the audience in question.

R & D

Bottlenecks, gaps and barriers

The challenges ahead of bioenergy (broadening of raw material base, bio-refineries, etc.) require a dramatically increased R & D effort across all science, engineering and business disciplines. Universities and research institutions across Europe are already addressing major research questions regarding bioenergy with great effort and dedication. Similar to the engineering field a **capacity bottleneck** exists regarding the number of available researchers, in particular in science and engineering disciplines.

The gap in this field is quantitative and qualitative in nature. It requires raising the attractiveness of bioenergy as a field for successful academic careers but also as a field of intensive co-operation between business and academia with the possibility of easy exchange of talent between these two career lines.

The challenges posed by bioenergy innovation are increasingly interdisciplinary. Current scientific careers however focus on disciplinary excellence, opening a competence gap. Successful technological development will require integrated chemical, thermo chemical, bio-chemical and mechanical skills, innovation along the value chain will draw on technological, entrepreneurial and social skills.

Research infra-structure for bioenergy from micro reactors to larger scale facilities is limited and its modernisation is a great challenge in many countries in Europe, especially on the pilot plant scale that is crucial for the transition from lab to market. A main **barrier** besides nationally varying forms of restrictions on R & D infra-structure at universities is here insufficient co-ordination between different member states as well as between academia and business to focus available resources and avoid parallel development. With regard to education (especially in engineering), these pilot plants may also play an important role in providing students with practical skills and the problem solving capacity they need in their future jobs.

Innovation Needs

- *Modernization of curricula to include multidisciplinarity, problem orientation and entrepreneurship*

Education on the PhD and Post Doc level needs to focus even more on multidisciplinarity, problem orientation and entrepreneurial skills as it does currently. On top of that attractiveness of research careers in bioenergy has to be massively improved. This is only possible if innovative skill profiles among research staff are encouraged and careers on the base of interdisciplinary scientific activity become the norm rather than the exception. The need here includes close co-operation of existing and future (see below) research facilities from industry and academia to form the infrastructure for a strong "bioenergy scientific community", offering international career plans as well as a strong research identity as a cutting edge research field for creative and innovative minds not restricted by disciplinary borders.

A particular need is exchange of researchers in their formative PhD phase between business and academia. This exchange is not only necessary to foster close co-operation between science and business in order to shorten lab-to-market times for innovations but must be seen as integral part of educational efforts to instil practice orientation into prospective researchers.

- *R & D as well as educational infra-structure*

Bioenergy is facing a wave of innovations as resources diversify, technological solutions proliferate and systemic utilisation of bio-resources is required by the advent of a Bio-Economy. The current European research infrastructure is severely deficient, in particular with regard to pilot scale facilities. It is an urgent need to build a well-integrated network of high quality research facilities in co-operation between academia and business all over Europe that pertain to the systemic challenges of utilising a broad range of feedstock providing key energy services (e.g. "just-in-time-electricity", biofuel, etc.) as well as other products within the framework of an encompassing Bio-Economy. The network must fill the gaps of existing pilot plant installations from both academia and industry by addressing strategic research and development topics currently not adequately covered (e.g. raw material conditioning and blending, multi-grid integration of bioenergy technologies, etc.).

This network is not only necessary to provide the hard-ware basis for bioenergy innovation in Europe. It will play an important role in the educational effort to form excellent researchers in the field. For this objective to achieve it has to provide high quality research education facilities enriching PhD and Post Doc curricula at European academic institutions and offer attractive careers for top scientists in bioenergy related fields.

- *Mobility of learners and teaching staff*

The research facility network proposed above needs to build on a focussed mobility program that allows exchange of students and post docs between the network, universities as well as business.

Public and decision makers

Bottlenecks, gaps and barriers

Market absorption of bioenergy technologies as well as bioenergy services is clearly dependent on public image of the sector and acceptance by political decision makers on all levels. The main **barrier** here is that bioenergy has a multiple image disadvantage against other energy technologies. On the one hand bioenergy is seen as less "high-tech" (e.g. than photovoltaic or hydrogen-based technologies), mainly because it is seen as already established technology, providing a less exciting service, namely heat. On the other hand when it provides biofuel and electricity from crops (e.g. RME-biodiesel and biogas from corn silage) it is seen to be a major competitor of the food sector and even a culprit of environmental degradation here and in developing countries (e.g. using palm oil from questionable plantations that are responsible for rain forest loss).

The major **gaps** here are on the one hand insufficient knowledge transfer to the general public by research as well as business as well as an occasional knowledge gap regarding energy consultants that are to a great extent influencing public opinion and political actors on all levels. The gap is aggravated by the complexity of the value chain of bioenergy, making issues relevant to this sector even less comprehensible to the public as well as decision makers. The message of bioenergy as a vital element in a future sustainable energy system for Europe, providing fuel and storable energy as well as income and jobs has to reach political decision makers and the general public. In addition to that energy consultants have to be trained to exploit the chances of bioenergy as an integral part of any comprehensive energy solution.

Innovation Needs

- *Modernization of curricula*

Energy consultants serving the general public as well as business, communities and regions are an emerging and powerful layer for information transfer for efforts to reach SET plan objectives. Training for these consultants is regulated on member state level if at all. There is an urgent need to modernise the curricula of training of energy consultants to include knowledge about the proper role of bioenergy for achieving SET plan objectives as well as about the particular chances, requirements and limitations of bioenergy systems.

- *Life-long learning*

Similar to the argument made for resource management and supply chain management, there is an immediate need for reaching energy consultants already active and providing them with a comprehensive picture of bioenergy and its role for achieving SET plan objectives. The only form to realise that is by developing targeted and attractive lifelong learning opportunities that increase their competitiveness in offering their services. These lifelong learning modules must take into account that energy consultants come with widely different training backgrounds and cater to different customers. This makes focussing these modules a challenging task.

Besides educating energy consultants there is a need to inform political decision makers on all levels about chances and requirements for bioenergy as well as about the relevance of bioenergy for the whole, complex value chain and SET plan realisation. This requires an intensive, sustained and much focussed program of information modules that support decision makers in their duties.

A co-ordinated PR effort to inform the general European public about the chances and requirement of a sustainable Bio-Economy and the role of bioenergy is an additional means to further support the implementation of the SET plan goals. As the utilisation of bioenergy is particularly dependent on local and regional context, such a PR initiative must also be adapted to the local level and to direct contact with individual citizens. Activities like town hall meetings, expert lectures and organised excursions to best practice examples can be employed to this end.

4 Recommendations

The following recommended actions address key needs to overcome gaps and bottlenecks identified in this report. These recommendations however have to be seen as examples rather than a comprehensive list of necessary actions, showing pathways to generate the educational basis for a workforce that is capable of fulfilling the role bioenergy has to play in achieving the objectives of the SET plans in Europe.

Filling the skills, competences and knowledge gap

Focus Area 1: Meeting the skill/competencies gaps of new and emerging technologies

Title: Prototype Bachelor, Master and Doctoral Curriculum "Bio-resource Value Chain Manager"

Action A prototype bachelor and subsequent master curriculum for a Bioenergy Value Chain Manager will be developed by an interdisciplinary team of educators with backgrounds in agriculture, economics and technology and practitioners from across the bioenergy value chain. The curriculum will enable alumni to manage the supply chain of bioenergy technologies in particular regional contexts and optimise resource utilisation within the framework of a Bio-Economy and objectives of SET plans.

In order to educate a new generation of experts for bioenergy with the capacity in renewing the whole business area also deep knowledge based on scientific understanding is needed. This type of education requires close connections to research and can/should be done together with industry and research institutes (e.g. with EERA). The prototype curriculum will provide a benchmark for European universities for the implementation of such curricula within their institutions.

EQF Level 6-8: R&D, engineering, developers, others

Timeframe The prototype curriculum will be developed until 2014 followed by curriculum implementation by 2016.

Objective As there is an urgent need for well-educated bioenergy value chain managers, developing a prototype curriculum will serve three objectives:

- speeding up the process of implementing such curricula by helping universities to structure these studies along a ready-made template
- ensuring the quality of curricula by using a broad range of experts from academia and business in the development of the prototype curriculum
- facilitate joint degree developments between different European universities by providing a sound benchmark for curricula development

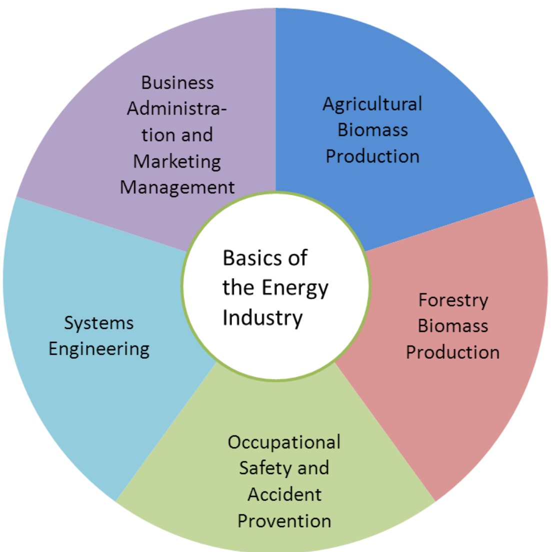
Title: Standardised vocational training for skilled biomass management and bioenergy personnel

Action The vocational education for biomass management and bioenergy is already an existing vocational education initiative in Austria and has good response. In the Austrian case the training comes in the form of a full dual, co-operative vocational training (with 3 years duration) as well as a re-training for personnel with an agricultural and/or forestry background. The action would build on this experience and implement this training in other EU-member states creating an EU-wide standardized curriculum.

The training could address:

- young people who aspire a vocational qualification in biomass and bioenergy
- farmers and foresters with appropriate practice
- workers from agriculture and forestry
- all persons interested in biomass and bioenergy with appropriate practice

The curriculum involves the following areas:



EQF Level 1-2: support (assistance, production, transport)

Timeframe Until 2014: Definition of an EU-wide standardized curriculum
From autumn 2014 on: Implementation in the EU-member states

Objective Bioenergy requirements need a new design and organization of vocational training. Organized as co-operative dual training with a strong practice element, specialized personnel will be qualified in the field of bioenergy and biomass management respectively personnel with background in agriculture and forestry will be re-trained to meet the challenges of bioenergy and biomass management.

Focus Area 2: Strengthening and developing existing skills/competencies

Title: Skills upgrade for conventional bio-based industries

Action Conventional bio-based industries like sugar, pulp & paper and food industry must play a key role in implementing bioenergy according to the SET plan goals. These industries already have excellent access to resources and good command over the supply chain associated with their key resource. They may supply energy services using residues generated along their supply chain (e.g. sugar beet leaves, straw, etc.) as well as from their own processes.

This action will develop tailor-made training modules targeted at mid to high management, engineering staff, procurement and marketing personnel to improve their awareness of chances posed by bioenergy utilisation as well as providing them with the necessary skills to implement bioenergy technologies within their industries. The courses will be addressed to each sector individually and provide a full program for skills-update for all involved employees and management.

The courses will be developed in co-operation between the sectoral industrial associations (e.g. Comité Européen des Fabricants de Sucre), EUA-EPUE and the KIC Innoenergy and made available through partner universities and innovation networks like ESEIA.

EQF Level 4-6: manufacturing, installation, O&M, etc.

Timeframe Start: 2013, implementation of courses 2017

Objective The main objective of the skills upgrade for conventional bio-based industries is to tap into the huge potential of bio-based industries to implement bioenergy solutions via removing the know-how deficit that exists in these industries regarding bioenergy in general and the application of complex bioenergy systems within their supply chain as well as their processes in particular.

Title: Skills upgrade for energy consultants

Action Energy consultants are key actors in promoting energy solutions in the public arena, business as well as in communities as they are primary contact persons for any actor willing to change his energy system. In many cases these consultants are however not qualified to provide reliable and practical advice regarding bioenergy, given the complex supply chain and demanding technological know-how necessary to implement bioenergy solutions.

The proposed action provides training modules targeted towards different groups of energy consultants (consultants to individuals, business and industry, communities/regions, etc.) and upgrades their know-how concerning bioenergy solutions within their sphere of activity.

The training modules will be tendered by the KIC Innoenergy who will also co-ordinate their implementation. Modules have to be developed for distance learning (using the European bioenergy virtual learning platform as a dissemination channel. National bioenergy associations (under co-ordination of the European Bioenergy Association) will then be tasked with organising courses in their national context.

EQF Level 3-8: management, finance/insurance, developer, IPP/utility

Timeframe Start: Tender 2014, implementation of courses 2017

Objective The main objective of the skills upgrade for energy consultants is to improve the qualification of key gate keepers to a change in the energy system. It is important to train energy consultants in understanding the function of the complex bioenergy supply chain as well as the particular features and chances offered by bioenergy systems in order to promote bioenergy implementation on all levels.

Focus Area 3: Online information and other tools

Title: European bioenergy virtual learning and information platform

Action The European bioenergy virtual learning platform co-ordinates and manages digital educational content in the field of bioenergy. It acts as a quality control institution, providing criteria for all digital educational content (streamed lectures, virtual classrooms, digital courses and course modules, etc.) for all levels, from vocational training to bachelor, master and doctoral level to digital lifelong learning modules.

As members of content development teams also senior experts could and should be involved to provide practical experience.

The platform will employ a content sharing system that remunerates the content providers while offering educational institutions a possibility to reduce the costs of providing their students with high quality education in fields where they may not (yet) have skilled staff.

EQF Level all

Timeframe Implementation of the platform: 2015

Objective The European bioenergy virtual learning platform has the objective to speed up the modernisation process for curricula relevant to bioenergy and in particular to increase the capacity for multidisciplinary education by providing quality controlled digital educational content at affordable costs to educational institutions.

Fostering public involvement, access and up-take by the labour market

Focus Area 1: Promoting mobility, life-long learning and workforce training

Title: European co-operative education mobility program for bioenergy

Action Practice oriented learning requires co-operative education between academia and business. This in turn requires special mobility programs, allowing students to move to business and/or pilot research facilities within their curricula. This mobility is different from current student mobility programs as it requires more flexibility regarding the duration of the stays as well as strict co-ordination between the universities and business/research facilities receiving students. Different programs for cooperation range from compact pilot plant exercises with durations of 2-4 weeks to team projects of 1-3 months to individual research projects with 1 – 2 semesters duration. The mobility plans have to include the definition of measurable objectives as well as a detailed schedule and procedures for grading student achievements. This mobility program will be initiated by the European Commission as an integral element within its academic mobility efforts in close co-operation with the EIT, BRISK as well as the enlarged European Network of Bioenergy Research Pilot Plant Facilities (see below).

EQF Level all

Timeframe Development of program framework and contract templates for co-operation between educational institutions, pilot plant networks and business until 2014
Implementation of student mobility: 2015

Objective These mobility programs aim at improving practice oriented education by providing a co-ordinated exchange of students between academia and business. Although internships are already common, this mobility program offers a new level of co-ordination between academia and business so that stints of students in companies are utilised to their full educational capacity.

Focus Area 2: Industry involvement and partnerships

Title: European Network of Bioenergy Research Pilot Plant Facilities

Action The European Network of Bioenergy Research Pilot Plant Facilities comprises installations from business, research institutes (e.g. EERA) and academia that feature research pilot plants for bioenergy technologies as well as key technologies along the bioenergy value chain (e.g. pelletizing, raw material conditioning, conversion processes, grid integration such as biogas cleaning, etc.). It builds on the existing BRISK network (http://www.briskeu.com) and enlarges it in both size and scope. The network co-ordinates

- research and technological development;
- interdisciplinary research education for PhD and post doc curricula;
- practice oriented educational programs offered to universities that are members (offering pilot plants of their own) or associate members (offering educational services) on the bachelor and master level;

- further enlargement of the network building pilot plant installations for strategic technologies within the bioenergy value chain.

The network will be an integral part of action within Horizon 2020 initiated by the EIT and EERA. It will take the form of a PPP with the EIT taking the responsibility for co-ordination of the network.

EQF Level 6-8: R&D, engineering, developers, others

Timeframe Implementation of the network merging the existing BRISK network with other national and European bioenergy pilot plant networks: 2016

Objective The European Network of Bioenergy Research Pilot Plant Facilities will serve four objectives:

- forming the infrastructural backbone to technological research and development of bioenergy in Europe
- providing a platform for practice oriented education in the field of bioenergy on all levels
- offering career tracks for top researchers in the field
- providing the field of bioenergy research with additional attractiveness for creative and innovative scientists, researchers and engineers.

Focus Area 3: Strengthening public involvement

Title: European Bioenergy Public Information Campaign

Action Public information is a key factor to involve the public in the endeavours to utilise biogenic resources in Europe to their fullest extend as well as to mobilise the workforce necessary to operate the complex value chain of a Bio-Economy in general and bioenergy in particular. Given the European significance of bioenergy and the strong link of bioenergy to the spatial context this Public Information Campaign must be co-ordinated on the European level but brought to the citizens in their local context. The action therefore involves town hall meetings about chances and requirements of a Bio-Economy, life-streams of expert lectures via internet to local outlets providing technical, environmental, social and economic knowledge about key issues of bioenergy to the public as well as moderated discussion for a in different regional settings addressing local issues of bioenergy implementation.

The campaign will be framed and co-ordinated by the European Commission in co-operation with the European Biomass Association, EPUE and other innovation networks involved in renewable energies. The organisation of the events will be entrusted to national contact points answering a tender by the EC. The European bioenergy virtual learning and information platform (see above) will be a partner in providing content to this campaign.

EQF Level undefined

Timeframe Development of campaign framework and tendering for national contact points until 2014
Implementation of campaign: 2015-2017

Objective This campaign will serve two objectives:

- accustom the general European public to the chances and requirements of a bio-based economy and the utilisation of their bio-resources within their local context and
- mobilising a workforce of young people entering the job market as well as job-seekers with other backgrounds to join the endeavour to utilise bio-resources for sustainable energy and material provision.

Planning and enabling skills development

Focus Area 1: Sector skills assessments and observatories

Title: European Bioenergy Skills Requirement Survey

Action Bioenergy is an extraordinarily broad field with a large number of different actors and sectors involved. In order to fine tune educational programs for the expected dramatic increase in well-educated employees and entrepreneurs in this field a comprehensive survey among business representatives about the skills expected from the future workforce is necessary. This survey should be oriented along the bioenergy supply chain (see fig.2) and should include all actors listed there. The survey must also take regional differences in the skill profile of different actors into account. It has to cover all levels of education but in particular vocational training and academic education.

This survey should be carried out by existing innovation networks as present in the core group and should be co-ordinated by the KIC Innoenergy.

EQF Level 3-5: manufacturing, installation, O&M, etc.
1-2: support (assistance, production, transport)

Timeframe Start: 2013, end report due 2014

Objective The main objective of European Bioenergy Skills Requirement Survey is to provide a base line of skill requirements as seen from the business side in order to help educators to fine tune their courses according to needs required by the labour market in bioenergy. A further objective of this survey is to provide a common reference system for education in the field of bioenergy, thus supporting co-operation as well as standardisation of European efforts to strengthen the skill base of the workforce.

Focus Area 2: Analysis of on-going activities

Title: European bioenergy vocational training report

Action The European bioenergy vocational training report analysis on-going activities throughout the Union according to

- content
- teaching methods and standards
- co-operation with business

The report will consist of national chapters, describing vocational training initiatives and exploring possible synergies between different training courses. It will cross-link the national chapters by analysing what European synergies are possible between national initiatives as well as what European educational standards may be implemented in order to facilitate mobility in vocational training.

EQF Level 3-5: manufacturing, installation, O&M, etc.

Timeframe Tendering of the report: 2012
Report finalised: 2014

Objective The report forms the base for European initiatives to standardise and improve vocational training for bioenergy in Europe. Besides that it lays the fundament for mobility programs on the vocational training level within Europe. It will become the starting point for strategic development of vocational training initiatives that meet the challenges of building and operating ever more complex bioenergy technologies as well as running the bioenergy value chain.

SET-Plan Energy Education & Training Carbon Capture and Storage (CCS)

Carbon Capture and Storage

Working Group Contributors

1.	**Rapporteur:** Olav Bolland	SEEIT and EUA-EPUE	NTNU, NO
2.	Philippe Mathieu	assisting the rapporteur	NTNU, NO
3.	Reza Fakhrai	KIC InnoEnergy	KTH, SE
4.	Hans Geerlings	SEEIT	TU DELFT, NL
5.	Antony Benham	EERA	Nottingham Centre for CCS, UK
6.	Régis Farret	ESFRI	INERIS, FR
7.	Nils A. Røkke	ESFRI	SINTEF, NO
8.	Pacelli Zitha	SEEIT	TU DELFT, NL
9.	Martin Pogoreutz	EPPSA	ANDRITZ Energy & Environment GmbH
10.	Martyn Fletcher	EPPSA	Doosan Babcock Power Systems Limited
11.	Andreas Brautsch	EPPSA	Alstom Thermal Power, CH
12.	Gian Luigi Agostinelli	EPPSA	Alstom Thermal Power, CH
13.	Fedora Quattrocchi	ZEP	Italian National Institute for Geology and Volcanology
14.	Nikolaos Koukouzas	ZEP	CERTH, GR
15.	Niels Poulsen	CO2GeoNet	CO2GeoNet Executive Committee; GEUS, DK
16.	Rui Pena Reis	EUA	Univ Coimbra, Pt

Helge Hellevang (University in Oslo, EUA) provided a useful review of the report.

Annexes

Annex 1: Questionnaire and replies

Annex 2: List of worldwide large-scale CCS projects (source: Global CCS Institute[1])

Annex 3: List of courses considered as essential for a storage education

Annex 4: Manpower needed for the various phases and skills to bring a project of a demonstration power plant with capture to completion

Annex 5: Non-exhaustive list of universities

Annex 6: Non-exhaustive list of CCS laboratory facilities, mainly from the ECCSEL initiative

[1] www.globalccsinstitute.com/data/status-ccs-project-database

Introduction

In order to meet the objectives of the SET-Plan, an exercise has been carried out in order to support the definition a European Energy Education and Training Initiative that builds on the technology and research initiatives of the SET-Plan. The goal is to work toward a coordinated approach to assess the current and future situation with regards to energy skills in Europe and to engage in actions aimed at building up and attracting energy expertise. This report deals specifically with Carbon Capture and Storage (CCS). A number of similar reports have been made for various other energy related areas.

This report aims to answer the following question: Do we need to up-scale, adapt/link existing instruments, or create new ones to meet the needs and fill the gaps within CCS Education and Training (E&T), now and in the next 15 years. A survey of the current situation and of the on-going actions has been carried out. In order to identify and list the work forces needed in the CCS chain today and in the next 15 years, a questionnaire was developed and sent out to a large number of CCS stakeholders. A non-exhaustive mapping of EU universities, research centres and laboratories with expertise and competences in CCS was done. A list of courses covering the CCS chain, i.e. capture, transport and storage technologies as well as legal issues and communication, was compiled. That exercise allowed identification of what are the needs and the possible gaps in E&T in the CCS chain. Final recommendations are derived from the analysis and processing of all the available data.

It should be emphasized that this work is the starting point of a long-term process. This report is a result of work in a rather limited time period, and the information about CCS related activities in Europe is not complete.

Definition and boundaries of CCS

From the technical point of view, CCS consists of the three links of a chain composed of capture, transport and permanent storage of the captured carbon dioxide (CO_2). The use or re-use of CO_2 in industrial processes is NOT taken into account in this work, except for Enhanced Oil Recovery (EOR) and Enhanced Gas Recovery (EGR), which can be associated with permanent storage in depleted hydrocarbon reservoirs. Anyway, the amount of CO_2 aimed at industrial applications is so much less than the projected amounts of CO_2 captured for climate change reasons that the permanent storage of large volumes of CO_2 is unavoidable in the strategy of the reduction of its emission to the atmosphere. In several pilot and demonstration projects, EOR/EGR is associated with CCS (see annex 2).

The use of biomass and biological wastes as a feedstock, alone or in mixture with a fossil fuel, for instance in IGCC power plants, may result in negative emissions or remove CO_2 from the atmosphere and consequently may reduce not only the emissions to come, but also the “past” emissions, provided the biomass utilisation is sufficiently low in life-cycle CO_2 emissions.

Energy saving as such is not inside the scope of the current work. However, the process integration, the risk management, and the techno-economic optimization of an industrial installation equipped with a CO_2 capture process belong to the objectives of E&T. Bio-technologies, and more particularly bio-mineralization, are not considered as being inside the scope, whereas mineralization of CO_2 is considered as a part of the storage options.

The storage options are essentially deep saline formations, depleted oil and gas reservoirs, coal seams, and mineralization (mineral carbonation). Storage in the ocean is excluded.

Economy of the global CCS system, legal, entrepreneurial, environmental, health and safety, social aspects and required workforce/personnel belong to the assessment of needs and gaps.

A prerequisite for the large scale deployment of CCS is the demonstration of the technical and economic feasibility of existing technologies. At the same time, the research programs should deliver more efficient and cost competitive CCS technologies based on improved components, integrated systems and processes to make CCS commercially feasible by 2020.

The report is assessing the needs and gaps as well as barriers and bottlenecks to set up E&T aiming at the achievement of these objectives.

1 Current situation

In order to have a good picture of the current situation and of the future trends of the workforces required in the CCS area, both technical and non-technical, a questionnaire was made and sent to a large number of stakeholders. The mailing lists of various associations were used, covering a large number of the players within CCS; CO2GeoNet, ZEP Platform, CATO, IEA GHG R&D Programme, and personal contacts of the group members. The questionnaire was sent to around 2000 e-mail addresses.

The questionnaire, shown in annex 1, shows the work forces expressed in man-years for the various items of the CCS activities.

From the replies, the results presented on Fig 1 were derived. There were 75 replies of which 50 came from EU+Norway (EU+No) so that the sample may be considered as representative, although not demonstrated as such by statistical methods, and hence provides a useful picture for the interpretation of the needed manpower. The results are presented in more details in annex 1.

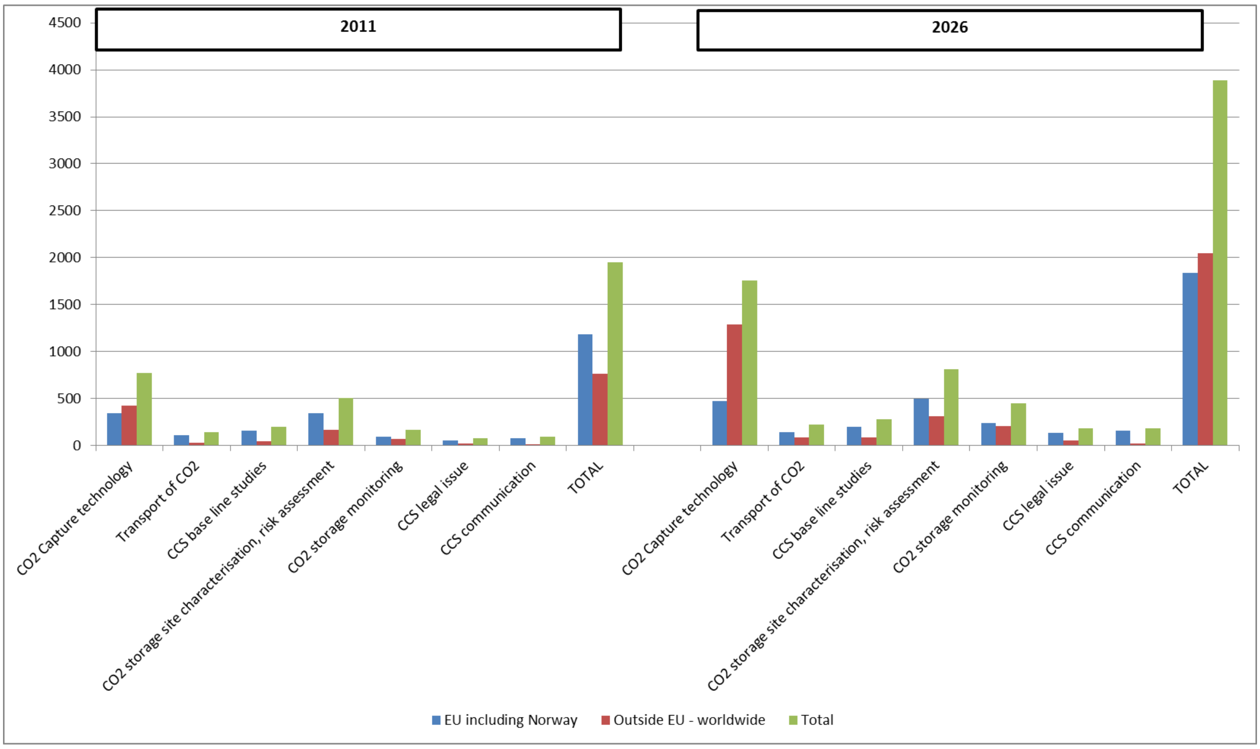


Fig 1 Manpower in man-years needed for the different parts of the CCS chain in 2011 and in 2026 in EU+No, and outside EU.

The analysis of the results shows that the needed manpower in EU+No and outside will both increase for all the items of CCS during the next 15 years and the need for manpower will be multiplied by about a factor 2 for the total CCS activities. However, if the CCS implementation does really take off, the needed manpower will most likely be more than doubled.

Today in EU+No, the manpower needed for storage (site characterisation + monitoring) is slightly higher than for capture whereas the needs are about equal for the rest of the world. However, in the next 15 years, the need in manpower in EU+No will be much higher for storage than for capture. The replies show that there will be a significant increase in demand of human resources for the next 15 years within the transport of CO_2, the legal issues and the communication techniques towards the stakeholders and the public at large. The need for personnel within legal issues, storage monitoring, and communication issues, increases significantly.

With that objective in view, a list of topics to be incorporated in a CCS education program is proposed (see annex 3). Courses on these topics are at present available in the electro-mechanical and chemical engineering programs for capture and in the geo-sciences for storage. Special attention was paid to the storage-related education since it will be crucial for public acceptance and hence for the deployment of CCS technology. Courses on legal issues and communication techniques, that turn out to be a real concern in the questionnaire's replies, should be picked up where they already exist and be adapted to the CO_2 issue.

In industry, the expertise and competences existing today can be shifted and extended to the fabrication, operation and maintenance of capture systems.

At this early stage of CCS development, industry will transfer its skilled personnel from its current jobs, in a power plant for example, to the operation and maintenance of a capture plant. Additional hiring will probably not take place until the CCS technology eventually starts to take off. Once it starts to be deployed at commercial scale, a large amount of skilled personnel will be needed.

Consequently, we will have to attract and educate a large number of students within CCS. They will have different backgrounds, and that will be a challenge to meet the demand but also to organize a highly multi-disciplinary CCS education program. A strategy needs to be developed (in universities for instance) to increase accordingly the number of lecturers and more generally of instructors. On top, courses on law issues should be created in law schools and courses on finances and economics should be created in business schools.

It should be noted that there could be a competition for highly skilled engineers and technicians between the oil/gas sector and CCS. If there is a lot of competence in industry and research institutions, it is not necessarily the same in universities. Consequently, there may be a need for creation of new positions of teachers and professors coming both from research institutions and industry.

In order to provide orders of magnitude of the work forces needed in CCS, the figures given here are for typical examples: one is for a 250 MWe power plant with capture (either post-combustion or oxy-fuel) and two other examples on storage. The first storage example is a saline aquifer at the Johansen formation near the Norwegian North Sea Utsira formation, and the second storage example is an onshore storage at Belchatow in Poland.

These examples show that, in case of massive deployment of the CCS technology, a huge amount of manpower will be needed.

Capture technologies

Executing and operating a Carbon Capture and Storage (CCS) plant requires considerable amount of work force distributed across different phases of a CCS project (project development, basic engineering, Engineering Procurement Construction, Operation)

In Figure 2, the work force demand is shown for a single 250 MWe project over the years: 5 years of Engineering Procurement Construction (EPC) and 10 years of Operation

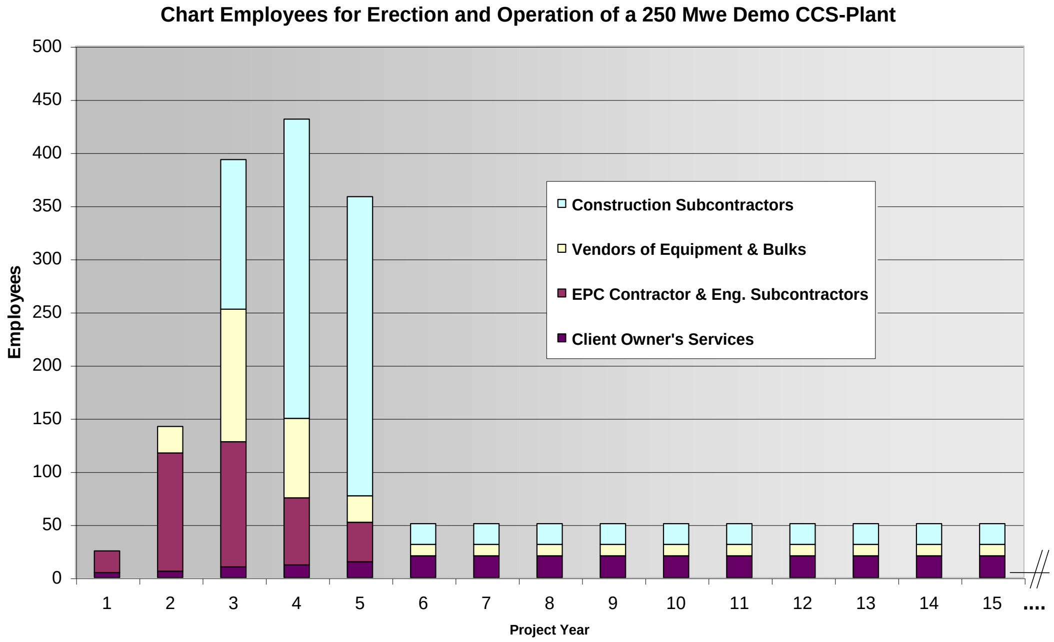


Fig 2 The work force demand (number of employees) generated by a 250 MWe CCS demo plant execution over 15 years

The work force demand during the EPC phase (first 5 years) is not constant but shows a peak reaching almost 450 full time employees in the 4th year. The need of personnel is high from year 3 to 5, especially due to the construction. During the operation phase (10 years), 50 employees are permanently needed. Considering a normalized value of 1 GWe equivalent plant size, the workforce demand over 15 years increases by a factor in the range of 2 to 2.4 for EPC phase (first 5 years) and around 1.2 to 1.3 as estimation for the Operation phase (10 following years).

More details as well as the splitting of the work forces by professions/skills are presented in annex 4. In industry, in the early stages, the existing competence can be extended to the engineering, fabrication, construction, procurement, operation and maintenance of capture systems.

However, a multiple parallel CCS projects execution will generate a high demand for skilled personnel and the extent of increase in new skills and competences will depend on how the existing, advanced and new technologies will evolve and how fast they will be implemented.

A similar possible extension of competence is also true for the technical aspects of CO_2 transport in pipelines, trucks, ships.

Examples for storage of CO_2

It is difficult to provide reliable numbers since the needed manpower, including the monitoring and legal issues (construction, permits, etc.), strongly depends on the storage site, for example off- or onshore, on the size of the storage (today the current injection rate at the sites in operation are about 1 Mt^2/year) and on a number of geological characteristics.

However, in the following some figures illustrating two planned storage demonstration projects.

1) The Johansen Formation situated offshore in the North Sea in Norway (source: Gassnova[3])

From the experience obtained from the maturation of CO_2 storage in an aquifer, namely the storage in the Johansen saline aquifer, it turns out that the screening may take 1 year and the qualification 2 years, including the collection of 3D seismic data. During this 3 years period, it is assumed that 5 to 15 man-years per year including evaluation of technical concepts are needed. Then there will be a construction period of 2-3 years where the main effort is the management of the project, which is the development of operational and monitoring plans and procedures as well as a limited effort at sub-surface.

In the subsequent phase, the work force for operation and maintenance and of any purchased services is estimated at 3 to 5 man-years/year and 3 to 5 man-years for the follow-up of the reservoir as well as for the general management and contracts.

Excluding the construction phase for which any information was not obtained, the site selection and qualification needs 5-15 man-year/year and the operation & maintenance need about 6-10 man-years/year for a site of 1 Mt/year.

It must be emphasized that these are rough estimates based on 1 or 2 projects with relatively significant storage volumes (at least 3 million tons a year). No complete calculations on specific individual tasks were however carried out.

2) The Bełchatów project onshore in Poland

Under the assumptions for NER300[4] applications and CCS-ready studies/assessments in Poland, a total manpower is estimated at a minimum of 37 to a maximum of 57 man-years for an injection of 2 Mt/year and is distributed as follows:

<u>I. Initial phase</u>: 10 to 13 man-years

1. Screening (1 year), 2D seismic acquisition, other surface geophysics during 2-3 months (4-5 man-years).

---

[2] Mt = million tonnes (metric)

[3] www.gassnova.no/?language=UK

[4] www.ner300.com

2. Construction: Drilling and completion of two wells: 2-4 months each (4-5 man-years)
3. Data interpretation, managing the project: 2-3 man-years

II. Second phase: 12 to 20 man-years

Qualification (2 years): 3D seismic acquisition, other surface geophysics: 1-3 months (2-4 man-years)

Drilling and completion of two wells, well tests: 4-8 months each (6-10 man-years)

Data interpretation, modelling, permit documentation, managing the project: 4-6 man-years

III. Third phase: 15-24 man-years

Site development (2 years):

Drilling two injection wells, testing: 4-8 months each (6-10 man-years)

Drilling one monitoring well, one control well: 3-4 man-years

Construction of the site infrastructure (manifold, compression/control facilities): 3-4 man-years

Baseline environmental & remote sensing monitoring (results of II used as baseline in case of seismic and well logging monitoring): 1-2 man years

Managing the project: 2-4 man-years

2 On-going actions

Several universities in Europe and in the OCDE countries have activities in CCS mostly in the form of advanced courses either for Master and post-graduate students or for PhD students (see annex 5). Several European laboratories have activities in CCS and many of them are in the inventory made in the ECCSEL[5] initiative (see annex 6). Some of the facilities are pilot installations in the framework of research for validation of models or for preparing the scale-up to a demonstration.

There are already a number of on-going courses and summer schools specific for CCS. One example is the IEAGHG CCS summer school[6]. Students with a diverse academic background, who are young scientists, e.g. PhD students or Post docs, are receiving a broad overview of the issues related to CCS.

There are further examples (not exhaustive) of CCS university courses[7][8][9][10][11] and industry courses[12][13][14][15][16][17][18][19]. Another initiative with a more general focus on energy issues is the Energy

[5] www.eccsel.org/
[6] www.ieaghg.org/index.php?/20091223124/summer-school.html
[7] www.kth.se/student/kurser/kurs/KE3040?l=en
[8] web.mit.edu/professional/short-programs/courses/carbon_capture_storage.html
[9] co2-ccs.unis.no/Education.html
[10] www.ivt.ntnu.no/ept/fag/fordypn/tep03/index.htm
[11] www.ed.ac.uk/schools-departments/geosciences/postgraduate/masters-programme/taught-masters/carbon-management/about
[12] www.kema.com/services/training/Training-courses/Gas-sustain-energy/CO2-transportation-introduction-course.aspx

Academy Europe (EAE[20]), which aims to be a centre of excellence in energy education (vocational, graduate and post-graduate training).

All these institutions involved with laboratory facilities may be considered as the future nodes or cells constituting a future education network covering all the CCS chain from theoretical concepts to practical works, covering both technical and non-technical topics. In EU, many projects in the framework programs FP6 and FP7 involve industry, research institutes and academia, and have as a common objective to demonstrate the technical feasibility of capture technologies on one hand, and that of storage technologies on the other hand, and to reduce the CCS cost by half by 2020. These projects have led to 10 planned CO_2 capture demonstration plants (5 for EU and 5 worldwide) based on the most promising options, namely post- and pre-combustion capture mostly based on chemical and physical absorption with solvents and oxy-fuel combustion capture (steam and fluidized bed cycles). Five commercial plants with CO_2 storage at the scale of 1 Mt/year injection are today operating in the world, mainly based on storing supercritical CO_2 in deep saline formations or for enhanced oil or natural gas production (EOR/EGR) (see annex 2).

All these activities constitute an excellent basis to organize Integrated Projects, Internships and Master theses as well as PhD theses. It suggests also that CCS education programs could be partly or totally included in future FP projects, especially for the storage component of E&T. Partners of FP6 and FP7 organize currently summer schools and short courses. An interesting benefit of our work would be implementation of education and training components in FP projects.

Non-exhaustive and incomplete lists of universities and of research institutes equipped of laboratories with CCS activities are given in annex 5.

In summary, their content is as follows.

<u>Courses on capture</u>:

1. Separation techniques
2. Power plants performance, costs and environmental impacts

   Coal as the fuel (supercritical cycles; Integrated Gasification IGCC; Fluidized Beds)

   Natural gas as the fuel (all types of combined cycles)

   Biomass in co-combustion and co-gasification
3. Removal of pollutants: sulphur and nitrogen oxides, particles, mercury
4. Capture technologies:

   Post-combustion capture

[13] www.adv-res.com/pdf/CO2%20Storage%20Short%20Course.pdf
[14] www.carbontechalliance.org/schedule/calendar/courses
[15] www.permianbasinccs.org/ecertification.htm
[16] www.co2crc.com.au/ccsw/
[17] www.spe.org/training/courses/ICO.php
[18] linkedenergy.net/content/ccs-risk-assessment-and-management-course
[19] www.energyinst.org/training/technical-training/carbon-capture-and-storage
[20] www.energyacademyeurope.nl/widget/22

Pre-combustion capture

Oxy-fuel combustion capture

Innovative concepts: zero-emission gas turbine cycles; chemical looping combustion; hybrid fuel cells (GT/SOFC)

Here is a non-exhaustive list of topics on capture techniques: absorption of CO_2 in solvents, oxy-fuel combustion in boilers, oxy-fuel gasification in fluidized beds, ionic liquids, cryogenics, phase change separation, separation by selective adsorption (PSA, TSA, ESA), adsorption in various frameworks (metal MOF, zeolites), by membranes for the separation of oxygen and nitrogen and separation of CO_2 and hydrogen, hybrid systems membranes/absorbers.

5. Purification and compression of the CO_2 product for transport and storage
6. Transport through a network of pipelines, by trucks, by ships
7. R&D for the reduction of efficiency penalty and of cost of capture
8. Pilot and demo plants, validation of modelling and up-scaling to commercial size

<u>Courses on storage</u>:

1. Site characterization
2. Dynamic modelling of CO_2 storage reservoir
3. Well engineering for CO_2 storage ; well design and well plugging techniques
4. Well performance specialist
5. CO_2 Monitoring
6. Environmental Risk Assessment
7. CO_2 Storage Economics

Detailed content of some courses on storage technologies are listed in annex 3.

3 Needs and gaps

CCS is a combination of quite different disciplines and should be a multi-disciplinary education and innovative program, built on the current and on-going master programs in electrical, mechanical and chemical engineering, logistics, geology, communication and law, already established and functioning well. The main question is "how such wide educational program" covering all the area of expertise should be organized.

Since there could be a competition for the hiring of highly skilled engineers and technicians between the CCS and other related sectors such as oil and gas, chemical industry, geothermal energy, power plants, in general large deployment of renewable energy, a large number of well-educated personnel will be needed if and when the CCS technology will take off. If not, the CCS competence can be used in the above mentioned sectors so that, whatever the future of CCS will be, there is little risk for a student to choose a specialization in CCS. For example, competence in capture technologies can be used in gas processing, refineries, and competence in storage technologies can be used within gas storage.

The following structure is proposed: Courses and practical works, existing or to be extended/adapted or newly created, are incorporated in MODULES. The MODULES are spread amongst the institutions participating to an EU network. The organization of interconnections between the nodes of the network is based on two key concepts: <u>mobility</u> and <u>flexibility</u>.

The objective of such a program should address the following topics, considering that a specialized engineer has to get an education in environmental and law issues:

- global warming and its link to CCS
- In-depth knowledge of the fundamentals of separation processes for CO_2 capture and the application to industrial installations with CO_2 capture
- Understanding and evaluation of key technologies and novel concepts related to CCS, with a particular emphasis on engineering aspects of power generation and CO_2 capture
- evaluation of economics, policy and regulatory frameworks necessary for decision-making to implement CCS projects
- Knowledge of geosciences including geochemistry and geomechanics in reservoirs, Geographical Information System and Interrogation Tools
- Development of emission reduction projects and associated tradable carbon credits
- Organization of a transfer of knowledge between specialists in the CCS supply chain, such as electromechanical and chemical engineers, geoscientists, regulators etc.
- Evaluation of environmental impacts for specific CCS sites. Interaction with the CCS industry and on-site practical experience
- Social sciences

A CCS program can be designed from now on at the Master level and as a post-graduate Master program. The Master courses can be offered as a joint program by a network of European Universities, research institutions and industrial installations federated around the CCS theme

As an example, the Master program could consist of two years:

<u>The first year</u> is mainly devoted to common basic courses during the first 6 months. During the following 6 months, the student has to make a choice between elective advanced courses available in different European Universities

Non-technical courses should be organized in law and business schools, or based on existing courses in universities, e.g. risk management.

<u>The second year</u> is mainly devoted to integrated project, possible internship and master thesis, which can be done in cooperation with the industrial partners, with laboratories or at one of the participating Universities and research institutions.

Although a close collaboration already exists with industry through FP projects, a benefit could undoubtedly come from a stronger training program in joint laboratories.

A possible way to go is the development of a network and the development of educational modules with a high degree of flexibility in their inter-connections. The development of modules of theoretical education could be based either on existing courses in European universities (a list is available in annex 5), and/or on the extension or adaptation of the existing instruments. These courses can be delivered in the premises of the network members but can also be implemented as e-learning. The courses on law issues should be organized in law schools while those dealing with finance and economics should be organized in business schools. For practical works, laboratories are existing today in education and research institutions and in industrial installations (see the list in annex 5).

All the European universities are not supposed to develop all the modules but on the contrary, develop modules either on capture, or on transport and or on storage or on 2 or 3 of them, i.e. there where they feel strong.

The organization of a 2-year CCS program based on a network of institutions should show a high flexibility regarding the combination of modules among different universities and laboratories and a high mobility both of students and of lecturers.

Another option is to organize the CCS program at the Master level. Then a multi degree (EU degree) master program could be set up by dedicating the last two years of the studies to a CCS education, including compulsory mobility for the students. Students with bachelor degree in mechanical, chemical, system engineering and geology, law and finance, communication are eligible to enter this type of program. Students will start the program at a mother university responsible of admission and administration. The first semester should include an introduction to the basic concepts of carbon capture and storage at one Mother University providing a common knowledge to the students with any background. In the second semester the student starts the specialization in one of the topics, capture or storage, in one of the collaborating universities through mobility options and according to their specialization choice.

A tentative specialization could be based on:

1) Chemical aspects of CCS (University 1 or ….)
2) Electromechanical and thermodynamic aspects of CCS (Universities 2 or …)
3) Geological aspects of CCS (University 3 or ….) : Geology and site selection, geophysics, geomechanics, geochemistry, CO_2 trapping mechanisms, modelling of flow in porous media, environmental impacts, monitoring and verification, long term risk assessment methods and storage safety
4) Transport in pipelines, trucks, ships (University 4 or/and ….),
5) Law and business schools (University 5 or …)
6) Social sciences, communication and public acceptance (University 6 or …)

As an engineering culture, system integration, process optimisation and risk management are everywhere throughout the CCS education.

In the final year the students will perform the MSc thesis project, either at one of the academic institutions or at one of the industrial partners involved in the program. The master thesis topics will cover different aspects within the field of CCS. It is obvious that educational programs in Capture on one hand, and Storage on the other hand, are completely different and it could be very difficult for students with such different backgrounds to feel easy and understand in-depth the concepts in the "opposite" discipline. Students with different backgrounds usually have a different way of work and understanding of the everyday industrial process, therefore a period of time for a team work on a case study or an integrated project can be used to understand how the different specialists work and should collaborate for the realization of a CCS project. Since the student in the second year is supposed to have chosen a specialty between Capture and Storage, each student will be given the chance to get a deep knowledge and understanding of one of these two scientific areas, without neglecting the rest of the CCS chain though.

An exhaustive list of courses and of accurate contents of the modules is out of the scope of this work as well as the practical organization of the links between the participants of the CCS network. However, the group has thought about it and concluded that it is clearer and easier to develop an engineering program on capture than on storage. As a general statement; no major gaps were identified in the capture area. All the needs for studying the current status of capture technologies and the technical challenges for a large-scale deployment can be met by using existing courses or by their extension and/or their adaptation. Regarding the fundamentals of the capture technologies, the education of electro-mechanical and chemical engineers is directly applicable. A non-exhaustive list of topics on capture and transport was given here above.

Similarly, no major gaps were identified on the transport sector.

Current technology and a history of CO_2 transport suggest that CO_2 transport through pipeline networks and with CO_2 vessels are technically feasible. However, designing, engineering and operating a CO_2 network requires knowledge of CO_2 fluid mechanics and thermodynamics. No insurmountable barriers to the implementation of large-scale CO_2 transport networks are identified. CO_2 compressors for up to 200 bars with state of the art technology are available with proven high availability.

The projection for the period 2020-2030 is the construction of 1,500 km of CO_2 pipelines per year on top of the existing ones, which will require a significant manpower.

No major problems are foreseen for the offshore construction. By contrast, onshore construction will co-exist with large projects in the natural gas distribution networks, constraining the size of the available skilled work force. Onshore CO_2 pipeline infrastructure will therefore be harder to construct than offshore infrastructure.

Shipping CO_2 with vessels to offshore storage locations might be appropriate in the early stages of a CCS project and for storage in small depleted gas/oil fields.

The technology to inject CO_2 in subsurface reservoirs is available today. Some issues remain, mostly on the operational level, such as the possible requirement of heaters when injecting into low-pressure depleted gas fields. The feasibility of large-scale CO_2 ship transport is to be demonstrated in early CCS projects. Ship transport can potentially play a vital role in the early phase of the development of the CO_2 transport infrastructure. The technology for transport and offshore unloading are available, but the feasibility of the complete ship transport system remains to be proven.

Regarding now the needs for an education on storage, it appears that there could be a gap on risk assessment in education and in the application of this new technology in practice, in spite of the advances in research. In our view, there is currently no course taught on CO_2 storage risk assessment in any university Master programs, while this topic is well addressed in research, meaning that there is a gap. Therefore the need is to transfer the knowledge from research to the engineering, biology and geology programs. Such a need is also relevant for related topics such as oil & gas, shale gas, geothermal energy sectors.

On the other hand, methods of risk assessment were developed in industrial safety, in underground activities such as waste disposals and in the management of environmental and sanitary impacts of pollutants. These methods were first developed in aeronautics, in astronautics, in nuclear engineering and in chemical industry from the sixties. It turns out that an education on risk assessment should be “adapted” to the case of CO_2 management.

In conclusion, with manageable adaptations of the existing instruments, an education on storage, even if not so obvious and if more difficult than that both on capture and on transport, can be set up from now on, without meeting insurmountable gaps or bottlenecks.

After thorough discussions in the group, an agreement on a tentative program on storage was made, see suggested list of courses in annex 3.

The group concludes that a CCS education program has to contain technical courses on capture and storage technologies including risk assessment and monitoring but also on CO_2 transport. On the other hand, since it is a wish that engineers get an education in environmental and legal issues, non-technical courses such as legal issues and communication techniques may have to be created in the framework of the program.

CCS is an area that could be characterised as a multitude of disciplines and specialty topics. It would be ideal for development of e-learning modules, where Europe’s top experts in a number of fields could contribute with state-of-the-art knowledge from comprehensive ongoing R&D efforts.

Educational and training programs should be coupled to Europe’s best laboratory facilities. The ECCSEL initiative is developing an open-access CCS laboratory infrastructure that could be integrated into various education and training programs.

4 Recommendations

Filling the skills, competences and knowledge gap

Focus area 1.1: Meeting the skill/competencies gaps of new and emerging technologies

1.1.1 Action

Three types of educational programmes in CCS can be set up

1) bachelor and subsequent master curriculum for a CCS Value Chain; elective courses introduced in existing curricula leading to an engineering degree with a sub-specialization in CCS technologies. Ex : electro-mechanical engineer (energetics orientation)
2) post-graduate complementary master in CCS ; 2 years program leading to a specialization CCS engineering degree
3) vocational programme intended to educate in CCS technologies technicians and engineers already working in industry, research institutes, regulation bodies

The programmes, which are highly interdisciplinary, will be developed on the basis of modules created in different institutes across Europe and organized in a network of education and research institutions, of laboratories and industrial installations.

An interdisciplinary team of teachers with backgrounds in CCS technologies, economics and legal and communication issues should be set up using personnel from across the CCS value chain.

In order to educate a new generation of experts in CCS with the capacity in developing the whole business area now and in the future, a deep knowledge based on scientific understanding is needed. This type of education requires close connections to research and can be done together with industry and research institutes.

A multi-disciplinary CCS education programme (master, post-graduate, PhD) for students in CCS, with different backgrounds, can be organized in a 2-year program, the Master courses being offered as a joint program by a network of European Universities, research institutions and industrial installations federated around the CCS theme. The 6 first months of the first year are devoted to common courses on basic concepts in CCS. Afterwards, the student will have to opt for a specialisation between capture and storage fields and choose elective advanced courses during the last 6 months. The 2nd year is devoted to internship, integrated projects and master thesis in collaboration with labs and industry.

This prototype curriculum could provide a benchmark for European universities for the partial or total implementation of such curricula within their institutions.

Gaps identified

The biggest part of a CCS programme can be based on existing courses today. Courses on capture and transport can easily be adapted and improved from existing ones. Regarding the courses on storage, a gap is identified on risk assessment and management of geological storage. Although this topic is well addressed in research, it is not properly taught today in University programmes. On the other hand, and this quite a challenge, courses on legal issues, economics and communication techniques should be adapted from existing ones in other areas (such as nuclear energy) or should be created from scratch in business and law schools associated to the network.

EQF Level 6-8: R&D, engineering, developers, others

Timeframe: The prototype curriculum can be developed from now on and can be based on a network of universities and laboratories for which a tentative list is provided in annexes of the full report. It could be followed by curriculum implementation 2 or 3 years later if the exercise starts now.

Objective As there is an urgent need for well-educated CCS value chain managers, developing a prototype curriculum will serve three objectives:

- speeding up the process of implementing such curricula by helping universities to structure these studies along a ready-made template and to build an appropriate network across EU installations
- ensuring the quality of curricula by using a broad range of experts from E&T institutions and from industry
- facilitate joint degree developments between different European universities by providing a sound benchmark for curricula development

It is recommended that the proposed programmes contain the topics listed in section 3 in the full report and be based on the courses on CO_2 capture, transport and on storage listed in the report and annexes. The courses can be designed and/or adapted and/or extended in institutions having already an expertise in CCS.

1.1.2 Action: The biggest gap is found in the non-technical faculties, that are supposed to address law, regulations, financial and social issues related to CCS. Therefore, it will be a strong need to create new positions of lecturers coming partly from research institutes and industry. Courses on law issues should be created in law schools and courses on finances and economics should be created in business schools. A participation of these latter schools in the CCS network is required.

1.1.3 Action: CCS education programmes could be included in future European FP projects, especially for the storage component of education and training. Partners of FP6 and FP7 projects organize currently activities like summer schools and short courses, and in the future could implement joint programs between different educational providers (on all levels; vocational/BSc/MSc/PhD).

1.1.4 Action: The courses covering a multitude of disciplines and technologies with a rapid development can be delivered in the premises of the network members but can also be an ideal area for the implementation of e-learning modules.

Focus area 1.2: Strengthening and developing existing skills/competencies

1.2.1 Skills upgrade for conventional industries involved in capture (power generation, industrial sectors such as petro-chemistry, chemicals manufacture, iron & steel and cement industry), in transport of fluids and in storage such as oil & gas industries

Action

Conventional existing industries must play a key role in implementing CCS according to the SET plan goals. These industries have already an excellent access to human resources over the CCS value chain associated with their expertise. Electro-mechanical and chemical engineers have a sound education for the operation and maintenance of capture units, fluid –mechanical engineers for the transport and geologists for the storage.

This action will develop in a first step tailor-made training modules targeted at mid to high level of expertise for these technicians and engineers either as in-house or as vocational education. The courses will address each sector individually, i.e. capture, transport and storage technologies.

EQF Level 4-6: manufacturing, installation, O&M, etc.

Timeframe: Start: 2013, implementation of courses 2 years later

Objective The main objective of the skills upgrade for conventional industries is to take manpower from the huge potential of their own personnel to implement solutions filling the deficits in their know-how regarding CCS in general and the application of CCS in particular to their own installations.

1.2.2 Skills upgrade for energy consultants

Action

Energy consultants are key actors in promoting energy solutions in the public arena, business as well as in communities as they are primary contact persons for any actor willing to change his energy system. In many cases these consultants are however not qualified to provide reliable and practical advice regarding CCS, given the complexity of the supply chain and the required technological know-how necessary to implement CCS solutions.

The proposed action provides training modules targeted towards different groups of energy consultants (consultants to individuals, business and industry, etc.) and up-grades their know-how concerning CCS solutions within their sphere of activity.

The training modules have to be developed for distance learning using different European platforms, such as the ZEP (Zero Emission Platform), EUA/EPUE, KIC-InnoEnergy, as dissemination channels. Another channel can be the IEA GHG R&D Programme www.ieaghg.org. Courses can also be organized in collaboration with international institutions, for example with the MIT in USA web.mit.edu/professional/short-programs/courses/carbon_capture_storage.html

National associations, several of them such as Tractebel Engineering and VITO (Vlaamse Instelling voor Techonogie Onderzoek) in Belgium having already a collaboration framework with universities and high schools, will then be tasked with organizing courses in their national context, under co-ordination of the European ZEP, for instance. Another possible initiative with a more general focus on energy issues is the Energy Academy Europe (EAE), which aims to be a centre of excellence in energy education (vocational, graduate and post-graduate training) www.energyacademyeurope.nl/widget/22. Non-exhaustive lists of institutions are given in annexes of the report.

EQF Level 3-8: management, finance/insurance, developer, utility

Timeframe: Start: Tender 2014, implementation of courses 2017

Objective The main objective of the skills upgrade for energy consultants is to improve the qualification of energy consultants and training them in understanding the function of the complex CCS supply chain.

Fostering involvement, access and up-take by the labour market

Focus area 2.1: Promoting mobility, life-long learning, workforce training

2.1.1 European education mobility programme for CCS

Action

Practice oriented learning requires co-operative education between academia and laboratories and industry. This in turn requires special mobility programs, allowing students to move to labs and pilot research facilities within their curricula. This mobility is different from current student mobility programs as it requires more flexibility regarding the duration of the stays as well as strict co-ordination between the universities and industry/research facilities receiving students. Different programs for cooperation range from compact pilot plant exercises with durations of 2-4 weeks to team projects of 1-3 months to individual research projects with 1 – 2 semesters duration. This mobility program will be initiated by the European Commission as an integral element within its academic mobility efforts and can use already existing bodies like ZEP, EUA/EPUE, EERA and existing projects like ECCSEL described in the full report

EQF Level All

Timeframe Development of program framework and contract templates for co-operation between educational institutions, pilot plant networks and industry until 2014
Implementation of student mobility: 2015

Objectives These mobility programs aim at improving practice oriented education by providing a co-ordinated exchange of students between academia and the other CCS stakeholders. Although internships are already common, this mobility program offers a new level of co-ordination between academia and industry so that the time the students spend in companies are utilised to their full educational capacity.

2.1.2 Action: Although there are no critical missing skills in industry to date, since it is possible to convert or use the existing skills into manpower in CCS, an appropriate

continuing education has however to be organized to keep the professionals updated (seminars, short courses, e- learning…).

2.1.3 Action area: Development of an EU network and cooperation with non-EU countries such as China, USA, Australia, Canada, India, and Japan.

Focus area 2.2: Industry involvement and partnerships

2.2.1 Action

From the analysis of the replies to our questionnaire, the needs in work forces within the CCS area will increase a lot (nearly double and most probably more, especially in industry) if CCS technology implementation takes off in the next 15 years. To go through the transition period from today to the operational phase of a larger number of CCS plants, the industrial companies have up to now used their in-house skilled personnel and shifted them from their normal daily job, but that will not be enough for the next 15 years.

Consequently, the cooperation between industry and academic and research institutes is required and has to be strongly fostered. In particular, industry can provide teachers and labs and pilot and demo installations for practical exercises, integrated projects, internships and thesis.

2.2.2 Action: Educational and training programmes should be coupled to Europe's best laboratory facilities. The ECCSEL initiative is developing an open-access CCS laboratory infrastructure that could be integrated into various education and training programs. The ECCSEL initiative should be supported and integrated with development of new educational programs.

Planning and enabling skills development

Focus area 3.1: Sector skills assessments and observatories

3.1.1 European CCS Skills Requirement Survey

Action

CCS is a broad field with a large number of different actors and sectors involved. In order to fine tune educational programs for the expected dramatic increase in well-educated employees and entrepreneurs in this field, a comprehensive survey among all sectors' representatives about the skills expected from the future workforce is necessary. This survey should be oriented along the CCS value chain and should include all actors listed in a still to be completed list in the report. It has to cover all levels of education. This survey should be carried out by existing networks and should be co-ordinated by an EU body, such as ZEP.

EQF Level 3-5: manufacturing, installation, O&M, etc.
1-2: support (assistance, production, transport)

Timeframe: Start: 2013, end report due 2014

Objective The main objective is to provide a base line of skill requirements as seen from the industry side in order to help educators to adapt the content of their courses to the needs of the labour market in CCS. A further objective of this survey is to provide a common "standard" reference system for education in the field of CCS.

Focus Area 3.2: "Train the trainer"

3.2.1 Action: There could be a competition for highly skilled engineers and technicians between the CCS sector on one side and oil and gas, chemistry, geothermal energy and power sectors on the other side, a lot of well-educated personnel will be needed. Although competence and expertise are existing in industry and research institutes, that is not necessarily the case in universities. New positions of teachers and trainers will have to be created and that particularly for non-technical topics such as law, regulations, business, communication.
Universities should organize themselves to hire (and pay them) educators from outside the academic body.

Focus area 3.3: Development of teaching materials and courses

3.3.1 Action: Development of modern teaching material that can be used to create continuously updated courses in CCS and should include teaching material enabling students trained in traditional disciplines to absorb sufficient specialised knowledge in the various disciplines in the CCS chain, in which they are not necessarily specialised themselves.
Teachers having an expertise in research and industrial applications should ensure a transfer of up-to-date knowledge and of the last research findings to students. Dedicated web sites can be designed and operated for E-learning.

Focus area 3.4: Online information and other tools

3.4.1 Action

The European bodies identified earlier such as ZEP act as a platform and co-ordinate and manage digital educational content of CCS courses. They act as a quality control institution, providing criteria for all digital educational content (streamed lectures, virtual classrooms, digital courses and course modules, etc.) for all levels, from vocational training to bachelor, master and doctoral level to digital lifelong learning modules.

As members of content development teams, senior experts, possibly retired, could and should be involved to provide practical experience.

In case of CCS take-off and development during the 15 following years, there will be a lack of teachers, in particular in the universities where new teachers from industry could be hired and existing professors should commit themselves to extend or adapt their courses to cover CCS.

EQF Level all

Timeframe Implementation of the platform: 2013

Objectives The European CCS virtual learning platform has the objective to speed up the modernisation process for curricula relevant to CCS and in particular to increase the capacity for multidisciplinary education by providing quality controlled digital educational content at affordable costs to educational institutions.

Annex 1: Questionnaire and replies

Dear CCS stakeholder,

The **European Energy Education and Training Initiative under the SET-Plan (Strategic Energy Technology Plan) is investigating** the human resources available for the implementation of the EU 2020 plan and future energy policy. The investigation addresses the quantity and quality of human resources required to implement these plans.

The SET-Plan, adopted by the European Union in 2008, is a first step to establish an energy technology policy for Europe. It is the principal decision-making support tool for European energy policy, with a goal of:

- Accelerating knowledge development, technology transfer and up-take;
- Maintaining EU industrial leadership on low-carbon energy technologies;
- Fostering science for transforming energy technologies to achieve the 2020 Energy and Climate Change goals;
- Contributing to the worldwide transition to a low carbon economy by 2050.
- The projected budget for the SET-Plan has been estimated at up to €71.5 billion.

The SET-Plan has two major timelines:

- **For 2020**, the SET-Plan provides a framework to accelerate the development and deployment of cost-effective low carbon technologies. With such comprehensive strategies, the EU is on track to reach its 20-20-20 goals of a 20% reduction of CO2 emissions, a 20% share of energy from low-carbon energy sources and 20% reduction in the use of primary energy by improving energy efficiency by 2020.
- **For 2050**, the SET-Plan is targeted at limiting climate change to a global temperature rise of no more than 2°C, in particular by matching the vision to reduce EU greenhouse gas emissions by 80 - 95%. The SET-Plan objective in this regard is to further lower the cost of low-carbon energy and put the EU's energy industry at the forefront of the rapidly growing low-carbon energy technology sector.

The EC SET-Plan **working group on Carbon Capture and Storage** (under DG Research & Innovation, Energy Education and Training Initiative) is producing an assessment report to EC DG Research & Innovation, which will be used as a basis for defining the initiative. The working group is led by Professor Olav Bolland, from the Norwegian University of Science and Technology (NTNU). The assessment report will cover the CCS technology sector and include the technology specific aspects of associated fields with the aim to identify opportunities, actions and barriers, where education and training could boost SET-Plan implementation. To produce this assessment report, the working group needs **your help** with answers to the following questionnaire to assess the current situation with regard to CCS expertise and experiences and to build up an attracting future for CCS in Europe.

Please help us by answering the questionnaire on the following and return it to Fedora (fedora.quattrocchi@ingv.it and nep@geus.dk) by May 31. Thank you in advance for your help.
Please feel free to call Fedora Quattrocchi (+39-06-51860302) or Niels Poulsen: +45 3814 2366) if you have any questions.

Sincerely, Fedora Quattrocchi & Niels Poulsen

Questionnaire:

1: name and nature of the institution (education, research, public body) and company: public, private

Do you reply on behalf of your institution or for your country? ______ Institution / _______ country

2: sector of activity (capture, transport, storage)

3: Workforces in person years (man .year). Current situation – existing workforces' profiles and workforces required to achieve the SET-Plan vision.

a) now in 2011

i. CO_2 Capture technology ____________________person year

ii. Transport of CO_2 ____________________person year

iii. CCS base line studies ____________________person year

iv. CO_2 storage site characterisation, risk assessment and dynamic behaviour ____________________person year

v. CO_2 storage monitoring ____________________person year

vi. CCS legal issue ____________________person year

vii. CCS communication ____________________ person year

b) expected for the next 15 years

i. CO_2 Capture technology ____________________person year

ii. Transport of CO_2 ____________________person year

iii. CCS base line studies ____________________person year

iv. CO_2 storage site characterisation, risk assessment and dynamic behaviour ____________________person year

v. CO_2 storage monitoring ____________________person year

vi. CCS legal issue ____________________ person year

vii. CCS communication ____________________person year

4. Other comments. Do you have:

- On-going actions – training initiatives, etc.
- Needs and gaps in education & training, in particular main barriers or bottlenecks for the different industrial or public sectors.
- Recommendations at EU and possibly Member State level.

EU	institution / country	sector of activity				2011								2026							
0 = no 1 = yes		country	capture	transport	storage	CO_2 Capture technology	Transport of CO_2	CCS base line studies	CO_2 storage site characterisation, risk assessment	CO_2 storage monitoring	CCS legal issue	CCS communication	TOTAL	CO_2 Capture technology	Transport of CO_2	CCS base line studies	CO_2 storage site characterisation, risk assessment	CO_2 storage monitoring	CCS legal issue	CCS communication	TOTAL
1	Amphos21 Consulting S.L.	0	1	0	1	1	0	5	2	4	0	3		1	1	7	3	6	1	5	
1	Austria and Geologische BUndesanstalt (Geological Surv	1	0	0	1	0	0	0	0.1	0	0	0.1		0	0	0.25	0.25	0	0	0.1	
1	BGR	0	0	0	0	0	0	3.4	3.4	3.4	3.4	3.4		0	0	3.4	3.4	3.4	13.4	3.4	
1	Biorecro AB, private company registered in Sweden	0									4					5			55	30	
1	BLOS International LTD	0	0	0	1	0	0	0	3	0	0	0		0	0	0	12.5	2	0	1	
1	BRGM	0	0	0	1	0	0	0	33	8	0.5	0.5		0	0	0	33	8	0.5	0.5	
1	British Geological Survey	0	0	0	1	0	0	1	5	4	0	0.5		0	0	4	8	6	0	1	
1	BTU Cottbus, Chair of Power Plant Technology	0	1	1	0	6	1	0	0	0	0	0		4	4	0	0	0	1	1	
1	CATO	0	1	1	1	75	52	50	75	25	10	25		40	20	20	40	20	5	20	
1	CIEMAT, Energy, Environment and Technology Researcl	0	0	0	1	0	0	0	4	0	0	1		0	0	0	6	0	0	1	
1	CO2-H2 Eurl	0	1	0	0	0.5	0	0	0	0	0	0		0.5	0	0	0	0	0	0	
1	DNV KEMA Energy & Sustainability	0	1	1	1	30	5	0	3	2	0	1		60	20	5	40	40	5	5	
1	ELCOGAS S.A.	0	1			2						0.4		2						0.4	
1	Energy Geoscience International Ltd.	0	0	0	1	0	0	0.3	0.1	0.5	0	0.1		0	0	0.2	0.1	0.3	0	0.4	
1	Energy research centre of the Netherlands	0	1	0	0	12	2	2	0.5	0.5	2	4		8	1	1	0	1	2	1	
1	Foster Wheeler Italiana (FWI)	0	1	0	0	28	1	12	0	0	0	0		50	4	25	2	0	1	1	
1	Fracture Systems Ltd	0	0	0	1	0	0	0	0	0	0	0		0	0	5	5	5	0	0	
1	Fraunhofer Institute for Systems and Innovations Researc	0	1	1	1	0.1	0.1	0	0.1	0	0	0.5		0.1	0.1	0	0.1	0	0	0.5	
1	Fundação Ensino e Cultura Fernando Pessoa / Universid	0	0	0	1	0	0	1.5	2.25	0	0.5	0.5		0	0	2	4	2	1	1.5	
1	Fundación Ciudad de la Energía (CIUDEN)	0	1	1	1	45	10	5	10	10	5	10		70	15	7	15	15	7	12	
1	Gassnova SF	0	1	1	1	21	9	0	10	0	1	5		21	13	3	10	3	1	5	
1	Gassnova SF	0	1	1	1	5	2	1	2	0	3	3		5	2	2	3	1	3	3	
1	Geogreen	0	0	1	1	0	1	2	2	1	0.5	0.5		0	4	4	10	20	2	2	
1	Geoinženiring d.o.o., Ljubljana, Slovenia	0	0	0	1	0	0	0	1	1	0	0		0	1	1	3	3	1	1	
1	Geological Survey of Belgium – Royal Belgian Institute of	0	0	1	1	0	0.25	1	0.5	1	0.25	0.5		0	1	1	2	1	1	1	
1	Geology Department; Faculty of Sciences; University of L	0	0	0	1	0	0	0	1	0	0	0		0	0	0	2	0	0	0	
1	German Ministry of Economics; public	0				0	0	0	0	0	1.5	0		0	0	0	0	0	1	0	
1	IFPEN	0	1	1	1	30	1	0	30	10	1	1									
1	IMPERIAL COLLEGE LONDON	0	1	1	1	5	2	5	40	5	2	0		10	5	10	70	8	4	0	
1	IMPERIAL COLLEGE LONDON, education, public	0	1	1	1	5	2	5	40	5	2	0		10	5	10	70	4	8	0	
1	Institute of Energy Systems, Hamburg University of Techi	0	1			12	1	0	0	0	0	0		14	1	1	0	0	0	0	
1	Institute of Geology at Tallinn University of Technology (T	1	0	0	1		0	0.3	1.5	0	0.6	0.3									
1	Instituto de Carboquímica, CSIC, Spain	0	1	0	0	24	0	0	0	0	0	0		35	0	0	0	0	0	0	
1	INSTITUTO TERRA E MEMÓRIA	0	1	1	1																
1	INSTITUTO TERRA E MEMÓRIA, Portugal	0				0	0	0	0	0	0	0		0	0	0	0	0	0	0	
1	IRIS – International Research Institute of Stavanger	0	0	0	1	0	0	0.5	7	2	0	0.3		0	0	2	10	3	0	0.5	
1	ISPE –Institute for Studies and Power Engineering	0				10	10	20	0	0	5	5		20	20	10	0	0	5	10	
1	Istituto Nazionale di Oceanografia e di Geofisica Sperime	0	0	0	1	0	0	3	5	2	0	1		0	0	45	75	60	7	30	
1	IVL Swedish Environmental Research Institute	0				0.1	0	0.1	0	0	0	0.5		0.5	0	0.5	0	0	0	1	
1	Laboratório Nacional de Energia e Geologia, I.P. LNEG	0	1	1	1	5	1	1	4	1	1	1		6	2	1	5	2	1	1	
1	Lappeenranta University of Technology (Finland)	0	1	0	0	4	0	0	0	0	0	0		75	0	0	0	0	0	0	
1	METBE – Ministry of Economy, Trade and Business Envi	1	1	1	1	15	10	30	10	0	5	5		20	20	10	20	5	5	10	
1	METU PAL	0	0	0	1	0	0	0	4	1	0	0		0	0	0	8	3	0	0	
1	Ministry of Economics, Poland	0	1	1	1	0.1	0.1	1	0	0	0.2	0.1									
1	Polish Geological Institute, PGI	0	0	0	1	0	0	0	20	3	2	2		0	0	0	10	5	3	2	
1	RD Partners	0	1	0	0	0.2	0	0	0	0	0	0		0	0	0	0	0	0	0	
1	SINTEF	0	0	0	1	0	0.1	0	4	2.5	0	0		0	0	0	8	7	0	0	
1	State Geological Institute of Dionyz Stur	0	0	0	1	0	0	0	3	0.2	2	0		1	0	0.5	0.5	0.2	0	0	
1	Technical University Hamburg Harburg, Institute of Therm	0	1	1	1	1	1	1	1	0	0	0		1	1	1	1	0	0	0	
1	The Geological Survey of Denmark and Greenland - GEU	0	0	0	1	0	0	1	8	1	0	0.1		0	0	1	15	2	0	1	
1	The Research Council of Norway, public	0	1	1	1	100	100	100	100	100	100	100		2000	500	500	2000	2000	2000	500	
1	uk.bp.com	0				2	0.25	0.1	4.5	3.8	0.1	0.15		1	0.1	2.5	3.5	1.5	0.25	0.25	
1	VTT Technical Research Centre of Finland	0	1	1	1	6.5	1	3	0	0	1	0.5		13	2	5	0	0	1	2	
1	Zero Emission Resource Organisation, ZERO	0	1	1	1	1	0.2	0.2	0.4	0.2	0	1		1.5	0.2	0.2	0.4	0.2	0	5	
0	ALSTOM Power - CO2 Capture Solutions (CCS)	0	1	0	0	300	0	0	0	0	0	0		1000	0	0	0	0	0	0	
0	Corporate R&D Institute of Doosan Heavy Industries & C	0	1	0	0	15	0	0	0	0	0	1		20	0	0	0	0	0	3	
0	Dalhousie University, Nova Scotia Canada	0			1		0	0	1	0	0	0		0	0	0	0	0	0	0	
0	Dept of Petroleum Engineering, Curtin University- Austral	0	1	1	1	8	10	0	12	14	0	0		5	5	0	10	50	0	0	
0	ECOPETROL. Colombian Petroleum Company	0	1	1	1	1	1	1	1	0	0	0		5	2	2	5	2	2	1	
0	Federal Government Research Institute	0	1	1	0	7	1	1	0	0	0	0		20	5	2	0	0	0	0	
0	Foster Wheeler Energy Limited (FWEL), Reading HQ	0	1	1	1	22	1	3	0	0	1	0		40	4	3	2	0	4	0	
0	Geoscience Australia, Government Department	0	0	0	1	0	1	4	50	10	10	0		0	5	20	100	50	20	0	
0	Global CCS Institute	0	1	1	1	1	0	0	1.5	1.5	2	3									
0	Gulf Coast Carbon Center, Bureau of Economic geology,	0	0	0	1	0	0	3	5	5	0.5	1		0	0	2	4	5	1	1	
0	Indiana Geological Survey - USA	0	0	0	1	0	0	0	3	0	0	2		0	0	1	2	0	0	0	
0	IPAC-CO2 Research Inc.	0	0	0	1	0	0	0	4.5	4.5	0	2.5		0	0	0	6.5	6.5	0	2.5	
0	JSC “All-Russia Thermal Engineering Institute”- VTI	0	1	0	0	2	0	0	0	0	0	0		45	15	15	30	30	0	0	
0	Lawrence Livermore National Laboratory	0	0	1	1	2	0	0	10	0.5	0	0		2	0	0	10	1	0	0	
0	MDA Geospatial Services Inc. (Canada)	0	0	0	1	0	0	0	1	1	0	0		0	0	0	4	4	0	0	
0	National Tsing Hua University, Hsinchu, Taiwan (mx.nthu.	0	1			15	0	0	0	0	2	2		25	0	0	0	0	5	3	
0	Northwest University (public)	0	1	1	1	5	3	5	50	30	2	2		10	5	6	50	30	2	2	
0	PETRONAS, O&G Company, Kuala Lumpur, Malaysia	0				5	0	1	1	0	0	0		5	2	2		2	1	1	
0	Rahbord Energy Alborz ltd Private company	0	1	0	1	36	10	25	20	0	6	0		100	40	30	80	25	15	10	
0	The University of Queensland	0	1	0	1	5	0	0	5	0	0	0		5	0	2	10	2	1	1	
0	University of British Columbia, Clean Energy Research C	0	1	0	0	3	0	0	0	0	0	0		4	0	0	0	0	0	0	
									2011								2026				

	CO2 Capture technology	Transport of CO2	CCS base line studies	CO2 storage site characterisation, risk assessment	CO2 storage monitoring	CCS legal issue	CCS communication	TOTAL	CO2 Capture technology	Transport of CO2	CCS base line studies	CO2 storage site characterisation, risk assessment	CO2 storage monitoring	CCS legal issue	CCS communication	TOTAL
EU including Norway	346.5	113	155.4	340.35	97.1	53.55	76.95	1182.85	469.6	142.4	195.55	498.75	237.6	135.15	159.55	1838.6
Outside EU - worldwide	427	27	43	165	66.5	23.5	13.5	765.5	1286	83	85	313.5	207.5	51	24.5	2050.5
Total	773.5	140	198.4	505.35	163.6	77.05	90.45	1948.35	1755.6	225.4	280.55	812.25	445.1	186.15	184.05	3889.1
							1948								3889	

Annex 2: List of worldwide large-scale CCS projects

(source: Global CCS Institute www.globalccsinstitute.com/data/status-ccs-project-database, July 2012)

Project Name	Description	State / District	Country	Volume CO_2	Operation Date	Facility Details	Capture Type	Transport Length	Transport Type	Storage Type
Val Verde Natural Gas Plants	This operating enhanced oil recovery project uses carbon dioxide sourced from the Mitchell, Gray Ranch, Puckett, Pikes Peak and Terrell gas processing plants and transported via the Val Verde and CRC pipelines.	Texas	UNITED STATES	1.3 Mtpa	1972	Natural Gas Processing	Pre-Combustion	132 km	Onshore to onshore pipeline	Enhanced Oil Recovery
Enid Fertilizer CO2-EOR Project	Since 1982, the Enid Fertilizer plant has sent around 680,000 tonnes per annum of carbon dioxide to be used in enhanced oil recovery operations in Oklahoma.	Oklahoma	UNITED STATES	0.68 Mtpa	1982	Fertiliser Production	Industrial Separation	225 km	Onshore to onshore pipeline	Enhanced Oil Recovery
Shute Creek Gas Processing Facility	Around 7 million tonnes per annum of carbon dioxide are recovered from ExxonMobil's Shute Creek gas processing plant in Wyoming, and transported by pipeline to various oil fields for enhanced oil recovery. This project has been operational since 1986.	Wyoming	UNITED STATES	7 Mtpa	1986	Natural Gas Processing	Pre-Combustion	190 km	Onshore to onshore pipeline	Enhanced Oil Recovery
Sleipner CO2 Injection	Sleipner is the second largest gas development in the North Sea. Carbon dioxide is separated from produced gas at Sleipner T and reinjected into a deep saline formation above the hydrocarbon reservoir zone. This project has been in operation since 1996.	North Sea	NORWAY	1 Mtpa + 0.2 Mtpa in construction	1996	Natural Gas Processing	Industrial Separation	0 km (capture same as storage location)	Onshore to offshore pipeline	Offshore Deep Saline Formations
Great Plains Synfuel Plant and Weyburn-Midale Project	About 3 million tonnes per annum of carbon dioxide is captured from the Great Plains Synfuel plant in North Dakota. Since 2000 the carbon dioxide has been transported by pipeline into Canada for enhanced oil recovery in the Weyburn and Midale Oil Fields.	Saskatchewan	CANADA	3 Mtpa	2000	Synthetic Natural Gas	Pre-Combustion	315 km	Onshore to onshore pipeline	Enhanced Oil Recovery
In Salah CO2 Storage	In Salah is a fully operational onshore gas field in Algeria. Since 2004, 1 million tonnes per annum of carbon dioxide are separated from produced gas and reinjected into the producing hydrocarbon reservoir zones for storage in a deep saline formation.	Wilaya de Ouargla	ALGERIA	1 Mtpa	2004	Natural Gas Processing	Pre-Combustion	14 km	Onshore to onshore pipeline	Onshore Deep Saline Formations
Snøhvit CO2 Injection	The Snøhvit offshore gas field and related CCS activities have been in operation since 2007. Carbon dioxide separated from the gas produced at an onshore liquid natural gas plant is reinjected into a deep saline formation below the reservoir zones.	Barents Sea	NORWAY	0.7 Mtpa	2008	Natural Gas Processing	Industrial Separation	152 km	Onshore to offshore pipeline	Offshore Deep Saline Formations
Century Plant	Occidental Petroleum, in partnership with Sandridge Energy, is operating a gas processing plant in West Texas that at present can capture 5 Mtpa of carbon dioxide for use in enhanced oil recovery. Capture capacity will be increased to 8.5 Mtpa in 2012.	Texas	UNITED STATES	8.5 Mtpa	2010	Natural Gas Processing	Pre-Combustion	256 km	Onshore to onshore pipeline	Enhanced Oil Recovery
Air Products Steam Methane Reformer EOR Project	This project in construction will capture more than 1 million tonnes per year of carbon dioxide from two steam methane reformers to be transported via Denbury's Midwest pipeline to the Hastings and Oyster Bayou oil fields for enhanced oil recovery.	Texas	UNITED STATES	1 Mtpa	2012	Hydrogen Production	Post-Combustion	101 – 150 km	Onshore to onshore pipeline	Enhanced Oil Recovery
Illinois Industrial Carbon Capture and Storage ProjectStorage Project	The project will capture around 1 million tonnes per annum of carbon dioxide from ethanol production. Carbon dioxide will be stored approximately 2.1 km underground in the Mount Si S d t d li f ti Simon Sandstone, a deep saline formation.	Illinois	UNITED STATES	1 Mtpa	2013	Chemical Production	Industrial Separation	1.6 km	Onshore to onshore pipelinepipeline	Onshore Deep Saline FormationsFormation s
Lost Cabin Gas Plant	This project will retrofit the Lost Cabin natural gas processing plant in Wyoming with CCS facilities, capturing around 1 million tonnes per annum of carbon dioxide to be used for enhanced oil recovery.	Wyoming	UNITED STATES	1 Mtpa	2013	Natural Gas Processing	Pre-Combustion	370 km	Onshore to onshore pipeline	Enhanced Oil Recovery
Coffeyville Gasification Plant	CVR Energy is developing a new compression facility at its fertiliser plant in Kansas. The plant currently produces approximately 850,000 tonnes of carbon dioxide which will be transported to the mid-continental region for use in enhanced oil recovery.	Kansas	UNITED STATES	0.85 Mtpa	2013	Fertiliser Production	Pre-Combustion	112 km	Onshore to onshore pipeline	Enhanced Oil Recovery
Kemper County IGCC Project	Mississippi Power (Southern Company) is constructing an air-blown 582 MW IGCC plant using a coal-based transport gasifier. Up to 3.5 million tonnes per annum of carbon dioxide will be captured at the plant and used for enhanced oil recovery.	Mississippi	UNITED STATES	3.5 Mtpa	2014	Power Generation	Pre-Combustion	75 km	Onshore to onshore pipeline	Enhanced Oil Recovery
Boundary Dam Integrated Carbon Capture and Sequestration Demonstration Project	SaskPower is currently retrofitting a coal-based power generator with carbon capture technology near Estevan, Saskatchewan. When fully operational in 2014, this project will capture around 1 million tonnes per annum of carbon dioxide.	Saskatchewan	CANADA	1 Mtpa	2014	Power Generation	Post-Combustion	100 km	Onshore to onshore pipeline	Enhanced Oil Recovery
Alberta Carbon Trunk Line ("ACTL") with Agrium CO2 Stream	Agrium's fertiliser plant in Alberta is currently being retrofitted with a carbon dioxide capture unit. Around 585,000 tonnes per annum of carbon dioxide will be captured and transported via the Alberta Carbon Trunk Line (ACTL) for enhanced oil recovery.	Alberta	CANADA	0.585 Mtpa	2014	Fertiliser Production	Pre-Combustion	240 km	Onshore to onshore pipeline	Enhanced Oil Recovery
Sinopec Shengli Oil Field EOR Project	Around 1 million tonnes per annum of carbon dioxide will be captured from an existing power plant in Shangdong and used for enhanced oil recovery.	Shangdong	CHINA	1 Mtpa	2014	Power Generation	Post-Combustion	51 – 100 km	Onshore to onshore pipeline	Enhanced Gas Recovery
Lake Charles Gasification	Leucadia and Lake Charles Cogeneration plan to build a gasification plant to produce synthetic natural gas from petcoke. Around 4 million tonnes per annum of carbon dioxide will be captured at the plant and used for enhanced oil recovery.	Louisiana	UNITED STATES	4.5 Mtpa	2014	Synthetic Natural Gas	Pre-Combustion	Not specified	Onshore to onshore pipeline	Enhanced Oil Recovery
Texas Clean Energy Project	Summit Power Group is developing a 400 MW IGCC polygeneration plant capturing 2.7 million of tonnes per annum of carbon dioxide to be used for enhanced oil recovery in the Permian Basin in West Texas.	Texas	UNITED STATES	2.5 Mtpa	2014	Power Generation	Pre-Combustion	≤50 km	Onshore to onshore pipeline	Enhanced Oil Recovery
Alberta Carbon Trunk Line ("ACTL") with North West Sturgeon Refinery CO2 Stream	Up to 1.2 million tonnes per annum of carbon dioxide will be captured at this new heavy oil upgrader in Alberta. In partnership with Enhance Energy, the carbon dioxide will be transported via the Alberta Carbon Trunk Line (ACTL) for enhanced oil recovery.	Alberta	CANADA	1.2 Mtpa	2014	Oil Refining	Pre-Combustion	240 km	Onshore to onshore pipeline	Enhanced Oil Recovery
Jilin Oil Field EOR Project (Phase 2)	More than 800,000 tonnes per annum (tpa) of carbon dioxide from a natural gas processing plant are planned to be injected into the Jilin oil field for enhanced oil recovery by 2015. Around 200,000 tpa are currently being injected at Jilin.	Jilin	CHINA	More than 0.8 Mtpa	2015	Natural Gas Processing	Pre-Combustion	Not specified	Onshore to onshore pipeline	Enhanced Oil Recovery
Lianyungang IGCC with CCS Project	This project will consist of a 1200 MW IGCC power plant and a 1300 MW supercritical power plant capturing up to 1 million tonnes of carbon dioxide per annum. Synthetic natural gas and chemicals will be co-produced at this plant.	Jiangsu	CHINA	1 Mtpa	2015	Power Generation	Pre-Combustion	201 – 250 km	Onshore to onshore pipeline	Enhanced Oil Recovery

Taylorville Energy Center	The Taylorville Energy Center is a proposed 602 MW IGCC power plant located in Illinois. Around 3 million tonnes per annum of carbon dioxide will be captured at the plant and stored in onshore deep saline formations or used in enhanced oil recovery.	Illinois	UNITED STATES	1.92 Mtpa	2016	Power Generation	Pre-Combustion	8 km	Onshore to onshore pipeline	Onshore Deep Saline Formations
ULCOS - Blast Furnace	The Ultra-Low-CO2-Steel (ULCOS) consortium proposes to build a prototype blast furnace that will efficiently capture up to 700,000 tonnes per annum of carbon dioxide from a steel plant. The carbon dioxide would be stored in a deep saline formation.	Lorraine	FRANCE	0.7 Mtpa	2016	Iron and Steel Production	Industrial Separation	60 - 80km	Onshore to onshore pipeline	Onshore Deep Saline Formations
Green Hydrogen	Air Liquide is building a new hydrogen plant in Rotterdam. The installation of a cryogenic purification unit at the plant, capturing up to 550,000 tonnes per annum of carbon dioxide, is under evaluation.	Zuid-Holland	NETHERLANDS	0.4 Mtpa	2016	Hydrogen Production	Industrial Separation	600 km	Ship/Tanker	Enhanced Oil Recovery
Dongguan Taiyangzhou IGCC with CCS Project	Dongguan Taiyangzhou Power Corporation intends to construct an 800 MW IGCC plant capturing up to 1 million tonnes of carbon dioxide per annum to be stored in depleted oil and gas reservoirs.	Guangdong	CHINA	1 Mtpa	2017	Power Generation	Pre-Combustion	101 – 150 km	Onshore to onshore pipeline	Onshore Depleted Oil and Gas Reservoirs
Kentucky NewGas	This project is a new build mine to mouth coal to synthetic natural gas plant in Kentucky proposing to capture around 5 million tonnes per annum of carbon dioxide for storage in a deep saline formation.	Kentucky	UNITED STATES	5 Mtpa	2017	Synthetic Natural Gas	Pre-Combustion	≤50 km	Onshore to onshore pipeline	Not specified
Browse Reservoir CO2 Geosequestration	Up to 3 million tonnes per annum of carbon dioxide would be captured at this proposed liquid natural gas development located on the Dampier peninsula in Western Australia.	Western Australia	AUSTRALIA	3 Mtpa	2017	Natural Gas Processing	Pre-Combustion	Not specified	Unspecified pipeline	Saline Formations or Depleted Gas Reservoir
Pegasus Rotterdam	This project is developing a 340 MW oxy-fuel natural gas-based power plant in Rotterdam that would capture around 2.5 million tonnes per annum of carbon dioxide. The project is part of the Rotterdam Climate Initiative.	Zuid-Holland	NETHERLANDS	2.5 Mtpa	2017	Power Generation	Oxyfuel Combustion	151 – 200 km	Onshore to offshore pipeline	Offshore Depleted Oil and Gas Reservoirs
Quintana South Heart Project	A 175 MW IGCC electric power generating facility in southwest North Dakota. The facility will convert lignite into hydrogen and power, capturing up to 2.1 million tonnes per annum of carbon dioxide for enhanced oil recovery.	North Dakota	UNITED STATES	2.1 Mtpa	2017	Power Generation	Pre-Combustion	Not specified	Onshore to onshore pipeline	Enhanced Oil Recovery
Emirates Aluminium CCS Project	This project proposes to capture around 2 million tonnes per annum of carbon dioxide from two natural gas-based power plants by 2017. The project is being developed as part of the Abu Dhabi CCS Network (Masdar).	Abu Dhabi	UNITED ARAB EMIRATES	2 Mtpa	2017	Alumina Production	Post-Combustion	351 – 400 km	Onshore to onshore pipeline	Enhanced Oil Recovery
Korea-CCS 1	This project proposes to capture up to 1.5 million tonnes of carbon dioxide per annum from an integrated circulating fluidized bed combustion (CFBC) power plant for storage in deep saline formations.	Not Decided	REPUBLIC OF KOREA	1.5 Mtpa	2017	Power Generation	Post-Combustion	251 – 300 km	Ship/Tanker	Offshore Deep Saline Formations
Bow City Power Project	The Bow City Power Project is a proposed super critical 1,000 MW coal-based power plant in Alberta, incorporating post-combustion carbon capture and storage. Around 1 million tonnes per annum of carbon dioxide will be captured for enhanced oil recovery.	Alberta	CANADA	1 Mtpa	2017	Power Generation	Post-Combustion	≤50 km	Onshore to onshore pipeline	Enhanced Oil Recovery
Surat Basin CCS Project (formerly Wandoan CCS Project)	This project is a new build 340 MW IGCC power plant that will capture up to 2.5 million tonnes per annum of carbon dioxide for storage. The capture scope is under review.	Queensland	AUSTRALIA	1 Mtpa	2017	Power Generation	Post-Combustion	151 – 200 km	Onshore to onshore pipeline	Onshore Deep Saline Formations
PurGen One	SCS Energy is proposing to build a 500 MW IGCC power plant in New Jersey. Around 2.6 million tonnes per annum of carbon dioxide would be transported by pipeline to deep saline formations about 160 km offshore.	New Jersey	UNITED STATES	2.6 Mtpa	2017	Power Generation	Pre-Combustion	160 km	Onshore to offshore pipeline	Offshore Deep Saline Formations
Hydrogen Energy California Project (HECA)	SCS Energy has taken over the HECA project from Hydrogen Energy. The new design will be a 400 MW polygeneration plant capturing 2.3 million tonnes per annum of carbon dioxide for enhanced oil recovery enhanced oil recovery.	California	UNITED STATES	2 Mtpa	2017	Power Generation	Pre-Combustion	6.4 km	Onshore to onshore pipeline	Enhanced Oil Recovery
Hydrogen Power Abu Dhabi (HPAD)	This project will convert natural gas into hydrogen and carbon dioxide. The 380 MW hydrogen power plant will generate over 5 per cent of all Abu Dhabi's current power generation capacity. Captured carbon dioxide will be used for enhanced oil recovery.	Abu Dhabi	UNITED ARAB EMIRATES	1.7 Mtpa	2017	Power Generation	Pre-Combustion	201 – 250 km	Onshore to onshore pipeline	Enhanced Oil Recovery
Eemshaven CCS	Essent (RWE Group) aims to capture and store around 1.2 million tonnes per annum of carbon dioxide from an existing 1600 MW coal- and biomass-based power plant.	Groningen	NETHERLANDS	1.2 Mtpa	2017	Power Generation	Post-Combustion	Not specified	Ship/Tanker	Not specified
Caledonia Clean Energy Project	Summit Energy proposes to replicate its Texas Clean Energy Project concept at this new build plant in Scotland. Carbon dioxide captured at the plant would be stored or used for enhanced oil recovery in the North Sea.	Scotland	UNITED KINGDOM	Not specified	2018	Power Generation	Post-Combustion	Not specified	Onshore to offshore pipeline	Enhanced Oil Recovery
CarbonNet Project	The Victorian Government is developing this carbon transport and storage hub project in the state of Victoria. The project aims to collect 1.2 million tonnes of carbon dioxide per annum from various capture facilities.	Victoria	AUSTRALIA	1.2 Mtpa	2018	Power Generation	Not Decided	51 – 100 km	Onshore to offshore pipeline	Offshore Deep Saline Formations
Southland Coal to Fertiliser Project	Solid Energy and Ravensdown have partnered to investigate a coal to fertiliser plant (1.2 million tonnes per annum of fertiliser) with carbon capture and sequestration in a deep saline formation. The plant is projected to begin operations in 2016.	Southland	NEW ZEALAND	1 Mtpa	2018	Fertiliser Production	Pre-Combustion	51 – 100 km	Onshore to onshore pipeline	Onshore Deep Saline Formations
Shen Hua Ningxia Coal to Liquid Plant Project (formerly Yulin)	This project developed by Dow Chemical proposes to build a coal to liquids plant capturing 5 million tonnes of carbon dioxide per annum. Various storage options are under evaluation.	Shanxi	CHINA	5 Mtpa	2019	Coal-to-liquids (CTL)	Industrial Separation	201 – 250 km	Onshore to onshore pipeline	Various
Korea-CCS 2	This project proposes to capture 1.5 to 2.5 million tonnes of carbon dioxide per annum from an oxyfuel or IGCC power plant. The carbon dioxide captured at the plant would be shipped for injection into a deep saline formation.	Not Decided	REPUBLIC OF KOREA	1 Mtpa	2019	Power Generation	Oxyfuel Combustion	251 – 300 km	Ship/Tanker	Offshore Deep Saline Formations
Maritsa Thermal Power Plant CCS Project	This project proposes to capture 2.5 million tonnes per annum of carbon dioxide from an existing lignite-based thermal power plant in Bulgaria. The plant belongs to the Maritsa Iztok Complex, which is the largest energy complex in South Eastern Europe.	Stara Zagora	BULGARIA	2.5 Mtpa	2020	Power Generation	Post-Combustion	Not specified	Onshore to onshore pipeline	Onshore Deep Saline Formations
Datang Dongying Carbon Dioxide Capture and Storage Project	The China Datang Group is developing a new power generation project with CCS, with a planned capture capacity of around 1 million tonnes per annum of carbon dioxide, which will then be used for enhanced oil recovery.	Shangdong	CHINA	1 Mtpa	2020	Power Generation	Not Decided	Not specified	Onhore to onshore pipeline	Enhanced Oil Recovery
Shenhua/Dow Chemicals Coal to Chemicals Plant Project (Ordos)	This project intends to capture around 1 million tonnes of carbon dioxide per annum from an existing coal-to-liquids facility by 2020. It is the second phase of the operating pilot-scale Ordos Shenhua DCL plant CCS Project.	Inner Mongolia	CHINA	1 Mtpa	2020	Chemical Production	Industrial Separation	≤50 km	Onshore to onshore pipeline	Various
Peel Energy CCS Project	This project is considered on hold. Ayrshire Power proposed to construct a new multi-fuel power station that would have captured around 2 million tonnes per annum of carbon dioxide for storage in depleted oil and gas reservoirs.	UNITED KINGDOM	North Ayrshire	2 Mtpa	N/A	Power Generation	Post-Combustion	301 – 350 km	Onshore to offshore pipeline	Offshore Depleted Oil and Gas Reservoirs
Shanxi International Energy Group CCUS project	This project will involve the construction of a new, super-critical coal-fired power plant with oxyfuel combustion capturing more than 2 million tonnes per annum of carbon dioxide.	Shanxi	CHINA	More than 2 Mtpa	Not specifi ed	Power Generation	Oxyfuel Combustion	Not specified	Not specified	Various
Full-scale CO2 Capture Mongstad (CCM)	StatoilHydro and the Norwegian government entered into an implementation agreement to develop carbon dioxide capture solutions at the Mongstad natural gas power plant, with a view to capture and store up to 1 million tonnes per annum of carbon dioxide.	Hordaland	NORWAY	1 Mtpa	Not specifi ed	Power Generation	Post-Combustion	Not specified	Onshore to offshore pipeline	Offshore Deep Saline Formations
Tenaska Trailblazer Energy Center	Tenaska is developing a site near Sweetwater, Texas, to construct a supercritical pulverised coal-based power plant designed to capture up to 85-90 per cent of the carbon dioxide that would otherwise enter the atmosphere.	Texas	UNITED STATES	5.75 Mtpa	Not specifi ed	Power Generation	Pre-Combustion	201 – 250 km	Onshore to onshore pipeline	Enhanced Oil Recovery

Annex 3: List of courses considered as essential for a storage education

CO_2 storage

1. Storage site characterization

A typical workflow for reservoir evaluation of potential sites for geological storage of CO_2 involves acquisition and interpretation of geophysical and petrophysical data, and geological modelling integrating different types of data (seismic data, logs, geological data, etc.). Geological modelling is a critical step which provides the key characteristics of the storage reservoir including the size of the storage site, porosity and permeability distributions, confining layers and boundaries and faults. Knowledge of these properties and other geological attributes is essential for estimating the storage capacity and for realistic dynamic reservoir modelling as described below.

The first geological reservoir also provides the baseline model for long-term monitoring of the storage site which requires acquisition and interpretation of seismic data at time intervals (4D seismic). Following workflow outlined above a time resolved depiction of the motion of the stored CO_2 is obtained. The 4D seismic images thus obtained are compared with predictions of the dynamic reservoir flow models to verify that CO_2 motion in the storage site proceeds according to predict patterns.

Geophysicists, petro-physicists and geologists involved in these activities have in general basic education and training in earth sciences. However they need to acquire expertise in CO_2 storage. In particular it is important that they master the following topics:

- interpretation of high-resolution seismic data for reservoir charged with CO2 (differences with natural gas reservoirs for instance arise from the phase behaviour: supercritical or liquid gas equilibrium at storage conditions)
- seismicity induce by injection of CO2, where re-pressurization of the reservoirs (depleted gas or oil reservoir will lead to redistribution of stresses in the formation)
- geochemical effects resulting from CO2 interaction with cap-rock and formation rock (this is critical input for the dynamic modelling of CO2 storage)
- static reservoir modelling based on high resolution seismic data with emphasis on geological reservoir heterogeneity, migration of fluids through faults
- It is very likely that high-resolution seismic data is not detailed enough to provide information on the heterogeneity and migration pathways of fluids. An improved modelling of existing depositional systems seems to be essential. These aspects deal mainly with risk knowledge on long term CO2 migration and escape.

2. Dynamic modelling of CO_2 storage reservoir

The static reservoir modelling is key input for CO_2 reservoir management. After selection of the CO_2 storage site a dynamic reservoir modelling should be done to achieve the following main goals:

- predict the long-term fate of the CO2 in the storage reservoirs (aquifers, depleted gas fields or EOR)
- help determining strategies (number and location of wells, injection rates, etc.) to assure optimum utilization of the storage capacity
- assert the stored CO2 will be contained within the boundaries of the reservoirs and that there are no risks of uncontrolled flow of CO2 to the surface
- identify risks of technical failure of the storage process and determine potential pathways for leakage into the atmosphere

Dynamic reservoir modelling requires extensive knowledge of the interaction of the CO_2 and the formation. Even in the case of depleted oil and gas fields where much information will be available at the start of CCS activities a dedicated dynamic modelling of the CO_2 will be critically needed.

Indeed CO_2 storage demands more attention to geo-mechanical aspects because re-pressurization of storage reservoir could potentially lead to large changes in the stresses. This could lead to formation of cracks, re-activation of faults and mechanical damage of the cap-rock. These effects can potentially create pathways through which store CO_2 might leak into the atmosphere.
When CO_2 is in contact with the cap-rock in presence of saline water there could be chemical reactions which may result in the formation of flow paths through which the CO_2 can escape toward the surface and ultimately the atmosphere.

The interaction of CO_2 with reservoir fluids (mainly saline water but also oil or gas) should play an essential role in whether storage capacity will be actually realized or not. The complex thermodynamic behaviour of CO_2 stems from the fact that at the reservoir pressures and temperatures CO_2 might be in the liquid, gas or supercritical phases. Dissolution of CO2 into saline water leads to large scale convective phenomena, chemical reactions and mineral precipitation or dissolution and geo-chemical processes. When CO_2 is contact with the cap-rock in presence of saline water there might occur chemical reactions, which may result in formation flow paths through the CO_2 can escape toward the atmosphere and the surface.

These factors will to a large extent determine the short- and long-term fate of CO_2 injected in the geological formations. CO_2 storage reservoir engineers need master the following topics:

- thermodynamics of CO2-water-hydrocarbons systems
- geochemistry of CO2-saline water-rock systems (including cap-rock and faults)
- rock-fluid physics properties (relative permeabilities, capillary pressures, wettability, etc.) and their dependence on geochemistry and thermodynamics
- CO2 mass transfer into water or oil (saline aquifers or depleted oil fields)
- convective mixing of CO2 mass with natural gas (depleted gas fields)

3. Well engineering for CO_2 storage

The well design (vertical and horizontal wells, well completion…) and the well plugging techniques (after closure) may come from the adaptation of the techniques developed in the oil & gas industry, and their improvement in terms of leakage and long-term safety.

During CO_2 injection into a reservoir (saline aquifer, depleted oil or gas field, etc.) the CO_2 will be subject to variations of pressure and temperature. Therefore the CO_2 will undergo phase changes that will impact the efficiency of the injection process. Even small amounts of water present in the CO_2 stream may lead to corrosion of metal parts constituting the well equipment (casing, tubing, valves, etc.). Finally stored CO_2 will be in contact with cement use to stabilize the casing. Technical specialists who are responsible for the design and construction of the wells used for the injection of CO_2 are required to have a highly specialized CO_2 knowledge about:

- thermodynamic behaviour of CO2, the physical chemistry of CO2-saline-water-natural gas systems
- materials science and engineering with emphasis on interaction of CO2 and casing materials the interaction of with materials used in well construction, i.e. casing and tubing used in the construction of casing and injection/production tubing and cement.
- chemical reactions of CO2 and cement and impact of such chemical processes on the integrity of the cement
- good understanding of the principles of corrosion by CO2 and the methods to prevent it.

Microbiological understanding of the subsurface is needed to understand how the presence of microorganisms can affect the pressure during the injection of CO_2. This is because pressure fluctuations have been reported in some injection wells due to the build-up of a 'biofilm' around the injection point caused by CO_2 loving bacteria.

4. Well performance specialist

The injection of CO_2 into geological formations requires careful planning to ensure optimum utilization of the existing injection capacity (volume per unit time) taking into account the

constraints imposed but supply of CO_2. For a proper design, planning and execution of CO_2 injection operations in saline aquifers and depleted oil or gas reservoirs extensive engineers should have extensive knowledge of the multiphase flow in the near-wellbore zone. For accurate modelling of the CO_2 injection process it is necessary to take into account the phase behaviour of CO_2-water-hydrocarbon systems, chemical reactions in the water phase, precipitation and dissolution of minerals and geochemistry. Good knowledge of these factors is require throughout the injection stages, to ensure carefully monitoring and of the injection parameters (pressures, temperatures, injection rates, etc.) is critical for a successful execution of the injection operation.
The following topics should be including in the education and training of well performance specialists for CO_2 storage:

- multiphase flow under near-wellbore flow conditions (extremely high flow rates)
- phase behaviour of CO2-water-hydrocarbon adiabatic cooling (Joule-Thompson effect, hydrate formation, drying effects)
- geochemistry of CO2-saline water-formation rock and related precipitation/dissolution of minerals
- effects on phase behaviour and geochemistry on petrophysical parameters (porosity, permeability, etc.) and rock-fluid properties (relative permeabilities, capillary pressured, wettability, etc.)
- effects if seasonal changes in CO2 delivery to the storage site on the injectivity
- laboratory testing of CO2 injection in aquifers (natural convection, mineral precipitation/dissolution, clogging, etc.)

5. CO_2 Monitoring

Monitoring entails observing the physical and chemical phenomena, which develop during the CO_2 injection process. It focuses on the influence that the presence of CO_2 has in the reservoir system, as well as the tracking of the CO_2 plume within and potentially outside the reservoir. Additionally the monitoring system used, should be able to identify a leakage long before it reaches the surface, ensure public health and confirm the reliability of trapping mechanisms. It can also, help verify the Co2 capacity of the reservoir and provide early warning of any storage failure. It should also be noted that monitoring of a CO_2 Storage Site is obligatory throughout the lifecycle of the project as per the EU Directive 2009/31/EC. The operational principles of monitoring are directly linked to the engineering principles of reservoir and wells performance, though a further inside and different perspective of these principles is essential for the construction of an effective and robust monitoring system. Additionally production data sampling, reservoir pressure regular measurements, logging and other processes can be part of a complete monitoring program. The following topics could be included in the relative module:

- Factors affecting leakage fluxes and Storage failures
- Identification of monitoring techniques.
- Applicability of the different monitoring techniques and their operational principles
- Results interpretation

6. Environmental Risk Assessment

All reservoir systems are geological formations of intense complexity. Their main components are the geology of the reservoir and overlying and underlying layers, various well types, groundwater flow regimes and fluid characteristics. The aforementioned processes should be well understood, in order to assist and identify all the mechanisms and critical parameters that could be relevant to the evolution and performance of the CO2 storage system. In that way one can get a good idea of how the system might evolve over a certain timeframe in the future, identifying possible future base or alternative scenarios. In general we can sum up that the risk assessment aims at assessing the long-term integrity of the reservoir seal, the integrity of the injection and production wells and the potential risk of human intrusion. More specifically the areas which can be covered within this MSc can be:

- Identification of CO2 Storage potential consequences

- Identification of leakage mechanisms and preventive actions
- Risk Assessment studies standards and procedures and scenario analysis
- Managing uncertainties and reducing risks.

7. CO_2 Storage Economics

An introduction to Energy and CO_2 storage economics is necessary for the Economic Evaluation and Sustainability of the project. Moreover, a basic knowledge of the economic terms and process can help to better understand the financial implications of engineering decisions, which are normally made in an environment of uncertainty, both from a financial but also an engineering point of view. The module could potentially involve concepts relative to:

- Financial terms (assets, market value, valuation concepts, depreciation etc.
- Evaluation Methods
- Cash flow methods and models and scaling up
- Budgeting
- Presentation of different Case Studies

Annex 4: Work forces in the CCS chain

WORK FORCE DEMAND FOR CCS DEMO PLANT EXECUTION AND OPERATION (Transport and Storage excluded)

By Gian Luigi Agostinelli, Alstom Thermal Power

Executing and operating a Carbon Capture and Storage (CCS) plant requires considerable amount of work force distributed among:

- different scope: CO2 Capture unit, Transport and Storage
- different stakeholders: Authorities, Plant owner, EPC contractor, EPC Equipment Suppliers, EPC Services Suppliers. Due to the fact that the project creates a cascade of work force demand here limited to the first sub level.
- different categories and skills (e.g. Engineering, Management, Expediting, controlling, construction, equipment installations, Environmental , Health & Safety)
- different phases of a CCS project (project development, basic engineering, Engineering Procurement Construction, Operation)

The analysis given below shows the work force demand generated by CCS Demo Plants execution under the NER300 funding plan for the following scope:

- EPC and Operation of CO2 Capture unit
    - Transport and Storage not included (see specific section for the analysis)
    - Operation and Maintenance is a long term effort that requires stable and constant work force

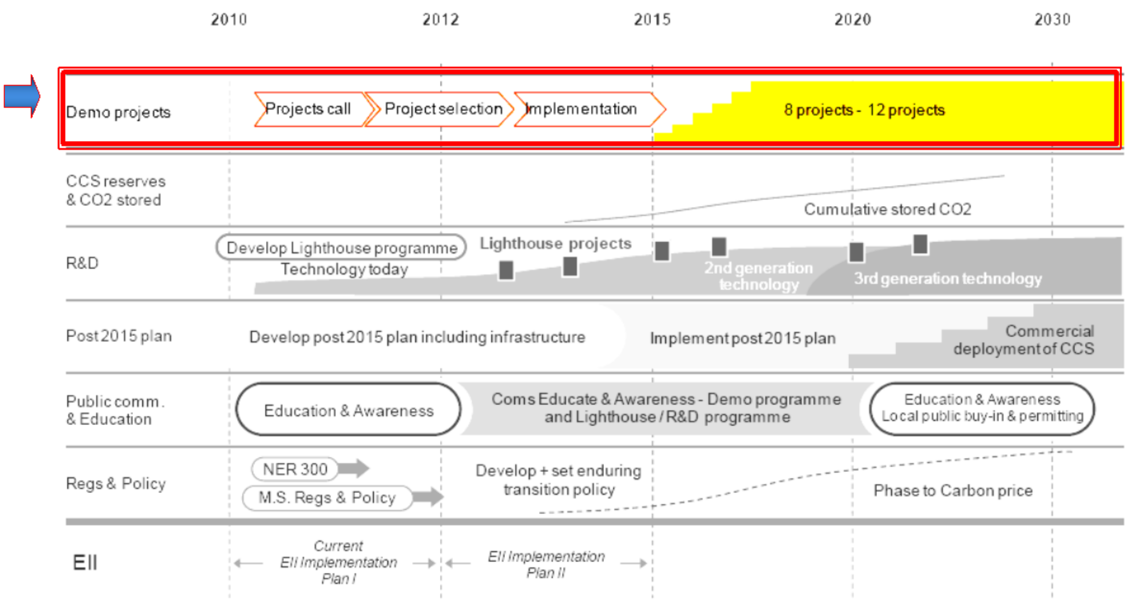


Figure 1. SET Plan and CCS DEMO Plants.

Although the projects planned for such demo phase are about 8 to 12 and each project is in the size of around 250 MWe, in order to have data more easily useable for later assessment, the work force demand has been calculated in a parametric approach assuming 1 GWe CCS demo Plants with the following assumptions:

- 4 units of 250 MWe each in different locations
- Europe

- CO2 capture technologies: Post combustion and Oxy combustion

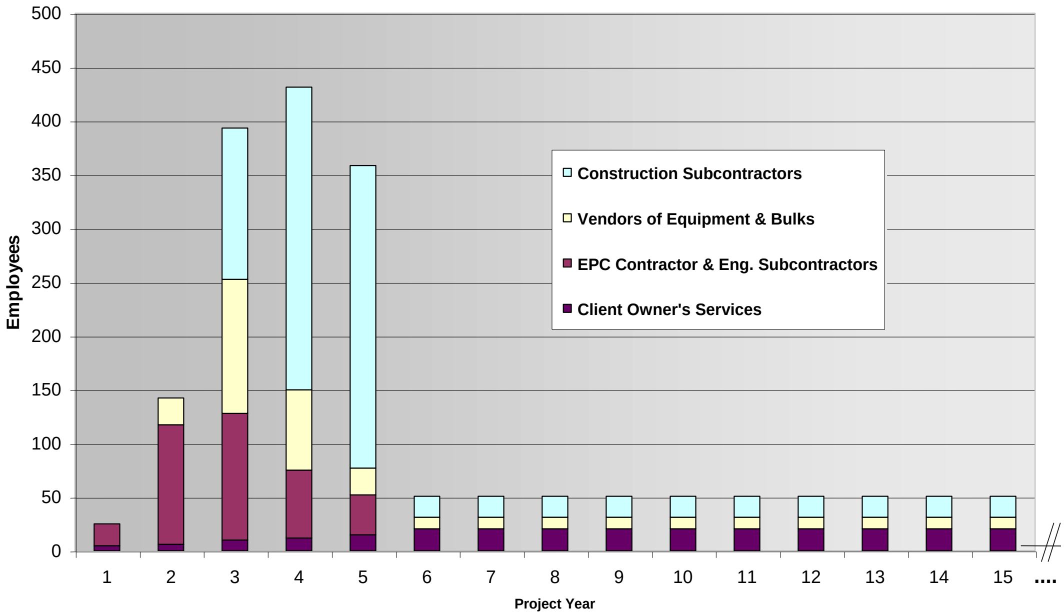
In the Figure 2 the work force demand is shown for only a single 250 MWe project over the years: 5 years of EPC and 10 years of Operation (we limited the operation to 10 years as this is period can vary substantially depending on the business plan of the Plant owner specifically the Plant lifetime).

The work force demand is split into the categories:

- Client Owner's services
- EPC contractor and Engineering sub-contractors
- Vendors of Equipment and Bulks
- Construction sub-contractors

It can be noted that the work force demand during the EPC phase is not constant but shows a peak reaching almost 450 full time employment demand per year.

A multiple parallel CCS projects execution in this regard could generate an issue of resource



availability.

Figure 2. Chart of Work force demand of 250 MWe CCS plant (only Capture scope).

1 GWe of CCS projects in this size would then generate the following average work force demand expressed in full time employed persons per year (Table 1).

Assuming then the overall CCS projects deployment of 8 to 12 CCS plants equivalent to 2 to 3 GWe (assuming a reference 250 MWe size for each of them), the total average full time employment for would range between

2200 to 3300 FTE's / Year for EPCS Phase

400 to 600 FTE's / year for Operation

Table 1. Average full time employment requirement for 1 GWe CCS plant: EPC (5 years) and Operation Phases

	Average full time work force for 5 years construction (*)			full time work force for operation (*)
	E Engineering	P Procurement	C Construction	O Operation
EPC Contractor & Eng. Subcontractors	280 [70/project]			204 [51/project]
Vendors of Equipment & Bulks	200 [50/project]			
Construction Subcontractors	564 [141 / project]			
Client Owner's Services	38 [9.5/project]			
Total	1082 [270/project]			

(*) persons / year

Once again this refers only to the CO2 Capture part, the Transport and Storage is not considered in this assessment and in general these figures have some degree of uncertainty due to the different plant type, locations, technologies applied, so in general a tolerance of +/- 10% should be kept in mind.

The workforce demand for CCS Plant installation after the Demo phase (post 2020) will depend mainly on two drivers:

- learning curve that includes both productivity improvement, optimization of designs, volume effect (synergies between parallel projects, standardization)
- plant size.

The plant size effect has slightly different impact on the different categories (engineering vs. erection and civil) and on the plant phases (EPC vs. Operation). Keeping the same normalized value of 1 GWe equivalent plant size, the workforce demand does not increase by factor 4 compared to the figures given for CCS Demo Plants under NER300 but in the range of around 2 to 2.4 for EPC phase and around 1.2 to 1.3 as estimation for the Operation phase.

The total average full time employment would range between

- 550 to 650 FTE's / Year for EPC Phase
- 60 to 65 FTE's / year for Operation

<u>Work force type of skills:</u>

Executing a CCS plant requires a wide spread of expertise and skills due to its multi disciplines aspects, equipment manufacturing and due to the extensive site works. For each of the stakeholders categories mentioned before the main activities are the following:

- Client Owner's services
  - Operation, Management
- EPC contractor and Engineering sub-contractors

    - Process and Technology, Mechanical, Electrical and Instrumentation, Civil, Plant Design, Project Services, Procurement, Administration and management, Construction Supervision
- Vendors of Equipment and Bulks
    - Heat Exchangers, Aircoolers, Towers, Trays, Vessels , Filter & Dryer, Tanks, Pumps & High Voltage-Motordrives, Pumps & Low Voltage-Motordrives, Compressors & HV-Drives, Booster Fans, Special-Electrical: Hoist/Crane, Plant Utilities incl. Waste Water Treatment, TEG, Reclaimer, Piping Material, Electrical Equipment, Instrumentation Material, Steel Material, Insulation Material
- Construction subcontractors
    - Equipment Erection, Piping Installation, Electrical Installation, Instrumentation Installation
    - Steel Construction, Civil Construction
    - Insulation & Painting Labour

Although it is difficult to figure out the details of the expertise involved in such activities on the Vendors side, the work forces have been filtered according to the following professional/skills main categories and for each category the relative percentage of work force has been derived (Table 2).

Source analysis of required skills:

The skills required to execute the **CCS Demo Plants** do exist and they can be found mainly in the Oil & Gas, Chemical Industry, Power industry fields. One aspect important is the new multi-disciplines scope, where the expertise from different fields have to meet, and have to face the challenges of understanding different technical backgrounds and different businesses culture, procedures and especially different needs. Therefore besides the professionals with a specific deep expertise there will be the need to grow more cross expertise professionals with the ability to integrate the CCS Plant into the Power Generation Plant needs. This process will be easier into EPC companies that will offer the full value chain of Power and CCS as OEM (Original Equipment Manufacturer) and into Universities with an existing broad teaching disciplines portfolio.

Table 2. Work force split by professions/skills.

Engineers (Chemical, Process, Material, Mechanical, Civil, Electrical)	15.5 %
Management, administration, procurement	12.5 %
Project services (logistic, health and safety, transport, environmental)	6.0 %
manufacturing / production qualified workers	10.0 %
Construction supervision	7.0 %
Equipment qualified installation workers	32.0 %
Civil and structure steel qualified workers	17.0 %

Another important aspect is the **evolution** of the skills required as CCS technologies will most likely evolve in a way that is however difficult to forecast.

The skills required by CCS will evolve as the type of process and the technologies applied to commercial demo plants and full commercial scale plants will evolve after 2020 with an evolution characterized by winning technologies, preferred solutions by specific stakeholders, second and third generations of products. This process will lead naturally to an evolution and adaptation of the skills applied and requested by the market and it will be a smooth process. We know that the R&D worldwide is very active in several directions not only on the separation process of CO2 but also on the reutilization of CO2. This mechanisms may lead either to integrate new technologies into existing processes (e.g. membrane, oxygen separation, contactors) in order to optimize the CC plant performance in terms of CoE decrease therefore impacting capital investment and efficiency (2nd generation) or may lead to new processes with different core concept (3rd generation). Therefore the extent of growing new skills and competences will depend on how this evolution will take place and how fast it will be implemented.

Annex 5: Non-exhaustive list of universities

This list has been provided by some of the group members and has to be completed in order to develop a flexible network of Institutes/organisations involved in CCS research

Institutes/organisations involved in CCS research in the UK

UKCCSRC, The UK CCS Research Centre: The UKCCSRC is funded by the RCUK Energy for a Low Carbon Future programme, with additional funding from the Department of Energy and Climate Change. The aim of the UKCCSRC is to provide a national focal point for CCS research and development in order to bring together the user community and academics to analyse problems, devise and carry out world-leading research and share delivery, thus maximising impact. A key priority is to help stimulate the UK economy by driving an integrated research programme focused on increasing the contribution of CCS to a low-carbon energy system for the UK. Members of the UKCCSRC are individuals working in the UK academic community who are currently participating in (or have recently completed) CCS projects. Membership of UKCCSRC therefore includes all of the institutes mentioned below.

The British Geological Survey: BGS is a major centre of geoscientific expertise and data curation, responsible for providing impartial geological advice and information to government, industry, academia and the public. Since co-ordinating the ground-breaking Joule II project in the mid-1990s, BGS has forged a leading role in CCS, with more than 40 staff involved in storage research funded by the EU, industry, UK and overseas governments and the UK research councils. Our work covers the full storage spectrum including site characterisation, performance prediction, monitoring and verification, and long-term processes, supported by state-of the-art laboratories. We have also been involved in developing regulatory frameworks for storage, and have provided technical advice to a number of authorities, including the European Commission, the UK government, the Australian Government, and the regional governments of Western Australia and Alberta. Andy Chadwick is Head of CO_2 Storage Research at BGS and brings 15 years broad experience in the. Sam Holloway is a lead author of the IPCC Special Report on CCS with research interests in storage capacity and integrity. Jon Harrington works on fluid flow processes in low permeability media and Julia West specialises in biological processes and environmental impacts of CCS.

University of Cambridge: The Cambridge Centre for Carbon Capture and Storage (C4S) brings together some 20 faculty with interests and activities in CCS-related research and is part of the Energy@Cambridge strategic research initiative. David Reiner has experience on diverse social, political and economic aspects of climate policy and CCS including public and stakeholder acceptance, economic modelling, scenario design and communications. Daniel Ralph works on computational methods for optimization and equilibrium models, including electricity markets and uncertainty. Stuart Scott works on carbon capture processes based on combustion and high temperature looping and is UK representative on the IEA-GHG high temperature looping network. John Dennis has published extensively on chemical looping combustion and gasification of fossil and renewable fuels, with CO_2 separation.

Cranfield University Cranfield University is a post-graduate university with a very strong industrial/engineering bias; industrial research funding is higher at Cranfield per academic than all other UK universities. Cranfield's activities include capture technologies development (oxy-combustion, gasification, Ca-looping, etc), process integration and modelling, reliability and risk, controls and instrumentation and environmental impact to pipeline and sub-sea engineering for CO2 injection. Cranfield has won over £5m of research funding in covering work related to CCS in these areas in the last few years. Professor JOHN OAKEY (Head of Centre for Energy and Resource Technology) has more than 30 years' experience of power generation systems and leads a range of UK and International energy research projects, including collaborations with the USA and China, involving many industry partners from the power sector.

Durham University: is a leading, research-intensive university ranked 83rd globally and 3rd in the UK. CCS research is done in Earth Sciences (RAE 2008, 70% of research 3&4*), Engineering and Anthropology. Durham University also leads N8 CCS. CCS research was initiated in 2005. Dong and Ikon Sciences fund the UK's first ever chair in Geoenergy & CCS (Prof Gluyas appointed). Dr Simon Mathias, who has a strong record of CCS research joined the team in 2009. The team of staff, research fellows and research students have already made significant contributions to work on injectivity, integrity and monitoring. About £2 million of research funding has been won by this team since late 2009. New research facilities include high pressure flow reactions cells enabling investigation of reactions between CO_2 with reservoir and seal and wellbore materials at storage conditions.

The University of Edinburgh: This research team has been researching and communicating on CCS since 2000 and several academics provide advice to Government committees and Ministers in Westminster and Holyrood. Research leadership by Profs Brandani, Gibbins, Haszeldine and Dr Shackley includes capture since 2002, UK CO_2 reservoirs since 2005, storage capacity since 2008, activity on gas CCS and gas separation since 2009, biomass sustainability and combustion since the 1970's and CCS public perception since 2000. The School of Engineering was ranked third in the UK during the 2008 RAE. The School of GeoSciences includes the world's first CCS programme. The Schools of Chemistry, Law, Social Sciences and Business are also involved in current CCS projects, with numerous industrial linkages. UoE is also one of three core partners in the Scottish Carbon Capture and Storage (SCCS) academic grouping. SCCS. It has a broad base of industry funding combined with close links with other stakeholders, including Scottish and UK Government and regulators. Prof Gibbins, has experience of running two major CCS consortium projects and a network: the UK CCS Consortium multidisciplinary research project (14 partners, 2005-2009), which led to the current, much larger RCUK CCS programme; the co- lead for capture in NZEC (www.nzec.info); and PI for the UK CCS Community Network project linking academic and other researchers (2009-) www.ukccsc.co.uk. Gibbins has worked on gasification and combustion for 30 years, at Foster Wheeler, Imperial and Edinburgh and on CCS since 2002, is CoI on many RCUK projects : MATTRAN (transport), Oxycoal UK (technical director), China OxyCoal, China FOCUS (adsorption), UKERC CCS innovations (interdisciplinary). He initiated carbon capture ready work for UK G8 Gleneagles initiative, followed up with an IEAGHG CCR report, input to UK standards, work in India and China, UK rep on international definition team. First CCS lectures in China 2003, subsequently led/participated in many missions, projects, invited presentation etc. on CCS as well as NZEC, also missions, invited lectures etc. in India, now also linking to South Africa, Brazil and Mexico (invited R&D programme reviewer). Links with CCS research in the USA and Canada, participated/led a number of missions, invited presentations for conferences, policymakers etc., invited member of SaskPower advisory panel, international reviewer etc.

Heriot-Watt University: We are recognised internationally as a leading centre of excellence in petroleum engineering and petroleum geosciences teaching, training and research with strong links to industry worldwide. Research activity within IPE (Institute of Petroleum Engineering) has traditionally spanned across the complete spectrum from exploration, through reservoir appraisal and development, to production technology. In addition our research remit includes focus beyond petroleum into the whole energy sector and related environmental issues. Within this broad remit we have 12 distinct research themes, each represented by an interactive grouping of academic/research staff and postgraduate research students. Because of the truly inter-disciplinary nature of much of our research, several of these themes span the rather artificial boundaries between exploration, development and production, while individual staff may also work across different themes. At the same time, several themes contribute to larger regional or national frameworks. Our research into CCS includes, but is not restricted to, the following research themes: Centre for Enhanced Oil Recovery and CO2 Solutions, and Carbon Capture and Storage, lead by Eric Mackay and Mehran Sohrabi.

Imperial College London: has one of the UK's largest CCS academic research program, with over 30 staff involved in CCS related activity. The college-wide research effort, in conjunction with the Energy Futures Laboratory and the Grantham Institute for Climate Change yields an integrated approach, from capture through transport to geological storage, with an overarching systems approach to ensure coherence. In addition, we are involved the analysis of legal and regulatory issues and researchers regularly present on CCS to the general public (*e.g.* at the Cheltenham Science Festival 2011; Nature virtual lecture). Paul Fennell works mainly on high temperature solids looping cycles and synergies with industrial CCS, Nilay Shah on multiscale systems modelling analysis and optimisation, Martin Blunt has broad expertise on multiphase flow in porous media and Martin Trusler on the measurement and prediction of thermophysical properties with application to capture, transport and storage. Each is a globally recognised leader in these respective fields, but all understand the broader context of CCS research.

The University of Leeds: The Centre for Computational Fluid Dynamics at Leeds is one of the largest virtual system simulation centres in the UK and is an EU Centre of Excellence in CFD (EU MC mono site grant of €2.4M). The CCS group within the Centre is aided by 7 post-doctoral fellows and 16 PhD students working on a wide variety of CCS modelling and experimental work encompassing gas/solid fuel combustion, emissions, gas turbines, process systems modelling and techno-economic studies. Prof M. Pourkashanian is the Head of the University Energy and Technology Innovation Initiative with over £5M of active research grants on capture related projects. Dr Kevin Hughes has extensive experience in chemical kinetic modelling and laser diagnostic measurement with a number of collaborative national/internationally funded projects. Dr Lin Ma specialises in CFD and power station simulation with three active research projects in the field.

Energy is a recognised research strength at **Newcastle University** and is one of the University's strategic priority research themes. The CCS Research Group within the School of Marine Science and Technology (MAST) reflects the core disciplines of MAST and has been conducting research into CO_2 transportation for over six years. MAST is the largest and most broadly based marine department in the UK with 65% of its research rated as world leading in the last RAE. Julia Race has worked as a senior materials engineer in the chemical, oil and gas and pipeline industries for 20 years. Since coming to Newcastle University in 2005, she has been PI on 5 projects related to CCS pipeline transport and is widely consulted on aspects of pipeline transportation for CCS (e.g. as a co-author of the IEAGHG report on building CO_2 pipeline infrastructure, as an invited member of British Standard and industry CO_2 pipeline standard committees and as a consultant member of the National Grid technical R&D. Prof John Mangan is an expert in shipping logistics and is PI on the 'Low Carbon Shipping' project, jointly funded by the EPSRC under the Research Councils RCUK Energy Programme and by Industry (partners include Maersk, Shell, Damco, LR and BP).

University of Nottingham: The research programme in fossil energy and carbon capture and storage carbon capture & storage has expanded enormously over the past 3 years with the current portfolio of projects amounting to *ca*. £14M. It encompasses a number of key projects and initiatives, including the Engineering Doctorate Centre in Efficient Fossil Energy technologies (EFET) led by Colin Snape which is the UK focal point for doctoral training in the field, and a number of EPSRC, ETI and China grants on CCS technologies. Overall research activities are integrated to cover novel capture technologies, transport and storage research. Trevor Drage works on developing solid sorbents and processes for capture in collaboration with Colin Snape as well as collaborating extensively with Mike George on measurement of physical properties of CO_2 mixtures for transport applications. Colin Snape and Hao Lui have extensive experience in oxygen enriched combustion and a number of collaborative national and internationally funded projects in the field. Barry Lomax specialises in plant responses to elevated CO_2, funded via National Grid and BBSRC.

Nottingham Centre for CCS (NCCCS): NCCCS is a collaborative research and training centre formed between the University of Nottingham (UoN) and the British Geological Survey (BGS). Research is cross-disciplinary bringing together engineers, mathematicians, bio-scientists, geographers and geologists. The Centre collaborates and is supported by industries, international energy policy advisors, government organisations, regional development agencies, national and international universities and other research centres. The Centre comprises approximately 50 researchers split roughly 50:50 between the BGS and the UoN, and as such is one of the largest groupings of CCS researchers in the UK.

Plymouth Marine Laboratory: PML undertakes leading international research responding to societal needs and promoting stewardship of the world ocean in relation to global change and sustainability of ecosystems. PML has led environmental research into CCS for 8 years, specialising in ecosystem impacts and modelling. Jerry Blackford leads the RCUK funded QICS consortium and is a work package leader on two EU funded projects (RISCS, ECO2), also serving on the advisory board of the UK CCS academic network. Steve Widdicombe leads the biological impacts research of QICS and ECO2, developing world leading experimental facilities. PML regularly provides advice to UK government departments, international organisations and environmental NGOs on issues related to climate change mitigation and CCS and is a delivery partner for NERC National Capability.

SCCS, Scottish Centre for Carbon Storage: SCCS is a partnership of The British Geological Survey, The University of Edinburgh and Heriot-Watt University. SCCS is the largest carbon capture & storage research grouping in the UK. We comprise in excess of 65 researchers and are unique in our connected strength across the full CCS chain, as well as in our biochar capability. SCCS builds on and extends the established world-class expertise in CO2 storage evaluation and injection, using petroleum and hydrocarbon geoscience (based on geology, geophysics, geo-engineering and subsurface fluid flow). The Centre comprises experimental and analytical facilities; expertise in field studies and modelling; key academic and research personnel, to stimulate the development of innovative solutions to carbon capture and subsurface storage. We undertake strategic fundamental research, and are also available for tactical consultancy. In addition, we perform a key role in providing impartial advice to help industry, the public sector and policy makers.

Institutes/organisations involved in CCS research in Norway

Norwegian University of Science and Technology (NTNU)

NTNU (The Norwegian University of Science and Technology) is a fully integrated university with emphasis on technology and engineering. It is the main technical university in Norway with over 80% of all master- and PhD-degrees awarded in science and technology. Over the last 30 years NTNU and the research institute SINTEF have jointly developed a research area covering 8,000 square metre hosting a 40 million Euro research facility, where 750 people work on mitigating emissions like CO2, NOx, SOx and other greenhouse gases. This includes removing such emissions from oil and gas production processes and from use in industry, buildings and transport.

NTNU is and has been involved in a series of national projects (BIGCO2, BIGH2, BIGCLC, BIGCCS) and EU projects (ENCAP, DYNAMIS, DECARBit, iCap) and has been the coordinator of the FP6 funded ENGAS-RI (Environmental Gas Management Research Infrastructure).

NTNU is also the coordinator of ECCSEL (European Carbon dioxide Capture and Storage Laboratory Infrastructure – www.eccsel.org) put on the official ESFRI Roadmap in 2008.

NTNU is working with a multitude of technologies both within capture, transport and storage of CO_2.

SINTEF Energy Research

SINTEF Energy Research (a legal entity affiliated to SINTEF) is a contract research institute focused on thermal power generation, conversion technologies, and the supply, distribution and end-use of energy. Over the last two decades it has established a sizeable group of people working on various topics relating to CCS technologies. In this area SINTEF ER has developed a considerable level of expertise pertaining to CCS, mainly related to capture techniques in power cycles, gas handling, gas pre-treatment, transport of CO2, as well as low-temperature processing. In collaboration with NTNU, SINTEF ER has more than 30 years of experience in numerical simulation of combustion processes and experimental capabilities (advanced laser diagnostics for combustion measurements). Of special relevance are a novel high pressure oxy-combustion facility (HIPROX) and a 150kW CLC cold pilot that is going to be extended with a hot pilot. Experience has particularly been gained on oxy-combustion and hydrogen combustion in CO2 capture processes through various projects under the Norwegian research programme CLIMIT, and the EU projects ENCAP, DYNAMIS, ECCO and DECARBIT – led or coordinated by SINTEF ER.

SINTEF ER possesses world-class expertise in refrigeration and cryogenics, including modelling and simulation capabilities covering components, working media and systems, and is i.a. responsible for advanced cryogenic air separation units in DECARBit. SINTEF ER was also in lead of the WP2 Capture Technologies in the Sino-European COACH project (2006-2009), much devoted to pre-combustion concepts, notably polygeneration in a Chinese context.

SINTEF ER is the coordinator of the national strategic R&D project BIGCO2 and the International CCS Research Centre BIGCCS. The BIGCCS Centre is considered to form the largest single R&D project portfolio in the world addressing the CCS chain from CO_2 capture to underground storage.

SINTEF Petroleum Research

SINTEF Petroleum Research (SINTEF PR) is a non-profit contract research institute affiliated with the SINTEF Group. It develops technologies and solutions for the exploration and production of petroleum resources. The institute early identified CO_2 storage as an option for reducing greenhouse gas emissions and has since 1986 established research activities within several topics critical for safe and cost-efficient CO_2 storage.

SINTEF PR has expertise to perform evaluation both of regional geology and of individual potential CO_2 storage sites, including assessment of temperature and pressure history from seismic depth maps and sedimentation history, fault seal analysis and building of digital geological models. With the state-of-the-art rock mechanical laboratory and numerical modelling tools the geomechanical response to CO_2 injection can also be investigated.

The reservoir technology laboratory combined with industry-standard or in-house developed numerical tools are being used to investigate short and long-term behaviour of CO_2 storage sites, including the effect of dissolution, diffusion induced gravity convection, potential mechanisms for leakage and well-reservoir interactions. SINTEF PR also has a long experience in experimental and numerical modelling of enhanced oil recovery using CO_2 flooding.

SINTEF PR is actively developing numerical tools for geophysical monitoring of CO_2 storage, including seismic inversion and forward modelling tools, CSEM modelling and inversion tools, and tools for joint inversion of seismic, gravity, magnetic and CSEM data.

SINTEF PR also holds extensive expertise related to drilling, well design and well integrity, and quantitative risk assessment. Multiphase well and pipeline flow is a main competence area including flow assurance simulation, experimental work in a large scale multiphase laboratory facility and models for well injectivity suited for flow simulation and well completion.

The institute has been participating in several EU projects (e.g. ULCOS, CASTOR, DYNAMIS, CO2ReMoVe, ECCO, CO2GeoNet, RISCS, SiteChar) as well as industry projects addressing CO_2 storage, process technology, concepts for reduction of CO_2 emissions, CO_2 based EOR and aquifer storage of CO_2. Currently, SINTEF PR coordinates the CO_2 Field Lab project, conducting shallow injections at the Svelvik site to develop and test monitoring systems and to validate CO_2 migration models. In the BIGCCS Centre, the institute leads the scientific work related to CO_2 storage. The research of SINTEF PR is performed in cooperation with several universities, predominantly the Norwegian University of Science and Technology (NTNU).

Bachelors and Masters Education in Carbon Capture and Sequestration – CCS

State of the art

Carbon Capture and Sequestration Technologies – Massachusetts Institute of Technology:

The Carbon Capture and Sequestration Technologies Program at **MIT** conducts research into technologies to capture, utilize, and store CO2 from large stationary sources. A major component of the program is the **Carbon Sequestration Initiative** (an industrial consortium formed to investigate Carbon Capture and Storage Technologies launched in July 2000). **MIT** research examines carbon sequestration from multiple perspectives, including technical, economic, and political. Current research interests include technology assessments, economic modelling, analysis of regulatory and political aspects, and development of a **Carbon Management Geographic Information System** (GIS).

For more information: http://sequestration.mit.edu/index.html

Carbon Mitigation Initiative (CMI) – Princeton University:

CMI through its affiliation with **Princeton University** serves as an interdisciplinary platform connecting innovative educational programs that engage and support undergraduate, graduate and post-doctoral students to become leaders in the fields of Climate Science, **Carbon Capture and Storage and Integration and Policy**.

Princeton University offers a wide range of opportunities to undergraduate students interested in topics related to carbon mitigation, ranging from courses and certificate programs, summer and year-round internships to student run organizations.

For more details about courses: http://cmi.princeton.edu/programs/education.php

Geologic Carbon Sequestration Program – Lawrence Berkeley National Laboratory:

The Earth Sciences Division (ESD) of **Lawrence Berkeley National Laboratory** has been carrying out research on **geologic carbon sequestration** since 1998. The GCS mission is to develop the knowledge and understanding of CO2 injection, storage, migration processes, impacts, and monitoring to inform and guide the safe and effective implementation of **geologic carbon sequestration**.

The GCS program can be categorized into six Research Areas like Monitoring, Site Characterization, Risk Assessment, Model Development, Laboratory Studies and Geochemistry/Geophysics Theory & Analysis.

For more details: http://esd.lbl.gov/research/programs/gcs/

Carbon Sequestration Program – University of Nebraska, Lincoln:

Carbon Sequestration Program of **University of Nebraska**, Lincoln focus on determining the potential for carbon storage in dry land and irrigated cropping systems in the north-central U.S.A and the factors that govern **carbon sequestration**. Research is being conducted at the western edge of the favourable rainfed "cornbelt" of the north-central USA, which is one of the most productive and largest agro-ecosystems in the world.

For more: http://csp.unl.edu/Public/index.html

Carbon Capture and Storage – Scottish Carbon Capture and Storage:

The CCS masters provide high-level interdisciplinary skills and training in the entire value chain of **carbon capture and storage**, including combustion, transport, geoscience and legal aspects.

The **Carbon Capture and Storage** (CCS) Masters is designed for science graduates in Engineering or Geoscience related subjects seeking an advanced academic qualification as a launch pad for careers in business, industry and government in the field of **low carbon energy production**.

For more details: http://www.ed.ac.uk/schools-departments/geosciences/postgraduate/masters-programme/taught-masters/carbon-capture-storage

Carbon Capture and Storage – Imperial College London:

Imperial College has the country's largest **CCS research program**, with over 30 staff involved in CCS related activity.

The Research Program aims at an integrated approach to Carbon capture, from capture, through transport to **geological storage**, but with overarching systems approach to ensure a coherent research effort and also involved in legal and regulatory issues.

More from here**:** http://www3.imperial.ac.uk/carboncaptureandstorage

Centre for Innovation in Carbon Capture and Storage — University of Nottingham:

The **Centre for Innovation in Carbon Capture and Storage** (CICCS) is an interdisciplinary, innovative, and international leading centre for research at the interface between science and engineering and international cooperation to accelerate the technological innovation needed for the wider deployment of **carbon capture and storage** (CCS). CICCS is active in a large number of research programs which include Decentralized options for CCS, Integration of capture and storage systems, Utilization of CO2 as a feedstock, CO2 capture: improving efficiency and reducing costs, Terrestrial CO2 storage, Public acceptability and regulatory issues and **Cleaner coal technology**.

For details of these research programs:

http://www.nottingham.ac.uk/carbonmanagement/research.php

Carbon Capture and Storage – School of Chemical Engineering, UNSW, Australia:

The School of Chemical Engineering and School of Petroleum Engineering at the University of New South Wales has a significant research group headed by Prof. Dianne Wiley investigating the economics of capturing CO2 from industrial sources and injecting it into underground reservoirs in Australia. The project team is seeking PhD or Masters by Research candidates to join our research team. This research is part of the work of the **Cooperative Research Centre for Greenhouse Gas Technologies** ("CO2CRC"), which is a joint industry / Australian Government sponsored programme that brings together the work of research institutions, Government agencies and private companies in Australia and overseas.

More: http://beasiswa.info/phd-and-research-masters-scholarships-in-carbon-capture-and-storage-at-unsw-australia.html

Online Courses for Carbon Capture and Sequestration:

This course is ideal for geologists, researchers, operators, landmen, engineers, and students who want to learn about carbon capture and sequestration. This course covers the fundamental concepts involved in carbon capture and sequestration, and explains the geological conditions required for successful carbon storage. It profiles extraction, transportation, injection, and monitoring of CO2. This course is offered at the beginning of every month. You may sign up for it at any time, and your course will begin the first day of the upcoming month. It is a 4-week online course which consists of 4 one-week units that involve readings, multimedia, guiding questions, and assignments for you to do and to email to your instructor.

Existing courses for CO2 capture:

Professor Olav Bolland at the Norwegian University of Science and Technology (NTNU) is offering a course CO2 capture in power plants

CO_2 capture in power plants: Brief review of thermal power plants (coal, natural gas). How is CO_2 formed? Why is CO_2 capture difficult; where dilution in flue gases and syngas is explained. Methods of gas separation; absorption, adsorption, membranes, distillation, anti-sublimation. Work requirement for separation of gases. Integration of CO_2 capture in power plants; pre-combustion, post-combustion and oxy-combustion methods. Examples of power cycles with CO_2 capture. Energy penalty/efficiency reduction caused by CO2 capture. Gasification and reforming for pre-combustion capture. Compression and conditioning of CO_2 for transport and storage conditions. Briefly about storage of CO_2.

More: http://www.ivt.ntnu.no/ept/fag/fordypn/tep03/index.htm

Annex 6: Non-exhaustive list of CCS laboratory facilities (ECCSEL initiative)

This is a document being expanded as we receive information about CCS lab facilities from European companies, research institutes and universities.

The following institutions have been suggested to be included in the list of European CCS laboratories:

1. INERIS, French Institute for Industrial Environment and Risks *(Regis Farret)*
2. Ecole des Mines de Paris, Mines-ParisTech *(Denis Clodic, Emmanuel Garbolino)*
3. INPL (Institut National Polytechnique de Lorraine) within Nancy University (and in association with CNRS), *(Jacques Pironon)*
4. Pau University (Université de Pau et des Pays de l'Adour), Lab of Complex Fluids *(D.Broseta)*
5. CIRED: Centre International de Recherche sur l'Environnement et le Développement *(Minh Ha Duong)*
6. University of Provence-Aix Marseille 1 (GSRC), together with CNRS-Geosciences Azur *(Yves Guglielmi)*
7. IPGP : Institut de physique du Globe de Paris (in association with CNRS), *(Pierre Agrinier)*
8. IFFSTAR (Institut français des sciences et technologies des transports, de l'aménagement et des réseaux – former Ecole Nationale des Ponts et Chaussées)
9. Conservatoire National des Arts et Métiers (CNAM and ENSAM - Paris and Chalons), *(Giovanni Radilla)*
10. Orleans University (ISTO)
11. Toulouse University (Paul Sabatier, Laboratoire des Mécanismes et Transferts en Géologie)
12. Montpellier University (Geosciences Montpellier)
13. Bordeaux University.

European CCS laboratories

No.	Short Name	Country
1	TUV	Austria
2	BRGM	France
3	IFPEN	France
4	USTUTT	Germany
5	CERTH	Greece
6	ENEA	Italy
7	IFRF	Italy
8	OGS	Italy
9	UniRoma1	Italy
10	DUT	Netherlands
11	TNO	Netherlands
12	NTNU	Norway
13	SINTEF ER	Norway
14	SINTEF-PR	Norway
15	SINTEF	Norway
16	PGI-NRI	Poland
17	BBU	Romania
18	CIUDEN	Spain
19	MATGAS	Spain
20	ETH Zurich	Switzerland
21	METU-PAL	Turkey
22	BGS	UK
23	UEDIN	UK
24	HWU	UK

Version 4, May 16, 2012 – Prepared by:

Morten Grønli, NTNU

On behalf of:

ECCSEL & ECRI Consortia

European Energy Education and Training Initiative under the SET-Plan

SET-plan working group on Carbon Capture and Storage

This is a document being expanded as we receive information about CCS lab facilities from European companies, research institutes and universities.

European CO_2 Capture and StoragE Laboratory infrastructure

Summary

The objectives of the ECCSEL initiative are to:

- establish a world class Carbon Capture and Storage (CCS) research laboratory infrastructure in Europe;
- integrate and upgrade existing laboratories and supplement with new ones;
- enhance European science, technology development, innovation and education in the field of CCS.

ECCSEL has been in preparation since 2006 and was posted on the roadmap of the European Strategy Forum on Research Infrastructures (ESFRI) in 2008. The goal is to have ECCSEL fully operational by 2015.

Background – the growing need for CCS research in Europe

NTNU and SINTEF believe that there is an increasing demand for CCS research in Europe, which cannot be met by today's research laboratories and organisations. This demand stems from the urgent and growing need for clean energy and the crucial role for CCS in meeting this need at a reasonable cost to society. IEA analysis suggests that without CCS, overall costs to reduce emissions to 2005 levels by 2050 will increase significantly (IEA CCS Roadmap, 2009).

ECCSEL is not a standalone project. It represents a robust strategy to build upon current research and the experience that will be gained through, for example, large scale CCS demonstration projects. These projects represent first generation CCS technology and further research is needed to:

- reduce the cost and energy penalty of CO_2 capture;
- ensure the safety of the CCS chain as projects grow in scale;
- develop new, second generation technologies.

The scale of further research will also have to increase if these benefits are to be realised in the required timeframe and at an industrial scale, as illustrated by the following statements:

> *"expanded global collaboration on CCS research and development and technology transfer will be critical to achieve the BLUE Map emissions target"* – IEA CCS Roadmap, 2009.
>
> *"Global public energy R&D funding should double, to around $20 billion, for the development of a diverse portfolio of technologies"* – Stern Report, 2006.

A new approach to funding CCS research laboratories will be required to achieve future goals in a cost-effective manner. Three challenges that need to be addressed in order to scale up CCS research in Europe are **cost**, **coordination** and **cross-fertilisation** of ideas. These are described below.

How will ECCSEL improve the cost-effectiveness of increased research?

- Increased costs may be expected to take the form of high CAPEX and OPEX for new upgraded laboratories and equipment. ECCSEL will allow for resources and budgets to be pooled in order to meet these higher costs.
- Cost sharing between ECCSEL partners may allow for reduced contributions from single sources.

- ECCSEL will provide a mechanism to create research facilities that would otherwise be unaffordable to any single institution, thus increasing the breadth and depth of research that will be performed.

How will ECCSEL coordinate increased research within Europe?

- Cross-institute access to labs and facilities will be coordinated within and between countries.
- ECCSEL will foster commitment to common research objectives and priorities between researchers, industry and EU demonstration projects.
- Duplication of effort and/or poor utilisation of resources shall be avoided by adjusting research priorities according to industrial needs and EC strategy.
- ECCSEL will coordinate the funding of new and upgraded research laboratories to an estimated value of 250 million Euros provided by European, regional and national agencies. Industrial funding would be additional.

How will ECCSEL promote cross-fertilisation of new research ideas?

- Research across the CCS chain will be promoted in order to integrate work that is currently organised in capture/ transport/ storage silos.
- Research efforts within specific discipline areas may be pooled in order to overcome institutional barriers that separate researchers within the same disciplines.
- ECCSEL shall facilitate interaction between researchers from different organisations in order to create new synergies and motivation.

ECCSEL organisation structure

Cooperation within ECCSEL will be managed by an Operations Centre with a light administration. The Operations Centre will be established as a separate legal entity to be governed by the ECCSEL Board and shall have the authority to manage access to equipment and facilities belonging to ECCSEL partner organisations. See **Error! Reference source not found.**. The management of such access will be based on agreements between the Operations Centre and the partners. In addition, the Operations Centre will perform the following functions:

- set daily rates for access to equipment and facilities based on established cost models;
- process applications for access to infrastructure from partner and non-partner organisations;
- coordinate development of the research laboratory infrastructure in accordance with the priorities to be determined by the ECCSEL Board;
- organise ‘knowledge markets’ that provide a forum for partners to interact, take place in workshops and explore mutual opportunities.

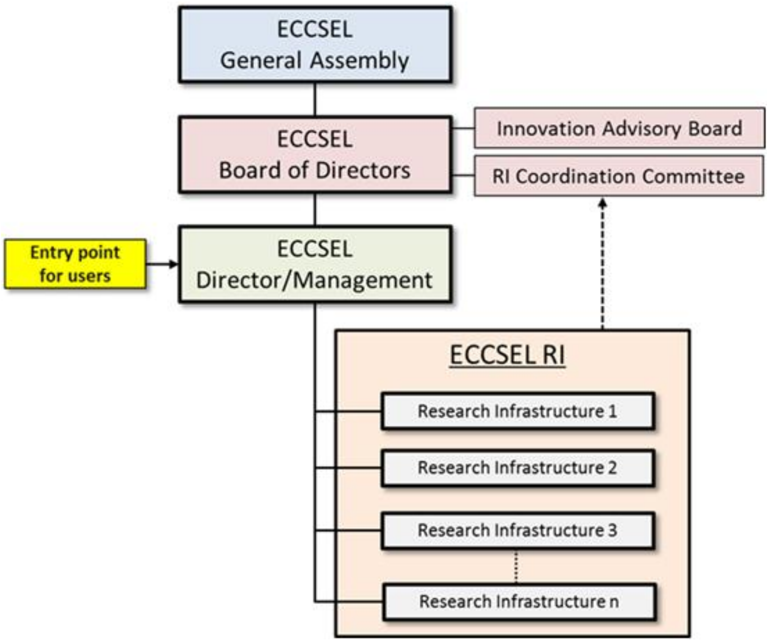


Figure 1: proposed organisation chart for ECCSEL

The required operating budget for the Operations Centre is estimated to be around 1 million Euros per annum. This estimate is based on the value of the activities that shall be performed within existing, upgraded and new CCS research laboratories. The value of the new and upgraded laboratories alone is estimated to be in the order of 250 million Euros.

The annual budget of the Operations Centre should be financed by ECCSEL partners with possible contributions from the host nation.

The geographical location of the Operations Centre is yet to be decided

ECCSEL – Q&A

Q) Will ECCSEL be able to dictate the work programme for members, thus stifling diversity of research?

A) ECCSEL shall be at the forefront of experimental research and make efforts to initiate new research facilities and coordinate their use. ECCSEL shall be an instrument to bring researchers and budgets together to accomplish more than they would be able to on their own. Innovation and novel ideas will be encouraged. ECCSEL will:

- recognise the importance of freedom of research;
- determine access to facilities based on transparent rules and priorities;
- judge the quality of proposed projects and the value of the research direction, but not dictate areas of research;
- ensure that relevant HSE standards are upheld.

Q) Will researchers come under pressure to give away their good ideas?

A) Equipment/infrastructure within ECCSEL may give rise to patentable ideas. The equipment itself, if patentable, should not be part of ECCSEL. The pool of ECCSEL equipment/ infrastructure should be generic. Synergy may be created by new ideas stemming from visiting researchers.

Q) Will the intellectual property rights of a researcher be compromised by collaborating with ECCSEL?

A) No. The legal framework for collaborative research is well established and ECCSEL will follow best practice in the field. Intellectual property rights will be protected.

Q) Could my organisation lose control over its own facilities and which activities get carried out?

A) No. The host organisation will have to approve the proposed activities at its site and may decline on the basis of, for example, HSE concerns. Risk assessments will be required.
Each facility within the ECCSEL network will agree a schedule of availability in advance

Q) How will ECCSEL handle the threat of industrial or academic espionage?

A) All research applications will be screened by the ECCSEL Operation Center and the Peer review Committee in order to exclude disreputable individuals or organisations. Individual researchers will be required to sign a confidentiality agreement. Research facilities may be organised with restricted areas to visiting researchers.

Q) Why should a researcher collaborate if they have sufficient funding already and require exclusive use of their own facilities?

A) In order to participate in research that would otherwise not be carried out. ECCSEL will be greater than the sum of its parts and by sharing knowledge and infrastructure a researcher will facilitate additional research over and above what is already planned.

Q) Who will cover operating expenses?

A) The user of the research laboratory infrastructure will cover operating expenses through daily rates that will be based on established cost models

Q) Who will be responsible for HSE?

A) The owner of the research laboratory infrastructure will be responsible for building and maintaining the infrastructure to local HSE standards. The user of the research laboratory infrastructure will be responsible for fulfilling local HSE requirements. ECCSEL will require partner organisations to demonstrate that they have appropriate HSE systems in place

Q) Who will have liability for breakdown?

A) Liability should be assigned on a case by case basis in an agreement between the owner and user of research laboratory infrastructure. The following would normally apply:

- the user will be liable for negligent use of research laboratory infrastructure (insurance may be required);
- the owner of research laboratory infrastructure will be liable for faulty construction or maintenance.

Short Name	Organisation name	Country
TUV	TECHNISCHE UNIVERSITAET WIEN	Austria
BRGM	BUREAU DE RECHERCHES GEOLOGIQUES ET MINIERES	France
IFPEN	IFP ENERGIES NOUVELLES	France
USTUTT	UNIVERSITAET STUTTGART	Germany
CERTH	CENTRE FOR RESEARCH AND TECHNOLOGY HELLAS	Greece
ENEA	AGENZIA NAZIONALE PER LE NUOVE TECNOLOGIE,L'ENERGIA E LO SVILUPPO ECONOMICO SOSTENIBILE	Italy
IFRF	FONDAZIONE INTERNAZIONALE PER LA RICERCA SULLA COMBUSTIONE - ONLUS	Italy
OGS	ISTITUTO NAZIONALE DI OCEANOGRAFIA E DI GEOFISICA SPERIMENTALE OGS	Italy
UniRoma1	UNIVERSITA DEGLI STUDI DI ROMA LA SAPIENZA	Italy
DUT	DELFT UNIVERSITY OF TECHNOLOGY (DUT)	Netherlands
TNO	NEDERLANDSE ORGANISATIE VOOR TOEGEPAST NATUURWETENSCHAPPELIJK ONDERZOEK - TNO	Netherlands
NTNU	NORWEGIAN UNIVERSITY OF SCIENCE AND TECHNOLOGY	Norway
SINTEF ER	SINTEF ENERGI AS	Norway
SINTEF-PR	SINTEF PETROLEUMSFORSKNING AS	Norway
SINTEF	STIFTELSEN SINTEF	Norway
PGI-NRI	PANSTWOWY INSTYTUT GEOLOGICZNY - PANSTWOWY INSTYTUT BADAWCZY	Poland
CIUDEN	FUNDACIÓN CIUDAD DE LA ENERGÍA	Spain
MATGAS	MATGAS 2000 AIE	Spain
ETH Zurich	EIDGENÖSSISCHE TECHNISCHE HOCHSCHULE ZÜRICH	Switzerland
METU-PAL	MIDDLE EAST TECHNICAL UNIVERSITY	Turkey
BGS	NATURAL ENVIRONMENT RESEARCH COUNCIL	UK
UEDIN	THE UNIVERSITY OF EDINBURGH	UK
HWU	HERIOT WATT UNIVERSITY	HWU

List of laboratories

1. AUSTRIA

1.1 TUV

Organisation name		Short Name	Country
TECHNISCHE UNIVERSITAET WIEN		TUV	Austria
Description of the infrastructure			
Name(s) of the infrastructure(s)*:	**100-150kW Chemical Looping Pilot Plant (CLPP150)**		
Location (town, country):	Vienna, AUSTRIA		
Web site address:	www.chemical-looping.at, www.vt.tuwien.ac.at		
Legal name of organisation operating the infrastructure:	Vienna University of Technology Institute of Chemical Engineering		
Location of organisation (town, country):	Vienna, AUSTRIA		

CLPP150 (Energy conversion systems, Chemical Looping)

Description of the facilities

General description:

The 120-200 kW dual circulating fluidized bed, pilot plant at Vienna University of Technology is the worldwide largest, currently operating facility for experiments in the field of chemical looping technologies. It was designed to feature chemical looping combustion as well as chemical looping reforming operation with utilization of gaseous fuels. In Figure 1 a sketch of the pilot plant (a), an overview of the pilot plant arrangement (b) as well as a photograph of the upward view of the non-insulated pilot plant (c), are shown. The pilot plant design is optimized in terms of gas-solids contact, overall solids inventory and solids circulation rate, whereby particular emphasis was placed on the scale-up potential of the reactor configuration.

Pilot plant arrangement and instrumentation:

A natural gas driven start-up burner together with an electric air-preheater are usually operated to reduce starting procedure to about 4 hours. The system is equipped with 30 online measurement points for temperature and pressure. Operation and monitoring of data points is performed by computer-integrated process control. The system temperature can be controlled via three air/steam cooled jackets attached to the air-reactor. Measurement of reactor pressure profiles allows online determination of the actual solids inventory. Although the pilot rig is designed for natural gas (98,7 vol% CH_4), the fuel reactor can also be operated with mixtures of CO, CO_2, H_2 and C_3H_8. The measurement and flow rate control of fuel gases is performed by rotary instruments (Elster Instroment RVG). The exhaust gas streams of both reactors are analyzed to evaluate the fuel conversion efficiency and possible gas leakages through the loop seals connecting both reactors. The fuel reactor exhaust gas is analysed within a Rosemount NGA 2000 for determination of CO- (0-100%), CO_2- (0-100%), O_2- (0-25%), H_2- (0-100%), CH_4- (0-100%) concentrations. In addition a Syntech Spectras GC 955 online gas chromatograph for N_2 measurements and cross-checking of carbon species is used.

The air reactor exhaust gas stream is analysed using a Rosemount NGA 2000, determining gas fractions of CO (0-100%), CO_2 (0-100%) and O_2 (0-25%). Downstream to the gas analysis units the exhaust gases are sent into a post-combustion unit. After passing a bag filter they are released into a chimney. One uniqueness and great advantage of the present pilot rig is that it allows simultaneous online measurement of exhaust gas concentrations together with bed material sampling from the loop seals. Therefore determination of particle oxidation state for each operating point is possible. This allows calculation of the overall solids circulation rate for accurate interpretation of experimental results.

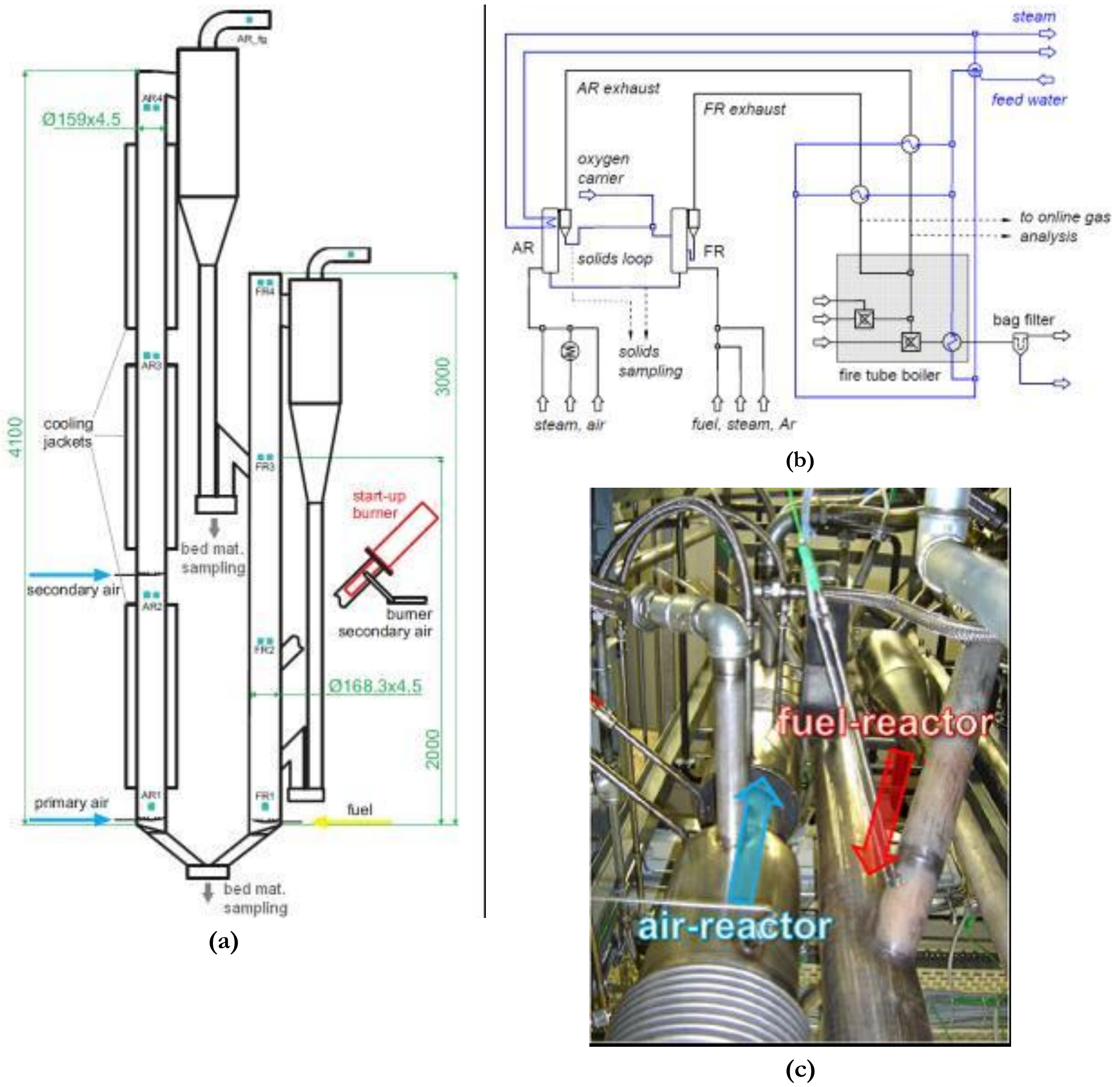


Figure 1- Chemical looping pilot plant at Vienna University of Technology

<u>Preparation of data:</u>

Experimental data are recorded and afterwards evaluated within a mass and energy based process model implemented in a process simulation software. Each operating point is determined within a time range of about 30min under steady-state operation. The mean values during a steady state operation period of 10-20 minutes constitute the data base for evaluation of the operating point. Data reconciliation methods are used in combination with the mass and energy balance requirements. Thus, a consistent data set is available for each operating point which represents the true values operated best in statistical terms.

<u>Results from experimental campaigns:</u>

The analysed data sets are usually documented within a standard report, including measurement point conditions (fluidization velocities, pressure profile, gas composition in reactor inlets, ...), oxygen carrier oxidation states (necessary for determination of solids circulation rate) and exhaust gas compositions.

State of the art

The 120-150 kW pilot plant in Vienna is the largest successfully operating facility for chemical looping combustion and chemical looping reforming. Since the erection of the plant, several experiments designated to process demonstration, oxygen carrier performance, fuel type influence, operating temperature influence and so forth have been conducted. Therefore, the staff working at Vienna University of Technology has large experience in plant operation as well as in evaluation of experimental data (see references below, more publications available at www.chemical-looping.at).

Future test campaigns

The development of oxygen carrier materials for chemical looping combustion and reforming has not yet come to fully satisfactory conclusions. The main requirements to be met are (i) high reactivity in the fuel reactor, (ii) high stability against attrition and fragmentation, (iii) no agglomeration in fluidized beds, (iv) environmental and safety risks, (v) cost of production, and (vi) access to the necessary raw materials. It is expected that new oxygen carrier candidates will be developed during the next years and testing at relevant operating conditions will be necessary to assess the application potential of these materials in full scale chemical looping. In this area, the need for sharing the pilot plant infrastructure is expected.

Further experiments may be conducted for example to investigate:

- Performance of novel oxygen carriers (reactivity, deactivation, attrition, …)
- Influence of sulphur components (including slight adaption of measurement equipment)
- Influence of higher hydrocarbons (including evaporated tar substances)
- Chemical looping combustion of liquid fuels
- Chemical looping reforming (CLR)
-

List of CCS related EU/national funded projects where the infrastructure was developed or used

- GRACE (EU/FP6), CCCC (EU/RFCS) .
- CLC GAS POWER (EU/FP6)
- CACHET (EU/FP6)
- UNIQUE (EU/FP7)
- G-volution (Austrian Climate and Energy Fund)
- INNOCUOUS (EU/FP7)

Achievements (original contributions to knowledge based on the infrastructure)

- Original modelling of chemical looping combustion by combining air reactor and fuel reactor
    - Prediction of the dynamic equilibrium governing the mean degree of oxidation of the oxygen carrier
- Development of the dual circulating fluidized bed (DCFB) design approach combining two circulating fluidized bed reactors in a novel way
    - High global solids circulation rates
    - Improved gas-solids contact for lower specific solids inventories
    - Stable solids distribution between air reactor and fuel reactor
    - Improved scalability avoiding bubbling bed reactors
- Successful construction and operation of the chemical looping pilot plant, the largest with successful operating data presented so far
    - High fuel conversion in CLC at reasonable specific oxygen carrier inventories
    - Demonstration of CLR with full CH_4 conversion in the fuel reactor and quantitative oxygen removal from the air stream in the air reactor

Bibliography

- Pröll, T., Kolbitsch, P., Bolhàr-Nordenkampf J., Hofbauer, H., 2009, *"A novel dual circulating fluidized bed (DCFB) system for chemical looping processes"*, AIChE Journal, 55 (12), 3255-3266.
- Kolbitsch, P., Pröll, T., Hofbauer H., 2009, *"Modeling of a 120kW chemical looping combustion reactor system using a NiO oxygen carrier"*, Chemical Engineering Science, 64 (1), 99-108.
- Kolbitsch, P., Pröll, T., Bolhàr-Nordenkampf, J., Hofbauer, H., 2009, *"Design of a Chemical Looping Combustor using a Dual Circulating Fluidized Bed Reactor System"*, Chemical Engineering and Technology, 32(3), 398-403.
- Kolbitsch, P., Pröll, T., Bolhàr-Nordenkampf, J., Hofbauer, H., 2009, *"Characterization of chemical looping pilot plant performance via experimental determination of solids conversion"*, Energy and Fuels, 23(3), 1450–1455.
- Pröll, T., Bolhàr-Nordenkampf, J., Kolbitsch, P., Hofbauer, H., 2010, *"Syngas and a separate nitrogen/argon stream via chemical looping reforming – A 140 kW pilot plant study"*, Fuel 89, 1249-1256.
- Kolbitsch, P., Bolhàr-Nordenkampf J., Pröll, T., Hofbauer, H., 2010, *"Operating experience with chemical looping combustion in a 120kW dual circulating fluidized bed (DCFB) unit",* International Journal of Greenhouse Gas Control, 4 (2), 180-185.

2. FRANCE

2.1 BRGM

Organisation name		Short Name	Country
BUREAU DE RECHERCHES GEOLOGIQUES ET MINIERES		BRGM	France
Description of the infrastructure			
Name(s) of the infrastructure(s)*:	**Technology platform Montmiral**		
Location (town, country):	Montmiral France		
Web site address:	Not yet		
Legal name of organisation operating the infrastructure:	BRGM		
Location of organisation (town, country):	Orléans France		

Technology platform Montmiral (Storage, Site characterization and monitoring/CO_2 impacts)
Montmiral is a natural gas field with 97-to 99% CO_2, in Triassic sandstones and Rhaetian to Hettangian carbonates at more than 2400 m depth. CO_2 has been exploited from 1990 to 2010 for an industrial use.

The infrastructure comprises:
- the Montmiral CO_2 well (V.Mo.2) – total depth 2480 m, currently immobilized by brine
- two nearby wells Saint-Lattier SL1 (2790 m deep) and SL2 (2425 m deep) at distances 8 to 10 km from Montmiral. SL2 well cross-cut CO_2 reservoirs in triassic to hettangian levels.
- two other CO_2 well exist in the Valence Basin: at Montoison (B.Mt1 – 50 km in the south of V.Mo.2, 3976 m depth) and at Brézin (Br.1- 25 km in the north of V.Mo.2, 1833 m depth)
- thirty springs (depth zero) and groundwater wells (up to depths 250 m) which exploit pliocene and miocene aquifers, within a radius distance of 15 km around Montmiral
- the knowledge acquired on the site through research projects

It is envisaged to upgrade the facility with:
- Reopening of the well to produce CO_2
- Surface installations to test impact of CO_2 on materials or CO_2 reuse technics
- On site small laboratory

Projects to fund these upgrades have been submitted

Unique infrastructure
Throughout the world there are many occurrences where natural CO_2 has been trapped in geological reservoirs. These reservoirs, called natural analogues, offer a unique opportunity to study the long-term behaviour of CO_2 underground, the chemical reactivity of the reservoir and caprock due to CO_2 interactions with rock minerals and fluids, the trapping mechanisms, and the nature of leakage if it occurs. Therefore, the studies of natural CO_2-rich reservoirs, which act as long-term laboratories and give specific examples in various settings of long term CO_2 behaviour and impact, raise lot of interest in the international scientific community. Long term observations at these sites usefully complement the investigations carried out at CO_2 storage pilots and demonstrators that have been operating at most 15 years and for which only short-term lab or field observations can be made, while long term behaviour can only be predicted. They also enable to integrate better the long term perspective for site selection, characterisation and risk management of future CO_2 storage sites.

The Montmiral research infrastructure is unique in Europe and even in the world due to the rare combination of the following characteristics:
- fluid samples from the CO_2 reservoir can be collected at the well-head of V.Mo.2, and along the CO_2 purification process chain;
- rock samples (cores) at various depths from the basement, the reservoir, the caprock and the

overlying formations are available (TOTAL corestore at Boussens)
- cuttings samples from the base to the top of the well (TOTAL corestore at Boussens);
- comparison possible between the CO_2 field and adjacent zones with no CO_2 in order to discriminate the effects due to CO_2
- Overlying fresh-groundwater in the surrounding area can be sampled
- extensive set of data and knowledge being acquired on this site from 2001, plus historical data acquired in the 1960s during oil & gas exploration (geochemistry, seismic, petrography, well test, diagraphies, ...) .

Fig1. Motniral CO_2 field and technology platform

State of the art

The areas of research supported at the Montmiral research infrastructure are:
- long–term behaviour of the reservoir and the caprock: CO_2-rock-fluid geochemical interactions, impact on the CO_2 trapping mechanisms, on reservoir physical properties (porosity, permeability, …), on geomechanical stability
- relationship between diagenetic history, tectonic events of the basin, and CO_2 migration along faults and fractures
- identification of leakage pathways, if any, through the caprock, the overlying formations and up to the surface; characterisation of mineral infills ; description of processes using logging tools and geophysical methods (active seismic, magnetotelluric (MT), Electrical resistivity imaging (ERT) and EM soundings).
- co-mobilisation of other substances than CO_2 (hydrocarbons, heavy metals, H2S, Rn, etc.)
- assessment of impacts on associated and overlying groundwater and on ecosystems at depth or at ground surface, or demonstration that no impact is observed.
- Monitoring techniques at surface or at depth to track the CO_2 or any indirect impact.
- Well behaviour after 20 years of CO_2 production.

Services currently offered by the infrastructure:

- Access to rock samples from the Paleozoic and the sedimentary column until the Oligocene.
- Access to fluid samples from the deep CO_2 reservoir at the well head of exploitation borehole and from overlying groundwater (springs and irrigation wells)
- Possibility of field monitoring at various depths and at surface using geophysical, geochemical, biological, remote-sensing techniques
- Access to specific equipment for field measurements, services for fluid and rock field and lab analyses
- Access to the knowledge already gathered around the site

The planned upgrades will allow:
- to study the impact of CO_2 on materials for surface storage and transport

- To test CO_2 reuse technology
- To simulate CO_2 leakage to study the dispersion of CO_2 in the atmosphere

The most interesting scientific achievements already obtained by users are the following:

- Mantle origin of the CO_2;
- The CO_2 induced in Triassic sandstones, the dissolution of K-feldspar and precipitation of kaolinite and carbonates; 3% increase of porosity
- CO_2 migration along faults was detected into Rhaetian and Hettangian formations by fluid inclusions studies CO_2 fluid inclusions are locally linked to hydrocarbon;
- This CO_2 migration is estimated to be of post-Pyrenean age during an extensive phase (35-23 My);
- Along the overall well, petrographical and geochemical data demonstrate a possible connection between Palaeozoic substratum and Triassic Liassic levels and a disconnection between the base and the top of the well created by the Jurassic marly level (575 m thickness);
- Concerning soil gas analyses, two field trips were done in 2006 and 2007. In the vicinity of the exploited CO_2 well, no evidence of leakage of deep origin is found, CO_2 concentrations and Rn activities suggesting a sub-surface or biologic-related origin. Nevertheless, at some distance (10 km to the NW), CO_2 concentrations can rise up to 8%, but with isotopic ratios apparently due to biologic soil activity. This discrepancy between high CO_2 content and depleted ratio is not well understood up to now, and need further studies (campaigns in winter during low biological activity, sampling at depth greater than 1 m).

This site has become a European research infrastructure from 2001 at the start of the FP5 NASCENT project entitled "Natural Analogues for CO2 Storage in the Geological Environment" (2001-2004). The has been used for further research activities within the **CO2GeoNet** European Network of Excellence (from 2004), a French research project (**ANR-Monitoring** 2006-2008) and a PhD thesis (2005-2008). The site is also part of the current FP7 project **CO2care** site abandonment and **RISCS** on impacts and safety of CO2 storage.
The following publications quoting scientific results acquired at the Montmiral infrastructure demonstrate that there is a widespread interest worldwide:

1. **Czernichowski-Lauriol I., Rochelle C., Gaus I. *et al.*** (2006) - Geochemical interactions between CO_2, pore-waters and reservoir rocks: lessons learned from laboratory experiments, field studies and computer simulations. In : Advances in the Geological Storage of Carbon Dioxide, p.157-174. Ed. by Lombardi, S. et al. Netherlands : Springer
2. CZERNICHOWSKI.LAURIOL.I., Persoglia.S., Riley.N. (2006) **On-going joint research activities within the CO2GeoNet European Network of Excellence on CO_2 geological storage**, in *Proceedings* of the *GHGT-8* International Conference on Greenhouse Gas Control Technologies - Trondheim - Norway - 18-22/06/2006, 6 p.
3. **Gaus I., Le Guern C., Pearce J. *et al.*** (2004) - Comparison of long-term geochemical interactions at two natural CO_2-analogues: Montmiral (Southeast basin, France) and Messokampos (Florina basin, Greece) case studies. 5-9 sept. 2004, GHGT7 - Vancouver, Canada.
4. **NASCENT project, Final report** (2005) - Natural analogues for the geological storage of CO_2. 92 p. IEA-GHG Report Number 2005/6.
5. **Pauwels H., Gaus I., Le Nindre Y. M. *et al.*** (2007) - Chemistry of fluids from a natural analogue for a geological CO_2 storage site (Montmiral, France): Lessons for CO_2-water-rock interaction assessment and monitoring. *Applied Geochemistry*, 22, p. 2817-2833.
6. **Pearce J. M., Shepherd T. J., Kemp S. J. *et al.*** (2003b) - A petrographic, fluid inclusion and mineralogical study of Jurassic limestones and Triassic sandstones from the Montmiral area of the Southeast Basin of France, *British Geological Survey External Report*. 76 p. (CR/03/144).
7. **Rubert Y** (2009) - Petrographic indicators of CO_2 migration in the Montmiral natural analogue. Phd

2.2 IFPEN

Organisation name		Short Name	Country
IFP ENERGIES NOUVELLES		IFPEN	France
Description of the infrastructure			
Name(s) of the infrastructure(s)*:	**TransProS (Transport Properties for CO_2 Storage)** **CRC (Caprock Characterization)** **U544 (CO_2 post combustion capture mini-pilot)**		
Location (town, country):	Rueil-Malmaison and Solaize (Lyon), France		
Web site address:	www.ifpen.fr		
Legal name of organisation operating the infrastructure(s):		IFP Energies nouvelles	
Location of organisation (town, country):	Rueil-Malmaison, France		

TransProS (Transport Properties for CO_2 Storage)

This research infrastructure provides advanced techniques for measuring capillary pressure (Pc) and relative permeability (Kr), needed for proper simulations of CO_2 behaviour. Due to the high mobility of gas, the measurement of Kr curves is not trivial and needs advanced techniques such as local saturation measurements during displacement experiments in a core sample. Furthermore, Pc should be measured on the same sample in order to perform the numerical interpretation of the collected data. We propose here two experimental installations to measure Pc and Kr curves: i) a CT scanner equipped with a flooding cell providing 3D saturation maps and ii) an automated centrifuge providing simultaneously Pc and Kr curves. The associated numerical tools for data interpretation are also included.

Centrifuge laboratory (Storage, Laboratory: Characterization and processes)

Description of the facilities

The centrifuge laboratory comprises two large size centrifuges with rotating speed up to 4000 rpm. One centrifuge has the capability of measuring the produced fluids continuously using an accurate capacitance based technique. Custom-build core holders can accommodate samples of diameter 40 to 50 mm, and length up to 60 mm, at a mean radius of rotation of 170 mm. Six samples can be analysed in a single experiment. The range of capillary pressure for the air-water fluid system is 50 mB – 15000mB.

Figure 2 Automated centrifuge at IFPEN

The second centrifuge can accommodate longer samples, up to 120 mm, without fluid measurement capabilities. It is mostly used to desaturate samples at irreducible saturation.

State of the art

The centrifuge experiment when performed with continuous recording of saturation, is well adapted for the simultaneous determination of air-brine Pc and Kr curves, in the entire saturation range. IFPEN's unique system overcomes frequently encountered technical difficulties of measuring precisely water saturation while rotating and is complemented by a dedicated numerical interpretation procedure. Centrifuge air-brine Kr experiments are largely superior to standard gas injection subject to fingering instabilities caused by local heterogeneities. At the end of drainage, samples can be immersed in water in order to obtain the residual gas saturation, another useful quantity for reservoir simulations.

Services currently offered by the infrastructure and achievements

Air-water capillary pressure curves in drainage, and water relative permeability curve; Oil-water capillary pressure curves in drainage and forced imbibition; Oil-water relative permeability curves in drainage and forced imbibition; USBM wettability tests

Relevant scientific publications

Fleury M., P. Poulain and G. Ringot, 'A capacitance technique for measuring production while centrifuging', Proceedings of the International Symposium of the Society of Core Analysts, La Haye, September 14-16, 1998.

Fleury M., P. Egermann, E. Goglin, A model of capillary equilibrium for the centrifuge technique, International Symposium of the Society of Core Analysts, 18-22 October 2000, Abu Dhabi, United Arab Emirates

Fleury M., S. Gautier, N. Gland, P. Boulin, B. Norden, C. Schmidt-Hattenberger, Petrophysical measurements for CO_2 storage: Application to the Ketzin site. International Symposium of the Society of Core Analysts, Calgary, Canada, 10-13 September, 2010.

X-RayComputed tomography (CT)

Description of the facilities

IFPEN's CT scanner is a commercial medical scanner GE Fxi. This equipment, combined with an appropriate flow cell, has the capability of measuring the fluids saturations in a core while flooding, from which the Kr curves can be deduced. If used with our semi dynamic approach both of Pc and Kr curves can be obtained. The measured local saturation profiles bring a significant improvement in the interpretation of coreflood experiments by a better accounting of the capillary pressure effects during the relative permeabilities determination.

Figure 3 CT Scan

State of the art

Relative permeabilities are usually determined from flow experiments performed on core samples using either the Unsteady Steady State (USS) or the Steady State (SS) method. The main advantage of the semi dynamic approach is to establish several equilibrium states between the viscous and the capillary forces within the sample by injecting one fluid while the other circulates at the outlet face. These equilibrium states enable the analysis of both the kr of the injected phase and the Pc curve. The kr of the displaced phase can also be obtained by history matching of the transient evolution of the pressure drop.

The in-situ saturation monitoring brings a significant added value to the interpretation process because it enables the direct identification of the influence of the capillary effects on the experimental data. Several ways exist to use this information in the inversion procedure of the kr data. To date, the local saturation profiles are either included in a global objective function (in addition to the production and the pressure drop data) that is minimized during the inversion process, or smoothed and used as input data in the simulation, which leads to non-smoothed simulated pressure drop.

Services currently offered by the infrastructure and achievements

Capillary pressure curves and both fluids relative permeability curves can be measured. In a standard experiment, Swi is first established. If the wettability has to be restored, the wettability is restored by aging at reservoir conditions with live oil. Then, the live oil is replaced by dodecane using several successive miscible displacements prior to injection of nitrogen at ambient conditions.

The gas injection experiment is conducted under the medical CT-scanner (voxel 0.12×0.12×1 mm3) to follow the evolution of the saturation profiles as a function of time (1 acquisition every 2 seconds). The oil and gas productions are recorded and CT-profiles are measured regularly during the experiment. Different differential pressure are successively applied. Further details on the experiment can be found in a previous paper dedicated to gas injection processes.

Achievements (include the most relevant scientific publications, up to 5)

Lombard J.-M., Egermann P., and Lenormand R., "Measurement of Capillary Pressure Curves at Reservoir Conditions", SCA n° 2002-09, Society of Core Analysts, Monterey, California, 2002

Egermann P., Robin M., Lombard J.-M., Modavi A., and Kalam M. Z., "Gas Process Displacement Efficiency Comparisons on a Carbonate Reservoir", SPE n° 81577, Middle East Oil Show, Bahrain, 2003

CRC (Caprock Characterization)

The research infrastructure provides advanced techniques for measuring porosity, permeability and entry pressure of caprock formation.

Caprocks may have very low permeabilities, down to 1 nD (10^{-21} m^2). Traditional equipments cannot be used at such low values. IFPEN developed in the recent years specific installations and protocols for measuring liquid permeability in a reasonable amount of time on standard plug sizes, including the effect of confining pressure. Using the same installation, entry pressure can be measured after permeability. In addition, orders of magnitude of permeability can be obtained quickly on cuttings when plugs are not available. This infrastructure is composed of two independent installations

NMR laboratory (Storage, Laboratory: Characterization and processes)

Description of the facilities

The laboratory comprises 4 NMR devices characterized by different resonance frequencies, different diameters and different capabilities:

- a 2.2 MHz device equipped with a 50 mm probe and 1D vertical gradient (50 G/cm)
- a 2.2 MHz device equipped with a 70 mm probe
- a 23.7 MHz device equipped with a 18 mm probe and 1D vertical gradient (300 G/cm), and a 10 mm probe with 3D vertical gradient (300 G/cm)
- a 20.7 MHz imaging system equipped with a 30 mm probe and 3D vertical gradient (150 G/cm)

e laboratory has also several home build interpretation software such as 1D and 2D inverse Laplace transforms, diffusion analysis software. Depending on the size of the probe, inter-echo time as small as 30 µs can be reached, allowing small relaxation time to be detected. The various diameter probes allows the NMR characterisation on powders, cuttings, small, standard or large size plugs. Temperature and pressure cells are also available with some devices.

Figure 4 Two NMR devices: 23.7 MHz (left) and 2.2 MHz (right)

State of the art

The NMR technique is unique for characterizing porous media in a non destructive way; it was initially developed at IFPEN to perform laboratory to log integration but is also used to measure porosity and pore size distribution, as well as pore connectivity from advanced 2-dimensional relaxation experiments. The NMR technique is particularly well suited for characterizing tight formation such as caprocks or coals because water contained in nano-pores can be detected easily.

Services currently offered by the infrastructure and achievements

The installation is used on an everyday basis for porosity and pore size distribution measurements, and control of these two quantities at different steps of experiments performed in other laboratories. It can be coupled with centrifuge and resistivity experiments in order to measure saturation and fluid distribution in porous media. For tight rocks, samples need not to be dried, and this is a clear advantage for not perturbing the pore structure of preserved samples containing clays.

Relevant scientific publications

Fleury M., D. Boyd and K. Al-Nayadi, Water saturation from NMR, Resistivity and Oil-Base core in a heterogeneous Middle-East carbonate reservoirs, Petrophysics, vol 47, 1, 2006.

Nicot B., S. Gautier, M. Fleury and S. Durucan, Pore structure analysis of coals using low field NMR measurements and thermogravimetry analysis, Proceedings of International Symposium of the Society of Core Analysts, Trondheim, Norvay, 12-16 September 2006.

Guichet X., M. Fleury, E. Kohler, Effect of clay aggregation on water diffusivity using low field NMR, J. Coll. Inter. Sciences, 327, 2008.

Fleury M., J. Soualem, Quantitative analysis of diffusional pore coupling from T2-store-T2 NMR experiments, J. Coll. Inter. Sciences, 336, 2009.

Berne Ph., P. Bachaud and M. Fleury, Diffusion properties of carbonated caprocks from the Paris Basin, Oil Gas Sci. Technol. – Rev. IFP 65 3 (2010) 473-484

Fleury M., S. Gautier, N. Gland, P. Boulin, B. Norden, C. Schmidt-Hattenberger, Petrophysical measurements for CO_2 storage: Application to the Ketzin site. International Symposium of the Society of Core Analysts, Calgary, Canada, 10-13 September, 2010.

VLP laboratory (Storage, Laboratory: Characterization and processes**)**

Description of the facilities

The VLP (Very Low Permeability) laboratory comprises two experimental set up to measure liquid permeability in the nanoDarcy range (10^{-21} m^2) within one day – one experimental set up to measure gas permeability – one experimental set up to measure entry pressure by more than four different methods – one device to measure low permeability on small size sample (used for screening purpose).

Water permeability measurement is performed using the steady state method with a pump in a push/pull configuration. One device is at a controlled temperature of 20 to 30 °C. The other one is at a controlled temperature of 20 up to 80°C. The confining pressure limit is 350 bar and the pore pressure limit is 300 bar. The measured permeabilities range from 0.1 nD up to 1 µD (10^{-22} m^2 to 10^{-18} m^2). Measurement can be fast (1 nD in one day) since high precision pumps are used. The device uses plugs of 40 to 50 mm diameter and 20 to 50 mm length.

Gas permeability experiments are based on transient and steady state techniques. Klinkenberg effect can also be assessed. Permeabilities from 10 nD up to 100 µD can be measured. The confining pressure limit is 350 bar and the pore pressure limit is 200 bar. The device uses plugs of 40 to 50 mm diameter and 20 to 50 mm length. For cuttings, a specific device called Darcygaz can be used, based on the GRI method. The experiment is made at 1 bar and no confinement is applied. The measured permeability are from 50 nD up to 100 µD (5 10^{-20} m^2 to 10^{-16} m^2). The plugs used here are 15 mm diameter and 20 mm length.

Figure 5 Water permeability measurement device

The experimental set up used for the entry pressure measurement can performe several techniques: step by step approach, dynamic method, dynamic racking method and the residual method. The gas used is nitrogen but the device will be upgraded in 2012 to be able to used supercritical CO_2. The device uses plugs of 40 to 50 mm diameter and 20 to 50 mm length. The confining pressure limit is 350 bar and thus entry pressure estimation limit is 300 bar.

The entry pressure device can be used now but an upgrade will be done in 2012. During one month in 2012, the sensor will be replaced and the system simplified to allow the use of supercritical CO_2. The upgrade is expected in June 2012.

State of the art

The water permeability device allow the measurement of water permeability within an estimate error of 10 to 20% due to the high resolution pump used. The measurement can be fast considering the amount of water that is measured (few µl). This technique is believed to provided more relevant permeabilities than pulse decay test usually performed on very low permeability tests.

The experimental device dedicated to entry pressure measurements can be used with different protocols. IFPEN laboratory is the only one performing the dynamic method that proves to be the most efficient way to measure entry pressure values in caprocks. In addition, the racking method has been implemented this year. This method is not new, not well known but it has a very good accuracy compared to other techniques. To our knowledge the racking method has never been involved in a CSS project.

Services currently offered by the infrastructure and achievements

- Entry pressure measurement / Permeability measurement with gas or water
- Entry pressure and permeability can be assed with 10 to 20 % uncertainties

Relevant scientific publications:

Boulin, P.F., Bretonnier, P., Gland, N., and Lombard, J.M., 2011, Contribution of steady state methods to water permeability measurement in very low permeability porous media, Oil & Gas Science and technology, article in press

Carles, P., Egermann, P., Lenormand, R., and Lombard, J.M., 2007, Low permeability measurements using steady state and transient technics, International Symposium of the Society of Core Analysts, Calgary, Canada, 10-14 September 2007.

Egermann, P., Lombard, J.-M., and Bretonnier, P., 2006, A fast and accurate method to measure threshold capillary pressure of caprocks under representative conditions, International Symposium of the Society of Core Analysts, Trondheim, Norway 12-16 September 2006.

Boulin, P.F., Bretonnier, P., Vassil, V., Samouillet, A., Fleury, M., and Lombard, J.M., 2011, Entry pressure measurements using three unconventional experimental methods, SCA 2011 Symposium, Austin, TX, USA, September, 2011.

CO_2 post combustion capture mini-pilot (Capture, Absorption)

Description of the facilities

Figure 6 General view of the pilot

This apparatus consists in a small laboratory pilot that corresponds to the process of post-combustion CO2 capture via amine based solvents. It mainly consists of two columns : the absorber, where the gaseous and liquid phases flow countercurrently and where the CO_2 contained in a synthetic gas is absorbed, and the stripper, a heated regeneration column where the CO_2 is desorbed.

The flue gas is synthetically prepared and is generally a mix of N_2, O_2 and CO_2. Small amounts of SO_2, NO and NO_2 can also be added. The mini-pilot plant is able to treat up to 1 Nm3/h of flue gas, whereas the solvent (generally an aqueous amine solution) will circulate at a rate of around 2 L/h.

The absorber consists in a glass plate column (10 cm in diameter, 1 m high) where CO_2 chemical absorption between the flue gas and the solvent occurs. The solution collected at the bottom of the column is rich in CO2, it is heated electrically and sent to the desorber column. The desorber is also a glass plate column (10 cm in diameter, 1 m high). There, the rich solution reaches its boiling point while flowing downwards to an electric reboiler. Elevated temperatures reverse absorption. As a result, a mixture of CO_2 and water vapour is released. The water vapour is condensed in the overhead condenser and returned to the regeneration column with total reflux. The stripped CO_2 is released. The regenerated solvent is collected in the storage tank and recycled back to the absorber for further CO_2 removal. The absorption section works at atmospheric pressure while operating pressure in the desorber is 2,5 bara. Reboiler temperature is 120 °C.

The gas flowing in the absorption column and flowing out from both columns can be sampled. The gas selected for analysis is directed towards a cold trap, then heated at 180 °C, in order to minimize condensation in the analysis equipment. In an analyses room located close to the unit, a FTIR module, equipped with a measuring cell with a 5 m optical path, is able to determine compounds such as NH3, NO2, SO2, CO2, H2O or CO. Alternatively, the user can also choose to analyse gas samples by gas chromatography. It is possible to follow amines concentration, CO2 loading and degradation products such as Heat Stable Salts by off-line measurements. Except for the glass columns, all the other components of the plant are built in 316 stainless steel.

State of the art

- The research infrastructure described here is fully automatic and allows to run long-term tests (up to several weeks), in order to study degradation properties of solvents. There is also the possibility to monitor corrosion in several locations of the pilot with corrosion coupons.
- The infrastructure is currently dedicated to CO_2 capture with amine solvents. But, other types of solvents can also be used, as long as the operating conditions are in the appropriate range. The infrastructure can also be used for gas treatment for H_2S capture.

Services currently offered by the infrastructure and achievements

If external users were interested in conducting research on this infrastructure, the access to a certain amount of off-line analyses (ionic chromatography, HPLC, ionic exclusion chromatography) would be allowed. Also, a room for off-line analyses, a control room, a workshop and a changing room would be available on the site of IFP Energies nouvelles.

The infrastructure is mostly used for internal research projects. The research performed on this pilot plant has allowed IFPEN to develop processes such as Hicapt™, Hicapt+™ or more recently, DMX™.

The infrastructure is expected to be upgraded during 2012 and the upgraded pilot could then be made available from mid-2013 on.

3. GERMANY

3.1 USTUTT

Organisation name	Short Name	Country
UNIVERSITAET STUTTGART	USTUTT	Germany

Description of the infrastructure	
Name(s) of the infrastructure(s)*:	**KSVA, BTS**
Location (town, country):	GERMANY
Web site address:	www.ifk.uni-stuttgart.de
Legal name of organisation operating the infrastructure:	Universität Stuttgart
Location of organisation (town, country):	Vaihingen, Stuttgart, Germany

Pilot scale 0.5 MWth combustion facility - KSVA (Energy Conversion Systems, Combustion)

Description of the facilities

The scheme shown in **Figure 1** depicts the KSVA in oxy-fuel configuration, which essentially simulates the flue gas side of a power plant in small scale including a flue-gas cleaning path with a high-dust SCR catalyst, an electrostatic precipitator (ESP) and a baghouse filter. Combustion air or recirculated flue gas is provided by a forced draught (FD) fan, an induced draught (ID) fan ensures the transport of the flue-gases through the flue-gas system towards the stack. Modifications essential for oxy-fuel operation are described in the following.

The combustion chamber consists of six cylindrical segments with a total length of 7,060 mm and an inner diameter of 800 mm. The combustion chamber is covered with a burner plate of 1,400 mm in diameter. In the centre the burner is installed.

Refractory lining covers the inner surface of the upper four segments of the combustion chamber to a distance of 4,000 mm from the burner. A water jacket is integrated into the double-wall of the reactor. Numerous measurement openings are integrated into the reactor wall with distances between each level of 150 to 170 mm. In several segments there are up to three ports per level, shifted by 90° one to another. Flame detectors are installed with inclined view to the combustion flame core. Either air or CO_2 is used for cooling of the detectors, depending on the applied combustion modes: conventional or oxy-fuel.

State of the art

Advantages/Special Features:

- Fuel flexibility: due to different dosing systems, it is possible to fire different solid fuel or blends.
- Flue gas recirculation
- Modular Flue Gas Cleaning (FGC) system: ESP, DeNOx (SCR), Fabric Filters and possibility to introduce Flue Gas Desulphurization (FGD) unit.
- The combustor is equipped with a flexible char and gas sampling system and in addition with a flexible overfire air/oxidant injection system. Both enable the performance of combustion tests over a broad residence time (1s-5s) and stoechiometrie (air ratio 0.7-1.3) range. Stage or unstaged combustion tests can be carried out.
- Furthermore, material testing with corrosion probes can be performed.

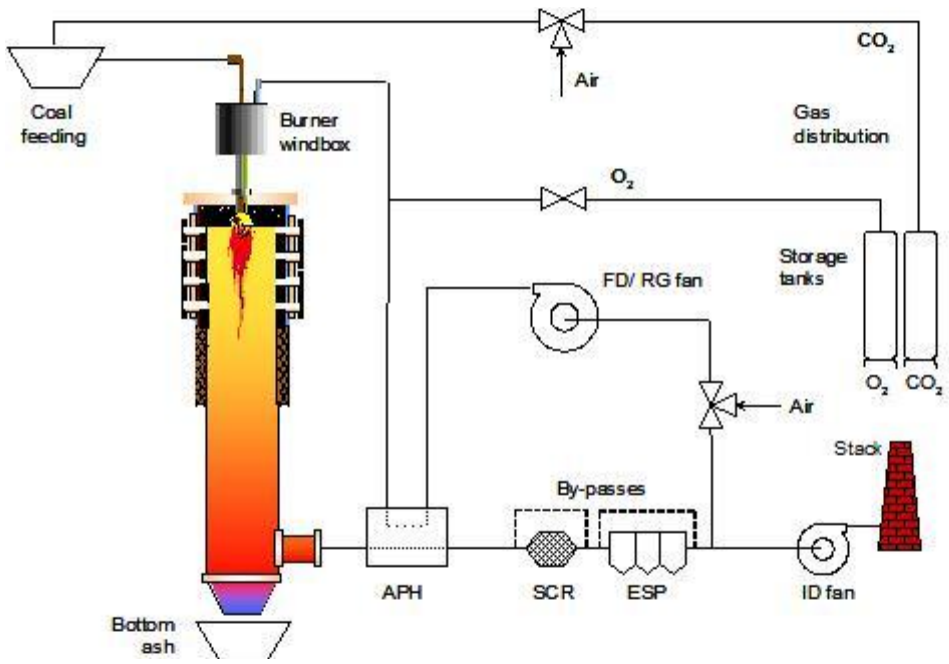


Figure 1. Scheme of 500 kWth test facility (KSVA)

Areas of research:

High efficiency and CO_2-free combustion processes, co-combustion of biomass/RDF in coal-fired power plants, optimization of burner setup and burner parameters, HCl, SOx behaviour, NOx reduction, slagging/fouling processes, high and low temperature corrosion, performance of FGC system (e.g. ESP, DeNOx, etc.), fly ash characterization. *Future areas:* biomass co-combustion in oxy-fuel

Scientific environment:

This test facility is one of several pilot test installations available at IFK and is surrounded by a very complete infrastructure. For instance, fuel pre-treatment facilities and several continuous flue gas analysers are readily available. Also, a well-equipped laboratory for fuels, ashes and slag characterisation operates at IFK. Additionally, other useful techniques for characterization of different solid samples (e.g. fuel, fly ash, etc.), such as XRD and SEM, are available at other institutes within the University. Furthermore, the facility is operated by experienced scientists and technicians and is equipped with state-of-the-art measurement equipment. Within several years of successful operation, it has proved to deliver high quality reliable results. This allows for the comparison of newly gained data against the experiences collected at IFK within the previous years and provides a possibility for better interpretation of data.

Services currently offered by the infrastructure and achievements

Every year up to 10 different projects (EU, national or industrial projects) make use of this facility. For instance, some ongoing EU-Projects at KSVA are RECOMBIO, DEBCO and Flox Coal. Specifically, some recent CCS related EU funded projects, where the infrastructure was used, are ENCAP, OxyCorr, Oxyburner and Oxymod. Besides other CCS related projects can be mentioned: OxyVal (industrial project) and ADECOS, KW21 (national projects).

A minimum of 3 publications per year are based on experimental results obtained in this facility. Here a list of the most recent scientific publications is presented:

1. Spörl, R.; Stein-Brzozowska, M.; Maier, J.; Scheffknecht, G.: *Schwefeloxidkonzentrationen bei Kohlenstaubfeuerung im Oxyfuel-Betrieb*. 43. Kraftwerkstechnisches Kolloquium. October 2011. Dresden
2. Stein-Brzozowska G., Babat S., Maier J., Scheffknecht G., *Influence of oxy-coal on fly ash transformations and corrosion behavior of heat-exchangers*, 2nd Oxyfuel Combustion Conference, Australia 2011
3. Grathwohl, S.; Maier, J.; Scheffknecht, G.: *Testing and Evaluation of advanced Oxyfuel Burner and Firing Concepts.*

2nd Oxyfuel Combustion Conference Australia 2011

4. Stein-Brzozowska, G.; Maier, J.; Scheffknecht, G.: *Impact of the oxy-fuel combustion on the corrosion behavior of advanced austenitic superheater materials* Energy Procedia 4 (2011) 2035-2042, ISSN 1876-6102, DOI: 10.1016/j.egypro.2011.02.085; 2011

5. Stein-Brzozowska, G.; Maier, J.; Scheffknecht, G.: *Deposition behavior and superheater corrosion under coal fired oxyfuel conditions.* IEAGHG Special Workshop on SO_2, SO_3, Hg and Boiler Corrosion under Oxy-fuel Combustion. 25/26th January 2011, London.

Technical scale 20 kW electrically heated combustor - BTS (Energy Conversion Systems, Combustion)

Description of the facilities

The electrically heated part of the ceramic tube has a length of 2500 mm and a diameter of 200 mm. The electrical heating with an overall electrical power of 57 $kW_{th\ el}$ makes it possible to adjust a constant wall temperature as well as a temperature profile along the furnace. This enables reliable investigations of a variety of temperature related combustion parameters from 800°C up to 1400°C. For the conventional air firing the pulverized coal is supplied by carrier air to the top-mounted burner through which it is injected into the combustion chamber. The feeding system consists of a volumetric conveyor and a screw feeder. The coal feed rate ranges from 1 to 2 kg/h and it depends on a thermal input of 8.5 kW_{th} and corresponds to approximately 1 kg/h for bituminous coals and about 1.5 kg/h for lignite. The combustion air is injected through annular clearances, divided into primary and secondary air. The facility provides a good environment to investigate staged combustion conditions because burnout air can be added at each position along the reactor axis by a probe from below. **Figure 2** shows a schematic outline of the BTS combustion chamber. For the oxy-fuel firing the combustion air is replaced by a mixture of O_2 and CO_2 from the gas storage tanks. The flue gas is extracted at the final section of the heated reaction tube. Standard emissions analysed are O_2, CO_2, CO, SO_2, NO and NO_X. Profile measurements of the flue gas composition can be taken by means of an oil-cooled sampling probe which transports the extracted flue gas to the standard analysers or a FTIR system.

State of the art

Advantages/Special Features: The test rig is equipped with a flexible char, fly ash and gas sampling system and in addition with a flexible overfire oxidant injection system. Both enable the performance of combustion tests over a broad residence time (1s-4s) and stoichiometry (air ratio 0.7-1.3) range. Due to that, staging can also be implemented in this facility.

Areas of research: Investigation of combustion behaviour of different coal qualities, combustion and co-combustion of various solid fuel mixtures (biomass, SRF, coals), coal burner development (flameless oxidation), oxyfuel combustion

Scientific environment: As in the case of KSVA, this test facility is also surrounded by a very complete infrastructure (fuel pre-treatment facilities, laboratories, etc.) and an experienced team of scientists and technicians.

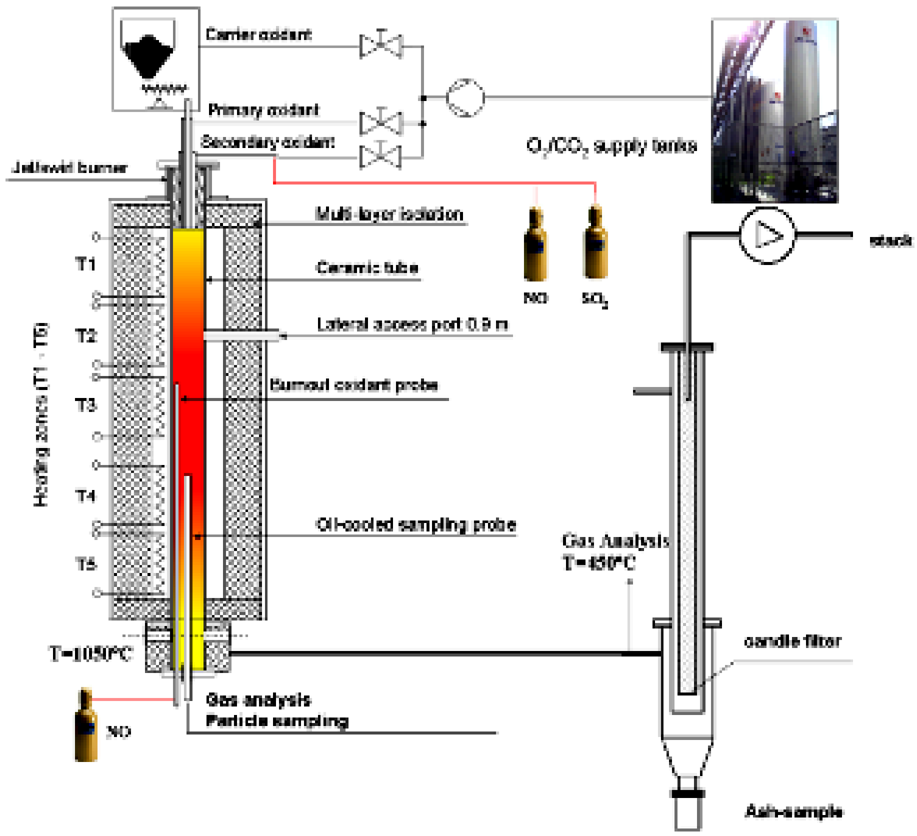


Figure 2. Schematic outline of BTS combustion

Services currently offered by the infrastructure and achievements

Every year up to 10 different projects (EU, national or industrial projects) make use of this facility. Some ongoing EU projects at BTS are RECOMBIO, DEBCO, Flox Coal 2. Specifically CCS related recent EU-Project are ENCAP, OxyCorr, Oxyburner and Oxymod. Other national and industrial projects that have made use of the facility are ADECOS, KW21 and Oxyval.

A minimum of 3 publications per year are based on experimental results obtained in this facility. Here a list of the most recent scientific publications is presented:

1. Dhungel, Bhupesh. *Experimental Investigations on Combustion and Emission Behaviour During Oxy-Coal Combustion*. Dissertation Universität Stuttgart, 2010.

2. Al-Makhadmeh, Leema. Coal *Pyrolysis and Char Combustion under Oxy-Fuel Conditions* . Dissertation Universität Stuttgart, 2009.

3. Dhungel, B.; Mönckert, P.; Maier, J.; Scheffknecht, G.: *Investigation of oxy-coal combustion in semi-technical test facilities*. Tagungsband: Third International Conference on Clean Coal Technologies for our Future, 15 - 17 May 2007, Sardinia, Italy; 2007

4. Dhungel, B.; Maier, J.; Scheffknecht, G.: *Emission behaviour during oxy-coal combustion in a 20 kW once through furnace*. Tagung: Ninth International Conference on Energy for a Clean Environment, 2-5 July 2007, Povoa de Varzim, Portugal; Veröffentlichung auf CD-ROM; 2007

5. Maier, J.; Dhungel, B.; Mönckert, P.; Scheffknecht, G.: *Combustion and emission behaviour under oxy-fuel condition*. Tagung: 39. Kraftwerktechnisches Kolloquium 2007, 11 und 12. Oktober 2007, Dresden; Veröffentlichung auf CD-ROM; 2007

4. GREECE

4.1 CERTH/ISFTA (GREECE)

Organisation name	Short Name	Country
CENTRE FOR RESEARCH AND TECHNOLOGY HELLAS	CERTH	Greece

Description of the infrastructure	
Name(s) of the infrastructure(s)*:	**CERTH/ISFTA Storage, CERTH/ISFTA Capture**
Location (town, country):	ATHENS, PTOLEMAIS, GREECE
Web site address:	www.lignite.gr
Legal name of organisation operating the infrastructure:	
Location of organisation (town, country):	Athens, Ptolemais, Greece

CERTH/ISFTA Storage

Description of the facilities

The CERTH/ISFTA Storage infrastructure provides facilities for the characterisation of a storage site. That includes an X-Ray Diffractometer for the mineralogical characterisation of the reservoir and cap rock, a spectrophotometer for the chemical analysis of the water samples, a CHNS analyser for the determination of the carbon, hydrogen, nitrogen and sulphur. The facilities can be seen in the pictures below:

Figure 1. X-Ray Diffractometer (left), CHNS analyser (middle), specrophotometer (right).

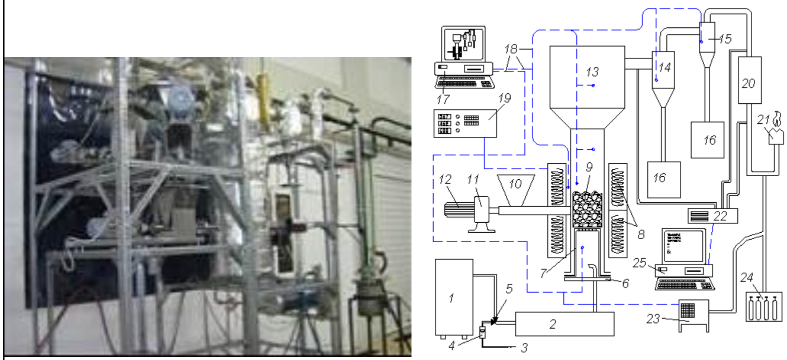
The laboratory is under ISO17025 certification for the determination of: moisture, ash, volatiles, total moisture, chlorine, CHNS, heating value, ash metals, as well as the biogenic fraction of SRF fuels. The process will be completed within next few months which lay the uniqueness of CERTH/ISFTA facilities in Greece.

Moreover, the CERTH/ISFTA Storage is equipped with an Atomic Adsorption Spectrometer (AAS) for the determination of chemical elements and a calorimeter (figure 2) for the measuring of the high heating value of coal and lignite samples.

Figure 2. Pictures of the Atomic Adsorption spectrometer (left) and the calorimeter (right)

CERTH/ISFTA Capture

Furthermore, CERTH/ISFTA has a 5kWth high temperature bubbling fluidized bed flexible in operation either for gasification or combustion experiments of coal/lignite that can be performed in the presence of Ca sorbents. The infrastructure can be seen in the figure below. Additionally, the CERTH/ISFTA Capture infrastructure can support activities relative to combustion and gasification technologies.



1	Electric steam boiler	13	Freeboard
2	Steam superheater/air heater	14/15	primary/secondary cyclone
3	Pressurised air flow	16	Ash collection bin
4	Air mass flow meter	17	PC/data collection system
5	Steam – air valve	18	Measuring system
6	Distributor flange	19	PID controllers
7	Distributor	20	Gas cleaning
8	Electric resistance	21	Product gas destruction system
9	Fluidised bed	22	Tar measurement
10	Fuel silo	23	Gas analyser Maihak
11/12	Inverter/electric motor	24	Sampling line for GC

Figure 3. Picture of the Bubbling fluidized bed gasifier (left) and its diagram along with an explanatory table (middle and right, respectively)

The replacement costs for the Infrastructure (€): 100,000

State of the art for TA5.1 and TA5.2

Over the last years, both CERTH/ISFTA's facilities are becoming more and more attractive for carrying out scientific research due to uniqueness of the services that it can provide. The equipment and the highly qualified personnel have drawn, also, the attention of the industrial sector. That led to a large private contract with Public Power Corporation (PPC). Also, one of the key assets of the infrastructure is the fluidised bed installation. One of the most important advantages of this is the in situ capture of CO_2 and SO_2 by calcined additives.

- The areas of research that are normally supported by the infrastructure are outlined below:
- Promotion, implementation and improvement of "cleaner" coal combustion technologies (CCTs).
- Minimization of pollutants including fly ash, other by-products utilization and CCS technologies.
- Optimization of coal deposits exploration techniques and development of innovative environmental management methods.
- Biomass and/or waste co-combustion with lignite in existing combustion/ gasification systems.
- Promotion and enhancement of gasification and hydrogen production technologies.
- Technology transfer from and to market operators and decision makers.

The CERTH/ISFTA's infrastructures are part of a larger ensemble and the scientific personnel of the Institute and the visiting scientists can be benefit from that by having access to other laboratories that will help achieve the expected, each time, results. Moreover, CERTH/ISFTA is the main Greek organization for the promotion of research and technological development aiming at the improved and integrated exploitation of solid fuels and their by-products. It develops a number of activities aiming to enhance the exploitation of the indigenous solid fuel supplies, such as lignite and solid biomass. The experience gained throughout the years and the collection of know – how, by undertaking large – scale R&D and demonstration projects, may classify CERTH/ISFTA among the Centres of Excellence and of equal importance to other European and non-European centres involved in solid fuels technologies. Furthermore, CERTH/ISFTA represents Greece in the Carbon Sequestration Leadership Forum (CSLF), the Euracoal and the Technology Platform for Zero Emission Power Plants. CERTH/ISFTA is involved in various European Commission's Research Projects related to CCS.

Services currently offered by the infrastructure and achievements

The services that are offered by CERTH/ISFTA Lab are achieved through the use of its equipment infrastructure and involve proof of concept experiments, heat balance studies, combustion and gasification studies, mineralogical and petrographical examination, cores/samples studies etc.

High-quality research can be performed in CERTH/ISFTA's infrastructure. Both visiting and CERTH/ISFTA's scientists can conduct experiments that will add value to the state-of-the-art energy research, by utilizing CERTH/ISFTA laboratory equipment, which consists of state-of-the-art instruments, of the latest technology. The constant use of this equipment within cutting-edge EU energy research projects, has resulted in a number of journal publications of significant importance by CERTH/ISFTA's scientists, with a clear increasing trend over the last 5 five years. Thanks to the possession and the continuous upgrade of such equipment, as well as by steadily training its scientists on the latest advances in energy research, CERTH/ISFTA has managed to build an important expertise in the field of conventional and alternative fuels. It is noted that such expertise is widely recognized and has led to the attraction of both major research and industrial projects. It is noted that CERTH/ISFTA has been recently officially evaluated as a Centre of Excellence in Greece; CERTH/ISFTA's infrastructures are currently under ISO17025 certification, which will led to its expansion both inside and outside the country's borders.

After 2000, CERTH/ISFTA has been awarded with over 90 EU- and national-research and industrial projects. Some of them are mentioned further below. Thanks to its overall research activity, CERTH/ISFTA has published over 500 papers at international scientific journals and conferences. Some of the most important research and industrial projects, CERTH/ISFTA has been awarded with, are:

Finally, in the last five years, a large number of scientists from Europe have chosen CERTH/ISFTA in order to perform their research in CERTH/ISFTA facilities. Amongst them, scientists from renown Institutes from Germany, Spain, and the UK have spent a sufficient time in CERTH/ISFTA's facilities conducting experiments for the successful advance of theirs projects. An overwhelming interest from scientists from China and India has been also expressed; the Institute is currently in the phase of considering such applications for short-term research visits.

List CCS related EU funded projects where the infrastructure was used, or other large initiatives

EC DG Research / RFCS: UCG-CO_2, CAL-MOD, ASSOCOGS

EC DG Research / FP6, 7: RISCS, ENCAP

Other EC DG Research: FENCO.ERANET

GSRT / Bilateral Cooperations – national projects: CO_2 mineralization

Other large initiatives: Solid and fossil fuels analyses according to ISO 17025

Achievements (include also 5 recent relevant scientific publications)

- N. Koukouzas, F. Ziogou, V. Gemeni (2011), *Cost of pipeline-based CO_2 transport and geological storage in saline aquifers in Greece*, Energy Procedia, 4, p. 2978-2983
- Pietzner, K., Schumann, D., Tvedt, S.D., Torvatn, H.Y., Naess, R., Reiner, D. M., Anghel, S., Cismaru, D., Constantin, C., Daamen, D.D.L., Dudu, A., Esken, A., Gemeni, V., Koukouzas, N., Ziogou, F. *Public Awareness and Perceptions of Carbon Dioxide Capture and Storage (CCS): Insights from Surveys Administered to Representative Samples in Six European Countries*, Energy Procedia, 4, p. 6300-6306
- Koukouzas, Gemeni, V., Ziock, H. (2009) *"Sequestration of CO_2 in magnesium silicates, in Western Macedonia, Greece"*, Int. Journal of Mineral Processing, 93 (2), p. 179-186
- N. Koukouzas, F. Ziogou, V. Gemeni (2009) *Preliminary assessment of CO_2 geological storage opportunities in Greece*, International Journal of Greenhouse Gas Control, 3 (4), p. 502-513.
- Koukouzas, N., Typou, I. (2009) *An assessment of CO_2 transportation cost from the power plants to geological formations suitable for storage in North Greece.* GHGT-9, Energy Procedia, 1, p. 1657–1663
- Kakaras E., Koumanakos A., Doukelis A., Giannakopoulos D., Vorrias I. (2007) *"Oxyfuel boiler design in a lignite-fired power plant"* Fuel, 86 (14), p 2144-2150

5. ITALY

5.1 ENEA

Organisation name	Short Name	Country
AGENZIA NAZIONALE PER LE NUOVE TECNOLOGIE,L'ENERGIA E LO SVILUPPO ECONOMICO SOSTENIBILE	ENEA	Italy

Description of the infrastructure	
Name(s) of the infrastructure	Infrastructure: **ENEA CCS PLATFORMS**
Location (town, country):	ENEA Casaccia Research Centre, Rome
Web site address:	www.enea.it
Legal name of organisation operating the infrastructure:	Italian National Agency for new technologies, Energy and sustainable economic development
Location of organisation (town, country):	Rome. Italy

ZECOMIX platform

Zecomix platform is aimed at studying H_2 and electrical energy production with advanced coal gasification and CO_2 capture processes, as well as post combustion technologies.

In pre-combustion case, the hydrogen and steam syngas produced can be feed a 100 kWe microturbine for electrical energy production. It is possible to test the gasifier with different O_2/steam temperature (until 600 °C. The fluid bed is olivine based with dolomite adding for tars and H_2S removal. The fluid bed gasifier of 50 kg/h of coal works at atmospheric pressure whereas the decarbonation section is based on a fluid bed reactor working at high temperature with solid sorbents alternatively in absorption and sorbent regeneration phase; the power production section, based on a microturbine, derived from a Turbec 100 kW model in which the combustor chamber has been modified to work with H_2 and steam. The plant has been designed to test both the whole process from gasification to power generation and the single sub-systems (gasification test, carbonator test, micro-turbine test).

Gasification island (Energy conversion, gasification)

Description of the facilities

The coal gasifier is a fluidized bubbling bed reactor having a nominal load of 50 kg/h of coal. Steam and oxygen are fed on different points of the reactor, in order to control the solids hydrodynamics, and the reaction rate all over the reactor. Dolomite is added to the coal helping tar removal and capturing the H_2S formed during coal gasification. The syngas, at 800°C, is sent to a regenerative heat exchanger to pre-heat inlet O_2/steam mixture, reducing its temperature around 600°C. Then the syngas can be introduced into the carbonation reactor, or can be clean-up in a scrubber, after a second cooling step to 350°C.

State of the art

Coal/biomass gasification in fluid bed reactor can be performed, changing oxygen/steam feed composition and flow rate in more inlet points. More types of additives can be added in fluid bed, also during operations, for "in situ" H2S and tars removing. The experimental activities in the infrastructure are supported by laboratory tests; the laboratory is equipped by several instruments for solid sorbents and coal analysis and characterization

Services currently offered by the infrastructure and achievements

By using the gasifier one can evaluate the purity of produced syngas against existing gas cleaning and conditioning systems, by means of fluidized bed reactor at pilot scale to provide sufficient and dependable information for industrial applications. Furthermore, by using a catalytically active agent such as dolomite and olivine, indeed primary tar reforming reaction could happen with a simultaneous sulphur compound removal. Particularly the effect of pre-treatment of olivine as catalyst agent for tar removal will be investigated.

References

A. Calabro`, P. Deiana, P. Fiorini, G. Girardi, S. Stendardo. Possible optimal configurations for the ZECOMIX high efficiency zero emission hydrogen and power plant . Energy 33 (2008) 952–962

S. Attanasi, A. Calabrò, S. Cassani, A. Dedola, C. Herce, S. Stendardo, L. Pagliari. Commissioning of the Zecomix Pilot Plant. Clean Coal Technologies CCT 2011 Zaragoza 8-12 May 2011.

P.Fiorini, E. Sciubba, A. Calabrò, P. Deiana, G. Girardi, S. Stendardo. Thermo-economic analysis of an innovative CO2 zero emission process for the co-production of fhydrogen and power. Clean Coal Technologies CCT 2011 Italy 15-17 May 2007.

__Carbon capture and mineral carbonation (Capture, adsorption)__

Description of the facilities

Decarbonising reactor is a cylinder 1m diameter and 4.5m height cylindrical chamber. At the bottom of the reactor there are two burners in order to increase temperature up to 900 °C for regenerating the sorbent. The incoming syngas can be added with methane and steam, to improve steam methane reforming and CO-shift reactions. The fluidized bed reactor is loaded with a mixture of Ni-based catalyst, necessary for the steam methane reforming, and Ca-based sorbent in order to capture CO2. Once the solid sorbent reaches at its ultimate conversion (after around one hour of operation which decarbonises approximately 120 Nm3/h of methane enriched syngas), it is sent back to the regeneration step activating the burners.

State of the art

The infrastructure permits to perform several tests on: a) advanced reforming of natural gas, with simultaneous CO2 capture and H2 production; b) CO-shift and CO2 capture of syngas with variable composition; c) post-combustion CO2 capture of NGCC or USC plants flue gas; all these tests are performed in a significant scale reactor in adiabatic conditions.

Services currently offered by the infrastructure and achievements

Particularly multi-cycling CO2 capture could be performed coupled with water gas shift and steam methane reforming reactions. This reactor could be used in a pre-combustion CO2 capture mode by reforming the fuel gas or in a post-combustion CO2 capture mode when flue gases are passed through the solid bed of CO2 acceptor. Finally in such a reactor different types of CO2 acceptor agent could be tested ranging from naturally occurring sorbents to synthetic ones. The experimental campaign will end up with a collection of data for model validation, developing or improving existing models. Particularly the hydrodynamics and kinetics interacting in the investigated fluidised bed reactor has been considered.

References

S. Stendardo, L. Di Felice, K. Gallucci, P. U. Foscolo. CO2 capture with calcined dolomite: the effect of sorbent particle size. Biomass Conv. Bioref. 1 (2011) 149–161;

K. Gallucci, S. Stendardo, P. U. Foscolo. CO2 capture by means of dolomite in hydrogen production from syn gas. Int. J. of hydrogen energy 33 (2008) 3049 – 3055;

S. Stendardo, P. U. Foscolo. Carbon dioxide capture with dolomite: A model for gas–solid reaction within the grains of a particulate sorbent. Chemical Engineering Science 64 (2009) 2343 – 2352;

S. Stendardo, L. K. Andersen, C. Herce, A. Calabrò. Experimental investigation of synthetic solid sorbents for multi-cycling carbon dioxide uptake. Clean Coal Technologies CCT 2011 Zaragoza 8-12 May 2011;

Power generation section (Energy conversion, combustion)

Description of the facilities

The power generation is produced by means a micro-turbine, modifying the Turbec T100, with 100 kWe of power output, by retrofitting with a hydrogen burner developed by Ansaldo Energy. The high H2 content syngas, at the outlet of the scrubber is compressed until 6 bar, by means a three stage intercooled compressor and then re-heated until 250 °C before mixing of a fixed amount of steam.

State of the art

The combustion chamber, designed for burning H2 and enriched air, is of lean pre-mix emission type achieving flue gases with low content of CO and NOx and unburned hydrocarbons. In order to prevent high temperature in the combustion chamber a certain quantity of water steam is injected.

Services currently offered by the infrastructure and achievements

The activities will test the hydrogen combustion technology at different scale levels and grades of integration with the whole experimental platform. In particular a dynamic model of the microturbine has been developed and integrated in a commercial power plant simulator. Such a model is a valuable tool for the simulation of a the microturbine in a number of operative conditions.

COHYGEN PILOT + SOTALABS

COHYGEN PILOT (Energy Conversion Systems, Gasification) PLANT

Description of the facilities

The plant has been developed in order to study and optimize the gasification process and to produce a syngas flow to feed the experimental syngas treatment process for combined production of hydrogen and electrical energy. It can be described into five sections:

Section 1 - Gasification process

The Pilot unit is based on a 50 kg/h of coal gasifier, where temperature profile is determined through a series of 11 thermocouples disposed over a metallic probe (which can operate up to 1200 °C) insert through the top of the gasifier and located near the reactor vertical axis. A series of three ceramic lamps allows the heat of the reactor, initially feed with wood pellets and subsequently charged with coke.

Section 2 - Dust and tar removal system

The raw syngas from the gasification process is sent to an integrated component which includes a wet scrubber, a first cold gas desulphurization stage and an electrostatic precipitator (ESP). Finally, the need to use coal with a very high sulphur content and to protect the electrostatic precipitator by the effects of acid atmosphere, suggested to insert, between wet scrubber and ESP, a first cold gas desulphurization stage, which generally uses sodium hydroxide (40% in volume, diluted in water), as solvent for H2S removal. Downstream the ESP, syngas can be sent to the power generation line or to the hydrogen production line.

Section 3 - Power generation line

Power generation line is constituted by the second cold gas desulphurization stage directly followed by an internal combustion engine (ICE), fed with clean syngas, eventually enriched in hydrogen. In particular, the second cold gas desulphurization stage is a packed column, made of polypropylene, in which hydrogen sulphide is chemically absorbed through a proper solvent.

Section 4 – CO_2 capture and Hydrogen production line

Hydrogen production line includes a compressor followed by an electric heater, a dry hot gas desulphurization process, an integrated water-gas shift (WGS) and CO2 absorption system and a hydrogen purification section. In particular, hot gas desulphurization process operates at about 300-500 °C and includes three main components: a catalytic filter for COS conversion and two H2S adsorbers.

In the catalytic filter, the small amount of carbonyl sulphide contained in syngas reacts with hydrogen to be converted in H2S, according with the hydrogenation reaction. The integrated water-gas shift and CO2 separation system includes both high and low temperature shift reactors with an intermediate and a final CO2 absorbers. In particular, WGS process takes place into two reactors (operating at 300-450 °C and about 250 °C, respectively) which have been installed in order to test different catalysts, including conventional Fe3O4/Cr2O3/CuO based catalysts for high temperature (HT) stage and CuO/ZnO/Al2O3 based catalysts for low temperature (LT) stage; to this goal, the reactors have been designed with a maximum bed volume of 9.6 and 17.5 dm3, respectively. Carbon dioxide absorption takes place into two identical bubbling reactors, in which syngas is injected through 40 diffusers based on ceramic membranes and reacts, at about 30 °C and atmospheric pressure, with amine-based solvents. In particular, different solvents, such as monoethanolamine (MEA) in different concentrations and a solution of methyldiethanolamine (MDEA) and piperazine (PZ), have been used in this process in some experimental tests. Finally, the hydrogen purification section is based on the pressure swing adsorption (PSA) technology, which is widely common in the industrial applications due to its low costs. In particular, PSA is composed by a simple double-stage process based on carbon molecular sieves.

Section 5 - Regeneration plant

The amine regeneration unit is able to regenerate continuously and batch amine solutions from sections of CO2 adsorption. In general, this system is very flexible and easy to use and does not require long time of switch on and switch off. The regeneration plant mainly consists of a stripping column and ancillaries components like heat exchanger, back wash tank; recirculation pump of the solution regenerated; column stripping back wash pump, Feed pump to the column of the solution to be regenerated, reboiler of the stripping column, Piping and control instrumentation.

State of the art

The plant has been widely tested, and now it's - together with ZECOMIX - one of the most important infrastructures involved in CCS national programme, mainly for studying capture technologies – both pre and post combustion – in power plants fed with low rank coal.

Services currently offered by the infrastructure and achievements

1. Availability of basic services as air, steam, gas, electricity supply
2. Availability of extended online monitoring and data acquisition of all operative plant parameters
3. Availability of gas analysis equipment that will enable users to conduct high quality research
4. Availability of laboratories for off line analysis of solid and liquid materials

References

A. Pettinau, F. Ferrara, C. Amorino, "An overview about current and future experimental activities in a flexible gasification pilot plant". Accepted for publication in: "Gasification: Chemistry, Processes and Applications" Nova Publishers, New York (USA), 2011, ISBN: 978-1-61209-681-0;

A. Pettinau, C. Frau, F. Ferrara, "Performance assessment of a fixed-bed gasification pilot plant for combined power generation and hydrogen production", Fuel Processing Technology, vol. 92, 2011, pp. 1946-1953.

<u>SOTALABS – (Energy Conversion and Capture Systems, Gasification /Absorption)</u>

Description of the facilities

The laboratories were built in the framework of the activities funded by the Italian Ministry of Industry in the field of CCS R&D. The main laboratories are:

1. Sample preparation e granulometric analysis
2. Elementary analysis (CHN + TGA)
3. Thermal analysis (CAL)
4. Chemical analysis
5. Porosimetry
6. Gas analysis (mGC)
7. Bench scale plant for hot desulphurization system by using oxide metallic sorbents

The main equipments are: Thermogravimeter Analyzer (TGA), CHN/S analyzer, Porosimeter, Jaw crusher, Cross Beater Mill and Sieve Shaker, Calorimeter, Gas chromatography.



State of the art

The main use of laboratories is in characterization of substancies and materials related to the activities carried in gasification and CO2 capture sperimentation. The areas of research normally supported by this installation is related to activities funded by the Italian Ministry of Industry in the framework of Carbon Capture and Storage R&D.

Services currently offered by the infrastructure and achievements

5. Availability of basic services as air, steam, gas, electricity supply
6. Availability of gas, liquids, solid analysis equipment that enable users to conduct high quality research
7. Off line analysis of solid and liquid materials.

5.2 IFRF

Organisation name	Short Name	Country
FONDAZIONE INTERNAZIONALE PER LA RICERCA SULLA COMBUSTIONE - ONLUS	IFRF	Italy

Description of the infrastructure	
Name(s) of the infrastructure(s)*:	**Livorno Experimental Area (L.E.A.)**
Location (town, country):	ITALY
Web site address:	www.ifrf.net
Legal name of organisation operating the infrastructure:	International Flame Research Foundation
Location of organisation (town, country):	Livorno , Italy

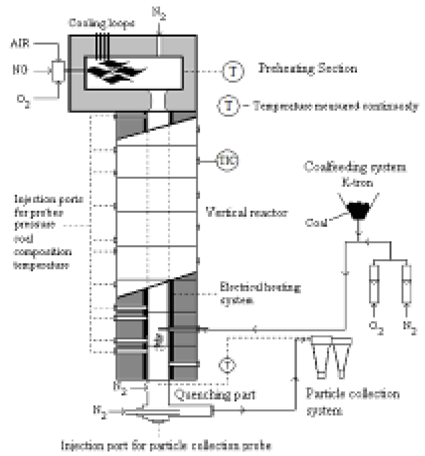
IFRF has access to ENEL I&I Experimental Area located in Livorno. The area has been developed to answer to the research needs coming from different aspects of power generation sector (fuel characterisation, combustion, heat transfer, emission treatment, industrial measurement, etc.) and includes several facilities of different scales.

The infrastructure is part of a network of research structures including the University of Pisa Engineering Departments (Energy, Processes and Systems Engineering) and ENEL I&I Research Centre, Pisa. Visiting scientists and industrial users would benefit of the opportunity to interact with Pisa research and academic environment.

In the frame of ECRI , IFRF is in the position to offer two installations (**TA 8.1 Isothermal Plug Flow Reactor (IPFR), TA 8.2 Experimental Furnace with flue gas recirculation (FOSPER)** that fit into combustion/gasification topic for CCS. .The two installations are unique, and are thought to be complementary among them, and between other facilities in ECRI project, since they range from 50kW to 3 MW and allow to perform tests in different controlled atmospheres of O2/CO2/H2O/N2/ and other gases (SO2, NO,etc.). Details are reported in the following.

IPFR (Combustion/gasification/chemical looping, solid fuel/sorbent characterisation)

IFRF has developed a drop tube reactor – the Isothermal Plug Flow Reactor (IPFR) - to characterize the combustion/gasification properties of pulverized coal, substitute fuels and blends in various atmosphere compositions (oxy-fuel combustion/gasification) and solid sorbent performances. This facility allows running tests under conditions similar to industrial applications, since pulverized solid fuel particles are injected into a high temperature reactor (1400ºC max) wherein they increase temperature rapidly due to the heat transmitted by the pre-heated gases flowing in the reactor and the hot tube walls. The particle heating rate is evaluated within the range of 10^4 – 10^5 K/s. The gases flowing into the reactor are preheated by an air - natural gas burner (max thermal input 60 kW) in the range of temperature of 900 – 1400°C; Secondary gases (O_2, CO_2, N_2, SO2, etc) can be injected to obtain the desired composition in the reactor (that can be checked *in situ* by a gas analyser). The reactor tube consists of eight modules that can be independently heated with 32 (4 each module) electrical Silicon Carbide (SiC) elements (max electrical input 32 kW) controlled by 24 thermocouples. In this way it is possible to adjust isothermal conditions within 10ºC over the whole reactor length. The tube has an operating length of 4.5 m and an internal diameter of 150 mm. It is built of Morganite Triangled 90V Alumina that allows the performing of test with very high concentration of O_2. Laminar or transient flow can be chosen by changing the flow of inlet gases. The pulverized solid fuel (minimum flow: 100 g/h) is injected in the drop tube reactor with a water-cooled probe that can be inserted at various heights in the reactor (there are 19 ports along the reactor) to simulate various residence times. The particles are quenched to 100ºC at the exit of the reactor by a cold nitrogen flow. For devolatilisation tests the particles are quenched inside a water-cooled sampling probe that can be inserted from the bottom of the reactor. Residence times obtainable are in the range of 5 to 1500 ms. The particles, after being quenched, are collected by a set of high-efficiency cyclones.



State of the art

The qualification activities (upgrading of specific components and diagnostic tests) and the experimental procedures developed for IPFR –make it a unique facility for providing data and parameters for advanced models of pulverized fuel combustors as well as innovative plants (e.g., oxyfiring and gasification, chemical looping). Users will be enable to conduct high quality research thanks to the qualification of the IPFR, that is a continuous in-progress activity consisting in improving the reactor characteristics, verifying the performance and validating the reliability of data obtained. The isothermal conditions of the reactor are a crucial issue to provide reliable data for combustion related investigation. The interpretation of the raw results requires further efforts, in particular on the balance of macro-products, that hardly closes, and the effective thermal history of solid particles, that may differ significantly from the nominal conditions of the reactor

The IPFR is used to study char burnout and devolatilisation properties of coals, secondary fuels and blends in a very large range of temperature (900 - 1400ºC), residence times (5 – 1500 ms) and atmosphere composition conditions, including oxygen-free and oxy-fuel combustion atmosphere. Combustion characteristics such as pyrolysis and combustion/gasification behaviour of pulverized fuels can be determined by analysing gaseous and solid combustion products thanks to the University of Pisa fuel characterisation lab (Elemental, Proximate, chemical analysis of samples, FTIR gas analyser for gas species O_2, CO, NO, SO_2, Scanning Electron Microscope (SEM) for sample) and ENEL research area, with additional pilot and semi-industrial facilities The slagging and fouling tendencies of ashes can be analysed by using specific probes for ash collection (slagging) and with a section of controlled gas cooling and ELPI diagnostics for inorganic aerosols (fouling).

Services currently offered by the infrastructure and achievements

The IPFR is currently used in several projects (EU, National projects, Private companies) for solid fuel characterisation and sub-model development for combustion/gasification-related heterogeneous phenomena.

The following projects will be running for the next four years: FP7-ENERGY-2010-2: RELCOM—*Reliable and Efficient Combustion of Oxygen/Coal/Recycled Flue Gas Mixtures*, FP7 GA 284498: BRISK- *The European Research Infrastructure for Thermochemical Biomass Conversion*

Recent publications

Simone M. Biagini E., Galletti C., Tognotti L. *Evaluation of global biomass devolatilization kinetics in a drop tube reactor with CFD aided experiments*, FUEL,vol. 88,pp 1818,tot.pag 10, **2009**

Karlstrom O., Brink A., Hupa M., Tognotti L., *Multivariable optimization of reaction order and kinetic parameters for high temperature oxidation of 10 bituminous coal chars,*Combustion and Flame,vol. 10.1016/j.combustflame.2011.03.003, pag 15,**2011**

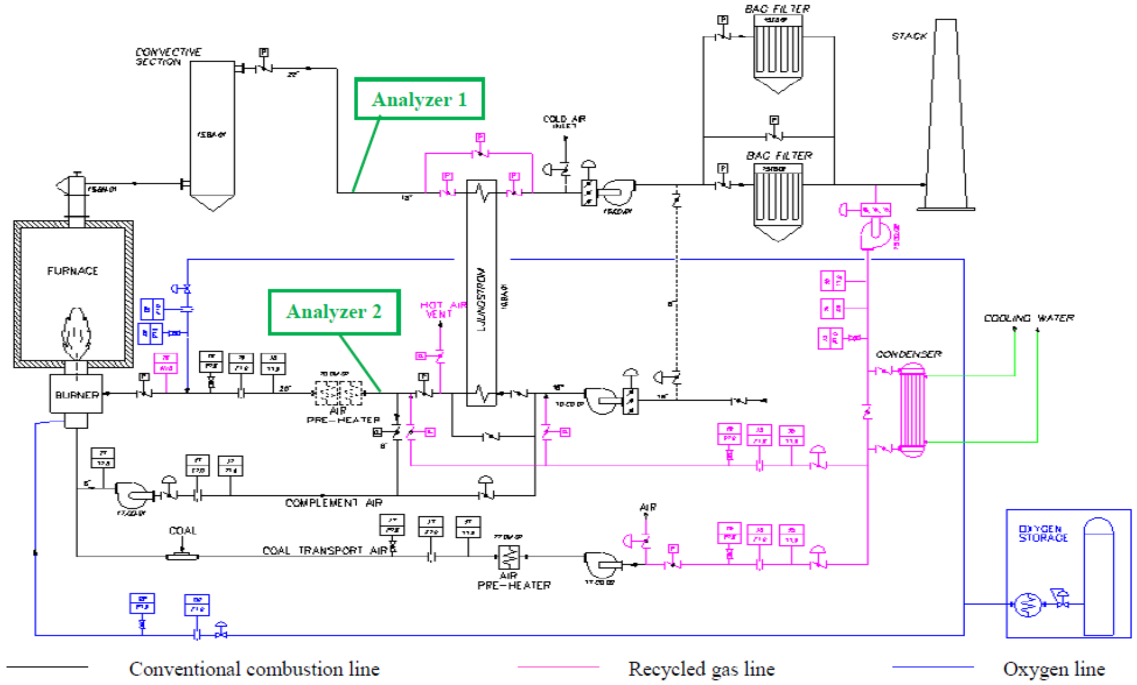
Hercog J., Oskar K., Brink A., Hupa M., Tognotti L., *Kinetic combustion parameters for chars using the IFRF solid fuel data base*, 16th IFRF Members' Conference, pp O1-O12, Boston, MA,**2009**

FOSPER (Combustion, oxy-FGR)

The furnace FOSPER is a replica of the IFRF Furnace N.1, a well-known and extensively tested 3 MW furnace which was specially designed for characterizing innovative burners fired with a wide range of fuels (gas, heavy fuel oil and coal but also coal-water slurries, petcoke, wood residues, sewage sludge…) in conditions similar to those encountered in boilers and other industrial combustion equipment (e.g. glass furnaces, petrochemical furnaces, iron and steel heat treatment furnaces). Recently the furnace and its ancillary equipment has been modified to allow the execution of oxy-fuel combustion tests. This special capability makes FOSPER one of the few in the world where new burners and combustion techniques for CO_2 capture can be studied

The FOSPER furnace is a single burner facility with maximum furnace wall temperature of 1600 °C and air preheating temperature up to 350 °C. The length of the test furnace can be varied between 2 and 5 m. If the total length of the furnace is used, burners designed for a total maximum heat input of up to 3 MW_{th} can be tested.

The furnace has several accesses for different measurement techniques. On the right side there are five viewports (∅ 50 mm) for flame visualization and in-flame measurements (a range of conventional and new designed IFRF probes is available for this scope, see JRA1.1s and figure 2). In order to characterize oxy-flames which can reach temperatures up to 2300 °C, a special pyrometer has been developed together with an innovative calibration system. In addition to conventional techniques for the on-line analysis of major pollutants (NO_X, CO, CO_2) both in flame and at the stack, special probes and in-lab techniques are available for measuring micropollutants both organic and inorganic. The FOSPER furnace is also equipped with a patented on-line carbon-in-ash analyser (MITER), which is particularly useful to check the steady operation of the furnace and the repeatability of tests when coal is used.



The full plant is shown in the Figure 1. The flue gas coming out the combustion chamber is sucked by a fan for flue gas extraction, set upstream the bag filters. This fan is used also to control the pressure inside the combustion chamber. The flue gases go in the first convective section where they are cooled down to about 400°C. This convective section is a flue/water heat exchanger that uses closed-circuit water. After the convective section the gas stream crosses the Ljungström exchanger that further reduces its temperature up to about 150°C, and increases the temperature of the comburent stream. The cooled flue gas then crosses through two bag filters, which remove the solid particulate, and afterwards it is divided in two streams, one is sent to the stack, the other is recycled. Another fan is set upstream the furnace and the Ljungström exchanger; it provides the secondary and tertiary RFG streams. RFG pass through two electrical pre-heaters; the secondary/tertiary RFG crosses first the Ljungström and then the electrical pre-heaters reaching a temperature about 300°C. All the pipelines are equipped with the instrumentation for measuring flowrates, temperature and pressure.

The plant allows a number of experimental configurations available:

Wet/Dry recycle – a condenser is installed in the flue gas recycle line, in order to enable both dry recycle and wet recycle. In this unit there is a system to neutralize the pH of the condensate, which is expected to be very low due to the solubilisation of the SO_x present in the flue gas. The neutralisation system uses a solution of NaOH and it is regulated by measuring the pH of the condensate. The dry recycled flue gas is used as secondary/tertiary comburent and also as primary transport gas for coal;

Ljungström mode – the Ljungström can be by-passed, both in comburent and in the flue gas sides, in order to study the influence of this equipment in the air-in leakage into the system. Hence it can be set in three modes: completely by – passed, completely in service, with flue gas in both the hot and the cold side; partially by-passed with air in the cold side and the flue gases in the hot side;

Oxygen injection – there is the possibility of feeding oxygen in the primary gas, injecting it in primary duct of the burner. As far as the secondary and tertiary gas are concerned, the oxygen is mixed with the flue gas prior to the burner. When coal is fired, is also the possibility of injecting part of oxygen directly in flame through lances located inside the burner (see later on burner description). The flexibility in the injection mode of the oxygen is crucial to study the influence of this parameter on flame stability and NO_X emissions, which is one of the issues about the design of oxy-burners, and one of the scopes of the research going on.

Service currently offered by the installation

- Study the feasibility of the conversion of power plant components from conventional combustion to oxy-combustion with recycled flue gas. In particular tests are carried out for evaluating the maximum CO2 level achievable in the system, and thus assess the air in-leakage amounts and their causes.
- Study the influence of the burner type and settings and of the recycle ratio on flame stability, heat transfer and pollutant emissions.
- Perform in-flame measurements both in conventional air combustion, to be used as baseline, and in oxy-combustion with recycled flue gas, to assess and compare flame structure and properties.

IFRF probes for in-flame measurements in FO.SPER

Test rig FOSPER provides unique opportunity in Europe regarding combustion testing of industrial scale burners with a wide range of gaseous, liquid and solid fuels in oxy-combustion conditions or in conditions similar to those encountered in the power, steel and glass industries.

CCS related EU funded projects where the infrastructure was used, or other large initiatives

Contract n° RFCR-CT-2006-00007 Cost Effective and Environmental friendly Oxyfuel Combustion of Hard Coals

Contract RFCR-CT-2009-00005: Boiler Corrosion under oxyfuel conditions

FP7-ENERGY-2010-2: RELCOM—Reliable and Efficient Combustion of Oxygen/Coal/Recycled Flue Gas Mixtures

Achievements

Coraggio G., Laiola M., Cumbo D., Rossi N., Tognotti L.,*Oxy-combustion tests on low nox burners at fo.sper. furnace,* 16th IFRF Members' Conference, pp 1-10, Boston,**2009**

Brunetti I., Rossi N., Galletti C., Sorrentino L., Tognotti L.*Numerical model of oxy-fuel experiments in a semi industrial furnace*, 10th Conference on Energy for a Clean Environment, pp CD Rom-, Lisbon,**2009**

Coraggio G., Cumbo D., Brunetti I., Tognotti L., *Retrofitting oxy-fuel technology in a semi-industrial plant: Flame characteristics and NOx production from a low NOx burner fed with natural gas*, PROCEEDINGS OF THE COMBUSTION INSTITUTE,vol. 33,pp 3423,tot.pag 3430,**2011**

5.3 OGS

Organisation name	Short Name	Country
ISTITUTO NAZIONALE DI OCEANOGRAFIA E DI GEOFISICA SPERIMENTALE OGS	OGS	Italy

Description of the infrastructure	
Name(s) of the infrastructure(s)*:	Data acquisition systems for terrestrial and marine natural field laboratories
Location (town, country):	ITALY
Web site address:	www.ogs.trieste.it
Legal name of organisation operating the infrastructure:	Istituto Nazionale di Oceanografia e di Geofisica Sperimentale - OGS
Location of organisation (town, country):	Sgonico (Trieste), Italy

Sites where natural CO_2 is produced and leaks are recognised as important field laboratories that provide unique opportunities to understand leakage mechanisms, migration pathways and travel times, chemical reactions, potential impacts of leakage on groundwater and ecosystem, and to test and improve techniques for monitoring and early warning. Italy has many of such sites and some of them have been widely used in previous researches, mostly supported by the EC. So, large data sets are available for these sites, together with the results of such previous studies and a comprehensive set of modern high quality cross-calibrated equipment for the geophysical and geochemical detection of CO_2 in the shallow underground and at the surface, both on land and off-shore, as well as monitoring and evaluating its impacts on marine ecosystems.

The infrastructure here proposed, consists in a series of installations for identifying and monitoring CO_2 leakages on land and at sea bottom, imaging the near subsurface, evaluating the effects of CO_2 on marine ecosystems, identifying target species to be used for quick alerts.

Aircraft and remote sensing instruments (CO2 detection over large areas)

Description of the facilities

The Piper Seneca II aircraft, of property of OGS, is managed by a team of expert researchers and technicians. It is equipped with the most advanced remote sensing instruments:

- Lidar sensor Riegl LMS-Q560 (full waveform digitizer)
- Hyperspectral sensor Specim Aisa Eagle 1K (Visible Near Infrared field)
- Thermal camera Nec TS9260 (from 8 to 13 μm)
- Digital camera Canon EOS 1Ds MkIII (21 million pixels)

The performance of the installation is very high. The aircraft can operate to a maximum height of 1500 m. The Lidar sensor can reach a spatial accuracy of 40 cm in xy and 15 cm in z axes. The hyperspectral sensor has a pixel of 70 cm for an average flight height of 1000 m; the bands number can be set up to 252. The thermal camera has a pixel of 50 cm for an average flight height of 800 m.

State of the art

The equipped Piper Seneca II is part of EUFAR (European Facility for Airborne Research); it is inserted and operates in an European context.

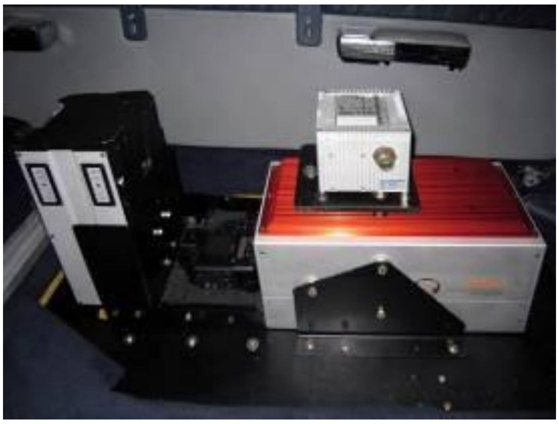
The entire instrumental equipment has been used to perform remote sensing surveys during several European projects, among which CO2 GeoNet, to detect leakages at natural field laboratories (Latera, Italy and Laacher See, Germany).

This aircraft is unique because it integrates different instruments on board and can accommodate additional new equipment provided by group of researchers. The data acquired are processed by the Remote Sensing Group at the

OGS central site, where specific codes for multiparameters leakages detection has been developed. All these computer programs are available and can incorporate new routines for novel instruments / images processing.

Services currently offered by the infrastructure and achievements

The aircraft can operate over the whole European territory. It can be used to perform accurate remote sensing surveys over wide areas, onshore and offshore (especially coastal areas). Data collected can be easily geographically referenced and integrated with other data collected over the natural field laboratories, for joint analysis. Flight crews will organise all logistics of the flights and will decide in consultation with the users the suitable time and atmospheric conditions for the acquisition of their data. When necessary, training on the processing and analysis of remote sensing data will be provided as well as support for the inclusion of new routines into the base processing packages.



Equipment for the geophysical imaging of the subsurface (CO2 pathways to the surface)

Description of the facilities

Geophysical methods are needed to accurately image the subsurface in order to understand the interaction of CO2 with rock formations, its migration mechanisms up to the surface, and to predict maximum CO_2 flow rates. To this purpose, many indirect prospecting method may be used, as multichannel reflection seismics, electromagnetic surveys (Ground Penetrating Radar), current measures (Earth Resistivity Tomography) and microgravimetry. The choice of the appropriate method depends on several factors, such as target depth, required resolution, environment characteristics, etc... However the joint availability of all these equipment is unique because it has been demonstrated that the integration of many geophysical methods can produces a better image of the subsurface at various depth ranges. The proposed installation is formed by the following data acquisition instruments.

High Resolution Multichannel Seismic

- DMT Summit telemetric system (24 bit, delta sigma technology) with 300 active stations
- several types of geophones (single, six-geophones arrays, 3 components, with 10 Hz, 100 Hz and 200 Hz natural frequencies)
- various energy sources (accelerated Power Weight Drop truck mounted, MiniVib T2500 IVI truck mounted with plates for P and S waves in the range of f5-500 Hz , various guns and hammers, and dynamite shooting systems)

Ground Penetrating Radar

- SIR2000 GSSI equipped with monostatic and bistatic antennas. The frequencies are 35 MHz and 70 MHz (Subecho), 100 MHz and 200 MHz.

Earth Resistivity Tomography

- Syscal R2 (Iris Instruments) with 64 electrodes, suitable for a multimode line 630 m long or shorter 3D area.

Gradiometer

- G-858G (Geometrics), a walking cesium gradiometer with 2 sensors. This instrument has a very high sensitivity, fast-sampling and GPS connection.

State of the art

The proposed installation is formed by a series of equipment for geophysical surveys that are used also by service companies and can be leased. What is peculiar is their joint availability and the support by a group of expert researchers and technicians involved in projects for CO2 imaging and can assist new users in similar surveys. The said data acquisition systems have been widely used to map the subsurface at the Latera field laboratory. Their joint use has allowed there to image the subsurface and to identify very small faults, interpreted as preferential pathways for the leaking CO2. Moreover, the data processing by Cat3D, a proprietary tomographic package developed by OGS, has identified there velocity anomalies in the near subsurface, in relation with "gas accumulation areas" feeding the leaking points at the surface.

Services currently offered by the infrastructure and achievements

All the data acquisition systems forming the installation are managed by a group of experts, who can provide support for new field campaign in Latera or other natural sites of interest. Such support can consist in one, many of all of the following actions: planning of the surveys, acquisition of the needed permissions, instruments calibration and test, data acquisition (by field crews), data processing, comparison with the data and results exploited in previous studies, data interpretation.

A large set of poro-visco-elastic 2D modelling programs, developed at the OGS is also available to model the subsurface seismic response and assist the researchers in the interpretation of the seismic data collected in complex geological settings.

Equipment for studying CO2 leakage at sea, and its impacts on marine biosphere

Description of the facilities

The BiO Department of the OGS offers a wide range of laboratories and technical and scientific facilities. This installation is equipped for studies in the marine biology field concerning biogeochemical analysis of sediments and overlayer water, characterization of plankton community from prokaryotes to zooplankton, characterization of benthic community from prokaryotes to macrobenthos, identification of the role of biological activities in the release (community respiration processes) or in the uptake (photosynthetic processes of phytoplankton and microphytobenthos) of CO2 in the water column and at the sediment-water interface, evaluation of microbial activities variation as consequence of CO2 concentration changes, determination of prokaryotic community structure, toxicological and physiological responses of invertebrates. The installation is complemented by equipment for measurements of physical parameters in the water column (CTD probe, Profiling Natural Fluorometer, etc), for samples collection (e.g rosette, boxcorer, plankton net, grab, etc), and with dark and transparent benthic chambers useful to perform in situ benthic flux measurements and to assess the potential importance of sediment-water nutrients exchanges for respiration and production processes. The equipment and expertise in the installation allow determining the main parameters necessary to describe both the carbonate system and the organic carbon cycle in order to fully characterized marine sites in terms of leakage detection and quantification. This installation may be considered "unique" due to its proximity to the sea, the availability of running seawater and the existing collection of planktonic organisms. Thus, field work at storage sites and natural

CO2 seeps that serve as analogues for potential CO2 leaks, can be supported by laboratory experiments as the installation allows performing ecological and ecophysiological studies under controlled conditions (light, temperature, pH, salinity), in order to estimate the immediate and long term effects of CO2 exposure on organisms and communities.

State of the art

The installation has been and is actually used within national and EC-funded research and demonstration projects in the fields of Energy, Environment and Marine Sciences, in the framework of CO2GeoNet Network of Excellence and in other CO2 related projects as RISCS (Research into Impacts and Safety in CO2 Storage - http://www.riscs-co2.eu), ECO2 (Sub-seabed CO2 Storage: Impact on Marine Ecosystems - http://www.eco2-project.eu), MEDSEA (Mediterranean Sea Acidification in a changing climate - http://medsea-project.eu), EUROFLEETS (Towards an alliance of European research fleets - www.eurofleets.eu). Recently, the installation has been used for defining the base-line in the off-shore area considered for the Porto Tolle CO2 storage demonstration project (in Northern Adriatic).

Services currently offered by the infrastructure and achievements

The BiO installation is located in the Gulf of Trieste - Northern Adriatic Sea – Italy. All analytical activities carried out in the Microbiological, Ecology, Primary Productivity, Molecular Biology and Biogeochemistry Laboratories are offered by this installation. The technical and logistic support offered to the users will be guaranteed both inside the laboratories as during the field activities.

<u>Equipment for characterising and monitoring offshore natural laboratories (oceanographic parameters)</u>

Description of the facilities

OGS has developed and used over marine field laboratories a series of support vehicles for collecting meteo-oceanographic physical and geochemical data. Floating buoys have demonstrated to be efficient and flexible, but generally too costly to be maintained at sea for long periods. More recently, OGS has preferred a new family of DeepLab Sea Floor Landers, with a stainless steel structure that allow to place scientific instruments at the sea floor. These stations are equipped with an underwater telemetry system with 5 miles range able to control the releasing of a subsurface buoy for the recovery of the lander. This has to be done at due interval to change batteries, verify and eventually re-calibrate the marine instruments, download the recoded data.

In the current configuration DeepLabs are equipped with base instruments to measure temperature, conductivity, pressure, dissolved oxygen, pH, dissolved CO2 , sea currents on the water column every 0.5 m and estimate waves height and direction.

The shape, size and weight/thrust of the DeepLabs make them particularly robust and suitable for long-term time-series measures, minimizing damages and data loss caused, for example, by fishing activities.

The modular design of power supply system and data logger, allows an easy integration with additional instruments provided by new users.

State of the art

The more recent version of the Deeplab Sea Floor Lander has been used successfully for collecting data in Nortnern Adriatic sea, continuously from November 2010 to July 2011, in the CO2 base-line survey of the Porto Tolle demonstration project.

Services currently offered by the infrastructure and achievements

Support in the use of the Deeplab Sea Floor Landers will consist in: planning surveys, acquisition of the due permissions for the areas of interests (sea natural laboratories), eventual installation of additional equipment, calibration of these new instruments, positioning at sea, maintenance and recovery of data by suitable support boats, pre-processing of the data, their upload to internet for a long-distance access.

An important component of the installation and the given services is the **Oceanographically Calibration Laboratory (OCL)** of the OGS Department of Oceanography.

Thermally-regulated and humidity-controlled, the OCL is currently equipped with primary physical standards, secondary transfer standards and support equipment for performing high-accuracy calibrations of devices and sensors measuring temperature, conductivity and pressure, the fundamental seawater parameters, across the full oceanographic range. It is also endowed with a number of instruments for making standard electrical measurements of various kinds. Recently, the OCL has been evaluated by the Consultative Committee of the Amount of Substance (CCQM) endorsed by the SCOR-UNESCO/IAPSO Working Group, resulting the more accurate (together with the Chinese IMGC) among 11 oceanographic calibration centres of excellence.

5.4 UniRoma1

Organisation name		Short Name	Country
UNIVERSITA DEGLI STUDI DI ROMA LA SAPIENZA		UniRoma1	Italy
Description of the infrastructure			
Name(s) of the infrastructure(s)*:	Terrestrial and marine natural field laboratories – access and support		
Location (town, country):	ITALY		
Web site address:	www.uniroma1.it		
Legal name of organisation operating the infrastructure:	Università di Roma "La Sapienza"		
Location of organisation (town, country):	Rome, Italy		

Sites where natural CO_2 is produced can be studied to make geological CO_2 storage sites safer. As some of these sites store the CO_2 in deep geological strata, they can be studied to understand what conditions permit long-term underground isolation. As some of these sites leak, these locations can, instead, be used to understand leakage mechanisms, migration pathways and travel times, chemical reactions, potential impacts of leakage on groundwater and ecosystem, and to test and improve techniques for monitoring and early warning. Most researchers do not have access, however, to these "natural" laboratories because these sites are concentrated in specific regions where the geology and tectonics are presently active. One such area is central Italy, where a large number of cutting edge CCS research projects (NASCENT, CO2GeoNet, CO2ReMoVe, RISCS, ECO2) have been conducted. Due to this work a strong scientific foundation exists for these sites on which new CCS research projects could be built.

The present work package consists of access to this natural laboratory infrastructure and logistical / scientific support for the associated CCS research. The various installations making up this infrastructure consist of individual sites, each having a unique geological, structural, hydrogeological setting. This variability allows for results to be extended beyond the confines of a single locale, and thus to develop generalised approaches / methods / results that can be applied to real-world CCS sites in different geological settings throughout Europe. Services offered include site access, logistical support, geological knowledge, access to historical and present-day site data, training facilities, and geochemical analysis equipment from UniRoma1, as well as the remote sensing, geophysics, biological, and oceanographic installations offered by OGS in WP19-TA11

<u>Field laboratories and support (Storage, Site characterization and monitoring / safety)</u>

The chosen natural laboratories provide the opportunity to study gas migration in different structural and geological settings. In general, Italy can be divided into two main stress domains. The area to the east is dominated by compression and hosts the main Italian oil and gas reservoirs; to the west the stress regime is extensional and is geologically active with volcanoes, high seismicity, and both non-leaking and leaking CO_2 caused by mantle degassing and thermo-metamorphic reactions. The chosen natural laboratories include both terrestrial (Latera, San Vittorino, Vasto/Maiella, Pecore, Fucino) and marine (Panarea) sites.

The Latera caldera, within the western extensional regime, is an agricultural valley about 60 km from Rome where naturally-produced CO_2 is leaking to the atmosphere. This extinct volcano has a high geothermal gradient which forms CO_2 via thermo-metamorphic reactions in carbonate rocks. This gas migrates along faults to the surface where it is released from gas vents. The site is unique because of the large data-set describing the deep subsurface (from geothermal exploration) and CO_2 leakage to the atmosphere (from various EC projects). The site has been studied for site characterisation, to understand the link between gas migration and faults, to test geophysical, geochemical, biological, and remote sensing methods for CCS leakage monitoring, and to study potential ecosystem impacts of leakage (Fig. 1a).

a) **b)** **c)**

Figure 1. Photos of a gas vent at Latera that impacts vegetation (a), a sinkhole at San Vittorino (b), and gas bubble leakage at Panarea (c).

The San Vittorino plain, located about 75 km from Rome, is an intermountain basin filled with up to 170 m of fluvial-lacustrine sediments, surrounded by peaks of carbonate and foredeep sediments, and cut by several regional faults. Large volumes of CO_2 migrate along these faults and are released at surface both from gas vents and bubbling mineralised springs, which are often associated with sinkholes (Fig. 1b) that were likely formed by CO_2-acidified ground waters. This site has been examined using various geophysical and geochemical tools and is particularly well adapted for the study of gas migration in plastic sediments and the potential impact of CO_2 on groundwater quality.

The Vasto natural gas field, located about 150 km from Rome in the Adriatic foredeep, is an example of a micro-leaking site where deep gas leakage to the atmosphere can only be defined using sensitive analytical equipment. About 100 small hydrocarbon fields have been discovered in this area since 1950, in what is primarily an over-pressured, gas prone province. Soil gas surveys in the area prior to, and 17 years after, major exploitation of one reservoir showed a decrease from high to low soil-gas helium values, implying that reservoir de-pressurising caused by hydrocarbon extraction resulted in reduced gas leakage. The outcropping carbonate rocks of the Maiella mountain to the west can be considered analogous of the buried hydrocarbon reservoirs, thus they can also be studied for structural, fluid migration, and fluid-rock reactivity purposes.

The Piano di Pecore (180 km from Rome) and Fucino Basin (90 km from Rome) are intramountain basins located in the Apennine chain that are seismically active, with the former being affected by the large 1980 Irpinia earthquake and the latter by the 1915 Avezzano earthquake. The geometry of soil-gas anomalies at the surface reflects the different gas-bearing properties of the seismogenetic versus the shallow-buried faults, with radon highlighting brittle fracture zones while helium defines better buried faults covered by surface sediments. Temporal variations related to seismic activity have also been observed at both sites.

The only marine natural laboratory is located near the island of Panarea (Aeolian Islands), where natural, thermo-magmatic CO_2 is leaking at substantial rates from the seafloor (Fig. 1c) at water depths ranging from 5 to 30 m. This natural CO_2-release field has been active for centuries, with gas emanating from a series of NW-SE and NE-SW trending fractures. In the early 1980's researchers began to conduct gas geochemistry surveys of the area, showing that the system was relatively stable in both gas chemistry (e.g. 98% CO_2, 1.7% H_2S plus trace gases) and flux rates. This site has been studied to better understand the potential impact of a CO_2 leak on water chemistry and biology, and to test marine leakage monitoring methods.

Description of the facilities – Support

The Department of Earth Sciences at the Università di Roma "La Sapienza" has conducted research at the described sites for many years, and will use this knowledge and experience to support researchers wishing to conduct research at the natural laboratory sites. To begin with, classrooms and meeting rooms will be made available for training purposes prior to leaving for the field. This could involve informative meetings to describe the sites to be visited, or could involve the teaching of methods for best practice, consultancy, and training courses. Various laboratories within the department will also be made available, including an aqueous chemistry lab equipped with ion chromatographs and an ICPMS, a gas chemistry lab equipped with various gas chromatographs, and a geotechnical laboratory for petrophysical testing. Innovative CO_2 monitoring probes and stations have been developed by UniRoma1, and are presently deployed at a number of the natural laboratory sites; these units, and others if required, will be made available to the researchers for real-time, continuous monitoring of CO_2 in the groundwater, the soil, or the atmosphere. A mobile laboratory can be used by the visiting scientists to conduct measurements or experiments; this vehicle is equipped with a diesel power generator and there is space to mount various laboratory instruments that can be provided by UniRoma1 (e.g. GC, IC, He spectrometer, etc.) or by the visiting researchers. Access will be provided during the summer months to avoid problems and difficulties related to the weather and to avoid overlap with courses taught at the university.

State of the art

Cutting edge research conducted at these sites has included testing of novel monitoring and site assessment technologies (remote sensing, open-path infrared lasers, soil gas and flux, seismic, GPR, EM, hydroacoustics, etc.), examination of potential impacts of leaking CO_2 in the near surface environment (botany, microbiology, mineralogy, groundwater chemistry, surface water chemistry, etc.), and the study the migration of gas along faults and fracture networks (field measurements, modelling with COMSOL and PETREL, etc.). Much of this work is published, and there has been extensive interest in the results due to the need for concrete "real-world" data.

This type of data, compared to that obtained in laboratory experiments or via computer modelling, is a much more realistic representation of natural geological complexities, of large spatial and temporal scales, of interacting site parameters, etc. In addition, as the CO_2 has been leaking for hundreds of years, and will continue to leak at the same rate for the foreseeable future, site experiments can be conducted for extended periods of time without being concerned with environmental permissions, permits, and CO_2 costs that would be associated with a man-made CO_2 leakage experiment.

Each site is unique, and provides characteristics that will allow for a very wide range of studies. Latera exhibits gas vents that appear to be aligned along fault structures, with channelled gas migration and spatially variable flow caused by different fracture-zone morphologies. Outcrops of faults allow for study of mineralogy related to gas-induced alterations and shear mechanical activity related to gas permeability, while a wide variety of vegetation allow for ecosystem impact studies. San Vittorino has gas leakage through plastic sediments, along intersecting fault systems, with the formation of sinkholes and the alteration of groundwater quality in correspondence with the CO_2 leaks. The presence of trace gases associated with the CO_2 can also be studied in terms of CO_2 stream impurities. Vasto is an area of hydrocarbon reservoirs where slow gas microseepage appears to have occurred in correspondence with seismically-defined faults, but where exploitation of these units appear to have affected gas migration towards the surface via a change in subsurface pressure conditions. At the outcropping analogue of the Vasto reservoir, at Maiella mountain, the reservoir and cover rocks can be sampled in the field for petrophysical studies (porosity, permeability, Young module, etc.). The Piano di Pecore and Fucino Basins are seismically active areas where gas migration has been shown to have a temporal variability due to movement along the structure, and where various gas species have given different types of information for the different fault styles. Finally, the Panarea site can be studied for the impact of CO_2 on surface water bodies, for testing sea and sub-sea monitoring technologies, and for examining the fate of released CO_2 and its eventual transfer to the atmosphere.

Besides studies addressing the types of issues given above, opening areas of research that could also be applied at these sites include new monitoring techniques, the study of impurities associated with injected CO_2, impact on different biological species, more detailed and realistic modelling of gas migration processes in reservoir rocks and overlying stratigraphy, secondary storage in aquifers, the vadose zone, and water water bodies, risk assessment, and public perception, to name just a few.

Services currently offered by the infrastructure and achievements

The services offered include logistical support (e.g. land access and permits, translation, transportation, finding accommodations, etc.), access to each site's historical data set (gas leakage locations and rates, geology, structure, chemistry, hydrogeology, etc.), and access to geochemical/geophysical monitoring data collected during the study via instrumentation already installed on site. In addition this can also be integrated with the other infrastructure offered by UniRoma1 described above (training facilities, mobile and laboratory geochemical analyses) and by OGS described in WP19-TA11 (geophysics, remote sensing, and biological / oceanographic monitoring). All the proposed terrestrial sites are centred within a range of between 100-200 km of the Department of Earth Sciences facilities at the University of Rome, whereas the marine site is located at a greater distance in the south of Italy off the coast of Sicily. It is expected that there will be significant interest in the use of these sites by European and international users based on the large number of researchers that have conducted "hands-on" research at the sites, which has been estimated to more than 50 people from across Europe over the last 5 years.

Regarding EU-funded CCS projects, the sites of Latera and San Vittorino have been used in NASCENT, CO2GeoNet, and RISCS, while Panarea has been used in CO2GeoNet, CO2Remove, RISCS, and ECO2. The other sites have been studied in national research initiatives, not always focused on CCS.

Achievements (include the most relevant scientific publications, up to 5)

E. Pettinelli, S.E. Beaubien, A. Zaja, A. Menghini, N. Praticelli, E. Mattei, A. Di Matteo, A. Annunziatellis, G. Ciotoli and S. Lombardi, 2010. Characterization of a CO2 gas vent using various geophysical and geochemical methods. Geophysics, 75(3): B137-B146.

B.I. Oppermann, W. Michaelis, M. Blumenberg, J. Frerichs, H.M. Schulz, A. Schippers, S.E. Beaubien and M. Kruger, 2010. Soil microbial comuity changes as a result of long-term exposure to a natural CO2 vent. Geochimica et Cosmochimica Acta, 74: 2697-2716.

S. Lombardi, A. Annunziatellis, S.E. Beaubien and G. Ciotoli, 2009. The study of CO2 natural reservoirs to develop criteria for risk assessment and safety strategy. First Break, 27: 61-70.

C. De Vittor, P. Del Negro, A. Paoli, C. Falconi, M. Celussi, B. Cataletto, C. Comici, C. Fabbro, K. A., G. Caramanna and S. Lombardi, 2008. Field experiment to evaluate impacts of pH decrease on marine microbial assemblage, EAGE CO2 Geological Storage Workshop, Budapest Hungary.

A. Annunziatellis, S.E. Beaubien, S. Bigi, G. Ciotoli, M. Coltella and S. Lombardi, 2008. Gas migration along fault systems and through the vadose zone in the Latera caldera (central Italy): Implications for CO2 geological storage. Int. J. Greenhouse Gas Control, 2/3: 353-372.

6. NETHERLANDS

6.1 DUT

Organisation name	Short Name	Country
DELFT UNIVERSITY OF TECHNOLOGY (DUT)	DUT	Netherlands

Description of the infrastructure	
Name(s) of the infrastructure(s)*:	**Thermolab**
Location (town, country):	The Netherlands
Web site address:	www.pe.tudelft.nl
Legal name of organisation operating the infrastructure:	Delft University of Technology
Location of organisation (town, country):	Delft, The Netherlands

Laboratory for thermodynamic experiments (Thermolab)

The laboratory for thermodynamic experiments in Delft is well known for its unique high-pressure facilities. The equipment used the synthetic-static method. The cell is filled with a sample of known composition. Phase boundaries are determined by visual observation by variation of temperature at constant pressure or of pressure at constant temperature . The pressure ranges are 0.2-15MPa (for Cailletet setups, 8 in total) and 0.5-4000MPa (for high-pressure autoclave setups). The temperature range is in all cases 240-473K.

Figure 2. High pressure autoclave setup (left) and Cailletet setup (right).

Typical thermodynamic properties that can be measured are: dew points, bubble points, gas solubilities. Since the 70s, the laboratory has been involved in many industrial projects involving the measurement of thermodynamic properties. In cooperation with companies like Shell, DOW and DSM, phase equilibria were determined with are relevant for transport of oil and gas, enhanced oil recovery, preventing wax and gashydrate precipitation in pipelines and high pressure polymer producing processes. Another line of research was the application of ionic liquids and supercritical carbon dioxide as green process solvents in various applications. Recent projects include for example: the application of hyperbranched polymers as process solvents for CO2 removal and the properties of acid gasses in mixtures with natural gas and water (both sponsored by Shell). Current research is focused on the application of liquid crystals to act as solubility switch for CO2 adsorption.

For this, accurate phase diagrams of liquid crystals+CO2 are being measured, thereby identifying the different phases. The lab is currently also participating in the Cato2 project by the Dutch government aiming at application of CCS in the Netherlands, as well as the ADEM innovation lab by the Dutch ministry of economic affairs. In the latter project, ionic liquids are screened in the lab for their potential use as absorbent for CO2. In some of these projects, molecular simulations are developed to complement the experimental measurements.

Replacement costs for all equipment is approximately 1.5Meuro. As the Cailletet setup require the use of Mercury, many safety features are currently installed to ensure a safe operation. Due to these large investment costs, our facilities are quire unique.

Recent publications:

- **Phase behavior of Hyperbranched Polymer systems: Experiments and Application of the Perturbed-Chain Polar SAFT Equation of State**
  M.K. Kozlowska, B. Jürgens, C.S. Schacht, J. Gross and T.W. de Loos
  J. Phys. Chem. B 113 (2009) 1022-1029.
- **Using Infinite Dilution Activity Coefficients for Determining Binary Equation of State Parameters**
  C.S. Schacht, L. Zubeir, T.W. de Loos, J. Gross.
  Ind. Eng. Chem. Res. 49 (2010) 7646-7653.
- **Phase behavior of the system hyperbranched polyglycerol + methanol + carbon dioxide.**
  C.S. Schacht, S. Bahramali, D. Wilms, H. Frey, J. Gross, T.W. de Loos.
  Fluid Phase Equilibr. 299 (2010) 252-258.
- **Using an analytic equation of state to obtain quantitative solubilities of CO_2 by molecular simulation**
  C.S. Schacht, T.J.H. Vlugt, J. Gross
  J. Phys. Chem. Lett., 2011, 2, 393-396.
- **Calculating Thermodynamic Properties from Fluctuations at Small Scales**
  S.K. Schnell, X. Liu, J-M Simon, A. Bardow, D. Bedeaux, T.J.H. Vlugt, S. Kjelstrup
  J. Phys. Chem. B, 2011, 115, 10911-10918.

6.2 TNO

Organisation name	Short Name	Country
NEDERLANDSE ORGANISATIE VOOR TOEGEPAST NATUURWETENSCHAPPELIJK ONDERZOEK - TNO	TNO	Netherlands

Description of the infrastructure	
Name(s) of the infrastructure(s)*:	1. TNO PILOT PLANT CO2 CATCHER 2. MINI/MICRO PLANT DEMONSTRATOR 3. QSCAN SOLVENT TEST STREET 4. CLC FIXED BED FACILITY **5.** HIGH PRESSURE ABSOPTION AND DESORPTION PILOT PLANT
Location (town, country):	Netherlands
Web site address:	www.tno.nl
Legal name of organisation operating the infrastructure:	TNO
Location of organisation (town, country):	Delft Netherlands

Access is offered to state of the art, from lab to pilot scale, demonstration technology for testing and optimization of carbon capture processes and the testing of new solvents:

1) Pilot plant at Rotterdam connected to a modern coal fuelled power plant, build in 2008 and highly successful test results with very promising Solvents. Installation is in operation.

2) TNO lab at Delft with the following unique facilities which are available and can be used on requested
   a. Micro- and Mini Plant for solvent preparation and testing
   b. High throughput solvent screening rig
   c. Chemical looping fixed bed facility
   d. High pressure absorption and desorption pilot plant

TNO PILOT PLANT CO2 CATCHER (Capture, Absorption)

Description of the facility

The TNO Pilot plant CO2 Catcher uses post combustion capture technology. New technology and solvents, which are developed in the laboratories, can be tested with this pilot plant at real flue gas conditions from a coal fuelled power station. The Rotterdam pilot plant serves as a flexible research and demonstration to test different types of solvents. The location, at the coal-fired power station of E.ON at Rotterdam was chosen because of the opportunity to obtain flue gas derived from coal. The pilot installation makes it possible to investigate the performance of CO2 removal under real industrial conditions. The TNO pilot plant CO2 catcher tests novel gas scrubbing methods and new solvents.

The pilot plant is directly linked to the stack of the second unit of the power plant, which is situated behind the desulphurisation process, which removes the sulphur from the flue gases. A small fraction of the flue gases are directed to the CO2 capture pilot plant for carbon dioxide removal. A maximum of 250 kg CO2 per hour can be removed from the stack. The installation in itself enables different CO2 capture techniques to be evaluated, monitoring all process conditions such as temperature, pressure, flows and content of CO2, SO2 and soot. Other parameters (such as the stability of the solvents that are used) can be measured separately. The pilot plant consists of a scrubber column for removing traces of SO2, which might damage the solvents, a 23-metre-high CO2 absorber column and an 18-metre-high desorber column) as illustrated in picture below. In the first stage, the SO2 is removed from the flue gas and the treated gas is transported to the absorber where the CO2 is removed by absorption in a liquid in a continuous operational mode.. The purified flue gas is emitted to the stack of the power plant. The absorption liquid is regenerated in the desorber and is ready for use again in the absorber. For bringing gas and liquid into contact, in addition to packed columns, membrane contactors are also tested for both desulphurisation and CO2 absorption.

State of the art

The fact that the installation is directly linked with a world top quartile coal fuelled power plant makes the pilot plants a pivotal point in the scale-up of post-combustion capture technologies.

This has also led to a methodology of finding and improving absorption liquids, based on statistical methods in combination with detailed analysis of the effects of different groups present in the absorption molecule on overall performance. Detailed models are available describing the power plant operations.

The construction of the pilot plant at the premises of the Rotterdam power plant has been a joint effort of TNO – as research partner - and E.ON Benelux – as industrial partner.

Services currently offered by the infrastructure and achievements

With this pilot plant major bottlenecks in the implementation of post combustion capture technologies can be analysed and studied obtaining detailed knowledge in a wide spread of areas e.g.: New Solvent testing, material testing, scaling-up of reactor design, effect of trace elements in the flue gas, dynamic response times, etc. Different solving test programmes with the Pilot plant are planned or are in progress.

The pilot plant is equipped with the latest technologies regarding process monitoring and process measurement. Furthermore the pilot plant offers good accessibility, user friendly operations and a smart process data collection system. Plant can be remotely controlled with advanced process control system. This enables smooth reporting, data evaluation, monitoring of all process conditions such as temperature, pressure, flows and content of CO_2, SO_2 and soot. Other parameters (such as the stability of the solvents that are used) can be measured separately.

- In the Dutch CATO very interesting results with CORAL, the pilot plant is successful used for Business to Business projects
- Achievements (include the most relevant scientific publications, see link below

http://www.carboncapturejournal.com/issues/CCJ8web.pdf

The replacement costs for the installation of the Infrastructure 3 million €:

MICRO/MINI PLANT DEMONSTRATOR (Capture, Absorption)

Description of the facility

The setup of the micro and mini plant consist of a skid with the process equipment [absorber (membranes), desorber, heat exchanger, pump, pipes, CO2 analysers, flow meters and controller and other small equipment, an automatic data logging / operation system, and a computer (unit)]. The difference of the Micro-plant and Mini plant is the size of the plant. The micro and mini plant are located at the TNO lab in Delft and can be relocated to another location.

Both micro-plant and mini-plant is as such that it is supporting the initial steps e.g.; preparation of the solvents and testing of the solvents stability. The absorption-desorption setup is used to determine the absorption and desorption capacity of CO2 capture solvents. The gas feed system setup is flexible.

The setup consists mainly of the absorption and desorption can be operated in continues operation. Measurement is to be carried out in a standard manner. The gases flowing out of the setup during the absorption or desorption step will be lead to a CO2 analyser (individually from each beaker).The gas stream can be analysed for the remaining CO2 content (after absorption) or desorbed CO2. It is possible to add a nitrogen flow which can be used as a sweep gas during desorption. Installation can be 24/7 continuously operated.

The phosphoric acid setup is used for analysis of the CO2 content of the absorption solvents. The principle of this setup is based on boiling phosphoric acid at high concentrations in which the solvent with CO2 is injected. After injection the produced gas is flushed out the beaker with a known nitrogen flow. The gas stream is analysed with the CO2 analyser, where the CO2 content of the system is being measured.

State of the art

With the micro and mini plant it is possible to really demonstrate new solvents types within reasonable time.

The micro and mini plant are equipped with the latest technologies regarding process monitoring and process measurement. Furthermore the pilot plant offers good accessibility, user friendly operations and a smart process data collection system.

Services currently offered by the infrastructure and achievement.

Significant amount of successful test runs have been accomplished within the following research programmes : Decab, Cato, Icap, Cesar,

The replacement costs for the installation of the Infrastructure: 400 k€ micro plant and 500 k€ mini plant.

QSCAN SOLVENT TEST STREET (Capture, Absorption)

Description of the facility

The Mini AutoClave (MAC) for quick scan purposes is set-up for medium throughput VLE equipment where six experiments can be performed in time. An advantage is the relatively small volume of solvent needed to run a proper test. All six reactors can run independently of each other and can be started and stopped at any time. A typical measurement takes about 24 to 48 hours.

The test set-up is divided into two temperature sections. Three reactors are heated to 40 °C by a water bath and three reactors are connected to an oil bath and can be heated to any temperature between ambient and 120 °C and these three reactors run at the same temperature. Vapour-liquid equilibrium measurements are performed in 0.1 litre reactors, equipped with a magnetic stirrer and a pressure gauche. Typically, 0.05 litre of solvent is used. The solvent in the reactor can be heated up and equilibriums can be determined at a constant temperature of the solvent. From these data so-called pressure-loading (P-α) curves can be constructed. The pressure (P) is obtained as a function of the loading (α). The loading is expressed in mol CO2/mol solvent.

For the glass reactors, measurements have an upper limit of about 7 bars. For safety reasons, a high pressure limit of about 5 bar was chosen. This implies that the P-α curves measured at the VLE set-up range from about 2 to 5000 mbar

State of the art

With the micro and mini plant it is possible to really demonstrate new solvents types within reasonable time.

Services currently offered by the infrastructure and achievements

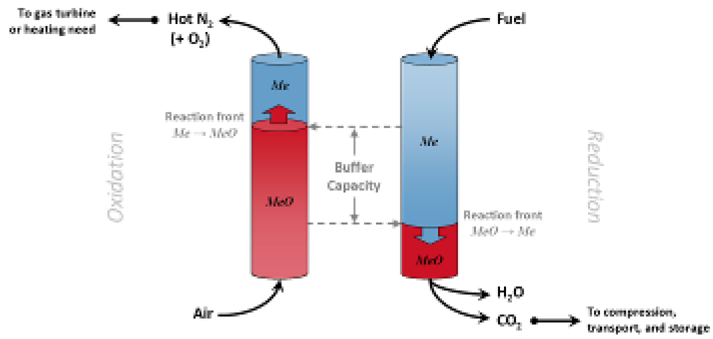
The Qscan solvent test rig is successfully used for Business to Business projects and other research programmes

The replacement costs for the installation of the Infrastructure: approx. 500 k€.

<u>CLC FIXED BED FACILITY (Capture, chemical looping)</u>

Description of the facility

CLC fixed bed facility consist of two circulating fluidized beds. Continuous production of separate streams—hot depleted air and CO2/H2O.Can be operated at elevated pressures. The CLC fixed bed facility is located at the TNO lab in Delft and can be relocated to another location.



State of the art

With the micro CLC fixed bed facility it is possible to really demonstrate Metal/metal oxide bed looped through oxidizing and reducing conditions. Next to this it provides insight in scaling up

Services currently offered by the infrastructure and achievements

The facility is successfully used for Business to Business projects and other research programmes such as Greenhouse applications, Production of gases Materials testing w/ international collaboration.

HIGH PRESSURE ABSORPTION AND DESORPTION PILOT (Capture, membrane gas desorption)

Description of the facility

The pilot plant consist of an Absorber and a conventional desorber and MGD, which can be operated in a continuously cycle mode. Currently test runs are in progress as part of the DeCarbit research work package programme. The pilot test facility can be upgraded with next stage MGD technology without large changes to the set-up. The pilot test is skid mounted and is easily to be relocated, due to its compact design. The gas supply setup is flexible and easily to adjusted to specific needs. The Desorber can be equipped with commercial structured packing material.

4-10 Nm3/h gas; 70-110 kg/h liquid circulation

State of the art

With the high pressure absorber and desorber pilot plant it is possible to demonstrate new solvents their stability at different process conditions. The high pressure absorber and desorber pilot plant is equipped with the latest technologies regarding process monitoring and process measurement. Furthermore the pilot plant offers good accessibility, user friendly operations and a very user friendly process data collection system.

Services currently offered by the infrastructure and achievements

Current DeCarbit program in progress.

7. NORWAY

7.1 NTNU

Organisation name	Short Name	Country
NORWEGIAN UNIVERSITY OF SCIENCE AND TECHNOLOGY	NTNU	Norway

Description of the infrastructure	
Name(s) of the infrastructure(s)*:	**NTNU MEMB-FAB , NTNU MEMB-PERM, ABSKIN,ABSDEG, ABSEQ**
Location (town, country):	NORWAY
Web site address:	www.ntnu.no
Legal name of organisation operating the infrastructure:	Norwegian University of Science and technology
Location of organisation (town, country):	Trondheim. Norway

NTNU MEMB-FAB (Capture, Membranes)

Description of the facilities

This infrastructure provides facilities and methods to fabricate polymer-based membranes in lab scale and pilot scale, including the spinning of hollow fibre membranes, carbonization to prepare carbon membranes and coating of thin composite membranes on flat sheet or hollow fibre supports. The facilities are listed below with pictures in Figure 1:

1. Spinning machine for hollow fibre fabrication and coating
2. Carbonization rig
3. Pilot scale flat sheet coating device

Figure 1. Pictures of the spinning machine (left), carbonization rig(middle) and the pilot scale flat sheet coating device(right)

The replacement costs for the Infrastructure (€): 500,000

NTNU MEMB-PERM(Capture, Membranes)

This infrastructure provides facilities and methods to test membrane gas permeation performance in lab scale and pilot scale in different conditions, including single gas, mixed gas, gas separation in humidified conditions and at high pressures, with either flat sheet or hollow fibre membrane modules. The facilities are listed below with pictures in Figure 2:

1. Membrane gas permeation test rig for single gas and mixed gas (GC for gas composition analysis)
2. Membrane gas permeation test rig for mixed gases at humidified conditions (GC for gas analysis)
3. Membrane gas permeation test rig for mixed gases at high pressures (MS for gas composition analysis)

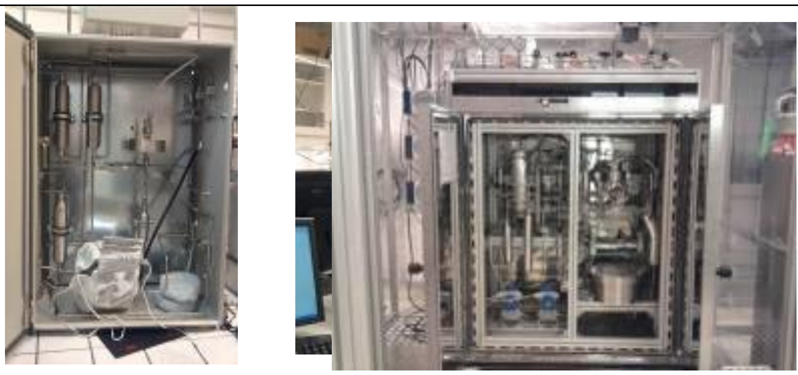


Figure 2. Pictures of membrane gas permeation test rig for single/mixed gas(left), membrane permeation test rig for humidified conditions(middle) and membrane permeation test rig for mixed gas at high pressures (right)

The replacement costs for the Infrastructure (€): 800,000

State of the art for TA1.1 and TA1.2

- In the TA1.1 NTNU MEMB-FAB infrastructure, the well-equipped facilities support broad techniques for the fabrication of polymer-based membranes, providing researchers the opportunity for 'one-stop' works in developing novel membranes of various materials or unique morphology that enhance the CO2 separation performance. The facilities are updated and easy to operate, which enables users to conduct high quality researches.
- In the TA1.2 NTNU MEMB-PERM infrastructure, the facilities provided are advance and updated, equipped with automatic controlling and indication system as well as devices for auto-sampling and auto data-recording, providing researchers the opportunity to test membrane gas permeation performances in different conditions with reliable and high quality data.

Services currently offered by the infrastructures TA1.1 and TA 1.2 and achievements

There is a widespread interest from users in other countries to conduct research in developing new and more efficient membranes for CO2 separation, and in testing gas permeation of membranes in different conditions. During recent years, researchers from our international partners from Italy, France, USA and China have also used the facilities.

The current users at NTNU have obtained many scientific achievements based on the services offered by the infrastructures, including EU projects, industrial and NFR projects, 5 patents and more than 30 papers:

<u>EU funded projects</u>: NaturalHy, Ulcos, Engas, NanoGlowa, etc.

<u>Other large initiatives</u>: SINTEF- NCSU (2 projects), NFR, Statoil, Alstom project, RECCO2 (NFR, Statoil for KMB and BIP projects)

<u>Selected patents</u>:

1. M. Sandru, T-J Kim, M.-B. Hagg, Gas separation membrane, WO2010086630A1, 2010.
2. Liyuan Deng, May-Britt Hägg, Taek-Joong Kim, CO2 capture membrane, European patent EP1897607, EP1900419 and US Patent US2008078290
3. Hägg MB, Lie, JA; Carbon Membranes, WO2007017650A

<u>Selected publications</u>:

1. Shao, L, Samseth, J, Hagg MB; Crosslinking and stabilization of nanoparticle filled PMP nanocomposite membranes for gas separations; J.Membr.Sci., 326 (2) 285-292 (2009)
2. M.Sandru, S.H. Haukebø, M-B Hägg, Composite hollow fiber membranes for CO2 capture, J.Membr.Sci., 346 (2010) 172-186
3. He, Xuezhong, Hägg MB, Structural, Kinetic and Performance Characterization of Hollow Fiber Carbon Membranes, submitted to J.Membr.Sci, April 2011

Kinetic studies (ABSKIN) (CO2 capture, absorption)

The package offers a possibility to measure absorption kinetics with string of discs apparatus and with wetted wall column. Both apparatuses are suitable for loaded and unloaded solutions. The String of discs can be used up to 70oC and the wetted wall column can be used up to 80oC. Additionally measurement of viscosity, density and physical solubility of CO2 using N2O analogy measurement can be measured.

Solvent degradation laboratory (ABSDEG) (CO2 capture, absorption)

Solvent degradation laboratory makes it possible to study fundamental solvent degradation. This installation includes 3 apparatuses. The oxidative degradation in closed-batch reactor is suitable for degradation studies at absorber temperatures (45-60oC) whereas the thermal degradation tests can be done up to 135oC. Additionally with a new screening apparatus for oxidative degradation, it is easy to test inhibitors and effect of metal. The degradation laboratory has a closed co-operation with analytical laboratory with SINTEF Biotechnology which does most of the

Figure 3 Oxidative degradation apparatus (left) and string of discs apparatus (right).

Thermodynamic studies (ABSEQ) (CO_2 capture, absorption)

The installation includes 5 different apparatuses. The low temperature VLE apparatus can be used to measure vapour-liquid equilibrium of loaded absorption liquids up to 80^{o}C and up to 35 vol% CO_2. In high temperature VLE, the VLE up to 120 ^{o}C can be measured. And an apparatus for liquid-solid equilibrium studies is available. The high pressure VLE apparatus is able to provide VLE information up to 20MPa. The reactor calorimeter is suitable for heat of reaction measurements under pressures from -1 to 100 bar gauge and temperatures of from -20 to 200 ^{o}C.

Figure 1. Pictures of low pressure VLE apparatus (left), reactor calorimeter (middle) and high pressure VLE apparatus (right).

State of art for TA1.3, TA1.4 and TA1.5

The installations Ta1.3, TA1.4 and TA1.5 are designed for CO_2 capture research. In-house activity based thermodynamic and kinetic models can be used to model the experimental results. The laboratory has a close co-operation with analytical laboratory (SITNEF Biotechnology), which makes it possible to analyse liquid samples for degradation products and amines. Additionally NMR can be used to find the speciation in the liquid.

***Services currently offered by the infrastructure and achievements for* TA1.3, TA1.4 and TA1.5**

Measurement of thermodynamic data, like VLE and heat of absorption, needed for example in process modelling can be performed. Absorption kinetics including measurement of physical properties is needed for sizing of absorber. Degradation studies will give fundamental understanding of the solvent as well as indicate the solvent make-up costs.

Part of experimental apparatuses have been / are used in CASTOR, CESAR, DeCarbit, ENGAS and iCAP EU-funded projects. There is a close co-operation with SINTEF Materials and Chemistry and a long history of collaboration with the Department of Thermal Engineering, Tsingua University, Beijing and the Department of Chemical Engineering, University of Austin, Texas through exchange of PhD students and research personnel. In the last 5 years, more than 30 peer reviewed journal publications has been published presenting data from these installations.

Selected publications related to TA1.1

Sholeh Ma'mun et al. Kinetics of the Reaction of Carbon Dioxide with Aqueous Solution of 2-((2Amino(ethylamino) ethanol", Ind. Eng. Chem. Res., (2007), 46, 385-394

Hartono A. et al. Solubility of N2O in aqueous solution of Diethylenetriamine, J.Chem Eng. Data 2008, 53, 2696-2700

Knuutila, H et al. Kinetics of the reaction of carbon dioxide with aqueous sodium and potassium carbonate solutions. Chemical Engineering Science, Volume 65, Issue 23, 1 December 2010, Pages 6077-6088.

Hartono A et al. Kinetics of carbon dioxide absorption in aqueous solution of diethylenetriamine(DETA), Chem. Eng. Science, 2009, 64, pp 3205-3213

Selected publications related to TA1.2

Kim I. et al. Enthalpy of absorption of CO2 with alkanolamine solutions predicted from reaction equilibrium constants, Chem. Eng. Science, 2009, 64, pp2027-2038

Qin F. et al. Study of the Heat of Absorption of CO2 in Aqueous Ammonia: Comparison between Experimental Data and Model Predictions, Ind. Eng. Chem. Res., 2010, 49(8), pp3776- 3784

Knuutila, H. et al. Vapor-liquid equilibrium in the sodium carbonate-sodium bicarbonate-water-CO2-system, Chemical Engineering Science, Volume 65, Issue 6, 15 March 2010, Pages 2218-2226.

Aronu U.E., et al. Vapor-liquid equilibrium in amino acid salt systems: Experiments and modeling. Chem. Eng. Sci. 2011, 66, 2191-2198

Ma'mun, S. et al. Experimental and Modeling Study of the Solubility of Carbon Dioxide in Aqueous 30 Mass % 2-((2-Aminoethyl)amino)ethanol Solution. Ind. Eng. Chem. Res. 2006, 45 (8), 2505 – 2512.

Selected publications related to TA1.3

Lepaumier, H., et al. Energy Procedia. Comparison of MEA degradation in pilot-scale with lab-scale experiments. **2011**, 4, 1652.

Lepaumier, H., et al. Chemical Engineering Science. Degradation of MMEA at absorber and stripper conditions. **2011**, 66, 3491.

Eide-Haugmo, I. et al. Chemical stability and biodegradability of new solvents for CO2 capture. Energy Proceedia 4 (2011) pp. 1631-1636.

7.2 SINTEF

Organisation name			Short Name	Country
STIFTELSEN SINTEF			SINTEF	Norway
Description of the infrastructure				
Name(s) of the infrastructure(s)*:	SINTEF MC			
Location (town, country):	Oslo and Trondheim, NORWAY			
Web site address:	www.sintef.no			
Legal name of organisation operating the infrastructure:		Stiftelsen SINTEF		
Location of organisation (town, country):		Trondheim , Norway		

SINTEF MC: Two laboratories at SINTEF Materials and Chemistry, TA 1.1 located in Oslo SINTEF site and TA 1.2 located in Trondheim SINTEF site will be made available for external use. In general, the two installations consist of testing facilities for solvents, sorbents and membranes for CCS applications. In addition, parallel techniques for the preparation and characterization of solid sorbents are offered. Such experimental facilities are essential for the development of new and improved capture technologies.

TA 18.1 Sorbent and Membrane characterization and evaluation Laboratory for CCS- (**SINTEF SMLab** in Oslo)(Capture, Sorbents and Membranes)

Description of the facility

The laboratory consists of 9 different units as described below:

1. Automated atmospheric and High Pressure Thermal Gravimetric equipment (TG)
   Both TG units have automated gas feeding, switching and mixing systems (H_2, CO_2, CO, CH_4, N_2, H_2O, Ar) which enable multiple cycle sorption measurements at temperatures from ambient to 1000ºC. The High Pressure TG is placed in a laboratory with separate ventilation system which allows experiments in sulphur environment.
2. Testing units for ceramic and alloy type membranes
   A well-equipped membrane permeation characterisation laboratory allows studies of permeation up to 40 bars and 600 °C (e.g. for studies of Water Gas Shift or Methane Steam Reforming). The gas mass flow and pressure controllers are regulated by a PC and the gas composition of feed and permeate is monitored continuously by MS and GC units. An advanced gas distribution infrastructure for multiple gasses (O2, H2, N2, CO, CO2, CH4, Ar, He, ...) and mixtures is installed.
3. CLC rig
   The CLC rig, handling about 3 kg of solid, is been operated as cold rig so far. The hot rig operation, 3 KW, is expected by end of 2012.
4. High Throughput material preparation and characterization
   Robots are used for material preparation by various techniques (impregnation, precipitation, etc.) where also solid handling is possible. A 48 samples in parallel format is used. Individual thermal treatment of 48 samples can be carried out using individual thermal treatment sequences. The solid products can be analysed in one run by a powder X-Ray diffraction unit by fast automated scanning over all 48 samples.
5. High throughput solid material testing,
   8 solid can be tested in a fully automated breakthrough unit (0.4 g of each sample) working at temperatures up to 800ºC and at pressures up to 30 atm. This is a unit where external users can have their sorbent samples tested at harsh conditions in an efficient way. An automated gas feeding and mixing system (H_2, CO_2, CO, CH_4, N_2, H_2O, H_2S, misc.) is used. Effluent gas analyses are done by IR or MS.
6. Solid and liquid state NMR
   For solid state NMR analyses a Bruker Avance III 500 MHz wide bore spectrometer equipped with four probes for different applications is available: Two MAS probes for solid samples, 3.2 and 4 mm. The 4 mm probe is useable up to about 300 C and has a wide tuning range covering NMR frequencies for all elements. One High Resolution probe for tissue samples, gels, and other liquid-solid dual phase samples. One flow probe for NMR studies of gases reacting with solids (in-situ). Useable up to 400 C. In addition a Bruker Avance III 400 MHz spectrometer is available for liquid samples equipped with one probe with extended tuning range.
7. Automated Breakthrough unit for sorbent evaluation

A two column breakthrough unit operating at temperatures up to m800ºC and pressures up to 30 atm with bed volume between 5 and 10 ml. The fully automated unit can perform multicycle testing. A variety of gas composition can be mixed by an automated gas feeding and mixing system (H_2, CO_2, CO, CH_4, N_2, H_2O, H_2S, misc.). Effluent gas analyses are done by IR or MS.

8. In-situ powder X-Ray diffraction
   A PANalytical Empyrean instrument equipped with an in situ cell can be used to get mechanistioc information on sorbnet function and possible degradation during operation. A variety of gas composition can be mixed by an automated gas feeding and mixing system (H_2, CO_2, CO, CH_4, N_2, H_2O, misc.). Effluent gas analyses can be done by IR or MS.
9. Volumetric adsorption Isotherm measurement units (From vacuum to 100 bar)
   A series of Belsorp instruments (Mini, Max, HP) are used to measure single component adsorption/desorption isotherms on solids with gases such as H_2, CO, CO_2, CH_4, N_2, Ar, misc over a pressure range from high vacuum to 100 atm and temperatures from -195ºC to 400ºC.

State of the art

The major part of the infrastructure contains various experimental techniques used to evaluate the performance of sorbents and membranes. All techniques offered are modern and the results obtained are expected to be of high scientific quality. The experiments can be conducted under realistic conditions at high temperatures, pressures, and under high partial pressures of steam. Also tests at sulphur environment can be carried out. The equipments are followed by skilled technicians/scientists. The choice of the right experiment/experimental conditions for a specific test can also be done in discussion with our experts.

Services currently offered by the infrastructure and achievements

We offer the above mentioned experiments to be carried out in one infrastructure. Skilled scientists and technicians are available to assist visiting partners. Also, a desk with internet access will be available during the stay.

We have in our laboratory analysed the extreme adsorption capacities that are achievable with metal-organic frameworks. We also have analysed the extremely high hydrogen fluxes that are possible to obtained using ultrathin Pd-Ag membranes (see publication list below).

The infrastructure has been central in the accomplishment of several national and international projects, and 6th and 7th FP projects such as DECARBit, CAESAR, CACHET, CACHET II, Democlock, iCap.

Some relevant recent publications:

- Egil Bakken, Paul D. Cobden, Partow Pakdel Henriksen, Silje Fosse Håkonsen, Aud I. Spjelkavik, Marit Stange, Ruth Elisabeth Stensrød, Ørnulv Vistad, Richard Blom
  "Development of CO_2 sorbents for the SEWGS process using high throughput techniques"
  Energy Procedia, **2011**, 4, 1104-1109.
- T.A. Peters, M. Stange, R. Bredesen
  "On the high pressure performance of thin supported Pd–23%Ag membranes—Evidence of ultrahigh hydrogen flux after air treatment"
  Journal of Membrane Science 378 (2011) 28– 34
- Pascal D. C. Dietzel, Vasileios Besikiotis and Richard Blom,
  "Application of metal–organic frameworks with coordinatively unsaturated metal sites in storage and separation of methane and carbon dioxide "
  J. Mater. Chem., **2009**, 19, 7362-7370; DOI: 10.1039/b911242a
- Pascal. D. C. Dietzel, Rune E. Johnsen, Helmer Fjellvåg, Silvia Bordiga, Elena Groppo, Sachin Chavan and Richard Blom

"Adsorption properties and structure of CO_2 adsorbed on open coordination sites of metal-organic framework Ni_2(dhtp) from gas adsorption, IR spectroscopy and X-ray diffraction"
Chem. Commun., **2008**, 5125-5127.

Lab scale absorption pilot plant (Capture, Absorption) (SINTEF AbsLab, Trondheim)

Description of the facility

The lab scale pilot plant is located at the Gløshaugen campus in Trondheim, Norway. It has been operated since 1998 for testing of new solvent and providing data for advanced process modelling. It is fully automated with continuous logging of the liquid and gas flows, the temperature profiles in the packed columns (8 probes in the absorber and 5 probes in the stripper), the CO2 concentrations in and out the absorber, the reboiler heat duty and temperatures and pressures in the pipes. The absorber has an internal diameter of 0.15 m and a packing height of 4.26 m whereas for the stripper the height and diameter are 3.89m and 0.10m. The water wash section has packing height of 2.1m and internal diameter of 0.15m. The pilot is operated continuously (24-hours) and no operator is needed present in the evenings/nights. The complete plant is run as a closed system, thus all CO2 that is absorbed is transferred back to the absorber. The laboratory is operated by SINTEF Materials and Chemistry, CO2 capture processes team and NTNU/Department of Chemical engineering.

Lab scale absorption pilot plant

State of the art

At the moment the plant is dismounted because the hall where it is located is under renovation. The facility is planned to be operational in spring 2012. In-house process models can be used to model the experimental results. The analysing facility is very good including advanced analysis of degradation products because of a very well equipped analytical laboratory at the place (SINTEF Biolab).

Services currently offered by the infrastructure and achievements

The pilot is very well suited for testing of new promising solvents before they are tested on larger units. Estimates of energy requirement, column heights, and operational aspects of the solvent will be revealed by pilot plant as well as data for process modelling. Researchers at SINTEF and NTNU have used the pilot for many years and will give valuable experience and help in operating and interpretation of the results.

Some relevant recent publications:

- Hanna Knuutila, Ugochukwu E. Aronu, Hanne M. Kvamsdal, Actor Chikukwa. Post combustion CO2 capture with an amino acid salt. 10th International Conference on Greenhouse Gas Technologies, GHGT10, Amsterdam, The Netherlands , 19th-23rd September 2010.
- Ugochukwu E. Aronu, Hallvard F. Svendsen, Karl Anders Hoff, Hanna Knuutila, Inna Kim, Øystein Jonassen. Amine Amino Acid Salts for Carbon Dioxide Absorption. The 5th Trondheim Conference on CO2 Capture, Transport and Storage, 16-17 June, 2009, Trondheim Norway.
- Tobiesen, F.A., Juliussen, O., Svendsen, H.F. 2007. Experimental validation of a rigorous model for CO2 post combustion capture using monoethanolamine (MEA). AIChE J. 53 (4), 846-865.
- Tobiesen, F.A., Juliussen, O., Svendsen, H.F. 2008. Experimental validation of a rigorous desorber model for CO2 post-combustion capture. Chem. Eng. Sci. 63, 2541-2656.
-

7.3 SINTEF ER

Organisation name		Short Name	Country
SINTEF ENERGI AS		SINTEF ER	Norway
Description of the infrastructure			
Name(s) of the infrastructure(s)*:	Chemical Looping Combustion Cold Flow Model (CLC-CFM); High Pressure Oxy-Fuel Combustion Facility (HIPROX); SINTEF Combustion Lab (SCOM Lab)		
Location (town, country):	Trondheim, NORWAY		
Web site address:	www.sintef.no/home/SINTEF-Energy-Research/		
Legal name of organisation operating the infrastructure:	SINTEF Energi AS		
Location of organisation (town, country):	Trondheim. Norway		

CLC – CFM (Chemical Looping Combustion, Large-scale Cold flow Model)

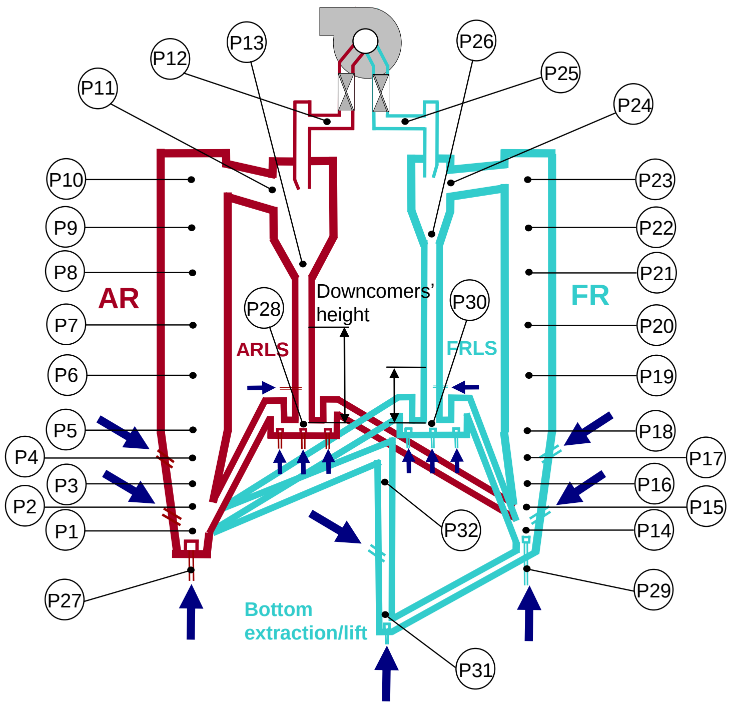
Description of the facilities

The cold flow model is a transparent version in scale 1 to 1 of a 150 kW CLC rig. It consists of a Double Loop Circulating Fluidized Bed (DLCFB) reactor system made of two Circulating Fluidized Bed (CFB) reactors, Air Reactor (AR) and Fuel Reactor (FR), interconnected by divided loop-seals and a bottom extraction (lifter). The divided loop-seals give the possibility for internal recirculation within each of the CFB loops. The loop-seals are operated with fluidization only, i.e. without a cone valve. Part of the solids flow from FR to AR can be exchanged by means of the bottom connection/lifter. The air and fuel reactors have a height of 5 meters and respectively a diameter of approximately 0.25 and 0.15 meters, i.e. a rather large scale cold flow model. The rig is equipped with 36 differential pressure transmitters and 14 automatic mass flow controllers. The fluidizing gas is air. The air is fed from a compressed air network in the lab. The air flow to the reactor system is about 10000 Nl/min at maximum reactor velocities. The system is controlled through a LavView control program with a user-friendly operator interface. The solid flows are measured using high speed automatic butterfly valves in both the downcomers and visually detecting particle accumulation during a short time interval. The reactors are equipped with large flanged openings up along the height for mounting of internal panels to mimic the hydrodynamics when inserting cooling panels or other flow restrictions to create flow variations. The outgoing air after the cyclones flows to a filter unit with fine filters in order to avoid particles to the atmosphere. The filter unit is placed on an accurate scale so that particle losses from the reactors can be easily detected. The filter is equipped with a frequency controlled fan in order to control the cyclone outlet pressure, as well as a filter cleaning system.

The unit has been built equal to a designed hot CLC reactor system. (The hot unit is planned for 2013). The cold flow model has been used to validate and improve the design with respect to gas/particle hydrodynamics and solid exchange between the reactors. But the system is quite general with respect to interconnected fluidized reactor systems.

State of the art

The cold flow model is a mature facility where different kind of hydrodynamic and particle related investigations can be performed. Accurate control and measurement systems are in place. In addition there is a high standard particle lab in a neighbouring building (the Particle laboratory of NTNU and SINTEF Materials & Chemsitry) where detailed particle measurements such as PSD, density, composition and other particle properties can be analysed.



Services currently offered by the infrastructure and achievements

The facility is part of BIGCCS, a large international research centre with SINTEF Energi as host institution. The infrastructure is highly relevant to activities on "looping particle systems" related to CCS. Reference is made to the IEA Greenhouse Gas High Temperature Solid Looping Cycles Network.

Some references:

- Bischi, A.; Langørgen, Ø; Saanum, I.; Bakken, J.; Seljeskog, M.; Bysveen, M.; Morin, J. X.; Bolland, O. Design study of a 150kWth double loop circulating fluidized bed reactor system for chemical looping combustion with focus on industrial applicability and pressurization. International Journal of Greenhouse Gas Control, Volume 5, Issue 3, May 2011, Pages 467-474.
- Bischi A., Langørgen Ø., Morin J.-X., Bakken J., Ghorbaniyan M., Bysveen M., Bolland O.. Performance analysis of the cold flow model of a second generation chemical looping combustion reactor system. Energy Procedia Volume 4, 2011, Pages 449-456.
- Bischi A., Langørgen Ø., Morin J.-X., Bakken J., Ghorbaniyan M., Bysveen, M., Bolland O.. Hydrodynamic viability of chemical looping processes by means of cold flow model investigation. ICAE2011 Perugia, Italy 16-18 May 2011

<u>SINTEF Combustion Lab (Capture, Combustion)</u>

Description of the facilities

The SINTEF Combustion Laboratory (SCOM lab) is a combination of a small and a medium scale combustion rigs aimed at studying combustion and flames from burners through the measurement of combustion performance. For the small scale unit, a comprehensive network of gas distribution lines allows for study of complex gas mixtures both for the fuel or oxidiser thus avoid the need for ordering special gas mixture. Two sets of gas pre-heaters allow independent heating of mixtures up to 600 C. The burner block is exchangeable, and some burners are available at the lab: jet nozzle in co-flow and variable swirl burner (so called IFRF Moveable block burner). The measurement capabilities cover emissions of pollutants by conventional a gas analysers or FTIR, flame stability by visualization methods, thermo-acoustic instabilities study by use of microphones and PMT. The combustion chamber can be equipped with optical accesses making the use of laser diagnostics possible. Such a method offered for transnational access is for example 2D Laser Doppler Velocimetry. The infrastructure is operative, however it is planned to be upgraded for more flexibility and higher pressure capability. The upgrading is planned in 2013. At medium scale, the SINTER Combustion Lab offer a Central European Norm (CEN) boiler, where burners and fuels or mixtures can be tested at a scale of 250 kW and in real boiler conditions. The infrastructure is equipped with fuel management of gaseous, liquid oil and heavy oil fuels. Access to in-boiler measurement is possible through port holes. Probes are developed to measure heat flux and a FTIR instrument is hooked on the flue gas exhaust line.

State of the art

The gas management system of the small scale facility is composed of 11 gas lines and two pre-heaters, and therefore allows for variable composition and temperature mixtures. When coupled with the FTIR instrument, able to measure several species simultaneously, the facility is particularly well suited for combustion studies with complex gas mixtures that can be found in post, pre and oxy-fuel combustion processes. Although with somewhat flexibility on the gas management, similar capabilities are available for the 250 kW CEN boiler with an oxy-fuel oxidizers preparation unit and steam from a 800kW/15 bar steam boiler. Several patented low NOx burners have been developed and tested in the CEN boiler.

Services currently offered by the infrastructure and achievements

The infrastructure is well adapted for proof of concept, prototype testing of burner or process concept. It has been used for developing new burners; characterize stability and emission performance in unconventional gas mixtures relevant to both the power and process sectors. The infrastructure has been used in the earlier EU FP6 funded program "ENGAS RI" for 2 activities hosting international researchers and various Norwegian industrial projects. On average the infrastructure is used by 3 international users, researchers or students per year. The infrastructure has generated several confidential technical reports and publications, such as:

- Investigation on the in-flame NO reburning in turbine exhaust gas, M. Ditarantoet al. Proc. Comb. Inst. 32(2):2659-2666, 2009.
- A comparison of low-NOx burners for combustion of methane and hydrogen mixtures, G. J. Rørtveit et al., Proc. Comb. Inst. 29(1):1123-1129, 2002.
- Experimental and Numerical Investigation of NOx Emission Characteristics of Swirled Hydrogen Rich Flames, J. Ströhle et al., GHGT-8, 2006.

HIPROX (Capture, Oxy-Fuel Combustion)

Description of the facilities

The High Pressure Oxy-fuel combustion facility (HIPROX) is a pressurized combustion rig for the study of combustion in oxy-fuel atmospheres, i.e. CO2 and O2 oxidizers. The combustion chamber is particularly suited for gas turbine type combustion system, where the gas streams can be distributed between primary and dilution zones. The defined power load with methane or natural gas as fuel is 125 kW at 10 bar with pre-heating of CO2 up to 300 C at 90 g/s. The installation can also be operated with air which can be heated up to 400 C at 150 g/s. The flexibility of the installation is such as custom design burner can be adapted to the pressurized unit, allowing external users to bring a burner provided it has been followed our construction specifications and necessary approval. The fixed monitoring of the unit is composed of dynamic pressure and total pressure, heat flux probe, internal chamber wall temperature, exit gas temperature, and an averaging sampling probe that can be coupled with conventional gas analysers or FTIR unit. In addition, four sides optical accesses around the flame zone allows for combustion radicals chemiluminescence imaging.

The infrastructure is at its "on-going start" stage and will be available to external users in the course of 2014, thus for a period of only 2 years.

State of the art

HIPROX is the possibility of using one stream of pure oxygen and 2 streams of pure CO2 at controlled mass flow and pre-heat temperature in a pressurized environment, and offers flexibility in the gas streams management. When coupled with the FTIR instrument, able to measure several species simultaneously, the facility is particularly well suited for combustion studies with gas mixtures that can be found in oxy-fuel combustion processes and able to monitor all parameters necessary for the operation of a gas turbine engine.

Services currently offered by the infrastructure and achievements

The HIPROX infrastructure offers assessment of the general combustion performance of oxy-fuel related processes, through the measurements of pollutants emissions or impurities, flame stability, thermo-acoustic instabilities, and in-chamber heat transfer. The parameters that can be easily varied are the CO2 and oxygen distribution, individual stream temperature, and the conventional combustion parameters (power, equivalence ratio).

7.4 SINTEF PR

Organisation name	Short Name	Country
SINTEF PETROLEUMSFORSKNING AS	SINTEF-PR	Norway

Description of the infrastructure	
Name(s) of the infrastructure(s)*:	**Reservoir Laboratory**
Location (town, country):	NORWAY
Web site address:	www.sintef.no
Legal name of organisation operating the infrastructure:	SINTEF Petroleum Research
Location of organisation (town, country):	Trondheim, Norway

The Reservoir laboratory will offer special core flooding studies and fluid studies at relevant conditions for CO_2 storage (i.e.: high pressure and high temperature, HPHT conditions). The laboratory is well equipped to cover a wide range of applications within flow processes in porous media and measurements of fluid properties relevant for CO_2 storage. The laboratory has been servicing the oil industry within research and development related to various recovery processes including CO_2 injection for enhanced oil recovery. The laboratory has been further developed to perform specific flow and fluid experiments for CO2 storage. The reservoir laboratory offers two installations for Transnational activities: Core flood (SCAL) laboratory and Fluid (pVT) laboratory.

Installation no. 1: Core flood (SCAL) laboratory

Description of the facilities

The special core analysis laboratory consists of several high pressure flooding rigs. The flooding rigs are equipped to perform 2- and 3-phase floods on core samples up to a pressure of 700 bars and temperature of 160 ^{o}C with a maximum core length of 120 cm (Fig. 1). Studies may include compositional analysis of produced fluids as well as additional chemical analysis of fluids as well as characterization of the core material. There is an on-going development of in-situ measurements of fluid saturation by gamma attenuation techniques. The laboratory has access to X-ray tomography for rock characterization as well as for in-situ fluid visualization.

A special 2D visual cell has been constructed in order to perform visual flow experiments in special designed porous media at ambient conditions. Fluid flow relevant for CO2 movement (migration, segregation, accumulation) in heterogeneous porous media can be studied in this apparatus.

Numerical modelling of the core floods is usually an integrated part of experiments.

Fig. 1: Core flooding apparatus

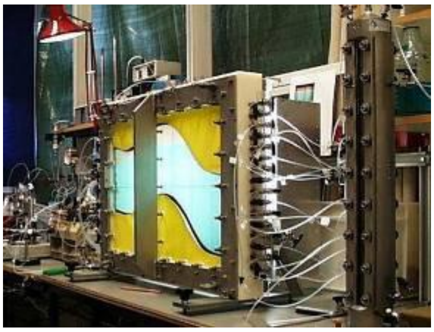


Fig. 2: 2D visual cell apparatus

State of the art

8. The core laboratory has flexible set-ups of flooding rigs which may easily adapt the specific needs regarding porous medium (sand packs, core sizes, etc.) and flooding conditions (volume rates, type of fluids, fluid phases, pressure and temperature). The laboratory may also offer support for rock characterization and in-situ fluid saturation. Experiments may be performed at high pressure and high temperature conditions.
9. The laboratory is doing research within multiphase flow processes in porous media. This work is mostly related to enhanced oil recovery (EOR) processes including CO_2 injection for EOR as well as studies of CO_2 flow and transport processes. There is a special interest in improvements of in-situ CO2 saturation measurement techniques to reveal new information from core flooding experiments.
10. The core laboratory is working in close connection with the fluid laboratory, and most core flooding projects will need fluid analysis to be included. The core laboratory is also working in close cooperation with other SPR laboratories within rock characterization and rock mechanics. In addition, SPF is collaborating with the laboratories of Institute of Petroleum, NTNU and especially on the use of X-ray computer tomography for rock characterization and in-situ fluid saturation.

Services currently offered by the infrastructure and achievements

The laboratory offers a wide range of services and special research type of experiments. Some of the more standard type experiments and tests are listed below:

- Steady-state and un-steady state 2- and 3-phase core flooding relative permeability experiments
- Capillary pressure measurements
- Porous plate experiments
- Migration and diffusion type of experiments for fluid transport in porous media.
- Core flooding experiments for measurements of displacement efficiencies (EOR, etc.)
- In-situ fluid saturation in core flooding experiments
- Rock wettability tests and contact angle measurements

Installation no. 2: Fluid (pVT) laboratory

Description of the facilities

The fluid laboratory consists of various fluid cells and apparatus for fluid studies:

- Automated pVT-cell up to 700 bars and 150 ^oC
- Special HPHT cells with working conditions up to 1400 bars and 210 ^oC
- Automated slim tube apparatus (700 bars, 150 ^oC)
- IFT cells (pendent drop, laser light scattering)
- Diffusion cell (temperature- and compositional gradients)
- Viscometers for HTHP conditions
- Additional fluid properties and characterization

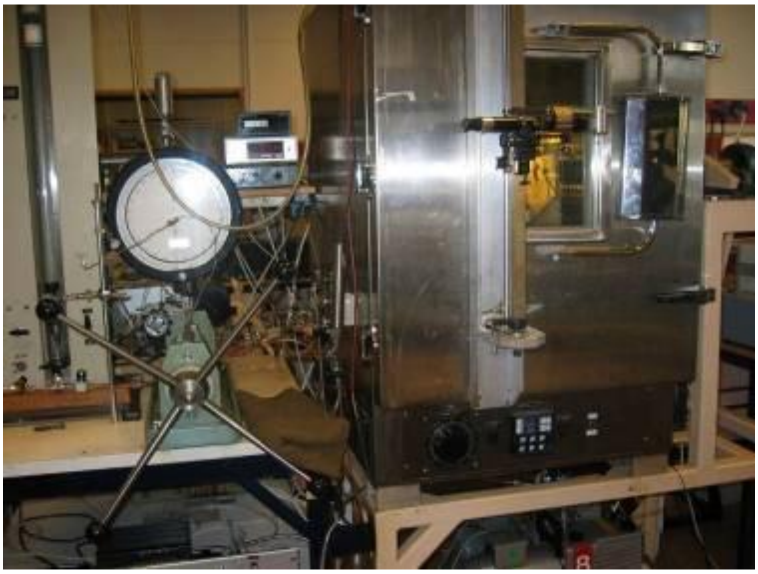


Fig. 3: Fluid pVT equipment (working conditions: 700 bar 1nd 150 °C)

Fig. 4: Fluid cell for IFT-measurements (working conditions: 700 bars and 180 °C

State of the art

11. The fluid laboratory is well equipped to perform a large range of fluid studies a realistic conditions including HPHT conditions up to 1400 bars and 210 °C. All basic fluid properties may be measured in the laboratory including preparations and recombination of fluid samples.
12. The laboratory is doing research within fluid behaviour and fluid properties including miscibility studies. The work is mostly related to enhanced oil recovery (EOR) processes including CO_2 injection for EOR as well as studies of CO_2 behaviour and diffusion properties. The laboratory is also equipped for compositional analysis and various chemical analyses.
13. The fluid laboratory is working in close connection with the core laboratory. The fluid laboratory is also working in close cooperation with other SPR laboratories within geochemical analysis and rock characterization and rock mechanics. In addition, SPF is collaborating with the laboratories of Institute of Petroleum, NTNU like fluid analysis and rheology.

Services currently offered by the infrastructure and achievements

The laboratory offers a wide range of services and special research type of experiments. Some of the more standard type experiments and tests are listed below:

- Preparation and recombination of fluids
- Fluid pVT studies (phase envelope, bubble point, fluid formation factor, compressibility, solution gas fluid ratio, etc.)
- Fluid properties like density, viscosity, molecular weight, composition
- Slim tube studies of miscibility
- Surface and interfacial tension measurements
- Diffusion measurements

Achievements (Paper refs.: input of relevant references)

8. POLAND

8.1 PGI-NRI

Organisation name		Short Name	Country
PANSTWOWY INSTYTUT GEOLOGICZNY - PANSTWOWY INSTYTUT BADAWCZY		PGI-NRI	Poland
Description of the infrastructure			
Name(s) of the infrastructure(s)*:	**Injection field lab**		
Location (town, country):	Dziwie, POLAND		
Web site address:	www.pgi.gov.pl		
Legal name of organisation operating the infrastructure:	Panstwowy Instytut Geologiczny - Panstwowy Instytut Badawczy		
Location of organisation (town, country):	Warsaw, Poland		

<u>**Injection field lab**</u> **(**Laboratory: Characterization and processes, Site characterization and monitoring)

Description of the facilities

The site is located in central Poland, in a halfway between Warsaw and Poznań, Koło county. It consist of an aquifer with following characteristics:

- **Class**: Lower Jurassic sandstones (injection into Upper Pliensbachian – depth 1250-1380, Lower Toarcian caprock – depth 1140-1250 m;
- **Total depth**: 1430 m (approximate), Temperature at the aquifer top: 42-44 C, Pressure: hydrostatic
- **Effective porosity:** 18-20%, Permeability: (sandstones) 200-500 mD

The following type of measurement can be performed:

- **Laboratory measurements (samples from the injection well):** soil gas, physical and chemical properties of the drill core samples, microfauna, petrology, brine, mud and comparative fluids, cement parameters.
- **Well logging measurements**: diameter, curvature, resistivity, acoustic, density, gamma, neutron porosity, self potential, cementometer, cavernometer, gamma spectrometric, dip, induced, temperature, neutron-gamma spectrometric, magnetic resonance, dipole acoustic, ultrasonic scanner, acoustic scanner, cable RTF/MTF logs. Also time-lapse VSP and micro-frac (optional).
- **Well tests**: minifrac for the storage complex; RST – brine samples for RSA, pore pressure and approximate vertical and horizontal permeability; Johnson filter for the reservoir range (optional, depending on reservoir properties); brine probes with optional test pumping; production logging (pressures, temperature, flow), polycyclic hydrodynamic production & interference tests.

Injection schedule: first phase, just after drilling, of total 3300 t CO_2 (~6 weeks); second phase of 10 000 – 12 000 t (continuously for year 1); third phase (year 2, full scale monitoring); total injection up to 30 000 t, two tracers are to be applied in order to investigate CO_2 migration to the research well at distance of 50 m and to exclude migration to the soil groundwater (to be investigated in shallow wells) . CO_2 will be transported in liquid phase, by trucks.

- Modelling of the injection: dynamic simulations for a model of the storage complex
- Monitoring: geophysical (microseismology, microgravity, cross-well EM & VSP 3C); geochemical (soil air composition measured by probes and in shallow wells; also chromatography and isotopic laboratory analyses of soil air; piezometers, groundwater sample measurements, tracers' measurements), biomonitoring (microbiological, other).
- Expected start of drilling - beginning of 2012, injection - Autumn/Winter 2012

State of the art

The infrastructure refers to pilot injection into Jurassic aquifer same as in case of the first Polish demo project - Bełchatów but the site is independent, not the part of demo project. By now it was preliminary agreed cooperation with Ketzin site because results of the injection in conditions similar to these at demo site will be complementary to Ketzin achievements and experiences from existing pilot site will be valuable for operations at the new site.

Services currently offered by the infrastructure and achievements

Infrastructure to be built. Awaiting contract signatures of all funding parties.

9. SPAIN

9.1 CIUDEN

Organisation name	Short Name	Country
FUNDACIÓN CIUDAD DE LA ENERGÍA	CIUDEN	Spain

Description of the infrastructure	
Name(s) of the infrastructure(s)*:	**CCS Technology Development Centre**
Location (town, country):	Cubillos del Sil (León) & Hontomín (Burgos), Spain
Web site address:	www.ciuden.es
Legal name of organisation operating the infrastructure:	Fundación Ciudad de la Energía
Location of organisation (town, country):	Ponferrada, Spain

The Fundación Ciudad de la Energía (CIUDEN) is a State owned, public R&D institution created by the Spanish Government in 2006. It was conceived to foster economic and social development in Spain through activities relating to the Energy and Environment sectors, especially regarding Clean Coal Technologies.

CO_2 Capture Infrastructure, Cubillos del Sil (León)

The **Technology Development Centre** allows advanced research, development and innovation on the field of oxy-combustion, capture and transport. CIUDEN´s installation is unique in that it allows the use of a wide range of fuels (coals, biomass and petcoke) and incorporates two different oxy-firing technologies, pulverized coal and circulating fluidized bed of semi-industrial scale, the latter being unique worldwide.

The Centre comprises the operation of a large scale integrated test facility for advanced technologies on CO_2 capture in coal power generation. The Centre incorporates the following technologies:

- **FUEL PREPARATION SYSTEM**

Anthracites, bituminous & subbituminous coals, pet coke, biomass
Crusher: 15 t/h Crushed coal silos: 240 m3
Mill: 5 t/h

- **PULVERIZED COAL BOILER (PC)**

20 MWth: 3.4 t/h pulverized coal
4 horizontal burners
Biomass co-combustion up to 25%
Steam 30 bar & 420°C
6.6 t/h O_2
Furnace size: 24 x 7.6 x 4.5 meters

- **CIRCULATING FLUIDIZED BOILER (CFB)**

30 MWth: 5.5 t/h crushed coal
Biomass co-combustion
DeSOx and DeNOx
Steam 30 bar & 250°C
8.8 t/h O_2
Furnace size: 20x2.9x1.7 meters

TDC General View

- **BUBBLING FLUIDIZED BED GASIFIER**

3 MWth: 15 t/d biomass feed
Oxidant: Air
0.3 barg and 800 °C
Efficiency: 98% (75% cold gas basis)
Commercial scale

- **FLUEGAS CLEANING SYSTEM**

Cyclon η, min. : 80%

DeNOx (SCR): < 40 ppmv NOX
Bag Filter: < 15 mg/Nm3
DeSOx > 95%
Stack 47 meters height
Design flow rate: 23200 Nm3/h

- **CO_2 PROCESSING UNIT**

Inlet Flowrate: 4500 Nm3/h
CO_2 captured: 11 t/d
Purity of CO_2 captured: > 99%

Control Room

The configuration of the test facility is flexible, modular and versatile in order to test a wide range of operation conditions and flue gas ranges including different types of coals (also with mixture of biomass and petcoke), and combustion conditions from air mode to oxy mode, co-combustion mode, etc, in independent but interconnected modules for simultaneous or separate operation.

Services offered by the Centre

Compression and Purification Unit

Outside the CCS installation facilities there are also technical buildings, laboratories and an interpretation building where the conferences and projects work meetings are hold. The technologist, scientists and researchers will benefit of an international environment, where many European funded projects are taking place and different companies, researcher institutions and technologist will be involved, being able to share work space and different know-how at their stay.

The Centre offers the following services: fully equipped laboratories and specialized operating staff. Offices and laboratories (3500m²) and contractors offices and workshop (1300m²), Personal Protective Equipment, Warehousing for tested equipment and Maintenance Shops (mechanical, electrical and Inspection and Control), IT support, offices and testing space.

In addition to the technological character of R&D activities carried out with regards to these infrastructures, important efforts are being made to engage actions towards knowledge sharing and human capacity building in the field of energy expertise.

Activities on going

- **OXYCFB300 (EEPR)** - The project of CIUDEN is involved in one of the six projects funded by the European Energy Programme of Recovery (EEPR) and its first phase has been granted with 180 M€. Technology development for CO_2 oxy-capture, inland transport and storage in saline aquifers supporting FID of a demo 300MW CCS oxy-CFB Power Station.

- **FLEXIBURN CFB (FP7)** - Demonstration of flexible high-efficiency CFB combustion technology in air and oxy-modes for CCS
- **RELCOM (FP7)** - R&D&D activities for reliable full-scale deployment of oxy-PC firing.
- **MACPLUS (FP7)** - Development and testing full-scale prototypes of components to improve performance and reliability of CCS Power Stations
- **ECCSEL PPI (FP7)** – To develop a European distributed, integrated Research Infrastructure, involving the construction and updating of research facilities
- **BRISK (FP7)** – Integration of networking activities and facilitating transnational access to research infrastructures for enhancing biomass utilization
- **R&DIALOGUE (FP7)** – Designed to improve social perception of low carbon technologies with CCS
- **O2GEN (FP7)** – To demonstrate the concept of 2nd generation oxy-fuel Power Station to reduce the efficiency penalty of CO_2 capture down to 5%
-

CO_2 Transport Rig, Cubillos del Sil (León)

CIUDEN´s CO_2 Transport Test Rig, is a semi-industrial size CO_2 transport installation integrated on the CCS capture plant at the centre which includes the following main units:

(a) Pumping system to transport CO_2 either from storage vessels (commercial quality) or the CPU (Compression and Purification Unit) of the Centre
(b) High pressure vessel to avoid fluctuations in the flow
(c) Recirculation pump and heat exchanger systems so as to set operation pressures and temperatures within the range of 80 - 110 barg and 10 - 31 ºC respectively. In order to operate the test rig in thermal conditions similar to those expected in CO_2 transport pipelines (mainly buried), the facility is located inside a thermal isolated building with temperature control.
(d) Dimensions of the industrial building are 23x18x9 m^3. Isothermal conditions in the interval of 15 to 28 ºC, The building is concrete pre-fabricated with an effective ventilation system to avoid sub-oxygenated atmospheres.
(e) Dosing equipment to add impurities and contaminants to simulate different CO_2 streams compositions expected in industry applications: H_2O, NO_x, SO_x, N_2, O_2, Ar, CO, H_2, H_2S, CH_4. It is important to point out that in addition to the oxycombustion technology, the CT experimental facility is designed to test CO_2 streams including typical contaminants from other CCS options such as pre-combustion technology (CO, H_2, H_2S and CH_4).
(f) Tube coils with variable length and materials: each coil has an equivalent length of approximately 300m and a 2" nominal diameter. Considering the number of tube coils, the length of the whole test rig is around 3,000 meters. It is also possible to by-pass one or several tube coils in order to be adapted to specific conditions.
(g) Test zones with pipes of different diameters in order to install new equipment or instrumentation to be tested in real conditions of CO_2 transport. The number of test zones is designed considering the different tests that will be carried out.

State of the art

The CIUDEN´s CO_2 Transport Test Rig that is installed in the CIUDEN´s Technology Development Centre for CO_2 Capture will provide real basis for the design, maintenance and operation of industrial CO_2 pipelines. The designed test campaigns will generate valuable information for material selection, impure CO_2 behaviour, depressurization and CO_2 safety operation; besides this and considering that the installation is located inside a building, it will be possible to test CO_2 small releases in order to study or validate dispersion models.

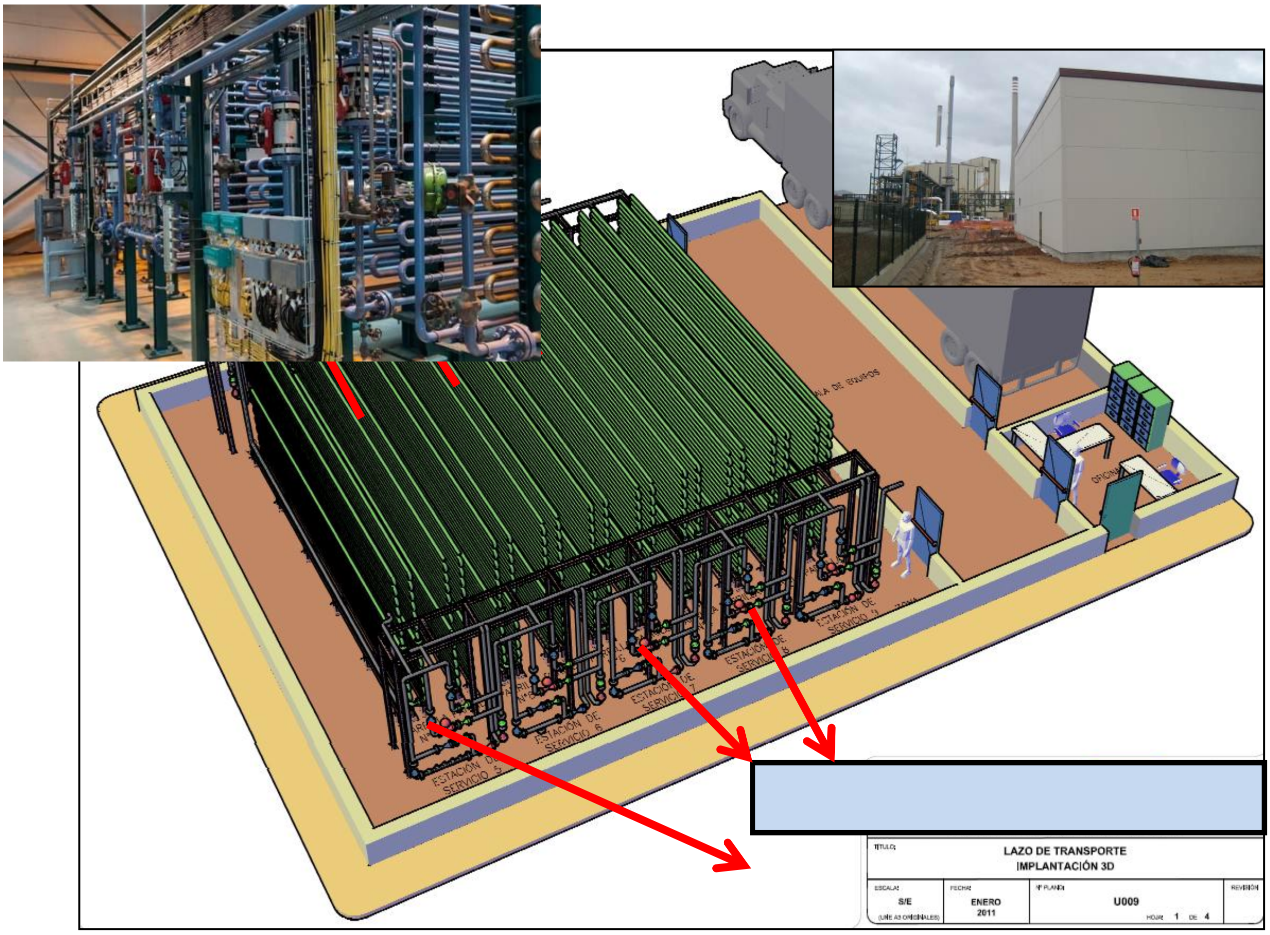
All wrap up with the lab facilities at the Centre, the offices infrastructures and the research environment should add an outstanding service to conduct high quality research.
A set of specific testing campaigns has been designed focused on the data acquisition for scaling-up the system, operator training and CO_2 safety operation. Table 1 shows the type of tests and the independent variables that will be modified during the tests performance.

List CCS related EU funded projects where the infrastructure was used, or other large initiatives

- **OXYCFB300 (EEPR)** Project co-financed by the European Union's European Energy Programme for Recovery. It's a 300 MWth Carbon Capture and Storage (CCS) integral commercial demonstration project including CO_2 capture transport and storage.
- **ECCSEL PPI (FP7)** – To develop a European distributed, integrated Research Infrastructure, involving the construction and updating of research facilities

Table 1. Summary of the test campaign

ID	Type of test	Independent variable
1	Corrosion rates in different materials.	Pressure, Temperature.CO_2 quality. CO_2 velocity.
2	Flow assurance (depressurization in the line).	Pressure, Temperature. CO_2 quality.CO_2 velocity.
3	Installation of industrial instrumentation or equipment.	Diameter. Pressure, Temperature. CO_2 quality.
4	Release studies.	TBD.



CO_2 Transport experimental facility & 3D Simulation of the facility with actual building

<u>CIUDEN CCSLab</u>, Cubillos del Sil (León).

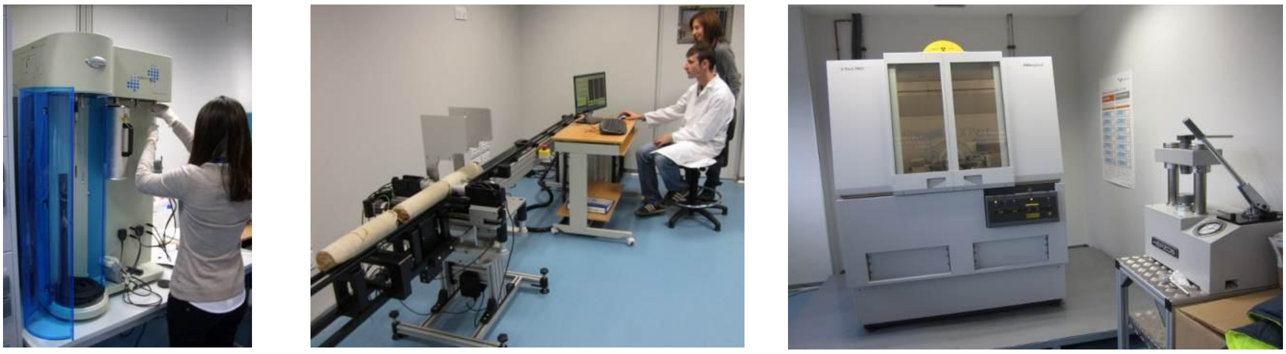
The aim of this fully equipped laboratory is to become a high class service facility for scientific research in all the fields of the CCS chain. It provides service to CIUDEN´s two Technological Development Plants (one on CO_2 Capture and the other one on Geological Storage) while carrying out independent investigation in the framework of national and international projects. The labs are divided in 15 rooms of a total area of approximately 700m² (additional facilities, such as sample preparation units and storage rooms, included).

a) The **Control Laboratory of the CO_2 Capture** unit is fully dedicated to the operation of the capture Plant, by the quality control of fuels, working fluids and combustion gases. The main equipment available includes: Thermo-gravimetric Analyser (TGA); Elemental Analyser, CHN, S; ICP-OES; Hg analyser; Carbon Analysers (TOC); Laser Granulometer; Ion Chromatography; Calorimeter; Thermo-mechanical Analyser (TMA).

b) The main objectives of the **Geology Laboratory** are (i) petrological and petrophysical characterization of storage and seal formations; (ii) analysis of water and gas samples during the monitoring; and (ii) the investigation of durability and reactivity of natural and engineering materials when in contact with $CO_{2\ (sc)}$ and under real storage conditions.

The main uniqueness of this lab is related to three equipment, two for the investigation of chemical and physical reactions in the CO_2 – brine – rock system under real storage conditions (i.e. high temperature and pressure): (i) the CO_2 permeability system will allow absolute and relative permeability measurements in steady and un-steady state applying CO_2, brine and/or gas; while (ii) the so-called High Pressure System will allow the monitoring of possible chemical reactions under storage conditions. In addition, the Multi Sensor Core Logger system is a non-destructive technique for the logging of various physical parameters of borehole cores, thus allowing the correlation of the in-situ borehole log measurements with laboratory data. The system will be equipped with the following sensors: electric resistivity, magnetic susceptibility, P-wave velocity, gamma density, and natural gamma.

Finally, the possibilities of arranging short-courses for acquiring the basis on "Lab techniques for CCS Characterization" are also offered.



View of the equipment within the CCSLAB

<u>CIUDEN PISCO2</u>, Cubillos del Sil (León)

The aim of this facility is to develop low cost sustainable biomonitoring tools for their application in the CO_2 storage programme. The main objective is to simulate diffuse leakage at the soil interface in order to identify efficient bioindicators of anomalous CO_2 concentrations. Ciuden is at the start-up of the PISCO2 facility.

The facility consists of 18 cells isolated by concrete. Each cell has an area of 16 square meters and a depth of 2.5 meters; and is equipped with (i) systems for controlled CO_2 injection at different depths (12 of the cells are instrumented with the injectors while the remaining 6 will be used as control ones) (ii) systems for sampling groundwater and gases and (iii) for monitoring different parameters, such as water content, pH, CO_2 flux, microbiological, botanical, and geochemical alterations and the chemical composition of water.

***Services currently offered by the Infrastructure*:**

a) The platform will serve to test how small CO_2 diffusive leakages can influence, microorganisms, lichens and soils in general and it aims to find low cost sustainable bio-indicators of CO_2 concentrations in wide areas. It will also serve as a laboratory for agricultural tests of the beneficial effects of low CO_2 emissions.

b) The installation will be a tool to test and calibrate measurement instruments such as accumulation chambers.

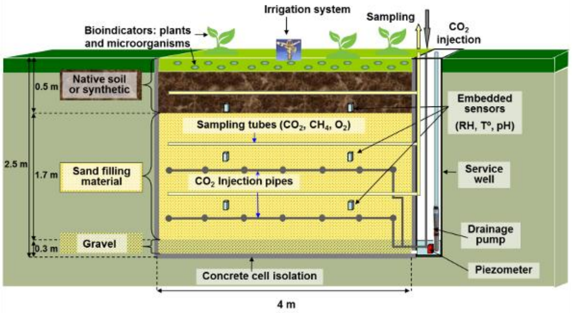
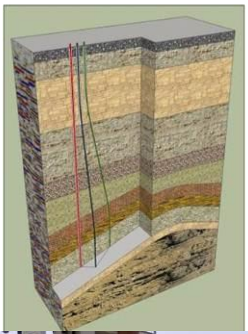


Diagram of the experimental cells

All the monitoring systems will be designed for remote online use. The design of the cells is flexible and it can be customized to the requirements of future investigations. Finally, the possibility of arranging short-courses for acquiring expertise on biomonitoring techniques and its associated role on safety of CO_2 Storage are also offered.

General View of the Infrastructure

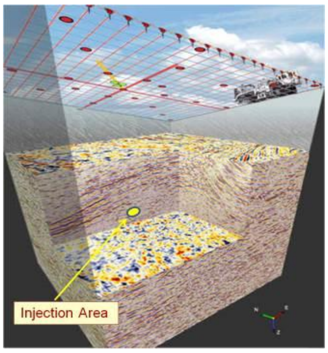
CO_2 Geological Storage Infrastructure, Hontomín (Burgos)



CIUDEN´s main facility on CO_2 Storage has been already designed and is expected to be fully operational in 2013. The main characteristics of this experimental site are:

- Three wells that will be around 1600m depth, one for injection (equipped with ERT, DTS, extensometers & pore pressure devices), one for geophysical monitoring (equipped with geophones, ERT, DTS, extensometers & pore pressure devices), and one for multi-level sampling (equipped with ERT, extensometers incorporated in a stand-pipe multi-packer system, DTS, pore pressure devices and a multi-level geochemical sampling design)
- The Visitor´s Centre will also include a monitoring room, focused on developing a "real-time visualisation of the CO_2 containment" at the Hontomín Centre.

Site drilling works for hydrogeological monitoring



3D Seismic Cube acquired in Hontomin

- Auxiliary facilities, such as tanks for CO_2 storage, pumps for pressurization, pools for water treatment, warehouses, etc., that are included in the area.

The activities and studies carried out during the project should help to gain experience and achieve optimal performance, at every stage of the life cycle of industrial CO_2 geological storage for academic, regulatory, technological and industrial purposes.

The deployment of the monitoring techniques, by means of several permanent instrumentation in the area, covers a wide range of levels, both at atmospheric, near-surface and subsurface. In addition, there are different techniques under development or to be deployed such as CO_2 detectors, water geochemical analysis, bioindicators, hydrogeological monitoring, InSAR imaging, permanent seismic network, or several kinds of time-lapse monitoring.

The main expected outcomes will be in connection with modelling injection strategies, study of long-term behaviour of CO_2 and its associated safety assessment, technologies & methodologies for injection of CO_2 and its consequent monitoring.

9.2 MATGAS

Organisation name	Short Name	Country
MATGAS 2000 AIE	MATGAS	Spain

Description of the infrastructure	
Name(s) of the infrastructure(s)*:	Gas separation lab, High pressure lab
Location (town, country):	Barcelona, Spain
Web site address:	http://www.matgas.org
Legal name of organisation operating the infrastructure:	MATGAS
Location of organisation (town, country):	Barcelona, Spain

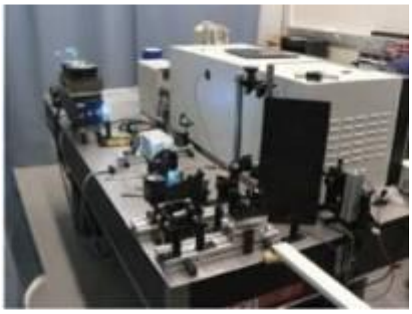
Gas separation lab (Separation and conditioning of CO2, absorption - adsorption)

Description of the facilities

The Gas Separation laboratory is a multi-functional facility equipped for the synthesis, characterization and simulation of sorbents for CO_2 separation under ideal and realistic operating conditions. The lab facilities can be split into three main groups: (A) synthesis and characterization of solid and liquid sorbents for CO_2, (B) gravimetric and volumetric equipment for the experimental studies of both equilibrium and kinetic CO_2 separation (either absorption or adsorption) processes and (C) a cross functional computing unit for the simulation of the materials' physic-chemical properties, as well as the interaction mechanism between the CO_2 and the sorbent.

Group A includes standard equipment for materials synthesis and a state of the art pool of equipment for surface and bulk characterization, such as a **Raman spectroscope**, an **Atomic Force Microscope**, a **Mastersizer** and a **Zetasizer** for measuring particle size distributions over a wide range of sizes.

Group B includes: a **Rubotherm Magnetic Suspension Balance** operating from vacuum up to 30 bar and from 5 to 450C, equipped with steam generation and multiple gas switching system, a TA Instruments Q5000IR **thermogravimetric apparatus**, operating at up to 1200C, a **Micromeretics ASAP 2020 BET** analyser with a chemisoprtion module. Finally a **double absorption column** is also available. This consists of 2 reactor of 1 L volume each, working at ambient temperature up to 750C and from vacuum to 30 bar. The rig is equipped with a steam generation system. Typical experiments run in these equipment are Pressure, Temperature and Swing Adsorption tests.



Raman spectroscope.

Magnetic suspension balance equipped with steam generation and multiple gas inlet systems.

Double 1 L absorption column.

Group C comprises a Computing unit of 60 nodes running in parallel, as well as dedicated simulation software and databases specifically developed for CO_2 separation applications. Furthermore, the lab's simulation capabilities include the implementation of the soft-SAFT equation for simulating fluids' thermochemical properties, as well as Monte Carlo simulation tools to obtain adsorption isotherms and information on the local structural arrangement of CO_2 and other compounds inside the materials. Finally, Molecular Dynamic simulations can be performed to investigate the influence of the transport properties (especially diffusion) on the overall adsorption of CO_2 both in pure form and in the presence of impurities.

State of the art

The Gas Separation Lab provides the implementation of a combined experimental-simulation approach thanks to the available pool of equipment, offering the necessary tools for a full characterization and testing of a sorbent under ***realistic*** CO_2 capture conditions.

This integrated facility allows performing applied research at relevant conditions for industrial applications as well as providing the necessary tools for fundamental research. The Lab currently supports research on novel CO_2 capture technologies, H_2 production and absorption by novel metal hydrides and research on development of carbon nanotubes for gas separation. The experimental work is complemented by using ad hoc simulation tools for modelling thermophysical properties as well as fluid-fluid and fluid-solid interactions.

The lab is physically located in the MATGAS Research Center, which houses three other state-of-the-art laboratories (high pressure, water treatment, food preservation). In particular, the high pressure lab described in TA1.2 supports research on CO_2 transportation and storage, which is complementary to CO2 capture, thereby offering research facilities for the whole CCS cycle.

Services currently offered by the infrastructure and achievements

The Gas Separation Lab is physically located in the MATGAS Research Center building, in the campus of the Autonomous University of Barcelona. The lab belongs to the three partners, Carburos Metálicos, from Air Products group, the UAB and the Spanish National Research Council; it is also open to external users depending on availability. Furthermore the Lab facilities have been employed in collaborative projects with foreign research institutions (Italy, UK, France, Germany and Portugal among others). Projects where the lab facilities have been used are:

- Synthesis and characterization of novel materials for CO_2 capture; synthesis and characterization of novel H_2 absorbents based on metal hydrides; design and commissioning of dedicated lab equipment for both CO_2 and H_2 separation (CENIT SOST-CO2 project, based on a consortium of 14 Spanish companies and 28 research institutions with a budget of 26.4 MM €).

Relevant published articles are:

Pacciani, R.; Torres, J.; Solsona, P.; Coe, C.; Quinn, R, Hufton, J.; Golden, T. and Vega, L. F. Influence of the Concentration of CO2 and SO2 on the Absorption of CO2 by a Lithium Orthosilicate-Based Absorbent. Environmental Science & Technology, 2011, 45, 7083-7088.
Builes S.; Roussel, T; Vega, L. F. Optimization of the separation of Sulfur Hexafluoride and Nitrogen by selective adsorption using Monte Carlo simulations AIChE Journal 2011 57(4), 962-974 DOI: 10.1002/aic.12312.
Llovell, F.; Valente, E.; Vilaseca, O. and Vega, L. F. Modeling Complex Associating Mixtures with [C-n-mim][Tf_2N] Ionic Liquids: Predictions from the Soft-SAFT Equation. Journal of Physical Chemistry 2011 115, 4387-4398
Builes S.; Roussel, T.; Ghimbeu, C.; Parmentier, J.; Gadiou, R.; Vix-Guterl, C. and Vega, L.F. Microporous carbon adsorbents with high CO_2 capacities for industrial applications. Physical Chemistry Chemical Physics, 2011, 13, 16063-16070

High Pressure Lab (Thermophysical properties and Integrity, Transport)

Description of the facilities

Laboratory including several equipments to work with gases up to 500 bars and 400 C ranging from 50 ml to 16 litres, focused mainly on $scCO_2$. The equipments available in the High Pressure Lab are **300 ml reactors:** equipped with high pressure pump, 300 ml high pressure vessel, magnetic coupling agitator and control box (pressure, temperature and flow); able to work up to 227 bar or 400 C with a maximum flow of 1.8 Kg CO_2/h and 10 ml cosolvent/min.

Pilot plant: equipped with 4 vessels of several volumes in series, able to work in several configurations for extraction, lixiviation, precipitation and recovery of liquids and solids. It includes two high pressure pumps (40 kg CO_2/h and 16 litres cosolvents/h), magnetic coupling agitators and a liquefier to recover and reuse the CO_2. Operating pressure and temperature ranges for each vessel are: 500 bar @ 100 ºC for 16 litres and 500 bar @ 400 ºC.

SCF View Cell Thar: Variable volume (5 to 20 ml), external piston vessel, equipped with a CCD digital camera to monitor the behaviour of materials exposed to CO_2 up to 410 bar and 150 C, and an impeller to homogenize operating conditions.

SCF View Cell: Equipment to analyse phase equilibrium and solubilities up to 300 bar in the temperatures range of -40 to 100ºC, 220 mm length sight glasses allow to observe the onset of precipitation or phase separation inside the reactor. The volume of vessel can be varied at constant pressure between 20 and 50 ml. Samples are homogenized by liquid phase recirculation.

SCF Mini reactor: 100 ml vessel able to work up to 200 bar and 200 C, equipped with a magnetic coupling agitator. The CO_2 is pumped by a Dual ISCO 260D pump feeding from 0.01µl to 25 ml CO_2/min.

Equipment available in the High Pressure lab: 300 ml reactor (left), pilot plant equipped with 16 litres high pressure vessel (centre) and SCF View Cell Thar (Right).

State of the art

The laboratory allows the characterization of the behaviour of materials in contact with CO_2 for transport and geological sequestration applications by exposing samples (like rocks, metals and other type of materials) to the same environmental conditions (pressure and temperature). The changes on the physicochemical properties can be analysed in the Gas Separation lab and others facilities in MATGAS. Also, phase equilibrium could be characterized determining solubilities of solid-liquid or liquid-liquid and the number of phases present at a specific pressure and temperature.

The equipment have been used in Carbon Capture and Storage (CCS) related projects for: (i) the characterization of pipeline materials for CO_2 transport; (ii) investigating the behaviour during CO_2 injection of rocks typically found in saline aquifers; (iii) employing supercritical CO_2 for applications such as extraction of natural products, degreasing, synthesis of biofuels, micronization, polymers foaming.

Services currently offered by the infrastructure and achievements

The High Pressure Lab offers a long research experience (more than 15 years) in applications of CO_2 at high pressure, near or above the critical point, and development of clean and safe technologies: in addition to MATGAS employees the lab facilities are also available to external users (currently more than 65 users are authorized to work in our laboratories). Services we offer are:

- Characterization of materials compatibility for CCS
- Characterization of rock behaviour for CO_2 sequestration (Salts precipitation, reduction on CO_2 permeability, chemical reactions, lixiviates, etc.)
- Determination of the optimal parameters and performance for high pressure CO_2 utilization
- Engineering and safety support for managing CO_2 at high pressures

Projects run in the lab include:

- Experimental characterization of $SCCO_2$ injection into storage materials located in Hontomín (Burgos), where the Geologic Sequestration Development Plant will be built. Funded by CIUDEN (Spanish Government)
- Singular studies related to the CO_2 purity definition and materials to be used for CO_2 pipelines for the Compostilla plant. Funded by ENDESA (Spanish Power Company)
- SOFC CCHP With Poly-Fuel: Operation And Maintenance (SOFCOM). Funded by UE FP7
- Sustainable Surface Technology for Multifunctional Materials (SURFACE T). Funded by UE FP6
- Supercritical Carbon Dioxide Processing Technology for biodegradable polymers targeting medical applications (PROTEC). Funded by UE FP6

Relevant published articles include:

Ana M. López-Periago, Roberta Pacciani, Carlos García-González, Lourdes F. Vega, and Concepción Domingo. A breakthrough technique for the preparation of high-yield precipitated calcium carbonate. *The Journal of Supercritical Fluids* **2010** 52(3), 298-305, doi: 10.1016/j.supflu.2009.11.014

C. Domingo, García-Carmona, J. Torres, J. Llibre, R. Rodríguez. Adsorption of low vapour pressure organic acids into amorphous and crystalline. Supercritical Fluids: Materials and Natural Products Processing 397-402 (1998) ISBN:2-905-267-28-3

Nora Ventosa; Santiago Sala; Jaume Veciana; Joaquim Torres; Juan Llibre. Depressurization of an expanded liquid organic solution (Delos): A new Procedure for obtaining submicron or micron-sized crystalline particles. Crystal Growth & Design 2001 299-303

P. López-Aranguren, J. Saurina, L.F. Vega, d and C. Domingo. Sorption of tryalkoxysilane in low-cost porous silicates using a supercritical CO2 method. Microporous and Mesoporous Materials, 2012,148, 15-24, DOI: doi:10.1016/j.micromeso.2011.06.035

10 SWITZERLAND

10.1 ETH ZURICH

Organisation name	Short Name	Country
EIDGENÖSSISCHE TECHNISCHE HOCHSCHULE ZÜRICH	ETH Zurich	Switzerland

Description of the infrastructure

Name(s) of the infrastructure(s)*:	**Two columns PSA setup (2-PSA); Adsorption Equilibrium Measurement Balance (ADS_EQ); Flue Gas Mineralization Unit (FGM)**
Location (town, country):	Institute for Process Engineering, Sonnegstrasse 3, ETH Zurich, Switzerland
Web site address:	www.ethz.ch/laboratories/spl
Legal name of organisation operating the infrastructure:	ETH Zurich
Location of organisation (town, country):	Zurich, Switzerland

Two-columns PSA setup

Description of the facilities

The two-columns lab PSA is a set up can be used to investigate the dynamic behaviour of commercial or newly developed adsorbents performing breakthrough experiments with different feed mixtures resembling either to flue gas (post –combustion) or syngas (pre-combustion). Furthermore it allows performing full PSA cycles with interconnected columns. Besides the hardware a detailed model in Fortran taking into account mass, energy and momentum balances as well as different constitutive equations is used to describe the breakthrough experiments, as well as the full PSA cycles.

State of the art

Breakthrough experiments as well as full PSA cycles can be performed in the proposed experimental unit. The columns (height: 1.2 m; inner diameter: 0.25 m) are manufactured in-house from a stainless steel pipe and are equipped with an electrical heater. Five thermocouples are placed regularly inside each column. Two mass flow controllers are used to control the feed flow rates, while the system pressures are controlled by two back pressure regulators mounted downstream of each column; additionally, the pressure drop across the beds is measured using four pressure transducers installed at the inlet and at the outlet of the columns, respectively. A combination of automatically and manually activated valves allows for a flexible choice of a PSA cycle. Online monitoring of the outlet gas composition is achieved by a mass spectrometer. The operating conditions are: Pprocess = 0.01 - 50 bar; Tprocess = 20 - 150°C; Tregeneration < 500°C; vfeed = 2-100 ln/min; xfeed --> any gas (as it is placed in a hood).

The PSA lab pilot plant was built in house and is therefore very flexible. Adaptation and small changes can be easily implemented. The mass spectrometer has a very high resolution (0.1 s), which allows to monitor also fast processes.

We consider inviting parties who have suitable alternative materials and are able to produce sufficient quantities of that material for the lab-scale pilot. This would broaden the chance of success for application of the process with new materials.

Services currently offered by the infrastructure and achievements

The research staff of the Separation Processes Laboratory at the ETH Swiss Federal Institute of Technology Zurich is constituted of 15 Ph.D. students and 3 post-doc research associates, from 8 different countries. The two column PSA setup is used in EU/FP7 DECARBit ("Decarbonise it", 2008-2011).

Joss L. , (2011): „Characterization of novel adsorbent materials for a CO2 capture pressure swing adsorption process" (small column). Master thesis

Casas N., Johanna S., Pini R., Mazzotti M. "Dynamic adsorption of different CO2/H2 mixtures on activated carbon" (big column / PSA)

Adsorption equilibrium measurement balance - AEMB (Capture, Absorption)

Description of the facilities

The adsorption equilibrium installation's central piece is a magnetic suspension balance (MSB, Rubotherm, Germany), used to measure excess adsorption isotherms. This balance maintains a sample of adsorbent attached to a permanent magnet suspended in a closed chamber by an electromagnet on the outside of the chamber. This allows for precise measurement of any changes in weight of the sample under conditions of temperatures up to 250°C and pressures up to 400 bar. In addition, the MSB has the capacity to measure the density of the gas phase in situ. The MSB was integrated into a circuit that connects it with a secondary, larger, adsorption chamber, a circulation pump, and a sampling loop for a gas chromatograph. This circuit can be used to measure multicomponent adsorption isotherms. The secondary adsorption chamber provides volume for a larger amount of sorbent, which ensures that the adsorption is sufficient to alter the composition of the gas phase. Once the gas mixture has been circulated long enough to be in equilibrium with the sorbent, a gas sample is taken from the gas phase and analysed using the gas chromatograph.

State of the art

The main advantages of the ADS_EQ installation are the ability to measure the density of the gas phase in situ, the measurement of multicomponent isotherms, and the conditions under which these measurements can be performed. In particular the ability to measure multicomponent isotherms makes this installation attractive, as that portion of the installation was designed and built in-house. The results obtained with this installation have been invaluable in the research are of carbon dioxide capture as well as storage. For capture processes, adsorption isotherms have been used to design pressure swing adsorption as well as temperature swing adsorption processes. Quantifying competitive adsorption helps in the validation of the models used to describe the behaviour of adsorption columns. For carbon dioxide storage, the obtained results were used in the research area of enhanced coalbed methane recovery (ECBM). Adsorbed amounts of methane under various conditions are used to estimate the gas in place in coal seams considered for ECBM, while carbon dioxide isotherms are used to estimate the capacity for sequestration. Among other projects, the results obtained have been used in the EU project DeCarbIt, which aims to enable zero-emission power plants in Europe by 2020 through the use of pre-combustion capture in an integrated gasification combined cycle (IGCC) power plant.

Services currently offered by the infrastructure and achievements

1. The research staff of the Separation Processes Laboratory at the ETH Swiss Federal Institute of Technology Zurich is constituted of 15 Ph.D. students and 3 post-doc research associates, from 8 different countries. Adsorption equilibrium measurement balance is used in EU/FP7 DECARBit ("Decarbonise it", 2008-2011) and in numerous projects funded by the Swiss National Science Foundation (SNF).
2. S. Ottiger, R. Pini, G. Storti, and M. Mazzotti, "Competitive adsorption equilibria of CO_2 and CH4 on a dry coal," Adsorption - Journal of the International Adsorption Society, vol. 14, no. 4-5, pp. 539-556, 2008.
3. R. Pini, S. Ottiger, L. Burlini, G. Storti, and M. Mazzotti, "Sorption of carbon dioxide , methane and nitrogen in dry coals at high pressure and moderate temperature," International Journal of Greenhouse Gas Control, vol. 4, pp. 90-101, 2010.

Flue Gas Mineralization unit - FGM (Capture, mineral carbonation)

Description of the facilities

Fixation of CO2 by mineralization Mineral carbonation means dissolving alkaline solid materials to leach out magnesium and calcium that reacts with the CO2 to form stable and environmentally benign solids. Our unit allows for parametric kinetic studies of mineral and alkaline solid waste dissolution and carbonates precipitation reactions. It is a temperature and pressure. Controlled autoclave (CSTR reactor) with the feature of gas flow through at elevated pressure and at different gas and reactor solution composition (liquid: salinity, acidity, alkalinity, gas: N2/CO2 mixtures). Liquid and gas residence time can be varied independently. Solutes and solids are monitored in-situ, online, and offline (e.g. Raman, IC, MS). Several natural minerals and industrial waste materials contain alkalinity, and mineral carbonation provides the technic to 1) store CO2 permanently away from the atmosphere and 2) turn meritless materials such as natural silicates or industrial wastes into profitable goods such as PCC, inert waste, aggregates, fillers.

Potential partners can provide and study alkalinity containing materials from their processes/industry, thus extending the capability of the unit to operate at conditions closer to the realistic cases.

State of the art

The installation is a temperature and pressure controlled CSTR with the feature of gas flow through at elevated pressure and any composition (e.g. synthetic flue gas). Residence times for reactor solution and gas phase can be independently adjusted. The unit allows for parametric kinetic studies of mineral dissolution and precipitation reactions. Analytical tools included are in-situ Raman spectroscopy for solids and molecules in solution, and online ion chromatography for cations in solution, pH meter, and mass spectroscopy for gas composition.

The unicity of the installation is represented by the direct CO_2 removal from flue gas by various natural silicate carbonation.

Services currently offered by the infrastructure and achievements

The research staff of the Separation Processes Laboratory at the ETH Swiss Federal Institute of Technology Zurich is constituted of 15 Ph.D. students and 3 post-doc research associates, from 8 different countries. *The Flue Gas Mineralization unit is used in projects with Shell (2010) , in numerous projects funded by the Swiss National Science Foundation (SNF), and in CARMA, a Swiss research project that aims to explore the potential and feasibility of Carbon dioxide Capture and Storage (CCS) systems deployment in Switzerland (www.carma.ethz.ch).*

1. Werner M., Hariharan S., Hänchen M., Zingaretti D., Prigiobbe V., Baciocchi R., Mazzotti M., "Activated Serpentine Carbonation for CO2 Capture and Storage", poster presentation at ISIC18, 18th International Symposium on Industrial Crystallization, Sep 13-16, 2011, Zurich, Switzerland.
2. Werner M., Gasser L., Zingaretti D., Hariharan S., Mazzotti M., "Dissolution and Carbonation of Activated Serpentine for Combined Capture and Storage", oral presentation at TCCS-6, 6th Trondheim CCS Conference, June 14-16, 2011, Trondheim, Norway.
3. Werner M., Verduyn M., van Mossel G., Mazzotti M., "Direct flue gas CO2 mineralization using activated serpentine: Exploring the reaction kinetics by experiments and population balance modelling", Energy Procedia 2011, 4: 2043-2049.
4. Werner M., Mazzotti M., "Direct Flue Gas CO2 Mineralization using Activated Serpentine: Exploring the Reaction Kinetics by Experiments and Population Balance Modeling", oral presentation at ACEME10, 3rd International Conference on Accelerated Carbonation for Environmental and Materials Engineering, Nov 29 - Dec 1, 2010, Turku, Finland.

11 TURKEY

11.1 METU-PAL

Organisation name		Short Name	Country
MIDDLE EAST TECHNICAL UNIVERSITY		METU-PAL	Turkey
Description of the infrastructure			
Name(s) of the infrastructure(s)*:	**METU-PAL PVT Analysis Lab,**		
Location (town, country):	Ankara, TURKEY.		
Web site address:	www.pal.metu.edu.tr		
Legal name of organisation operating the infrastructure:	Middle East Technical University, Petroleum Research Center		
Location of organisation (town, country):	Ankara, TURKEY.		

Petroleum Research Center (PAL) is established in 1991. The centre is a part of the Middle East Technical University in Ankara. Routine fuel quality control analyses are performed in the laboratories of the centre for gasoline, diesel, biodiesel, fuel oil, LPG and natural gas (more than 3000 samples per year). PAL laboratories are accredited according to ISO 17025. PVT laboratory is fully adequate to perform gas analysis including carbon dioxide using gas chromatography. Total sulphur in the gas samples is measured by ultra violet detector. The analytical equipment as well as core displacement test systems are used for academic research as well as contracted research. PAL manages a national inter-laboratory proficiency-testing program. The participant laboratories receive twice a year gasoil, gasoline, biodiesel, fuel oil, mineral oil and LPG samples. The statistical evaluation and reporting of these schemes are performed in METU-PAL. Centre is also conducting researches related to oil/ gas and geothermal reservoir evaluations as well as natural gas demand modelling. Several case studies were conducted for fields in Turkey on natural gas storage and Kızıldere geothermal and for oil fields in Azerbaijan and Kazakhstan. Recently PAL has conducted a national research project jointly with Turkish Petroleum Corporation about the assessment of the availability of Turkey's geologic CO_2 storage sites that involved reservoir-modelling studies. For reservoir modelling purposes CMG-GEM, Schlumberger-Eclipse, Schlumberger-Petrel, LBNL-ToughReact and LBNL-Tough2 software are used.

The research activities related to MSc and PhD degrees have contributed to the understanding of fundamentals of CO_2 storage in different media, such as coal, saline aquifers or depleted gas fields.

METU-PAL PVT Analysis Lab **(Transport and Storage of CO_2, Gas Analysis, Site Characterization)**
Description of the facilities

- In the PVT lab CO_2 composition analysis is performed using gas chromatography according to ASTM D1945 method.
- Total sulphur in gas samples is analysed using ultra violet detector.
- Fluid displacement test systems are used for academic and research studies. High-pressure cells are available for this reason. Ambient temperature is also controlled using air and fluid baths.
- Formation and dissociation of methane and CO_2 hydrates can be studied in PVT lab as well.

Figure 1 Composition analysis using GC

Figure 2 Total sulphur analysis using UV detector.

State of the art

14. METU-PAL is the first established fuel quality control laboratory in Turkey. It is also the first one that was accredited according to ISO 17025 standard. Research Centre is the only institution that manages inter-laboratory proficiency testing schemes in between national fuel analysis laboratories. In addition to the fuel quality control analyses performed in METU-PAL, centre conducts researches related to oil/gas and also geothermal reservoir evaluations.
15. Completed and ongoing academic and research study topics related with CCS are well cement integrity under CO_2 storage, geochemical and geomechanical effects, multiphase flow modeling, CO_2 natural analogues and monitoring and site characterization. CO_2 storage under the deep sea sedimentary basins is another study subject conducted in the PVT laboratories.
16. METU-PAL is a part of Middle East Technical University and is managed by the teaching staff of Petroleum and Natural Gas Engineering Department. This close relation of research centre and the department helps METU-PAL be a vivid scientific environment. Visiting scientists are able to access department owned software and work facilities. The campus supplies all the needs related to the accommodation of the visiting scientists.

Services currently offered by the infrastructure and achievements

- More than 3000 fuel samples a year are analysed in METU-PAL requested both public and private sector. The interlaboratory proficiency-testing scheme has more than 60 participants. Every year new analyses are added. Several research projects has been completed and some are on-going including Turkey's natural gas demand assessment, evaluation of oil fields located in Azerbaijan and Kazakhstan, Kızıldere geothermal field evaluation. Due to the close ties between department and the research centre, many MSc and PhD studies were performed using the centre's facilities. Core displacement, PVT analysis and core tomography facilities are used to carry out these studies. Static and dynamic reservoir simulation software packages including CMG's GEM, Schlumberger's Petrel and Eclipse as well as LBNL's Tough2 and ToughReact are used for the validation of experimental and reservoir characterization studies.
- The centre has been involved in the European 7th Framework project named as Pan-European Coordination Action on CO_2 Geological Storage.
- Following is a list of some of the major project and thesis conducted by the research team in PAL.
- Assessment of CO_2 storage potential in Turkey, modelling and a prefeasibility study for injection into an oil field, presented in GHGT-10.
- Sayindere cap rock integrity during possible CO_2 sequestration in Turkey, presented in GHGT-10.
- The Effect of CO_2 Injection on Cap Rock Integrity (PhD thesis work)
- Modelling of Enhanced Coalbed Methane Recovery from Amasra Coalbed (PhD thesis work)
- Simulating CO_2 Sequestration in a Depleted Gas Reservoir (MSc Thesis work)
- Experimental and Numerical Investigation of Carbon Dioxide Sequestration in Deep Saline Aquifers (MSc Thesis work)
- Simulating Oil Recovery During CO_2 Sequestration Into A Mature Oil Reservoir (MSc Thesis work)
- Development of a Predictive model for Carbon Dioxide Sequestration in Deep Saline Carbonate Aquifers (MSc Thesis work)

12 UK

12.1 BGS

Organisation name	Short Name	Country
NATURAL ENVIRONMENT RESEARCH COUNCIL – BRITISH GEOLOGICAL SURVEY	BGS	UK

Description of the infrastructure	
Name(s) of the infrastructure(s):	BGS National Physical Properties and Processes Laboratory (NP^3L)
Location (town, country):	Keyworth, Nottingham, UK
Web site address:	www.bgs.ac.uk
Legal name of organisation operating the infrastructure:	UK Natural Environment Research Council (NERC)/British Geological Survey (BGS)
Location of organisation (town, country):	Keyworth, Nottingham, UK

BGS National Physical Properties and Processes Laboratories (Storage, Characterisation and Processes)

Description of the facility

The NP^3L is one of two centres of excellence that showcase BGS's laboratory based research, the other being the National GeoEnvironmental Laboratories (NGEL). The NP^3L undertakes research on physical properties and processes in the subsurface, with a focus on key science challenges such as radioactive waste disposal, carbon storage, clean coal technologies, groundwater and pollution modelling, and engineering hazards. The facility is comprised of a series of complementary laboratories with unique, specialist, state-of-the-art equipment and capability, and years of expertise in research relevant to CO_2 storage. The facility is part of the UK's National Capability, and receives about half of its funding for in-house research through its parent body, the Natural Environment Research Council (NERC). Other funding is secured through commissions from a wide variety of government, industry, and academic sources, including EC research grants. The BGS undertakes most of its research using its dedicated laboratory staff, but also collaborates widely with other partners and researchers across Europe and the rest of the world.

The facility welcomes the CCS research community to access its facilities via the ECRI transnational access programme. The laboratories will be open to access both individually for focussed studies on one aspect of research, or collectively for multi-disciplinary studies. Much of the research within the NP^3L is underpinned by specialist supporting expertise in sample handling, geochemical analysis and mineralogical and petrographical characterisation that is conducted within BGS's other centre of excellence, NGEL. Access will be given to facilities within the NGEL where necessary. All of the facilities accessible to researchers under ECRI are fully operational.

A more detailed description of the installations that comprise the overall facility infrastructure is given in the following sections:

BGS Physical Properties Laboratories

MTS rig in the Physical Properties Laboratory

Characterisation of rock properties is an area of research that has a long history at BGS. The facility specialises in advanced geotechnical rock engineering and geomechanical testing, including measurement of strength (triaxial and uniaxial), deformability, porosity, permeability, thermal properties, geophysical properties and density. The centrepiece of this facility is a recently purchased MTS 815 rock testing system, the only installation of its type in Europe. This is a geotechnical system for determining the strength, deformation and other engineering properties of rock specimens under both unconfined and triaxially confined conditions. In addition, the system is capable of determining permeability, P&S wave velocities, thermal properties and Brazilian indirect tensile strength. The system has an operating range of up to 140 MPa and 200°C. Research in this laboratory has been used to improve the understanding of material behaviour and processes related to the mechanical and physical properties of rocks, and hence contribute to process models and performance assessment related to CO_2 storage and other applications. Recent studies have focussed on the geomechanical parameters of reservoir and cap rocks from CCS sites in Austria (Atzbach Schwanenstadt), Norway (Snovite) and Spain (Casablanca), as part of the EU funded CASTOR project.

BGS Transport Properties Research Laboratory (TPRL)

Intrinsic permeametry measurement in the TPRL

The TPRL is one of the leading centres in Europe for the study of fluid movement in ultra-low permeability media. The facility is well known within the radwaste and CO_2 sequestration sectors for long-term high quality experimental work and process-based interpretation. The main emphasis of the laboratory's output has been on multi-phase flow in ultra low permeability materials (such as reservoir seals, well bore cements and reservoir traps), and their associated hydromechanical (deformation) behaviour. Properties measured include: saturation and consolidation properties; intrinsic permeability (or transmissivity); anisotropy; specific storage; coupled flow parameters (e.g. osmotic permeability); capillary entry, breakthrough and threshold pressures; gas permeability function; drained and undrained compressibilties; and rheological (creep) properties. Laboratory experiments are performed under simulated in situ conditions of stress, pore pressure, temperature and chemical environment. Experiments are aimed at the provision of quantitative data for mathematical modelling of leakage and migration, together with an understanding of the principal transport processes. Key equipment includes: high pressure isotropic permeameters (70 MPa); high pressure triaxial permeameter (70 MPa); heavy duty shear-rigs; high temperature high pressure geochemical flow reactor (130 MPa at 140 C); and novel tracer systems (nano particle injection or radiological tagging of gas) to help identify and characterise potential leakage pathways.

BGS Hydrothermal Laboratory

The 'Big Rig' reactor in the Hydrothermal Laboratory

The Hydrothermal Laboratory has over 30 years' experience in the experimental study of fluid-rock reactions under conditions of temperature and pressure typical of the upper few kilometres of the Earth's crust. The facility's range of capability and expertise are unique, and it is highly regarded nationally and internationally for its research into geothermal energy and storage of radwaste and CO_2. The laboratory has undertaken CO_2-water-rock reaction studies for over 15 years, and is one of the leading centres in Europe for such experimental research. The laboratory contains a variety of equipment capable of maintaining controlled conditions of temperature (up to 400°C) and pressure (up to >500 atmospheres) for timescales of months to several years. Reactor volumes range from 1 ml to 12 litres. Studies include: investigation of pure CO_2-fluid-rock and CO_2-fluid-borehole (cement-steel interfaces) reactions occurring within the reservoir and cap rocks under in situ conditions, including kinetics of mineral dissolution in CO_2 rich fluids. Reactions are followed by various means, including: visual observations, monitoring fluid chemical changes over time, and detailed mineralogical analysis of the reaction products. Full analytical support (e.g. mineralogical and fluid chemical), is provided by other laboratories at the BGS. Various arrangements of reactors are available, and include: batch reactors, column reactors, high pressure windowed reactors for optical studies, and high pressure/temperature direct sampling batch reactors (Dickson-type autoclaves).

BGS Hydrates and Ices Laboratory

This laboratory provides temperature-controlled chambers within which relatively low temperature experiments can be carried out that can simulate processes occurring within permafrost, seafloor and deep subsurface environments. The chambers are large enough to accommodate high pressure equipment or other testing rigs, and have a range of operating conditions (-20°C to +60°C) controllable to better than 0.5°C. The facility is relevant to storage of CO_2 as a hydrate (either by design or as a secondary backup trapping mechanism) and as liquid CO_2, e.g. sub-permafrost or below the bed of deep seas. Most of the focus of the laboratory over recent years has been the investigation of how CO_2 hydrate behaves within sediments and the impact the hydrate has on the physical properties of the sediments. The research has been directed towards understanding processes that might exist if CO_2 were to be stored in cool, deep-water sediments – an alternative and somewhat novel approach to underground CO_2 storage. Indeed, although the equipment in this laboratory is relatively 'standard', it is its application to more novel underground CO_2 storage methodologies and the expertise and experience of the facility staff that make this laboratory unique.

Walk-in freezer chamber in the Hydrates and Ices Laboratory

BGS Geomicrobiology Laboratory

This is a Class 2 bio-containment facility specialising in evaluating the impacts of CO_2 injection on deep subsurface indigenous microbial populations and the effects of those organisms on the movement of CO_2, solutes and contaminants. The facility has conducted extensive research in both the UK and overseas for over 5 years, and is currently involved with several EU projects assessing the environmental issues relating to the geological storage of CO_2. The laboratory is unique in examining the impacts of CO_2 injection on deep subsurface microbial populations and the impacts of those organisms on CO_2 movement in the deep subsurface using the in-house developed Biological Flow Apparatus (BFA). It is the first research centre in Europe to be able to provide quantitative information on interactions between microbes and injected CO_2 in fractured or intact rock cores under realistic pressure and temperature conditions. In addition, the facility has extensive experience of working in the field on evaluating the environmental impacts of CO_2 on surface ecosystems, e.g. botany, followed by laboratory based microbiology, e.g. epifluorescence and microtox.

Anaerobic chamber in the Geomicrobiology Laboratory

BGS Near-Surface Gas Monitoring Facility

This facility includes a wide range of state of the art equipment for field measurement and sampling of CO_2 and other gases. Capability includes innovative survey methods for CO_2 leakage detection, such as the use of mobile open path laser systems, innovative use of techniques more usually applied in different fields of study, e.g. eddy covariance and continuous flux monitors, and a capability to determine the origin of gases through examining the relationship of CO_2 to other gases and the use of carbon isotopes. The monitoring techniques available can capture data at high rates (1 Hz, 10Hz), lower rates (e.g. hourly or half hourly) or as part of data collection through one-off surveys or repeated, e.g. seasonal, observations. These techniques directly address the need to monitor large areas rapidly with sensitive equipment in order to detect and determine the extent of leakage, quantify the amount of leakage, and assess temporal variability of the gas emissions. Gas measurements are also an essential part of ecosystem impact studies, being used to define affected areas and exposure levels and to assess when recovery conditions apply. The facility has gained extensive experience in the use of these methods through their use at natural analogues sites (where natural seepage of CO_2 is taking place) in Italy, Germany and Greece and at industrial scale CO_2 storage sites such as Weyburn, Canada and In Salah, Algeria.

CO_2 measurement with a mobile open path laser system

Selected publications

Bateman K, Rochelle CA, Lacinska A, Wagner D, Taylor H and Shaw R. 2011. CO2-porewater-rock reactions - Large-scale column experiment (Big RIG II). *Energy Procedia*, **4**, 4937-4944.

Cuss RJ, Harrington JF and Milodowski AE. 2011. Fracture transmissivity as a function of normal and shear stress: first results in Opalinus Clay. *Physics and Chemistry of the Earth* (in press).

Harrington JF, Noy DJ, Horseman ST, Birchall JD and Chadwick RA. 2009. Laboratory study of gas and water flow in the Nordland Shale, Sleipner, North Sea. In: M Grobe, JC Pashin and RL Dodge (Eds), Carbon dioxide sequestration in geological media - State of the science. *AAPG Studies in Geology*, **59**, 521– 543.

Kjøller C, Weibel R, Bateman K, Laier T, Nielsen LH, Frykman P and Springer N. 2011. Geochemical impacts of CO2 storage in saline aquifers with various mineralogy - Results from laboratory experiments and reactive geochemical modelling. *Energy Procedia*, **4**, 4724-4731.

Krüger M, West JM, Oppermann B, Dictor M-C, Frerichs J, Joulian C, Jones D, Coombs P, Green KA, Pearce J, May F and Möller I. 2009. Ecosystem effects of elevated CO_2 concentrations on microbial populations at a terrestrial CO_2 vent at Laacher See, Germany. *Energy Procedia*, **1**, 1933-1939.

Maul P, Beaubien S, Bond A, Limer L, Lombardi S, Pearce J, Thorne M and West JM. 2009. Modelling the fate of CO_2 in the near-surface environment at the Latera natural analogue site. *Energy Procedia*, **1**, 1879-1885.

Rochelle CA, Camps AP, Bateman K, Gunn D, Jackson P, Long D, Lovell MA, Milodowski AE and Rees J. 2009. Can CO_2 hydrate assist in the underground storage of carbon dioxide? In: D Long, J Rees, MA Lovell and CA Rochelle (Eds) Sediment-hosted gas hydrates: new insights on natural and synthetic systems. Geological Society Special Publication 319, 171-183.

West JM, McKinley IG, Palumbo-Roe B and Rochelle CA. 2011. Potential impact of CO_2 storage on subsurface microbial ecosystems and implication for groundwater quality. *Energy Procedia*, **4**, 3163-3170.

Contribution to EU and other major CO2 storage related projects

BGS co-ordinated the ground-breaking Joule 2 project in the mid-1990s and since then has taken a leading role in CCS research via a number of major projects. In the last two years BGS has carried out more than 50 CO_2 storage projects for a range of customers, including the EU, industry and the UK and overseas governments. Examples of recent CCS laboratory-based research projects include:

International Energy Agency (IEA) Weyburn project – researching the feasibility of long-term geological storage of CO_2 as part of an enhanced oil recovery (EOR) operation in south-eastern Saskatchewan, Canada.

NASCENT – EC Framework 5 project led by BGS studying storage processes associated with natural accumulations of CO_2.

CASTOR (CApture to STORage) – EC project addressing issues associated with capture and sequestration of CO_2. Research involved provision of mass transport parameters for assessment of gas field sealing, evaluation of geomechanical parameters and assessment of chemical reactivity of reservoir and cap rocks.

CO2GeoNet – EC project co-ordinated by BGS. Various JRA projects including: investigation of possible mechanisms controlling gas flow in unlithified sediments; interaction of CO_2 with borehole infrastructure and host rocks; impacts of CO_2 leakage on ecosystems; and surface gas measurements.

CO2ReMoVe – an ongoing EC project dealing with monitoring and verification of CO_2 storage. BGS are involved in the development of new monitoring tools for surface gas monitoring and their testing at natural analogue sites (in conjunction with CO2GeoNet) and application at storage sites such as In Salah and Weyburn.

CRIUS – A NERC funded research project with Cambridge, Manchester and Leeds universities investigating CO_2-water-rock reactions in laboratory experiments, natural analogues and via theoretical modelling.

National capability (NERC) funded research on formation and stability of gas hydrates, and mechanisms governing movement of CO_2 through low permeability materials such as reservoir seals and well bore cements.

ECCSEL – A wide range of BGS laboratories are contributing to this EC FP7 Capacities funded European CO_2 Capture and Storage Laboratory Infrastructure consortium.

12.2 UEDIN

Organisation name			Short Name	Country
THE UNIVERSITY OF EDINBURGH			UEDIN	UK
Description of the infrastructure				
Name(s) of the infrastructure(s)*:	1. COFR: CO2 Flow Rig 2. GREAT: GeoReservoir Experimental Analogue Technology 3. COFP: CO2 Flow at Pore Scale Laboratory 4. FoAM: Fundamentals of adsorption and membranes Laboratory 5. AMP: Adsorption and Membranes Processes Laboratory			
Location (town, country):	Scotland			
Web site address:	http://www.eng.ed.ac.uk/carboncapture/ http:// www.see.ed.ac.uk/~xfan1/Xianfeng_Fan.html http://www.geos.ed.ac.uk/homes/cmcdermo			
Legal name of organisation operating the infrastructure:		University of Edinburgh		
Location of organisation (town, country)		Edinburgh, Scotland		

COFR: CO2 Flow rig, Transport and Storage, Laboratory: Characterization and processes

High pressure flow through cell for multiphase experimental work on rock cores of up to 38mm in diameter and 75mm in length and is rated to 10,000psia, 90^{o}C and suitable for CO_2 and brine being made of 316 stainless steel. The heating bands keep the temperature constant at 80^{o}C so that in situ reservoir conditions can be recreated experimentally. The pump is designed for supercritical CO2 and all wetting parts are in 316 stainless steel or PEEK to limit corrosion. We have the possibility of creating multi-phase flow systems, accurately measuring pressure, flow rates and masspectrometry analysis of tracer behaviour. Mass spectrometer connection still pending, should be available April 2012. State of the art & Services Currently Offered and Achievements: In situ reservoir conditions of fluid flow, pressure and temperature, unique flow through fractured caprock. Publications in preparation.

GREAT: GeoReservoir Experimental Analogue Technology

Experimental equipment to simulate in situ reservoir conditions of true tri-axial conditions, fluid pressure, temperature, chemistry and fluid flow for the experimental investigation of coupled-reservoir processes. Effective stress of at least 80 MPa pressure, temperature at least 100°C (in situ reservoir conditions circa 3 Km deep) on samples with a diameter of 15 to 20 cm capable of containing fracture networks. Equipment under construction, and should be available by January 2013.State of the art & Services Currently Offered and Achievements: Unique in-situ conditions for large scale fractured samples.

COFP: CO_2 Flow at Pore Scale Laboratory: Characterization and processes of CO_2 flow at pore scale

Investigation of pore wettability, the displacement of pore fluids by supercritical CO_2 and gas CO_2 at pore scale, and for investigation of the impact of mineralogy, interfacial chemistry, pore wettability, pore structure on the displacement, reservoir seal capacity, reservoir storage capacity and three-phase flow in pores and core samples under reservoir conditions.

State of the art: direct measurement of the displacement of pore fluids by CO_2, pore wettability and the impact of mineralogy, pore size, CO_2-water-mineral interfacial properties on the seal capacity of caprocks and minerals under insitu conditions. The working pressure can be upto 10,000psia. The temperature can be upto 90^{o}C.

FoAM: Fundamentals of Adsorption and Membranes Laboratory

The adsorption and membrane fundamentals lab provides a complete characterisation of the basic properties of solid materials for carbon capture all in one place – equilibrium isotherms; heats of adsorption; diffusion in nanoporous solids; macropore diffusion in structured materials; influence of water; stability to SOx and NOx. It comprises

- Quantachrome PoreMaster 33 Mercury Porosimeter study from >950 micron to 0.0064 micron pore diameter.

- Quantachrome AutoTap and Ultrapycnometer For bulk and skeletal density measurements
- Quantachrome Autosorb-iQ-C For BET surface and volumetric adsorption isotherm system
- Setaram Sensys Evo TG/DSC For gravimetric and calorimetric measurements (equilibrium and kinetic).
- Two Zero-Length Column (ZLC) systems. Rapidly rank the capacity of adsorbents using small quantities of sample (<15 mg) and low gas consumption (image below)

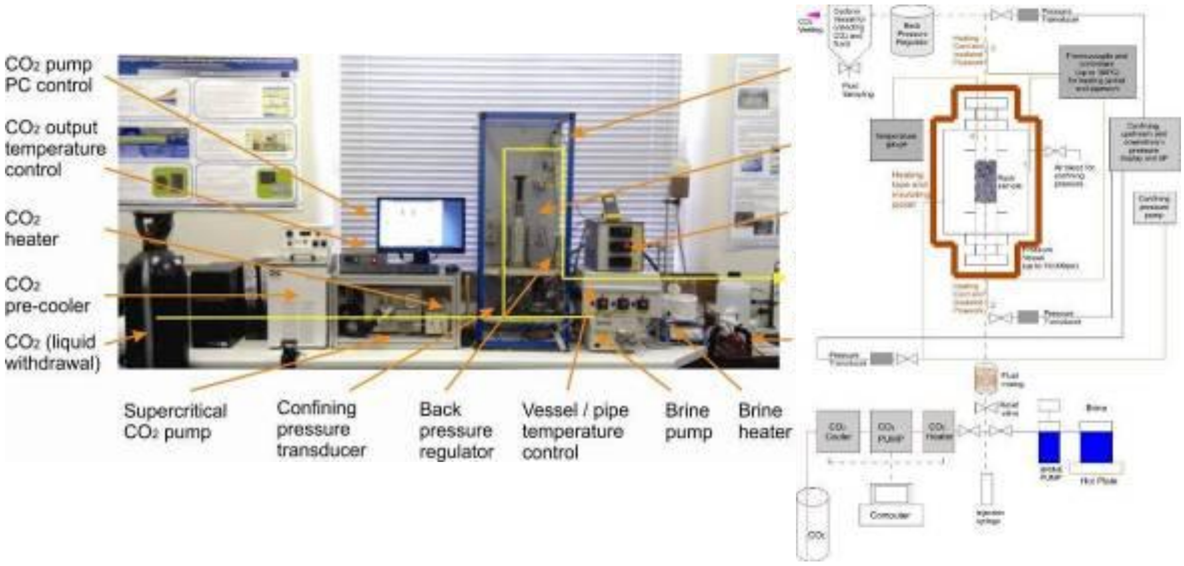


Fig 1 .COFR: CO2 Flow rig Transport and Storage, Laboratory

Fig 2 . FoAm Lab

The installation has been used for several projects funded by the Engineering and Physical Sciences Research Council (UK) and the US-DOE: EP/G062129/1 – IGSCC-Innovative Gas Separations for Carbon Capture; EP/F034520/1 – Carbon Capture from Power Plant and Atmosphere; EP/I010939/1 – FOCUS – Fundamentals of Optimised Capture Using; EP/I016686/1 – Carbon Nanotubes for Carbon Capture; and DE-FC26-07NT43092 – Carbon Dioxide Removal from Flue Gas Using Microporous Metal Organic Frameworks (US-DOE). The lab will also be used for the EU funded project OFFGAS – OFFshore GAs Separations (FP7-PEOPLE-2011-IRSES, 252000 € starting in May 2012)

The achievements include several publications, a selection of which are

- Wang H., Brandani S., Lin G. and Hu X. Flowrate Correction for the Determination of Isotherms and Darken Thermodynamic Factors from Zero Length Column (ZLC) Experiments, *Adsorption*, **2011**, *17*, 687-694.
- Brandani S., Hu X., Benin A.I. and Willis R.R. *A Semi-Automated ZLC System for Rapid Screening of Adsorbents*

for Carbon Capture. Fundamentals of Adsorption 10, Awaji, Japan, May 23-28, 2010.

- Brandani S., *Experimental adsorption and diffusion in nanopores*. Gordon Research Conference on Nanoporous Materials, Invited Plenary Lecture, Waterville, Maine, USA on June 15-20, 2008.
- Brandani S. On the Chromatographic Measurement of Equilibrium Isotherms Using Large Concentration Steps, *Adsorption*, **2005**, *11*, 231-235.
- Brandani F., Rouse A., Brandani S. and Ruthven D.M. Adsorption Kinetics and Dynamic Behavior of a Carbon Monolith, *Adsorption*, **2004**, *10*, 99-109.

AMP: Adsorption and Membranes Processes Laboratory

The facility consists of different apparatuses that allow the characterisation of solid materials for next generation carbon capture in dynamic conditions. These include

- Dual Piston Pressure Swing Adsorption / Vacuum Swing Adsorption System (DP-PSA)

- Quantachrome Porometer 3G zh

- Permeation Cell

- Multibed Pressure Swing Adsorption system

State of the art & Services Currently Offered and Achievements: The unique Dual-Piston apparatus allows for testing of rapid adsorption cycles up to 1.5 Hz with a single column. The system is closed and can test the performance of adsorbent materials without using large amounts of gases. The Multibed PSA can be utilised to test various cycle configurations where multi-stage pressure equalisation, light or heavy reflux, and backfill can be included. As the columns are contained in a temperature-controlled oven, the effect of temperature variance of the surroundings can be minimised and an in-situ regeneration of the columns is possible.

The Quantachrome Porometer 3Gzh is the first system of this kind installed in the UK. It can be used to test the porosity of both selective film and supports as flat membranes as well as fibres. It allows for the characterisation of the porosity both inside and outside the fibre and for the detection of defects.

The installation has been used for several projects funded by the Engineering and Physical Sciences Research Council (UK) and the US-DOE: EP/G062129/1 – IGSCC-Innovative Gas Separations for Carbon Capture; EP/F034520/1 – Carbon Capture from Power Plant and Atmosphere; EP/I010939/1 – FOCUS – Fundamentals of Optimised Capture Using; EP/I016686/1 – Carbon Nanotubes for Carbon Capture; and DE-FC26-07NT43092 – Carbon Dioxide Removal from Flue Gas Using Microporous Metal Organic Frameworks (US-DOE).

The lab will also be used for the EU funded project OFFGAS – OFFshore GAs Separations (FP7-PEOPLE-2011-IRSES, 252000 € starting in May 2012)

The achievements include several publications, a selection of which are

- Ferrari, MC; Galizia, M; De Angelis, MG; Sarti, GC. Gas and Vapor Transport in Mixend. *Ind. Eng. Chem. Res.* **2010**, *49*, 11920-11935
- Fiandaca G., Fraga E.S. and Brandani S. A Multi-Objective Genetic Algorithm for the Design of Pressure Swing Adsorption, *Engineering Optimization*, **2009**, *41*, 833-854.
- Ahn H. and Brandani S. A New Numerical Method for Accurate Simulation of Fast Cyclic Adsorption Processes, *Adsorption*, **2005**, *11*, 113-122.
- Ahn H. and Brandani S. Analysis of Breakthrough Dynamics in Rectangular Channels of Arbitrary Aspect Ratio, *AIChE J.*, **2005**, *51*, 1980-1990.
- Ahn H. and Brandani S. Dynamics of Carbon Dioxide Breakthrough in a Carbon Monolith Over a Wide Concentration Range, *Adsorption*, **200**5, *11*, 473-477.

12.3 HWU

Organisation name		Short Name	Country
HERIOT WATT UNIVERSITY		HWU	UK
Description of the infrastructure			
Name(s) of the infrastructure(s)*:	1. Monitoring Infrastructure 2. Geochemical Trapping and Mineral Carbonation Infrastructure 3. Capture Infrastructure		
Location (town, country):	Edinburgh, UK		
Web site address:	www.hw.ac.uk		
Legal name of organisation operating the infrastructure:	Heriot Watt University		
Location of organisation (town, country):	Edinburgh, UK		

Apparatus for laboratory monitoring

The main effect of an increased level of CO_2 is the lowering of the pH. The resultant acidification may modify the chemistry of the environment with mobilization of potential pollutants such as heavy metals and alterations in the availability of nutrients in the sediments and soils. Pollutants may also migrate toward the groundwater reservoirs. Lab rigs have been developed to analyse these effects in a controlled and simplified environment; the results of the lab experiments are also compared with observations from field-lab studies and from the Panarea marine area (natural analogue).

Two rigs are used for simulating seepage in terrestrial environments (storage site or pipelines). The columns can be filled with soils and at the base of the column CO_2, both as gas and dissolved in water, is injected. Sensors monitor pH variations and the soil-moisture. Interstitial water and sediment samples are collected to verify the potential chemical modifications due to the presence of CO_2.

A third rig is used to simulate sub-seabed seepage. In this case the sediments occupy the first 60 cm of the column, and the upper part is filled with water. A plume of bubbles can be generated and particle imaging velocimetry (PIV) and passive acoustic techniques are applied for the study of the physical features of the plume and the interactions with the surrounding water. In both the columns the CO_2 concentration in the head-space is monitored by IR analysers and by discrete sampling.

State of the art

These unique rigs give researchers the opportunity to test monitoring equipment for both the terrestrial and marine environment. They are very versatile, with opportunities to look at different types of soils and sediments and compare results to field sites. They also provide the opportunity to test and develop new monitoring equipment.

Services currently offered by the infrastructure and achievements

These rigs are currently being used to compare results from Panarea and ASGARD. This infrastructure can be used to (1) study potentials CO2 seepages from geological storage sites or from the injection rig may affect the surrounding environment; and (2) to develop reliable detection techniques for such seepages a laboratory rig was designed that is composed of three vertical Plexiglas columns.

Recent Publications:

G. Caramanna, Y.Wei, M. M. Maroto-Valer, M. Steven, P. Nathanail, Design and development of a laboratory rig for the study of the chemical-physical effects on aquatic environments of potential seepage from CO_2 storage sites, Greenhouse Gases: Science and Technology, 2012, 2:136–143 (2012); DOI: 10.1002/ghg.

G. Caramanna, Y.Wei, M. M. Maroto-Valer, M. Steven, P. Nathanail, Laboratory experiments and field study for the detection and monitoring of potential seepage from CO_2 storage sites, Applied Geochemistry, 2012, Accepted.

Geochemical Trapping and Mineral Carbonation Infrastructure

The infrastructure includes 2 Parr 600ml high pressure/high temperature bench stand stirred reactors (left picture; model series 4545) with a temperature and stirrer controller (model series 4843) and a set of twelve reactors mounted in a shaking table (right picture). These reactors are used to study carbonation reactions at different temperature and pressure conditions for both underground and above-ground. Each reactor is manufactured in Alloy C276 and fitted with high torque seals magnetic stirrer drive unite in Alloy C276 and 1/8 hp variable speed electric motor. It offers working pressures to 5000psi (345 bar) at temperatures to 350 ^{o}C that can cover all the range of T/P conditions for current mineral carbonation reaction. Each reactor has an individual pressure control, individual temperature control and integrated mixing for all vessels (shaking table). The maximum pressure that can be reached is 200bar and they are suitable for corrosive gas injection as well as different gas mixtures.

Services currently offered by the infrastructure and achievements

The reactors can be used to study carbonation reactions (both for underground mineral trapping and above ground mineral carbonation), including the assessment of the effect of impurities (such as SO_2, NO_2, and O_2) on CO_2 storage by changing the different gas cylinder for mix gases injecting. Moreover, it could be used to identify the extent of mineral carbonation reaction with corresponding reaction time by using $^{13}CO_2$ isotope.

Recent Publications:

Liu Q., and Maroto-Valer M. 2011 Parameters affecting mineral trapping of CO_2 sequestration in brines Greenhouse Gases: Science and Technology Volume 1, Issue 3, pages 211–222

Garcia, S., Rosenbauerb, R.J., Palandric, J. and Maroto- Valer, M. Experimental and simulation studies of iron oxides for geochemical fixation of CO_2-SO_2 gas mixtures. Energy Procedia 4 (2011) 5108–5113

Capture Infrastructure

Description of the facilities

CO_2 adsorption and/or desorption performance is measured using a thermogravimetric analyser coupled with a mass spectrometer (TGA-MS). Studies can be conducted to determine temperature versus CO_2 adsorption tests (thermogravimetric analysis under flux of CO_2), time versus CO_2 adsorption tests (isothermal tests) and multi-cycle of CO_2 adsorption tests. To analyse the influence of the CO_2 partial pressure, also different gas mixtures of CO_2 can be employed, e.g. pure CO_2 flow and a ternary mixture of 15% CO_2, 5%O_2 and 80% N_2 that could simulate a real flue gas stream in a power station. In the thermogravimetric analysis, the weight change of the adsorbent (wt.%) was recorded to evaluate the effect of the temperature (from 25 to 120 °C at 5 °C min−1) upon adsorption capacity. In the isothermal tests the weight change (wt.%) of the adsorbent is recorded versus time. CO_2 capture steps at different temperatures can also be conducted followed by regeneration step to determine the long-term performance of the materials tested.

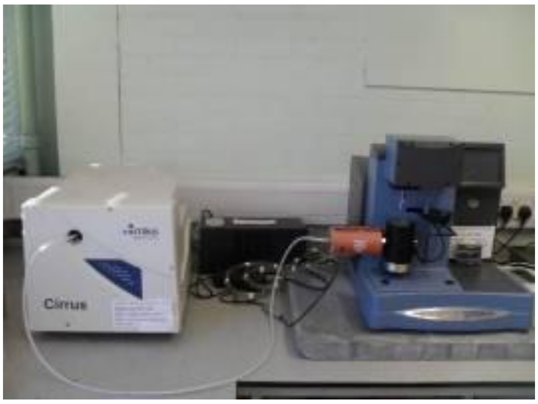
TGA: Thermo-gravimetric analysis (TGA) is a well-known method of quantitatively studying the loss/uptake of weight from a sample. This can be done isothermally to study weight loss during operation or with a temperature ramp. Techniques that can be used include: multiple step ramps, isothermals, auto stepwise methods, special pans (e.g. laser pierced pans for controlling volatiles). The Q500 we used is the world's selling, research-grade thermo-gravimetric analyser. Its field-proven performance arises from a responsive low-mass furnace, ultra-sensitive thermo-balance, and efficient horizontal purge gas system (with mass flow control).

MS: Cirrusfrom MKS offers the versatility of state-of-the-art quadrupole mass spectrometry in a convenient bench-top configuration. Cirrus systems are ideal for the on-line monitoring and analysis of gases and gas mixtures including trace contaminants in process gases; solvent vapours; hydrocarbons and atmospheric and inorganic gas species. Gas compositions can be tracked over a wide dynamic range (ppb to percentage levels) with a speed of up to 250 data points per second. The heated silica capillary inlet ensures a rapid response to changes in gas composition.

State of the art

Coupled together, the TGA and MS represent a powerful instrument that can be used to investigate performance of capture sorbents during the adsorption/stripping cycles and also it can be used to determine the selectivity of the investigated material on different probe molecules (e.g. CO_2, O_2, SO_2, NOx etc.).

This equipment can also be used to support activities to quantify the amount of CO_2 sequestered in above and under-ground processes. Moreover, the instruments can also be used to ascertain whether "impurities" such as SO_2, NOx etc. are mineralised together with the CO_2.



Services currently offered by the infrastructure and achievements

The services offered by this infrastructure include (1) performance and selectivity of sorbents as well as degradation of sorbent materials during the capture and stripping processes; and (2) quantification of CO_2 sequestered in above and under-ground processes.

Recent Publications:

M. Olivares-Marín, T.C. Drage, M. M. Maroto-Valer, Novel lithium-based sorbents from fly ashes for CO_2 capture at high temperatures, International Journal of Greenhouse Gas Control, 2010, 4(4), 623-629

M. Olivares-Marín, M.M. Maroto-Valer. Preparation of a highly microporous carbon from a carpet material and its application as CO_2 sorbent. Fuel Processing and Technology, 2010, 92, 3, 322-329

M. Olivares-Marín, S. García, C. Pevida, M.S. Wong, M. M. Maroto-Valer, CO_2 capture capacity of carpet waste-based sorbents, Journal of Environmental Management, 2011, 92 (10), 2810-2817

SET-Plan Energy Education & Training
Concentrated Solar Power (CSP)

Concentrated Solar Power

Working Group Contributors

Peter Heller (Rapporteur)

Fabrizio Fabrizi

James Spelling

Björn Laumert

Christoph Richter

Manuel Silva

Enrique Soria

Björn Karlsson

We would like to thank Piero de Bonis (European Commission) for his support and review of the manuscript.

1 Current situation- existing workforces, labour intensity, future trends, workforces required

General remarks

The solar electricity generation systems, like CSP and PV, stand as commercially renewable energy technologies suitable to exploit the immense solar resource in Southern Europe, the MENA region, and elsewhere. In the CSP technology, a high temperature heat source is created by concentrating the sun rays to produce electricity in a thermodynamic cycle. CSP enables many other applications besides electric power generation, like co-generation of electric and thermal power, production of solar fuel, desalination and so on.

A CSP plant may be divided in five main sub-systems, see Figure 1: concentrating system, solar receiver, thermal storage, back-up system (an auxiliary firing in substitution or coupled with storage), and power block. Solar radiation transfer or fluid transport links them together.

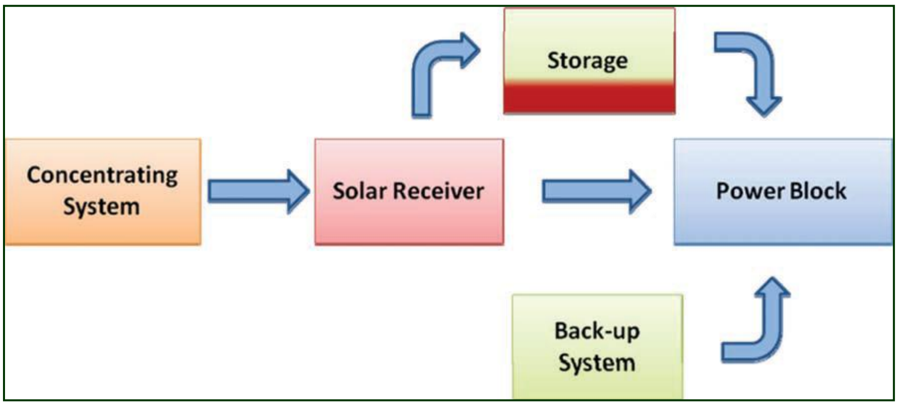


Fig. 1: Main sub-systems of a CSP plant including storage and back-up system (from [1])

The main characteristic of CSP is the inherent possibility to incorporate a thermal energy storage, which enables to generate power “night and day” and distinguishes it for its dispatchability in comparison to Wind and PV. As illustrated in Figure 2, there are four main CSP technology families that can be classified according to the way they focus the sun rays and the receiver technology. In systems with a line focus (Parabolic Trough and Linear Fresnel) the mirrors track the sun along one axis. In those with a point focus (Tower and Parabolic Dish), the mirrors track the sun along two axes. The receiver may be fixed, as in Linear Fresnel and Tower systems, or mobile as in Parabolic Trough and Dish Stirling systems.

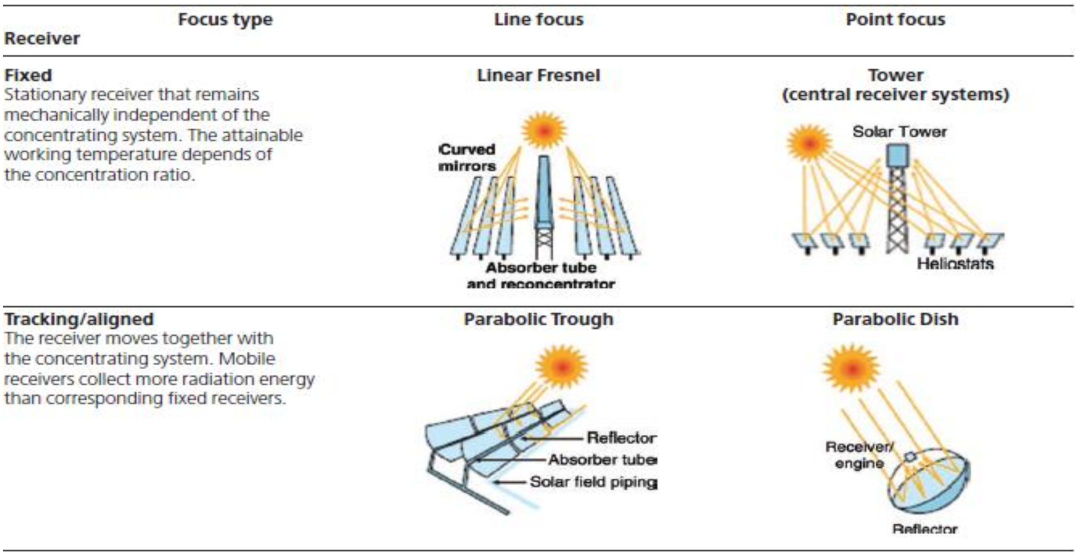


Fig. 2: The four main CSP technology families (from [1])

Current status and technological developments

In 2012, as illustrated in Figure 3, there were 2.4 GW of CSP operational worldwide, 3.2 GW under construction, and another 13 GW under promotion, i.e. projects either with signed PPAs or corresponding to short term national programmes [2]. The actual application of this technology is exclusively related to STE (Solar Thermal Electricity), to which we mainly refer in this document; considerations for other uses will be highlighted when appropriate.

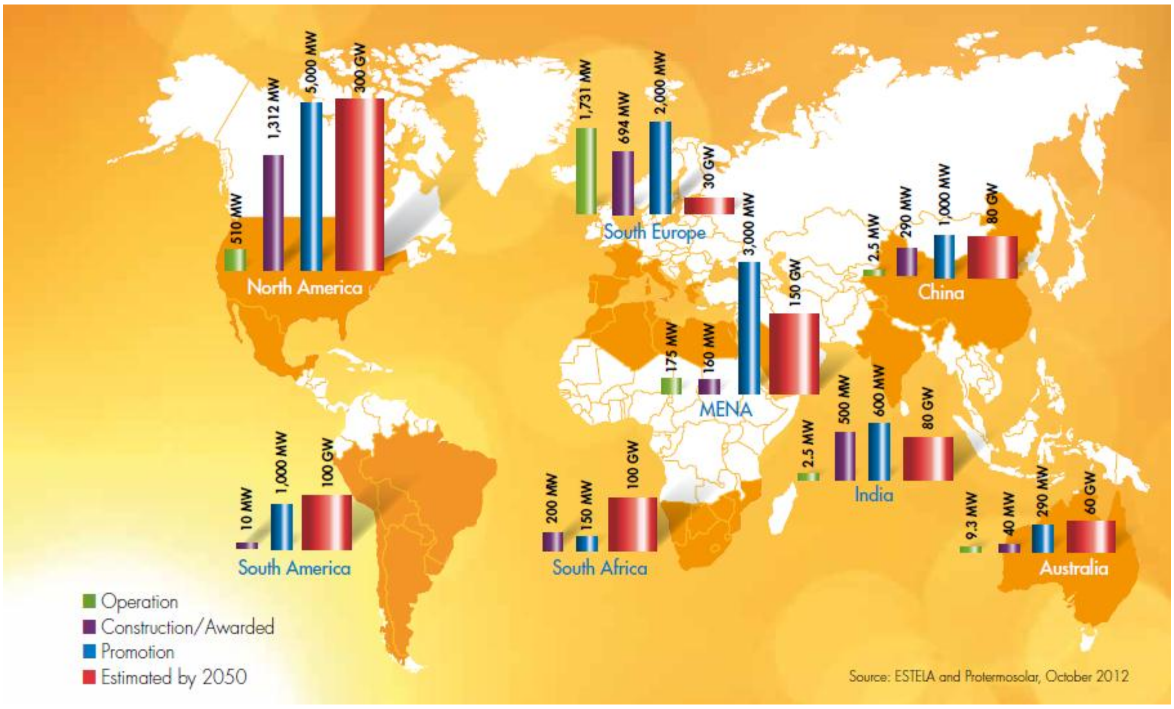


Fig. 3: STE estimate map of the world by 2050 (from [12])

In 2012, parabolic trough technology accounts for about 96% of global CSP capacity; tower technology accounts for 3%; the others are at initial commercial development [1].

The European Solar Thermal Electricity Association (ESTELA) has created a STE Power Plants Map on its official website [L1]. This map displays STE power plants that are in operation and under construction worldwide in their locations. The worldwide main research facilities are also displayed in the map.

The IEA roadmap [5] foresees a rapid expansion of CSP capacities in countries with excellent DNI (Direct Solar Radiation), and computes its electricity production as progressively growing percentages of the overall consumption forecast. In neighbouring but less sunny regions, a lower contribution of STE is expected, which mixes local production and electricity from nearby sunnier areas. Plants built before 2020 mostly respond to intermediate and peak loads, while a first set of HVDC lines is built to connect some of the CSP plants in sunny areas to large demand centres, e.g. MENA areas to European cities.

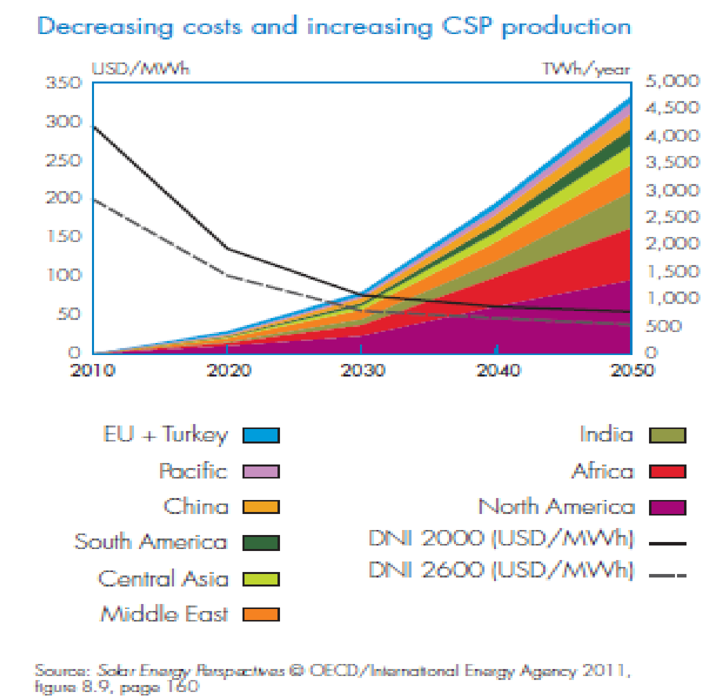


Fig. 4 – CSP expected production and LCOE by 2050

From 2020 to 2030, as costs are reduced and performance enhanced, the deployment of CSP continues with base-load plants, thus maximizing CO_2 emission reductions. After 2030, while CSP continues to develop, solar fuels enter the global energy mix. By 2050, CSP represents about 11% of global electricity production. Figure 4 shows the growth of STE production by region according to this roadmap, and the foreseen reduction of the LCOE (Levelised Cost Of Electricity) at two different condition of DNI. This projection takes into account a significant amount of electricity transportation by meanwhile built HVDC lines.

Among the future renewable energy generation mix, STE profits by its distinct characteristics as dispatchability, storage and hybridization potential, which result in large capacity factors and firmness of the electricity supply [2]. The prospects included in the IEA publication "Solar Energy Perspectives" are shown in Figure 4: as it can be seen, the expected production in 2030 will be around 1,200 TWh/year, and in 2050 around 4,800 TWh/year. Regarding Southern Europe and its own neighbours in the MENA region, STE is expected to take the major share in the long future as shown in the figure where a contribution of 1,000 TWh/year by 2050 is highlighted. Figure 3 shows the expected world map for 2050 [12].

Three main drivers for cost reduction are: scaling up, volume production and technology innovations [1]. A comprehensive study of the potential for cost reduction of CSP was undertaken in the 'ECOSTAR' project (Pitz-Paal et al., 2005) [9]. ESTELA provides more actual data on the estimated evolution of Power Purchase Agreements (PPA) for a given contractual period and radiation level that would make it possible to build the plants (see Figure 5). The curves allow the estimation of necessary subsidies to cover the gap between the PPA and the current market prices [12].

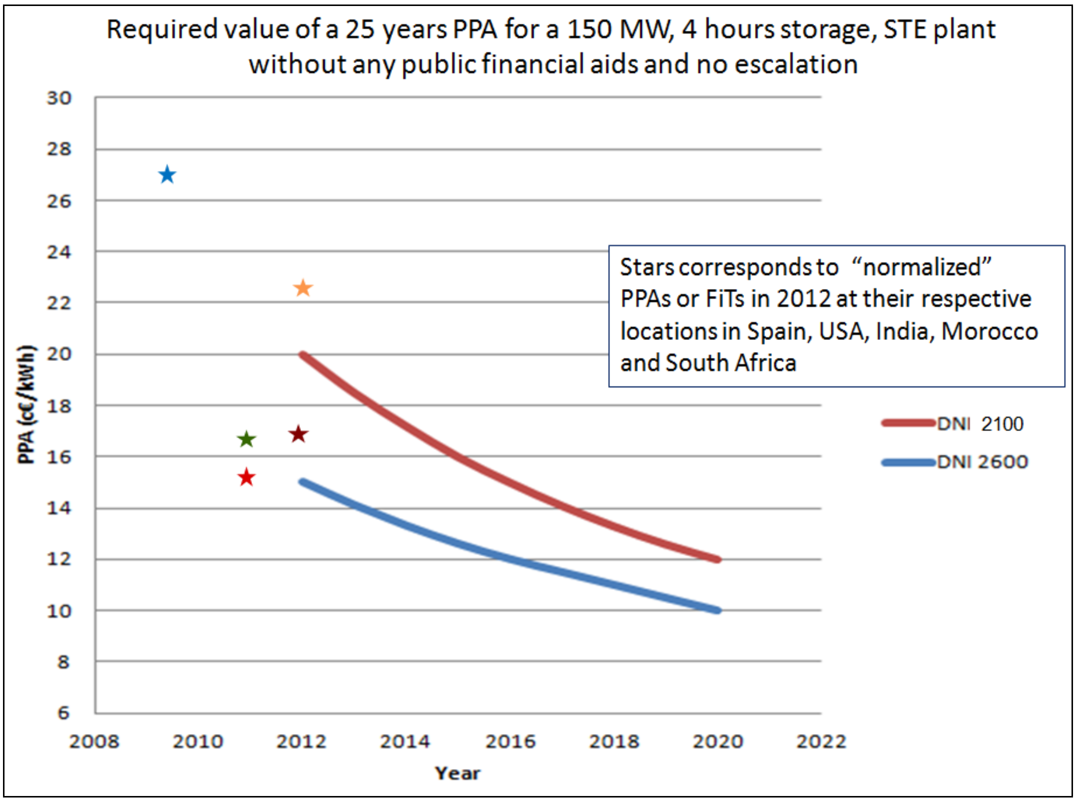


Fig. 5 – Evolution of PPAs for a given contractual period (from [12])

For large, state-of-the-art trough plants, current investment costs are USD 4.2/W to USD 8.4/W depending on labour and land costs, technologies, the amount and distribution of DNI and, above all, the amount of storage and the size of the solar field. Plants without storage that benefit from excellent DNI are on the low side of the investment cost range; plants with large storage and a higher load factor but at locations with lower DNI (around 2000 kWh/m2/year) are on the high side. The investment costs per watt of a trough plant with storage are expected to decrease for larger trough plants, going down by 12% when moving from 50 MW to 100 MW, and by about 20% when scaling up to 200 MW. Costs associated with power blocks, balance of plant and grid connection are expected to drop by 20% to 25% as plant capacity doubles. Investment costs are also likely to be driven down by increased competition among technology providers, mass production of components and greater experience in the financial community of investing in CSP projects. Investment costs for trough plants could fall by 10% to 20% if DSG (Direct Steam Generation) or MS (Molten Salt) Direct System, i.e. the same MS mixture used as Heat Transfer Fluid and storage medium, were implemented, which allows higher working temperatures and better efficiencies. Turbine manufacturers will need to develop effective power blocks for the CSP industry. In total, investment costs have the potential to be reduced by 30% to 40% in the next decade [5], while by 2050 the above-mentioned objective of more than 60% reduction [10] should be reached.

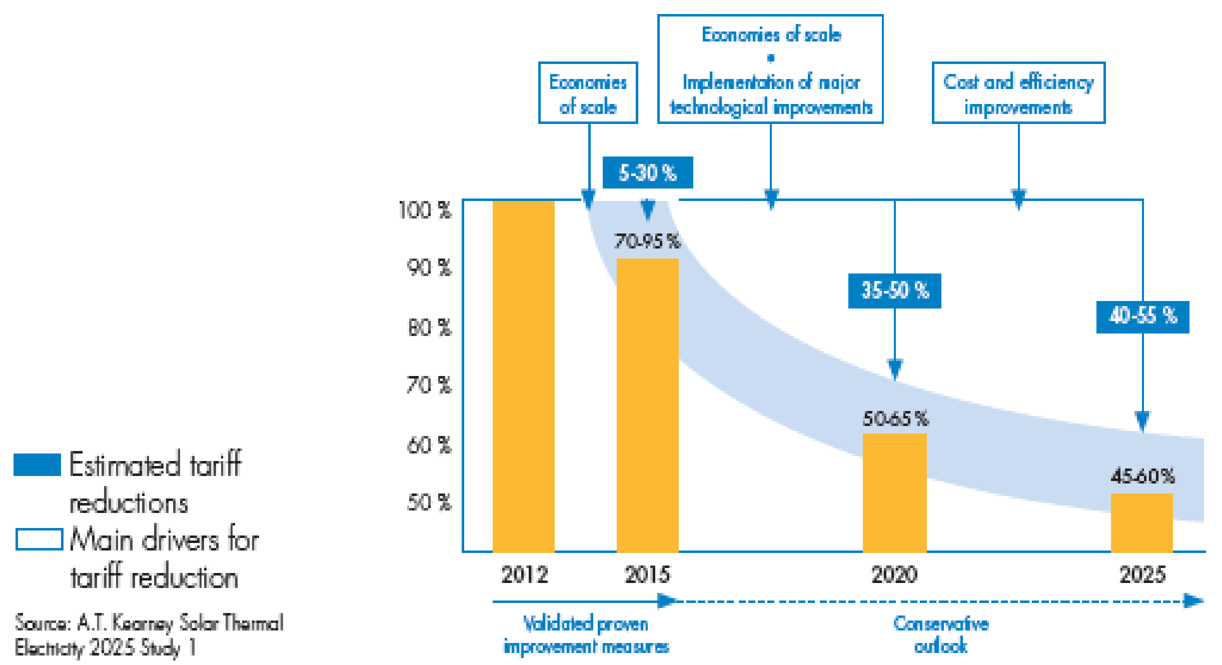


Fig. 6 – Roadmap for STE cost reduction (from [2])

In order to realise these technology breakthroughs and associated cost and efficiency improvements, it is essential to coordinate the different research, development and demonstration efforts with a market incentive that favours cost reduction by innovation over cost reduction by mass production of state-of-the-art technology options. Research without the chance to implement the technology in the market, and to improve and adapt it over a couple of technology generations, has a high risk of failure in a competitive market. [2].

Increased research funding and a stronger integration of fundamental and applied research, together with demonstration programs and market incentives, are required to speed up the innovation cycle. Fundamental research on new materials, heat transfer fluids, and coatings is needed, and integrated programs should enable smooth progression of promising technologies from laboratory scale prototype systems to pilot plants and demonstrations units. Results of the individual phases should be independently evaluated and benchmarked with respect to their impact on system cost targets before starting on the next phase. As a supporting action to that ESTELA created the Strategic Research Agenda. It may be assumed that the investment cost will be halved by 2020 [2].

The following scenario resumes the perspective for the CSP sector, see also Figure 6 :

1. The market value/size in October 2012 corresponding to the plants already in operation in EU, i.e. only Spain and Italy, is 1731 MW; in the rest of the world it is 699 MW; at global level it is 2.430 GW; investment costs are USD 4.2/W to USD 8.4/W;

2. The market value/size of the plants in construction in EU is 694 MW that corresponds to a growth rate of about 0.23 GW/y; in the rest of the world it is 2.512 MW with a growth rate of about 0.84 GW/y; investment costs should be USD 3,4/W to USD 5,3/W with an estimated 20% decrease;

3. The market value/size of the plants in promotion (i.e., promotion means projects either with signed PPAs or corresponding to short term national programmes to be completed by 2020) in EU is 5000 MW that corresponds to a growth rate of about 0.5 GW/y; in the rest of the world it is 8000 MW with a growth rate of about 1 GW/y; investment costs should be USD 2.1/W to USD 1,7/W with an estimated 50% decrease;

4. The market value/size of the plants estimated (i.e., estimation from ESTELA [12] to be completed by 2050) in EU is 30 GW that corresponds to a growth rate of about 1.00 GW/y; in the rest of the world it is 820 GW with a growth rate of about 27 GW/y; at global level they are 850 GW and 28 GW/y; investment costs should be USD 1.7/W to USD 2.6/W with an estimated 60% decrease.

Industrial Companies and Research Institutes involved in the CSP sector.

The companies involved in the CSP sector comprise manufacturers of components, EPC (engineering, procurement and construction) organizations and utilities. The CSP value chain is similar to the other thermoelectric energy industrial sectors, i.e. based on fossil fuels. The fossil fuel is substitute with a complete solar field (with its TES and backup systems, if any) of comparable power, while the remaining part of the plant, i.e. power block, electrical parts, control system, etc., is more or less the same for an equivalent installed power unit. This means that CSP exploitation doesn't negatively affect the thermoelectric industry, which instead is revitalized. The effect is positive because it reduces the import of fossil fuels and increases the domestic industrial activities as an equivalent of the money saved from less importations of fossil fuel.

ESTELA has today 60 direct members, representing more than 200 companies and institutions. Three national associations are members of ESTELA: the Spanish Protermosolar with more than 100 members, the Italian ANEST with more than 30 and the French SER with around 30. With this data, we can estimate that the companies associated in Europe are >200, not considering others not associated companies more or less involved in the CSP sector [2].

The main research institutions and universities in the MSs of the EU are actually involved in the RTD of the CSP sector. This fact arises from the above-described capability of the CSP technologies to involve not only the specialised solar industries, e.g. solar collector, receiver tubes, etc., but also the existing industrial sectors of thermoelectric energy and civil works and constructions. The leading Research Institutes belong to the MSs fronted to the Mediterranean Sea, i.e. Spain, France, Italy, Portugal, Greece, Cyprus, plus Germany and Swiss: they own the main European solar research facilities, that cooperate in the frame of the EERA for a RTD JP on CSP technologies aimed to support the SET-PLAN. The most part of them are partners in various FP7 Projects, in the frame of which besides specific RTD targets, they constitute a transnational access network that put at disposition of the scientific and industrial European community free access to the facilities and educational-training services (SFERA, EU-Solaris, STAGE-STE).

Employment in the CSP sector

ESTELA [2] reports a summary of a study from Protermosolar [6] on macroeconomic impact and job creation of CSP in Spain. The study has been elaborated for the year 2010 with the participation of a wide spectrum of companies covering all the value chain of the CSP sector in Spain.

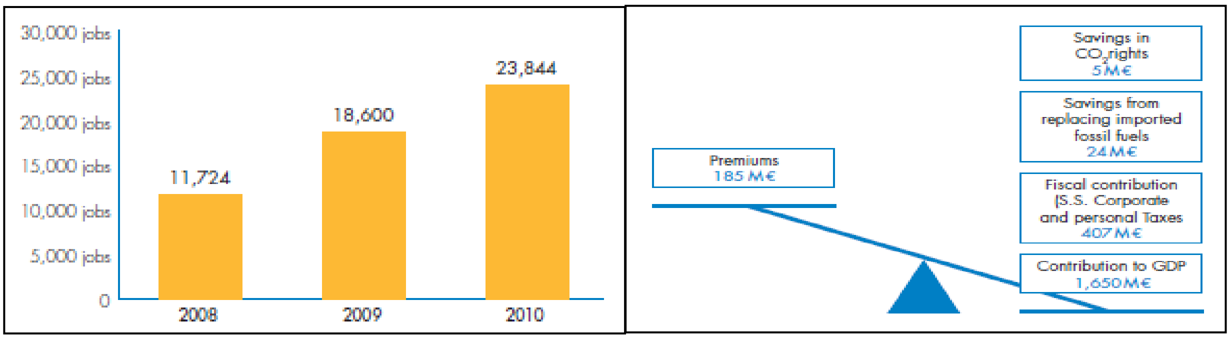


Fig. 7: Job creation and breakdown of GDP contribution by STE industry sector - Spain 2008-2010 - (from [2])

The main results of the study reveal a much greater economic contribution compared to the received premiums for the production, thus incentive policy for this technology was an efficient economic and technological decision for Spain: The impacts in the coming years regarding savings in imported fuels and in CO_2 emissions will be much higher as more plants will be fully operational. There are other very important factors that cannot be quantified in economic balance but have the same importance, see Figure 7:

- Jobs creation: Only in the year 2010, almost 24,000 jobs were created in the STE sector.
- Leadership of the Spanish industry: Spanish companies are very good positioned in emerging STE international markets.
- Industrial development: The local content in the Spanish STE plants grew from 50% in 2008 to 80% in 2011.
- Reducing hourly pool price of electricity.
- Contribution to regional economic convergence between Spanish regions.
- Local taxes paid by the porters of the plants.

Breakdown of GDP contribution by industry sector of STE reveals that the biggest contribution is in the sectors affected by economic crisis: construction and assembly, manufacturing of metal products, professional services (engineering, consulting, legal, etc.), metallurgy, manufacture of mirrors, chemicals, transport, land, machinery and mechanical equipment, etc. The jobs creation during this first phase of STE implementation in Spain has grown strongly and continuously.

In the other MSs, we have not so deepened studies, but leading states with large industrial investment are Germany and Italy, now followed from France, Portugal, Greece and Cyprus. As example, large manufacturing facilities for receiver tubes for Parabolic Trough are now existing in Germany (Schott) and Italy (ASE), besides Spain (Schott), with more than one thousand employees.

For completeness we can refer to the study from US EERE-DOE [3] that illustrate a scenario vision (SunShot) for PV and CSP value chain up to 2050. In particular it relates about the existing types and levels of employment in the solar industry for CSP. The CSP industries include a variety of jobs across their supply chains and in support roles. In measuring economic impact, jobs can be divided among three categories: direct, indirect, and induced jobs. Direct jobs accomplish final production along the solar industry supply chains, e.g., manufacturing, installation, and R&D. Indirect jobs are in industries that support the solar industry, e.g., glass, steel, and office-equipment industries. Induced jobs result from the economic activity stimulated by the solar industry, e.g., jobs related to people buying more goods and services in a region that hosts a manufacturing plant or project under construction.

The distributed energy model afforded by solar technologies is a key factor influencing solar employment characteristics. The multiplicity of small- and midsized solar energy systems yields more installation and operations jobs compared to common central station energy technologies, per energy unit [e.g., megawatt-hours (MWh)] produced. These jobs are more widely distributed in communities across the nation, including rural locations. This enables communities to "in-source" energy production, expanding local economies and providing jobs that cannot be moved offshore.

From an international policy view point, cross-country cooperation under the scope of collaborative STE related project developments like HVDC connection deployment, creation of a green energy market mechanism or energy supply agreements, can contribute to the strengthening of trustful relationships between countries which will further drive common prosperity. For MENA region countries STE also poses the opportunity to install energy producing capabilities without relying on politically arguable energy sources, like nuclear power.

Assuming the scenarios and the definitions of [3] and [4], the value chain – core occupation in the CSP sector can be estimated by accounting for three classes of jobs:

- (i) manufacturing/distribution and (ii) installation jobs for CSP, based on annual production and installation demand and,
- (iii) O&M (Operations and Maintenance) jobs for CSP, based on the cumulative deployed solar capacity.

Several assumptions are necessary to estimate job growth, including the increase in domestic manufacturing capacity to meet solar market demand, the impact of automation on manufacturing labour intensities, and the increase in labour productivity due to streamlining solar manufacturing and installation methods. According to [3] job estimates can be developed by establishing the current job intensity for CSP (i.e. job index = 1) and then accounting for improved labour productivity as solar price and performance improvements are achieved. For this analysis, a Full-Time Equivalent (FTE) job for CSP industry in Europe is defined as 1760 hours per year of employment [6], which could represent a single full-time employee or several part-time employees.

CSP job intensities for 2010 [3] (the same for 2011) were based roughly on McCrone et al. (2009) [10], with job intensities adjusted slightly upward to account for labour inefficiencies during industry scale-up. A significant fraction of U.S. and Spain CSP full-time equivalent jobs in 2010 were likely focused on business development, R&D, regulatory issues, and production scale-up. CSP job intensities were estimated at 25 jobs per MW in manufacturing/ distribution and 15 jobs per MW in installation. The operation and maintenance job intensity for CSP in 2011 was estimated at 2 jobs per MW, that is a value assumed more realistic for the current situation, i.e. a technology at the take-off, as compared with the value 1 job per MW proposed in [3]. These job intensities will be assumed as current in 2011-2012 and also representative of the European market. The CSP jobs index and job intensity is based on the declining cost of CSP-generated electricity, that depends also from the size of the plants. In Europe the size should remain not greater than 50 MWe, while in other areas up to 500 MWe size are scheduled. For these reasons the job index and the job intensity in Europe remains higher than in other countries during the time.

The value chain – required core occupations at the present and in the future are listed in Table 1. The estimate of the Europe CSP workforce may be referred to two different markets: (i) plants installed in Europe, i.e. internal market; (ii) plant installed outside Europe, in MENA regions and others in the world, i.e. external market:

(i) In the internal market the Europe CSP workforce is expected to grow, in gross jobs, from about 12,662 in 2012 to 22.950 by 2020. This is a 30% increase of the workforce for all the three classes of jobs. There are some uncertainties concerning the Spanish market progress, which has grown in 2011/2012 significantly and even more than expected by the job intensity prediction in [10], but due to the moratorium in 2012 cannot be precisely forecast. After stabilization of the Europe's market, the annual growth of the installed power should remain constant, i.e. approx. 1 GW/y, taking into account the limited resources of land in Europe suitable for CSP installation. The workforce for manufacturing and installation decreases to the half due to improved labour productivity as solar price and performance improvements are achieved. The CSP industry total jobs will almost double to 46.667 jobs.

(ii) In the external market the percentage contribution from European CSP industry has to be estimated according to the distance and to the level of integration with the interested countries. For the MENA regions the assumption of 30% jobs from European industry seems reasonable, assuming for the rest of the world the value of 10% jobs from EU. Accounting these assumptions, by 2020 the Europe CSP workforce is expected to reach 30.167 jobs, due to the expansion of the CSP industry out of EU. By 2050 the European CSP workforce only for the external market grows up to 3 times the number of employees for internal market, i.e. a total of 164,378 more jobs compared to 2020. By 2020 the distribution in the classes of jobs is 2/3 for manufacturing/installation and 1/3 for O&M; by 2050 the distribution in the classes of jobs is 1/3 for manufacturing/installation and 2/3 for O&M.

Tab. 1 – Value chain – required core occupations for CSP sector: forecasts up to 2050 (data from [2], [3], [4], [5] and [10])

		2012	2015				2020				2050			
		EU	EU	mena (30% jobs from eu)	others world (10% jobs from eu)	total	EU	mena (30% jobs from eu)	others world (10% jobs from eu)	total	eu total	mena (30% jobs from eu)	others world (10% jobs from eu)	total
Annual installed capacity	MW/y	230	231	53	784	1.069	515	533	433	1.481	833	4.900	22.165	27.899
cumulative installed capacity	MW	1.731	2.425	335	2.876	5.636	5.000	3.000	5.040	13.040	30.000	150.000	670.000	850.000
manufacturing and distribution rate	jobs/MW	25	25	25	25		18,75	16,5	16,5		12,5	12,5	8,25	
installation rate	jobs/MW	15	15	15	15		11,25	9,9	9,9		7,5	7,5	4,95	
O&M rate	jobs/MW	2	2	2	2		1,5	1,32	1,32		1	1	0,66	
manufacturing and distribution	jobs	5.750	5.783	400	1.960	8.143	9.656	2.638	714	13.009	10.417	18.375	18.286	47.078
installation	jobs	3.450	3.470	240	1.176	4.886	5.794	1.583	428	7.805	6.250	11.025	10.972	28.247
O&M	jobs	3.462	4.850	201	575	5.626	7.500	1.188	665	9.353	30.000	45.000	44.220	119.220
total industry	**jobs**	**12.662**	**14.103**	**841**	**3.711**	**18.656**	**22.950**	**5.409**	**1.808**	**30.167**	**46.667**	**74.400**	**73.478**	**194.545**

Notes:

Annual and cumulative installed capacity: data from [2], [6], [11], [12], [13]

Manufacturing and distribution rate, Installation rate, and O&M rate: These include direct and indirect (e.g., supply chain) jobs supported as a result of increased solar-industry activity. These do not include induced jobs

Manufacturing and installation jobs: they are proportional to the annual installed capacity (i.e., equal to the annual installed capacity × manufacturing/installation jobs per MW)

O&M jobs: they are proportional to the cumulative installed capacity (i.e., equal to the cumulative installed capacity × O&M jobs per MW).

Total industry: they are the sum of the direct and indirect jobs, not including induced jobs

Workforce profiles required to achieve the SET-Plan vision

CSP industries include a variety of jobs across their supply chains and in support roles [3]. In measuring economic impact, jobs can be divided among three categories: direct, indirect, and induced jobs, as defined in par. 1.1.4. . Not considering induced job, the range of direct and indirect solar jobs includes the following:

- Manufacturing: Technology research, engineering, raw materials production, assembly line, quality control, shipping, and marketing,
- Project planning: Mechanical, electrical, and structural engineers, energy transmission engineers, architects, project developers, land brokers, contract personnel, environmental consultants, utility procurement staff, local permitting officials, lenders, and investors,
- Installation: Construction managers, installers, pipefitters, electricians, plumbers, labourers, and truck drivers,
- Operations, maintenance, and ownership: System monitors, field technicians, warranty servicing, and accounting,
- Decommissioning and disposal: Demolition, transportation, and recycling services,
- Education and training: Professors, instructors, and administrators,
- Policy, program administration, research, and advocacy: Energy officials, utility program administrators, government-relations staff, trade associations, market analysts, non-profits, and media.

2 Ongoing Actions

With the increasing focus placed by the EU on sustainable power generation, there has been a rapid growth in the number of education programmes dealing with the renewable energy technology sector. CSP is included in a large number of both national and international Master's programmes that deal with sustainable energy; however, the subject is typically lumped together with other solar technologies or even forms only a small part of a general 'renewable energy technology' course. Those programmes that do contain material relevant to CSP systems generally focus simply on comprehension of the operating principals behind CSP technology, with little-to-no emphasis on power plant analysis and design.

The analysis, synthesis and design of CSP-systems demand a highly multi-disciplinary skill-set, with key competencies required in the following fields: solar concentrating optics, high temperature materials, thermal power block engineering, thermal energy storage (both design and operation) as well as grid integration, transmission and power plant operation.

All these issues need to be considered not only from a technical point of view, but also incorporate important economic and social aspects. At the current time, no programmes specific to CSP technology could be found, and as such, the existing programmes do not cover all the different aspects of the required skill-set in sufficient depth.

EU-Wide Educational Programmes

A number of EU-wide educational programmes exist at both the Master of Science and Doctoral levels, in which CSP technology is taught at some level. An EU-wide programme is identified as one which is coordinated between institutions in more than one MS. All these programmes have as their focus the more general topics of renewable or sustainable energy systems, but include the option to study some aspects related to CSP technology. Mobility is a key feature, with all programmes requiring that the students spend time at more than one institution or university.

Master of Science Programmes

Five EU-wide Master of Science programmes have been identified as being relevant to the CSP field, and are presented in the table below. All these programmes accept world-wide applicants, as long as the basic study requirements are met, although tuition fees and the availability of scholarships varies depending upon whether the applicant is from an EU/EEA country. All programmes are taught in English, which facilitates mobility and the recruitment of international students.

The identified programmes all contain some courses relevant to CSP-technology, although none cover the entire skill-base. The majority of the identified programmes contain topics related to thermal design of the CSP power block and some simplified analysis of the concentrator system and thermal energy storage. The SENSE programme covers the issues of grid integration and transmission, which is of key importance for CSP systems; this aspect is largely lacking from all other programmes. Key missing aspects from the existing programmes are a detailed treatment of the optics of solar concentrating systems as well as the high-temperature materials required for the development of solar receiver technology.

A critical issue is the lack of involvement of the key European CSP research institutes in these education programmes, which will significantly limit the scope and quality of the education that can be offered in subjects related to CSP technology.

Organiser	**Programmes**	**Level**	**Mobility**	**Subjects Covered**
KIC InnoEnergy	RENE SELECT ENTECH SENSE	EU	Yes	Power Generation Technology Renewable Energy Technology (*including CSP-systems*) Business & Entrepreneurship
Erasmus Mundus	ME3	EU	Yes	Power Generation Technology (*including CSP-systems*) Business & Entrepreneurship

Doctoral Programmes

Two EU-wide Doctoral programmes have been identified as being relevant to the CSP field, and are presented in the table below. These programmes are the following:

Organiser	**Programme**	**Level**	**Mobility**	**Subjects Covered**
KIC InnoEnergy	SELECT+	EU	Yes	Renewable Energy Technology (including CSP-systems) Entrepreneurship & Social Issues
Erasmus Mundus	SETS	EU	Yes	Grid Integration & Transmission Economic & Regulatory Context

The content of the Doctoral programmes are subject to a great deal of variation, based on the particular research topics made available to the students. PhD-projects related to CSP technology can only be undertaken where a suitably qualified supervisor is available at the institutions in question.

National Educational Activities

In addition to the EU-wide educational activities, a number of nationally organised programmes exist (i.e. involving a single MS) in which CSP technology is taught.

Master of Science Programmes

A specific Master on solar energy is offered by the University of Almería (CIESOL) in collaboration with PSA/CIEMAT which covers both CSP and PV technology in detail. However, this program is poorly promoted and is only available in Spanish, which significantly limits the recruitment of international students. The University of Seville offers a programme on Thermal Systems Engineering with a strong focus on solar thermal power engineering.

The vast majority of technical universities in different MSs offer training in energy-related fields, in which CSP technology is a *possible* topic. Where the university is a recognised centre of excellence the level of individual CSP courses can be very high. However, the courses may form part of an integrated BSc. and MSc. programme, or have university-specific perquisites which make them relevant only to students completing their entire education at one institute.

It is out of the scope of this document to identify all the university-specific courses relevant to the CSP field, but some cases can be highlighted, such as:

- In collaboration with DLR-Solarforschung, RWTH Aachen (Germany) offers courses in CSP technology as part of the Energy Engineering Master programme.
- In collaboration with PSA, the University of Almería (Spain) offers a 9-month master-level course on solar energy, covering CSP, PV and low temperature systems.

Two additional national Master of Science programmes which are designed as self-contained programmes have been identified as being relevant to the CSP field; these programmes welcome international applicants. These programmes are the following:

Programme	**Organiser**	**Level**	**Mobility**	**Subjects Covered**
REMENA	University of Kassel (and Cairo University)	MS	Yes	Renewable Energy Technology (*focused on the MENA region*) Intercultural Communication Economic & Social Issues
REEM	Escuela de Organización Industrial (Madrid / Seville)	MS	No	Renewable Energy Technology (*including CSP-systems*) Economic & Regulatory Context

It is interesting to note that the Master program in Renewable Energy offered by the prestigious ParisTech group of universities does not contain CSP in its syllabus. There is thus a general lack of visibility for the CSP field in renewable energy; the competing field of PV has a much higher visibility and form part of almost all renewable energy programmes.

Master of Science Thesis at National Research Institutes

To obtain of a MSc. degree requires the successful completion of a Master Thesis. Students at universities which have an active research department in the CSP-field have the possibility to perform their Master Thesis on CSP-related topics under the supervision of qualified researchers.

Additionally, a number of high-profile national CSP research institutes offer the possibility to perform Master Thesis projects. In this way students gain the possibility to work at cutting-edge facilities amongst leading experts in the field; however the number of Master Thesis positions offered each year is necessarily limited.

Key research centres involved in CSP-related education through the provision of Master Thesis positions are:

- DLR: German Aerospace Centre, Institute of Solar Research
- IMDEA: Madrid Institute for Advanced Studies
- CIEMAT: Centro de Investigaciones Energéticas, Medioambientales y Tecnologicas
- PSA: Plataforma Solar de Almeria (affliated to CIEMAT)
- Fraunhofer ISE: Institute for Solar Energy Systems
- CNRS PROMES: Processes, Materials and Solar Energy
- ENEA: Agenzia Nazionale per le Nuove Technologie, l'Energia e lo Sviluppo Economico Sostenibile
- CTAER: Centro Tecnológico Avanzado de Energías Renovables

While the completion of a Master Thesis is a good means of providing students which detailed knowledge in one area of CSP technology, if their preceding education has not contained a significant breadth and depth of CSP-related subjects, the topics that can be covered in a Master Thesis are relatively limited.

Doctoral Programmes

The possibility to pursue a PhD in a CSP-related field exists wherever a MS university has an active research department in CSP technology. Additionally, one national Doctoral programme has been identified as a self-contained programme which is relevant to the CSP field; this programme welcome international applicants.

Programme	Organiser	Level	Mobility	Subjects Covered
SES	MIT-Portugal	MS	No	Renewable Energy Technology (*including CSP-systems*) Business & Entrepreneurship

Again, the range of topics on offer for a Doctoral thesis is strongly affected by the specific research focus of the institute in question, and can only be undertaken where a suitably qualified supervisor is available. Most of the institutions mentioned in chapter 1.2.2.2 are offering such opportunities frequently. Apart from that, the EU-SOLARIS research infrastructure project will greatly enhance the ability of doctoral candidates to access top-quality experimental facilities (such as those offered by the institutes listed above).

National and EU-Wide CSP Training Activities

Thanks to the early uptake of CSP-technology in Europe (particularly Spain) the EU has established a dominant position in CSP-related activities. Specific training courses for CSP are offered by German and Spanish research facilities.

Summer/Winter schools form a complement to the MSc. and Doctoral programmes, and can be attended by those enrolled in these programmes as well as members of industry.

- The SFERA (Solar Facilities for the European Research Area) network offers biannual schools on a wide variety of CSP-related topics.
- The annual ISU^{energy} summer school organised by the Helmholtz Institute, Berlin also covers CSP-technology as part of a wider-ranging summer school on renewable energy topics. Invited experts from different EU research institutes are responsible for the teaching.
- The on-going enerMENA programme of the DLR to support the implementation of the CSP technologies in the MENA region offers extensive expert and practical CSP training The activities are funded by the German Ministry of Foreign Affairs. Engineers and technicians from the MENA region may apply for participation. The courses include training at R&D facilities and at industry.

- CIEMAT offers a 2 weeks training course in CSP covering the basic fields of CSP plants using technologies for parabolic troughs, central receiver and Stirling dishes (solar resource assessment, solar field design, plant components and O&M, receivers and materials).

International CSP Training and Education Activities

Numerous countries worldwide are active in CSP and also offer education and training.

The German funded enerMENA international programme managed by DLR developed advanced CSP teaching materials designed for Master courses at MENA and European universities. A network of 12 universities or engineering schools from Morocco, Tunisia, Algeria, Egypt and Jordan are participating in the programme. The implementation process of teaching materials has started by organizing workshops to train the local professors followed by deploying the materials at pilot Master courses at Jordan University, Tunis Engineering School (ENIT), Solar Institute Juelich, Kassel University and Cairo University.

Within Europe, both Swiss Federal Institutes of Technology (EPFL & ETHZ) have active research departments in solar technology, and teach CSP in their MSc. programmes. ETHZ's collaboration with the Paul Scherrer Institute Solar Technology Laboratory also offers the possibility for Master Thesis and Doctoral research at a leading CSP research institute. Additionally, geographical proximity to the EU has allowed Swiss universities to participate in numerous joint research and education programmes.

Several universities in the United States are active in the field of CSP, especially in regions with high solar resources such as California, Nevada, Colorado and Texas. However, undergraduate education in CSP at American universities suffers from similar difficulties to those in Europe, with subject major dispersed between different departments and certain key subjects taught only on a superficial level. At the Master and Doctoral level, there are numerous high-level institutes offering thesis projects, including the National Renewable Energy Laboratory (NREL) in Colorado and the Southwest Research Institute (SwRI). Top-level American universities such as Stanford and MIT are also involved in CSP research.

In Australia, CSP education is centred in universities with access to CSP research facilities, such as the Australian National University (ANU) (with their 500m^2 parabolic dish system). The Commonwealth Scientific and Industrial Research Organisation (CSIRO) also operates research facilities in CSP, and thus offers the possibility for Master Thesis and Doctoral level activities.

The Weizmann Institute Solar Research Facilities and the Ben-Gurion University of the Negev in Israel are active in research and education in the CSP-field, with excellent facilities for Master Thesis and Doctoral research.

In general, outside the EU there are numerous opportunities for PhD-level studies at high quality institutes, but there is a global lack of coordinated CSP-education at BSc. and MSc. levels.

3 Needs and gaps for Education and Training

Specific Education and Training (E&T) in CSP technologies are required both to foster the technology competitiveness by the compilation and transmission of the lessons learned with the technology deployment and by the contribution of an excellent education to accelerate innovation and to accelerate the required training in design, construction, operation and maintenance of the CSP plants.

The actors in the education and training process for CSP are in several sectors and may play different roles, namely:

- Universities (providing a deep and specific education for instructors at all levels, scientists and engineers);
- Training Facilities and Research centres (providing technology overviews and stages for practical training. These facilities may be provided by the commercial CSP plants or by specialized R&D centers);
- Professional E&T platforms (providing short courses and seminars. Some private firms, R&D and technology centres already offer short courses in STE, oriented to different levels. In some cases the training consist in e-learning programs and/or the comprehensive exchange of expertise leading to exams and certification).
- Developers of training tools (like CSP plants simulation software for operation and maintenance).

Most of these actors may play a double role, both as providers and users in the E&T process.

The CSP industry is the main final 'consumer' of the E&T process. In the CSP industry we find different needs, depending on the workforce profile:

- Researchers;
- Engineers, O&M management and technicians;

There is also a need of specific E&T activities directed to decision makers: officials of the different administrations, project consultants, etc.

Research and high-level education

R&D scientists and engineers have normally a background in engineering (mechanical, chemical, energy…), physics or chemistry with a post-grad specialization in CSP-related fields obtained either by following master or doctoral courses or by practical training at the industry or research centres. Researchers play a prominent role in the development of an emerging technology as CSP is. There is a strong interest in young graduates to work in the CSP field. As an example, not less than 40 CSP-related Final Projects and M. Sc. Theses have been presented at the Seville Engineering School (Spain) during the last 5 years [L2].

Bottlenecks, gaps and barriers

- *Lack of CSP-oriented or -specialized courses and programs at the master and doctoral levels*

These courses would help the recent graduates achieve the required knowledge and abilities in a rational and orderly way. Currently available courses are very general and usually have a very broad scope related to all or several renewable energies. In addition, they are usually taught in the national language and lack visibility. The complexity of large CSP plants requires specific educational programs to cover in a proper manner all the aspects involved (solar field, power block, thermal storage, automation and control, operation and maintenance requirements,..). These programs should be complemented with practical training in adequate labs and facilities, which most of European universities don't have.

- *Lack of specialized or "CSP-educated"[1] teaching and technical staff*

This lack of specialized staff is a clear bottleneck to implement good and efficient E&T programs on STE, because efficient programs require a staff composed primarily of people who are at the same time good teachers and technical experts with practical experience. Such specialized staff is required not only for teaching, but also to define the planning and content of the courses.

- *Limited training capabilities of R&D centres and universities*

Although there are several outstanding European R&D centres, laboratories and universities with experience and CSP experimental facilities, they all have a very limited capacity to host trainees because of the lack of appropriate infrastructure or training staff.

Needs

- *Development of specific programmes at postgraduate level including practical training in R&D centres and industry*

There is an obvious need and demand of such programmes as the best way to educate and train future researchers and educators in an orderly and rational way. Theoretical education has to be complemented with practical training at R&D facilities and labs, either at specialized R&D centres, universities or industry.

- *Increase of the training capabilities of university departments and R&D centres.*

The <u>creation of specific training departments with allocation of proper budget and staff</u> at R&D centres and the improvement of existing labs and facilities or the creation of new ones at selected university departments with activity in CSP would provide more opportunities for training to future researchers and educators.

---

[1] Hi-level education for scientists and engineers will require not only a broad understanding of the CSP technology, but also more specific courses –for example: mechanical and optical design of concentrators. This instruction can be provided by professors specialized in the relevant subjects, but they must understand the specifics of the application of their knowledge to the CSP field.

- *Elaboration of a Catalogue of European laboratories, universities and R+D centres with experimental facilities available for training*

This catalogue should provide a complete overview of resources currently available. Such a catalogue, although not exhaustive, would allow the identification of gaps in the capacities available for training, and priorities for new infrastructure could be thus defined.

The availability of a catalogue would also allow the identification of synergies among different centres to share their resources and define joint or complementary training programs. Some steps have been already given in this direction to make use of synergies among centres. The Sollab alliance (composed of the European R+D centres devoted to solar concentrating systems) is a clear action aimed at achieving a better and more efficient collaboration among the partners.

- *Enhancement of exchange and mobility programs between R&D centres, universities and industry*

Cooperation and exchange within the R&D European community has been promoted via the successive European Commission Framework Programmes in general, with more specific actions like SFERA and the recently initiated EU-Solaris, which constitute a transnational access network that put at disposition of the scientific and industrial European community free access to the facilities and educational-training services. The existing programmes are clearly insufficient and should be enhanced with other specific actions at the university level, for exchange of students and educators between departments of different European universities and R&D centres.

Engineering, O&M

Bottlenecks, gaps and barriers

- *Insufficient availability of skilled engineers and technicians*

As in the case of the R&D staff, there is a bottleneck in the CSP industry due to the unbalance between demand and availability of skilled engineers and technicians. This reflects the existing gap in the education and training system, where specific education and specialization programs at graduate level are practically inexistent. An efficient educational program directed to engineers wishing to work in the CSP industry must include both theoretical knowledge and practical training. While theoretical education can be provided by universities, R&D centres or even by private firms, the best training for CSP engineers and scientists willing to work at the industry is that taken on-site at commercial CSP plants, where students can learn how to face both usual O&M problems and unexpected situations. The day-to-day work with the staff of the commercial plant will provide the students with an invaluable experience and training, which will be very much appreciated by the companies searching for qualified manpower.

- *Absence of CSP topics at the graduate level curricula*

The lack of CSP-related topics in the curricula of the different engineering majors at graduate level, with only a few exceptions in the European universities, has already been identified as one significant gap in the CSP educational system.

- *Lack of practical training offer*

On-site training at commercial CSP plants is without any doubt the best option concerning operation and maintenance issues. For scientific, design and engineering practical issues, R&D centres and test facilities and universities with experimental facilities can provide a valuable training and hence would perfectly complement the theoretical training. CSP plant owners are very reluctant to provide practical training, because they are worried about the possibility of losing technological advantages if another competing company then contracts the students. This attitude is very common at the early stages of emerging technologies, when intellectual property and confidentiality issues are a very important concern, and CSP is clearly an emerging technology. However, it is foreseen that this situation will change in a few years, once the CSP technologies are more mature and the number of companies involved in this market increases.

Needs

- *Basic CSP related topics in the engineering curricula at the grade level*.

The inclusion of CSP related topics, like solar radiation or introductory courses to the technology, would increase the awareness of the technology among students and the number of potential researchers in the CSP field.

- *Virtual specialization courses.*

The development of high quality virtual specialization courses by skilled teachers would provide engineers working at the industry, as well as other engineers interested in the field, with a means to continue their education without the need to be subject to strict timetables and at a lower cost.

- *Improve the training capabilities of universities and R&D centres*.

As explained before, the establishment or improvement of training facilities at universities and R&D centres, with allocation of proper budget and staff to the training departments, would increase the currently limited capacity for training at R+D centres and universities.

- *Development of Training CSP Plant Simulators*

Besides the "hardware" tools (laboratories, test facilities), an excellent education and training requires the access to excellent "software" tools. Among the different types of software tools used in the CSP sector, perhaps the most relevant for the training of engineers and operators are the Training Simulators. The purpose of this type of tools is to shorten the commissioning time, increase the quality and train the operators of a CSP plant. Training Simulators have to provide, among others, the following capabilities:

- Interactive and quasi- real time training environment.
- Design verification of Control Software (e.g. Open Loop Control and Closed Loop Control)
- Operator training environment for DCS-System and CSP plant operation, including the capability to simulate start up and shutdown, part load, transient and critical plant operating conditions.

Management, consultants, decision makers

Bottlenecks, gaps and barriers

- *Insufficient technical background*

Managers, consultants and decision-makers at all levels frequently lack sufficient technical background, especially referred to CSP. However, they need at least a basic knowledge of the technology in order to perform adequately their functions and be able to take decisions or report on specific items.

Needs

- *Executive courses oriented to management and consulting*

There is a demand of specialized, executive education from the management and consultants acting in the CSP industry. This demand has been covered so far by different types of events, like conferences, meetings and symposiums, mainly organized by private firms with experience in the organization of these events oriented to different fields. Most of these firms seek support in the industry itself as well as R&D centres and departments. The proliferation of these events has not gone always together with the necessary quality requirements. On the other hand, these events tend to be expensive and time-consuming, although frequently they add the possibility of networking to their attractiveness. The organization of executive short courses oriented to managers and consultants by universities or other institutions related to education would help to clarify the panorama in this field, while guaranteeing the quality of the education. These courses could have even a broader acceptance if they were virtualized, making it easier for the target audience to follow them.

4 Recommendations at EU and MS level

As an overall conclusion it may be stated that CSP is a technology field that requires a broad variety of skills and such the education and training activities should be harmonized with other technology fields with similar needs. The action proposed in the following may also be valuable for other technologies, although variations and specializations are additionally required for each technology, so for CSP.

In this chapter concrete actions are proposed to fill the gaps of skills, competences and knowledge, to foster the public involvement, access and up-take by the labour market and finally to plan and enable skills development, transfer and recognition.

Heading 1: Filling the skills, competences and knowledge gap – actions where the focus is on education and training

1.1 Clusters of Excellence

Clusters of Excellence are an important strategic instrument to connect universities with leading research institutes and businesses. The actual situation in the CSP R&D sector is dominated to a high extent by technological development. A broad basic research, in other sectors typically performed by universities, is actually realized by some research institutes and even at industry with only limited resources. The main focus actually lies in a quick deployment of innovative ideas towards the product. This may be typical for young technologies. However, there should be made an effort to link the three sectors (universities, research institutes and industry) through clusters of excellence. This would not only be beneficial for the R&D work and progress itself but also have a strategic impact on education and training. Support on EU level for such Clusters of Excellence would help to fill the skills, competences and knowledge gaps.

The instruments to implement Clusters of Excellence should be basic and applied R&D clusters, operating for an extended time frame of up to 5 years that focus each on specific technology topics such as innovative coatings, high temperature absorber materials, innovative cycles etc. These clusters should base on already existing knowledge at some universities but not limited to them and be extended significantly during the course of the projects. Young scientists in a larger number than today should be allowed to do basic research through their master and especially PhD careers together with their professors. The transfer of this basic research results into applied research should be realized through the research institutes. CSP requires often large infrastructure when it comes to applied research. These are only available at the research centres and should be made available through specific access programs to the researchers from the universities. On the other hand, the research institutes rely on staff that had been already educated at universities with a high degree of specialization on the CSP topics. A frequent exchange of personnel through instruments such as Clusters of Excellence foster the dissemination of knowledge between the universities and research institutes and such help to prepare teaching materials of high quality and, especially when linked closely to the industry, also materials with an extremely high practical value.

Action 1: Creation of Network for advanced CSP technology development

Ideally, all fields of CSP subtopics relevant for a broad education and training such as optical components, thermal transfer, absorbers, heat exchangers, turbines, thermal and chemical storage, cooling etc. should be covered by different Clusters of Excellence to be able to progress as much as possible in the technology development. Taking into account limited resources it is recommended to create only one Cluster of Excellence ("Network for advanced CSP technology development"). This should conduct joint and collaborative R&D activities in the above listed fields and implement education and training programmes for young researchers.

EQF level 6-8
Time frame: Start Year 0 for 5 years

1.2 Network of Universities

Advanced network for CSP education and training

This network to be created should focus on the design and implementation of education and training materials. Due to the strong interdisciplinary character of CSP many different technology fields must be covered to provide a good and appropriate education and training according to the demand of research institutes and industry sector. The network should develop and implement relevant curricula at the university level. Since CSP is not just relevant for the domestic market involving the southern member countries in the EU, the curricula should be opened as much as possible to neighbouring countries from the southern Mediterranean through joint degrees. This is especially important since the largest market for CSP will be in this region and well educated and trained local personnel is required for a proper building and operation of the solar plants.

Action 2 European Bachelor, Master and Doctoral Curriculum "Concentrating Solar Power"

After the creation of the network involving the universities already involved in the education and training in CSP, a programme should be developed for the implementation of new BA, MA, PhD curricula. The network should make a detailed analysis on capacities at universities how to cover all the different disciplines necessary for these curricula, but also where to allocate these curricula evenly over Europe. It should also be elaborated how to realize double or joint degrees on the European, but also on the EU-MENA level. A concept for life-long learning as well as e-learning should be elaborated and implemented. The teaching materials should be prepared involving the networks stakeholder including also the research institutes and industry. The implementation of the curricula should take into account that industry should be involved as much as possible and linked to the students already during their university career to disseminate first-hand information from industry.

EQF level 6-8
Time frame: Start Year 0 for 4 years; prototype curriculum should be implemented in Yr 3, final broad implementation in Yr 4

1.3 Network of Professional Training Centres

Education and especially training in CSP involves today mostly large installations and facilities. These are mainly available at research institutes and should be taken into consideration especially for the use in the training activities. However for vocational training it would be advisable to setup laboratory scale training facilities distributed over Europe which not essentially requires large scale facilities normally only available in the southern countries.

Action 3: Implementation of Vocational Training

This action should comprise the analysis of the actual situation and needs and the development of a strategy for a proper implementation of vocational training activities. Furthermore the training materials should be elaborated and prepared. The training scope should be focused on laboratory scale with some additional and optional component with access to large scale facilities for training purposes. Sun simulator technology should be considered to support those institutions in providing reliably and flexible the training capacities.

EQF level 1-5 (Vocational training)

Time frame: Start Year 0 for 4 years

Heading 2: Fostering public involvement, access and up-take by the labour market – actions where the focus is on spending time in industry/research organisations

Education and Research/Industry Partnerships

Cooperation and exchange in European networks and alliances would be very helpful for universities (for designing their modules and programmes) and students (looking for orientation for their career choices) and industry (looking for experts and qualification programmes).

2.1 Mobility and Cooperation Partnerships

For CSP it is extremely important to provide mobility and cooperation possibilities since many of the research staff, but also industry or other institutions have only scarce choices for access to facilities or research cooperations. Actually initiatives like SFERA, EERA, EU-Solaris are already taking account of those limitations and offer special access programs, but they are restricted to these individual programmes and thus time limited. However, mobility and cooperations should be long term and continuous activities. They should not be limited to research institutions, but rather open also new facilities and institutions for such mobility programmes. The networking and joint planning of universities and research institutes concerning education and training will help to provide much more options than those that are available today.

Action 4: Establishment of a mobility and cooperation programme

The programme should address research and technical staff in higher education and research institutions but should also include industry. Goal is to provide access to facilities such as laboratories at universities as well as large scale facilities at research institutes. Additionally and if possible, industry should provide first-hand experience through special programmes with access to their pilot or demonstration plants. There should be frequent Call for Proposals for such access, at least twice a year. Although it is desirable to initiate also research cooperations through this programme, it should not be limited to this. Teaching staff should be supported by this programme to enlarge their knowledge about the different aspects of the CSP technology and foster the implementation of this knowledge into the teaching materials which are to be constantly improved and updated.

Another aspect is the provision of opportunities for research and teaching staff to take part in industry activities. Although particularly difficult due to IP considerations, there should be a strong support where ever possible and desired. It is important to prepare a standard legal base to ease and support such desired stays or cooperations.

Also, there should be drawn special attention to the cooperation with the MENA region and its teaching staff. The progress of the CSP technology in desert regions will be to a high degree depend on such cooperations. The local staff should be supported since this will be the appropriate way to enhance relationship in technology deployment in the MENA region. These cooperations should cover both the educational as well as the industry sector. Exchange of research personnel and the support of scientific cooperations is the adequate measure to be applied.

EQF level 4-8
Time frame: Start Year 0 for 4 years

2.2 Industrial Doctorate Programmes

In order to allow industry for a quick development of innovative products, excellent applied research is an appropriate method from the idea to the product or product improvement. Industry often is not aware of opportunities to catalyse the desired development by excellent research. Thus a programme is needed to facilitate access to available skills at universities or research institutions.

Action 5: Establish industrial doctoral programme

The establishment of such programme should enable industry to localize skilled partners from universities and research institutions to provide academic support to the doctoral career of candidates working in industry. A data or information base is required to ease the contact and find efficiently suited partners. A quality control should be applied to guarantee a high degree of success. Standards for IP relevant aspects should be implemented.

EQF level 6-8
Time frame: Start Year 0 for 4 years

2.3 Infrastructure Support to Education and Training:

There is a variety of different infrastructures or facilities in CSP desirable to be provided for education and training. The education sector demand is rather focused on small scale infrastructures for teaching purposes which is located directly at the universities. These may be laboratories which provide hand-on experimental hardware based on artificial radiation sources as sun simulators and instruments and facilities in laboratory scale. Additionally, access to large scale facilities to experiment also real scale conditions must be provided since not all topics of CSP can be covered in the lab scale. The large scale facilities should complement the lab scale facilities in a well-structured and organized way to be cost-effective. This infrastructure support may be on a national but also international level, depending on the national capacities. Those countries that lack such national programmes should be provided with programmes on EU level. This is essential to be able to increase the number of PhD students, since they need such access to infrastructure over a long period of time to conduct complex studies and complete them during several experimental phases.

Action 6: Programme to build up infrastructure for education and training purposes

A programme should be established to develop in a first step a plan for necessary infrastructures both at universities and research institutes. The scope is to provide excellent education and training conditions through available infrastructure for different levels of curriculums (BC, MA, PhD). Hardware should be acquired and teaching staff must be prepared to upgrade current available capabilities in infrastructure and human resources. A programme for the trainer's education as well as for the training itself should be elaborated and prepared based on the requirements for the curricula. An access programme for external researchers or cooperation partners should be established. Specific measures are to be defined for the integration of infrastructures outside the EU into this programme, namely from the MENA region. Research and test platforms combined with training centres are actually planned or already under construction in several countries which could provide excellent conditions and possibilities for access to pilot or demonstration scale plants for European researchers.

EQF level 3-8
Time frame: Start Year 0 for 4 years

2.4 Industrial Training Centres (not applicable)

2.5 Knowledge Alliances (included in 1.1)

Heading 3: Planning and enabling skills development, transfer and recognition

3.1 Virtual learning and information platforms

Since the speed and flexibility in learning and information gathering is constantly increasing it is important to also adopt to these circumstances in the education and building sectors. A lot of benefits can be drawn when it is achieved to provide information with remote access and not limited to a certain period of lifetime of the staff (lifelong learning). Today many employees have limited or no access to specific educational measures and rely a lot on commonly available information or on the companies willingness for further education beside the daily job.

Action 7: Creation of an information data base for CSP

Due to the fact that technical and economic data of CSP are often not available or accessible, a data base is proposed to be established to ease information gathering for the educational sector.

EQF level 6-8
Time frame: Start Year 2 for 2 years

Action 8: Simulator for operational personnel

The plant operation is a complex matter and many information need to be accessible for an operator to avoid loss of performance of the plant or endanger the safety of personnel or equipment. Today, operators are trained mainly by more experienced personnel of the operation companies. If new concepts or schemes are implemented operation errors may occur due to the lack of experience. Also, it is important to structure the teaching and training of operation personnel accordingly to prepare such personnel to all eventually upcoming problems. This training in simulators is also important for experienced personnel to frequently fresh up information and simulate possible upcoming problems.

EQF level 3-8
Time frame: Start Year 0 for 4 years

References

[1] EASAC 2011

[2] ESTELA Five Years Report Final 2012

[3] EERE SUNSHOT VISION STUDY 2012

[4] ESTELA Roadmap 2010

[5] IEA-OECD Technology Roadmap - Concentrating Solar Power 2010

[6] Protermosolar - Macroeconomic impact of the STE Industry in Spain, October 2011

[7] 2010 - ESTELA - STE-ESII Implementation 10 05 26 - REV-4

[8] Estela and AT Kearney, June 2010. Solar Termal Electricity 2025. Available online on http://www.estelasolar.eu/fileadmin/ESTELAdocs/documents/Cost_Roadmap/2010-06%20-%20Solar%20Thermal%20Electricity%202025%20-%20ENG.pdf

[9] Pitz-Paal, R., Dersch, J. and Milow, B. (2005). European Concentrated Solar Thermal Road-Mapping (ECOSTAR): roadmap document. SES6-CT-2003-502578

http://www. promes.cnrs.fr/uploads/pdfs/ecostar/ECOSTAR.Summary.pdf

[10] McCrone, A.; Peyvan, M.; Zindler, E. (2009). *Net Job Creation to 2025: Spectacular in Solar, but Modest in Wind, Research Note*. London: New Energy Finance.

[11] 12th EurObsrevÉR Report: The state of renewable energies in Europe, Edition 2012 (available online at http://www.energies-renouvelables.org/observ-er/stat_baro/barobilan/)

[12] ESTELA Position Paper: The essential role of solar thermal electricity, October 2012

[13] Protermosolar; press release available online at http://www.helioscsp.com/noticia.php?id_not=1721

[L1] http://www. estelasolar.eu/index.php?id=116

[L2] http://bibing.us.es/proyectos/materia/solar. Accessed September 28th, 2012.

SET-Plan Energy Education & Training
Electricity Grids

Electricity Grids

Working Group Contributors

Edited by Lothar Fickert (Rapporteur), Graz University of Technology, Austria

Based on the SET Plan Education for Electricity Grids Working Group consisting of :
(in alphabetical order)

Yvon Besanger, (Grenoble-INP, FR) Grenoble Institute of Technology, France

Antoneta Bradcu, (Grenoble-INP, FR) Grenoble Institute of Technology, France

Andrés Llombart Estopiñán, Universidad de Zaragoza, Spain

Lothar Fickert Graz (Rapporteur), University of Technology, Austria

Olav Fosso, Norwegian University of Science and Technology, Norway

Terje Gjengedal, Statnett, Norway

Thomas Hamacher, Munich University of Technology, Germany

Paulien Herder, Delft University of Technology, Netherlands

Luciano Martini, RSE, Italy

Mart van der Meijden, Tennet

The authors would like to thank the following persons for their valuable input:

Dipl.-Ing. Dr. Klaus Bernhard

Dr. Barbara Schmidt, Österreichs Energie

Dipl.-Ing. Eva Pfiszter, Graz University of Technology

Dr. Michael Narodoslawsky, Graz University of Technology

Karin Sonnleitner, University of Graz

1 Current Situation

Electricity Generation and Distribution

In 2010 the total net electricity generation in the EU-27 amounted to 3.18 million gigawatt hours (GWh)– which marked a 4.5 % increase compared with the previous year and almost fully offset the reduction of 4.9 % that had been posted in 2009 (reflecting the impact of the financial and economic crisis) – see Table 1. As such, the level of net electricity generation in 2010 returned close to its peak level of 2008 (3.20 million GWh).

In 2010, Germany had the highest level of net electricity generation among the Member States, accounting for 18.6 % of the EU-27 total, just ahead of France (17.1 %); the United Kingdom was the only other country with a double-digit share (11.5 %).

The pattern for the EU-27, observing declined electricity generation in 2009 and a recovery in 2010, was reproduced in the majority of the Member States. However, there were some notable differences, as net electricity generation declined during consecutive years in Greece and Malta, while there was a reduction of 62.2 % in electricity generation in Lithuania in 2010; the latter may be attributed to the closure (at the end of 2009) of Lithuania's last nuclear reactor. By contrast, neighbouring Estonia saw its net electricity generation rise by 48.8 % in 2010, in part due to an increase in renewable energy sources — combined heat and power plants consuming wood fuel and generation from wind energy.

More than one quarter of the net electricity generated in the EU-27 in 2010 came from nuclear power plants (27.3 %) while almost double this share (54.8 %) came from power stations using combustible fuels (such as natural gas, coal and oil). Among the renewable energy sources shown in Figure 1, the highest share of net electricity generation in 2010 was from hydropower plants (12.2 %), followed by wind turbines (4.6 %) and solar power (0.7 %).

The relative importance of renewable energy sources in relation to EU-27 net electricity generation grew between 2000 and 2010, while there was little change in the relative importance of combustible fuels and a reduction in the amount of electricity generated from nuclear power plants. The share of net electricity generation from nuclear energy declined from 31.2 % in 2000 to 27.3 % in 2010. Among the renewable energy sources the proportion of net electricity generation from solar and wind increased greatly although the share of solar remained small, increasing from close to nothing in 2000 to 0.7 % by 2010; the share from wind turbines increased from 0.8 % in 2000 to 4.6 % by 2010.

Table 1: Net electricity generation, 2000-2010 (in TWh)[1]

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	Share in EU-27, 2010 (%)
EU-27	2'863	2'943	2'964	3'050	3'119	3'140	3'182	3'196	3'203	3'045	3'181	100.0
Euro area	1'995	2'040	2'069	2'136	2'194	2'204	2'245	2'258	2'275	2'159	2'268	71.3
Austria	59.1	60.1	59.9	57.4	61.4	63.5	62.2	63.2	64.6	66.8	68.3	2.1
Belgium	80.3	76.2	78.1	80.9	81.7	83.4	82.0	85.1	81.4	87.5	91.4	2.9
Bulgaria	36.9	39.6	38.6	38.5	37.5	40.3	41.6	39.1	40.7	38.7	42.2	1.3
Cyprus	3.2	3.4	3.6	3.8	4.0	4.1	4.4	4.6	4.8	4.9	5.1	0.2
Czech Republic	68.0	68.8	70.4	76.7	77.9	76.2	77.9	81.4	77.1	76.0	79.5	2.5
Denmark	34.4	36.2	37.3	43.8	38.4	34.4	43.2	37.4	34.9	34.5	36.8	1.2
Estonia	7.6	7.6	7.7	9.2	9.2	9.1	8.7	11.0	9.5	7.9	11.7	0.4
Finland	67.3	71.2	71.6	80.4	82.2	67.8	78.6	77.8	74.5	69.2	77.2	2.4
France	516.9	526.3	534.9	542.5	549.7	550.3	549.1	544.6	548.8	515.2	544.5	17.1
Germany	538.5	548.2	549.3	567.9	576.8	581.6	597.2	598.4	598.9	556.8	591.4	18.6
Greece	49.9	49.7	50.6	54.3	54.9	55.7	56.5	59.1	59.4	56.1	53.4	1.7
Hungary	32.3	33.7	33.5	31.4	31.3	33.2	33.3	37.2	37.4	33.3	34.6	1.1
Ireland	22.7	23.7	23.9	24.1	24.4	24.8	26.1	26.9	28.9	27.1	27.5	0.9
Italy	263.3	266.0	270.8	280.2	290.0	290.6	301.3	301.3	307.1	281.1	290.7	9.1
Latvia	3.7	3.7	3.5	3.5	4.2	4.4	4.5	4.4	4.9	5.2	6.1	0.2
Lithuania	10.0	13.2	16.1	17.9	17.7	13.6	11.4	12.9	12.8	14.1	5.3	0.2
Luxembourg	1.1	1.6	3.7	3.6	4.1	4.1	4.3	4.0	3.5	3.8	4.6	0.1
Malta	1.8	1.8	1.9	2.1	2.1	2.2	2.1	2.2	2.2	2.0	2.0	0.1
Netherlands	86.0	89.9	92.1	93.0	98.4	96.2	94.4	100.9	103.4	108.9	114.3	3.6
Poland	132.2	132.7	131.4	138.4	140.8	143.6	147.7	145.4	141.5	137.9	142.9	4.5
Portugal	42.2	44.8	44.4	45.4	43.5	45.0	47.5	45.9	44.6	48.7	52.8	1.7
Romania	48.6	50.4	51.1	51.3	52.7	55.5	58.4	56.2	60.1	52.8	55.6	1.7
Slovakia	27.7	29.6	30.0	28.7	28.2	29.3	28.9	25.8	26.6	24.1	25.4	0.8
Slovenia	12.8	13.6	13.7	12.9	14.3	14.1	14.1	14.0	15.4	15.4	15.4	0.5
Spain	214.4	226.0	232.7	250.2	268.7	282.1	287.7	293.2	301.5	283.4	292.1	9.2
Sweden	141.6	157.6	143.2	132.5	148.5	154.6	140.4	145.1	146.4	133.3	145.3	4.6
United Kingdom	360.8	367.4	370.1	380.1	376.9	380.5	378.8	379.1	372.4	360.2	365.3	11.5

Electricity Market Shares and Market Liberalization

One measure that is used to monitor the extent of electricity market liberalisation is the market share of the largest generator in each country (see Figure 7). The small island nations of Cyprus and Malta were both characterised by a complete monopoly in 2010, with 100 % of their electricity being generated by the largest (sole) generator. Five other Member States – Estonia, Latvia, France, Luxembourg and Greece – reported shares of at least 85 %. In 13 of 24 Member States for which data are available, the largest generator provided less than 50 % of the total electricity generated, with the lowest share (17.4 %) recorded in Poland.

[1] http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Electricity_production,_consumption_and_market_overview

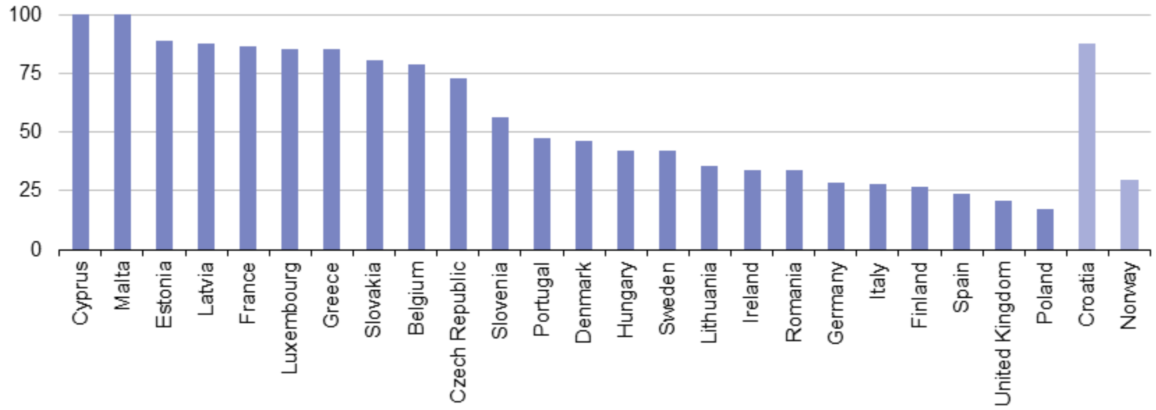


Figure 7: Market share of the largest generator in the electricity market, 2010; (% of total generation) Bulgaria, the Netherlands and Austria, not available. Source: Eurostat (online data code: tsier060)

Household Electricity Consumption

During the ten-year period from 2000 to 2010, the consumption of electricity by households in the EU-27 rose by 18.0 % (see Figure 8). There was higher development in a number of Member States, in particular Spain, Cyprus, Romania, Portugal, Poland and all of the Baltic Member States – where growth was at least double the EU-27 average. At the other end of the range, household electricity consumption fell in four of the Member States – Sweden, Malta, Belgium and Slovakia – in the latter the reduction in electricity consumption by households was almost 20 %. This figure on overall household electricity consumption are likely to be influenced, in part, by the average number of persons living in each household and by the total number of households – both of which are linked to demographic events.

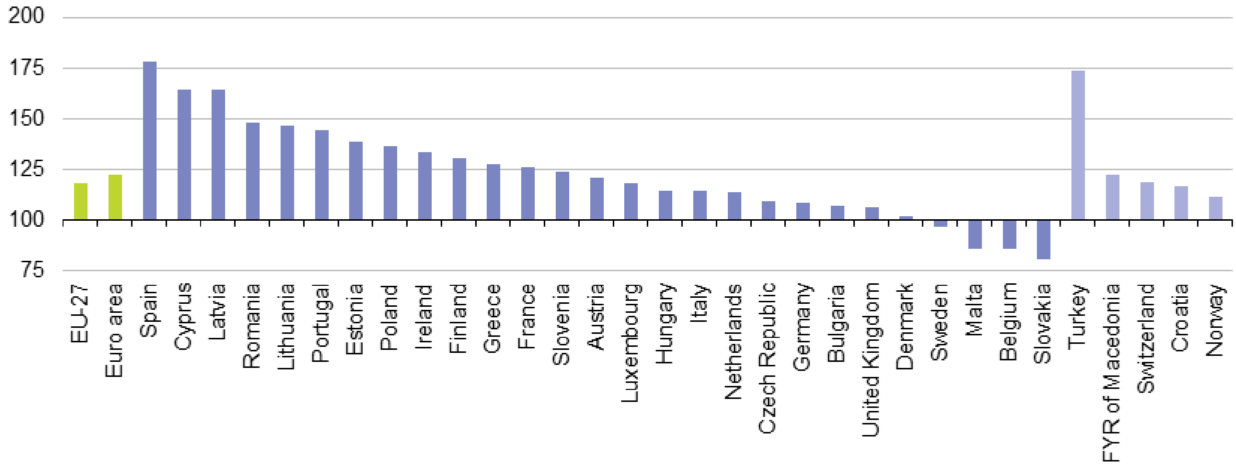


Figure 8: Electricity consumption growth by households, 2010 (year 2000=100%)

Future Trends

Qualitative Trends

The main challenge in the field of electrical networks is on the one hand growing in feed of small-scale distributed generation and on the other hand the integration of renewable energy on a large scale into the electrical networks. The electrical networks as a whole can be understood as "transportation machine": the electric power system is controlled by the consumer and the electrical power must be provided practically without delay because of the fundamental principle of energy conservation. More precisely: the electric power system is controlled by the load.
Therefore, the load or the load developments are used as a starting point for the future developments in the following.

Due to the increase in decentralized generation, which is defined as generation connected to the distribution levels (0.4 kV up to 45 kV), investments have to be made in this voltage level on order to enable these networks for their new task. It is expected that these low voltage levels in the information and communication technology (ICT) are increasingly gaining a significant impact. Therefore these networks are also known as smart grids. It is expected that especially in these smart grids new ICT skills will be necessary. As these networks make up the predominant share of the realised investment costs, a considerable demand both in investments from the network operators as well as new products supplied by the electrical energy equipment manufacturing companies and in accordingly trained personnel is expected.

The integration of renewable energy on a large scale requires the creation of new transport paths for the transmission of bulk electrical energy over long distances. Here, the high voltage direct current technology (HVDC) is currently provided. This technology involves many challenges (multi-point networks, circuit breaker solutions, protection, etc.) which are to be solved by appropriately trained professionals.

Apart from these technical issues, the desire to increase the system's overall efficiency leads to new solutions, for example load management and load condition-based adjustments to the network topology.

Current Situation and Outlook Concerning the Workforce and Qualification

General Remarks

In this section the current situation of the workforce is described and an outlook is given for the estimated development in the timeframe from 2013 till 2030.

The workforce is allocated either to

- network companies who organise the investment activities and manage the operation of the existing networks
- electrical energy equipment manufacturing companies

Workforce Status Quo and Outlook for Network Companies in EU-27

▸ *Status Quo for Network Companies*

Network companies are entities which transport and distribute electrical energy. Due to the present unbundling approach in the European Union they are neither involved in the production nor in the application of electrical energy.

▸ *Methodology:*

Based on the validation of the following methodology by using Austrian network companies the energy turnover of all the network companies' sector in EU-27 is determined. In a second step – by applying the tariffs for the transport and distribution – the annual financial turnover of this sector is determined. Taking the turnover per employee (TPE) as key performance indicator (KPI), the total workforce is determined in a last step.

▸ *Energy Turnover*

The total annual turnover of electrical energy in EU-27 is given by statistics as **3'200 TWh**

This amount of transported and distributed electrical energy is divided into

- private consumption:
  65% (estimate) of 3'200 TWh = 2'100 TWh
- industrial consumption (small, medium and big enterprises):
  35% (estimate) of 3'200 TWh = 1'100 TWh

▸ *Transport and Distribution Cost*

As basis for the resulting transport and distribution costs (= grid costs) the different tariffs for the a.m. sectors are given on an average basis for EU-27 by

- private consumption: 0.054 €/kWh (EU-27 average)
- industrial consumption: 0.030 €/kWh (EU-27 average)

▸ *Total Cost of Transport / Distribution of Electricity:*

By merging these data the total cost of transport and distribution (= grid costs) is derived:

- private consumption: $2'100*10^9$kWh @ 0.054 €/kWh = $110*10^9$€
- industrial consumption: $1'100*10^9$kWh @ 0.030 €/kWh = $33*10^9$€

Together this yields as total cost of transport / distribution = **turnover: $143*10^9$€**

▸ *TPE (Turnover per Employee)*

As turnover per technical employee a value of 570'000€ per employee (P) is considered for further calculations. (As a reference from Austria see Appendix 2)

▸ *Total Work force*

$143*10^9$ € / $570*10^3$ €/P = $0.25*10^6$ €/P = **250'000 technical employees in network companies**

▸ *Assignment of the Workforce to Different Network Types and Workgroups*

Assuming a distribution of the total technical workforce (see above) into the different grid voltage level types (EHV + HV) : MV : LV as 5% : 15% : 80% as in Table 2; and also a certain share of different workforce **qualification** into research / engineers / technicians / vocational for the different grid voltage level types as given in Table 3

Table 2: Distribution of workforce in network companies into different grid voltage level types

Workforce		
Grid Type	EHV + HV	5 %
	MV	15 %
	LV	80 %
	Sum	100 %

Table 3: Share of workforce qualification in network companies for the different grid voltage level types per 2013

Workforce		Qualification				
		Research	Engineers	Technician	Vocational	Sum
Grid Type	EHV + HV	2.5 %	57.5 %	30 %	10 %	100 %
	MV	2.5 %	35 %	37.5 %	25 %	100 %
	LV	1 %	9 %	10 %	80 %	100 %

The resulting allocation of the total workforce of 250’000 in terms of % and qualification respective to the different grid voltage level types is given in Table 4.

Table 4: Resulting allocation of workforce qualification in network companies respective to different grid voltage level types per 2013

Workforce			Qualification			
			Research	Engineers	Technician	Vocational
Grid Type	EHV + HV	5 %	0.1 %	2.9 %	1.5 %	0.5 %
	MV	15 %	0.4 %	5.3 %	5.6 %	3.8 %
	LV	80 %	0.8 %	7.2 %	8.0 %	64.0 %
Total Workforce		100 %	1.3 %	15.3 %	15.1 %	68.3 %

Multiplied by the total number (250’000) the allocation of the technical employees in terms of absolute number and qualification respective to the different grid voltage level types is given in Table 5 as per 2013.

Table 5: Total number of workforce qualification in network companies respective to different grid voltage level types per 2013

Workforce 2013			Qualification			
			Research	Engineers	Technician	Vocational
Grid Type	EHV + HV	13’000	310	7’200	3’800	1’300
	MV	37’000	940	13’000	14’000	9’400
	LV	200’000	2’000	18’000	20’000	160’000
Total Workforce		250’000	3’300	38’200	37’800	170’700

Outlook for Network Companies

It is a reasonable point of view to correlate the workforce with the total annual turnover of electrical energy to a certain degree. Within the context of this assessment report the main line of deriving an outlook is given by the fact that – on one hand - electrical grids, due to their planning and operating characteristics and to the impact of the huge amount of invested money, have a lifetime of 30 to 40 years and – on the other hand – by the assumption that no real profound and all-pervading revolution is foreseen in the field of technology of electrical networks.

Further the electric power industry (especially network operators) is in a restructuring phase. Within this process the regulators tend to increase the networks' efficiency. This in turn stimulates zero growth in the workforce. These restrictions are assumed to last until 2020.

Subsequently it is expected that the workforce starts to grow again in correspondence to the expected annual growth in electricity consumption of 2.4%, but not to the full extent. Assuming that 50% of this increase will be offset by rationalization, it is expected that from 2021 until 2030 the number of technical employees in the networks is increasing at 1.2% per year.

Forecast of the Development of the Number of Technical Employees

In a next step the development of the number of technical employees is calculated for the workforce in the network companies (see Figure 9).

A more detailed representation of the development of the estimated workforce of technical employees in the network companies for the period 2013-2030, divided into different grid voltage level types resp. according to the workforce qualification is given in the Appendix 3, see Figure 14.

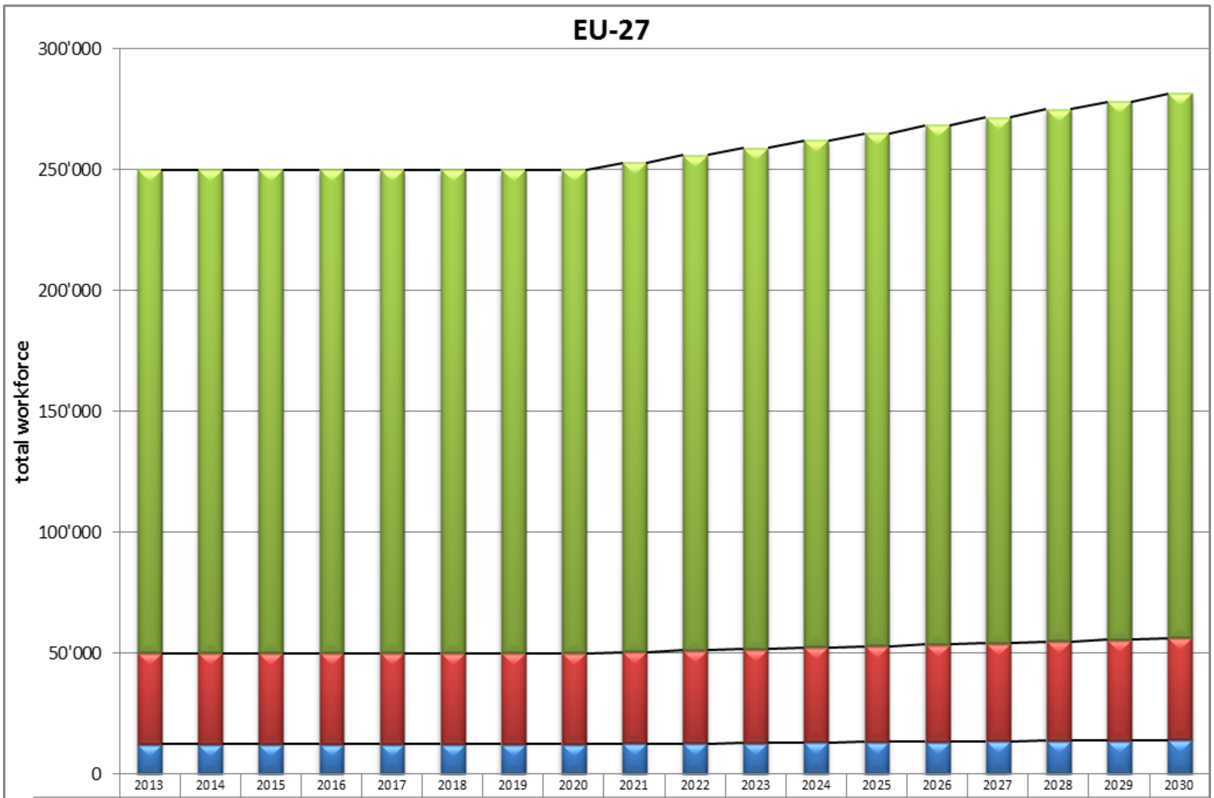
Workforce Status Quo and Outlook for Electrical Energy Equipment Manufacturing Companies in EU-27

Status Quo for Electrical Energy Equipment Manufacturing Companies

In this part of the assessment report the workforce status quo and outlook for companies which produce electrical energy equipment and services for transport and distribution companies (see section 1) are investigated.

Methodology:

Based again on the validation of the following methodology by using Austrian electrical energy equipment manufacturing companies as an example the workforce for those companies in EU-27 is taken.



	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
LV Workforce	200'000	200'000	200'000	200'000	200'000	200'000	200'000	200'000	202'400	204'800	207'300	209'800	212'200	214'800	217'400	220'000	222'600	225'300
MV Workforce	37'500	37'500	37'500	37'500	37'500	37'500	37'500	37'500	37'900	38'400	38'800	39'300	39'700	40'200	40'700	41'200	41'700	42'200
EHV + HV Workforce	12'500	12'500	12'500	12'500	12'500	12'500	12'500	12'500	12'700	12'800	13'000	13'100	13'300	13'400	13'600	13'800	13'900	14'100

Figure 9: Estimated workforce of technical employees in network companies for the period 2013-2030, divided into different grid voltage level types

Workforce for Electrical Energy Equipment Manufacturing Companies in EU-27

Work force

A total of 2'800'000 employees are employed in electricity industry[2]. This database is taken as the basis for 2013 due to the conjectural influence of the financial crisis. Of these employees an estimated proportion of 33 %, i.e. 920'000 employees, works in electrical energy equipment manufacturing companies (including technical employees and commercial employees).
A differentiation of these 920'000 employees into

- 50 % technical staff and
- 50 % commercial staff

is further assumed, which leads to an amount of 460'000 technical employees in electrical energy equipment manufacturing companies.

[2] http://ec.europa.eu/enterprise/sectors/electrical/competitiveness/index_de.htm (database 2007).

Assuming the same distribution of the total technical workforce (see above) into the different grid voltage level types (EHV + HV) : MV : LV as 5 % : 15 % : 80 % as in Table 2 (see Table 6)

Table 6: Distribution of workforce in the electrical energy equipment manufacturing companies into different grid voltage level types

Workforce		
Grid Type	EHV + HV	5 %
	MV	15 %
	LV	80 %
	Sum	100 %

And also a certain share of different workforce **qualification** into research / engineers / technicians / vocational for the different grid voltage level types as given in Table 7

Table 7: Share of workforce qualification in the electrical energy equipment manufacturing companies qualification for the different grid voltage level types per 2013

Workforce		Qualification				
		Research	Engineers	Technician	Vocational	Sum
Grid Type	EHV + HV	5 %	18 %	37 %	40 %	100 %
	MV	5 %	18 %	37 %	40 %	100 %
	LV	5 %	18 %	37 %	40 %	100 %

The resulting allocation of the total workforce of 460’000 in terms of % and qualification respective to the different grid voltage level types is given in Table **8**.

Table 8: Resulting allocation of workforce qualification in the electrical energy equipment manufacturing companies respective to different grid voltage level types per 2013

Workforce			Qualification			
			Research	Engineers	Technician	Vocational
Grid Type	EHV + HV	5 %	0.3 %	0.9 %	1.9 %	2.0 %
	MV	15 %	0.7 %	2.7 %	5.5 %	6.0 %
	LV	80 %	4.0 %	14.4 %	29.6 %	32.0 %
Total Workforce		100 %	5.0 %	18.0 %	37.0 %	40.0 %

Multiplied by the total number (460’000) the allocation of the technical employees in terms of absolute numbers and qualification respective to the different grid voltage level types is given in Table **9** as per 2013.

Table 9 Total number of workforce qualification in the electrical energy equipment manufacturing companies respective to the different grid voltage level types per 2013

Workforce 2013			Qualification			
			Research	Engineers	Technician	Vocational
Grid Type	EHV + HV	23'000	1'200	4'100	8'500	9'200
	MV	69'000	3'500	12'400	25'500	27'600
	LV	368'000	18'400	66'200	136'200	147'200
Total Workforce		460'000	23'100	82'700	170'200	184'000

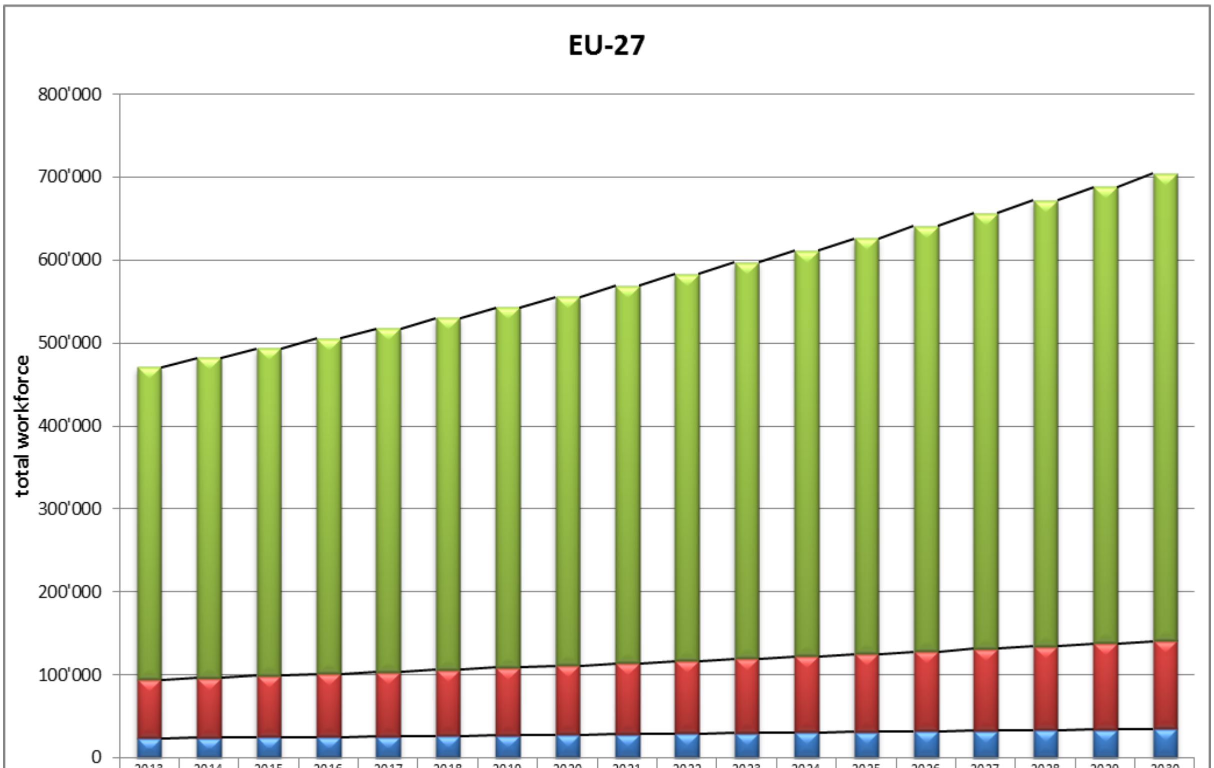
- ***Outlook for Electrical Energy Equipment Manufacturing Companies***

As pointed out in the chapter "Outlook for Network Companies" (s.a.) also for the workforce in the electrical energy equipment manufacturing companies the assumption is taken that no real profound and all-pervading revolution is foreseen in this field of technology. The workforce is expected to be correlated to a certain degree with the total annual turnover of electrical energy. With an expected annual growth of 2.4 % in electricity consumption of households and in industry taken as a whole also the number of employed people in the electrical energy equipment manufacturing companies is increasing at 2.4 % per year, which is more dynamic than the development in the network sector.

- ***Forecast of the Development of the Number of Employees***

In a next step the development of the number of technical employees is calculated for the workforce in the network companies (Figure 10)

A more detailed representation of the development of the estimated workforce of technical employees in the electrical energy equipment manufacturing companies for the period 2013-2030, divided into different grid voltage level types resp. according to the workforce qualification is given in Appendix 4, see Figure 17.



	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
LV Workforce	376'800	385'800	395'100	404'600	414'300	424'200	434'400	444'800	455'400	466'400	477'600	489'000	500'800	512'800	525'100	537'800	550'600	563'800
MV Workforce	70'700	72'300	74'100	75'900	77'700	79'500	81'500	83'400	85'400	87'500	89'600	91'700	93'900	96'200	98'500	100'800	103'200	105'700
EHV + HV Workforce	23'600	24'100	24'700	25'300	25'900	26'500	27'200	27'800	28'500	29'200	29'900	30'600	31'300	32'100	32'800	33'600	34'400	35'200

Figure 10: Estimated workforce of technical employees in electrical energy equipment manufacturing companies for the period 2013-2030, divided into different grid voltage level types

Workforce Status Quo and Outlook for Total Workforce in the Electricity Grids Business

By merging the results for

- network companies and
- electrical energy equipment manufacturing companies

the development of the total technical workforce for the whole electricity business in the field of electrical grids is obtained.

Result for EU-27 – Status Quo

The total technical workforce is given by the sum of the

- employees in network companies 250’000
- employees in electrical energy equipment manufacturing companies 460’000

Total technical workforce (2013) = 710’000 P

- *Division of the Workforce into the different divisions and workgroups*

From Table **5** and Table **9** the total number of the total technical workforce (710'000) is allocated in terms of absolute number and qualification respective to their training classification as per 2013 in Table 10.

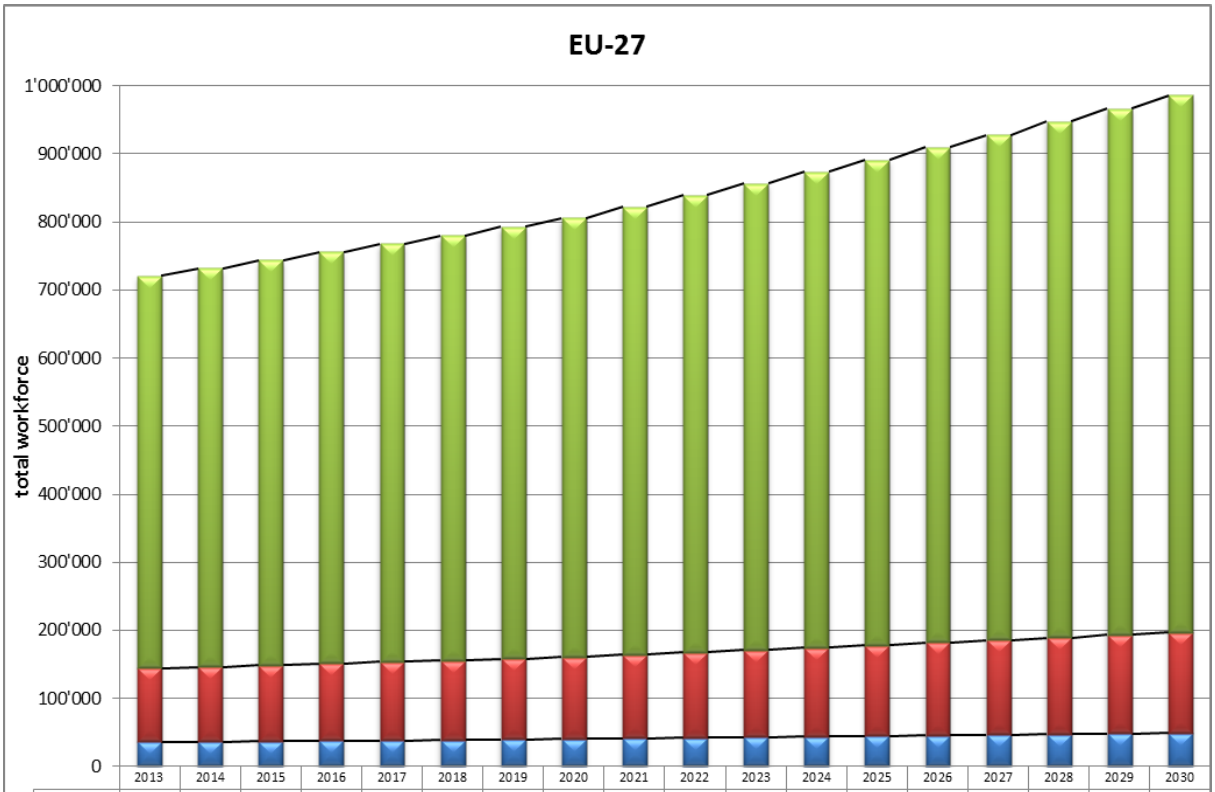
Table 10 Total number of workforce qualification in electricity business respective to their training classification per 2013

Workforce 2013			Qualification			
			Research	Engineers	Technician	Vocational
Grid Type	EHV + HV	35'500	1'500	11'300	12'200	10'500
	MV	106'500	4'400	25'500	39'600	37'000
	LV	568'000	20'400	84'200	156'200	307'200
Total Workforce		710'000	26'300	121'000	208'000	354'700

- *Workforce Outlook (Merged for Network Companies and Electrical Energy Equipment Manufacturing Companies)*

From Figure 9 and Table 9 the outlook for the total number of the technical workforce, merged from Network Companies and Electrical Energy Equipment Manufacturing Companies is obtained in Figure 11

A more detailed representation of the development of the estimated workforce of technical employees in the electrical power business companies for the period 2013-2030, divided into different grid voltage level types resp. according to the workforce qualification is given in Appendix 5, see Figure 20.



	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
LV Workforce	576'800	585'800	595'100	604'600	614'300	624'200	634'400	644'800	657'800	671'200	684'900	698'800	713'000	727'600	742'500	757'800	773'200	789'100
MV Workforce	108'200	109'800	111'600	113'400	115'200	117'000	119'000	120'900	123'300	125'900	128'400	131'000	133'600	136'400	139'200	142'000	144'900	147'900
EHV + HV Workforce	36'100	36'600	37'200	37'800	38'400	39'000	39'700	40'300	41'200	42'000	42'900	43'700	44'600	45'500	46'400	47'400	48'300	49'300

Figure 11: Estimated workforce of technical employees in the electrical power business companies for the period 2013-2030, divided into different grid voltage level types

Requirements for Education and Training

In a final step the requirements for education and training are obtained from the “Workforce Outlook (Merged for Network Companies and Electrical Energy Equipment Manufacturing Companies)”, see above, applying the following methodology:

Starting from the total “Estimated workforce qualification of technical employees in the electrical power business companies for the period 2013-2030, the growth - divided into different categories – is assumed for

Network companies

- growth between 2013 – 2020 0%
- growth between 2021 – 2030 1.2%

Electrical Energy Equipment Manufacturing Companies

- growth between 2013 – 2030 2.4%

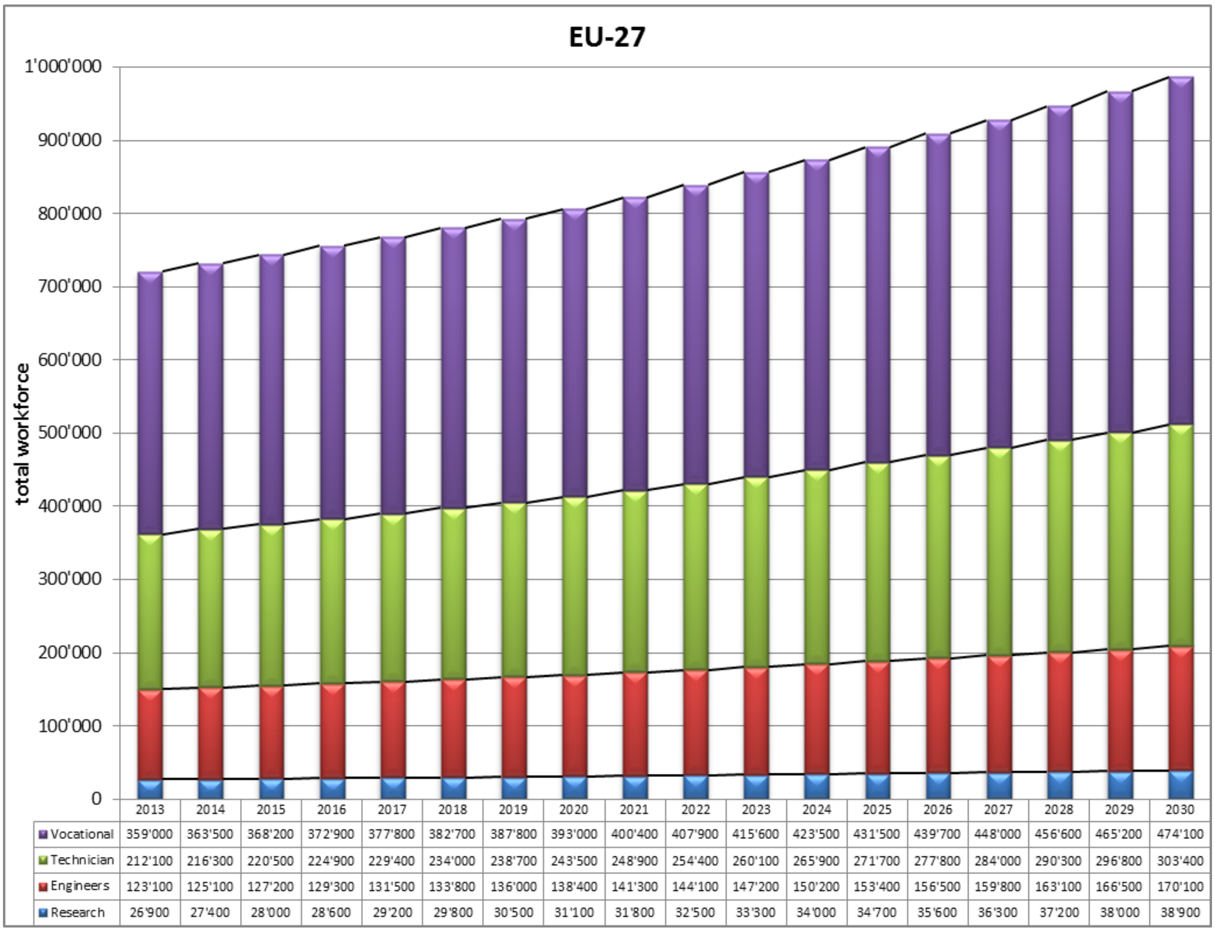


Figure 12: Estimated workforce qualification of technical employees in the electrical power business companies for the period 2013-2030, divided into different workforce qualifications

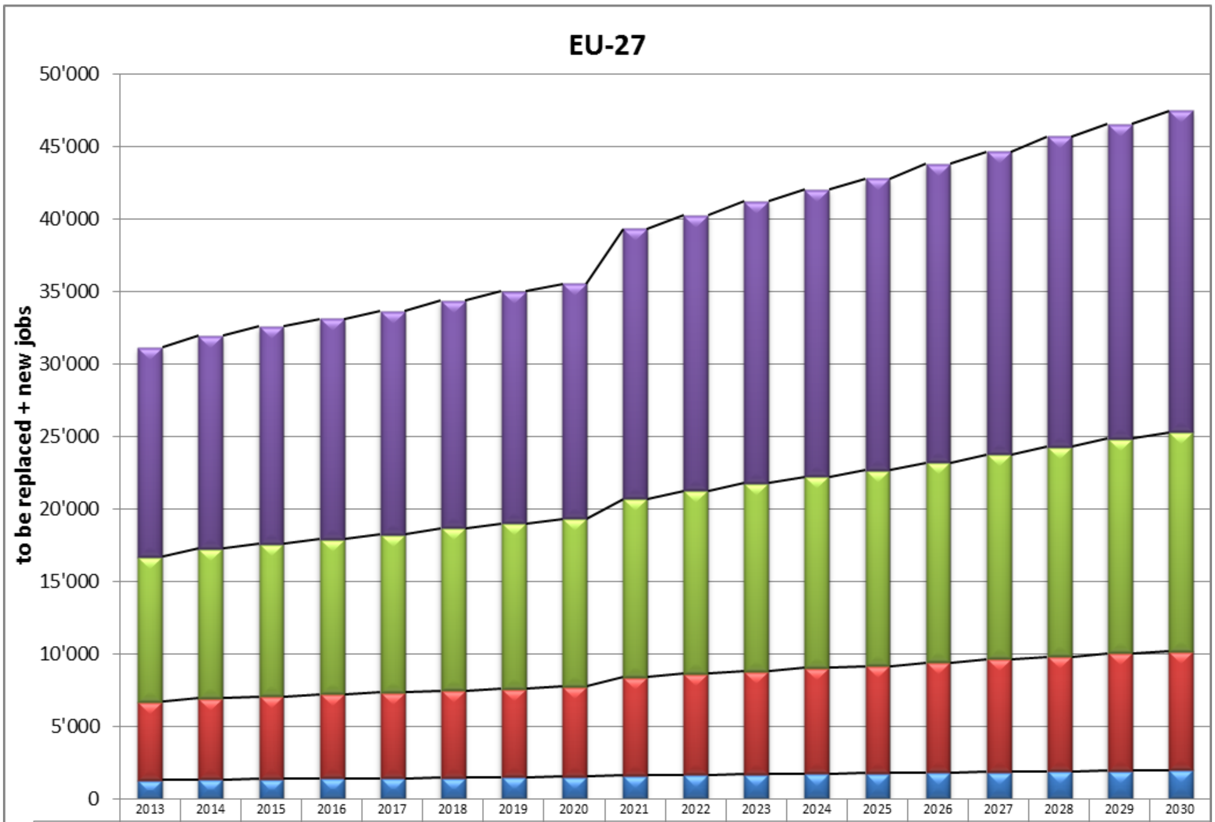
From this the real new jobs' figures are derived.

Additional to those increments in absolute numbers the necessary replacements are determined and added on the basis of a professional life span of 35 years. The resulting total need in new positions + replacements is given in the following table (Table 11).

Table 11: Education and training needs for network companies and electrical energy equipment manufacturing companies

EDUCATION AND TRAINING NEEDS – European Union Member States and Associated Countries			
Qualification	European Workforce 2013	Estimated Education & Training Needs for the period 2013-2020 (new positions + replacements)	Estimated Education & Training Needs for the period 2020-2030 (new positions + replacements)
NETWORK COMPANIES AND ELECTRICAL ENERGY EQUIPMENT MANUFACTURING COMPANIES			
TOTAL	710'000	267'100	433'500
Researchers	26'300	11'200	17'700
Engineers	121'100	46'700	75'200
Technicians	208'000	86'600	136'900
Vocational	354'600	122'600	203'700

A more detailed view of the annual development of the estimated needs in education & training for the whole period 2013-2030 is given in Figure 13.



	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Vocational	14'400	14'700	15'000	15'200	15'400	15'700	16'000	16'200	18'600	19'000	19'400	19'800	20'100	20'600	20'900	21'400	21'700	22'200
Technician	10'000	10'300	10'500	10'700	10'900	11'200	11'400	11'600	12'300	12'600	13'000	13'200	13'500	13'800	14'100	14'500	14'800	15'100
Engineers	5'400	5'600	5'700	5'800	5'900	6'000	6'100	6'200	6'800	7'000	7'100	7'300	7'400	7'600	7'800	7'900	8'100	8'200
Research	1'300	1'330	1'360	1'390	1'420	1'450	1'490	1'520	1'590	1'630	1'680	1'710	1'750	1'790	1'830	1'870	1'920	1'960

Figure 13: Needs in Education and training for network companies and electrical energy equipment manufacturing companies

2 On-going Activities

This section lists the main on-going training activities concerning education and life-long training.

There is a well-developed system of education in the field of electrical networks planning and operation on the different levels like

- Research
- Engineering
- Technicians
- Vocational

The first sector is looked after by universities (technical, universities of applied sciences) with studies like electrical power engineering, control systems, electronics and computer sciences.

The education at Technical Universities leading to the title of MSc or Dipl.-Ing., respectively, is consciously kept on a broad and solid scientific / technical basis for training. By this approach the abilities of the absolvents will not only keep pace with the on-going developments in the field of electrical grids, but also enable the absolvents to push the technical frontiers further ahead and to lead the innovation process.

An outstanding feature of the university education is that the teaching of sustainable scientific methods is preferred to the option of proliferating short-lived facts and examples of best practice.

The second and third sector is taken care of in the sense of education by engineering colleges and schools for technicians. The focus is rather on present day practices and a ready application of the learning contents.

The last sector (vocational training) is not systematically organized in EU-27: Whereas in central Europe (e.g. Germany, Austria, Switzerland,) there exists the system of "dual training and education" this regime does not exist in other countries.

As for the lifelong training there are courses in many countries offered by professional bodies or semi-private institutions.

The need for reconversion schemes so far was not an urgent one or necessary on a broad base due to the fact that in the past a general shortage of person-power could be observed, so no overhead in the workforce had to be re-trained.

Staff Development Strategies of Business

Companies employ different enrolling and training strategies depending on their size and strategic goals:

Network companies employ rather workforce in the operational and network planning field than researchers. Still it is regarded as necessary that the higher management positions (up to the second level) are filled by employees with a solid scientific training in order to enable them to foresee future trends and developments and to set the right course of their network's future. It is a specialty in the electrical network field that due to the longevity of the equipment and the need to adjust and extend the system under full continuous operation that requires both a large background in the knowledge of the past and present technologies and also to judge the implications of intended improvements.

Electrical energy equipment manufacturing companies are – concerning technology - very future-oriented. Therefore a good and stable partnership with the network companies is necessary to establish a good transition of research results into the field of application.

For both types of industry the hiring strategy is mainly based on excellent quality of traditional science and engineering curricula. They operate internal training programmes particularly on financial and environmental topics.

On-going Educational Activities

Electrical networks are seen as an educational discipline in its own right and there is a well-engineered curriculum for both the basics (Maxwell's laws, etc.) and for the individual applications, such as load flow and short circuit calculations, design and application of protection algorithms, etc.

Therefore the vast majority of curricula on all levels of education, from vocational training to bachelor to master courses and doctoral schools, is defined by the need of generic fields like mathematics, mechanical, chemical and electrical engineering and – additionally to the technical subjects - economics. On the vocational level the same rational applies, maybe with the exclusion of economics.

3 Needs and Gaps

Human resources are a critical dimension of the knowledge economy. This section focuses on the education and training needs for the development in the field of electrical networks.

It has to be remarked that the initial working group univocally is in favour of a broad – and n o t specialized – education in order guarantee its sustainability. This broad education should on all education levels (research, engineering, technicians, vocational) be preferred to a narrow and too focussed education.

For electrical networks education should be based on both scientific and technical fundamental knowledge. In the past the nearly exclusive focus of all education was on the technical knowledge and abilities.

As a consequence the flexibility of people to respond to up and down in the energy job market is a key issue. It is recommended to have a **broad, profound basic education** (physics, mathematics, electro technics), with a subsequent specialisation on particular areas. This would allow people to switch to neighbouring sectors if needed.

Due to the fact that economics are more and more pervading society a need is felt to broaden the education. When analysing the factors for success an additional economic knowledge and understanding has turned out to be decisive.

These demands on education define the educational base for the workforce in electrical networks.

Some gaps between existing education and future requirement of skills of the workforce are seen in the following areas:

- Engineering, technology development and operation
- Business innovation and supply chain management
- Improving skills in existing industries in the field of electrical networks
- Public involvement and decision making

Within these topical areas success of electrical networks in Europe depends on innovation in educational approaches and organisation of learning. In particular, innovations are needed concerning the modernization of curricula, practice and problem orientation of education, infra-structure for research and development (R & D) as well as education, new teaching methods, including virtual education and tele-learning, mobility of learners and teaching staff, life-long learning.

Soft Skills - an Important Component for Graduates of Technical Universities

Besides of that a certain amount of time should be also devoted to the field of Soft Skills. These will enable the researchers, engineers and technicians to obtain a larger and more creative way of fulfilling their tasks.

Social competence is seen as the ability "to act adequately in situations with others", and to act "organized, communicative and cooperative even to successfully implementing or developing goals and plans in social interaction". Furthermore dealing with human cooperation, assertiveness, empathy, conflict resolution, etc. do play a central role.

Not least in the universities is a growing awareness to make their curricula developing competence. International studies argue for a specialization in the field of communication, conflict, criticism and teamwork skills, which are in professional and work life most often requested and required.

In addition, students have the opinion of the technical leadership and project management as well as interview skills and soft skills for their future professional activity.

Results of a study conducted among human resources managers show that candidates are expected to have communication skills and analytical skills of cooperation and teamwork skills for their professional activities besides general knowledge

Therefore it is essential for engineers and technicians in addition to the acquisition of professional skills to acquire also soft skills for their future careers.

Innovation Needs

Some exemplary categories are seen in the field of ICT for smart grid applications and for the modernisation of curricula to include multidisciplinarity, entrepreneurship and teamwork in multicultural groups.

An overview of more concrete fields of innovation is given below.

- Control of renewable energy conversion systems
- Grid integration of renewable energy conversion systems
- Smart meters and communicating devices for energy networks
- Communication protocol standards for energy networks

Practice and Problem Orientation of Education

A major factor for improving both effectiveness and attractiveness of education is to link training with practice. In recent years a decline in the financial means for the infra-structure for research and development (R & D) in the field of electrical networks has taken place due to the static situation of this sector of electricity business.

But with the arrival of the "energy turnaround" ("Energiewende") in Germany and the re-thinking of the European energy situation innovations are also needed concerning the modernization of curricula, as well new teaching methods, including virtual education and tele-learning and life-long learning.

More concrete contributions concerning Practice and problem orientation of education are given below.

- Problem-oriented and project-oriented learning
- Design and development of virtual didactic laboratories

4 Recommendations at EU and MS Level within Specific Target Dates

The following recommended actions address key needs to overcome gaps and bottlenecks identified in this report. These recommendations however have to be seen as examples rather than a comprehensive list of necessary actions, showing pathways to generate the educational basis for a workforce that is capable of fulfilling the role electricity grids has to play in achieving the objectives of the SET plans in Europe.

Filling the Skills, Competences and Knowledge Gap

Focus Area 1: Meeting the Skill/Competencies Gaps of New and Emerging Technologies

Action 1: European Master and Doctoral Curriculum "Smart Electricity Grids Engineer"

The goal of this master curriculum and subsequent doctoral curriculum is to enable alumni to develop and engineer advanced electricity grids economy systems within the framework of the electricity grids economy and the objectives of the SET-Plan.

It will be developed by an interdisciplinary team of educators with backgrounds in physics, chemical and electrical engineering, control engineering, information and communications engineering, game theory and mechanism design, techno-economic and social studies such as institutional economics (tariff structures), and other related fields.

In order to ramp up this important field as soon as possible, this European master and doctoral curriculum needs to be implemented in at least four universities of technology that offer a sufficient thematic support as well as a sensible geographical spread across Europe.

EQF Level: 6-8
Timeframe: Year 0 – onwards

Action 2: Development of Modern Modular Curricula and Joint Teaching Projects for Photovoltaic Integration into Electricity Grids

The curricula will address essential core elements from the value chain, creating links between traditional disciplines and smart electricity grids, thus providing bridges between existing courses and skills needed to develop, manufacture, install and maintain the methodology needed to implement photovoltaic into electricity grids. In addition, teaching modules should be created which will aid the integration of smart grids in the environment. Although eventually growing into many full scale bachelor and master programmes in connection with smart grids, this scheme will also be used to develop professional courses in academia for staff in the field who need (re-)training for specific parts of the value chain.

EQF Level: 5-8
Timeframe: Year 0 - onwards

Action 3: Development of Modern Modular Curricula and Joint Teaching Projects for Transnational Bulk Carrier Grids

Planning and operations of European transmission networks and markets is crucial to ensure appropriate cross-border coordination and support European standardisation and interoperability, enabling access to any type of grid users.

The curricula should address the development of joint processes optimizing the transmission grid infrastructure in local, regional or European context, for example design, development and operation of pan-European electricity markets by load-flow control to alleviate loop-flows and increased interconnection capacities.

EQF Level: 5-8
Timeframe: Year 0 – onwards

Focus Area 2: Strengthening and Developing Existing Skills/Competencies

Action 4: Standardised Vocational Training in the Field of Advanced Electricity Grids

The objective of this action is to develop dual, cooperative vocational training (with 3 years duration) as well as a re-training for personnel with an electricians' background.

The training will address:

- young people who aspire to a vocational qualification in international transmission and local distribution electricity grids (especially smart grids)
- workers from classic electricity grid activities
- all persons interested in international transmission and local distribution electricity grids (especially smart grids)

The curriculum will cover different areas related to smart grids as outlined above.

EQF Level: all
Timeframe: Year 0 – onwards

Fostering Involvement of Business and Research, Access and Up-take by the Labour Market

Focus Area 1: Mobility and Cooperation Partnerships among Education and Training Providers, Research Institutes and Businesses

Action 5: A European Collaborative Education Mobility Programmes for Electricity Grids

This program is aimed at students at university level as well as at participants in different vocational training schemes for energy and electricity grid technologies. They are different from current student mobility programmes as they require more flexibility regarding the duration of the stays as well as strict coordination between the universities or different vocational training schemes and business/research facilities receiving students. Different programmes for cooperation range from compact pilot plant exercises with durations of 2-4 weeks to team projects of 1-3 months to individual research projects with 6 months to 3 years duration. Innovative schemes such as collaborative learning exchanges through different academia, research and business organisations would also be encouraged. The mobility plans have to include the definition of measurable objectives as well as a detailed schedule and procedures for grading student achievements. A quality control should be applied to guarantee certain performance and integrity criteria.

While some of the programmes for energy and electricity grid technologies could be elaborated as integrated part of educational programmes, others could be developed as independent from university programmes or other vocational training schemes and offered to interested students as an additional framework where they could gain further technology competences in the field.

The mobility programmes may be implemented in close collaboration with the Networks of Universities, the Vocational Training Networks and the Infrastructure Programmes. Mobility and cooperation programmes will be implemented within Europe but also in collaboration with countries and regions outside of the EU where European research and industrial actors have an interest for collaboration in the field of energy and electricity grid technologies.

EQF level: all
Timeframe: Year 0 – onwards

Action 6: Mobility and Cooperation Programmes for Research and Technical Staff, Professors and Trainers for Electricity Grids

The Mobility and Cooperation Programmes for Research and Technical Staff, Professors and Trainers seek to provide access to facilities for energy and electricity grid technologies such as laboratories at universities, large-scale facilities at research institutes, industrial pilot or demonstration plants, and vocational institutes. They aim to facilitate participation of research and teaching staff in industry activities, while industrial/research staff will be invited to give lecturers to students and professionals in the field at higher education institutions and vocational institutes.

Such collaboration frameworks support knowledge exchange and scientific cooperation for the advancement of knowledge and developments in the field.

This measure will facilitate also the update and development of teaching materials.

Mobility and cooperation programmes will be implemented within Europe but also in collaboration with countries and regions outside of the EU where European research and industrial actors have an interest for collaboration in the field of energy and electricity grid technologies.

EQF Level: all
Timeframe: Year 0+1.

Focus Area 2: Infrastructure Support to Higher Education and Vocational Training

Action 7: A Programme for Access to Research Infrastructure for Education and Training Purposes in Smart Electricity Networks

This Action establishes the necessary agreements to provide access to both students and external staff to research infrastructures, pilot and demonstration plants in the smart electricity networks field, including European infrastructure networks such as DERRI (Distributed Energy Resources Research Infrastructure).

EQF Level: 4 – 8
Timeframe: Start in Year 0, to be in place in Year 0+1, but with further actions as needed.

Planning and Enabling Skills Development, Transfer and Recognition

Focus Area 1: Virtual Learning and Information Platforms

Action 8: Virtual Learning and Information Platform(s) for Electricity Grids

The Virtual Learning and Information Platform(s) covers all energy and, specifically, electricity grids technology fields, with the following objectives:

- To speed up the modernisation process for relevant curricula and in particular to increase the capacity for multidisciplinary education by providing quality controlled digital educational content to educational and training institutions.
- To facilitate education and training activities in the field when key expertise is concentrated at relatively few universities or training centres (vocational institutes), while the education and training needs are quite widespread.
- To establish virtual education and training programmes and modules as well as other open educational resources, allowing the inclusion of expert lecturers via a virtual faculty exchange.
- To provide access via distance learning tools to remote research infrastructures, test facilities, data banks, and other valuable components in education and training.

- To enable the quick implementation of programmes for continued education, including "train the trainers" programmes.
- To strengthen networking between knowledge centres.
- To offer on the public side an open portal to create awareness about energy and electricity grid technologies.

The programmes for energy and electricity grid technologies will be developed within the education and training networks as well as via other relevant frameworks. This will also include the development of a fully online open source master programme in sustainable energy with engineering, financial, social, entrepreneurial and humanitarian content, including a process for introduction of latest relevant research results from all the partner institutions into the programme.

In addition, the Platform(s) will integrate a number of databases, for example:

- A database for open access e-learning material. The objective is to make learning materials readily available, facilitating up-take at institutions new to the advanced fields of energy technologies.
- An inventory of relevant European-level infrastructure facilities, which are open for education and training purposes, as well as for research and development activities.
- A database on scholarships and a job portal with a possible link to Euraxess.

Specific procedures for contribution, quality assurance and use of the databases in the field of energy and electricity grid technologies will be elaborated as part of this action.

EQF Level: all
Timeframe: Year 0 - onwards

Appendix 1 - Turnover and Workforce in the Electrical Power Business

	Network costs 2011 (EUR per kWh) (1)		Net electricity generation (2)	Net electricity consumption				Total annual cost of transport / distribution of electricity turnover			
	for household consumers (3)	for industrial consumers (4)	2010 (TWh)	for household (in % of generation)	for industry (in % of generation)	for household (TWh)	for industry (TWh)	for household (in Mio €)	for industry (in Mio €)	total (in Mio €)	Technical Employee (P)
EU-27	0.054	0.030	3'181	65%	35%	2'068	1'113	110'955	33'552	144'507	250'000
Euro area	:	:	2'268	50%	50%	1'134	1'134	:	:	:	:
Belgium	0.084	0.033	91.4	50%	50%	45.7	45.7	3'827	1'522	5'349	9'400
Bulgaria	0.030	0.015	42.2	50%	50%	21.1	21.1	640	310	950	1'700
Czech Republic	0.075	0.036	79.5	50%	50%	39.7	39.7	2'976	1'438	4'414	7'800
Denmark	0.064	0.035	36.8	50%	50%	18.4	18.4	1'176	639	1'815	3'200
Germany	0.059	0.024	591.4	50%	50%	295.7	295.7	17'386	7'156	24'542	43'100
Estonia	0.045	0.033	11.7	50%	50%	5.9	5.9	261	195	456	800
Ireland	0.060	0.035	27.5	50%	50%	13.7	13.7	825	475	1'300	2'300
Greece	0.028	0.017	53.4	50%	50%	26.7	26.7	737	451	1'188	2'100
Spain	0.076	0.033	292.1	50%	50%	146.0	146.0	11'070	4'819	15'889	27'900
France	:	:	544.5	50%	50%	272.3	272.3	:	:	:	:
Italy	0.044	0.024	290.7	50%	50%	145.4	145.4	6'353	3'416	9'769	17'200
Cyprus	0.036	0.025	5.1	50%	50%	2.6	2.6	93	64	157	300
Latvia	0.056	0.043	6.1	50%	50%	3.0	3.0	170	130	300	500
Lithuania	0.052	0.054	5.3	50%	50%	2.7	2.7	140	145	285	500
Luxembourg	0.072	0.025	4.6	50%	50%	2.3	2.3	165	57	221	400
Hungary	:	:	34.6	50%	50%	17.3	17.3	:	:	:	:
Malta	0.022	0.022	2.0	50%	50%	1.0	1.0	22	22	44	100
Netherlands	0.056	0.020	114.3	50%	50%	57.2	57.2	3'225	1'149	4'374	7'700
* **Austria**	0.064	0.036	68.3	50%	50%	34.1	34.1	2'189	1'226	3'415	6'000
Poland	0.048	0.030	142.9	50%	50%	71.4	71.4	3'415	2'107	5'522	9'700
Portugal	0.044	0.031	52.8	50%	50%	26.4	26.4	1'167	815	1'982	3'500
Romania	0.050	0.028	55.6	50%	50%	27.8	27.8	1'397	786	2'184	3'800

	Network costs 2011 (EUR per kWh) (1)		Net electricity generation (2)	Net electricity consumption				Total annual cost of transport / distribution of electricity turnover			
	for household consumers (3)	for industrial consumers (4)	2010 (TWh)	for household (in % of generation)	for industry (in % of generation)	for household (TWh)	for industry (TWh)	for household (in Mio €)	for industry (in Mio €)	total (in Mio €)	Technical Employee (P)
Slovenia	0.054	0.022	15.4	50%	50%	7.7	7.7	419	168	587	1'000
Slovakia	0.074	0.062	25.4	50%	50%	12.7	12.7	942	789	1'731	3'000
Finland	0.045	0.018	77.2	50%	50%	38.6	38.6	1'718	703	2'420	4'300
Sweden	0.070	0.027	145.3	50%	50%	72.6	72.6	5'092	1'990	7'082	12'400
United Kingdom	0.033	0.026	365.3	50%	50%	182.7	182.7	6'064	4'731	10'795	19'000
Norway	0.082	0.034	123.5	50%	50%	61.7	61.7	5'044	2'124	7'168	12'600
Switzerland	:	:	66.1	50%	50%	33.1	33.1	:	:	:	:
Croatia	0.038	0.036	13.6	50%	50%	6.8	6.8	259	243	502	900
Turkey	0.029	0.013	203.0	50%	50%	101.5	101.5	2'924	1'350	4'274	7'500

Table 12: Workforce extrapolated EU widely

(1) Source: Eurostat (online data codes: nrg_pc_204, nrg_pc_205, nrg_pc_202 and nrg_pc_203), http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Energy_price_statistics

(2) Source: Eurostat (online data code: nrg_105a); http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Electricity_production,_consumption_and_market_overview

(3) Annual consumption: 2 500 kWh < consumption < 5 000 kWh; data are currently unavailable online.

(4) Annual consumption: 500 MWh < consumption < 2 000 MWh; excluding VAT; data are currently unavailable online.

Appendix 2 - Determination of the TPE (Annual Turnover per Employee) in Austria – Used as an Example

- *Work Force*

12’000 employees in electricity network companies (including Craftsmen and commerce)
A share of 50 % to 50 % between technical staff and commercial staff is assumed → 50 % of 12’000 → **6’000 technical employees**

- *Energy*

Total annual electrical energy: **68 TWh**
Private consumption: 50 % of 68 TWh = 34 TWh
Industry (big and small) consumption: 50 % of 68 TWh = 34 TWh

- *Transport and Distribution Cost*

Basis for transport and distribution cost (= grid costs):
Private consumption: 0.064 €/kWh
Industry consumption: 0.036 €/kWh

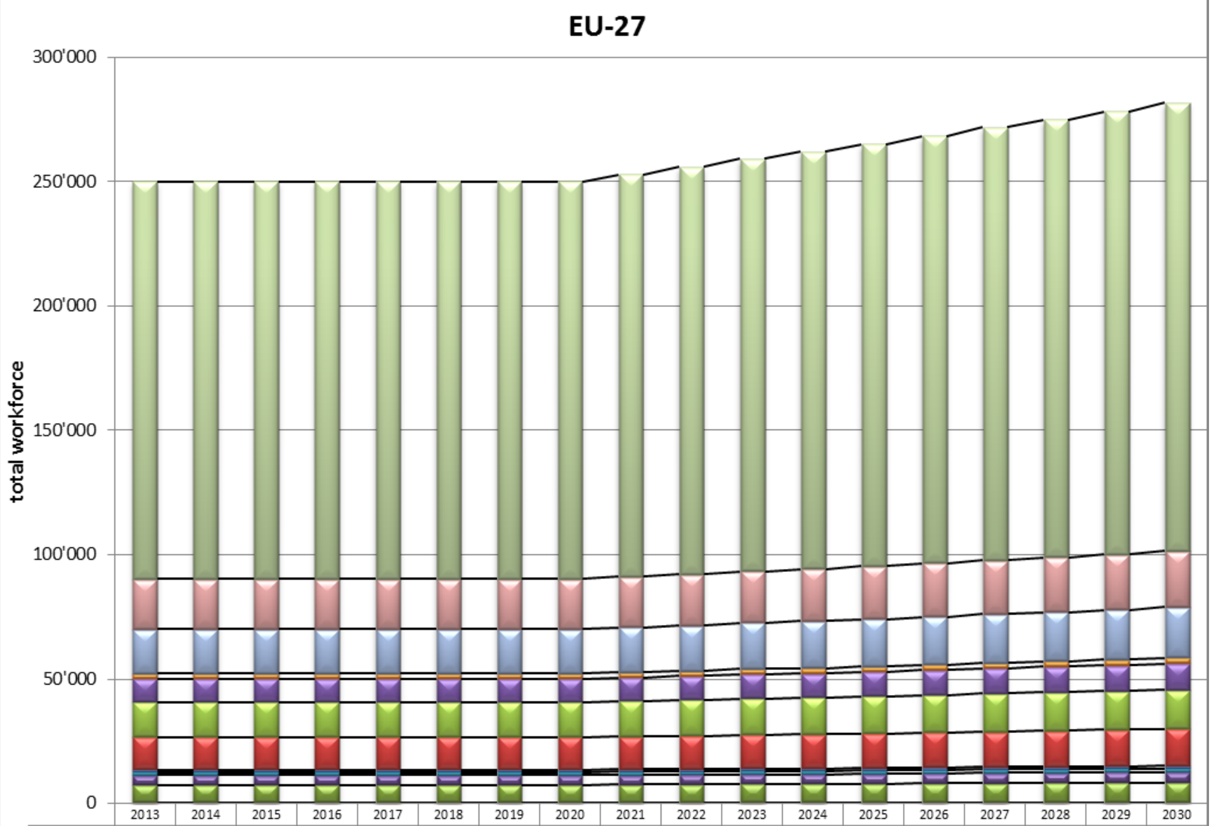
- *Total Annual Cost of Transport / Distribution of Electricity:*

Private consumption: $34*10^9$ kWh @ 0.064 €/kWh = $2.2*10^9$€
Industry consumption: $34*10^9$ kWh @ 0.036 €/kWh = $1.2*10^9$€
Total cost of transport / distribution = **turnover: $3.4*10^9$ €**

- *TPE - Annual Turnover per Employee (P)*

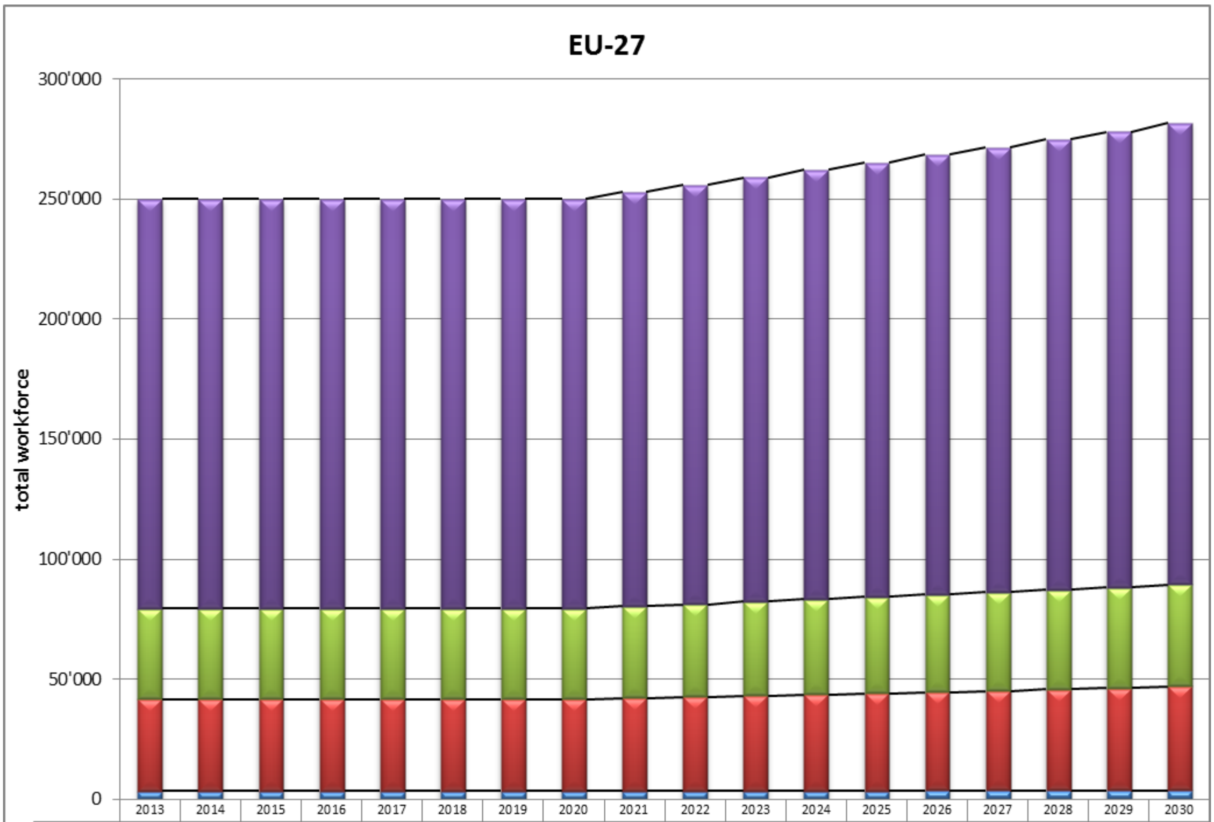
Turnover / Technical Employee = $3.4*10^9$ € / $6*10^3$ P = $0.57*10^6$ €/P = 570’000 €/Person

Appendix 3 - Workforce Estimation for Network Companies in EU-27



	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
LV Vocational	160'000	160'000	160'000	160'000	160'000	160'000	160'000	160'000	161'900	163'800	165'800	167'800	169'800	171'800	173'900	176'000	178'100	180'200
LV Technician	20'000	20'000	20'000	20'000	20'000	20'000	20'000	20'000	20'200	20'500	20'700	21'000	21'200	21'500	21'700	22'000	22'300	22'500
LV Engineers	18'000	18'000	18'000	18'000	18'000	18'000	18'000	18'000	18'200	18'400	18'700	18'900	19'100	19'300	19'600	19'800	20'000	20'300
LV Research	2'000	2'000	2'000	2'000	2'000	2'000	2'000	2'000	2'000	2'000	2'100	2'100	2'100	2'100	2'200	2'200	2'200	2'300
MV Vocational	9'400	9'400	9'400	9'400	9'400	9'400	9'400	9'400	9'500	9'600	9'700	9'800	9'900	10'100	10'200	10'300	10'400	10'600
MV Technician	14'100	14'100	14'100	14'100	14'100	14'100	14'100	14'100	14'200	14'400	14'600	14'700	14'900	15'100	15'300	15'500	15'600	15'800
MV Engineers	13'100	13'100	13'100	13'100	13'100	13'100	13'100	13'100	13'300	13'400	13'600	13'800	13'900	14'100	14'200	14'400	14'600	14'800
MV Research	940	940	940	940	940	940	940	940	950	960	970	980	990	1010	1020	1030	1040	1060
EHV + HV Vocational	1'300	1'300	1'300	1'300	1'300	1'300	1'300	1'300	1'300	1'300	1'300	1'300	1'300	1'300	1'400	1'400	1'400	1'400
EHV + HV Technician	3'800	3'800	3'800	3'800	3'800	3'800	3'800	3'800	3'800	3'800	3'900	3'900	4'000	4'000	4'100	4'100	4'200	4'200
EHV + HV Engineers	7'200	7'200	7'200	7'200	7'200	7'200	7'200	7'200	7'300	7'400	7'500	7'500	7'600	7'700	7'800	7'900	8'000	8'100
EHV + HV Research	310	310	310	310	310	310	310	310	320	320	330	330	330	340	340	350	350	350

Figure 14: Estimated workforce qualification in network companies respective to different grid voltage level types for the period 2013-2030

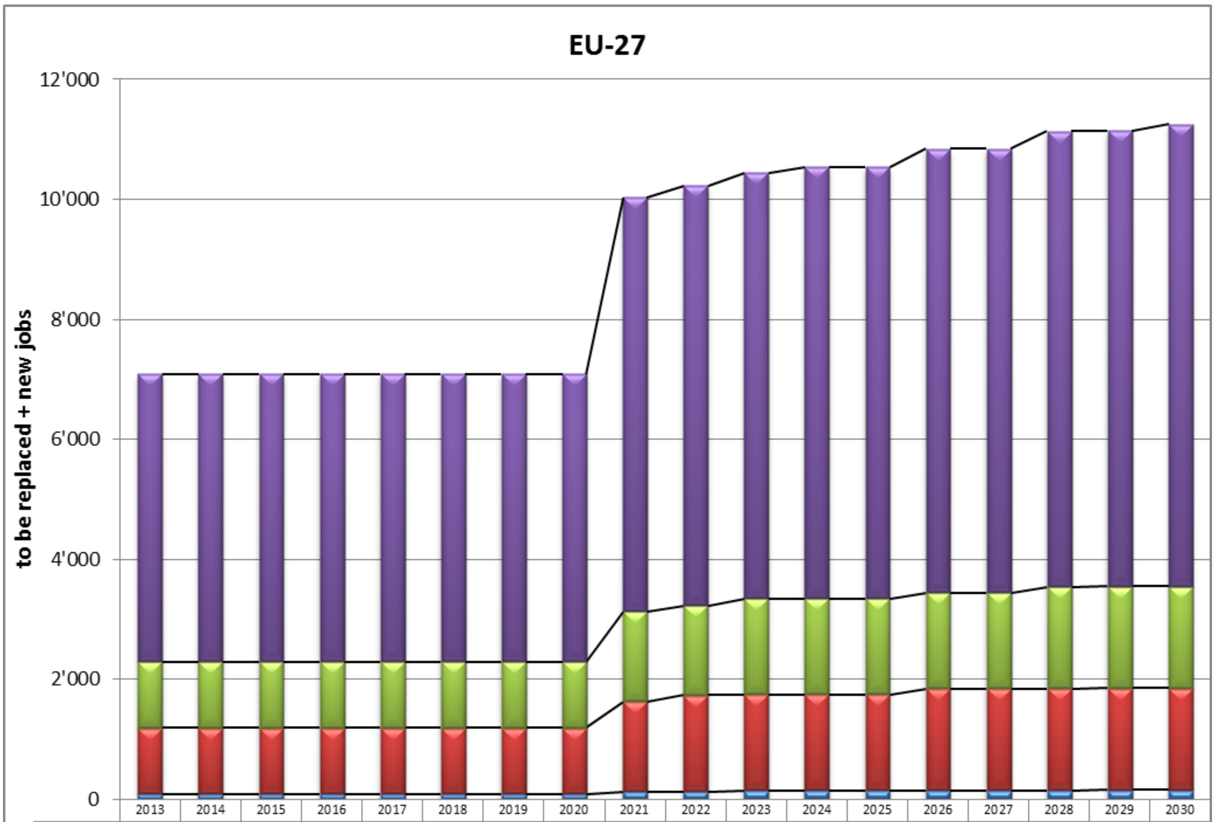


	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Vocational	170'600	170'600	170'600	170'600	170'600	170'600	170'600	170'600	172'700	174'700	176'800	179'000	181'100	183'300	185'400	187'700	189'900	192'200
Technician	37'800	37'800	37'800	37'800	37'800	37'800	37'800	37'800	38'300	38'700	39'200	39'700	40'100	40'600	41'100	41'600	42'100	42'600
Engineers	38'300	38'300	38'300	38'300	38'300	38'300	38'300	38'300	38'800	39'200	39'700	40'200	40'700	41'100	41'600	42'100	42'600	43'200
Research	3'300	3'300	3'300	3'300	3'300	3'300	3'300	3'300	3'300	3'300	3'400	3'400	3'400	3'500	3'500	3'600	3'600	3'700

Figure 15: Estimated workforce qualification of technical employees in the electrical network companies for the period 2013-2030, divided into different workforce qualifications

Table 13: Education and training needs for network companies

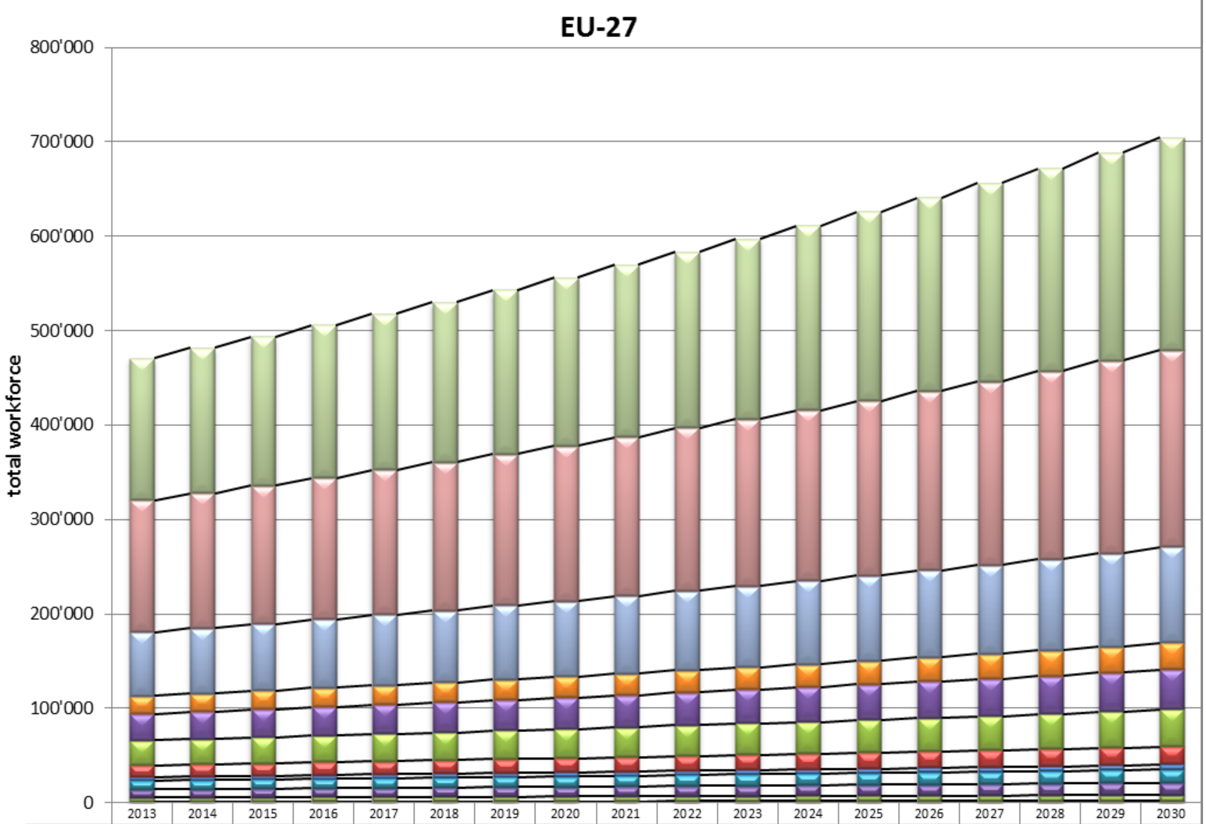
EDUCATION AND TRAINING NEEDS – European Union Member States and Associated Countries			
Qualification	European Workforce 2013	Estimated Education & Training Needs for the period 2013-2020 (new positions + replacements)	Estimated Education & Training Needs for the period 2020-2030 (new positions + replacements)
ELECTRICITY NETWORK COMPANIES			
TOTAL	250'000	56'700	107'000
Researchers	3'300	700	1'400
Engineers	38'300	8'800	16'400
Technicians	37'800	8'800	16'100
Vocational	170'600	38'400	73'100



	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Vocational	4'800	4'800	4'800	4'800	4'800	4'800	4'800	4'800	6'900	7'000	7'100	7'200	7'200	7'400	7'400	7'600	7'600	7'700
Technician	1'100	1'100	1'100	1'100	1'100	1'100	1'100	1'100	1'500	1'500	1'600	1'600	1'600	1'600	1'600	1'700	1'700	1'700
Engineers	1'100	1'100	1'100	1'100	1'100	1'100	1'100	1'100	1'500	1'600	1'600	1'600	1'600	1'700	1'700	1'700	1'700	1'700
Research	90	90	90	90	90	90	90	90	130	130	140	140	140	140	140	140	150	150

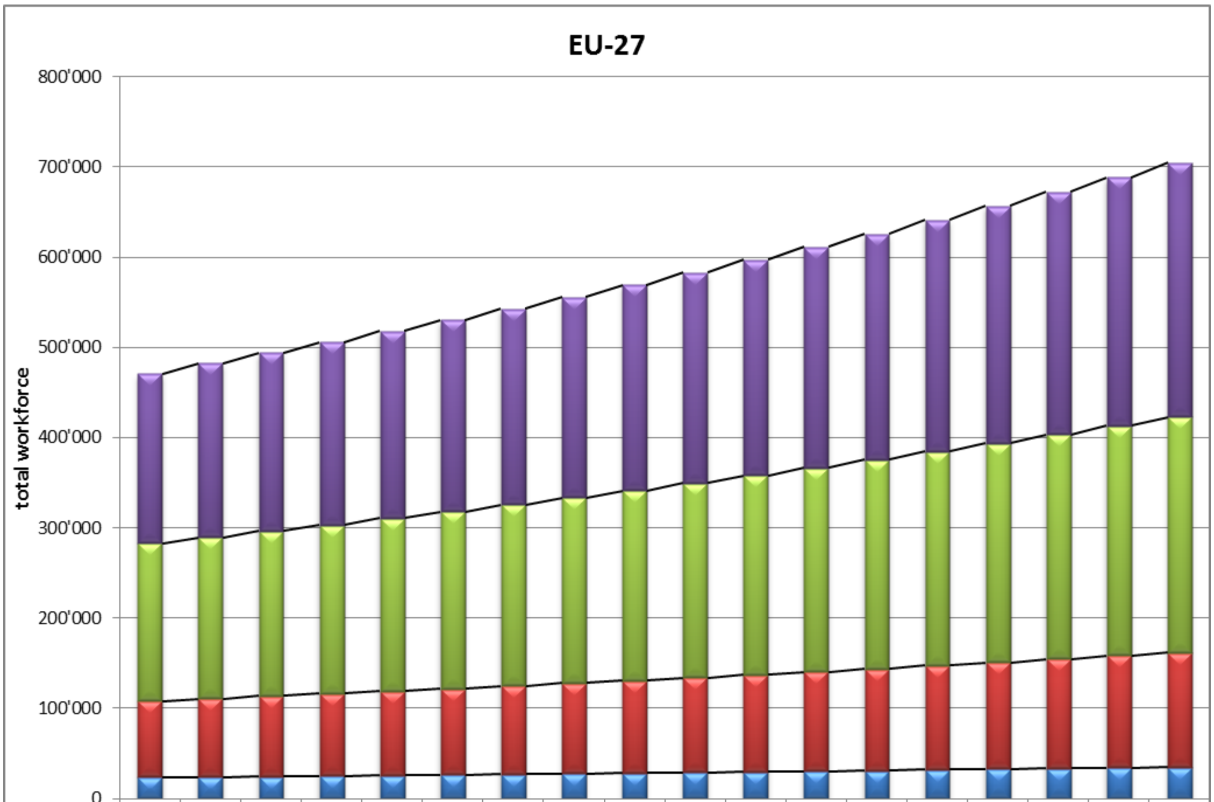
Figure 16: Needs in Education and training for network companies

Appendix 4 - Workforce Estimation for Electrical Energy Equipment Manufacturing Companies



	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
LV Vocational	150'700	154'300	158'000	161'800	165'700	169'700	173'800	177'900	182'200	186'600	191'000	195'600	200'300	205'100	210'000	215'100	220'200	225'500
LV Technician	139'400	142'700	146'200	149'700	153'300	157'000	160'700	164'600	168'500	172'600	176'700	180'900	185'300	189'700	194'300	199'000	203'700	208'600
LV Engineers	67'800	69'400	71'100	72'800	74'600	76'400	78'200	80'100	82'000	84'000	86'000	88'000	90'100	92'300	94'500	96'800	99'100	101'500
LV Research	18'800	19'300	19'800	20'200	20'700	21'200	21'700	22'200	22'800	23'300	23'900	24'500	25'000	25'600	26'300	26'900	27'500	28'200
MV Vocational	28'300	28'900	29'600	30'400	31'100	31'800	32'600	33'400	34'200	35'000	35'800	36'700	37'600	38'500	39'400	40'300	41'300	42'300
MV Technician	26'200	26'800	27'400	28'100	28'700	29'400	30'200	30'900	31'600	32'400	33'200	33'900	34'700	35'600	36'400	37'300	38'200	39'100
MV Engineers	12'700	13'000	13'300	13'700	14'000	14'300	14'700	15'000	15'400	15'800	16'100	16'500	16'900	17'300	17'700	18'100	18'600	19'000
MV Research	3500	3600	3700	3800	3900	4000	4100	4200	4300	4400	4500	4600	4700	4800	4900	5000	5200	5300
EHV + HV Vocational	9'400	9'600	9'900	10'100	10'400	10'600	10'900	11'100	11'400	11'700	12'000	12'200	12'500	12'800	13'100	13'400	13'800	14'100
EHV + HV Technician	8'700	8'900	9'100	9'400	9'600	9'800	10'100	10'300	10'500	10'800	11'100	11'300	11'600	11'900	12'100	12'400	12'700	13'000
EHV + HV Engineers	4'200	4'300	4'400	4'600	4'700	4'800	4'900	5'000	5'100	5'300	5'400	5'500	5'600	5'800	5'900	6'000	6'200	6'300
EHV + HV Research	1200	1200	1200	1300	1300	1300	1400	1400	1400	1500	1500	1500	1600	1600	1600	1700	1700	1800

Figure 17: Estimated workforce qualification in electrical energy equipment manufacturing companies respective to different grid voltage level types for the period 2013-2030

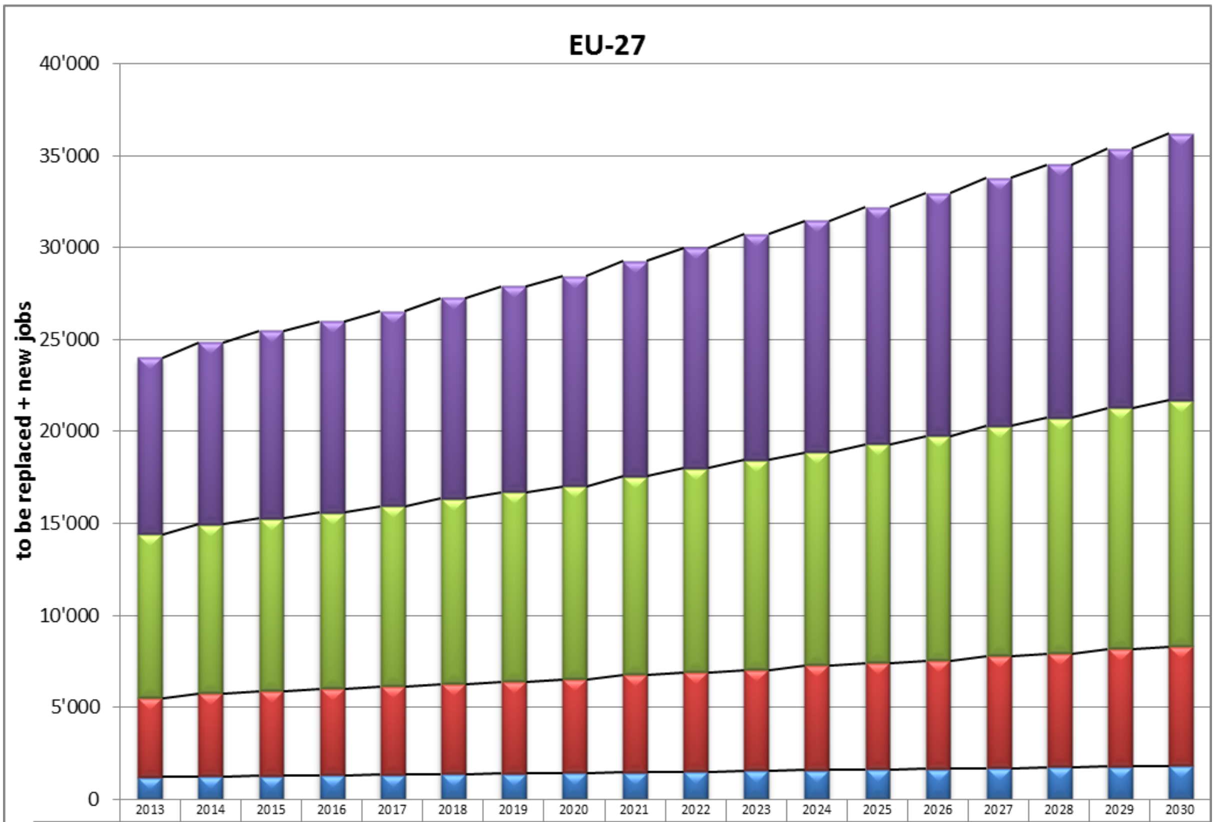


	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Vocational	188'400	192'900	197'600	202'300	207'200	212'100	217'200	222'400	227'700	233'200	238'800	244'500	250'400	256'400	262'600	268'900	275'300	281'900
Technician	174'300	178'500	182'700	187'100	191'600	196'200	200'900	205'700	210'600	215'700	220'900	226'200	231'600	237'200	242'900	248'700	254'700	260'800
Engineers	84'800	86'800	88'900	91'000	93'200	95'500	97'700	100'100	102'500	104'900	107'500	110'000	112'700	115'400	118'200	121'000	123'900	126'900
Research	23'600	24'100	24'700	25'300	25'900	26'500	27'200	27'800	28'500	29'200	29'900	30'600	31'300	32'100	32'800	33'600	34'400	35'200

Figure 18: Estimated workforce qualification of technical employees in the electrical energy equipment manufacturing companies for the period 2013-2030, divided into different workforce qualifications

Table 14: Education and training needs for electrical energy equipment manufacturing companies

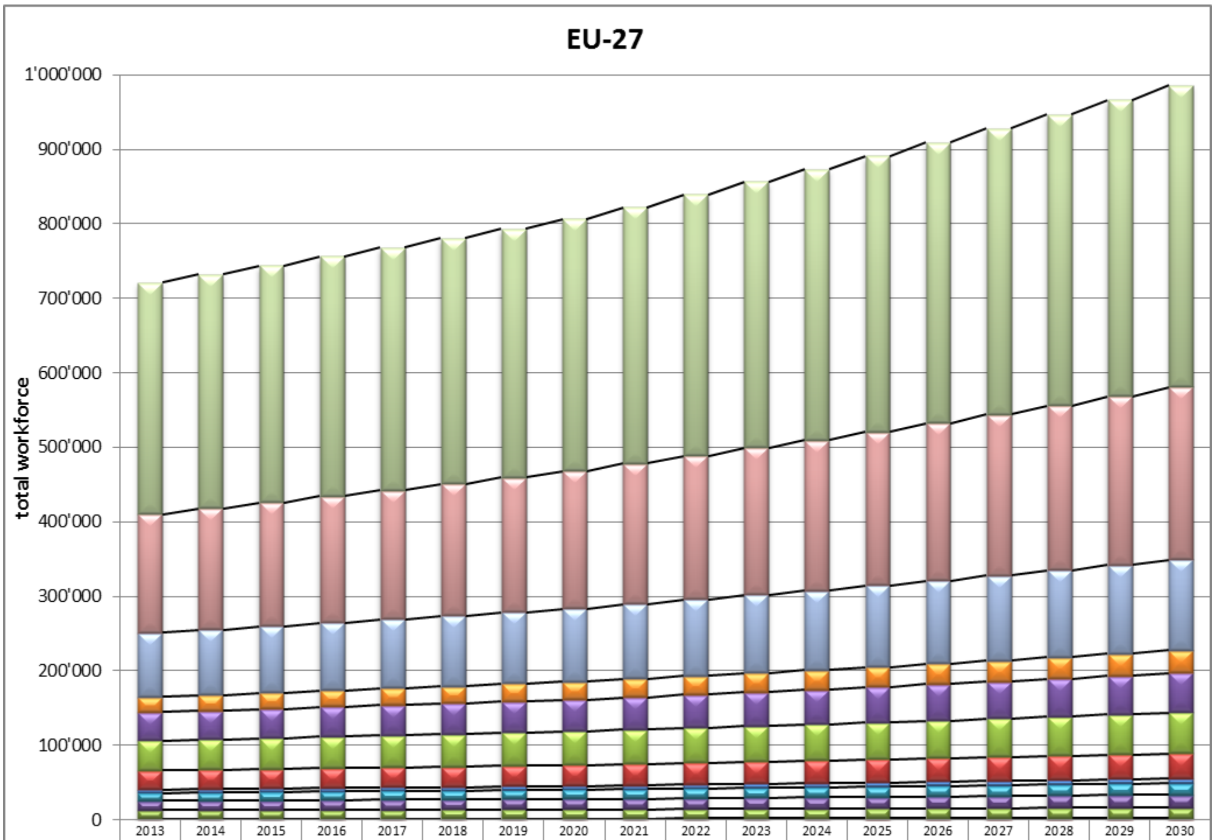
EDUCATION AND TRAINING NEEDS – European Union Member States and Associated Countries			
Qualification	European Workforce 2013	Estimated Education & Training Needs for the period 2013-2020 (new positions + replacements)	Estimated Education & Training Needs for the period 2020-2030 (new positions + replacements)
ELECTRICAL ENERGY EQUIPMENT MANUFACTURING COMPANIES			
TOTAL	460’000	210’400	326’500
Researchers	23’000	10’500	16’300
Engineers	82’800	37’900	58’800
Technicians	170’200	77’800	120’800
Vocational	184’000	84’200	130’600



	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Vocational	9'600	9'900	10'200	10'400	10'600	10'900	11'200	11'400	11'700	12'000	12'300	12'600	12'900	13'200	13'500	13'800	14'100	14'500
Technician	8'900	9'200	9'400	9'600	9'800	10'100	10'300	10'500	10'800	11'100	11'400	11'600	11'900	12'200	12'500	12'800	13'100	13'400
Engineers	4'300	4'500	4'600	4'700	4'800	4'900	5'000	5'100	5'300	5'400	5'500	5'700	5'800	5'900	6'100	6'200	6'400	6'500
Research	1210	1240	1270	1300	1330	1360	1400	1430	1460	1500	1540	1570	1610	1650	1690	1730	1770	1810

Figure 19: Needs in Education and training for electrical energy equipment manufacturing companies

Appendix 5 - Workforce Estimation for Total Workforce in the Electricity Grids Business



	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
LV Vocational	310'700	314'300	318'000	321'800	325'700	329'700	333'800	337'900	344'100	350'400	356'800	363'400	370'100	376'900	383'900	391'100	398'300	405'700
LV Technician	159'400	162'700	166'200	169'700	173'300	177'000	180'700	184'600	188'700	193'100	197'400	201'900	206'500	211'200	216'000	221'000	226'000	231'100
LV Engineers	85'800	87'400	89'100	90'800	92'600	94'400	96'200	98'100	100'200	102'400	104'700	106'900	109'200	111'600	114'100	116'600	119'100	121'800
LV Research	20'800	21'300	21'800	22'200	22'700	23'200	23'700	24'200	24'800	25'300	26'000	26'600	27'100	27'700	28'500	29'100	29'700	30'500
MV Vocational	37'700	38'300	39'000	39'800	40'500	41'200	42'000	42'800	43'700	44'600	45'500	46'500	47'500	48'600	49'600	50'600	51'700	52'900
MV Technician	40'300	40'900	41'500	42'200	42'800	43'500	44'300	45'000	45'800	46'800	47'800	48'600	49'600	50'700	51'700	52'800	53'800	54'900
MV Engineers	25'800	26'100	26'400	26'800	27'100	27'400	27'800	28'100	28'700	29'200	29'700	30'300	30'800	31'400	31'900	32'500	33'200	33'800
MV Research	4'440	4'540	4'640	4'740	4'840	4'940	5'040	5'140	5'250	5'360	5'470	5'580	5'690	5'810	5'920	6'030	6'240	6'360
EHV + HV Vocational	10'700	10'900	11'200	11'400	11'700	11'900	12'200	12'400	12'700	13'000	13'300	13'500	13'800	14'100	14'500	14'800	15'200	15'500
EHV + HV Technician	12'500	12'700	12'900	13'200	13'400	13'600	13'900	14'100	14'300	14'600	15'000	15'200	15'600	15'900	16'200	16'500	16'900	17'200
EHV + HV Engineers	11'400	11'500	11'600	11'800	11'900	12'000	12'100	12'200	12'400	12'700	12'900	13'000	13'200	13'500	13'700	13'900	14'200	14'400
EHV + HV Research	1'510	1'510	1'510	1'610	1'610	1'610	1'710	1'710	1'720	1'820	1'830	1'830	1'930	1'940	1'940	2'050	2'050	2'150

Figure 20: Estimated workforce qualification in the electricity grids business respective to different grid voltage level types for the period 2013-2030

SET-Plan Energy Education & Training
Energy Storage

Energy Storage

Working Group Contributors

Fabio Bignucolo	University of Padova, Italy
Luisa F. Cabeza	University of Lleida, Spain
Marcello Chiaberge	Politecnico di Torino, Italy
Irene Fastelli	ENEL, Italy
Christian Folke	E.ON Gas Storage GmbH, Germany
Gabriel García-Naveda	CENER, Spain
Raquel Garde	CENER, Spain
Viktoria Martin	KTH – Royal Institute of Technology, Sweden (Rapporteur)
Fokko Mulder	TU Delft, Netherlands
Delphine Riu	Grenoble Institute of Technology, France
Hans-Juergen Seifert	Karlsruhe Institute of Technology, Germany
Franz Stelzer	TU Graz, Austria
Carlos Ziebert	Karlsruhe Institute of Technology, Germany

Introduction

Effective integration of energy storage in our energy systems is a key to sustainability. Energy storage takes care of the mismatch between energy supply and our demands (instantaneous, hourly, daily, weekly, yearly) of energy services like electricity, heat, cold and clean water. It can further contribute to the improved transportation of thermal energy over distances, thus also taking care of a mismatch in space of an energy source (such as industrial surplus heat) and demand – the next generation of "district heating" realised by advanced thermal energy storage technologies.

Energy can be stored in many ways, using the principles of electrochemical, chemical, thermal, mechanical, and superconducting magnetic energy storage. Each of these technologies can be further subdivided into specific subgroups, e.g. mechanical storage into pumped hydro, compressed air energy storage and flywheels, respectively. Each technology has its merits in particular applications, and through the assessment work presented here, it is evident that for sustainability, there will be no single winning technology. To alleviate peak demands, ensure security of supply, and realise a transition to sustainable energy mix in society, all options are needed to their fullest technical potential – the task at hand, is to enable this potential to become practical and economically sound.

The scope of this report is a broad assessment of the concept of energy storage in the context of an evaluation of the demand for storage in the future, i.e. the market growth potential, and those skills needed that will be of significance for satisfying this demand. This report has identified skills needed, and presents some proposed actions for education and training in this area. No particular storage technology is managed in-depth but this work rather relies on already published analyses and other literature available. An estimate has been conducted to allow for presentation of indicative values regarding market and work force potentials for several storage technology options, as well as fresh input from industrial and academic contributors via a survey. The report starts with a present-state assessment (Section I), followed by a summary of some ongoing actions regarding training and education, where storage in some cases is, but in most cases should be, included as a key technological concept (Section II). In Section III, the needs, gaps and bottlenecks for the advancement in the field is described, followed by some recommended actions presented in Section IV. Finally, Section V contains the Concluding Remarks from our work.

Summary of Recommendations

With the above introduction, the recommendations of the Working Group on Energy Storage are, in brief:

- The creation of on-line training activities, using modern ICT, to be able to make training accessible to a significantly larger number of professionals than what is possible through conventional education and training actions, of which a MSc programme is one (e.g. Erasmus Mundus EMMC[1] with 20-50 participants per cohort).
- Pooling of resources for rapid enabling of expertise and learning material, including:
    - Energy Storage Collaborative R&D Infrastructure
    - Energy Storage virtual faculty exchange
    - Learning Modules for integration in Higher Education Traditional Programmes
- Cross-disciplinary programmes (MSc and PhD), or part of programmes:
    - focussing on combining sciences for the design and development of energy storage technology
    - focussing on sustainable energy systems understanding and optimisation including tools to assess a variety of storage options
- All actions designed with University-Industry interaction and cooperation, to be facilitated by e.g. easier and especially faster access to public funding for joint projects.

[1] Erasmus Mundus Joint Masters Courses

1 Current situation – existing workforces (value chain), labour intensity, future trends, and workforces required to achieve the SET-Plan vision.

Background

Humanity's need for energy services, like electricity and heat is steadily increasing with known negative consequences to earth's resources, climate and the environment. For sustainability we need to provide these energy services by matching environmentally and economically sound alternative supplies (renewable energies) to the demands. However, there is often a mismatch in time, between such sound supplies and our demand. Due to the high diversity of technologies used for energy storage, their role is poorly described in many pathways to a low-carbon economy. These complex technologies cover timescales from seconds to months, requiring detailed analysis of systems and sub-systems to identify the economic and environmental benefits they may bring. Energy storage can e.g. help to manage the large-scale deployment of intermittent renewable energy generation. Storage technologies have the potential to substitute for new peak power generation plants and allow the electricity network to handle increasing power flows [1]. A closer look reveals the multitude of required energy storage applications for i) generation and system level applications (utility systems), ii) Transmission and distribution system applications and iii) End-user applications as shown in Fig. 1.[2] This figure considers time scales up to hours, i.e. long term seasonal storage is not included. For the integration of intermittent renewables, it is however essential to also consider seasonal storage and then cost and abundance of materials becomes an increasingly important issue.

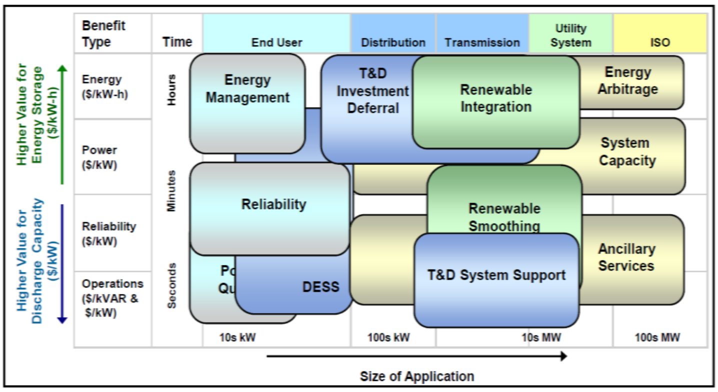


Fig. 1 Operational Benefits Monetizing the Value of Energy Storage for timescales between seconds and hours. [2] [Courtesy of EPRI]

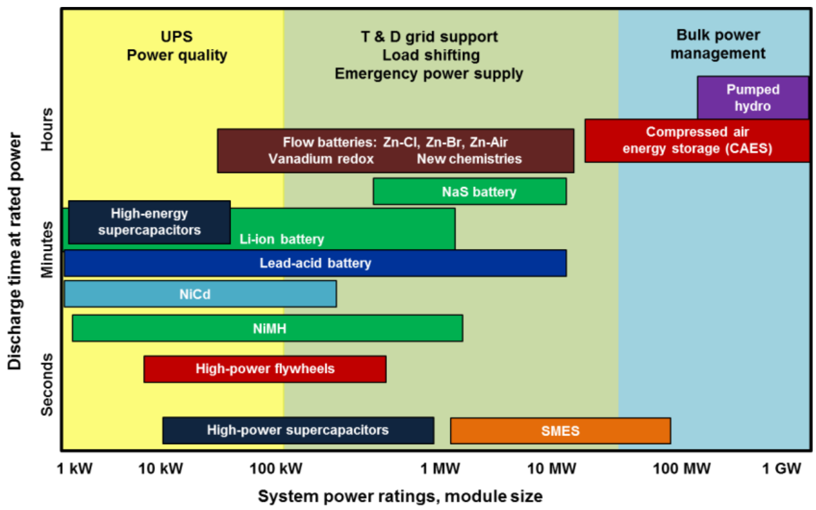


Fig. 2 Comparison of discharge time and power rating for various electrical energy storage technologies. The comparisons are of a general nature because several of the technologies have broader power ratings and longer discharge times than illustrated.[2] [Courtesy of EPRI]

Energy can be stored in so many ways, as exemplified in Fig. 2 which only illustrates the characteristics of various electric energy storage technology options in terms of system power ratings and discharge time at rated power.[2] Commonly five different energy storage technologies are defined: electrochemical, chemical, thermal, mechanical, and superconducting magnetic energy storage. Each of these technologies can be further subdivided into specific subgroups, e.g. mechanical storage into pumped hydro, compressed air energy storage and flywheels, respectively. Each technology has its merits in particular applications, and through this assessment work based on evaluation of 20 major reports [1-20] it is evident that for sustainability, there will be no single winning technology. Instead most storage options must be put to use to ensure security of supply, un-interrupted power supply, low emission generation, and cost-effectiveness, because none of the technologies listed is capable of solving the challenge alone.[3] Additionally there is an increasing need to combine different types of storage technologies in hybrid systems such as e.g. fuel cells, supercapacitors and batteries. Additionally, either energy or power density is more important depending on specific technological requirements. Timescale demands will also vary with the application, from milliseconds in electrical grids to seasonal storage in the ground for solar heating of the building sector.

Installed Energy Storage Capacity

For electric energy storage the current situation according to the Electric Power Research Institute EPRI is shown in Fig. 3: pumped hydroelectric systems account for 99% of the worldwide installed storage with 127 GW of discharge power. A similar value of 100 GW is given by the Boston Consulting group [5]. Compressed air energy storage (CAES) is a distant second at 440 MW with only two installations worldwide - in Germany and the U.S., followed by sodium-sulphur batteries (Na/S) with some 200 installations worldwide, accounting for 316 MW of discharge power. All remaining electric energy storage resources world-wide are presently less than 85 MW in total. [2]

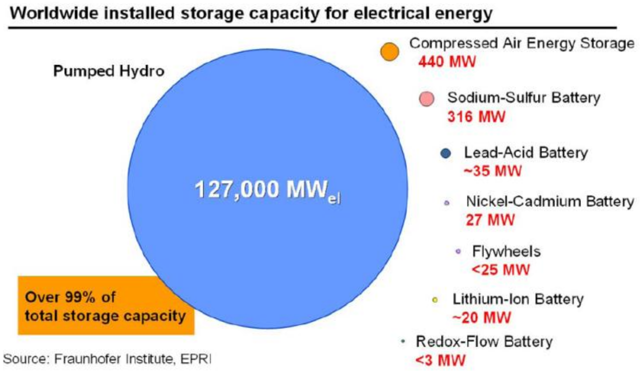


Fig. 3 Worldwide installed rated power of storage facilities for electrical energy. Such powerlevel can be sustained for up to several hours or shorter[2].

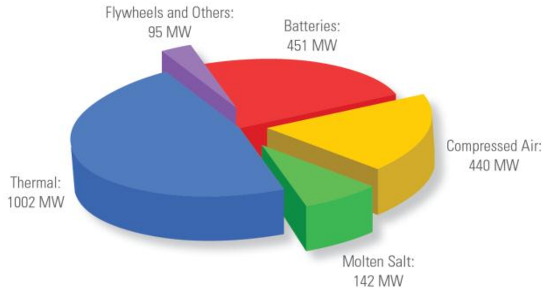


Fig. 4 Current Estimated Worldwide Installed Advanced Energy Storage Rated Power.[7]

Similar data were given by the California Energy Storage Alliance (CESA) including additionally a thermal energy storage power of 1 GW, as shown in Fig. 4. However there are some minor discrepancies between both reports concerning the estimated installed rated power of batteries and flywheels. An important point to consider here is that for the technologies mentioned the rated power can only be delivered during a limited time of the order of hours or less. This would imply that the energy storage capacity using these technologies appears to be as limited as < 10 GWh (compared to the global daily energy use of ~ 15 TW x 24h = 360TWh). More discrepancies have been found for the thermal energy storage because KEMA estimates only for the U.S. 1 GW of installed rated power, which is the same value as given by CESA for the worldwide thermal storage power. According to SGI energy, of the 1,572 MWh of molten salt thermal energy storage capacity installed worldwide at the end of 2010, all but 72 MWh of this capacity was installed in Spain.[17] Molten salt TES accounts for 97% of all TES installed with CSP plants as of the end of 2010. Usually original sources for such data are not given in the 16 major reports we evaluated. The fact that even ***the present installed energy storage capacity is not known exactly shows how difficult the forecast for the future is***, which will be discussed in the next section.

Estimation of Market Potential for Energy Storage

Energy storage will be one key technology for the future, and its market volume value is expected to increase dramatically over the next few decades. However there is a large difference in the predictions from different reports and statements. According to a BCC report the global alternative electrical power storage market in 2011 is worth more than $325 million, including more than $236 million worth of electrochemical batteries. This market is expected to grow at a compound annual growth rate (CAGR) of 5.4% between 2011 and 2016 under a consensus scenario resulting in a $423 million global market in 2016, including $322 million worth of electrochemical batteries [13]. A study from US analysts Pike Research earlier this year estimated the potential market for energy storage systems at 122 billion US$ by 2021.[11] In a recent interview of *BusinessGreen* with Jillis Raadschelders, vice president of the newly-formed European Association for Storage of Energy (EASE), he predicted the sector could be worth 500 billion € by 2030, although he added that technology was changing so quickly, he was *"hesitant to put a quantitative"* figure on the market size.[21] According to a report of Frost & Sullivan, in 2015 the world market for secondary batteries that can be used for energy storage will be about 60 billion US$.[15] Though all sectors of the energy storage market show strong potential, from an application perspective distributed generation devices, renewable systems, and ancillary services show the greatest near term growth potential. Global opportunity over the next 10 to 20 years is estimated at upwards of 300 gigawatts (GW) in size, which translates into $200-$600 billion in value according to KEMA.[7] The only publically available worldwide market potential estimation that differentiates between some major energy storage technologies was published by the Boston Consulting Group (BCG).[5] BCG has calculated an additional market potential of about 330 GW of storage distributed among the different technologies analysed, which agrees well with the KEMA report. This translates into an additional cumulated investment need of approximately 280 billion € to 2030, including replacement.[5] The details how these potentials are summed up from different technologies are shown in Fig. 5. According to BCG balancing power on timescales up to hours will drive about one third of the market potential; in terms of regional distribution Western Europe, the U.S. and China will take the largest shares. Batteries will account for almost 50% of this market in terms of rated power and financial investment, see Fig. 5 right side, although they will represent a very small part of the storage capacity needed by 2030. Compared to the presently globally installed rated storage power shown in Fig. 3 this is a tremendous predicted increase for CAES from 440 MW to 133,000 MW or for batteries from 400-450 MW to 141,000 MW and only a modest increase of pumped hydro from 100,000 to 150,000 MW (mainly caused by the limited number of available geographically suitable pumped hydro sites).

In the above presented numbers, it should be noted that storage is only treated for timescales up to hours. However, with the increasing installed power of renewables such as solar and wind power also seasonal fluctuations become important. The insolation in Europe varies by a factor 5-6 on average between summer (high) and winter (low). The lower energy yield in winter is currently compensated by using more fossil fuels, but in a future with reducing fossil fuel availability other means of storage need to replace them. For this reason BCG predicts a gradual replacement of both pumped hydro and CAES by hydrogen storage after 2020 without giving exact figures. The switch to hydrogen where hydrogen from electrolysis is fed into the existing natural gas grid is being investigated recently in e.g. Germany. The goal is to make better use of the peak electricity delivered by wind power (Enertrag AG).

According to a recent report of SBI energy the $2.5 billion global high temperature energy storage (HTS) market of 2020 is going to be dominated by the sale and construction of molten salt storage systems for concentrated solar power (CSP) plants. This report considers that the HTS market is composed of three categories: sodium-sulphur (NaS) batteries (operating temperature 290-360 °C), sodium-metal halide (NaMx) batteries (operating temperature 270-350 °C), and molten salt thermal energy storage (TES) systems. While NaS has been the strongest category ever since the first commercial systems were sold in 2003, it is molten salt TES systems that became the largest HTS category in 2010. The molten salt market has been growing by leaps and bounds since 2006, climbing 16-fold between 2006 and 2010 to $250.4 million. Thus this report forecasts a market potential of at least $1 billion for molten salt thermal energy storage for 2020. Here, it should be noted that from a scientific point of view it is not a good choice to mix molten salt and batteries in a definition for High Temperature Storage as was done in this report, since for the electrochemical process of the battery, it is not really the temperature that is the parameter for obtaining storage density but how much energy can be charged in the electrochemical process.

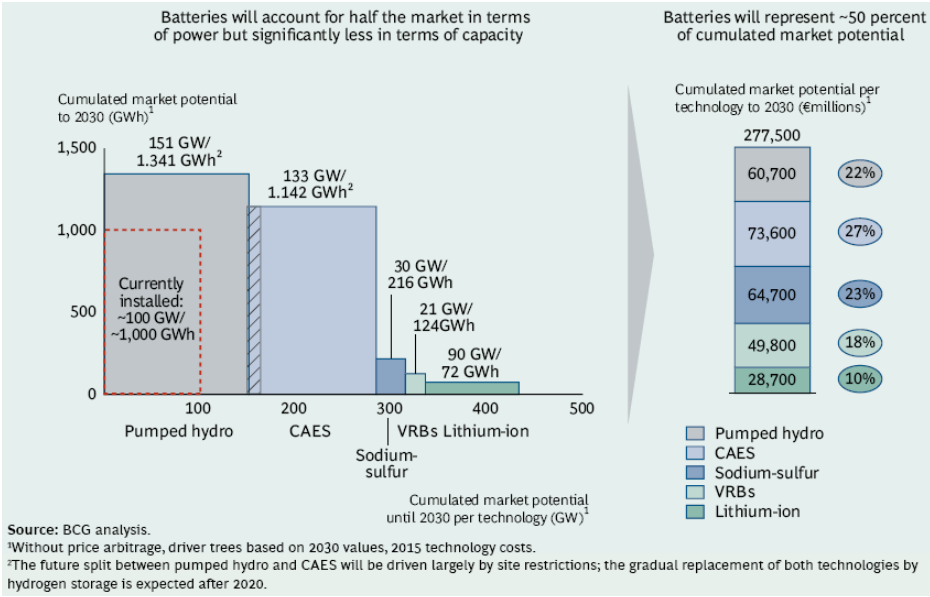


Fig. 5 Market Potential of the Storage Technologies for timescales up to 10 hours and less, the energy storage during seasons is not taken into account in this figure.[5].

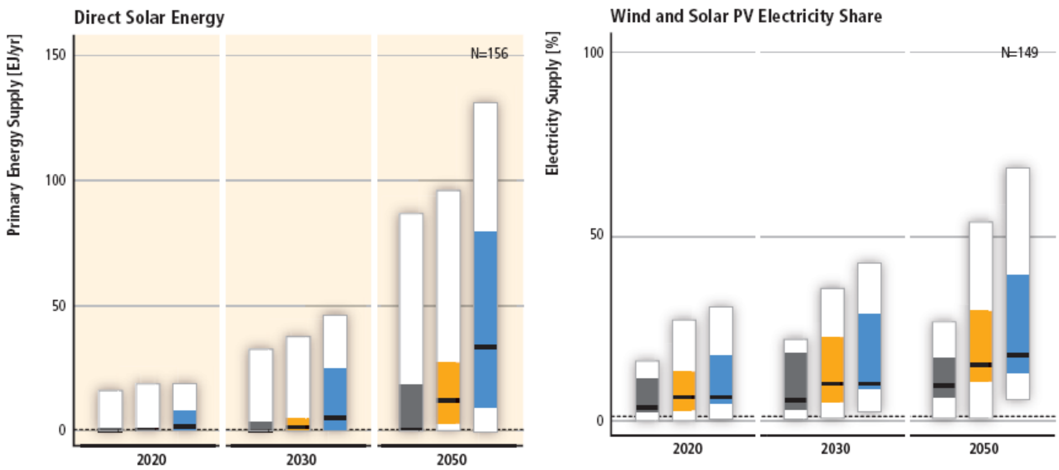


Fig. 6 Figures from the IPCC SRREN report 2011 indicating (left) the primary energy supply from direct solar power (thermal methods + PV) and (right) the electricity share of solar PV and wind power in the years indicated.[20] The different bars indicate different categories of scenarios that are taken into account (not explained here)

Long term energy storage to cope with renewable energy generation fluctuations on timescales of days up to seasons is not considered in the above Fig. 6. To come to an estimation of long term storage a simple approximate approach may be followed. In the blue bars in Figure 6 the approximate scale of future global renewable energy generation is indicated for 2050 as 30-40 EJ/yr for direct solar energy and 20% of electricity from PV and wind. This should be compared to the current ~500 EJ/yr energy use and ~70 EJ/yr electricity. The total from direct solar and wind energy does not become immediately clear but one could consider a level of 37 - 47 EJ/yr coming from fluctuating solar and wind sources by 2050.

Solar energy varies significantly between seasons; at a latitude of ~52° (Netherlands) there is a factor of 6 between summer and winter, in northern Africa a factor of ~2. On average one may use a factor of ~ 4 for direct solar power generation capabilities between summer and winter. Assuming a sinusoidal behaviour between 25% and 100% (i.e. around an average of 62.5%) and peaking in the summer could represent the direct solar energy output throughout the year. A useful amount of stored energy between seasons would then correspond to the half sinus above the average corresponding to ~ 38% of the yearly generated direct solar energy. This would amount to around 10 - 14 EJ/yr = 3700 – 5200 TWh/yr (by 2050 on a world scale, Europe is a fraction of that). Such amount would then be used up in the low energy generation season. In 2030 it could be 1/3 of that ~ 1200 – 1700 TWh/yr. Clearly this is a rough approximation but since the scenarios deviate strongly from each other there is not much possibility to make more accurate estimations. Wind power fluctuates less during the year and may thus be mainly stored locally during short term, daily, fluctuations.

For large scale long term storage of direct solar energy at a 1000 TWh scale there are thermal methods for low temperature heat in e.g. (underground) heat storage or in more versatile chemical energy storage based on abundant chemistries. Such chemical storage includes hydrogen made from water and electricity, liquid ammonia made from nitrogen and hydrogen, as well as hydration/dehydration of salts. The technology to generate hydrogen and ammonia at large scale is available since about 1% of the world energy consumption is used for ammonia production for agricultural fertilizers. However, currently this is performed using hydrogen produced from fossil fuels, which should be altered to hydrogen production by e.g. the direct solar energies. Other methods of chemical storage utilising reversible chemical reactions, like hydration of salts, and sorption processes are presently under development to enter the market within the next 10-20 years. Such high energy density storage methods are promising for managing the “winter season” demand for electricity with solar energy chemically stored from the “summer season”.

For the thermal energy demands (heating and cooling), primarily in the building sector, there is a large opportunity for long term thermal storage (presently underground thermal energy storage/UTES like borehole fields and aquifers, but extremely promising thermochemical storage technologies encompassing reversible chemical reactions and sorption processes) to accomplish 100% renewables in buildings. While discharging stored summer heat in the winter, the UTES is actually charged with “cold” for the summer cooling demand. This must however go hand in hand with end use efficiency and the design of functional passive energy buildings – yet another example of how storage must be seen in the context of its application and not as a free-standing component in the energy conversion chain.

Another key aspect of a sustainable energy system is the world-wide utilisation of surplus industrial heat. For economic, as well as environmental reasons industry of all kinds already implement process integration to a large extent, to make proper use of internal surplus energy flows in its own processes. However, there is still a surplus that is not possible to use internally. For example in steel mills, the surplus is close to 3 TWh for one single mill producing in the order of 2 million tonnes of steel directly from iron ore (including their own coking process)[22]. Often, there is a mismatch both in time and space for making it technically and economically feasible to utilise this surplus externally – the mills are located far from the built environment to e.g. allow for a pipe-based district heating transfer of the surplus to meet local demands. Also, the surplus is available in batches as many industrial processes are batch-type which makes it difficult to use the heat for e.g. continuous power generation. Then, the concept of thermal energy transportation using truck, train or boat in combine with high energy density storage technology such as sorption or phase change material technology becomes an option. The amount of surplus industrial heat in Europe alone is in the order of 1000 TWh/year, and allowing for an invested mobile storage to work in many cycles per day for economic feasibility, the need for storage in this area could be in the order of 500 GWh.

In terms of energy storage volume, the seasonal storage clearly outnumbers the currently available storage methods that are meant for hourly storage. This means that a whole new storage economy will be required to accommodate such storage volumes, if one requires independence of fossil fuels. In the transition stage one could simply run more on fossil fuels during winter, and on renewables plus short term storage during summer. Such lack of long term storage would imply investing in both the full capacity for fossil generating capabilities as well as for renewables.

Thus, with regards to education and training, this forecast will highlight those general skills presently missing to a large extent but have been judged essential for the successful technology development described above.

For the future, the value chain of promising energy storage options must be considered when assessing the need for training and education. For this, a few example value chains are described in the figures below pertaining to: 1) Advanced Batteries; and 2) Phase Change Material-based thermal energy storage.

Types of Value Chains for Energy Storage

Technology value chains can be constructed on different levels: 1) the *general technologies* like power supply / value chain and heat supply / value chain, respectively, 2) the *specific energy storage technologies* such as lithium ion batteries, fly wheels, superconducting magnetic energy storage - just to name three of many others and 3) *technology application* value chains.

General technologies

Fig. 7 shows the Electricity / Power value chain. Obviously energy storage technologies in this sector are relevant for the 1 GW to 10 kW power level covering large to small scale levels and additionally *Electric Vehicle* (Vehicle to Grid technologies, V2G). This approach reveals the cross-linkage of energy storage technologies with all other technologies related to generation, transmission, distribution and customer consumption. This makes it clear that experts (mechanical, electrical and electronic engineers) with skills and knowledge related to the particular technology interfaces are required.

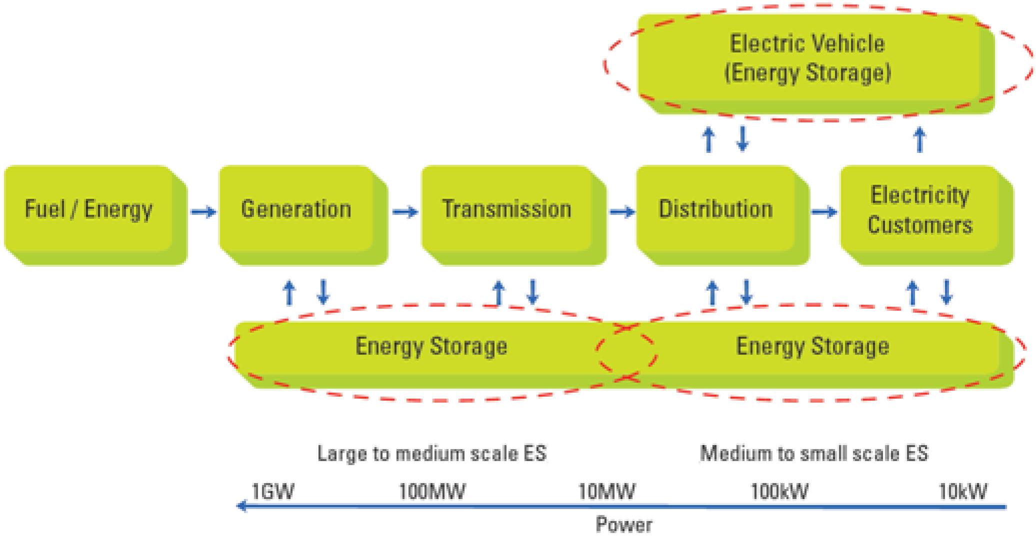


Fig. 7 Electricity Value Chain. [6]

Specific energy storage technologies

Fig. 8 shows the value chain for lithium ion batteries as one example of many others for a specific energy technology. This value chain starts with materials level and ends at the battery manufacture level. On materials level (Current collector, active materials, separators, electrolyte), obviously skills in materials science and engineering incl. physics, chemistry and electrochemistry are required. Also separation and purification of pure raw materials at a large scale is an issue. On electrode and cell levels the expertise of electrochemists, physicists and electrical engineers is of major importance. Thermal, gas and battery management levels require mechanical, electrical and electronics engineering competencies. Such skills are also important on stack manufacture and battery manufacture levels. Close collaboration is also required with experts in process engineering.

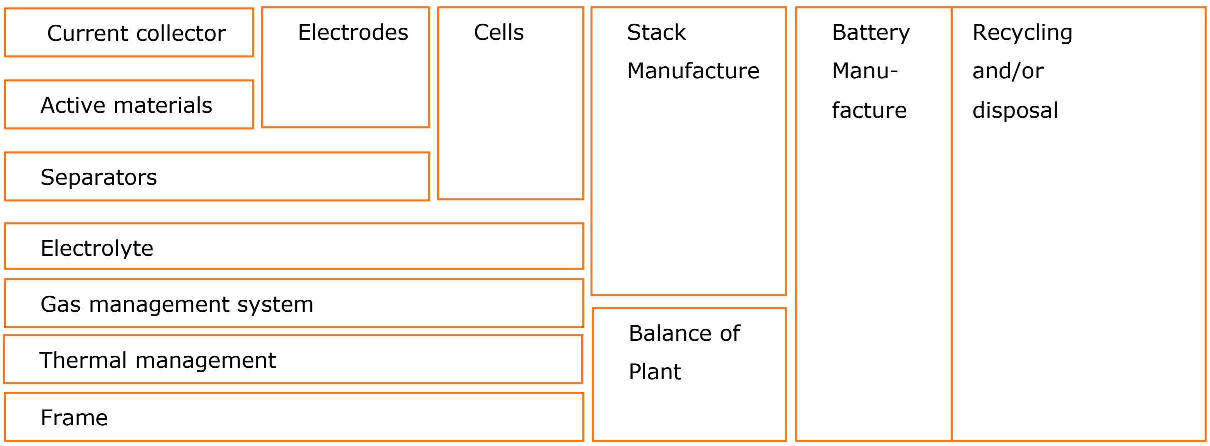


Fig. 8 Example Value Chain: Advanced Battery Technology.

Basic R&D	Storage Design	Manufacturing	O&M
•Advanced material design/molecular modelling •Properties: ✓Measurement techniques ✓Conductivity enhancement ✓Electrochemical properties •Etc	•Materials engineering: ✓Materials compatibility ✓Electrochemical kinetics •Transport phenomena: heat transfer and fluid dynamics •Modelling/computational fluid dynamics •Control development •System integration/economic optimization •Component design (collectors, electrodes, etc.)	•Raw Materials vs Quality •Components manufacturing •Stack manufacturing •Battery manufacturing (including Balance of Plant components) •Power electronics manufacturing •Production Line-benefit of scale cost reduction	•Maintenance protocol

Fig. 9 Advanced Battery Technology: summary of skills and activities needed in the different levels of system deployment.

One more example is for the merging thermal energy storage technology using phase change materials (PCM technology) shown in Fig. 10.

BASIC R&D	Storage Design	Manufacturing	O & M
▪ Advanced material design/molecular modelling ▪ Crystallization aspects ▪ Phase Equilibrium ▪ Properties : ✓ Measurement techniques ✓ Conductivity enhancement ✓ Phase separation ✓ Standardization ▪ Etc	▪ Materials engineering: ✓ Crystallization kinetics ✓ materials compatibility ▪ Transport phenomena: heat transfer and fluid dynamics ▪ Modelling/ computational fluid dynamics ▪ System Integration/Thermo-economic optimization ▪ Component design (heat exchangers etc)	▪ Raw Materials vs Quality ▪ PCM manufacturing (including additives) ▪ Heat exchangers ▪ Storage containers ▪ Filling of storage (gelled PCM) ▪ Production line – benefit of scale cost reduction	▪ Maintenance protocol ▪ Supply and demand matching: ✓ Controls: charging/discharging

Fig. 10 PCM Thermal Energy Storage: summary of skills and activities needed in the different levels of system deployment.

Here, the PCM technology value chain starts with materials research and development addressing the important phase change in terms of crystallisation, the knowledge of potential and stability of new material mixtures through phase equilibrium, as well as appropriate measurements techniques for determining properties. In the storage design phase, engineering sciences are central with special emphasis on advanced heat transfer, modelling and system integration and optimisation. In the manufacturing segment, key aspects lie in developing a low cost production line that can make use of the benefit of scale and cheaper (less pure) raw materials, and still managing the task of high-quality filling a storage with liquid PCM which can risk crystallising on cooling surfaces. Finally, for the overall sustainability (energy, environmental, and economical) the O&M segment needs the skills of establishing appropriate system maintenance protocol including the PCM storage, as well as the ability to match supply and demand through sound control strategies that maximises the benefit of each installed Wh of storage.

Regardless of technology, there comes a time for recycling or disposal of the storage (or parts of it) which requires its own skills, from material science to engineering, to manufacturing and process skills similar to the above first cycle skills presented.

Here, the emphasis in presentation is on a functional level recognising that the active skills in the processes range from scientists/engineers to good workers without university degrees but who would benefit from practical training and education.

Energy storage applications

The situation becomes even more complex when specific energy storage applications are considered. The EPRI report[**Error! Bookmark not defined.**] lists ten major applications for energy storage (out of many others) and defines as value chains to be considered:

1) Generation and System-level applications (wholesale energy services; renewables integration)

2) Transmission and distribution applications (Stationary storage for transport and distribution support; transportable storage for transport and distribution support; distributed energy storage systems; Energy services company aggregated systems; Commercial and industrial power quality and reliability; Commercial and industrial power energy management) and

3) End-user applications (Home energy management; Home backup). For each application a full value chain should be constructed. However, such information is not available. Pike Research anticipates that among the various application segments in this market, the integration of renewable energy – primarily wind power – will represent approximately 50% of the total capacity deployed for long duration energy storage. The firm forecasts that load levelling/peak shifting will represent 31% of the total market, followed by arbitrage (12%) and T&D upgrade deferral (7%).[**Error! Bookmark not defined.**]

Job creation estimates associated with energy storage is complicated by the requirement to decide on which general type of value chain and which specific technologies should be considered. Such analysis is only known for the US market provided in the report by KEMA and the Electricity Storage Association (KEMA summary of ESA storage jobs report) [8]. To our knowledge similar reports for European market are not available.

Current workforces profiles Europe

The example value chains presented above do not include information/education/training for decision processes (e.g. investment decisions) leading to the integration of energy storage. It could be one important factor, since *most* energy conversion systems *function without* energy storage, but *most* systems functions *better with* energy storage.

To our best knowledge the EUROBAT white paper[9] is the only publication which gives a specific number for employees in the EU Battery Industry. It represents over 40,000 employees in this area.

Hydrogen is an interesting candidate for high energy density short/long term storage of energy. Current hydrogen production is strongly linked to ammonia production for fertilizers; about 50% of the hydrogen is produced and used in ammonia production plants and about 35% in oil refineries. Numbers are not available to our knowledge, but extrapolating from the number of employees of Yara International (7600 by 2010) and its worldwide 20% market share in ammonia trade one could estimate a total number of workers of the order (1/0.2)x(1/0.5)x7600 ~ 80000, but this is with a large uncertainty.

To estimate the number of employees in Europe related to Energy Storage also requires a knowledge of how to categorize such an employee. There is really no reliable way to estimate whether an employed person should belong to Energy Storage or more related to any of the other fields assessed in the SET-Plan, like "CSP", "Fuel Cell and Hydrogen" or Smart Cities. For this reason, a conservative estimate of non-overlapping employees are presently 50,000, with the majority (50%) being engineers, and the remaining equally distributed among researchers and technicians.

The following sections examine what type of work forces could be behind these numbers.

Forecast for human future resources

BCG has calculated an additional market potential worldwide of about 330 GW of rated storage power for the eight applications

(i) price arbitrage

(ii) balancing energy

(iii) provision of black-start service

(iv) stabilising conventional generation

(v) island and off-grid storage

(vi) T&D deferral

(vii) industrial peak shaving

(viii) residential storage distributed among the different technologies analysed.[5]

This translates into an additional cumulated investment need of €277.5 billion until year 2030, including replacement. Today, the storage market for these applications is worth around €1 billion per year.

With these numbers as reference, an assessment of the human resources needs in the future can be carried out following a similar methodology to the one developed by KEMA in its study "Assessment of Jobs Benefits from Storage Legislation".[8] This methodology involved quantifying the key storage market application areas, creating a market penetration curve for the application areas, assessing the yearly MWs of energy storage penetration, and then calculating the revenues associated with those MWs. From the revenues created through the yearly MWs, the model then also calculated the increase in jobs that will be expected in each of the areas. Based on guidance from ESA and other industry sources, KEMA applied a job creation factor of $200,000 in sales revenue to create one job for one man year or equivalently, five man years created per $1 million in sales revenue. This estimate does not include indirect and induced jobs which would be created in the supply chain from such an investment in storage.

Then, according to the previous figures of BCG, it could be expected **1,387,500 new man years** related to electricity energy storage **by 2030**, distributed in 303,500 in Pumped Hydro, 358,000 in CAES, 323,500 in NaS batteries, 249,000 in redox batteries and 143,500 in Li ion batteries all over the world. Furthermore, taking the $2.5 billion global high temperature energy storage market in 2020 from SBI energy, which will be dominated by molten salt for CSP plants, this translates into 12,500 man years related to high temperature TES. It is difficult to extract data for Europe from these global figures. According to BCG balancing power on timescales up to hours will drive about one third of the market potential of €277.5 billion; in terms of regional distribution Western Europe, the U.S. and China will take the largest shares. From this it can be estimated that balancing power alone accounts for a market potential of about € 90 billion. And from this the fraction of Europe might be about 1/3, i.e. € 30 billion, which translates into at least **150,000 new man years in Europe** only for the application of balancing power.

Besides the short term energy storage technologies long term energy storage technologies are required. The long term energy storage requires other technologies such as hydrogen, and heat storage, and devices to utilise these chemical and thermal storage, such as storage devices and depots, fuel cells, heat exchangers and auxiliary equipment. An estimation of the market growth is to our knowledge not available presently. However, here a scaling approach will be used, scaling from current production volume to the anticipated useful energy storage volume of ~ 1,200 – 1,700 TWh/yr by 2030. Current production of hydrogen (mainly for ammonia) corresponds to 6 EJ/year = 1,667 TWh/yr. On the production side one may thus see a doubling of the production workforce for hydrogen, assuming the future renewable production (e.g. electrolysis) requires a similar workforce as current production from fossil fuels. This would imply 80,000 man years of new jobs by 2030 for production of hydrogen. The workforce for storage of hydrogen is currently essentially absent, because the hydrogen produced now is directly used in ammonia production or refineries.

The lower limit of 1,200 TWh long term storage corresponds to 136 GW continuously, or 4 times that value = 544 GW if one assumes that such storage is producing power only during the low winter season and storing at similar power rates only in summer. Taking the ratio between jobs generated and power similar as above (1.4 million jobs / 330GW = 4,200 jobs / GW) we would arrive at ~ **2,200,000 man years of new jobs created for long term energy storage in chemical fuels and heat**.

Finally, analysing the amount of actual new people that will be needed to fill these needs for man year, one can make an estimate as follows:

(1,387,500 + 2,200,000 man years) x (1 / 20 years) x (2 since people may stay 'only' 10 years in the same job on average) = 138.500 + 220.000 people.

These people are then the basis for estimating a need for number of people to be trained and re-trained during the next 20 years

Profiles and workforces and skills

A vast variety of skills is in operation for present storage projects ("electrical"/thermal/chemical storage), and here a brief summary is presented, guided by a few detailed examples. However, in general skills on an operational level are always important but the support comes from engineers and scientists in many fields, including: chemical/mechanical/electrical/civil engineering, material science, chemists and physicists.

Battery technology has the particular need for knowledge in electrochemistry and material sciences, in the value chain from basic R&D through manufacturing through recycling and materials re-use. As an illustrative example, data from a European battery manufacturer will be used to show how the global figures presented in the previous section can be used to extract more specific information for which skills additional education will be needed. Table 1 shows the staff distribution of this battery manufacturer in per cent.

Table 1. Staff distribution in per cent for permanent and temporary White and Blue Collars for both genders for a European battery manufacturer

	WC		WC_AP		BCI		BCI_AP		BCD		BCD_AP		
	M	W	M	W	M	W	M	W	M	W	M	W	Total
R&D	2.95	0.43	0.06	0.00	0.37	0.00	0.06	0.00	0.00	0.00	0.00	0.00	3.87
Central Functions	2.15	2.33	0.03	0.03	0.09	0.03	0.00	0.00	0.00	0.00	0.00	0.00	4.66
Commerce Dept.	5.22	4.05	0.06	0.12	0.86	0.00	0.28	0.00	0.00	0.00	0.00	0.00	10.59
Production Dept.	6.01	1.56	0.06	0.12	10.16	0.74	2.79	0.71	26.33	8.59	15.34	8.47	80.88
Total other WC than R&D	13.38	7.95	0.15	0.28									21.76

Based on this example the scientific and engineering skills could be distributed as follows: 3.87% R&D and 6.52% others, considering that 30% of the other White Collars (21.76%) have high scientific educational skills. According to the data from the previous section, about 716,000 man years for new jobs could be created all over the world by 2030 that are related to battery techniques for energy storage. This gives a need for about 74,400 man years for (74,392) new skilled workers in the battery sector. Guessing that one third of the market is developed in Europe, about 24,800 man years for people with higher education skills will be necessary in Europe to cover the demand of the battery industry for stationary electricity storage alone. So this has been identified as the main area where training is needed, even though lots of "blue collar" job opportunities will come. However, the training for these is not so different from e.g. manufacturers or installers of other technology. Storage is high-tech on the development side and the system side, but once the system is designed and scaled up the actual manufacturing process or installation is not a big challenge anymore that needs a lot of high-level training.

For the continuing success of incorporating long term, thermal energy storage into a sustainable energy system, Sanner et al[23] highlight the need for engineers and contractors qualified in the installation of ground source heat pumps, to be used in combine with the UTES systems. Skills regarding drilling technology as well as geologists are needed in addition to traditional mechanical and HVAC engineers understanding transport phenomena (heat/mass/fluid flow).

The implementation of merging storage technologies, like PCMs in buildings and long term chemical storage, the rather few successful commercial installations have depended on very few specialised companies. In this e.g. architects and “regular” HVAC engineers have had the special knowledge of advanced storage (through collaboration with universities and research institutes) and applied holistic system approach in design.

Summary

Energy storage involves numerous technologies, applications, regulatory entities, and grid processes. The complex technologies cover timescales from seconds to months, which needs detailed analysis of systems and sub-systems to identify the economic and environmental benefits it may bring. Moreover for each application a full value chain should be constructed. All these aspects make it very difficult to make forecasts on future human resources and the skills that will be needed to realise the extremely large expansion of the installed rated power or capacity of the different energy storage technologies in order to reach the 20-20-20 goals and finally a decarbonised European energy system by 2050. Each technology has its merits in particular applications, and through this assessment work based on evaluation of 20 major reports it is evident that for sustainability, there will be no single winning technology. Instead most storage options must be put to use to ensure security of supply, un-interrupted power supply, low emission generation, and cost-effectiveness, because none of the technologies listed is capable of solving the challenge alone.

Using the few available estimations of market potential **1.4 million man years for new jobs** could be expected related to electricity energy storage **by 2030**, distributed in 303,500 in Pumped Hydro, 358,000 in CAES, 323,500 in NaS batteries, 249,000 in redox batteries and 143,500 in Li ion batteries all over the world, and at least 12,500 man years of jobs related to high temperature thermal energy storage. The need to fully meet the need for long term seasonal, and hourly/daily thermal energy storage, another **2.5 million man years of new jobs could be expected**. Science and Engineering is at the centre of skills presently identified as in most pressing demand. However, operators and workers in general will have to be available in sufficient numbers to ensure the successful realisation of the new thermal energy storage market for sustainable energy systems. It is believed that the major part of the new jobs expected will be related to such hands-on occupations. Still, close to a million new jobs for academic professionals are expected. For two examples it is shown how data for Europe for human resources and skills could be extracted from global data. At least **150,000 man years for new jobs in Europe** can be estimated only for the application of balancing power and about **24,800 man years for people** with higher education skills will be necessary in Europe to cover the demand of the battery industry for stationary electricity storage.

2 Ongoing actions

Section 1 of this report describes how Energy Storage will be a key component of large scale implementation of Renewable Intermittent energy sources like solar and wind, as well as for levelling of peak energy demands for robust grid operation and security of supply. Energy efficiency in many industrial processes, as well as in the building sector is also better enabled by the integration of storage – storage is the key for harnessing the "Negawatt hours" in a global sustainable energy system.

However, storage is not a technology meaningful in itself but is always present in the context of an application: wind, concentrating solar power, smart grid functioning, comfort cooling, hot water supply and demand, etc. Also, energy storage technology is an extremely broad area making use of a variety of physical and chemistry fundamental processes, e.g.: electrochemistry (battery); mechanical (fly-wheel and pumped hydro); chemical (hydrogen or thermochemical storage through e.g. hydration/dehydration reactions); and thermal (heating/cooling of a material, with or without phase change). For these reasons, education and training in storage is presently not available as a free-standing topic, but rather taught as learning modules connected to topics on particular applications (Smart Grids, Solar Energy, HVAC, and so on), and then not all storage options are valid such that they are all covered to allow for a comparative understanding of the physical and chemical principles of each option. Thus, to present a picture on what is presently being taught, we have identified a mapping of higher education in renewable and sustainable energy education as relevant.

Table 2. Sustainable Energy Related MSc programmes – World-Wide Examples

Location	**Title of MSc**	**Duration**	**Remarks**
EIT KIC InnoEnergy	RENE – Renewable Energy	2 years	Joint MSc, UPC Coordinator, Knowledge triangle to be emphasised: Innovation/Education/Research and Technology
EIT KIC InnoENergy	SENSE -- Smart Electrical Networks and Systems	2 years	Joint MSc, KTH Coordinator, Knowledge triangle to be emphasised: Innovation/Education/Research and Technology
Erasmus Mundus/EIT KIC InnoEnergy	SELECT – Environomical Pathways for Sustainable Energy Engineering	2 years	Joint MSc, KTH Coordinator, presently 100 students enrolled. Knowledge triangle emphasis, as RENE above.
Erasmus Mundus	ME3 – Management and Engineering of Environment and Energy	2 years	Joint MSc, EM Nante Coordinator
Erasmus Mundus	EWEM	2 years	Delft University of Technology Coordinator
Erasmus Mundus	STEPS	2 years	University of Oviedo Coordinator
Erasmus Mundus	ALISTORE/MESC	2 years	Joint MSc, www.alistore.eu, Materials for Energy and Conversion devices
Essen (Germany)	BSc Energietechnik	4 years	Joint University of Duisburg-Essen and House of Technoloy Essen

Univ. Flensburg (Ger)	Energy and Environmental Management	18 months	Management, society oriented
Karlsruhe Institute of Technology	Energy Engineering	2 years, 120 ECTS	Interdisciplinary (Mechanical, Chemical and Process, Electrical Engineering, Information Technology), 2 main subjects (32 ECTS): Renewable Energy and Energy Storage, Energy in Buildings, Energy Economics
Imperial College	Sustainable Energy Futures	1 year	Technology 50% Society 50%
Queen Mary Univ. London	Sustainable Energy Systems	1 year	Technology oriented
Univ. Utrecht	Energy Science	2 years	Society, economy, oriented
University of Glamorgan	Renewable energies and resource management	1 year	Focus on waste management
University of Dundee Renewable	Renewable Energy and Environmental modelling	1 year	Similar to SET, includes climate modelling
University of Edinburgh	Sustainable Energy Systems	1 year, including 3 month project	Technology oriented, 58 students in 2009
University of Reading	Renewable Energy	1 year	Technology, building sector
Univ. Vienna	Renewable Energy in Central and Eastern Europe	2 year part time	Focus on economy, planning
Glasgow Caledonian Univ.	Sustainable Energy Technologies	1 year	Includes energy conservation, current technologies
Ecole de Mines Paris, Loughborough, Zaragoza, Oldenbourgh, Athens, Kassel, Northumbria	European MSc in Renewable Energy	3 semesters/ 16 months; 1 sem. Core, 1 sem. specialisation, 1 sem. thesis	51 students in 2009, mainly from partner universities
Murdoch Univ., Perth, Australia	MSc in Renewable Energy	1 year	50 % technology or societal courses, 50% projects
Univ. of Calgary	Sustainable Energy Development	16 months	Mostly environmental and society
Univ. Delft U Eindhoven,	Sustainable Energy Technology	2 years	Since 2006, in 2011 about 100 + 45 + 20 1st year students. 75% science/technology, 25% economics. Research master.
Univ of Ulster	MSc Renewable Energy & Energy Management	PgDip plus MSc 2+1 years	
KTH	Sustainable Energy Engineering	2 years, 120 ECTS	In place since 1997, over 700 students from 70 countries hosted.
Universidad de Córdoba	Master in Distributed Renewable Energies	1 year, 60 ECTS	
Universidad de La Laguna	Ms in Renewable Energy	2 years, 120 ECTS	
Universidad de Valladolid	Energy: Generation, Management and Efficient Use	2 years, 120 ECTS	

Universidad Carlos III de Madrid	Ms in Renewable Energies in Electrical Systems	1 year, 60 ECTS	New
Universidad Europea de Madrid	Ms in Renewable Energies	60 ECTS	On-line
Universidad Politécnica de Maddrid	Ms in Energetic Engineering	1 year, 60 ECTS	
Universidad Rey Juan Carlos, Madrid	Ms in Energetic Technology and Resources	1.5 years, 90 ECTS	
Universidad San Pablo, Madrid	Ms in Renewable Energies	60 ECTS	On-line
Universidad Pública de Navarra	Ms in Renewable Energies: Electrical Generation	1.5 years, 72 ECTS	
Univesidad de Extremadura	Ms in Renewable Resources and Energetic Engineering	2 years, 120 ECTS	
Universidad del País Vasco - EHU	Ms in Photovoltaic Components and Systems	1 year, 60 ECTS	
Universidad del País Vasco – EHU	Ms in Engineering of Renewable Materials	1 year, 60 ECTS	
Universidad del País Vasco – EHU	Ms in Intregration of the Renewable Energies in the Electrical System	1 year, 60 ECTS	
Universidad del País Vasco - EHU	Ms in Research in Energetic Efficiency and Sustainability in Industry, Transport, Buildings and Human Settlements	1 year, 60 ECTS	

Also available are some relevant Initial Training Networks funded under Marie Curie. Examples are high-lighted in Table 3.

The impact of the large presence of higher education related to renewables and sustainable energy are primarily two-fold:

- A growing awareness of the complexity of integration of renewable and sustainable energy solutions, regardless of where in the energy conversion chain, which means that there is a growing need for knowledge in system optimisation and system performance evaluation.
- A growing awareness of the need for storage in order to integrate intermittent energy sources, and to achieve energy efficiency through stable "base load" operation of many energy conversion processes (regardless of scale). A piece of equipment operating at constant design load is much more efficient than similar equipment working under varying load (off design load) conditions.

Table 3. Examples of Marie Curie ITN:s of relevance to the field of Energy Storage

Title	**Project Acronym**	**Reference**	**Coordinator country – University**	**Time**
Materials and interfaces for energy conversion and storages	MATCON	FP7 - 238201	Sweden – University of Uppsala	2009-2013
Training future mechanical, civil, electronic engineers and computer scientists in system identification, condition & health monitoring for a new generation of wind turbines	SYSWIND	FP7 - 238325	Ireland – College Green	2009-2013
Sustainable hydrogen generation	SUSHGEN	FP7 - 238678	UK – Univ. of Newcastle upon Tyne	2009-2013
Initial training network for wave energy research professionals	WAVETRAIN 2	FP7 - 215414	Portugal – Wave Energy Centre	2008-2012
Functional nitrides for energy applications	FUNEA	FP7 - 264873	Germany – TU Darmstadt	2011-2015
Complex solid state reactions for energy efficient hydrogen storage	COSY	FP6 – 35366	Germany - GKSS	2006-2010
Production and storage of hydrogen	HYDROGEN	FP6 - 32474	Netherlands – University of Leiden	2006-2011
Hydrogen storage research training network	HYTRAIN	FP6 - 512443	UK - University of Salford	2005-2008
Atmospheric modelling for wind energy, climate and environment applications: exploring added value from new observation technique	MODOBS	FP6 - 19369	Denmark – DTU	2006-2009

We can conclude that energy storage very likely (and often confirmed) is taught to “some extent” in these programmes. It needs to be pointed out that this is an exemplifying mapping, not at all exhaustive but nevertheless containing a vast number of programmes of high relevance to the topic. Still, based on a fresh survey by industrial and university representative, we can conclude that the actions so far are not effective (see also section III) to the extent needed for the expected growth in market in the next 10-20 years.

3 Needs and gaps, barriers and bottlenecks for the industrial sectors and their markets

The need for training in Energy Storage – the industrial perspective

In order to capture the industrial view on such a broad topic as the need for training and education on Energy storage, a fresh survey has been especially designed for this assessment. The results are shown in Fig. 11. The European industries represented are covering many sectors (power transmission, utility, engineering, component manufacturers, building construction) and are of various sizes and nationalities. Also, they are not so many so the points of views and information should be considered more as indications to guide us in the design of future educational efforts in the area of energy storage.

As shown, most actors agree that there is indeed a need for people trained in Energy Storage, but one should then remember that when each particular industry is asked "what technology" they are emphasising it varies from battery, to large scale underground thermal energy storage.

Presently, the view exists that energy storage is not a fully developed and widely implemented technology. Beyond universities and very specialised companies, there are not enough people trained to realise a large scale implementation of new installations for many of the storage options. Therefore, the need for people trained (and re-trained) in this area is also expected to increase in the next 10 years, while at the same time training on Energy Storage in higher educations is presently not adequate. One very important aspect resulting from the survey is that traditionally design engineers and technicians have explored changes/developments of energy facilities by considering base load and average demands. Still, with energy related costs increasing, and the sustainability and security of supply aspects being high-lighted, the peak power demand will become increasingly important such that energy storage for load shifting will become extremely valuable.

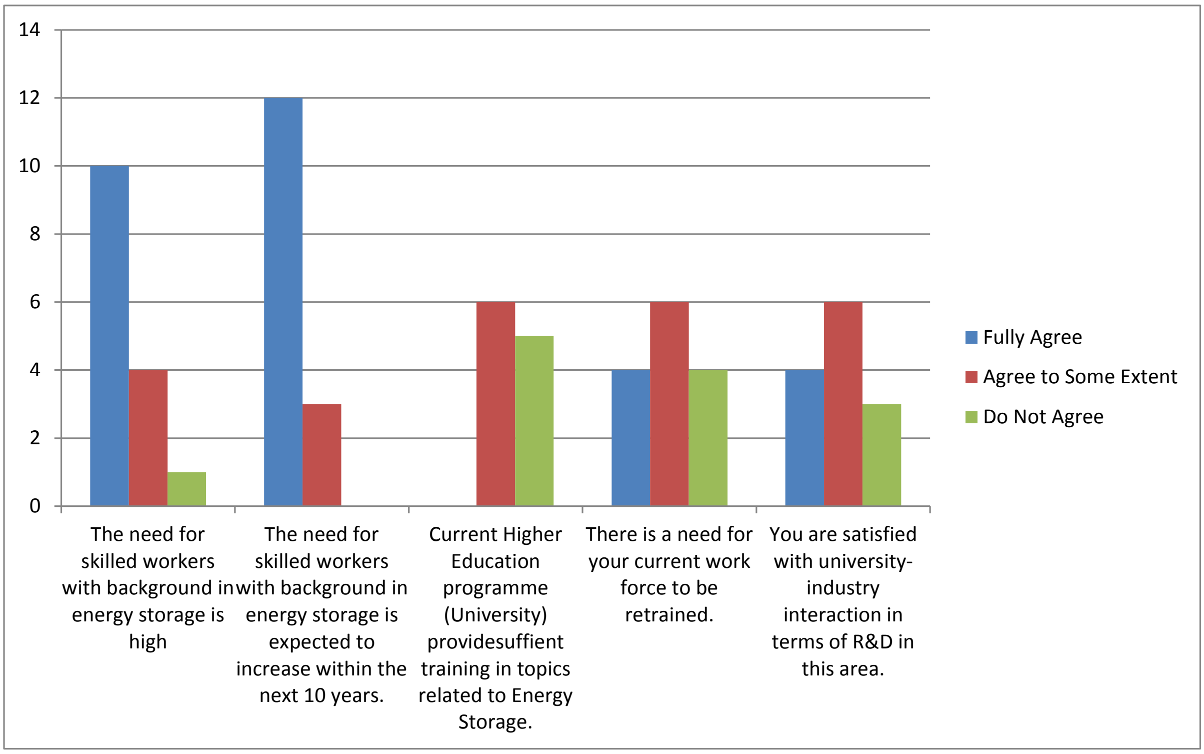


Fig 11. Industrial perspective on Needs and Gaps in training and education pertaining to Energy Storage (vertical axis indicate number of responses).

"Storage is not a science of its own…", says one industrial representative, and highlights that the required knowledge and skills are distributed among various other academic sectors. What is still missing, the same representative points out, is the full energy system view. Furthermore, short term storage as stand-alone technology is of very limited value, so a deeper understanding of markets and applications is crucial. Long term energy storage in fuels or heat can, on the other hand, be highly valuable as stand-alone systems since they may be used at the time of demand (e.g., just as traditional oil reserves have been used to date).

Thus, training leading to the ability of taking on a holistic view to avoid sub-optimisation, and design of system for robust solutions have been brought forward as important. One contributor mentioned that knowledge about storage forces a system understanding rather than sub-optimisation of individual components. In addition, to include training on operation and maintenance of storage equipment, including safety and health aspects have been discussed. One industrial contributor specifically high-lighted the need to also bring on board sales engineers (in the HVAC field) to consider energy storage in a complete offering.

Even more practical training, for example regarding design and construction of Underground Thermal Energy storage (UTES), as well as drilling skills related to UTES have been mentioned. Another identified gap of training is the need for HVAC engineers being able to utilise system optimisation modelling in the design of integrated systems.

In battery technology, a wish for a better connection in education and training between electrochemistry and electrical engineering aspects has been brought forward. Similar cross-disciplinary connections in sciences are needed for storage technologies in general – the complexity of sound design and implementation of these technologies need competencies from a number of traditional science fields (chemists/chemical engineering, mechanical and electrical engineering, and material scientists). The need for multi-disciplinary (referring to traditional educational topics) training and education become evident.

From another perspective, one representative organised a wish-list for areas for improved education and training in terms of a bulleted list as follows:

- Storage Technologies (Chemistry, Performances, Hybridisation)
- Profiling and Engineering complete systems, also a need for sales engineers to have this knowledge
- Economic model for ES Systems

To a certain extent, this list can act as a summary of the combined input from many industrial actors.

The University Perspective

Based on a survey among university faculty engaged in the R&D as well as teaching in Sustainable Engineering and Renewable energy, some defining information on the situation can be described by high-lighting some of the comments received.

There is a lack of university level courses on energy storage in common programmes. As mentioned before, storage is often taught in smaller modules in the context of a certain application, like solar energy. Thus, science and engineering courses on thorough energy storage design, linked to sustainable energy system optimisation is desirable. There is then also a need to derive sub-routines to properly handle storage in existing modelling tools (IDA ICE, TRNSYS, ...). The boundary conditions of systems where storage is integrated may be significantly different than for systems without storage. This area needs to be explored in education and training.

The subject of storage is cross disciplinary, while some outline of storage measures can be given at undergraduate level, postgraduate level is judged to be the best area, most commonly proposed by faculty. There is a need for energy engineers to have a better understanding of materials suitable for energy storage, their chemistry, composition, material handling, analysis, performance, durability, life-cycle and environmental issues. Then it is clear that engineering needs solid insights into chemistry, physics and material science.

On the other hand, chemists/ chemical engineers need to understand the potential uses so that they can develop materials (i.e., they need to understand the concept of energy systems, load shifting, dispatchable energy, inter-seasonal storage, energy demand and sizing).

One faculty high-lighted the need for “Best Practices” (BP) examples with regards to storage to be available. Can a collection of such BP examples be organised in the context of European level virtual university level library? Laboratory facilities regarding energy storage is also desirable and it is suggested that a European level infrastructure inventory, of use with regards to education, training and R&D is carried out (naturally separated by nature of storage technology: battery, PCM, etc).

Regarding the integration of knowledge from various science disciplines, storage design (thermal and electrical) is described as excellent opportunity for students to practice multi-disciplinary development in projects – one example of how storage is successfully taught at the university level.

University-Industry interaction

From the survey regarding university-industry interaction for the R&D, commercialisation it is evident industry as well as universities see the need for improved collaboration. One voiced opinion is that there are clear benefits for industry to collaborate with universities like:

- access to in-depth insights on a topic,
- the university's freedom of research,
- access to relatively cheap researches, etc.

One major drawback is that to secure funding for the collaboration, e.g. through joint applications to the EU/FP or national programmes, takes too long, from idea to project. For industry, it goes much faster to do it alone. Thus, it becomes hard for universities to do research close to the market since public funding is needed.

When it comes to collaboration, one perspective brought forward is the need to consider how energy storage technologies are integrated into energy markets – then knowledge about markets models, economics, business case building is needed. This calls for a triple helix – to ensure the collaborative actions of academia, industry, and government. A more holistic system approach in all collaborative efforts is another matter highlighted, such that product skills will be properly combined with the knowledge of energy conversion system aspects.

One concrete example of university-industry interaction is proposed as including a learning module on energy storage when installation engineers are trained and re-trained. Another emphasis clearly given is the desirable collaboration surrounding basic research topics.

Of special importance is the view from industry that there is not enough attention and visibility given to this "booming sector" in universities and education.

Concluding Remarks – Barriers and Needs

Section I of this report describes the large need for "smart energy buffers" of much varying sizes and for varying time scales: fly-wheel, battery, chemical fuels, pumped hydro, thermochemical, molten salt, phase change material, underground thermal energy storage, and so on. Section I also presents that through the identified huge market development for storage, ***an estimated 3 million + man years for NEW jobs*** related to energy storage implementation would be needed. Of these, about one third is estimated as highly trained professionals such as engineers and scientists and then the need for NEW educational efforts is mostly related to this category. The training needed for the more hands-on "blue collar" type of work forces is not that different from training related to conventional industrial processes, installation technicians etc. and therefore, it is believed that new educational activities for this category is not the most pressing need.

From the work presented here in section III, the skills presented in section I are confirmed. However, a significant barrier is the need for improved understanding of system integration in the overall development of a sustainable energy society. Academic, as well as industrial actors see storage as a key component, but also recognise that the vast variety of energy storage options are not widely known. For the advancement of technologies to meet the future demand for "smart energy buffers", not only new graduates in science and engineering are needed, but graduates trained in combining science and engineering approaches from a variety of disciplines in combination. For example, engineers with improved knowledge of materials and chemistry, as well as chemists with a good understanding of transport phenomena and thermodynamics.

Responsible for training of engineers and scientists are the universities. A survey among universities presents a lack of university level courses on energy storage in common programmes. Storage is often taught in smaller modules in the context of a certain application, like solar energy. Thus, science and engineering courses on thorough energy storage design, linked to sustainable energy system optimisation is desirable. To truly advance the education and training in the field, hands-on experiences for the students through laboratory installations are high-lighted, and a European level infrastructure inventory of laboratory facilities regarding energy storage is proposed.

Finally, although training on a higher education level is judged to be the most pressing to put in place to meet future skill demands, such actions should be designed to also enable a deepened and strengthened collaboration between industry and academia. Section III-3 highlights that there are many areas of attention to enhance these collaborations. Some examples to include in new education and training actions are: industrial advisory boards to educational programmes, industrial representatives in e.g. MSc thesis examination committees, pre-planned industrial internships in training actions, industrial lecture series that could be shared among many actors through webinar series, and special training actions in re-training/continuing education of professionals in some key areas like electrochemistry, system optimisation etc. (could be part of an interactive completely on-line training action).

4 Proposed actions

Based on the assessment of sections 1-3 in this report, the following actions are proposed. They are all addressing the EQF levels primarily pertaining to R&D, Engineering, Developers (6-8). Although the majority of the New Jobs estimated related to the Energy Storage market development are for the lower levels, it is the need for highly skilled engineers and scientists to drive the development of new promising storage concepts that has been identified as the bottleneck.

Furthermore, there is a need to size the below mentioned actions to match the estimated demand for 1 million + man years for new scientists and engineers in the area globally, with up to one third being placed in Europe. Due to the large uncertainties even in the number 1 million, it is unfortunately not possible to present such sizing with large precision. However, based on the fact that the "need" is presented for the next 20 years (section I) and the industry has identified a LARGE need for the next 10 years (section III.1) one could judge that the demand for training is the largest for the first 10 years at 15 000 /year globally with the rest following in the years to come. Of these 15000/year trained people, a reasonable sizing could be that at least half of these should in some way benefit from the actions proposed below. The numbers are thus MUCH larger than the impact possible through traditional MSc programmes, e.g. in the framework of Erasmus Mundus with about 20-50 students per year being impacted per programme. This mean that a new model for higher education and training must come in place – to make use of ICT in learning environments to foster effective collaboration, while keeping a humble respect for teaching traditions developed over centuries.

Title: Energy Storage Collaborative R&D Infrastructure

Action: Inventory of Energy Storage R&D infrastructure, formation of a community for infrastructure exchange in life-long learning, EU capacity building

Time Frame: start 2013

Objectives:

- To determine the Energy Storage R&D infrastructures in Europe
- To analyse the capabilities of the R&D infrastructures and groups
- To create an infrastructure network and a network of excellence, <u>including Industrial partners</u>
- To characterise the synergies with Energy Storage groups, e.g. EERA

Title: Energy Storage Fundamentals for Professionals (LLL)

Action: A joint storage "academy" with links to industry.

Time Frame: 2013-2014

Objectives:

- To develop a public document including fundamentals and challenges of ESS for Industry
- To analyse the skills needed to develop and operate the Energy Storage Infrastructure Network
- To establish a strong relationship with EASE
- To include in the documents the advantages and capacities of ESS from an industrial point of view

Title: Energy Storage Learning Modules for integration in Higher Education Traditional Programmes

Action: Collaboration among scientists, university faculty and industry to develop open source learning material related to Energy Storage, for the rapid advancement of knowledge in the field.

Time Frame: 2013 and onwards – something to build upon, with continuous formative evaluation.

Objectives: The development of electronically available, open source learning modules on energy storage systems' technology, which in turn is expected to:

- - promote the development of European MSc and doctorate programmes devoted to including ESS in the curriculum to a large extent.
- - define the topics included in the Educational Plan including the industrial view
- - promote the practical works in the European infrastructures and the exchange of researchers among European Infrastructure Network

Title: Facilitating the Implementation of Renewables through Energy Storage

Action: MSc programme mobility track (e.g. in KIC InnoEnergy or Erasmus Mundus, or the next generation consortia-based university programme), as well as an Marie Curie Action (or in the new coming programmes) on the topic.

Time Frame: 2014 and onwards.

Objectives: assess measurable positive impact of Energy Storage integration, define state-of-the- art (always needed) IN ORDER to design an innovation pathway (need for Storage innovation and a realization/commercialization pathway).

Title: Energy Storage Virtual Faculty Exchange

Action: Pooling of resources through a virtual faculty mobility programme.

Time Frame: 2014 and onwards

Objectives: The objective is to create an Energy Storage virtual faculty mobility programme. Storage is a multi-disciplinary field requiring skilled teachers from a variety of basic science backgrounds which makes this action especially interesting. New technology enables virtual learning experiences with the top European teachers relevant to the subject, as well as research scientists and industry lecturing for added value in building a knowledge base.

Title: Electrochemical energy conversion and storage

Action: Electrochemistry plays a major role in all kind of batteries, electrolysers, and fuel cells.

Time Frame: Several courses

Objectives: Renewable electricity storage requires inter conversion of electricity and chemicals. Electrochemistry is an area in need of being revived in many European universities

Title: High and low temperature thermal energy storage

Action: High temperature in relation to CSP, low T in relation to air conditioning and chemical processing

Time Frame: Several courses

Objectives: Solar thermal methods require storage during short terms (CSP) or long term (low T)

5 Concluding Remarks

The electrical storage market is forecasted to grow, tripling in size from 100 to 300 GW installed power capacity in the next 10-20 years. The market value of this increase is estimated to the order of 500 billion €. To enable the ambitious forecasts for Renewable Energy of 30-40 EJ/yr by 2050, there is a need of supplementing the electrical storage capacities with introducing large scale long term storage of direct solar energy at an order of magnitude 1000 TWh/year or around 500 GW installed power capacity.

The confirmed traditional competencies working on storage technology are: engineers and scientists in many fields, including: chemical/mechanical/electrical/civil engineering, material science, chemists and physicists. Furthermore, to advance technologies to meet the future demand for "smart energy buffers", not only new graduates in science and engineering are needed, but graduates trained in combining science and engineering approaches from a variety of disciplines. Through the identified huge market development for storage, one can thus conclude that the need for these skills will increase in the next ten years to fill an estimated 1 million + man years in NEW jobs of this category, in addition to several million new man years of jobs for e.g. technicians, in manufacturing, and O&M. Europe is estimated to require about 1/3 of these new jobs.

With regards to job categories, this assessment also has shown that although the majority of new jobs in the field will belong to the blue collar/worker category, the bottleneck is the availability of professionals highly education in the area of energy storage – a multi-disciplinary field of many sciences.

In addition, a deepened and strengthened collaboration between industry and academia is desired in all education and training actions. This assessment has brought forward that there are many areas of attention to enhance these collaborations. Some examples to include in new education and training actions are: industrial advisory boards to educational programmes, industrial representatives in e.g. MSc thesis examination committees, pre-planned industrial internships in training actions, industrial lecture series that could be shared among many actors through webinar series, and special training actions in re-training/continuing education of professionals in some key areas like electrochemistry, and system optimisation.

To truly advance the education and training in the field, a new model for higher education and training must come in place – to make use of ICT in learning environments to foster effective collaboration between university and industry, while keeping a humble respect for teaching traditions developed over centuries. For example, actions regarding open on-line learning modules and virtual faculty exchange for the area of energy storage will be pillars for an envisioned LLL programme on Energy storage. Such actions may be supplemented by hands-on experiences for the students through laboratory installations, and thus a European level infrastructure inventory of laboratory facilities regarding energy storage is proposed. In the next step, also the physical infrastructure can to some extent be made available virtually through the development of remotely controlled laboratory exercises.

As a final point, all these actions could be part of an interactive completely on-line European training action in Sustainable Energy – a potentially disruptive tool for assisting in realising the challenge of Europe's ambitious goals of reducing CO_2 emissions by ensuring the availability of highly educated and properly trained professionals.

References

[1] The future role for energy storage in the UK, June 2011 Energy Research Partnership Technology Report.

[2] Electricity Energy Storage Technology Options - A White Paper Primer on Applications, Costs, and Benefits, Report 1020676, Electric Power Research Institute, Palo Alto, CA, 2010.

[3] C. Pieper, H. Rubel,Electricity Storage – Making Large-Scale Adoption of Wind and Solar Energies a Reality, BCG, Inc., 2011

[4] J. Lin, G. Damato, Energy Storage – a Cheaper and Cleaner Alternative to natural Gas-Fired Peaker Plants, StrateGen and CESA Research, February 8, 2011

[5] C. Pieper, H. Rubel, Revisiting Energy Storage - There is a Business case, BCG, Inc., 2011

[6] Energy Storage Technology Primer: a Summary, National Climate Change Secretariat (NCCS) and National Research Foundation of Singapore (NRF), 2011

[7] KEMA, Market Evaluation for Energy Storage in the United States, 2012

[8] KEMA, Summary of ESA Storage Jobs report, 2010

[9] EUROBAT, White Paper – Importance of Battery Energy Storage for Renewable Energy Supply, May 2011

[10]P. Capros, L. Mantzos, N. Tasios, A. De Vita, N. Kouvaritakis, EU energy trends to 2030 - UPDATE 2009, ISBN 978-92-79-16191-9, doi: 10.2833/21664

[11]Pike Research, Energy Storage on the Grid, 3Q 2011

[12]IMS Research, The World Market for Distribution Substation Equipment - 2011, February 2012

[13]BCC Research, Electrical Power Storage Technologies for Alternative Energy Sources, May 2011

[14]J. Eyer, G. Corey, Energy Storage for the Electricity Grid: Benefits and Market Potential Assessment Guide, Sandia report, SAND2010-0815, 2010

[15]Frost & Sullivan,Analyzing the Global Battery Market, 2009

[16]S.-I. Inage, Prospects for large-scale energy storage in decarbonized power grids, International Energy Agency, 2009

[17]SBI energy, High Temperature Energy Storage: NaS, NaMx and Molten Salt, August 2011

[18]H.Ö. Paksoy, Thermal Energy Storage for Sustainable Energy Consumption, Fundamentals, Case Studies and Design, Proceedings of the NATO Advanced Study Institute on Thermal Energy Storage for Sustainable Energy Consumption - Fundamentals, Case Studies and

Design, Izmir, Turkey, 6-17 June 2005 Series: Nato Science Series II: (closed), Vol. 234, 2007, XII, ISBN 978-1-4020-5288-0

[19]Dincer, Marc A. Rosen, Thermal Energy Storage. Systems and Applications, John Wiley & Sons, ISBN 978-0-470-74706-3

[20]IPCC, 2011: IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation. Prepared by Working Group III of the Intergovernmental Panel on Climate Change [O. Edenhofer, R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, T. Zwickel, P. Eickemeier, G. Hansen, S. Schlömer, C. von Stechow (eds)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2011

[21]BusinessGreen, http://www.businessgreen.com/bg/news/2117431/energy-storage-market-reach-eur500bn-2030

[22]Hauer, A., Gschwander, S., Kato, Y., Martin, V., Schossig, P., and Setterwall, F., 2010, Transportation of Energy by Utilization of Thermal Energy Storage Technology, IEA/ECES Annex 18 Final Report, www.iea-eces.org

[23]Sanner B., Karytsas, C., Mendrinos, D., Rybach, L., 2003, " Current status of ground source heat pumps and underground thermal energy storage in Europe", Geothermics, 32, pp. 579-588.

SET-Plan Energy Education & Training
Energy Systems Integration

Energy Systems Integration

Working Group Contributors

Compiled by:

Teresa Ponce de Leão	University of Porto and LNEG, Portugal
Claude Ayache	CEA, France

Based on the SET Plan Education and Training for Integrated Systems Working Group consisting of:

Russell McKenna	Karlsruhe Institute for Technology, Germany
Wolf Fichtner	Karlsruhe Institute for Technology, Germany
Asgaier Tomasgard	Industrial economics and technology management - NTU, Norway
Lars Heide	Copenhagen Business School, Denmark
Mark Idwal Howells	KTH Department of Energy Technology, Sweden
Luigi Crema	Fondazione Bruno Kessler, Italy
Manuel Matos	INESC TEC & Faculty of Eng Univ. Porto, Portugal
Jean-Pierre Rognon	G2ELAB, Grenoble INP, France

Task division:

(1) Industrial survey – Russel McKenna(coordinating), Mark Idwal Howells, Claude Ayache, Luigi Crema

(2) Search of existing System integration Educational Programmes – Asgeir Tomasgard (coordinating), Mark Idwal Howells, Lars Heide, Russel McKenna, Teresa Ponce de Leao, Jean-Pierre Rognon

(3) Examples to build suggested programming – Luigi Crema (coordinates), Manuel Matos, Asgaier Tomasgard, Jean-Pierre Rognon

The authors would like to thank the following persons for their valuable input:

Paulo Partidário	National Energy & Geology Laboratory, Portugal
António Gomes Martins	University of Coimbra, Portugal

Executive Summary

The trends that drive growth in energy demand and carbon dioxide (CO2) emissions associated with climate change continue to surge forward at an inexorable speed.

The energy society is deeply inter-related with the world evolution as development cannot be achieved without energy and this involves mainly the way we deal with energy, the way we use energy, the way we save energy, the way we convert energy. The energy sector is changing due to some unavoidable and irreversible facts:

(1) Worldwide has concentrated attention over the threat of climate change and committed to reductions on pollutant emissions. Meanwhile, two other concerns have emerged. The **financial crisis** reinforced the concern that high energy prices can debilitate economic growth and threats to **energy security**.

(2) For several years, the European Commission as well as the OECD countries have been presenting the case that an energy revolution, based on widespread deployment of low-carbon technologies, is needed to tackle the climate change challenge but also, more recently, as a way to animate economy, as a powerful tool for enhancing energy security and economic development.

(3) Concern about energy security, the threat of climate change and the need to meet growing energy demand (particularly in the developing countries) all pose major challenges to energy decision makers. Advancing the low-carbon technology revolution needs a mix of choices. No technology should be disregarded and all they must be integrated in a responsible manner.

Energy professionals must be able to answer the needs of society, industry, policy makers, regulators and end-users. Energy systems are complex by nature and most of times integrating different technologies that compete for the same purpose and that must be efficiently integrated in order to reach the goals. This report concentrates on the skills needed for Systems Integration.

The working Group split the analysis into analysing the needs from the offer side (existent and desirable), the need from the market side and some flagships of systems integrated. The analysis leaded into some recommendations.

1 Current Situation

From a deep study on employment from Fraunhofer Institute[1] it is clear that there is a great opportunity for skills in energy. This report, published late in 2009, results from a comprehensive study during 2009 and involves intensive data analysis and economic modelling. The overall framework links several models to reduce uncertainty of results. Also an uncertainty mitigation analysis is made. The inputs and results for each individual modelling step are presented in detail. It concludes that the renewable energy sector is a very important one in terms of employment and value added. New industries contribute about 0.6% to total GDP and employment in Europe. There is a tendency for the improvement of these results provided that there are synergies among several factors, **policies are improved**, manufacturers invest on these technologies and in innovation and countries invest on research to reduce the costs of renewable energies by **exploiting their full learning potentials**.

The benefits of RES for securing supply and mitigating climate change can go hand in hand with economic benefits. The two most important objectives for increasing the share of RES in EU are (1) the reduction of CO^2-emissions and other environmental impacts and (2) the increased security of energy supply due to a reduced dependency on imported fossil fuels. It is therefore doubly beneficial that increasing the share of RES not only does no harm to the economy, but can even contribute to it in a positive way by creating jobs and increasing GDP.

The main conclusions from this first detailed analysis of the full macroeconomic effects of renewable energy deployment at EU level can be summarised as follows:

(1) The current high economic benefits of the RES sector can be increased

RE sector is already very important in terms of employment and value added. New industries with strong lead market potential have been created and contribute about 0.6% to total GDP and employment in Europe. This development is likely to accelerate if policies are improved in order to reach the target of 20% RE in Europe by 2020.

(2) if support policies are improved to stimulate innovative technologies appropriately

In order to maintain the positive balance in the future it will be necessary to uphold and improve the competitive position of European manufacturers of RES technology and to reduce the costs of renewable energies by exploiting their full learning potentials.

Therefore policies which promote technological innovation in RES technologies and lead to a continuous and sufficiently fast reduction of the costs will be of major importance. Besides the implementation of strong policies in the EU, it will be of key relevance to improve the international framework conditions for renewable energies in order to create large markets, exploit economies of scale and accelerate research and development.

[1] http://ec.europa.eu/energy/renewables/studies/doc/renewables/2009_employ_res_report.pdf

(3) The benefits of RES can go hand in hand with economic benefits

Two objectives for increasing the share of RES are the reduction of CO_2-emissions and other environmental impacts and the increased security of energy supply due to a reduced dependency on imported fossil fuels. It is therefore doubly beneficial that increasing the share of RES not only does no harm to the economy, but can even contribute to it in a positive way by creating jobs and increasing GDP.

(4) Uncertainties on the future perspectives exist but mitigation options were used

Combining scenario analysis for the EU-27 countries and comparing results from two models (NEMESIS and ASTRA) in the assessment

This study highlights the importance of a RES economy but also the need for cost reduction to global competitiveness. This is an illustrative example of the importance of detailed analysis of full value chain to exploit all gains in the different processes and systems. This is a clear contribute that reinforces the importance of System Integration competences for planning, technological projects and also for policies design

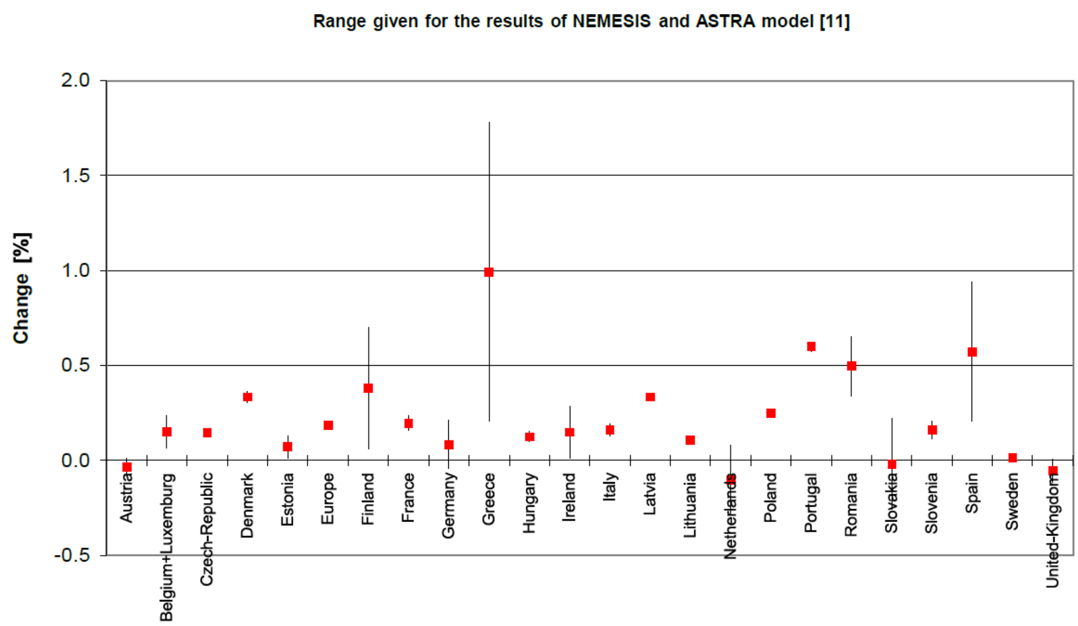


Figure 1 - Employment change due to RES policy – accelerated deployment policy (ADP) in 2020

Although easy to understand from the statements and analysis, in this report there is still no meaningful awareness to the importance of systems integration which reinforces the requirement for a special attention to this need.

Background

As a part of the European Commission's Roadmap Energy Technology (SET) Plan, the Education and Training Exercise is responsible for determining the educational and training requirements to guarantee that the objectives of the SET Plan are attained, namely that we maintain the acceleration knowledge development at a good pace, while maintaining industry leadership and fostering science in compliance. This purpose is valid for energy technologies as well as for technology facilitator like ICT.

Through Working Groups assembled out of experts in the field, the exercise covers eleven technologies and two cross cutting fields. The task of this Working Group for System Integration is to assess the current supply, e.g. through the Higher Education System and other levels, like professional education, of skills relating to System Integration, and the demand through industry, both now and in the future. The target will be to identify specific needs translated in to recommendations.

Given the objectives of the EC SET Plan Education and Training Exercise:

- Define and assess the rationale for a European Energy Education and Training exercise;
- Elaborate a vision on how to address this SET-Plan pillar dealing with human resources and capacities;
- Investigate a number of avenues that could be the core of this exercise; in an open and informal manner,

as well as the Assessment reports & Strategic document, within the EC SET-Plan Training & Education Exercise

- Assessment reports: to provide a comprehensive analysis of the current situation and future needs; to be used as a basis for the drafting of a Roadmap document (June 2012);
- Roadmap document: to define if a SET-Plan European Energy Education and Training Exercise is needed, and what might be its shape;

and coming from the point of view of European Commission[2] perspectives as stated on the Strategic Energy Technology Information System (SETIS) the following goals are to be met:

- Up to 20% of the EU electricity will be produced by **wind energy technologies** by 2020;
- Up to 15% of the EU electricity will be generated by **solar energy** in 2020. However if the DESERTEC vision is achieved, the contribution of solar energy will be higher, especially in the longer term;
- The **electricity grid** in Europe will be able to integrate up to 35% renewable electricity in a seamless way and operate along the "smart" principle, effectively matching supply and demand by 2020;

[2] http://setis.ec.europa.eu/about-setis/technology-roadmap/the-set-plan-roadmap-on-low-carbon-energy-technologies

- At least 14% of the EU energy mix will be from cost-competitive, sustainable bio-energy by 2020;
- **Carbon capture and storage** technologies will become cost-competitive within a carbon-pricing environment by 2020-2025;
- While existing nuclear technologies will continue to provide around 30% of EU electricity in the next decades, the **first Generation-IV nuclear reactor** prototypes will be in operation by 2020, allowing commercial deployment by 2040;
- 25 to 30 **European cities** will be at the forefront of the transition to a low carbon economy by 2020,

…and also drawing from the *Energy Technology Perspectives (ETP)*[3] , the International Energy Agency's publication (from OECD countries) on new developments in energy technology. It demonstrates how technologies can make a decisive difference in achieving the objective of limiting the global temperature rise to 2°C (2D scenario) and enhancing energy security.
ETP 2012 presents scenarios and strategies to 2050, with the aim of guiding decision makers on energy trends and what needs to be done to build a clean, secure and competitive energy future and highlights the importance of not underestimate any energy technology or energy efficiency as a key role for energy objectives. Also ETP enhances the need for evaluation, monitoring and quantification of expected results. According to IEA, ETP 2012 the following observations are made, issues addressed and challenges outlined:

- Current **progress on clean energy** deployment, and what can be done to accelerate it
- How **energy security and low carbon energy** are linked
- **How energy systems** will become more complex in the future, why systems integration is beneficial and how it can be achieved
- How demand for **heating and cooling will evolve dramatically** and which solutions will satisfy it
- Why **flexible electricity systems are increasingly important,** and how a system with smarter grids, energy storage and flexible generation can work
- Why **hydrogen could play a big role in the energy system of the future**
- Why **fossil fuels will not disappear but will see their roles change**, and what it means for the energy system as a whole
- What is needed to **realise the potential of carbon capture and storage** (CCS)
- Whether available technologies can allow the world to have **zero energy related emissions by 2075** – which seems a necessary condition for the world to meet the 2°C target.

[3] http://www.iea.org/w/bookshop/add.aspx?id=425

This analysis, SET Plan objectives and ETP, contributes to highlight that **Systems Integration Education & Training** should be oriented through the **sustainability** paradigm. That means we must tackle this topic from a **holistic perspective,** regarding the three pillars of sustainability and consequently a matrix structure comprising the following main components (Jerneck et al, 2010):

- core themes (scientific understanding, sustainability goals, sustainability pathways/ strategies and implementation);
- cross-cutting critical and problem solving approaches;
- any combination of the sustainability challenges (e.g. climate change).

According to the UN:

Energy System development should be 'concerned with: (i) enabling appropriate, affordable and adequate service access; (ii) ensuring the energy-system can do so in a sustainable manner; and (iii) ensure that the broader interactions between systems does not compromise the planet's sustained development.' (UNDESA 2012)

Given the current evidence that sustainability challenges are multi-scalar, multifaceted and strongly interrelated in complex ways that require integrated (and sometimes urgent) solutions across scales and domains, in order to structure education and training on sustainable energy-related systems within the EC SET-Plan Training & Education Exercise, a driving question could be formulated and this report aims to answer:

What are the main Scientific and Technical (S&T) competencies, knowledge mix and social learning effects required to:

a) Promote trajectories towards sustainable energy production and consumption, and manage sustainable transitions?
b) Understand the interaction of global processes with ecological, economic and social systems, and guide them along systemic and integrative approaches including both technologic and non- technologic factors?
c) Integrate the effects of key processes across the full range of both time and space scales, including the account for both the temporal inertia and urgency of processes (e.g. ozone depletion, climate change, critical resource depletion)?
d) Address such issues as the behaviour of complex self-organizing systems, as well as the responses (irreversible, or not) of the nature-society system to multiple and interacting stresses?
e) Foster problem-driven interdisciplinary research, enabling different actors to work and learn in participatory procedures and concerted actions, even with much uncertainty, with limited information (including the risk by unintended consequences of scientific progress) and/or if action lies outside a particular research domain?

A first attempt to answer this wide-scope question would involve knowledge competencies namely on the following:

Core themes:

- Earth system science and world system dynamics;
- Sustainable energy system analysis;
- Sustainable resource management ;
- Resilience and material flow analysis in complex socioecological systems;
- Energy saving: technological efficiency (industry, buildings) and user/consumer behaviour
- Renewable energy sources and vectors
- Sustainable energy conversion technologies and critical materials (solar, wind, biomass, geothermal, hydrogen);
- Cleaner power generation and carbon capture and storage;
- Power grids, energy storage and conversion;
- Monitoring (remote sensing, field work)
- Mathematical modelling and energy systems simulation
- Energy Technology R&D potentials
- Energy policy, geopolitics and security
- GHG mitigation and adaptation
- …

Cross-cutting approaches:

- Integration of social and natural cycles;
- Sustainability in complex production-consumption systems;
- Assessments of energy projects (environmental, economic, organizational and political) and project evaluation;
- Stakeholder interaction and the systematic use of networks for societal learning;
- Scenario building and strategic planning of innovation;
- Problem solving and critical research on barriers to sustainability;
- Design of energy systems and of facilitation policies
- Design of low-carbon energy related products
- Policy, planning and governance;
- Scientific work methods, project management and team work;
- Institutional theory and organization models for a sustainable energy management;

- Intergenerational and intersectional justice and fairness;
- Sustainable Energy Economics, and design of sustainable business models;
- Marketization, regulation, and democratization through deliberation;

Investment in renewable energy is increasing. A number of countries are considering building new nuclear power stations. New emergent sources of energy are taking place, like shale gas. The rate of energy efficiency improvement in OCDE countries is starting to accelerate again, after a period of modest gains. There is awareness that we need to explore the whole range of energy solutions and think that handle all them is essential for the success of common goals.

Public investment for low-carbon technology research, development and demonstration (RD&D) devotes attention from governments and EU even in a crisis period. In transport, major car companies are adding hybrid and full-electric vehicles to their product lines and many governments have launched plans to encourage consumers to buy these vehicles. Yet these encouraging developments represent but the first small, fragmented steps on a long journey towards transforming the way we supply and use energy.

It is clear that, at present, the energy technology revolution is coming from "bottom up". In many ways, this is a healthy sign: many energy challenges have the greatest impact on local populations – and those populations need to find solutions that work for their local contexts. Ultimately, the scale of the challenge demands a global strategy, many of these efforts already reflect stronger engagement between government, industry and civil society. The common thinking about this revolution is the need to integrate, to "think globally, act locally"[4].

Moreover the systems must be sustainable that means the long-term maintenance of responsibility, which has environmental, economic, and social dimensions. Sustainability means optimization taking into account these three pillars or criteria whether preferred. So when we talk about integrated systems we also talk about sustainable systems.

From this setting, it is most obvious that sustainable systems need a new common thinking about education and training. By sustainable systems we mean all sources of energy when tackled from a sustainable perspective, efficient use (generation or consumption) without compromising coming generations. Sustainable systems are closely related to integrated systems were all perspectives are taken into account.

The foregoing leads to the definition of the term "system integration":

1) A System of systems that results from the aggregation of cooperating subsystems so that the global system is able to deliver the overarching functionality were all elements compete for the same goal in a synchronized way. System integration involves integrating existing, often disparate systems, and putting them in communication.

[4] The origin of this phrase is not clearly set but we can say that several environmentalists, economists and journalists have used it when talking about the need to act in a global coordinated way. It is also referred that we can attribute this phrase to Yoko Ono.

2) A dynamic approach, multi-time frame, about adding value to the system, capabilities that are possible because of interactions and upgrading between subsystems.
3) Understanding the impacts of an integrated energy system on and from other resource systems such as the economy, the physical environment and society.

As the principle suggests the topic is transversal to all energy fields and technologies. This means that inputs from all technologies must be integrated and a matricial analysis is needed. System Integration is most important as we carry on this energy transition toward the low carbon society. This means conceiving and operating multi-scale systems able to accommodate evolving and fluctuating energy mix, needs and usages. Technological solutions that must be safe and ensure security of supply at minimal environmental and economical cost. Education and training in the field of System Integration is thus essential to create and maintain human resources adapted to the challenge throughout our lifetimes.

The role of System Integration deals with three levels: (1) technical, (2) management and (3) strategic. To tackle with these levels of intervention several disciplines are needed. In today's connected world, the role of system integration engineers is becoming more and more important: more and more systems are designed to connect, both within the system under construction and to systems that are already deployed. Capacities on the analysis of integrated complex systems that may be tackled as a "LEGO" system are to pursue.

If we consult employers needs regarding Systems Integration we become aware of those needs mainly regarding IT technologies[5]. The philosophy behind system integration is identical to IT technologies. We need to put working together in an orderly and optimized way a great number of different technologies concurring for the same purpose. In IT we talk about hi-tech systems. The same applies for energy systems like smart-cities or smart grids or biorefineries, as examples.

2 Already existing curricula

This methodological approach towards skills derived from training is already present in some high level training institutions as follows in the next section. Nevertheless this concept must be extended to all levels of professionals.

Learning objectives

Current debates and trends in energy, both within the EU and worldwide, highlight some significant energy systems challenges. The first of these is the need **to reverse the energy consumption and emissions trends.** Meeting greenhouse gas emissions targets is a challenge that calls for new ideas, tools, technologies, and policies, along with highly educated people to develop and implement them.

Devising strategies to **cost-effectively meet these challenges** requires new energy systems methodologies that capture the dynamics and drivers of energy demand—including consumer

[5]http://www.oilcareers.com/content/categories/IT_Communications_Systems_Integration.asp
http://jobsearch.naukri.com/job-listings-System-Integration-Validation-Reference-Engineer-First-Intellect-Consulting-Pvt-Ltd--Gurgaon-5-to-10-years-030512003253?utm_source=Indeed&utm_medium=organic&utm_campaign=Indeed&f=-030512003253

behaviour, energy resources (especially renewable resources) and the networks that connect the two.

With these challenges in mind, the expected Sustainable Energy Systems should have as focus area's prime objective is to engage industry and government in innovative research and educational programs to develop standard approaches, methods, and policies for improving the long-term performance of the nation's energy sector while addressing climate change and energy security concerns.

The ability to integrate in-depth knowledge from more than one functional area in order to look at technological problems as problems embedded in a larger context must be at the heart of what any programme of study and require students to systematically relate knowledge from different areas of expertise in order to analyse a phenomenon from different frames of reference. The students should be trained in actually performing such integration processes on real-life problems.

> *Internal integration of economic-administrative areas of knowledge:* The student should be able to demonstrate how to integrate qualitative, organizational-oriented knowledge with quantitative, economically-oriented knowledge and use this to solve a real-life problem
>
> *External integration of technological knowledge with economic- administrative areas of knowledge:* The student should be able to demonstrate how to integrate purely technological analysis with an economic-administrative analysis to solve a real-life problem.

Examples of some courses already going on

From a University survey we could list some courses that are central from a system integration perspective. Full details from university programmes can be seen in annex I. This section summarizes the objectives of the courses as well as the general contents.

The courses can be roughly divided into more **technical** issues, **management** level and **strategic** issues. The main topics of specialization concentrate on:

- Economics: focusing on managerial economics, finance and energy markets
- Optimization: focusing on modelling and optimizing large industrial systems
- Strategy and management

Main courses at technical level

Energy Systems

Provide basic knowledge about energy carriers. The student will learn about the most important physical and technical characteristics of these energy carriers and about the basic methods for analysis of energy flow in networks.

Environmental Consequences

Provide an understanding of the environmental consequences of energy systems, of quantitative impact assessment methods, and skills for building simple models for the purpose of environmental impact assessment.

Buildings

Become familiar with the concepts related to the thermal balance, energy use and energy efficiency of buildings.

Understand the methods for evaluating the energy demand of buildings and for achieving efficient solutions.

To be able to perform energy simulation and assessment of simple buildings;

Understand the main technologies of Heating, Ventilation and Air Conditioning in Buildings. To know the methodology, phases and expected outputs of energy audits in existing buildings.

Become aware of the non-strictly technical issues influencing the energy performance of buildings.

Markets and Regulation

Be able to analyse the most relevant models that have been used to form the new skeleton of power systems:

Unbundling of the integrated tariff systems in order to create additive non-biased systems; regulation and regulatory approaches;

Nodal marginal pricing; equilibrium models for energy pricing and investment analysis;

Future markets and the use of real options for pricing electricity and evaluating generation plants.

Electrical Systems with Renewables

Become familiar with different energy conversion systems that exploit renewable power sources (hydro, PV, wind, wave energies).

Become familiar with the control techniques used namely in PV and wind generation. Obtain a deep view of the existing control techniques used in wind energy conversion systems.

Be capable of identifying the main problems for operation and expansion of electric power systems resulting from a large scale integration of renewable power sources.

Be capable of understanding the needs for protection coordination in power systems new energy conversion systems.

Become familiar with different micro-generation technologies and its dynamic models for dynamic stability studies.

Understand Micro-Grid operation, management and control strategies for islanded and grid-connected operation.

Main courses at management level

Systems Analysis, Planning and Operation

Formulate and solve central problems within technical-economic-environmental planning and operation of stationary energy supply systems, both electrical and thermal. Based on a set of given technical possibilities, give a methodical basis for optimization of solutions, and investigation of technical, economic and environmental consequences when meeting the demand for electrical and thermal energy, which is in turn derived from the demand for energy services.

Become familiar with a comprehensive approach towards Energy Systems, including the demand for services, energy demand, supply and transformation and transport processes.

Understand the concept of energy matrix of a region or country.

Understand the energy chain from primary supply to end-use and to be able to make Sankey and reference energy system (RES) diagrams.

Understand and be able to coordinate the assessment of endogenous energy resources.

To develop competences in the optimization of the match supply-demand, in the national, regional and local contexts.

Become able to develop an energy plan for a region. Understand the role of scenarios.

Micro Economics and investment analysis

Understand basic theory, models, methods, and concepts on: Theory about consumer behaviour

Models for the decisions of firms in different market structures

Theory about market equilibrium and its implications for social welfare - quantitative methods for analysing and valuing investments and the theory about the pro and cons of each method The concepts of risk and utility in economic and financial theory

The concept of investment portfolio, the Markowitz model and the connections between expected return, risk and the correlation between investment options decisions.

Buildings

Give basic knowledge and methods for planning, analysis, design and implementing of energy efficient solutions in both new and existing buildings.

Energy Efficiency

Gain knowledge on advanced technologies, processes and systems for efficient energy conversion.

Evaluate energy efficiency in market environment. Be able to advice on policies for energy efficiency.

Demand Side Management

Gain a comprehensive approach towards the Energy Demand Side Management at an Energy System;

Develop a methodology of critical analysis of the energy needs and of the factors that influence it in each of the Energy Systems sub-sectors: Buildings (residential and Non-Residential), Transportation, Industry, Agriculture, others.

Review the state-of the art and expected energy efficiency / demand side management technologies and processes in each of the energy system sub-sectors.

Review the international and national trends on energy-efficiency / demand side management, including policies and market mechanisms.

Understand the role of ‘smart’ or ‘responsive’ demand.

Main courses at strategic level

Optimization and Decision Support Techniques

Be familiar with several optimization techniques covered in the course, including linear programming models (LP) and formulate LP models on the basis of verbal problem descriptions Solve LP problems and perform sensitivity analysis

Recognize practical contexts that require the use of integer variables in the formulation of mathematical programming problems.

Be familiar with the principals underlying the algorithms for finding an optimal solution to integer programming models.

Be capable of using performance assessment methods, in particular Data Envelopment Analysis. Understand the principles of multicriteria decision-aid, and to be able to formulate and address multicriteria problems, multiobjective problems and decision problems in an uncertain environment.

Formulate integer programming models and solve using spreadsheets

Formulate non-linear programming models and identify classes of non-linear programming models

Formulate models using dynamic programming and calculate the solution Understand the role of scenarios

Undertake sensitivity, uncertainty, robustness and related analysis

Environmental Science, Ecosystems and Sustainability

Show the correlation between energy and its impact on the environment. The key issues are effective and environmental friendly obtaining, exploration and conversion of energy resources, likewise distribution, transport and end-use of energy in different sectors.

Give a theoretical and practical basis for combining ecological knowledge with human use of nature and natural resources to support the endeavours for securing people's wellbeing and security, and the ecosystems capacity and quality. The subject shall give knowledge about international environmental status and politics, and by using environmental reports and sustainability indexes shall the student be trained in discussing environmental issues and using such documents and instruments in the work for environmental improvement within business and enterprises.

Propose a background knowledge on critical energy issues such as sustainability and environment, global and local, in order to make students aware of values to refer to when dealing with more specific themes related to energy conversion and, in particular, energy use and management rather than just energy economics or even energy technologies. The emphasis on the energy system approach to tackle the energy issues is permanently stressed as the one that is long lasting and sustainable one.

Environmental Management and Corporate Governance

Give knowledge, understanding and skills to support the endeavours for sustainability, better environmental management and industrial practise under the vision of sustainable development and corporate social responsibility. The subject shall give understanding of ethical dilemmas and show connections between environmental and social responsibility in global value chains.

Energy Economics

Read and work with energy balances at national and firm level

Conduct research studies on the relationship of the energy sector and the economy

Understand and discuss the economy and environmental impact of the different energy carriers and technologies

Build Reference Energy Systems adequate to model energy systems

Understand the energy and gas markets in terms of fundamentals and price formation Understand the main policies and measures with impact on the energy sector and its emissions.

Other courses that might be added

Electric Power System Stability

Give basic knowledge about the dynamic mechanisms behind angle stability problems in electric power systems, including physical phenomena, modelling issues and simulations.

System Simulation

Learn to perform mathematical modelling, analysis and optimization of various technical systems. Bridge the gap between basic and special courses, through modelling and simulation practising and intensive Matlab use, making the student a secure performer of numerical modelling and analyses.

Hydro Power and Hydraulic Structures

Give knowledge about the functions of and design of important hydraulic structures.

Energy from Environmental Flows

Describe and analyse atmospheric and oceanic flows. The student will learn to understand the major factors controlling large-scale flows in the atmosphere and oceans, and methods for analysis and determination of local flow fields. Based on this understanding, the student will gain insight into the types of technological devices suitable for exploitation of renewable energy from such flows. The purpose of the course is to provide the student with knowledge of adequate level allowing her/him to independently evaluate and analyse the energy potential of environmental flows, along with identification of technology suitable for exploitation of this energy potential.

3 Needs and gaps

Aiming to understand industry needs, a questionnaire was launched (see annex II). The survey was distributed among several companies from different energy sectors, activities and size. The next table summarizes the profiles from participants in this exercise.

TABLE

Sector	Activity	Size
Research, development and production of Power Train Systems Electricity Utility Learning Systems for automation and mechatronics Sector Energy, Division Oil and Gas Energy Economics	Internal combustion engines Production, Transmission, Distribution and Commercialization of Electricity Gas- and Steam Turbines, Compressor, O&G solutions Energy system analysis	1100 700 150 17000 7 In total: 18957

The interviews took place from general management, planning departments, production department and sales department trying to cover all different sensibilities and needs as well as the whole production chain. Clustering the collected answers it is possible to make a list of the main concerns from industry:

About Claimed Skills

From industry perspective there is a need of capacity to integrate crossover technologies into the production method and products. There is the need, for instance, to be able to apply the best combination of hardware, software and components. This requires multidiscipline engineering know- how.

- It is important to acquire the capacity to recognize to adapt to new situations, to new developments either from technology or new advances in the sector, to be pro-active and present a dynamic behaviour.
- To have the sensibility to understand mutual balance between system and environment.
- To have general knowledge about technologies or capacity to acquire knowledge about technological trends skills in economics and engineering (electrical and mechanical).
- To have skills in mathematics and Operation Research, especially experience in several programming tools (such as MATLAB, GAMS, etc.)
- Capability to **integrate** crossover technologies into the production method and products;
- Capability to **integrate** different systems involving hardware, software and technical components or solutions;
- Multidiscipline engineering knowledge;
- Flexibility to change: handle new situations, new developments, new technologies and new advances in the sector, pro-activity and dynamic behaviour;
- Ability to recognize patterns;
- Understand mutual balance between system and environment
- Good skills in economics and engineering (electrical and mechanical), but also in mathematics and Operation Research, especially experience in several programming tools (such as MATLAB, GAMS, etc.)
- Capacity to apprehend the overall problem, including policy, economics, urban planning, managing, IT, and business
- Capacity to handle available data by good knowledge of statistics and risk management.
- Some required specific skills :
    - process knowledge, battery limits, interface technology
    - system design and integration knowledge
    - technical competence in electrical, mechanical and in particular thermodynamics
    - project management
    - material engineering and standards
    - risk management and HSE

From the analysis to the industry statements some general comments are produced. There is a perception that training did not follow technology evolution, is not agile enough to a permanent adaptation to fast evolution from industry and the geographical differences are very pronounced, and programs on the EU level do not help to spread and improve existing knowledge by tackling the language barriers where relevant.

- There is no exchanged of know-how from an older generation to the next generation, partly because, in knowledge is not deep enough and additional experience from working in projects is necessary.

- Although system integration is almost everywhere (if you think about singular technologies each one of them is the result of integration of systems), the great challenge is to understand the problem from a global perspective.

Skills and educational requirements from industry's perspective

About Relevance

- System integration is one of the essential criteria to stay competitive, especially in the market segment of Power Industry, where the quantities are much lower as in the automotive industry. Due to the smaller market volume it is important to integrate and to adapt proven technologies into this business segment. On the other hand the power to weight ratio technology is much more advanced in this market segment as compared to automotive. Also it is important to develop technologies and products which are affordable – under the consideration of different worldwide standards – this is one essential key to stay successful.

- For an electricity company that deals with nine isolated electric systems and has the goals of constantly improving systems efficiency and increasing its renewable share, system integration (from an energy perspective) is crucial. System integration becomes even more important since, nowadays, increasing renewable share and efficiency involves the accommodation and contribution of new technologies and equipment, multiplying by many the number of electric system components. As an example, our larger electric system comprises HV transmission network, MV distribution network, around a dozen substations and eleven main power plants of 4 main forms of production (thermal, geothermal, hydro and wind). In the future, with the increase of distributed generation, the arising of demand side management and the most likely proliferation of electric vehicles (only to quote some of the expected changes in electric systems), and therefore the increase in complexity of electric systems, it is obvious the important role that system integration will have to play.

- When a lot of complete systems like learning factories which have to be set up completely the importance of integration is at the centre of request. Customers are willing to pay integrated solutions, not the summary of components.

- Usually system integration is a key element of oil & gas business activities. The investor, owner and operator of oil & gas industry expect that a supplier of the relevant components is capable to plan, organize and realize the system integration.

About existent education profiles vs. industrial needs

- Due to the fast development of new technologies in all segments a permanent learning; up grad process of the staff / engineers but also of the teachers and universities is required. Therefore a much better and faster transfer process between – Industries and Academia needs to be developed and established.

- Also an open mind process (think out of the box) is required as well a much better interdisciplinary process is needed to enhance the know how skills.

- In the energy sector, there is an interesting interaction between education and industry. However, the constant development makes it necessary for education providers to adapt themselves constantly and rapidly, which is not always easy, especially for time reasons.
- In some aspects, it would be useful for companies that education could be more straight to the point in the treatment of some certain very specific matters related, directly linked to the recent developments from last decade.
- In most cases the knowledge is not deep enough, additional experience (from working in projects is necessary)
- More or less, yes. This is due to the fact, that we as university educate our personal by ourselves. Thus we try to teach, what is required by the market and this is also useful for us.

The following matrix identifies the main needs from industry (1 – less, 3 – higher)

	Assessment of the suitability of (existing) skills					**Fields in which (additional) training is required**									
	knowledge than needed	High level of knowledge	Sufficient knowledge	Small gaps	Large gaps	Energy supply	Smart grids	Energy demand	Energy-storage	carriers(e.g. gas, electricity	communication technology	analytical thinking	Other (please specify)	Other (please specify)	Other (please specify)
	1	**2**	**3**	**4**	**5**										
Chemical engineers				2		1	1		1	1	1	1			1
Civil engineers				1		2	1	1	1	1	1	1			
Architects				1	1	2	2	2	2	2	2	2			
Economists				1	1	2	2	1	1	1	1	2	1		
Political scientists					2	2	2	2	2	2	2	2			
Lawyers					2	2	2	2	2	2	2	3	1		
IT specialist					3	3	3	3	2	3	2	2	1	1	
Business Engineers				1		1	1	1	1	1	1	1			1
Electrical Engineers		1		2	1	4	3	3	2	3	2	3	2		
Mechanical Engineers				2	1	2	1	3	2	3	2	3	1		
Managemen	1				2	2	2	2	2	2	1	3	1		1
Craftsmen					1	1	1	1	1	1	1	1			

Some examples

In this section a few symbolic examples on system integration needs are presented. A Roadmap approach to Education and Training needs on energy skills should take into consideration the emerging concepts in society, namely the distributed energy generation, smart buildings and cities, new bio refineries and industrial complex production systems. This concept is more important if we think that as long as economy develops population tends to concentrate in big metropolis. This sector has a wide context comprising several levels, from the single building to a Region, passing through a district, a community, a city. Each of such levels requires a different approach and includes different systems and technologies, but with common philosophic approach:

1. The end user is often part of the technology context, either as an owner of technologies or as a shareholder, or as a local administrator;

2. Technologies are based on local availability of renewable sources. In some cases a local cogeneration of electrical power and heat by fossil fuels may be included (e.g. natural gas on fuel cells). Future scenarios take into account the potential new approach for integrated and/or hybrid technologies;

3. The new most strategic energy management level will be based on the Regions. Regions will be responsible of Regional Energy Plans, looking at local needs and local energy potential.

4. The strategic regional plans must be implemented looking at global performance but also planning mechanisms of continuous monitoring as well as involving people from the regions by raising awareness and commitment. (the following picture (figure 2.) shows the iterative process to such a strategic approach);

Each of such levels requires a different and specific approach at the strategic level, as identified and described by Figure 3 and Figure 4. Common characteristics can be identified, among which:

1. *End Users and Distributed Generation:* the end user is often part of the technology context, either as an owner of technologies or as a shareholder, or as a local administrator;

2. *Technologies and System Integration:* technologies are based on local availability of renewable sources. In some cases a local cogeneration of electrical power and heat by fossil fuels may be included (e.g. natural gas on fuel cells). Future scenarios take into account the potential new approach for integrated and/or hybrid technologies;

3. *Regions and Energy Management:* the central for management and development of strategic actions will be more and more based on Regions. Regions will be responsible of Energy Action Plans, in agreement with European standards[1] and looking to the local energy potential;

[1] There's a potential risk for defragmentation of standards due to Regional based solution. Simultaneously to the bottom – up approach coming from local districts and communities (distributed level), it is required a top –down approach, to maintain an alignment and agreement with upper level decisions, such as for standards.

4. ***Enterprises and New Business Models:*** enterprises, synergistically with above levels, should develop new business models to enter new and wide markets, e.g. new Energy Service Company and related models, new energy contracting, …

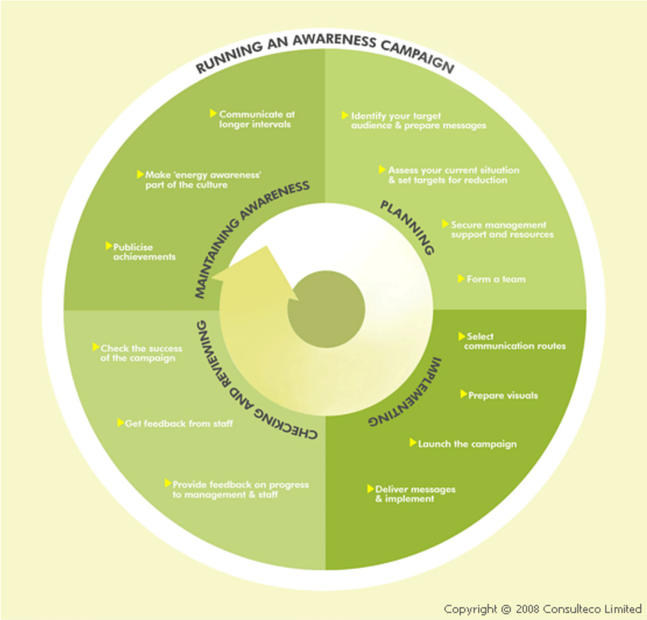


Figure 2 – The energy management Cycle Source: www.energyxchange.eu

Different scientific and societal themes will realize a new and strategic approach to energy sector, the market and the society as well:

- *Integrated and Systemic approach:* the new paradigm will be "system integration" and "integrated planning and operation". Different competences must converge in one during the development of a project or an initiative: from energy efficiency, to ICT, to energy generation and management, to policy framework, to social context, considered along all phases of evaluation, analysis, modelling, realization and execution;

- *Energy efficiency:* this is the main element to foster wide impact of renewable sources. A possible direction of development may be focused on "retrofitting existing buildings", "building continuous monitoring", "industry, in general, value chain continuous monitoring" and "new paradigm for transport" where new technologies, new materials, new systems, different behaviour are envisaged;

- *Micro–cogeneration from renewable and distributed sources:* at all levels of the Regional approach, micro-cogeneration of energy will be more and more a strategic for development of the energy sector. Market barriers should be broken down and potential should be unlocked. An available market is the necessary condition for the development and penetration of new technologies;

- *Policy framework and standards:* local authorities should have new instruments for the development of local policies at support of the energy plans. On the other side, to prevent defragmentation (e.g. of standards, of systems), an integrated approach is envisaged within European and National frameworks;

- *Social aspects and end user acceptance:* an essential aspect is the end user participation to the process. The end-user is one of the main unlocking elements of the market;
- *Energy management and infrastructure:* new implementations in the actual energy infrastructure will be necessary (smart grids) including a complex energy management and the integration of new energy storage technologies.
- *New markets, roles and services:* The changes mentioned above will lead to new roles in the energy value chain, new services and in many cases new market places and time resolutions for existing markets.'

The next energy society – smart buildings

The next energy society will be based on a new element, which will become more and more integrated with the present energy framework: the prosumer. In the energy field the prosumer[2] will be someone that will generate his own energy needs. This will be meaningful and of great impact mainly in cities where each consumer will be able to solve his needs without energy coming from centralized generation.

In the cities, the prosumer will have an essential role, at all levels of society, being at the same time a producer and a consumer of energy can be negligible regarding energy needs from centralized power. This new figure will have impact at all levels regarding energy needs. Energy systems will have to take into account this new paradigm.

Different levels of grouping analysis (house, community, city, region, etc.) will involve a new way to intervene where we need to integrate and manage a mix of different energy carriers in the same systems integrated and towards sustainable systems. Differently from the present required expertise, it will be required more a holistic approach.

Another very important issue is the need to ensure the integration on environmental technology awareness as well as life cycle perspectives to promote the sustainability aspects of system integration. Another issue that must be taken into account is the user acceptance and engagement that must be dealt with.

---

[2] - Alvin Toffler, The Third Wave (1980) Bantam Books ISBN 0-553-24698-4 (Alvin and Heidi Toffler are known around the world for their work that has influenced presidents and prime ministers, top leaders in fields ranging from business to non-profit organizations, as well as educators, psychologists and social scientists - …… They explain the role of "prosumers" - whose unpaid work as parents, do-it-yourselfers, NGO volunteers, hobbyists and open-source software programmers pumps "free lunch" into the economy Revolutionary Wealth separates industries into those that are "singly" and "doubly" intangible and probes the six "truth filters" that shape our daily behaviour and the choices we make in our family life, work, values and politics.)

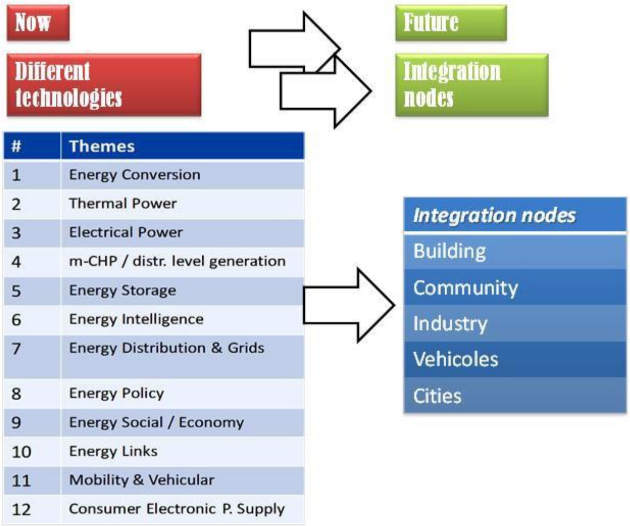


Figure 3. - Introductive concepts on next energy society

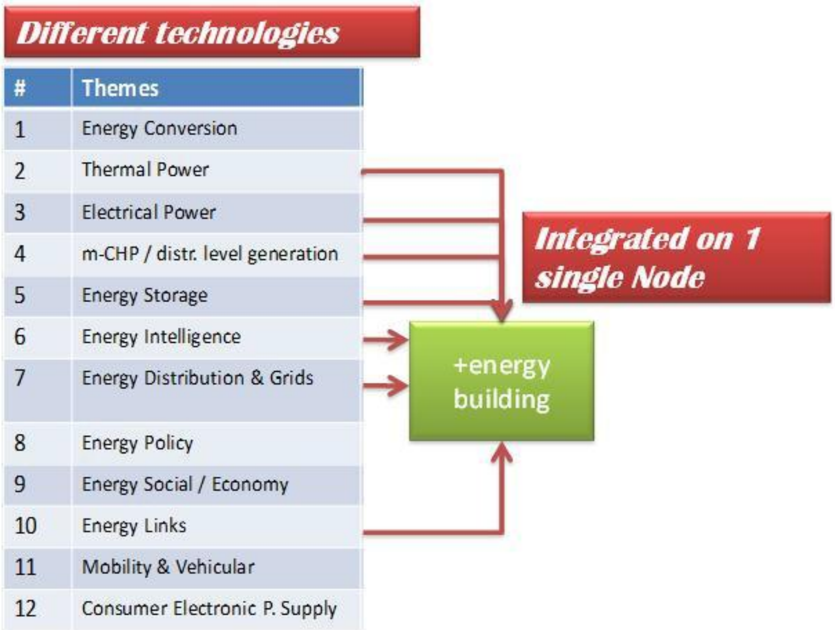


Figure 4. Introductive concepts on next energy society: from technologies to System Integration

As an illustrative example the diagram from figure 5 lists the large number of factors which contribute to the performance of a building. The correlations among them involve the need for an integrated analysis. This example presents the same philosophical approach as figure 8 applied to a bio-refinery.

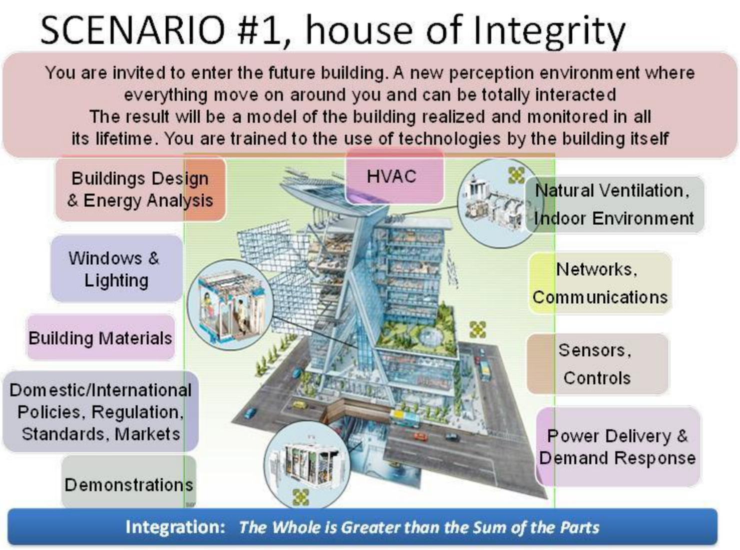


Figure 5. System integration and a Future Scenario on Smart Buildings ½

This scenario emphasizes the multidisciplinary nature of the problem at the building level. This scenario can be replicated at quarter level, municipal level. Regional level, etc..

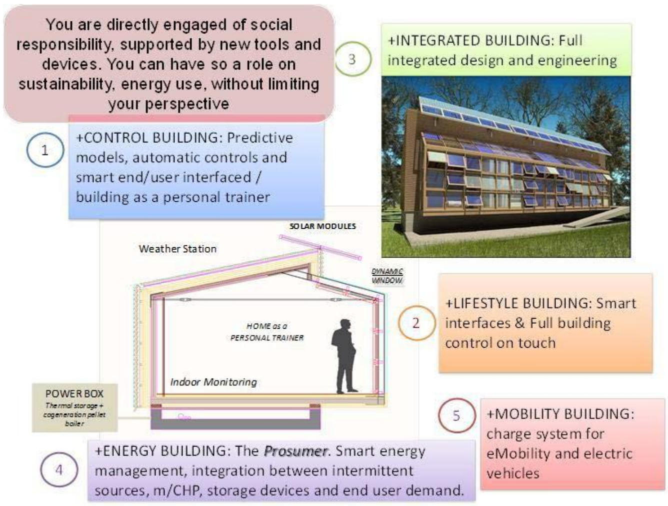


Figure 6. System integration and a Future Scenario on Smart Buildings 2/2

The next energy society - Pan-European power grid[3]

Another paradigmatic example is the need that Europe has to create the conditions to accommodate the electric energy that is capable to produce at a European level, that will be the Pan-European power grid.

The European Union's targets to increase the share of renewable energy to 20% by 2020, and to reduce greenhouse gas emissions by at least 80% below 1990 levels by 2050, pose a major challenge to the power grid throughout Europe. The existing electricity grid is mostly based on technology which was developed more than 30 years ago, for one-way energy flows from large production plants to the consumer.

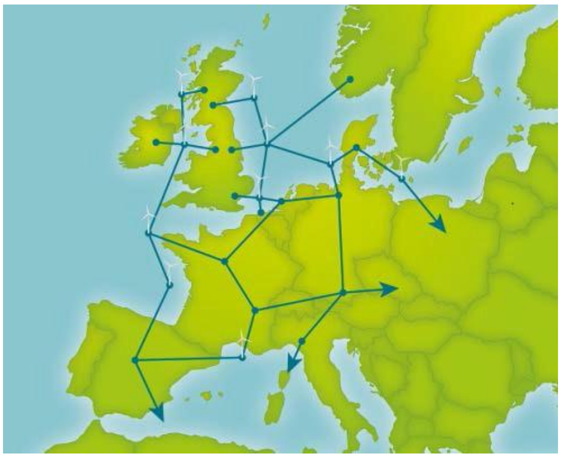


Figure 7a. System integration | pan European electricity grid

Unlike the conventional power plants, which enable full control of the production of energy, the sources of renewable energy have natural variability, particularly wind and solar energy, but also hydraulic energy, which are all dependent upon weather conditions. Additionally, there is also a major paradigm shift as we move from a highly centralized network to decentralized production, where the consumption points can also inject electricity into the power grid, through micro and mini-production of electricity. Figure 7a illustrates how European Electricity Grid must be connected in the near future.

To accommodate the massive deployment of renewable and decentralized energy sources (figure 7b), a stronger and smarter electricity grid is required, with significant benefits deriving from the creation of a single interconnected grid throughout Europe in terms of energy security and affordably.

[3] http://www.smartgrids.eu/documents/EEGI/EEGI_Implementation_plan_May%202010.pdf

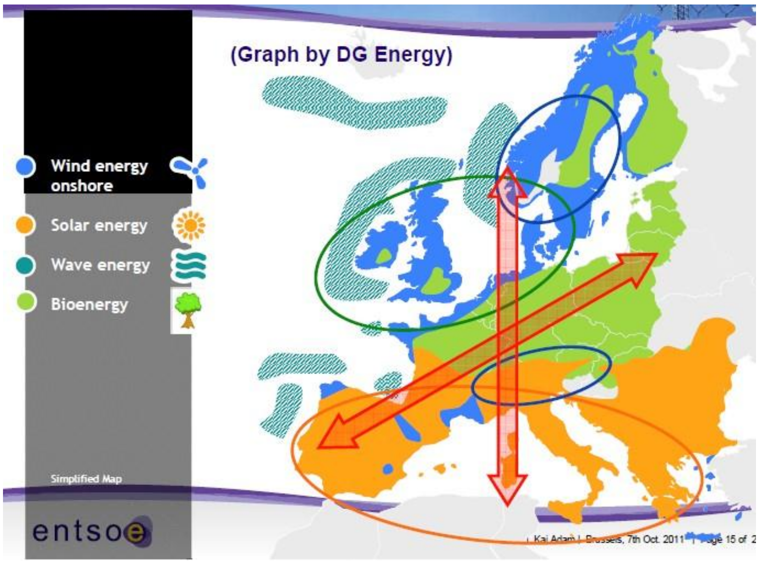


Figure 7b. System integration | pan European electricity grid

On the supply side, the wide geographic integration cancels-out part of the local variability of renewable energy sources and reduces the need and level of curtailment of the conventional power plants to avoid temporary surplus in electricity production. "The increase in transmission capacity and crossborder coordination of market operations will also allow sharing of reserve capacity between regions reducing total reserve requirements by approximately 40%, avoiding significant redundant investment." (ROADMAP 2050 - Practical guide to a prosperous, low carbon Europe). On the demand-side, the demand curves are also softened.

Changes in the European electrical network infrastructure and operation are critical to the delivery of the decarbonisation of the power sector and of the economy. Considering the importance of the electricity networks to a low-carbon Europe, the Strategic Energy Technology Plan includes the European Electricity Grid Initiative (EEGI) in coordination and cooperation with other initiatives, namely photovoltaics, concentrated solar power, and wind energy. The EEGI initiative is deeply needing methodologies able to integrate in an optimized way different technologies[4].

The next energy society - Smart Energy Generation, BioRefinery

Although presenting a long tradition in Europe, BioEnergy traditional courses show a delay regarding adaptation to the needs of a fast transition towards low-carbon society.

[4] EEGI is based on a 9-year European research program for development and demonstration, with focus on system innovation rather than on technology innovation. It addresses the challenge of integrating new technologies under real life working conditions, including new intermittent renewable resources at the different voltage levels, recharging infrastructure for electric vehicles and active demand from end users. The initiative includes the smart grid model (functionalities necessary), transmission, distribution and the coordination of the different networks.

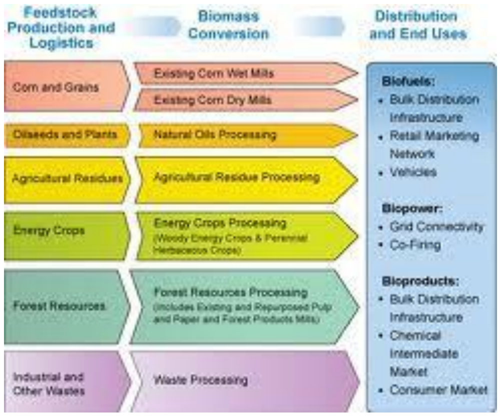


Figure 8. System Integration | Biorefinery (a system of systems)

Figure 8 illustrates the whole process from different natural sources of primary energy, methods of conversion and products for final use. As sources we deal with primary materials from corn to industrial waste, the several conversion systems include different technologies as gasification, liquidification, and the result can be different sources of transformed energy ready to use (thermal, electricity, bio-fuels).

From several sources including the EET report on BioEnergy we can realise that modernisation of curricula including multidisciplinarity, entrepreneurship and team work in multicultural groups is needed.

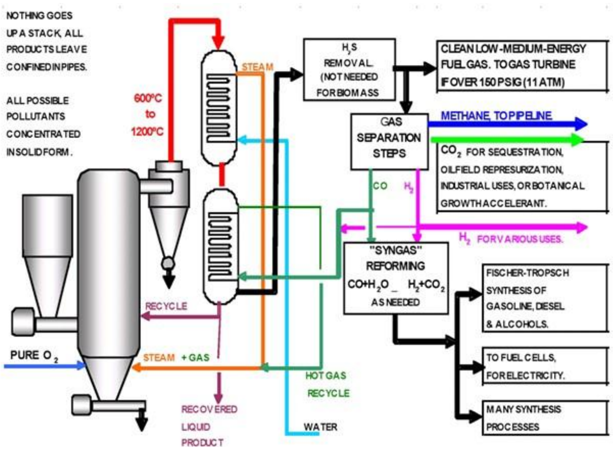


Figure 9. System integration for bioenergy

Within a single process like the one present in figure 8 is clear to understand the great deal of opportunities for optimisation in the biorefinery processes.

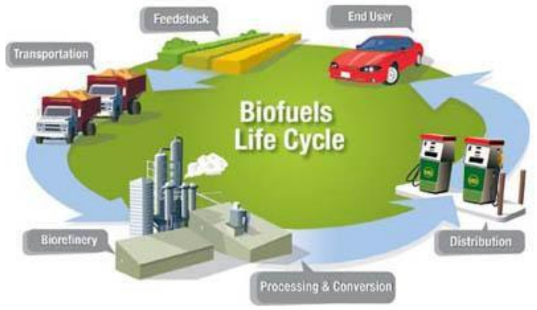


Figure 10. System integration and Biofuels Life Cycle

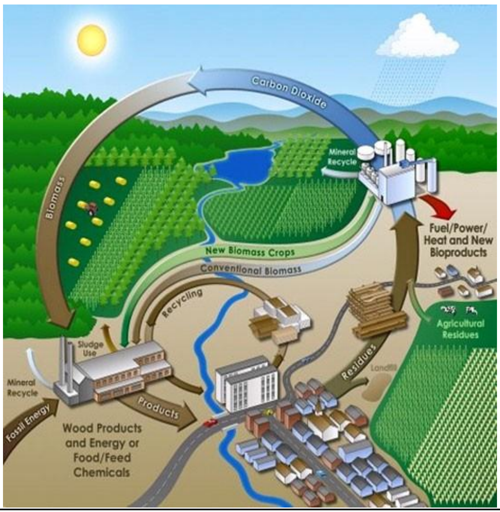


Figure 11. System integration and BioEnergy Life Cycle

Education and Training Program - gaps

In such a context System Integration will be a required professional figure and expertise, in terms of capacity of technical, social and economic management of interfaces between different professional sectors.

Table 1 intends to summarise the needs from industry for professional profiles for different application sectors. This report tries to make a relation with related job opportunity, education and training program and potential employment.

Table 1. Identification of profiles for System Integration

sectors	Profiles	Job	programme	employment
industry	***in field expertise***	Craftsmen Engineers	secondary schools + lifelong learning	All levels
Public companies and government	***Design and management of complex systems***	engineers	university level	all levels
Consultants	***system integrators*** (building, city, region)	advanced engineers	PhD science or engineering, post doc science + economics + policies	all levels
	energy managers and authorities	advanced economists	PhD economics + science + policies	all levels

The above scheme requires the identification, per each single profile, of required skills and related education programs. A proposed list of profiles applied to the sector of smart buildings is reported below.

Table 2. Identification of System Integration Competences and related Education programmes

	COMPETENCES per PROFILE
Craftsmen	*basic of physics, electricity, mechanic, energy* *strong practical attitude: laboratories, stages in industries (6 - 12 months)*
Designers	*basics on mathematic and physic, methods for management of integrated (energy) systems* *methods of modelling (tools on modelling - FEM, CFD, 1-D models)* *methods of integration (system controls and interface)* *methods of management (risk assessment, standards)* *Training*
System integrators	*all a the* ***design level*** *+ energy economics + energy policies* *analysis methods, statistic science* *Training*
Energy managers and consultants	*energy economics + energy concepts land management*

Natural sciences[5] - branches of science that seek to elucidate the rules that govern the natural world by using scientific methods.

Social sciences[6] - field of study concerned with society and human behaviours. "Social science" is commonly used as an umbrella term to refer to a plurality of fields outside of the natural sciences.

[5] Ledoux, Stephen F. (2002). "Defining Natural Sciences" (PDF). Behaviorology Today 5 (1): 34. http://behaviorology.org/pdf/DefineNatlSciences.pdf Retrieved 2012-03-15. "Fundamentally, natural sciences are defined as disciplines that deal only with natural events (i.e., independent and dependent variables in nature) using scientific methods."

[6] The natural sciences are branches of science that seek to elucidate the rules that govern the natural world by using scientific methods. L. Garai and M. Kocski: Another crisis in the psychology: A possible motive for the Vygotsky-boom. Journal of Russian and East-European Psychology. 1995. 33:1. 82-94.

4 Recommendations

In this section we summarize the main ideas coming out from the previous sections discussion in the format of recommendations.

General Comments

The rapid evolution of technology and the global world imply that professionals must be exposed during and after their studies to the newest developments in the various disciplines. Long life learning is now unavoidable. The energy sector is no different and adds to the problem the need to tackle, most of time, very complex systems. Furthermore, energy professionals must also be able to oversee the links between aspects of energy-related issues, and the relations between different parts of the energy chain.

When refereeing to system integration this is even more evident as the output depends on the interaction of different independent but correlated systems often very complex.

The curricula must be able to put together a diversity of disciplinary expertise and approaches. Energy professionals must be trained at a transversal concept including in teaching profile also a great knowledge and sensibility not only to natural sciences but also to social sciences.

Close interaction between research and teaching, and between more conceptual and practical approaches must be fostered. As a result, a new generation of energy professionals and knowledge workers will be trained, who can bring together existing practices and innovative knowledge, and who can draw on insights from a variety of disciplines.

Systems Integration E&T needs to deliver professional competences on how:

1) To get improved solutions for design, operation and planning problems.
2) To formulate models for process modelling, process and supply chain optimization and synthesis, and how to solve them with advanced computer tools.
3) To enhance management in understanding and introducing these tools in your working environment.
4) Better research to quickly testing new process ideas and concepts through the use of optimization-based strategies.

The next paragraphs will describe the most important ideas to better create these competences. The suggestions can be looked at as a prototype suggested curricula.

EU dimension

- It is very important that all the synergies will be used in the EU. Also the education system shall become in line with the EU Strategy 2050
- The young kids shall be made properly aware about – future sustainable technologies and job opportunities.
- Technology and production is key for the success of EU
- The added field in the above table (Renewables: constraints and influence in electric systems) is one very specific that most concerns us at the present moment. The less information available

on this matter(s) nowadays (when compared to others of the same area), can be explained by the previously mentioned recent and constant development on the area (and others mentioned such as energy storage or smart grids), which makes it harder for education providers to have sustainable and mature contents. Also, the short maturation period of some recent technologies contributes for this gap in educational sector. One other reason for this is that this issue is much more relevant in small isolated systems like island systems than in mainland interconnected networks with infinite short-circuit power, and thus receives very little attention for R&D purposes, given the small market it represents.

- We regard 3 levels forming the “house” of system integration:
  - “Groundflor”: interconnectivity of topics -> interdisciplinary learning,
  - “Flor”: understanding feed-back loops in processes, structure and organization patterns,
  - “Roof”: mind-set by reducing complexity, recognising “weak signals” from outside, ability to think and act in multioptional contexts.

Assessment by Industry

- It is important that teachers /Professors will gain additional experience in the industries before the start with their career as teachers /Professor. Same goes for skilled professionals – it should be possible that professionals with more than 25 years’ experience become Trainers/teachers for young kids starting from the Kindergarden to Primary school shall be the best in providing the skills of future sustainable technologies to the young kids and their salary shall be awarding.
- There is no doubt that given the (each time more!) complex and interconnected domain of industry (in general, not only in energy sector) and its needs for competitiveness and multi-tasking, system integration must play an essential role on this current and future demand. Therefore, one of the improvements suggested is the approach between education and industry, in a way such that education can “learn” much more directly the needs of industry sector and thus focus on the truly important aspects and contents for industry and maximize its own efficiency.
- Experience (by doing real projects), usual procedure in universities of applied science, not so usual in universities.
- Methods of system analysis, thinking in energy systems, energy economics, market integration.

Specific Recommendations

Focus area 1: Meeting the skill/competencies gaps of new and emerging technologies

Title: Bachelor, Master and Doctoral Curriculum "SI Management"

There is an urgent need for well-educated value chain managers (see BioEnergy report or Nuclear Energy report) as well as different society stakeholders like industry (see: annex II) or regional managers opinion. This action intends to prepare excellent high level professionals that must have a strong connection with academia and be able to tackle with holistic approaches.

Action

A bachelor and subsequent master and doctoral curriculum for Systems Integration will need interdisciplinary curricula in mathematics, economics, energy technology and practitioners from across the systems like Smart Grids, BioEnergy, Process Integration, Smart Cities, Energy Networks, Energy Systems, Regional Management and Government Advice. The curricula must enable alumni to manage complex systems including integration of different technologies not necessarily only energy ones.

The professionals must be able to integrate different tools adequate to solve:

a) Difficult and complex problems;
b) Deal with data management and analysis (often incomplete);
c) Optimisation of processes often resulting from the connection of different subsystems;
d) Deal with uncertainty related to the problems (scenarios, statistical, fuzzy analysis);
e) Management of information
f) Multiobjective, multicritera tools
g) To get adequate partnerships and create/manage multidisciplinary teams to solve complex problems;

Incentivise the inclusion of social sciences curricula as a complement to natural sciences. Professionals must be able to develop a critical feeling about impacts in the society and handle the adequate tools (social sciences) to mitigate the impacts in the society.

In this regard, the new generation of experts must be able to deal with regional contexts and optimise resource utilisation within the framework of a Bio-Economy in line with SET Plan objectives.

Timeframe

Elaborate an EU prototype curriculum within a time frame of two years. There exist already very good and proved examples in EU Universities (see annex I) that could be looked at as already running examples.

Title: Standardised Vocational Training (VET)

Action

Incentivise vocational training in a standardized way without neglecting specific needs in a regional basis. There exist already good examples to be followed (see annex I). Traditionally, VET courses focus on providing practical and work-orientated occupational skills.

Incentivise professional education with training ship inside industry. Incentivised straight collaboration between universities and society needs.

Design a vocational training system at EU dimension. It should be organized with a strong practice element. Specialized personnel should be qualified in the field of renewable technologies and energy efficiency and have the capacity to look at technological problems in a holistic way.

h) provide quality training
i) deliver courses developed with industry
j) issue a nationally recognised qualification.

The curriculum should be designed with inputs from the industry and mainly involve the following areas:

- Basics of Energy
- Technology knowledge
- Standards and legal framework
- Multidisciplinary training
- ......

Timeframe

Until beginning of 2014: Definition of an EU-wide standardized curriculum

From September 2014 on: Implementation of a directive in the EU-member states

Title: Create consciousness in the society

Action

Promote actions from kindergarten level to secondary, include branch organisations. Introduce the importance of technology to very young kids and train the educators to teach the importance of engineering sciences, logic thinking (ex. Using meccano at school).

Timeframe

Until beginning of 2014: Definition of an EU-wide standardized curriculum for kindergarten and secondary level

From September 2014 on: Implementation of a directive in the EU-member states

Focus area 2: Strengthening and developing existing skills/competencies

Title: Skills upgrade for systems integration professional using a credit obligatory system

The main objective of the skills upgrade for conventional energy curricula is to guarantee that professional have access to a permanent actualization of technological evolution. The credit system from certified training organization ensures quality.

Action

As engineering disciplines become more specialised, continuing education becomes more crucial to managing a rising career. Life-Long Learning (LLL) actions must be designed. This action should develop tailor-made training modules targeted at mid to high management, engineering staff, procurement and marketing personnel to improve their awareness of the systems complexity and the need to cope activity with sustainability.

The courses should result from a commitment/compromise among, industrial associations, professional associations (Engineers/architects/economists Association), EUA-EPUE and the platforms already positioned to act at regional level like KIC Innoenergy and innovation networks like ESEIA. To achieve this, partnerships among industry, universities, professional associations should be incentivized.

Timeframe:

Start: 2013, implementation of partnerships 2014 and courses beginning 2015.

Title: Skills upgrade for systems integration consultants using a credit obligatory system

Action

The main objective of the skills upgrade for energy consultants is to improve the qualification of consultancy so important for the success of policies and dissemination actions as well as industry investments.

Energy consultants are key actors to promote and advice. The proposed action provides training modules targeted towards different groups of energy consultants (consultants to individuals, business and industry, communities/regions, etc.) and up-grades their know- how concerning integration of solutions in a framework of evaluation of impacts by monitoring and measuring.

This training should be subject by certification from an European issuing body.

Timeframe:

Start: Tender 2014, implementation of courses 2015.

Heading 2: Fostering involvement, access and up-take by the labour market

Focus area 1: Promoting mobility, life-long learning, workforce training

Professionals, at all levels, must be conscious of the need of permanent update. Depending on the level of education, create a mechanism within professional associations were professionals must regularly update the knowledge.

Training professionals must be aware of the need of updated offer. Curricula must be evaluated at a regular base. Education institutions must be evaluated by their capacity of placing graduates on the labour market.

Action

To incentivize mobility in order to promote the exchange of experiences industry must be involved in the design of curricula (take advantage of Industrial Initiatives).

Governments should create incentives to involve employers in the training cycles.

Timeframe:

Start: 2014 start the discussion among member states to get a common framework for LLL credits and evaluation system.

Focus area 2: Industry involvement and partnerships

Title: European Network of Education and Training

Action

The Industrial Initiatives (EII) as well as research programmes from institutes (e.g. EERA) as well as Knowledge Innovation Communities (KIC), Universities and other networks like the European Sustainable Energy Innovation Alliance (ESEIA) should be requested to work together to create a network involving all actors and stakeholders. This could be an EU initiative by launching terms of reference and incentives to the performance of work (ex. The network co-ordinates and/or advises on:

- research needs;
- interdisciplinary research education (graduation, master, PhD and Post-Doc.);
- practice oriented educational program;
- Life Long Learning;
- further enlargement of the network building pilot plant installations for strategic technologies within the bioenergy value chain.

Timeframe:

Implementation of the network that should launch the dialogue among all other networks to be delivering middle 2014.

Heading 3: Planning and enabling skills development

Focus area 1: Sector skills assessments and observatories

A formal discussion within the SET PLAN committing governments and deriving in a Concerted Action to be set later as an Education and Training directive should take place. This discussion should involve Education Ministers in a mandatory way.

Title: European low-carbon technology Skills Survey

Action

Energy has broad fields with a large number of different actors and sectors involved. In order to monitor educational programs, analyse the needs and fill the gaps, an European observatory should be created. This observatory should make the analysis of all sectoral energy education areas and turn the needs coherent and working together in an integrated way. The survey must also take regional differences in the skill profile of different actors into account. It has to cover all levels of education.

Timeframe:

Start: 2013, end report due end 2014.

Objective

The main objective of European Skills Survey should provide an overview from the needs of industry and serve as input to educating systems to tune their courses matching the needs required by the labour market in all systems integration, Smart Cities, Smart Grids, BioEnergy, Nuclear, etc. Standardisation of European efforts to strengthen the skill base of the workforce should be another objective.

Focus area 2: "Train the trainer"

Title: Raise responsibility of educators

Action

Promote actions from kindergarten level to secondary. Introduce the importance of technology to very young kids and train the educators to teach the importance of engineering sciences and logic thinking.

Involve regions, municipalities, agencies (environment, energy, science) to induce this wave of technology from very young ages.

Timeframe

Start: 2013 in a continuous procedure

Focus area 3: Online information and other tools
Create a Euro-Observatory for build-up skills taking into account the offer, the needs and the employability. This is a general request nevertheless it is most needed on the Systems Integration on account of its cross-cutting nature and less obvious nature. Engage the European University Association towards an offer matching the market needs and to create a monitoring system regarding employability. • Evaluate how professionals are absorbed by the society by creating channels to the industry in order to up-date curricula. • Foster the discussion on at a pan-European level and create mechanisms to engage the industry (technology platforms) with a dialogue together with education institutions at secondary level, high level and professional level. Create mechanisms to learn by doing. • Engage professional associations to create a credit system for life-long learning.

References

[1] Uwe Schneidewinda, Karoline Augenstein, “Analyzing a transition to a sustainability- oriented science system in Germany” (2012), Environmental Innovation and Societal Transitions 3, 16–28, Elsevier

[2] UNDESA (United Nations Division of Economic and Social Affairs). Perspectives on Sustainable Energy for the 21st Century. Available online: http://www.un.org/esa/dsd/dsd_sd21st/21_pdf/SD21_Energy_Final.pdf

[3] Electricity network planning until 2050 – the MoDPEHS initiative (2011), “2nd International Conference of the EU Project SUSPLAN„ Towards a European energy infrastructure – from strategies to implementation “, Brussels;

[4] Training For Renewables And Energy Efficiency In Building Sector (2011), Build Up Skills, December 2011, Portugal

[5] Louise Warwick-Booth, Community based research and evaluation models: their applicability to social regeneration programmes debated through an analysis of the literature,

[6] Smart Grid Today’s Authoritative Guide to US Interoperability Standards (2011), Smart Grid Today’s Exclusive Industry Report | December 2011

[7] Technology Map of the European Strategic Energy (2011), Technology Plan (SET-Plan), JRC Scientific and Technical Reports, EUR 24979 EN – 2011

[8] Skills and Occupational Needs in Renewable Energy (2011), International Labour Office, Geneva, European commission

[9] Investment in renewable energy generates jobs. Supply of skilled workforce needs to catch up, International Labour Office, Geneva, European commission

[10]Transfer, recognition and accumulation of individuals’ learning outcome in Europe, European ECVET Network, http://www.ecvet-team.eu/

[11]EmployRES, The impact of renewable energy policy on economic growth and employment in the European Union, Final report, Contract no.: TREN/D1/474/2006

SET-Plan Energy Education & Training
Fuel Cells and Hydrogen

Fuel Cells and Hydrogen

Working Group Contributors

- Prof. Yann Bultel, Institut Polytechnique Grenoble, France
- Prof. Dr. Bernard Dam (Rapporteur), Delft University of Technology, The Netherlands
- Prof. Dr. Jürgen Garche, Weiterbildungszentrum Brennstoffzellen Ulm (WBZU), Ulm, Germany
- Dr. Dennis Hayter, Intelligent Energy
- Dr. Antoine Mazas, Air Liquide/Ecole Centrale de Paris, France
- Dr. Amelia Montone, Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile (ENEA), Italy
- Prof. Gérald Pourcelly, Université Montpellier 2, France
- Prof. Dr. Robert Steinberger-Wilckens, University of Birmingham, UK/Universität Oldenburg, Germany
- Linghua (Lily) Li (assisting the Rapporteur), Delft University of Technology, The Netherlands.

1 Current situation and outlook

With the expected market introduction of FCH technologies, demands for a skilled workforce dedicated to developing and manufacturing FCH products will increase while other areas of the population will gradually also become involved during the process of technology acceptance. These developments require an education and training strategy. In this section we focus on projections of the FCH market for the year 2020 and the workforce required.

Introduction

Overall objectives SET-Plan. Sustainable, secure and competitive energy supply and transport services are at the heart of the Europe2020 strategy for a low carbon economy [1]. Innovation and deployment of new clean technologies are essential for a successful transition to a new sustainable economy as there is no silver bullet technology capable of progressively replacing fossil energy sources. In addition to creating a healthier environment and securing energy supply, innovation further provides huge opportunities for the European economy.

The European Strategic Energy Technology Plan (SET-Plan), adopted by the European Union in 2008, is a first step to establish an energy technology policy for Europe. It is the principal decision-making support tool for European energy policy, with a goal of:

- Accelerating knowledge development, technology transfer and up-take;
- Maintaining EU industrial leadership on low-carbon energy technologies;
- Fostering science for transforming energy technologies to achieve the 2020 Energy and Climate Change goals;
- Contributing to the worldwide transition to a low carbon economy by 2050

The SET-Plan provides a framework to accelerate the development and deployment of cost-effective low carbon technologies. With such comprehensive strategies, the EU is on track to reach in 2020 its 20-20-20 goals of a 20% reduction of CO2 emissions, a 20% share of energy from low-carbon energy sources and 20% reduction in the use of primary energy by improving energy efficiency by 2020.

The role of fuel cell and hydrogen technologies. Fuel Cell and Hydrogen (FCH) technologies have been identified as one of the SET-Plan strategic technologies. In 2011, the European FCH industry, gathered under the flagship of the New Industrial Grouping (New-IG) of the FCH Joint Undertaking (FCH JU), has proposed a Technology Roadmap, which was endorsed by the General Assembly. The roadmap describes the objectives of the European FCH community: to provide clean, efficient and market-ready solutions that exploit the properties of hydrogen as energy carrier and fuel cells as energy converters. These solutions will play a key role in transforming the European Energy and Transport Systems and contribute to the EU competitiveness and integrated energy and climate change goals.

Actions required. A wide range of actions is required for the market introduction of these technologies by 2020. As part of the efforts by the FCH JU to accelerate the development and deployment of FCH technologies through an integrated European programme of RTD activities, the aim of the Energy Education and Training Initiative is to address the required workforce.

Education and Training Initiative. This report discusses the current situation and expected needs per job categories (technicians, engineers, scientists) as well as describes the actions required (in relation to undergraduate, graduate, post-graduate education, life-long training, reconversion schemes, professional training) within the FCH sector. The required number of people with workforce skills in FCH technologies should be available in time in order to be properly prepared for the development of hydrogen technologies.

Current involvement of FCH consortia in education and training

The Fuel Cells and Hydrogen Joint Undertaking (FCH JU) is at the focal point of collaborative FCH R&D activities involving industry, academia and the European Commission. Education and training activities are among the priorities of the FCH JU. As stated in the Multi-Annual Implementation Plan (MAIP) of the FCH JU [1.1], education and training activities are part of the “cross-cutting issues” benefiting from high levels of public funding, together with Regulations Codes and Standards (RCS), Pre-Normative Research (PNR), socio-economic research, technology and life cycle assessments, market support (particularly for SMEs) and public awareness.

The main on-going projects supported by the FCH JU in the field of education and training are the following:

- **HyFacts:** a 1 M€ project aiming to develop and initiate dissemination of training material for Regulators and Public Safety Officials. Public safety and regulatory issues concerned with FCH technologies become increasingly important with the upcoming installation of hydrogen-related technologies in public areas, companies, universities, research centres, fairgrounds, harbour sites and other places. Hyfacts is conducted by TUV Süd Akademie (DE), Air Liquide, CCS Global, FAST, Health and Safety Laboratory (UK) and the University of Ulster (UK). Project website: www.hyfacts.eu
- **HyProfessionals**: European project aiming to develop training initiatives for technical professionals and a well-trained workforce that will secure the required mid- and long-term availability of human resources for hydrogen technologies. The project addresses various educational levels: industry, SMEs, educational institutions and authorities. Hyprofessionals is conducted Foundation for Hydrogen in Aragon (SP) Environment Park (I), UNIDO ICHET (TR), Federazione delle Associazioni Scientifiche e Techniche (B, I), WBZU (DE), San Valero Foundation (SP), Association Midi Phyrenees (F) , JRC (B), Centre for Process Innovation UK) . Project website: www.hyprofessionals.eu
- **TrainHy**: is a project led by the University of Birmingham aiming at establishing a European curriculum in Fuel Cell and Hydrogen technologies. One module is the organisation of the Joint European Summer Schools on Fuel Cell and Hydrogen Technology. The project is driven by the following institutions: University of Birmingham (UK), University of Ulster (UK), Technical University of Denmark (DK), Forschungszentrum Jülich (DE) and Heliocentris Energy Solutions (DE).

These projects are of importance for the training of people who are today working on FCH technology development, mainly in R&D activities. With the projected growth of the FCH sector, the efforts should be sustained and reinforced. Further, additional education and training initiatives will be needed in the next decade to support the market introduction of FCH technologies. It will be especially crucial for Europe to benefit from high-quality education programmes to train the workforce to be employed by industrial companies.

Preparing the future: market objectives by 2020

Industry efforts for developing fuel cell and hydrogen technologies are currently organized around four application areas:

- **Transport** (fuel cell electric vehicles and Hydrogen refuelling stations)
- **Energy production** (Hydrogen production)
- **Early markets** (e.g. forklifts, power generation)
- **Heat and power generation** (stationary fuel cells)

These efforts are growing quickly, as there is an increasing interest in developing the use of green sustainable Hydrogen as an energy vector. FCH technologies are already on the market in specific applications such as forklifts or power systems for isolated systems. Current end-users include for instance Coca-Cola, Wall-Mart, and La Poste. Car companies will progressively put Hydrogen cars on the market from 2015. The technology and market objectives of the FCH sector by 2020, as presented in the SET-Plan Technology Roadmap, are summarized in Fig. 1.

A. Transport

FCH technologies will address challenges in transportation and refuelling through the introduction of 500,000 Fuel Cell Electric Vehicles (FCEVs) on European roads by 2020. In parallel, a refuelling infrastructure should be built for providing hydrogen to these FCEVs, with a target of 1,000 hydrogen stations built by 2020.

B. Energy production

Hydrogen production and distribution are already mature technologies in Europe. Core efforts in that field consist in increasing the part of hydrogen which is produced from renewable energy and from zero-CO2-emission sources: reforming technologies based on biofuels or biogas, cost-efficient water electrolysis powered by renewable power, biomass-to-hydrogen conversion process, carbon capture and storage for conventional hydrogen production processes. In addition, it will be needed to adapt and to extend the hydrogen supply-chain to provide gas to mass-market end-users.

C. Early markets

Material handling vehicles, back-up power sources, power generation for remote sites not connected to the grid are among the early markets that have been identified to value FCH technologies first. The development of these markets is in progress and is one of the sector priorities by 2020.

D. Heat and power generation

Stationary fuel cells for combined generation of heat and power have already been introduced in Japan for residential and industrial applications. In Europe, by 2020, a particular focus will be placed on the demonstration of combined heat and power generation both at domestic and industrial scale, allowing flexible and decentralized power-generation that is decoupled from oil. It is targeted to contribute to the transformation of the energy sector by providing heat and power to more than 50,000 households using stationary fuel cell systems in 100 European districts and in 100 industrial sites.

In addition to these four current application areas, **energy storage** has been identified as one of the main challenges of the next decade for enabling the integration of a larger share of renewable energy sources to the European grid. The intermittent nature of sustainable energy sources requires the development of reversible energy storage facilities on a large scale. Already now, in Germany and Denmark, part of the wind energy can only be fed into the grid at a negative revenue. Large-scale energy storage will have to be developed (>1000 TWh worldwide by 2030). One of the options that can reach sufficiently large scales is storage in chemical forms of energy, including hydrogen. The objectives of the FCH sector in the field of energy storage for the period 2014-2020 have thus been included in the SET-Plan Technology Roadmap.

Transport	• Contributing to 500000 Fuel Cell Electric Vehicles (FCEVs) and 1000+ hydrogen refuelling stations towards the transition of the transport sector towards electric drives
Energy production	• Contributing to the transformation of the European Energy Mix by producing 50% of H_2 used for these applications from renewable energies or from zero-CO_2-emission sources
Energy storage	• Contributing to the integration of intermittent renewable energies (wind, solar) by applying hydrogen storage capacity up to 500MWh as part of a grid scalable storage
Early markets	• Contributing to the demonstration of cost-efficient solutions with clean and sustainable FCH technologies for material handling vehicles, back-up power and portable power applications
Heat and Power generation	• Contributing to the transformation of the energy sector by providing heat and power to more than 50,000 households using stationary fuel cell systems

Fig. 1 – Technology objectives of the FCH sector by 2020 as outlined in the SET-Plan Roadmap

Implications for the workforce

By 2020, FCH technologies will progressively shift from R&D activities to first-of-a-kind commercial projects to be ready for mass-market introduction at the end of the decade. However, market introduction is far from straightforward and requires additional efforts in terms of product standardisation, industrialisation, building of production facilities, launch of mass production processes, etc. In addition, market introduction requires that a qualified workforce is available for both production and after-sales services.

The current workforce involved in FCH technologies consists mainly of:

- Researchers and research technicians active in basic and applied research, both in academics and corporate R&D centres;
- A qualified workforce (engineers and specialized technicians), mainly dedicated to applied research and technology development.

This will evolve in the next decade with the integration of all competencies needed for mass production and market introduction, including:

- Industrial engineering, production and supply-chain;
- Production management, manufacturing methods;
- Product development and marketing;
- Sales and commercial services;
- Aftermarket, maintenance and after-sales services.

Part of these new jobs will be net job creation; part of them will be a transfer of existing workforce from technologies FCH systems aim to substitute, as it will be the case for instance in the automotive industry. Estimating the volume of new jobs is not easy since there will also be a new eco-system of FCH companies which does not exist yet, and that will include companies in charge of integration, manufacturing, aftermarket, maintenance, repairing, etc. As FCH technologies will be introduced in the market as substitution technologies, there will be significant needs of **continuing education**, especially for employees who will have to switch to another type of production/maintenance.

For each of the application areas introduced previously, a first estimate of market values and employment needs is presented in Table 1. Based on the projections presented in the SET-Plan Roadmap, the FCH sector could induce around 60,000 jobs in 2020 and 190,000 in 2030. These figures are <u>rough estimates</u> and <u>should be considered cautiously</u>. They however give an order of magnitude of the number of persons to be trained in the next twenty years. It is expected that an in-depth analysis of the job creation impact due to the development of FCH Technologies will be conducted by an independent consultancy mandated by the FCH JU in the coming months.

Main education needs are likely to concern qualified workers, technicians and engineers, partly in continuous training schemes. It is crucial that the development of these trainings leading to a qualification can be elaborated by the industry and the education community together, with the support of public institutions. From this perspective, the FCH JU 2.0 would be, for the period 2014-2020, the legitimate institution for building and funding a comprehensive FCH education offer with the industry and the academics.

Table 1 - Current workforce and workforce projections for 2020 and 2030.
CAGR = Compound Annual Growth Rate; SME = Small or Medium-size Enterprise

2012									
	Est. annual production		Market value	CAGR	Number of companies involved		Employment		
Application area	Unit		(M€)		SMEs	Large companies	Workers	Technicians	Engineers
Fuel cell electric vehicles	#	100	5	---	10	8	250	750	1500
Hydrogen refuelling stations	#	20	20	---	10	5	133	133	133
Hydrogen Production	ton	895	9	---	15	5	447	447	447
Stationary fuel cells	#	50	2	---	18	5	83	83	83
Early markets - forklifts	#	300	4	---	18	6	25	25	25
Early markets - power generation	#	500	1,2	---	18	5	25	25	25
TOTAL			**41**				**964**	**1464**	**2214**

2020									
	Est. annual production		Market value	CAGR	Number of companies involved		Employment		
Application area	Unit		(M€)	2012-2020	SMEs	Large companies	Workers	Technicians	Engineers
Fuel cell electric vehicles	#	100 000	3 000	45%	5	12	12 500	6 250	6 250
Hydrogen refuelling infrastructure	#	150	135	12%	3	7	750	750	750
Hydrogen Production	ton	145 447	1 164	32%	10	10	4 848	4 800	4 800
Stationary fuel cells	#	50 000	625	45%	10	7	5 000	5 000	5 000
Early markets - forklifts	#	10 000	100	21%	10	8	417	417	417
Early markets - power generation	#	20 000	28	22%	10	7	208	208	208
TOTAL			**5 052**	**30%**			**23 723**	**17 425**	**17 425**

2030									
	Est. annual production		Market value	CAGR	Number of companies involved		Employment		
Application area	Unit		(M€)	2020-2030	SMEs	Large companies	Workers	Technicians	Engineers
Fuel cell electric vehicles	#	500 000	12 500	7%	2	15	62 500	31 250	31 250
Hydrogen refuelling infrastructure	#	300	420	3%	3	7	2 250	1 125	1 125
Hydrogen Production	ton	425 635	3 405	5%	5	10	11 350	11 237	11 237
Stationary fuel cells	#	150 000	1 500	5%	5	8	11 250	5 625	5 625
Early markets - forklifts	#	30 000	240	5%	5	8	1 000	1 000	1 000
Early markets - power generation	#	30 000	42	2%	5	8	500	500	500
TOTAL			**18 107**	**7%**			**88 850**	**50 737**	**50 737**

2 Ongoing education and training activities

In this section, we provide an overview of current education and training activities within individual EU member states and at the European level.

Introduction

As a result of the fact that FCH technologies are mostly in the R&D stage at the present time, the working group has mostly encountered academic education and training elements. In comparing education and training within different countries, the following terms are used:

Level	Cycle	Bologna terminology
Undergraduate	First Cycle	Bachelor's degree
Postgraduate	Second Cycle	Master's degree
	Third Cycle	Doctoral and post-doctoral studies

Four types of education and training can be distinguished [3]:

A. Occasional training modules such as workshops, short courses and (summer) schools not part of a larger educational programme;

B. Higher education course modules concerned with FCH as part of an educational programme that's not focussed solely on FCH but on a wider area such as Energy;

C. Higher education programmes fully dedicated to FCH technologies;

D. Relevant Marie Curie actions.

Map of existing educational and training activities

A: Occasional training modules

Various universities, institutes for professional education and other organizations currently offer occasional training modules broadly targeted at engineers, planners, department managers, manufacturers, system integrators, inspection and safety bodies, and researchers. These modules treat the basic principles of Hydrogen technology, including topics such as physical properties, production, processing, conditioning, cleaning, compression, storage and transport. In addition, various applications are addressed such as fuel cells (PEMFC and SOFC), heating technologies, hybrid systems, and smart grids. Each module has an audience of roughly 10-30 persons.

Training institution	Country	Duration	Course title
TÜD SÜD Akademie	DE	1 day	*Hydrogen technologies*
	DE	1 day	*Basics of hybrid and FC technology in vehicles*
	DE	3 days	*Hydrogen installations for vehicles according to TRBS1203*
	DE	1 day	*Uninterruptible Power Supplies with FC*
University of Ulster	UK	5 days	*International short course of advanced research workshop in hydrogen safety*
Haus der Technick Essen	DE	1 day	*Hydrogen and its meaning for the energy sector*
	DE	3 days	*Hydrogen and FC for mobile applications*
Weiterbildungszentrum Brennstoffzelle Ulm e.V	DE	1 day	*Fuel Cell and Hydrogen technology*
	DE	3 days	*Safety aspects when handling hydrogen*
	DE	5 days	*Polymer electrolyte FC*
	DE	1 days	*Uninterruptible Power Supplies with FC*
Inst. für Berufliche Bildung	DE	10 days	*Fuel Cells*
HyFacts consortium	EU	2-5 days	*Training short courses for regulators*
Hychain	EU	1-5 days	*Hydrogen, PEMFC and mobile applications*
HyFC Academy School, Aalborg University	EU	4 days	*various topics*
Christian-Doppler- Lab. for Fuel Cell Systems with Liquid Electrolytes	AT	4 days	*International Summer School on PEFC*
Ostfalia University of Applied Sciences	DE	12 days	*International Summer University "Sustainable Energy Technologies*
Solar-Institut Jülich	DE	15 days	*Summer School Renewable Energy*
Menéndez Pelayo Intern. Univ (UIMP), Spain	ES	3 days	*"Hydrogen and Fuel Cells: electric vehicle and energy storage"*
European Fuel Cell Forum	CH	1 day	*Fuel Cell Tutorial*
University of Birmingham / Forschungszentrum Jülich (2010 and 2013 -)	UK/DE	5 days	*European Summer School on SOFC*

Several training and education activities are part of specific (EU) projects. At the end of these projects, training will end as well. These activities are mostly (summer) schools:

Training designation	**# of trainings**	**Project's name**	**Project's duration**
Technical schools on FCH	4x	H2FC	48 months
Joint European Summer School on FCH Technology (2011 & 2012)	2x	TrainHy	24 months
Real-SOFC summer school (International SOFC summer school 1st-4th) (2004-2007)	4x	EU Integrated project Real-SOFC	48 months
LargeSOFC summer school (International SOFC summer school 5th-7th) (2008-2009)	2x	EU Integrated Project LargeSOFC; Forschungs-zentrum Jülich	24 months
The European Summer School on Hydrogen Safety (2006-2009)	4x	University of Ulster	48 months
Niedersächsischen Brennstoffzellen Summer School (Lower Saxony Summer School on Fuel Cells)	3x	Institut für Turbomaschinen und Fluid-Dynamik, Leibniz Universität Hannover	48 months
ISCARW courses	10x	University of Ulster	10 years

B: Higher education course modules

Several educational programmes in Europe address the issue of FCH technologies through dedicated course modules, with a mean course weight of 5 ECTS credits (corresponding to 125-150 hours of work for the student). The availability of undergraduate modules is extremely poor: there are only two dedicated undergraduate modules, which both focus on fuel cells and do not consider hydrogen. Both course modules are offered in Sweden:

Undergraduate module	**University**	**ECTS***	**Country**
The Fuel Cell (KH1405)	KTH Royal Institute of Technology	6	Sweden
Fuel Cell Technology (LU2730T)	Lund University	6	Sweden

*60 ECTS correspond to one year (1500-1800 hrs)

The contents of these undergraduate courses deal with a general comprehension of fuel cells including both theoretical and practical aspects. At the end of the course, the student can decide what fuel cell systems are preferred for a given application. These courses aim to provide deeper knowledge, a wider scope and improved understanding of the mechanisms as well as a better insight into theories, analysis and design of fuel cell and integrated energy systems.

In the area of postgraduate course modules, there are 18 modules addressing FCH aspects (mostly part of educational programmes on energy) offered in 6 European countries:

Postgraduate module	University	ECTS	Country
Hydrogen energy and FC (26130)	Denmark University of Technology	5	DK
SOFC and Electrolysis		5	DK
Materials for H_2 production, storage and FC applications (45200)		5	DK
Experimental SOFC and electrolysis (45103)		5	DK
Fuel cell systems (WB4425-09TU)	Delft University of Technology	3	NL
Sustainable hydrogen and electrical energy storage (SET3031)		2	NL
Introduction to Fuel Cell Systems (WB3570TU)		2	NL
Materials for the H_2 economy (MS4221)		2	NL
Automotive FC systems (3C5625)	KTH Royal Institute of Technology	7.5	SE
Fuel cell (KE2170)		6	SE
Renewable fuel production processes (KE2130)		6	SE
The Fuel Cell (KH1405)		6	SE
Hydrogen technology, FC and solar cells (TMT4285)	Norwegian University of Science and Technology	7.5	NO
Renewable energy: H_2 & FC technology	University of Newcastle	5	UK
Hydrogen, Fuel Cells and their Applications	University of Birmingham		UK
Fossil fuel based hydrogen technology (6KM40)	Eindhoven Univ of Technology	3	NL
FCH Technology (Tfy-56.4332)	Helsinki Univ of Technology		FI
Materials for the hydrogen economy	Heriot-Watt Univ Eindburg	5	UK
45101- Functional Ceramics: Defect Chemistry and Transport Properties	Denmark University of Technology	5	DK
26120- Hydrogen and Fuel Cell Chemistry-Experimental course		5	DK
MES-R-13-K Fuel Cells for Stationary Application	FH Aachen – Univ. of Applied Sciences, Jülich Campus	2.5	GE
Conversion des ressources fossiles et des vecteurs énergétiques. Hydrogène GMCH213	Université Montpellier 2	5	FR
Convertisseurs électrochimiques : Piles à Combustible GMCH34C		2.5	FR
New power production technologies	Ecole Centrale de Nantes	3	FR
Hydrogen derived technologies	Université de Nantes	4	FR
Matériaux et Technologies de l'Energie FC&H2	Université Paris Sud & Paris Est	2	FR
Energies renouvelables : présentation des différentes filières	Grenoble Institute of Technology	2	FR
Electrochimie pour l'énergie		4	FR
Composants électrochimiques	INP Toulouse	5	FR
Vector Hidrógeno I	Universitat de Barcelona – Universitat Politècnica de Catalunya	2.5	ES
Vector Hidrógeno II		2.5	ES
Pilas de Combustible		2.5	ES
Aplicaciones de pilas de combustible a micro y		2.5	ES

macro escala			
Hidrógeno y pilas de combustible (66331)	Universidad de Zaragoza	5	ES
Pilas de combustible y sus aplicaciones (66317)		5	ES
MÓDULO II: PILAS DE COMBUSTIBLE	Universidad Internacional Medéndez Pelayo	21	ES
MÓDULO III: HIDRÓGENO		5	ES

The mean duration of these modules is closed to 5 ECTS (125-150 hrs). In general, the course modules present a general overview of FCH, from fundamental aspects to applications. For example, hydrogen as an energy carrier, basics of fuel cell technology, electrochemical principles, thermodynamics, ion conductors, catalysts, hydrogen storage, fuel, processing, hydrogen production, system integration, applications etc., along with demonstration experiments.

It should be noted that among the disciplines that are of importance to FCH technologies, the area of **electro-chemistry** has been declining in the past decades. When this situation perpetuates, the lack of electro-chemistry expertise will likely cause significant damages to the FCH sector. Industry recommendation is that the education efforts in those fields should be sustained, for both initial and continuous training.

C: Fully dedicated educational programmes

Nine fully dedicated educational programmes have been identified, taking place in two countries:

Name	**University**	**ECTS**	**Country**
Post-graduate Cert in Hydrogen Safety Engineering	University of Ulster	60	UK
Post-graduate Dip in Hydrogen Safety Engineering		120	UK
Post-graduate in Hydrogen Safety Engineering		120	UK
MSc in Hydrogen Safety Engineering		180	UK
MRes in Hydrogen, FC and their applications	University of Birmingham	60	UK
MSc in FC and Hydrogen Technology	Aalborg University	120	DK
PhD with integrated Study in Hydrogen, FC and their applications	University of Birmingham	240	UK
Master of Science in Engineering (Sustainable Energy) ▪ Study line in hydrogen and fuel cells ▪ Elite master education “Fuel Cells and Hydrogen”, an industrial oriented education under Sustainable Energy	Denmark University of Technology	120	DK

Each post-graduate full programme has about 10-20 students. The curricula of the dedicated FCH programmes are shortly presented below.

MSc in Hydrogen Safety Engineering	**University of Ulster**	**90 ECTS**	**UK**

This programme is intended for students who wish to pursue a career in hydrogen safety and for professionals already working in industry (process, energy, civil works, aerospace, automotive industry), transport and distribution, fire and rescue brigades, insurance, teaching institutions and legislative bodies. It is composed of 6 modules: (i): Principles of Hydrogen Safety (30 ECTS) compulsory; (ii): Hydrogen Safety Technologies (30 ECTS), compulsory; (iii): Regulations, Codes and Standards (30 ECTS), compulsory; (iv-a): Hydrogen Powered Transport and Infrastructure Safety (30 ECTS) optional or (iv-b): Progress in FC and Hydrogen Technologies (30 ECTS) optional; (v): Dissertation module: research project (60 ECTS) compulsory.

MRes in Hydrogen, FC and their applications	**University of Birmingham**	**30 ECTS**	**UK**

This programme provides a systematic knowledge and understanding of hydrogen, fuel cells and their applications, including developments and problems at the forefront of the discipline. The curriculum consists of taught modules in science, engineering and team building, as well as business and management, and a dissertation. Core modules deal with topics such as: (i): Materials for H&FC technologies; (ii): The energy system; (iii): Marketing and Total Quality Management; (iv): Effective project management; (v): Business methods, Economics & Strategy. The research thesis will focus on many points, all related to FCH.

MSc in FC and Hydrogen Technology	**Aalborg University**	**120 ECTS**	**DK**

This FCH programme gives an in-depth understanding of the technologies of FC systems and Hydrogen production and storage. The programme is multidisciplinary, integrating general engineering disciplines, such as thermal systems, fluid dynamics, control engineering and electrical engineering. The taught course modules take up three semesters. The fourth semester is devoted to a Master's Thesis in FCH technology.

PhD with integrated Study in Hydrogen, FC and their applications	**University of Birmingham**	**240ECTS**	**UK**

This integrated programme lasts 4 years. The taught modules are in the first year, focusing on Science, Engineering, Energy, Teambuilding, Business, and Economics & Management. It is based within the Doctoral Training Science in Hydrogen, FC and their Applications. Led by the University of Birmingham in collaboration with Loughborough University and the University of Nottingham, this is the first centre of its kind in Europe.

D: Marie Curie actions (as part of FP7 People)

Under the Seventh Framework Programme several "People" actions deal specifically with FCH or Energy including FCH. Among these actions, three can be distinguished that contain an educational element:

D.1: Initial Training Networks (ITN)

The objective of the ITN action is to improve career perspectives of early stage researchers in both academia and the private sector.

SUSGHEN: Sustainable Hydrogen Generation (12-2009 to 11-2013) coordinated by the University of Newcastle Upon Tyne (UK). The aim of this ITN is to form a collaborative training programme that focuses on hydrogen production from water using advanced, medium-temperature proton exchange membrane electrolysers. Other partners are: NTNU, Trondheim (Norway); CNRS (France), Fundacion CIDETEC, San Sebastian (Spain); Institute of Electrochemistry & Energy Systems, Bulg. Acad. Sci., Sofia (Bulgaria), Centre for Process Innovation Ltd, Redcar (UK); Advanced Energy Technol. AE Ereunas, Athens (Greece).

D.2: International Research Staff Exchange Scheme (IRSES)

The objective of IRSES is to reinforce the extra-European dimension of the European Research Area through mobility, training, knowledge transfer and cooperation.

BIOWET: Advanced Biological Waste-to-Energy Technologies (01-2012 to 12-2015) coordinated by Institute for Chemical Technology, ICT, Praha (Czech Republic). The aim of this research is to apply biological methods for energy production using waste, contaminated materials or polluted environments, thus coupling energy production to waste minimization/reclamation. Other partners: Czech Republic, UNESCO-IHE for Water Education (Netherlands), University of South Florida (USA)

D.3: Industry-Academia Partnerships and Pathways (IAPP)

The objective of IAPP is to open and foster dynamic pathways between public research organisations and private research commercial enterprises.

ATLAS-H2: Advanced Metal Hydride Tanks for Integrated Hydrogen Applications (07-2010 to 06-2014) coordinated by DEMOKRITOS National Center for Scientific Research, Aghia Paraskevi (Greece).

The aim of this partnership is to develop and test (in the short term) and bring to the market (in the medium to longer term) integrated advanced metal hybrid tanks with added value applications especially for stationary systems and hydrogen compression. Even if the training & education aspects are less developed than in the two previous ones, the dynamic pathways between public and private research entities generate staff formation. Other partners: CNRS (France), Hystore Technol. Ltd, Lefkosia (Cyprus), McPHY Energy Sa., La Motte Fanjas (France).

E: Cost networks

The European Action MP1103 "Nanostructured Materials for Solid State Hydrogen Storage" was started on 25/10/2011, supported by the intergovernmental framework for European Cooperation in Science and Technology (COST) adopts the "COST Strategy towards increased support for early stage researchers (ESR)". This COST Action put into practice ESR related measures foreseen by the COST Action community, such as Short Term Scientific Missions (STSMs), Training Schools, Conference Grants, and ESRs as national MC delegate. This year 7 STSMs have been given to 7 ESR, 3 for 15 days and 4 for 30 days. Moreover, The First European Early Stage Researcher's Conference on Hydrogen Storage will be held in Belgrade on 3-5 /12/2012. This Conference will strongly promote the involvement of European ESRs into the Action. Recent results on nanostructured materials for SSHS achieved mainly by the partners of this Action will be discussed, highlighting the cooperation among partners and the support gained by the STSMs instrument in favour of ESRs.

Analysis and conclusions

The analysis of existing educational and training activities in Europe in the field of FCH exhibits a number of training activities in the forms of programmes, short courses and (summer) schools. In spite of the number of undergraduate and postgraduate modules, the activities in higher education sector are at a rudimental level unable to supply Europe with a professional workforce sufficient to realize the 2020/2030 projections. The Working group on Cross Cutting Issues [3] has estimated that during the FP7 program (2007-2013), already 500 new graduates from post-graduate studies on FCH are needed on an annual basis in all of Europe, both in the industrial and research sector [4]. Our estimate for the entire workforce in FCH-related industry amounts to 60,000 jobs in 2020 and 190,000 in 2030. This required number of people with workforce skills in FCH technologies should be available in time in order to be properly prepared for the development of hydrogen technologies.

What actions are required to achieve this level and volume of education and training?

- The overview of existing university courses around Europe shows that several courses are offered that cover the various aspect relevant to FCH technologies quite well. There is no coordination among these courses. A combination of various elements to make up a full FCH multi-institutional programme appears practically unfeasible as the semester terms and quality demands vary from university to university and the distances of educational facilities are often large. Instead, a central depository of tools and expertise is needed to create and support (new) local courses all over Europe.
- Training and education as part of European projects are essential enough to warrant continuation beyond the current project duration.
- There is a need for an easy way for students (and lecturers) to obtain information about short courses, modules and summer schools in Europe. This information should include a detailed overview of curricula, course materials, course frequency, examinations, ECTS, costs, e-learning if available, etc.
- In industry, there is mostly interest for short courses, both general overview courses and specialized courses on a specific topic. There is also a need for tutorials to be given at or near the industry location.

As a conclusion, currently, there is a small number of local programmes and course modules in Europe which needs to increase EU-wide. Furthermore, the EU has significantly invested in occasional trainings through summer schools and Marie Curie Actions. These efforts have to continue. But it will not be enough to bring European education and training to a required level securing Europe's leadership and competitiveness in the field. Support for basic and applied research needs to be continued, by supporting post-graduate professional development training, development of an EU network of graduate courses, development of an EU-wide national curriculum integration programme for FCH, encouraging human capital investment in adults by the private sector and development of an educational package to increase the connection between university and the private sector [6]. In any case, a more accurate analysis should be based on an up-to-date 10 year FCH Technology Roadmap for Europe.

3 Gaps and bottlenecks

The deployment of low carbon energy technologies requires a comprehensive set of skills linked to an interdisciplinary approach to educate and train a workforce that will use hydrogen and fuel cells technologies. The previous section highlighted that several teaching and training modules or programmes are available at various educational levels. Despite these significant efforts, the number of well-trained specialists is far below the forecast to realize the FCH Roadmap objectives and Europe2020 ambitions in general. To anticipate the need of competence at industry and research levels and accompanying the deployment of hydrogen and fuel cells, we identify the education and training needs for each group of stakeholders and highlight existing gaps, barriers and bottlenecks in education and training that hinder the deployment of hydrogen and fuel cells technologies.

Identification of education and training needs for stakeholders

Human resources are a critical dimension of the knowledge economy. This section focuses on the education and training needs for the deployment of FCH technologies as low-carbon energy technologies. These needs are explored at various levels: specialists, non-specialists, teachers/trainers, stakeholders in the area of safety, users of the FCH technologies of today and potential users of these technologies tomorrow.

A: FCH post-graduate specialists

FCH researchers and research technicians are needed to envision and design new technologies, products and services. Section 2 presented higher education programmes and modules at postgraduate and undergraduate levels in Europe. For the first cycle i.e. undergraduate level no specific programmes focused on hydrogen and fuel cells technologies exist. Therefore, students have to reach postgraduate level to receive a specific education on hydrogen and fuel cells. From that point onward, the students can specialize in FCH technologies as an engineer or a researcher.

Specialists in hydrogen and fuel cells technologies should master the core and generic skills as listed below:

Core skills:

- ✓ Electrochemistry
- ✓ Process engineering
- ✓ Power electronics
- ✓ Architecture of electric systems – energy management systems
- ✓ Risk management and hydrogen safety
- ✓ Advanced materials and new synthetic techniques for hydrogen storage and fuel cell components
- ✓ Nanomaterials and nanotechnologies
- ✓ Characterization methods including 3-D and in-situ techniques

Generic skills and competences:

- ✓ Chemistry adapted to energy including hydrogen and fuel cells
- ✓ Energy management/electrical engineering
- ✓ Heat and mass transport
- ✓ Electronics and control
- ✓ Mechanicals engineering
- ✓ Thermodynamics, Kinetics
- ✓ Testing protocols, standardisation, methodologies of quality control

This is of course essential to develop knowledge useful for hydrogen and fuel cells technologies but is not sufficient as such to support their deployment. Teaching is built around disciplines and hydrogen and fuel cells are not a university discipline as such, but require interdisciplinary approach and an understanding of the evolving environment of these breakthrough technologies that is linked to social acceptance aspects.

Indeed, education and training on hydrogen and fuel cells need to be integrated in a more global approach that implies to highlight the specificity of energy, industrial and policy needs to give specialists in hydrogen and fuel cells technologies the updated knowledge that requires this evolving and interdisciplinary field. Although universities should put the topics they teach in a broad societal context, our survey (as discussed in Section 2) shows that very few universities in Europe have developed teaching programmes that take into account both industrial and policy needs.

An integrated educational approach is needed in which academic interests, industrial needs and policy need to go hand in hand, so that curricula are updated continuously and the resulting workforce is adapted to the present reality and challenges. Europe needs a direct connection with the productive system, ensuring the reception of industrial requirements and reducing the gap between scientific research achievements and technology transfer. This requires the establishment of continuous and permanent synergies between teachers/trainers/educators, industry, and public policy.

B: FCH specialists in industry

An important portion of the FCH workforce consists of specialists at technician level with the appropriate skill in the area of hydrogen and fuel cells technologies. First of all, technicians are needed to manufacture products, design products and services, commercialize them or do industrial innovation on FCH technologies. The skills required for these specialists are very similar to those discussed under (A): FCH specialists in academia. The working group found that very few major companies have the internal resources to develop specific curricula to train their staff in internal training centres. This, however, is clearly not the case for the majority of FCH industry and especially SMEs or start-ups. The use of the SOFC summer schools by European SOFC developing industry for training the newly recruited staff is a vivid example of how industry can directly profit from training activities. The same applies to schemes of continuous improvement (CIP) where industry can use the various training schemes in universities and vocational training institutions.

At technician and undergraduate levels, the working group also found a need to have an introduction to Energy management in general in the different modules and courses. It is necessary to have a workforce that understand the specificity of energy, especially reinforcing the complementarities between low-carbon technologies and avoiding opposition between technologies such as batteries vs fuel cells or hydrogen versus photovoltaic. It seems relevant to give future workforce the elements to place hydrogen in the global energy context. It is also to be pointed out that hydrogen is more than a fuel, it is also an energy vector to be coupled with all the sustainable and renewable energies. Indeed, same remarks concerning the teaching of interdisciplinary and evolving field made above applied here.

C: FCH system integrators/operators/O&M staff

Technicians are also needed for the installation, monitoring and maintenance in particular performance assessment of hydrogen & fuel cells devices. Europe currently is lacking system integrators and operators of a technology at the technician level. This is not specific to hydrogen and fuel cells but the general scarcity of these skills in Europe will impact the deployment of hydrogen and fuel cells. Indeed, Europe needs the skills and jobs related to designing, manufacturing, specialized technicians able to read and understand a complex electric scheme adapted to the energy field. These skills are needed both at industry and research levels.

D: Non-specialist-level workers

With very few exceptions, no systematic approach of technicians or undergraduate including people looking for a job, and technicians working on technologies that will be replaced by FCH technologies has been developed to teach or train a workforce on the hydrogen and fuel cells breakthrough technologies.

E: Teachers and trainers

Europe needs different types of teachers or trainers including schoolteachers with basic insights in the meaning of FCH to high-level teachers for engineers or technicians. A specific category of teachers is that of the educational programme architects who are able to propose curriculum or programmes in hydrogen and fuel cell technologies that are interdisciplinary and constantly evolving in terms of technologies, codes and standards, regulations, policy and social acceptance dimensions.

Introducing the low carbon economy starts with the young. Children could already be familiarized with new technologies such as hydrogen and fuel cells at schools. Therefore, specific training should be developed for teachers to help them understand the technologies, as well as teaching materials for use in schools. Other useful activities in this respect include: special training programmes for highschool teachers on high-tech innovations, visits to research centres and the regular communication of R&D results and innovation results from research centres to schools. As discussed elsewhere in this document, the working group recommends that teachers/trainers should be made aware of the importance of taking into account (in real time) both industrial needs and public policy.

F: Professional users of FCH technologies

With the emergence and constant evolution of FCH technologies, the professional users of technologies, technological products and services need to update their knowledge about hydrogen and fuel cells technologies. This mostly concerns working people who are using similar/conventional products and services but can be interested in using FCH technologies in their current or future employment.

While the FCH Technology Roadmap as presented in Section 1 focuses on the manufacturing of FCH products, their large-scale deployment will also impact stakeholders such as building contractors, architects, energy auditors, designers or other potential end-users of the technologies. Below, an estimate is presented of the potential workforce that needs to understand the technology, its positive and negative aspects and impact in order to make an informed choice of the suitable technology for their activity, and in order to use and integrate it in their work in the most efficient manner. The level of knowledge and understanding of these stakeholder on how to use FCH technologies will play a role in realizing the ambition set out in the Roadmap and the successful deployment of hydrogen and fuel cells technologies.

Three typical groups of professional users are discussed in the following:

Building contractors:

The professional association for building contractors CEETB (mainly electrical, heating, air conditioning, ventilation and plumbing contractors) represents 450,000 European companies with 2,400,000 employees in Europe and beyond. Their turnover represents within the European Union about 200 billion €. Specialist contractors represent one quarter of the turnover in the entire field and 31% of that of the building sector. For certain projects, the technical equipping of buildings represents 50% or more of the total project costs.

Architects:

According to the European Association for Architectural Education (EAAE), more than 140 active Member Schools in Europe from the Canary Islands to the Urals exist, representing almost 5,000 tenured faculty members and more than 120,000 students of architecture from the undergraduate to the doctoral level. The Architects' Council of Europe (ACE) represents 480,000 architects.

Energy auditors, ESCOs, EPCs:

Energy service companies (ESCOs) and energy performance contracting (EPC) are common tools to enhance the sustainable use of energy through promoting energy efficiency and renewable energy sources. The market for energy efficiency services in Western Europe was estimated to be 150 million € per annum in 2000, while the market potential was estimated to be 5 to 10 billion € per year [7].

G: Safety and certification stakeholders

Hydrogen and fuel cells products and services to be deployed have to be certified. For this reason, there is a need for certifiers or companies in charge of conformity assessment and certification services understand the technologies. A related workfield deals with the use of hydrogen system and safety concerns. Firefighters are a prominent part of this group.

In the USA, California is at the forefront of deploying hydrogen and fuel cells. Firefighters in California are able to follow roving schools helping them to master the safety of hydrogen. Europe could follow this example. European stakeholders include Fire Protection Associations and the Confederation of Fire Protection Association Europe (CFPA-Europe). Indeed, fire prevention & protection issues as well as issues related to safety, security and other associated risks, should be addressed as part of increasing awareness and facilitate the use and understanding of hydrogen and fuel cells technologies.

Most countries have various categories of firefighters with the main two groups consisting of professional firefighters in the public sector and voluntary firefighters. Other smaller categories include military firefighters and private sector firefighters. Numbers are given in the table below, concentrating on public sector professional and voluntary firefighters.

Country	**Firefighters [8]**		
	Professional	***Voluntary***	***Other***
Belgium	5,250	16,690	
Croatia	2,400	60,000	1,745
Czech Republic	10,797	350,000	2,828
Denmark	1,217	2,952	4,469
Estonia	1,600	100	
Finland	2,940	19,400	690
France	42,000	200,000	2,000
Italy	26,000	7,000	
Netherlands	4,000	21,000	1,500
Slovakia	4,296	10,000	1,546
Spain	19,886	3,437	3,745

H: The general public

Educating general public is key to get people familiar with and accept new technologies such as hydrogen and fuel cells. The deployment of hydrogen and fuel cells technologies relies on social or public acceptance. To prevent public opposition, the new technologies need to be addressed appropriately. The environmental and economic advantages have to be demonstrated to the general public while it also has to be shown that the safety risks can be managed. However, this is more of a public awareness action than an educational issue.

A structural approach to disseminating the state-of-the-art

Until now no initiative is undertaken at EU level to present on a regular basis an updated, unbiased and comprehensive overview of what Europe has to offer in the area of FCH products and services. European industrial sectors do not provide a common list or catalogue of products or services, no company profiles of FCH manufacturers are produced at the European level, no systematic information exists about FCH users including the reasons why these users have chosen these technologies – contrarily to the situation in the United States of America.

Best practice from the US: the Breakthrough Technologies Institute

A publication from November 2011, entitled *The Business Case for Fuel Cells 2011: Energizing America's Top Companies* provides a comprehensive overview of current FCH products, services, manufacturers and corporate users in the United States. This report was originally proposed by the Fuel Cells 2000 initiative as part of the activities of the Breakthrough Technologies Institute (BTI), a non-profit independent educational organization that identifies and promotes environmental and energy technologies that can improve the human condition. The BTI covers a wide range of topics such as air quality, climate change, energy efficiency and energy independence. It was established in 1993 to ensure emerging technologies have a voice in environmental and energy policy debates. One of BTI's activities is Fuel Cells 2000, which aims to supply accurate, unbiased industry information and develop and disseminate summary materials accessible to general audience.

In the US, the independent Breakthrough Technologies Institute (see inset) has proven to be a powerful instrument to identify the needs and to supply continuous working activities on breakthrough technologies. Neither such an institute nor this type of compilation exists in Europe. Based on the comprehensive compilation on products, services and manufacturers tailored training initiatives to raise awareness on hydrogen and fuel cells technologies can be carried out focusing on different target groups.

The approach in Europe is now mainly based on specialist training as part of projects. But deployment means also to gauge and raise the interest of different groups of stakeholders and potential users in these new technologies and innovations, and to raise awareness on how hydrogen and fuel cells technologies are used today and can be useful for tomorrow's objectives of European industries. In existing national FCH associations, the first activities targeting end-users are indeed emerging. For example in France, AFHYPAC proposes to set up end-users networks to support the deployment of FCH technologies. Clearly, the time has come to take a next step at the European level and understand the needs for education and training of these end-users in order to make the technologies more visible to other potential users.

Existing gaps, bottlenecks and barriers

In the previous Section, the training and education needs for the various stakeholders and end-users have been discussed. In this Section several issues (gaps, barriers, bottlenecks) are identified that hinder the build-up of a sufficient high-quality European educational capacity for all stakeholders involved. Clearly, a successful European system of FCH training and education cannot be achieved by simply establishing additional educational programmes. The issues listed in this section need to be addressed as well. **In Section 4 we propose specific actions within the realm of training and education. The current Section also includes several recommendations to the European Union for overbearing actions.**

Barrier: Local lack of expertise

FCH technologies are emerging technologies. Not everywhere in Europe the multidisciplinary expertise currently exists that can be used in creating teaching capacity and teaching materials of sufficiently high quality on the short term. Still, it would be unwise to wait for local FCH industries to mature before setting up training and education. Even when local expertise is lacking, the workforce and public need to be educated in order to embrace the new technologies. Clearly, some form of sharing (educational) expertise among Member States should take care of this barrier.

Barrier: Lack of ties between educational curricula, industry, policy needs

FCH education and training need to be integrated in a more global approach in which academic interests, industrial needs and policy needs go hand in hand, so that curricula are updated continuously and the resulting workforce is adapted to the present reality and challenges. Europe needs a direct connection with the productive system, ensuring the reception of industrial requirements and reducing the gap between scientific research achievements and technology transfer. This requires the establishment of continuous and permanent synergies between teachers/trainers/educators, industry, and public policy.

Gap: Lack of a comprehensive overview of industrial needs

The fuel cells industry is at a very interesting period of transition, moving from primarily R&D to commercial production. Fuel cells manufacturers are in particular located in the US, Japan, Canada, Scandinavia, South Korea, China and Germany. Fuel cells vehicles are appearing in countries where hydrogen infrastructures are under construction such as the USA, Germany, Norway and the United Kingdom. Commercial supply chains have developed throughout the world since the Millenium. Growing activity concerns key components and process steps such as membranes, catalysts, MEA suppliers, gas diffusion layers, bipolar plates, gaskets, stack assembly or hydrogen production and storage.

Work on this report revealed that only a fragmented and incomplete picture exists of the plans, needs and ambitions of the FCH industry. The working group noticed a variety of reports discussing the fuel cell industry, the demand for hydrogen from fuel cells and internal combustion engines or hydrogen production and storage.

However, a comprehensive panorama and status of industrial needs in terms of education and training in European Union does not exist to the best of our knowledge. The hydrogen and fuel cell technologies are breakthrough technologies addressing different potential markets and industries that need to be developed and supported at European level in order to create growth and employment.

In writing Section 1, the working group found it difficult to follow roadmaps and foresight studies to determine the needs of industry especially as FCH markets are at different levels of maturity, the technologies impact different markets and industrial sectors and are linked to public policy and social acceptance to accompany its deployment. Clearly, the analysis of the industrial needs in terms of education and training is a complex challenge. One difficulty that the group faced in writing Section 1 is the selection of a representative panel of industries (manufacturers, users, etc.) to get the data. During the process of drafting this report, the group faced questions such as: who has the legitimacy to raise the question of industrial needs? How to formulate the question? Which methodology to use to answer the question? Who has the skills to assess the needs of education and training to accompany the development of breakthrough technologies not yet implemented?

→ Recommendation: The working group suggests that the European Commission launches a call for tender to have such an analysis. We propose to target polling organizations that will be in charge of selecting a panel of representative industries in Europe, make the inquiry and the analysis of the industrial needs taking into account the public acceptance of these breakthrough technologies.

Gap: Lack of a European Strategy

Several Education and Training actions on hydrogen and fuel cells have been undertaken at the international level (e.g. within the International Partnership on Hydrogen and Fuel Cells – IPHE [9]), at the European level (e.g. projects funded by the Fuel Cells and Hydrogen Joint Undertaking FCH JU, and Framework Programmes) and at the individual Member State level.

Section 2 shows that as a result of these actions, several course modules, workshops and programmes on hydrogen and fuel cells are offered, and laboratory exercises and materials are available, aimed at technicians, engineers and researchers. This is a first step but not sufficient to meet the demand for the well-trained workforce needed to meet the Europe2020 ambitions.

For hydrogen and fuel cells technologies, no massive training and education plan in all universities or training institutions is needed at the European level. What needs to be done instead is to aggregate projects in a joint European FCH strategy. It seems to the group that the members of the FCH JU are well positioned to address this challenge. These members understand the crucial topics, can ask transversal and interdisciplinary questions and analyse the rapidly changing FCH environment. In particular, N.ERGHY, the association member of the FCH JU Governing Board, represents 66 universities and research centres all over Europe working on FCH topics. As such, it covers all different disciplines involved in education and training. The question of technicians also has to be addressed, for example through a partnership with technical training centres.

At the same time however, no European decision-makers are identified being responsible for education and training on hydrogen and fuel cells. Therefore, there is a lack of a European policystrategy on education and training for hydrogen and fuel cells to support the deployment of these technologies and the creation of a European industry. As a first step towards such a European strategy, stakeholders will have to identify shared objectives that they would like to achieve at the European level and the actions they would like to develop at European level.

It is interesting to make a parallel with the batteries industry. Currently, SAFT is one of the very few batteries manufacturers in Europe. The extinction of industrial competences in Europe in this domain followed the delocalization of the manufacturing to Asia. Today, European industries have difficulty to catch up and compete with Asia due to a lack of investment of these industries in Europe in the past.

→ *Recommendation: The working group suggests that European Commission proposes a European strategy on education and training for FCH breakthrough technologies with shared objectives, actions and identifies a common process for teachers and trainers to take into account in real time both industrial needs and public policy including social acceptance needs in hydrogen and fuel cells which is an evolving and multidisciplinary topic.*

Gap: A projects approach without European systematized and coordinated follow-up

The previous sections of this report highlighted that current actions on FCH are undertaken at project level. These projects lack a continuous follow-up. The European Union needs to go beyond its projects approach on FCH and create the synergies necessary to arrive at a European strategy. For example, people who have currently received FCH training have done so *ad-hoc*, very often without follow-up. Jobs such as operators of technologies at technician level, energy auditors, and designers, building contractors or other potential end-users of hydrogen and fuel cells products could benefit strongly from continuous training. However, no links and follow-up with these jobs, human resources divisions, specialists or professional associations have been developed at European level and systematized.

→ *Recommendation: the working group proposes that the European Union build a more structural approach to training and education on FCH technologies that goes beyond its current project-based approach.*

The global transition to a Low-carbon energy system will require going beyond existing measures. The deployment of the hydrogen and fuel cells technologies is embedded in new products or services. Manufacturers will need support from the European Union to get their products and services commercialized. Specific qualified workforce will therefore be needed if Europe takes the decision to manufacture products and sell them, in the framework of a massive deployment of Low-carbon energy system in 2020.

4 Proposed actions

Filling the skills, competences and knowledge gap

Focal area 1.1: Meeting the skill and competencies gaps of new and emerging technologies

A key part of the future FCH workforce will need to have a high degree of specialisation. It has proven in the past that a too narrow, limited and specialised training at a too early stage in the education of young people can hinder the further development of their careers. Therefore it is not advisable to create special topical courses on FCH topics at various European institutions in a centralized manner.

Rather, the main focus of the proposed activities is the supply of teaching materials and opportunities delivering a high level of tuition quality. In this sense the provision of material of high standard across Europe is seen as a major goal. This will allow universities, schools, other training and educational institutions and even industry to draw on the same base of high-quality teaching material and be able to refer its supply throughout Europe.

Action area 1.1.1: Availability of high-quality teaching materials

Objective

This action should result in the wide availability of high-quality, multi-purpose teaching materials (including simple demonstration equipment) at a range of levels, which can be incorporated in local programmes to support local training and education in the area of FCH.

- *Target programmes*: courses delivering basic training to engineers (mechanical, chemical, electrical etc.) and scientists (physics, chemistry etc.) at universities, but also in educational programmes at secondary schools, high schools, vocational training schools (such as Berufsschule) and in industry. The teaching material also includes the aspect of Continuous Improvement Projects (CIP) necessary for engineering professions in many member states. The material is later to be extended also to basic (primary) and preparatory (Kindergarden) school level in order to display the possibilities of fuel cell and hydrogen technology to even the youngest of pupils.
- *Distribution:* mostly in print or electronically, via web portals (e-learning, web-based reference library)
- *EQF-level:* initially 3-8 (R&D, Engineering, Developers, Others; engineers & technicians: Manufacturing, Installation, O&M, etc.; Management, Finance/insurance, Developer, IPP/Utility), later extended to also cover 1-2 ("unskilled": Support: assistance, production, transport)
- *Language:* Depending on the target programme level and requirements, the material will be developed in English only or in all European languages.
- *Execution:* The structure of the teaching content is being developed by the FCH JU project TrainHy (European Curriculum in Fuel Cell and Hydrogen Technology). Although the specific activity of TrainHy is directed at post-graduate teaching and learning, the same structure, with

content at a somewhat simplified level, also serves for undergraduates, vocational (technician) training, and school pupils. A project or subcontractor will develop the teaching material, with the participation of academia and industry for the content development, of teachers from various countries for the form the material takes, and of a network of translators.

Implementation, timelines and scope

- Implementation of project group: 2013

  Development of programme framework and co-operation with European universities: until 2014

  Extension to European schools: until 2016
- *Size of project:* 5 to 10 partners (specialising on the different training and school types) with 10 subcontractors (translators)
- *Industry role:* sponsoring of follow-up activities from the TrainHy project; qualified input to teaching topics and course content; supply of practical teaching materials and laboratory equipment
- *Total cost:* 5 million € for initial development of material (incl. translations), followed by summer school events, alumni meetings, continuous updating, maintenance and further development of curriculum, extension to lower school levels etc.

Objectives and deliverables

- *Barrier addressed:* local lack of expertise
- *Final deliverable:* A standardised curriculum and teaching material in English. In case of school training and vocational training: translations of the standardised material into all relevant European languages. Detailed requirements will need further refining and elaboration in the years to come.
- *Intermediate deliverables:* Development of curriculum; development of teaching content and materials; integration into Member States CIP schemes for engineers (and possibly scientists); development of e-learning content and website; student laboratory equipment and financing scheme.

Action area 1.1.2: Doctoral Training at Universities

Doctoral training is a phase in vocational training that embeds students in the larger R&D community, allows them to work closely with R&D leaders and scientific peers and often brings them in touch with mid-termed practical developments in industry. In the UK, so-called Doctoral Training Centres (DTCs) are sponsored by the British funding agency (EPSRC) as university centres where up to 50 students (5 years, 10 students per year) are trained on different but related topics e.g. fuel cells and hydrogen, electrochemistry, energy storage etc. Another example are Research Training Groups established by universities to promote young researchers. They are funded by the German Research Foundation (DFG) for a period of up to nine years. Their key emphasis is on the qualification of doctoral researchers within the framework of a focused research programme and a structured training strategy. These actions concern doctoral training in the area of FCH technologies.

Objective

Creation of Doctoral Training Centres (DTCs) similar to those of the EPSRC at the European level with 20 Centres of Doctoral Training distributed across the member states. Each centre has a specific specialization and delivers training across a number of topics.

- *Barrier addressed:* lack of coordination between academic, industry and policy requirements for education

Implementation, timelines and scope

- Development of the programme framework and co-operation with European universities: until 2014

  Call of interest for establishment of DTCs across Europe: 2014

  Installation of approx. 20 DTCs across Europe: 2015-2016
- *Industry role:* supply of student bursaries (incl. tuition fees); assignment of cooperation projects; provision of materials and laboratory equipment
- *EQF-level:* 6-8 (R&D, Engineering, Developers, Others)
- *Total cost:* 5 million € per centre and 8 years of operation.

Deliverable

- About 20 DTCs across Europe, where students are exposed to a multidisciplinary R&D environment under guidance of highly qualified supervisors

Fostering involvement, access and up-take by the labour market

Focal area 2.1: Promoting mobility, life-long learning, workforce training

Action area 2.1.1: European student and staff mobility programmes

Within the FP6 'Integrated Projects' it was good practice to implement student exchange projects. These included small projects (typically 3 months duration) undertaken between research institutions by sending a member of staff (typically a doctoral student) to the partnering institution to perform specialized work only possible at those laboratories. Both institutions benefit from the more intensive communication between the institutions during a placement and from the exposure of the staff/students to another research context and environment. Whilst exchange programmes for doctoral and post-doc studies exist (such as the Marie Curie scheme), the lower level, short-term exchange can be just as rewarding but is currently not fostered.

Objective

This mobility programme aims at improving the interaction between research institutions across Europe, at fostering small, joint research projects, and at exposing students to multi-lingual, multi-ethnic, and multi-national environments.

- *Barrier addressed:* lack of coordination between academic, industry and policy requirements for education

Implementation, timelines and scope

- *Timing:* - Development of programme framework and contract templates for co-operation between educational institutions: until 2014
  - Implementation of student mobility: 2015
- *Target audience:* This action is aimed at motivated students. Grant of placements on basis of review of application materials allowed on a continuous, first-come-first-served basis with a minimal amount of administration. Total placements per year: 100.
- *EQF level*: 4-8 (R&D, Engineering, Developers, Others; engineers: Manufacturing, Installation, O&M, etc.; Management, Finance/insurance, Developer, IPP/Utility)
- *Costs:* Incentive per placement: 3,000 € for additional travel, materials, subsistence.
- *Industry role:* sponsoring of additional placements (above the number mentioned above)
- *Total cost* for 100 placements per year: 300,000 € per year

Deliverables

- Enhanced interaction among European research institutions through short-term joint student research projects
- About 100 students projects finalized per year

Focus area 2.2: Industry involvement and partnerships

Action area 2.2.1: Industry – research partnerships

Targeted R&D activities require a close co-operation between academia and businesses. Academia has to understand the needs of industry, especially market introduction, while companies have to understand new research results and development options. This requires special interaction between the two groups. In order to generate new insights and ideas, this has to take place outside of the targeted R&D actions undertaken within the usual technology funding programmes (e.g. FCH JU MAIP). This action is not directed at 'blue skies' developments but at research and industry partners working in a joint area and wishing to make better use of each other's competencies. It is therefore different from usual workforce mobility programmes as it requires more flexibility regarding the duration of the stays as well as strict co-ordination between the universities and business/research facilities receiving staff members.

Objectives

This mobility programme aims at improving the innovation potential in European businesses by exposing industry staff to new scientific developments and technological possibilities. This will generate new ideas developed between scientific and industrial employees. This activity also has an element of CIP.

- Businesses develop a one-year R&D programme with an educational or research organisation
- Within this time frame a member of staff works at the research laboratory for a minimum of two periods of two to three months duration each.
- Grant of placements on basis of competitive calls (4 per year)

Implementation, timelines and scope

- *Timing:* Development of programme framework and contract templates for co-operation between educational institutions and businesses: until 2014

  Implementation of new research mobility programme: 2015
- *Number of placements:* 40 per year
- *Incentive per placement:* 12,000 € for additional travel, materials, subsistence
- *Industry role:* co-funding of placements (above the incentive mentioned before)
- *EQF*-level: 4-8 (R&D, Engineering, Developers, Others; engineers: Manufacturing, Installation, O&M, etc.; Management, Finance/insurance, Developer, IPP/Utility)*Total cost:* 480,000 € per year

Deliverables:

40 one-year placements of private sector staff members at educational or research organisations per year

Planning and enabling skills development

Focal area 3.1: Development of teaching materials and courses

→ See Action area 1.1.1

Focal area 3.2: Online information and other tools

Action area 3.2.1: Project and technology status web site

The Fuel Cell and Hydrogen Joint Undertaking (FCH JU), the public-private organisation between the Commission, industry and the research community, is running a web site that serves as a base of communication between the JU, its partners, and the general public. This existing site supplies some general information, shows details of the running projects and attempts to communicate the results, findings and recommendations coming from the funded projects. Due to the relatively short period the JU and the associated projects have been operational, the site is not yet fully equipped. Since the FCH JU is located at the proper interface between the Commission itself, the industry and research partners, and the public, it could easily be extended to supply more and comprehensive information to all stakeholder groups.

Objective

Extension of the current FCH JU website to supply all FCH stakeholders with up-to-date information about FCH technologies.

- *Barrier addressed:* local lack of expertise

- At least some of the information – directed at the general public – will be available in all EU languages.

Implementation, timelines and scope

- *Timing*: - Project group implemented by 2014
  - First implementation of the new website by 2015
  - Further refining and updating from 2015-2020
- *Project team:* 1 coordinator with 10 subcontractors (translators)
- *Role of industry:* sponsoring, supply of information
- *EQF-level:* not applicable
- *Total cost:* 250,000 € for first year, 250,000 € for translators, 500.000 € for 5-year maintenance and updating period

Deliverables

A web site with instructive materials translated into all relevant languages of the EU

- Providing information on the technology status of national and European projects (showcasing)
- Providing industrial supply base information
- Providing general information on FCH technologies

Action area 3.2.2: Museum activities

Objective

Supply information and exhibits about FCH technologies to the general public through the existing technology museums in Europe. The supply of high quality information on FCH technologies is essential in building the understanding for the technology and encouraging especially young persons (pupils) to get involved in these technologies. Since public demonstration programmes are always limited in scope (essentially by the limited availability of the 'exhibits') a permanent exhibition in a space that is regularly visited by school classes would be a prime place to promote the technology. Pupils are a specifically interesting target group in that students are reached and influenced at an age where they take base decisions on their future vocational interests and careers.

- *Barrier addressed:* local lack of expertise

Implementation, timelines and scope

- *Implementation*: from 2014
- *Size of project*: coordination of a network of participating museums
- *Role of industry*: sponsoring and supplying exhibits
- *Cost:* 250 k€ per year, including funding of meetings and selected exhibits

- *EQF-level:* not applicable

Deliverables

Supply exhibits about FC&H2 technology to existing technical museums in Europe.

Summary

Education and training essentially contribute to the building of the European human resources base for developing fuel cell and hydrogen technologies.

The measures sketched here include all levels of education from schools to postgraduate programmes. In parallel and at the same time vocational training and schemes of continuous improvement have to be addressed for the more industrially oriented training.

Measures addressing the general public in the sense of general information have their long-term merits but were not considered as part of education and training here, and left to the market introduction programmes necessary in the future.

It is strongly recommended that education and training are placed at the centre of European activities since they are an essential requirement in preparing the skills necessary for this innovation.

References

[1] COM(2010)2020, Europe 2020, A Strategy for smart, sustainable and inclusive growth

[2] FCH JU, Revised Multi-Annual Implementation Plan 2008-2013, adopted by the Governing Board in November 2011, available on www.fch-ju.eu

[3] Wancura H, Mayo B, Reijalt M., Mertens J.J., Classen P., *Draft implementation report WG5 cross cutting issues*. The European Hydrogen and FC Technology Platform, Implementation Panel

[4] "HYFACTS" (From Deliverable 5-2: Map of existing educational and training activities in Europe)

[5] "TrainHy" 1: *Atlas of European Training Measures for Young Professionals* (from Deliverable D1.1); 2: Requirement profile for training courses for young professionals in the fields of FCH (from deliverable D1.2)

[6] "Roads2HyCom" (From Deliverable 6.2.2. Socio-economic conditions for FC and Hydrogen technology development)

[7] Bertoldi, P., Berrutto, V., De Renzio, M., Adnot, J., Vine, E., 2003. *How are ESCOs behaving and how to create a real ESCO market.* In ECEEE summer study proceedings, 335-340. Editor: ICE et Butson, J., 1998. *The potential for energy service companies in the European Union*. In Proceedings of the First International Conference on Improving Electricity Efficiency in Commercial Buildings (Amsterdam, September 1998). Excerpt from DG JRC, *Latest Development of Energy Service Companies across Europe - A European ESCO Update*

[8] Data taken from www.epsu.org/a/6651

[9] See http://www.iphe.net/about.html

[10] See *The great transformation: decarbonising Europe's energy and transport systems*, 2 January 2012, Bruegel Blueprint Report, pages 95-96

SET-Plan Energy Education & Training
Geothermal Energy

Geothermal Energy

Working Group Contributors

Rapporteur : Eva Schill (GEIE Expoitation Minière de la Chaleur, Soultz-sous-Forêts, France) schill@soultz.net

In the course of the elaboration of the here presented report the following European experts have been involved. Their scientific contributions and teamwork shall be highly appreciated.

Ruggero Bertani	Enel Green Power, Italy)
Christian Boissavy	AFPG, France
Mario Gaia	Turboden, Italy
Halldór Pálsson	University of Iceland, Iceland
Thomas Kohl	KIT, Germany
Adele Manzella	CNR, Italy
Isabella Nardini	CNR, Italy
Alcides Pereira	University of Coimbra, Portugal
Burkhard Sanner	EGEC, Europe
Jörg Uhde	Axpo AG, Switzerland
Jan Diederik van Wees	TNO, Netherlands
Paul Younger	University of Glasgow, U.K.

Introduction to the different geothermal technologies

Geothermal energy (2009/28/EC)

A definition of *geothermal energy* is provided in Article 2 of the directive 2009/28/EC on the promotion of the use of energy from renewable sources. The following definitions also apply:

(a) *energy from renewable sources* means energy from renewable non-fossil sources, namely wind, solar, aerothermal, geothermal, hydrothermal and ocean energy, hydropower, biomass, landfill gas, sewage treatment plant gas and biogases;

(b) *geothermal energy* means energy stored in the form of heat beneath the surface of solid Earth;

(c) *hydrothermal energy* means energy stored in the form of heat in surface and subsurface water;

At present the calculation of the share of energy from renewable sources described in Article 5 for geothermal energy (Article 5, 1(b)) concerns mainly the gross final consumption of energy from renewable sources for heating and cooling. This is in accordance with the current type of energy utilization from geothermal sources in most European countries. Although geothermal heating and cooling is having a recognized increment and technological development, the most ambitious perspective of geothermal technology is electric power production and co-generation, from natural hydrothermal and enhanced geothermal systems.

Concerning information, education and training the directive 2009/28/EC foresees certification schemes or equivalent qualification schemes for installers in Article 14, 3. An outline of such certification schemes is provided in the Annex IV of the directive. In the field of geothermal energy, an accredited training programme or training provider is foreseen to certify installers of shallow geothermal[1] energy systems. An overall coordination of information, education and training regarding medium to deep energy systems is still lacking. In addition, for deep geothermal energy systems from low to high enthalpy resources a comparable certification scheme is not foreseen by the directive.

Classification of geothermal energy and skill matrix for installers

As defined above geothermal energy is stored in the form of heat beneath the surface of solid Earth. In terms of energy, we may distinguish low- and high enthalpy resources. A number of different disciplines ranging from exploration and exploitation of the subsurface to heat- and power installations at the surface are involved in the production of geothermal energy. There are different types of technologies to produce this heat (e.g. from multi deep well completions to shallow single borehole heat exchangers) as well as different utilisations (e.g. from electricity production in the order of tens of MWs to space heating using heat pumps of a few kW). Some of these technologies are well established in the market, e.g. electricity production from high enthalpy

[1] Shallow geothermal systems are typically producing from a shallow aquifer (open systems) or operated by circulation of a working fluid in a closed tube (closed systems) in the shallow subsurface (typically < 400 m).

sources and space heating using heat pumps, whereas others are under development, e.g. electricity production from low enthalpy resources.

With this in mind, geothermal energy production requires a broad knowledge in general fields of Earth sciences, engineering and other disciplines (Table 15). Nevertheless, according to the type of resource and the utilisation, special skills within these fields are necessary. In the following, we will present different types of geothermal energy according to their geological situation, their enthalpy (and temperature) range as well as their type of utilization.

Table 15: Different scenarios of geothermal energy with respect to their geological setting, their enthalpy and temperature ranges, as well as their type of utilization. In the left column a workflow regarding exploration, exploitation and utilization of geothermal energy is established. Necessary skills for the different classes are weighted according to their importance and the future challenges in principal skills (dark grey) and additional skills (light grey).

	Geological setting				
	Active volcanic zones	Active magmatic zones and metamorphic basement	Crystalline basement	Sedimentary basins	Shallow aquifers, sediments or solid rocks
	Utilization				
	Electricity (co-generation)			Co-generation (electricity, heat)	Heat (acclimatization)
	Enthalpy (heat carrier)				
	High (water and steam)			Low (water)	
WORKFLOW					
Prospect mapping					
Geothermics					
Tectonics					
Volcanology/petrology					
Sedimentology					
Structural geology					
Thermo-hydraulic modelling					
Heat and power demand					
Surface exploration of prospects					
Tectonics					
Volcanology/petrology					
Sedimentology					
Structural geology					
Exploration geophysics					
Geochemistry					
Grid connection					
Exploration drilling					
Shallow Drilling					
Deep drilling					
Borehole geophysics					
Fluid chemistry					
Hydrogeology (e.g. well testing)					
Reservoir					
Reservoir geology					
Reservoir geophysics (e.g.					

monitoring)					
Reservoir Engineering					
THC modelling					
THMC modelling					
Fluid chemistry					
Hydrogeology (e.g. monitoring)					
Utilization					
Heat pumps					
Direct use					
Power conversion					
Geochemistry (corrosion, scaling, well cleaning)					
Engineer (pump technology)					
Engineer (cooling technology)					
Material					
Material sciences (e.g. casing, cementation)					
Radioactivity					
Economics					
Economist					
Insurance					
Legal aspects					

Sectorial barriers and synergies (e.g. energy storage, CCS, nuclear waste, hydrocarbons, unconventional hydrocarbons)

Geothermal energy involves the development of subsurface resources at various depths ranging from few meters to several kilometres. In particular, in the field of shallow low-enthalpy geothermal systems, synergies with the construction industry on the heating and cooling sector are evident. This concerns mainly building physics and the installation of hybrid systems. Utilisation of heat at higher temperatures involves engineering knowledge in the fields of district heating and process heat utilisation.

Earth science knowledge and engineering techniques for finding and development of deep or shallow high-enthalpy resources, respectively, have many similarities with required skills and techniques for the finding and the development of hydrocarbons, capture and subsurface storage of CO_2 (CCS), and nuclear waste disposal. The hydrocarbon industry, globally employing over 10 million people at a turnover of 500 billion euros or more, is at present dominant in the development of subsurface technology in all fields of geo-energy including deep geothermal. CSS and nuclear waste are marginal and largely in a proof on concept stage.

Oil and gas methodologies have been instrumental in starting developments in direct heat production and enhanced geothermal systems, in particular in the field of exploration and drilling. There are, however, significant differences with the skills required for the hydrocarbon industry, nuclear waste and CCS sectors. Geothermal encompasses a range of uses from power generation to direct use of heat, which requires skills in understanding and managing a variety of underground conditions. Environmental issues are different for hydrocarbons, nuclear waste and CCS with respect to geothermal. Generating and selling heat and electricity also require peculiar skills.

The employability outlook in the hydrocarbon industry and CCS for the next decades is positive. Fossil fuel resources will remain of significant importance for our economy the next 50 years. A shift from easy oil, of which reserves are starting to decline relative to demand, towards natural gas and unconventional resources such as shale gas, requires new explorative and technological developments. Due to soaring energy prices and the replacement of baby boomers (referred to as the big crew change) oil and gas industry is continuously in need of talented staff, with similar skills as required for deep geothermal. CCS is anticipated to grow significantly the next decades to come (IEA, 2011), and will require more staff with similar skills as required for hydrocarbons.

Potential competition from the oil and gas sector is due to the salary level for comparable skill, producing difficulties in bringing or attracting younger staff into the areas of drilling, plant operation and the consulting sector.

In addition, synergy with the sector of engineering is observed in the field of energy conversion. In high-enthalpy power plants classical vapour turbines are employed, whereas in low-temperature conversion using binary cycles, technology developments are adapted e.g. from biomass power plants.

1 Current situation – existing workforces (value chain), labour intensity, future trends, and workforces required to achieve the SET-Plan vision

This section will provide an overview on the existing market and its growth rate as well as the current situation in European geothermal research and education. Our investigation reveals a total number of employees of 45'000 people in Europe (see chapter 0) in both, heat and power production. A number of about 850 people holding a university degree (chapter 0) are employed in the electricity producing sector of geothermal energy. As indicated, the geothermal energy market covers to a large extent heat supply. In the following market and research analysis, however, highest priority is given to electric power production.

Market value/size, growth rate, number of companies and research institutes, total employment numbers for the technology sector

Geothermal sector experienced a main boom in the '70s and '80s, and reached, in the power generation sector as well as direct uses, an employee level that remained essentially constant for many years. The exact figures are difficult to obtain since a comprehensive skill survey at European level and tacking the wide range of geothermal uses is not available. Additionally, due to synergies with other industry sectors, many organisations cover broader interests and skills other than just geothermal. On the other side there is large potential for geothermal expertise, for example, in the hydrocarbon industry.

A source of data is provided by the World Geothermal Congress country update, where every 5 years a rough estimate of labour forces in the geothermal sector is provided. Table 16 shows the number of professional personnel (only with a university degree) reported in European countries. Although the numbers are, most probably, underestimated, it is clear that the sector has seen a growing in the last 5 years, especially in highly skilled academic jobs. It is important to notice the reduction of employment reported in 2005 with respect to the year 2000, especially in the industry sector, which was mostly due to a lack of turnover of many specialised jobs. The raising interest for geothermal energy, especially for the geothermal heating and cooling and power production sector, resulted in an increase of available jobs between 2005 and 2010. It is continuing to present day.

Increasing interest in geothermal energy research and development is observed in the field of high-enthalpy and deep geothermal systems. This resulted in an increased number of researchers involved in the sector, mainly Earth scientists and engineers. Consequently, also the number of universities and research institutes involved in geothermal research and development has rapidly increased. This is illustrated best in the geothermal power generation sector, where most of the European geothermal research centres (22 universities and research centres from 15 countries) were organised in the years 2005-2008 in the Coordination Action ENGINE financed by the European Commission. The EERA-Joint Program on Geothermal Energy (EERA-JPGE) funded in 2010, starting with 10 partners, today groups 25 partners from 11 countries and the number is rapidly increasing. It institutionalised, thus, the collaboration established during the coordination action. At present, EERA-JPGE involves a total of 354 man/year including researchers and PhD students.

Table 16: Number of professional personnel (only with a university degree) in the high enthalpy and deep geothermal sector reported in European countries (Bertani, 2010).

Person/year of professional personnel	2000 industry	2000 other	2000 TOTAL	2005 industry	2005 other	2005 TOTAL	2010 industry	2010 other	2010 TOTAL
Albania							11	13	**24**
Austria				4	1	**5**	5	2	**7**
Belarus					3	**3**			
Bosnia							2	1	**3**
Croatia	12	6	**18**	15	3	**18**	18	4	**22**
Czech	12	8	**20**						
Georgia							16	15	**31**
Greece	30	6	**36**						
Hungary	17	3	**20**	27	2	**29**	38	10	**48**
Iceland	74	38	**112**	78	39	**117**	130	81	**211**
Irish				10	3	**13**	30	15	**45**
Italy	110	55	**165**	88	25	**113**	62	25	**87**
Lithuania	9	6	**15**	19	9	**28**	30	9	**39**
Norway				1	4	**5**	10	2	**12**
Poland	12	5	**17**	65	25	**90**	50	25	**75**
Portugal				5	10	**15**	15	11	**26**
Romania	25	12	**37**	21	14	**35**	30	14	**44**
Russia	75	80	**155**						
Serbia					2	**2**	1	3	**4**
Slovak	12	4	**16**	13	4	**17**	20	9	**29**
Slovenia	7	1	**8**	8	2	**10**	12	1	**13**
Spain				4	3	**7**	8	2	**10**
Sweden							2	5	**7**
Switzerland	6	6	**12**	8	5	**13**	18	6	**24**
Turkey	50	70	**120**	62	83	**145**	37	46	**83**
United Kingdom				5	1	**6**			
TOTAL	451	300	**751**	433	238	**671**	545	299	**844**

A large potential is attributed to EGS technology, which has been technically demonstrated in the scientific project of Soultz-sous-Forêts (FP5-European Hot Dry Rock Programme NNE-2000-00092, FP6-EGS Pilot Plant SES6-CT-2003-502706). The scientific outcome and related teaching of this project is equally demonstrated in more than 40 PhD theses completed and about 250 peer-reviewed scientific publications.

Market growth forecast

Market growth forecast for Europe is rather difficult to provide, since especially in the electricity producing sector of geothermal energy, technologies develop at very different velocities. High-enthalpy areas such as Iceland, France, Italy, and Turkey and have developed in terms of installed capacity from about 1000 MW in 2005 to about 1500 MW in 2010 (Bertani, 2010). The forecast for 2015 is of more than 2000 MW installed capacity. World-wide installed capacity was about

16 GW in 2010. World-wide market forecasts indicate a potential for conventional geothermal systems of about 70 GW (e.g. Fridleifsson et al., 2008). Forecasts on the growth of an EGS market strongly depends on the technology development. The potential attributed to EGS technology world-wide differs according to different organisations. Conservative estimates of about 70 GW are given by Fridleifsson et al. (2008). The MIT report (2006) on geothermal energy estimates an EGS potential for the US only of about 100 GW.

Market growth forecast can be inferred from the today's learning curve in conventional geothermal systems (Schilling and Esmundo, 2009), which has been established for the US market. Depending on the cumulative financial support for research and development ranging from about 1000 US $ millions up to 4000 US $ millions (calculated for 2005 value of US $), geothermal energy shows the steepest and continuing increase of produced energy per US $ from below 10 kWh per US $ to above 25 kWh per US $. This implies that still today research and development along with education and training has not reached saturation, neither in conventional geothermal energy, nor in development of EGS.

In terms of developments in research, major activities are planned especially in central Europe which traditionally has always been one of the nuclei of low-enthalpy geothermal research apart Italy and Iceland. A number of 5-10 university chairs in the field of geothermal energy or closely related fields have been recently added to the existing ones or will be created and filled in the near future in Switzerland, Germany and France. A number of these chairs are sponsored by drilling or electricity industry. Some of these chairs are concerned with hydrothermal aquifer utilisation, but most of them focus on EGS. We expect this number to increase further due to research demand especially in EGS. A signal of increasing interest in this research field is the expanding number of presentations on scientific congresses. An example is the European Geoscience Union annual meeting, at which the number of sessions related to "Energy" with focus on geothermal energy increased from 1 on 2009 to 4 in 2012.

Value chain – core occupations in the geothermal energy sector.

The value chain of the geothermal energy sector is based on the natural geothermal resource, which per se is of variable energy content according to the temperature and the condition of the carrier fluid that is used to extract the energy from the subsurface. The major aim of geothermal resource management is the sustainable and economic viable exploitation of geothermal energy. At present, this is tackled by means of selected activities in the field of deep geothermal energy such as prospect mapping, surface exploration of prospects as well as exploration drilling and reservoir development (Figure 21; Table 17). Sustainable exploitation is concerned mostly with the technical operation of the reservoir, whereas economic viability among other issues strongly depends on future material development resistant to high temperature and high pressure as well as chemically aggressive environment. Both, economic and legal aspects of geothermal projects often depend on conditions related to reservoir development and exploitation. Parallel to the development of the subsurface heat exchanger the utilization of the stored energy is based on the heat and electricity demand of the population. The major challenge is to identify and guarantee the necessary connection to the respective grids, to plan and install the optimal conversion process and finally to guarantee an energetically and economically optimized operation of the plant. At the end of the lifecycle of a geothermal plant dismantling or flexible multi-well concepts have to be considered.

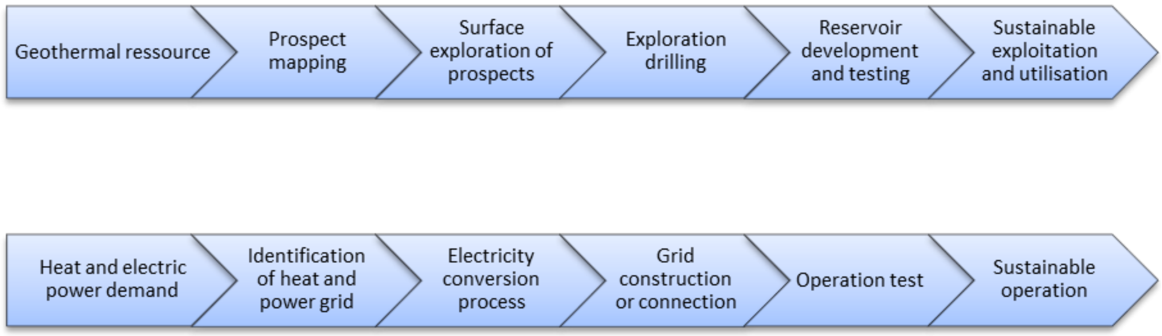


Figure 21: Value chain of the geothermal sector

The weighting of existing core occupation is based on the experience in the European countries. It should be noted that exploited geothermal energy in volcanic areas in the European Union is limited to few islands off the European mainland and that although granitic resources reveal highest potential, EGS technology is not yet brought to market. Thus, in both fields there is little market for employees.

The comparison of Table 15 and Table 17 reveal a large discrepancy between the currently applied techniques and the skills regarded necessary for the future. Due to reduced in education in geothermics[2] over several decades after the first attempts to develop Hot Dry Rock (HDR) systems world-wide in the 70-ties and a peak development in conventional geothermal energy, we observe a strong need of education in this field today.

[2] Physical and chemical processes related to heat stored and transported in the Earth

Table 17 : Classification of different types of geothermal energy according to their geological setting, their enthalpy and temperature ranges, as well as their type of utilization. In the left column a workflow regarding exploration, exploitation and utilization of geothermal energy is established. Present day core occupations for the different classes are weighted according to their importance in principal core occupations (dark grey) and additional occupations (light grey).

	Geological setting				
	Active volcanic zones	Active magmatic zones and metamorphic	Crystalline basement	Sedimentary basins	Shallow aquifers, sediments or solid rocks
	Utilization				
	Electricity (co-generation)		Co-generation (electricity, heat)		Heat (acclimatization)
	Enthalpy (heat carrier)				
	High (water and steam)		Low (water)		
WORKFLOW					
Prospect mapping					
Geothermics					
Tectonics					
Volcanology/petrology					
Sedimentology					
Structural geology					
Thermo-hydraulic modelling					
Heat and power demand					
Surface exploration of prospects					
Tectonics					
Volcanology/petrology					
Sedimentology					
Structural geology					
Exploration geophysics					
Geochemistry					
Grid connection					
Exploration drilling					
Shallow Drilling					
Deep drilling					
Borehole geophysics					
Fluid chemistry					
Hydrogeology (e.g. well testing)					
Reservoir					
Reservoir geology					
Reservoir geophysics (e.g. monitoring)					
Reservoir Engineering					
THC modelling					
THMC modelling					
Fluid chemistry					
Hydrogeology (e.g. monitoring)					
Utilization					
Heat pumps					
Direct use					
Power conversion					
Geochemistry (corrosion, scaling, well					

cleaning)					
Engineer (pump technology)					
Engineer (cooling technology)					
Material					
Material sciences (e.g. casing, cementation)					
Radioactivity					
Economics					
Economist					
Assurance					
Legal aspects					

Classical subjects in Geosciences are taught at university level. They, however, are not yet employed to a satisfactory level in the different types of geothermal energy prospection and exploration. Thus, we miss the link to geothermal energy in the existing education. Although, geophysical exploration is applied in all necessary fields of geothermal energy, we observe a lack in diversity, since different geophysical methods address a variety of relevant reservoir parameters, in particular, if used in an integrative approach. It should be noted here that currently exploration geophysics is a disappearing subject in many geophysical curriculums. In the field of drilling exploration current activities seem to be in agreement with the necessary skills. However, although geothermal exploration benefits strongly from innovative technological developments such as "automatic drilling" and “logging while drilling”, these technologies find little application in geothermal projects. We relate this to a lack of education of project developers. In general, we observed a lack in drilling personnel in the entire geo-energy sector. One of the largest discrepancies between the state of the art and the necessary skills is evident for the development of the reservoir. Although it is a crucial field for geothermal energy exploration and exploitation, apart from few countries in Europe strongly involved in hydrocarbon production, reservoir geology / - geophysics / - engineering does not appear as a major subject in the current Earth science curricula. There is also a strong discrepancy between the current educations in reservoir modelling. In particular, modelling of fully coupled processes such as THMC[3] require highly mathematically and physically skilled personnel with a sound education in geothermics, hydraulics, rock-mechanics and rock-water interaction. Considering EGS technology, an effort in enlarging education in these particular fields of reservoir development, is expected to lead to a break-through in this type of technology. In conclusion, geothermal energy exploration and exploitation builds up to a large extend on existing curricula. In some fields, however, special education is required due to the fact that the reservoir conditions overcome the classic hydrocarbon exploration and exploitation requirements (e.g. deep resources, high temperature, chemically aggressive fluids, electricity conversion at low temperature, etc.).

[3] Coupled thermo-hydraulic-mechanic-chemical processes

Labour intensity (jobs per megawatt /or other power unit/ of average capacity) of the various technology chains, and foreseen developments.

In conventional geothermal energy production jobs, requiring university education have been increased with the installed capacity and energy produced. We observed that due to a positive and steep learning curve (Schilling and Esmundo, 2009), the number of jobs per megawatt and electric energy produced could be reduced from 0.094 jobs per GWh_{el} (0.64 jobs per $MW_{installed}$) to 0.077 jobs per GWh_{el} (0.55 jobs per $MW_{installed}$).

The first experience from hydrothermal to EGS power plants in Germany reveals about 0.3 jobs per megawatt for the power plant management (Weimann, 2011). Assuming a 30 year life cycle and about 10 employees during a 3 year exploration phase, we estimate about 0.45 jobs per $MW_{installed}$.

Different profiles of workforces and skills required to achieving the SET-Plan vision for the particular technology sector

Recently, the skills required for geothermal installations, especially in regard to shallow geothermal, have been the subject of the EU-funded project called GEOTRAINET (www.geotrainet.eu). For instance, the curriculum for the formation of designers of shallow geothermal installations have been compiled and tested along different editions of short courses given in different places across Europe. The curriculum includes:

1) fundamentals and constraints of shallow geothermal systems,
2) introduction to the design,
3) subsurface exploration and installation,
4) surface installation and regulations.

A detailed description of the above mentioned topics is elaborated by the project members (www.geotrainet.eu).

As mentioned above, exploration and exploitation of high-enthalpy and deep geothermal systems requires a broad range of profiles of workforces and skills. This involves technical and non-technical workforce and special skills. This is reflected in the first step of such a geothermal project, the feasibility study. Here, workforce is required in financial planning and modelling, engineering, geosciences and environmental impact assessment.

Detailed surface exploration requires workforces in:

1) geology, geophysics, geochemistry, and reservoir engineering. Of particular interest are special skills linked to geothermal challenges such as high temperature, geochemically aggressive fluids and high flow reservoir engineering.
2) remote sensing, geographic Information System (GIS), environment and community liaison.

Well testing pads and road construction requires skills in civil engineering, artisans, machine operators, building technicians, project engineers, and logistic officers.

A particular focus should be drawn to material sciences, which due to aggressive chemistry, high temperatures and pressures is an issue throughout the entire life cycle of a geothermal project. Apart from workforce in deep drilling including mechanical engineering, mud logging, geology, and rig maintenance, geothermal well drilling requires special skills in:

1) high temperature drilling with large diameter,
2) underbalanced drilling,
3) logging in high temperature, high salinity and chemically aggressive condition, and
4) high flow rate production and injection testing.

Development stage involves production drilling and testing (required skills, see above) and plant construction. Especially in deep or high-enthalpy hydrothermal and EGS projects, reservoir engineering requires additional skills with respect to conventional hydrocarbon reservoir engineering, since significantly higher flow rates are required for economic viability of the project:

1) Enhanced hydraulic stimulation including strong skills in rock mechanics and seismicity
2) Chemical stimulation in basement and volcanic environment including rock-water interaction
3) Enhanced chemical fracking
4) Chemical cleaning of near-well volume during operation

Furthermore, it requires workforce in engineering. Special geothermal issues are:

1) Appropriate design for highly variable geothermal production condition
2) Treatment of gases and water fraction in the surface cycle

The power plant operation including maintenance of equipment and plant requires workforce in electrical and mechanical engineering. Similar, in the case direct utilization, if geothermal resources are used for heat supply, engineering workforce for system design and operation is required. In both cases, special skills are required in geochemistry due to chemical properties of the fluid, e.g. corrosion, scaling prevention and management, radioactivity in scalings, etc.. Furthermore, environment and community liaison is an issue during the whole life cycle of a geothermal project.

As demonstrated in chapter 0, electricity production from geothermal energy requires a large number of highly educated personnel in industry and others (Table 16). From an academic point of view, the field of geothermal energy covers a broad range of subjects taught in Natural sciences in general and Earth and Engineering sciences in particular. At the same time it bears a significant number of much specialised topics within these sciences. Thus, an ideal curriculum is based on a broad Bachelor education in Natural sciences, including mathematics, numerics, physics, chemistry, engineering and informatics. Specialised knowledge on the different fields from geothermics, geological, geophysical and geochemical exploration, drilling, reservoir engineering, plant development and management shall be acquired during a Master program. This specialised education program reveals synergies with other branches of geo-energy such as hydrocarbon, CO2 storage, nuclear waste etc.. A special focus on geothermal energy may be guaranteed by scientific platforms at different geothermal sites, such as currently practiced at Soultz-sous-Forêts. Such platforms allow also for practical training in the different fields.

Scale – how many (in approximate numbers) of the profiles described above are required? By when?

Since we have some statistics on the development of university educated employees in geothermal energy production only, in this paragraph we focus on the primary labour market for higher educated employees. We estimate the secondary labour market to be 5 to 10-times higher, especially when considering the synergy with conventional electricity production. In chapter 0, we have estimated the labour intensity for the different technologies used to produce electricity from geothermal energy. In the following, we are using published forecasts of geothermal electricity production to estimate the potential labour market in Europe and world-wide.

Table 18 : Potential number of jobs in the field of electricity production from geothermal energy in Europe and world-wide.

	MW	jobs/MW	Total jobs
Conventional hydrothermal by 2015 (Europe, Bertani, 2010)	2015	0.54	1088
Potential of conventional hydrothermal (worldwide, Fridleifsson et al., 2008)	70000	0.54	37800
Low temperature hydrothermal and EGS forecast by 2050 (worldwide, IEA roadmap, 2011)	130000	0.43	55900
Unconventional geothermal energy (EGS and supercritical) in Europe forecast by 2050 (EGEC, Vision 2050, Geoelec, 2009)	90000	0.43	38700

The geothermal market today is largely dominated by heat supply technologies. In the following, we would like to point out that the number of employees we are forecasting for 2050 in the electricity market is comparable to the geothermal heat market of 2010. The total number of employees in the 2010 geothermal heat and electricity market and the forecast for 2020, regardless of the degree of education, has been compiled for this report and is listed in Table 19.

Table 19 : Number of jobs in 2010 and the forecast for 2020 in geothermal energy including both, heat and electricity production.

Total jobs	2010	2020
Austria	1335	2090
Belgium	311	535
Bulgaria	43	185
Cyprus	0	10
Czech Republic	353	790
Denmark	367	500
Estonia	148	285
Finland	1839	2660
France	4036	11480
Germany	5159	13938
Greece	95	290
Hungary	1972	3445
Iceland	6140	12200
Ireland	372	792
Italy	7717	11380
Latvia	2	38
Lithuania	121	265
Luxembourg	38	95
Malta	0	4
Netherlands	1270	4040
Poland	624	1674
Portugal	218	570
Romania	212	414
Slovakia	55	592
Slovenia	138	385
Spain	23	609
Sweden	7034	8550
Turkey	614	2400
United Kingdom	359	1575
TOTAL	**46694**	**85090**

2 Ongoing actions (Academic partners)

Training activity in Europe is performed as academic and professional training. Basic concepts of geothermal apply to any use of geothermal energy and are covered by most courses. Specialized courses, however, require different technical background and skills, and differ for the exploitation of shallow and medium-deep geothermal system.

Geothermal education has tradition in Italy and Iceland since 1970 and 1978, respectively. Two out of four UNESCO geothermal schools had been established in Europe in the 70-ties, offering professional training to students from developing countries. During its 35 years of activity, the school in Pisa (Italy) has organised 22 long-term courses in Italy (lasting 5 - 10 months), attended by 324 graduates from 22 countries; additionally, it has also organised until 2006 short courses as well as conferences all over the world. Between 1979 and 2009, 424 fellows from 44 countries have completed the 6 months training at UNU-GTP in Reykjavik (Iceland, www.unugtp.is), about 14% of them coming from Central and Eastern European countries. This geothermal training programme offers 9 lines of specialised training: geological exploration, borehole geology, geophysical exploration, borehole geophysics, reservoir engineering, environmental studies, chemistry of geothermal fluids, geothermal utilization, and drilling technologies. Since 2000, 20 have graduated with MSc. In 2009, thirteen have pursued their MSc and three their PhD studies at the University of Iceland. The UNU-GTP also organizes workshops and short courses all over the world.

The International Summer School for the Direct Application of Geothermal Energy (ISS) has been established in 1989 by the International Geothermal Association (IGA) and its European branches. It organizes international courses and workshops, usually one event per year. ISS has organised 13 events including courses, seminars and workshops in 9 European countries.

The main on-going education and training activities that support geothermal energy at university level are given in Table 20.

It becomes evident that the academic education programs are organised on member-state level. Post-graduate education is often organised under international coordination (e.g. IGA or UNESCO). There is little coordination from European side. The impact of education programs may be best evaluated for the example of the UNESCO program where training students from developing countries (e.g. principal nationalities at UNU-GTP: China, Kenya, Philippines, El Salvador, Ethiopia, Indonesia, Costa Rica) lead to a significant increase of geothermal energy production (principal producers in developing countries in 2010: Indonesia 3500 MW, Philippines 2500 MW, Mexico 1140 MW, Kenya 530 MW, El Salvador 290 MW, Nicaragua 240 MW, Costa Rica 200 MW). Education and training for electricity production in Europe and European labours can hardly be quantified at this stage.

Table 20 : Overview over the academic education in geothermal energy in Europe.

Ongoing education	Undergraduate and Bachelor	Master	Post-graduate and other
Austria		several courses	
Bulgaria			ISS course
France		several courses	
Germany[4]	several modules training and certificate	1 full Master (120 ECTS); several modules	professional training courses ISS course
Greece[5]	several courses	several courses	ISS courses
Hungary		several courses	
Iceland	-	several modules 1 Master	UNU-GTP (see above)
Italy	several courses, several modules	Several modules	several, non periodic, courses
Macedonia			ISS course
Netherlands	several modules (2ECTS each)	several modules (2ECTS each) 1 course (1ECTS)	
Norway	1 course	2 courses	
Poland			ISS courses
Portugal			ISS courses
Romania[6]	several modules	several modules	5 courses on demand (ICTG)
Slovenia			ISS course
Spain	several modules	several modules	
Sweden[7]	courses		Professional training
Switzerland[8]	Training and certificate	1 full Master (120ECTS) 5 courses (16ECTS) Several 1-day courses	CAS (10ECTS)
Turkey[9]	several courses	several courses	Professional training Short courses ISS courses

[4] RWTH Aachen, Technical University Berlin, Applied University Biberach, Applied University of Bochum, Technical University Clausthal, Technical University Darmstadt, Bergakademie Freiberg, Karlsruhe Institute of Technology KIT, Technical University München, LMU München, and others

[5] Aristotle University ; University of Athens

[6] University of Oradea

[7] Lund University

[8] University of Neuchâtel, ETH Zürich

[9] Technical University Istanbul, Middle East University

3 Needs and gaps, in particular main barriers or bottlenecks for the different industrial sectors and their markets

In general, replacing an ageing workforce with adequately trained new personnel is a problem faced by many engineering based industries around the world. Moreover, the gap between limited student interest in science and engineering careers and industrial needs for developing new technologies is relevant to a much wider section of society and industry than geothermal alone. This general gap is well described, for example, in the First UNESCO report on Engineering: Issues and Challenges for Development (UNESCO, 2008). Nonetheless, if the geothermal industry is to benefit from increased numbers of science and technology graduates, then it must participate in and contribute to programs encouraging these career choices, and encouraging public interest in scientific endeavour.

More focused on geothermal energy, it should be noted once more that the future of electricity production from geothermal energy is widely accepted to be linked to the development of EGS technology. Since there is only a very small number of prototype EGS power plants operating today, largest discrepancy between the current state of technology and future needs is observed in this field.

Needs and gaps for industry

The developments associated with geothermal resources on industrial level require a wide range of skills related to the activities in feasibility studies, due diligence, permitting, exploration, drilling, engineering, operation, and maintenance. In-house scientific and engineering skills are an issue for the major developers, whereas for smaller developers possibly request external support. A number of practical skill examples are provided from industry:

- General scientific support for exploration and operation
- Drilling support for exploration or operational drilling
- Project management support
- Environmental support for field consent application work
- Reservoir engineering support for development or operational fields
- Technical support at consent hearings for the developer, for decision makers, possibly for administration, and for the various appellants
- Expertise in feasibility studies
- Expertise in due diligence for projects up for sale, or to set up documentation ready for due diligence
- Detailed engineering and science roles in support of the contractor
- Construction skills
- Operations and maintenance skills

The example from UNU-GTP reveals that existing education programs are thematically appropriate to develop conventional geothermal energy production in high-enthalpy fields on industrial level. Moreover, they have been proven to contribute substantially to the development of geothermal energy technology itself. The main barriers or bottlenecks for the different profiles of workforces that hinder the achievement of the technology goals within the SET-Plan vision in Europe mainly originate from the limited number of education programs (see chapter 0) and the development of engineering techniques for unconventional geothermal resources such as EGS (see chapter 0). Their implementation in broader education programs such as "Geo-Energy" may raise student's interest. To meet current energy industry demand, an increase in the number of university graduates from engineering, commerce, science and geography entering employment in the energy sector is needed. In general, there appears to be a need for cross-disciplinary university education relating to geo-energy, which would require an improved contact between energy stakeholders and universities/education and training centres, as well as research institutions.

The quantitative evaluation of the current state and future needs reveals that mainly highly educated employees are required for the development geothermal based electricity production in general and of EGS technology in particular. The analysis of the expected market for geothermal electricity production until 2050, the evolving state of technology and required jobs per MW (about 0.45/MW) indicates a total number of university educated personnel of about 40'000 by 2050 in Europe. Since the forecasted growth of geothermal based electricity production is exponential (e.g. IEA roadmap, 2011), we expect that one third (about 13'000) needs to be educated by 2030. It should be noted that less than 10% of this extrapolated number of workforces is educated and employed today and this almost exclusively in projects of conventional geothermal technology. This reveals a number of about 500 students per year starting from 2013 to about 1000 students per year in 2030 need to be educated in the fields of geosciences, material sciences, mechanical engineering, computational sciences, economic and legal sciences.

Needs and gaps of the educational stakeholders

The challenge to develop geothermal energy from a point of view of education institutions is to overcome the limited number of education programs on Bachelor and Master levels in geothermally relevant fields (see above). This accounts in particular for conventional hydrothermal technology, which may be considered a world-wide well-established technology in the respective countries, where education lacks mainly in the number of graduates in the different fields. Since unconventional geothermal energy utilisation (mainly EGS) has not been yet been introduced fully into the market and EGS technology is in the early prototype state, education in this field goes along with research. Practically, this means that at present education is mainly based on a scientific PhD level. This is well illustrated, for example, at the European EGS research site Soultz-sous-Forêts, where a number of 42 PhD theses have been completed. This advanced education is fundamental for the initial phase of EGS technology development. This is currently also reflected also in the constitution of the EERA Joint Program on Geothermal Energy. From a total of 24 members, only nine institutions offer education programs, while a number of 15 are research institutions. In-line with the above identified gaps and needs for the industrial development of geothermal based electricity production, the major challenge for educational stakeholders is education on Bachelor and Master degrees. This will require a stronger commitment and implication of universities also in geothermal technology development.

In terms of education programs on Bachelor and Master level, geothermal technology development will also in future be based on classical professional careers such as petroleum, chemical or mechanical engineer, geologist, (structural geologist, mineralogist), geophysicist (exploration, seismologist) or geochemist. Thus, a need of overriding importance is the planning dependability of education in the field of geo-resources. The current concern is a coupling between education programs and the hydrocarbon market mainly regarding both, financial issues and employment possibilities for students.

A first step for education institutions will be to fill the specific gaps in the curriculum of these professions occurring with the transition from the development conventional reserves at present to unconventional in future. This concerns most of the fields in the classic curriculum such as basic research in geothermics, reservoir, material, power plant, utilisation, economics and legal aspects.

First order modifications in the curriculum are to be made in

1) Reserve estimating and forecasting: concerning e.g. reservoir characterisation, production properties, economics and risk assessments
2) Reservoir simulation: concerning e.g. petrophysical parameters
3) Reservoir optimization techniques: concerning cost-effective reservoir monitoring, analysing pressure transient
4) Material sciences: concerning e.g. corrosion, scaling, casing maintenance, radioactive deposits, heat exchanger, evaporator, pumps
5) Power plant and utilisation: concerning e.g. design of primary circuit, precipitation, adaptation on P-T level, cogeneration, district heating, cooling

Numerical skills are relevant in all fields, since processes in Earth Sciences are typically complex and thermally, hydraulically, mechanically and chemically coupled.

In order to respond to the demand on labours by the geothermal industry and to implement the above listed necessary modifications in the current curriculum an increase in number, size and technical orientations of related faculties and teaching infrastructure in particular fields will be necessary. This concerns mainly Earth Sciences, where we observe a lack in necessary teaching and research infrastructure such as laboratories, field test sites and underground laboratories (see also chapter 0).

A need of overriding importance is the planning dependability of education in Earth Sciences in general. Throughout the European community three major factors are identified to drive the interest in Earth Science education over long-term:

1) Demand and price of geo-resources
2) Employment perspective (related to item 1) above)
3) Social issues (i.e. interest of students grows with natural hazards such as earthquakes in Italy)

Needs and gaps of the research community

As mentioned above, the current situation of education is strongly linked to research, in particular for the development of unconventional technologies. Since EGS technology is not fully developed, we foresee a comparably high number of researchers of about 25 and 15% until 2020 and 2030, respectively. Analysing the current situation of research institutions involved in geothermal energy development, we may draw the following situation:

1) Research funding:
   With regard to the different framework programs FP1 to FP6 the share for energy research has decrease from about 50% to <20%. Although the demand in energy is continuously increasing and a strong focus on sustainability and renewable energy, which is linked to the development of new technologies, is expected. It should be mentioned, however, that the total amount of funding increased by about 2.5 from FP6 to FP7. The funding situation is particularly tightened for geothermal energy development. Since 2002, in the framework of FP6 and FP7, about 20 Mio €[10] have been invested into deep geothermal research by the European Commission. This represents less than 1% of the budget foreseen for the development of sustainable energy systems. (FP6: about 810 Million €; FP7: about 2350 Million €). A similar situation is observed in the member states.

2) Research infrastructure:
   Energy technology development is strongly linked to experimental sites. Representative examples are the international collaboration on ITER for fusion technology (expected total investment about 15000 Million €) and rock laboratories (e.g. Mont Terri, Äspö, etc.) for geo-scientific applications. In the past, before 1987, a number of test projects have been operating throughout Europe. The expertise has been concentrated in the Soultz projects (total investment 100 Million €. A second scientific site for the development of deep geothermal systems has been established by Germany in Gross Schönebeck with a similar total investment. Apart from planned sites in Belgium and U.K., these are currently the only scientific laboratories for EGS or unconventional geothermal system development. Since the success of the development of geothermal energy in Europe will be strongly linked to practical tests, we see a large need for new test sites as well as a need for further investment.

Needs and gaps for interaction and partnerships among stakeholders

Since test sites for geothermal development are very limited, interaction and partnerships among stakeholders is fundamental. In contrast to other energy technologies (e.g. hydrocarbon industry), the laboratory infrastructure of research institutions compared to industry is more advanced. Thus, industrial development of geothermal energy benefits strongly from such collaborations, in particular in developing technologies such as EGS. Since scientific test sites are identified as gap for technology development, in this situation interaction of research institutions with industry is fundamental to get access to test and operational data. The collaboration between educational stakeholder with industry and research institutions has been evidenced above by demonstrating the state of technology development. In the case of conventional technology, education and training benefits from industrial know-how, whereas in the case of unconventional and EGS technology,

[10] The funded projects are GEISER (FP7), LOW-BIN (FP6), ENGINE (FP6), I-GET (FP6), HITI (FP6), EGS PILOT PLANT (FP6). The IMAGE project, currently under negotiation, is not included.

education is still strongly linked to research. Quantification of the needs and gaps are difficult, but we certainly suggest and support intensification of co-operation.

4 Conclusion and recommendations at EU and MS level within specific target dates

The above presented expected acceleration in the development of geothermal energy utilisation and the demand in labours from industry show the present need for a fast increase in highly qualified specialists. The transition from exploration and exploitation of conventional towards unconventional reserves requires the introduction of modification in the existing curricula in different fields of geothermal energy such as basic research in geothermics, reservoir, material, power plant, utilisation, economics and legal aspects. Training in geo-resource exploitation is typically linked to test sites due to the complexity of natural subsurface systems.

Furthermore, the evaluation of the current state and future needs in education and training in the field of geothermal energy reveals substantial diversity for the heat and electricity market due to the differences in the contribution of geothermal energy to the existing and future energy mix. While geothermal technology for heat provision from shallow depth is well established in the market and thus, education is on-going in mainly in applied universities and/or industry, electricity production is currently in a pilot stage with increasing demand. This is in-line with increasing expectations mainly in university education primarily in geosciences and engineering sciences. The analysis of the expected market for geothermal electricity production until 2050, the evolving state of technology and required jobs per MW (about 0.45/MW) indicates a total number of university educated personnel of about 40’000 by 2050 in Europe, only. Since the forecasted growth of geothermal based electricity production is exponential (e.g. IEA roadmap, 2011), we expect that one third (about 13’000) needs to be educated by 2030. It should be noted that less than 10% of this extrapolated number of workforces is educated and employed today and this almost exclusively in projects of conventional geothermal technology. The growth in geothermal energy, however, is foreseen in the developing technology (Enhanced Geothermal Systems EGS), of which only about five prototypes exist in Europe and world-wide; this shows also that Europe is leader in technology development. Since the expected growth in geothermal energy is exponential, a number of about 500 students per year starting from 2013 to about 1000 students per year in 2030 need to be educated in the fields of geosciences, material sciences, mechanical engineering, computational sciences, economic and legal sciences. We expect that about 10% of the future personnel needs to be educated in special geothermal training centres, while 90% may be educated in existing curriculum in the above mentioned subjects. Thus, based on the potential master theses per professorship, we expect a successively increasing need of university professorships in the above mentioned fields of a number of 100-300 by 2030.

With this in mind recommendations were developed to achieve the technology goals within the SET-Plan vision in Europe:

Heat market

In the field of heat supply professional training is well established in many member states. The Geotrainet initiative (www.geotrainet.eu), supported by the European Commission’s IEE programme

("Altener"), aims to develop a European-wide educational programme as an important step towards the certification of geothermal installations. The vision of the GEOTRAINET project is that the training and certification programs will be recognised all over Europe and provide benchmark standards for consistent voluntary further education in the field of shallow geothermal in all participating countries. The training is essential for people interested in becoming shallow geothermal accredited designer and drillers.

The network on professional training centres aim on:

- ensuring equal quality standards within Europe by developing training curricula with common standards for the sector

- ensuring high level education throughout Europe by disseminating the developed curricula and install a platform for improving the curricula

Timeframe

After a phase of at least 2-3 years of acquiring experience with the developed curricula, a revision shall be approached by around 2016.

Electricity and co-generation market

The recommendations are structured in a step-wise approach, which shall guarantee to satisfy in a first step the urgent needs of the geothermal industry. In a second step the number of full academic education shall be heavily increased in different fields of interest for geothermal development. Strong networks between the related fields shall be established and comprehensive education shall then be completed by field test sites.

In the following we will present an overview on the recommended concept for the necessary fast enlargement of education programs for highly skilled personnel.

Target 1: Education from broad existing expertise

1) Certificate of Advances Studies (CAS, within the European Credit Transfer System ECTS)
2) Master of Advanced Studies (MAS, within ECTS)
3) Block courses with special focus on the combination of geoscience and mechanical engineering

In this phase industrial necessities shall be met using existing practical expertise, which shall be included in continuing education programs and the coordination of academic institutions. An interdisciplinary education is a major focus from the first phase on.

Target 2: Master in Geoenergy (with specialisation in geothermal energy)

1) Geoscience / Georesources
2) Material science
3) Mechanical engineering
4) Computational sciences

5) Power plant, direct utilisation of heat

6) Economics and legal aspects

Based on a mathematical-physical-geoscientific Bachelor a Master in Geoenergy (with specialisation in geothermal energy), a Master program in geoenergy shall include all relevant disciplines for conventional and unconventional geothermal energy with the necessary modifications. This education shall prepare highly qualified labours for the future market in geothermal energy production. Such a comprehensive education is of interest for geoenergy in general and fosters synergies with other disciplines within geo- and renewable energies.

Both, phase 1 and 2 shall be accompanied by a Network of Universities

As estimated in the assessment report, about 90% of the future employees will be educated in existing curricula. To guarantee equal quality standard among the different universities as well as exchange in specific competences, a network of universities involved in geothermally relevant education is foreseen. The nucleus of this network will be the EERA-Joint Program on Geothermal Energy (JPGE). EERA-JPGE regroups major European competences linked directly to geothermal energy. Specific, complementary competences required for further development of geothermal energy are, however, linked to other fields of geo-energy or energy research in general. Thus, strong interlink with other joint programs within EERA and the European University Association is recommended.

The structure of this network goes beyond existing examples of mainly bi-lateral cooperation between universities and thus, may require start-up financing from European level. The network is planned to be active on different educational levels such as:

- BA, MA, PhD programmes
- European double degrees or a European joint degree
- Industry Doctoral Programmes
- Development of teaching materials (in particular, virtual teaching)

The network on universities aims on:

- ensuring equal quality in geothermal education throughout Europe by defining common criteria for basic courses and by opening specific courses to the university network students
- ensuring high level education throughout Europe by introducing a review processes that benefit from experts from academia and industry
- developing joint degrees between different European universities
- developing new teaching concepts with regard to industry/academia cooperation and e-learning

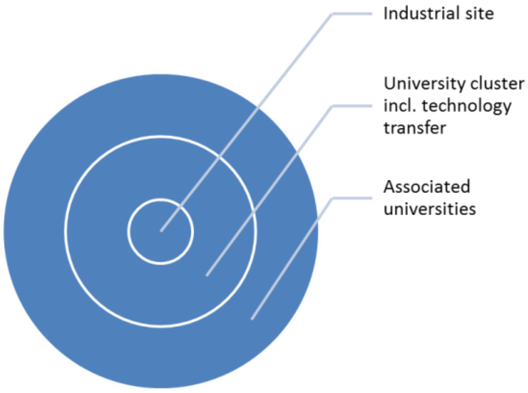
Timeframe

Preparation of a European university network shall start in 2013 within EERA-JPGE. A roadmap shall be developed by 2014.

Target 3: Specialized EGS training centres and test sites (Cluster of Excellence)

Utilisation of geological systems on large-scale-industry level (e.g. mining, nuclear waste deposit, CCS, etc.) typically goes along with in-situ deep underground rock laboratory or test site including boreholes. This will not only allow for the establishment of scientific platforms, but also increase the quality of education.

A number of 50 to 100 students per year (10% of the needs) are foreseen to be educated in specialized training centres. In the following, we will outline the structure and highlight the most important criteria for potential partners in this type of education. These training centres shall originate from industrial geothermal project operators (nucleus of the training centre). An international university cluster shall be established around the operating and preferably EGS site. For specific competences further universities may be associated. In order to guarantee a wide-spread distribution of the related research technology transfer shall be a central element in the training centre.



Different requirements have to be fulfilled by the different partners. Industrial partners shall operate an EGS prototype power plant or commit themselves to allow for enhancing their reservoir with the respective technology. The operator shall hold an own scientific team that may take over part of the education program. The operator shall also provide full access to operational data in the framework of Master theses. The preferentially international university cluster shall cover the entire range of departments mentioned above. A full Master program in "Geothermal energy" is required to be established by the cluster. In order to guarantee maximum access to the industrial site for the students, the universities participating in the cluster should be ideally located in the vicinity of the industrial site. For special competences further universities may associate to the training centre. The university cluster is responsible to establish a technology transfer program. Major aim of the technology transfer is the development of teaching material for broader public with a focus on continuous education.

Within the framework of the EGS training centre joint research programs will be develop to complete the status of a centre of excellence and guarantee the education and training of young researchers. In this international framework European joint Master and PhD degrees are approached.

The EGS training centres aim on:

- ensuring the relation to practice of a new university curriculum by implementation of industrial sites as central element into the university cluster
- ensuring the quality of industrial training by the university cluster using a broad range of experts from academia and industry
- speeding up the process of EGS technology development and technology transfer by joint research and education
- developing joint degrees between different European universities

Timeframe

The prototype EGS training centre will be developed until 2014 followed by curriculum implementation by 2016.

References

Bertani, R., 2010. Geothermal Power Generation in the World 2005–2010 Update Report. Proceedings World Geothermal Congress 2010, Bali, Indonesia, 25-29 April 2010

Fridleifsson, I.B., R. Bertani, E. Huenges, J. W. Lund, A. Ragnarsson, and L. Rybach 2008. The possible role and contribution of geothermal energy to the mitigation of climate change. In: O. Hohmeyer and T. Trittin (Eds.) IPCC Scoping Meeting on Renewable Energy Sources, Proceedings, Luebeck, Germany, 20-25 January 2008, 59-80.

Schilling, M.A.,Esmundo, M., 2009. Technology S-curves in renewable energy alternatives: Analysis and implications for industry and government. Energy Policy, v. 37, p. 1767–1781.

MIT report, 2006. The future of geothermal energy. http://geothermal.inel.gov. 358pp.

SET-Plan Energy Education & Training
Nuclear Energy

Nuclear Energy

Working Group Contributors

François Weiss (Rapporteur),	Grenoble Institute of Technology/CNRS – KIC InnoEnergy
Ulrik von Estorff	EHRO-N
Veronika Simonovska	EHRO-N
Marjatta Palmu	IGD-TP, Posiva Oy
Hans Menzel	Cern, MELODIE
Guy Parker	Foratom
Alexandre Bredimas	SNETP
Georges van Goethem	EC
Hamid Aït Abderrahim	EUA-EPUE
Josef Safieh	ENEN
Emilia Janisz	ENS
Miroslav Hrehor, Martin Ruscak	REZ/CZ
Enrique Gonzalez	CIEMAT
Monica Ferraris	Politecnico di Torino
Niek Lopes Cardozo,	TU Eindhoven, FOM – Fusion

ABBREVIATIONS

ABET	Accreditation Board for Engineering and Technology
ANENT	Asian Network for Education in Nuclear Technology
ANS	American Nuclear Society
BNEN	Belgian Nuclear Education Network
CANDU	Canada deuterium–uranium reactor
CERN	European Organization for Nuclear Research
COG	CANDU Owners Group
CPD	Continuing professional development
DEMO	DEMOnstration Power Plant
ECTS	European Credit Transfer System
ECVET	European Credit System for Vocational Education and Training
EERRIEFDA	Eastern European Research Reactor Initiative
EFDA	European Fusion Development Agreement
EHRO-N	European Human Resources Observatory in the Nuclear Energy Sector
EIT	European Institute of Technology
EMSNE	European Master of Science in Nuclear Engineering
EMINE	European Master in Innovation in Nuclear Energy (KIC InnoEnergy)
ENEN	European Nuclear Education Network Association
ENEF	European Nuclear Forum Energy
ENS	European Nuclear Society
ENSREG	the European Nuclear Safety Regulators Group
ESFRI	European Strategy Forum on Research Infrastructures
EU	European Union
F4E	Fusion for Energy
FIIF	Fusion Industry Innovation Forum
FTE	Full-time equivalent
FUSENET	European Fusion Education Network
HEI	Higher education institutes
HRD	Human resource development
IAEA	International Atomic Energy Agency
IGD-TP	Implementing Geological Disposal of Radioactive Waste Technology Platform
ITER	International Thermonuclear Experimental Reactor
KIC InnoEnergy	Knowledge and Innovation Community InnoEnergy
LANENT	Latin American Network for Education in Nuclear Technology
MELODI	Multidisciplinary European Low Dose Initiative
NEA	OECD Nuclear Energy Agency
NEPTUNO	Nuclear European Platform of Training and University Organizations
NKM	Nuclear knowledge management
NPP	Nuclear power plant
NSERC	Natural Science and Engineering Research Council
NTEC	Nuclear Technology Education Consortium
OECD	Organisation for Economic Co-operation and Development
R&D	Research and development
SNETP	Sustainable Nuclear Energy Technology Platform
UNENE	University Network of Excellence in Nuclear Engineering
WNA	World Nuclear Association
WNU	World Nuclear University

Extended summary, Key Messages and Recommendations.

Education, training, and research in the nuclear science and engineering community - keys to sustain nuclear energy's future role in the European Union.

This report is one part of the SET Plan European Energy Education and Training Initiative launched by the European Commission (EC) in November 2011 and is assessing the educational and training needs of future professionals in the field of Nuclear Energy for both Fission and Fusion.

The key messages and recommendations of this report are based on an extensive survey of studies, statistics and reports provided during the last decade under the Initiative of the EC and, at a broader international level, by several international organisations (IAEA, OCDE..).

They are complemented by the personal contributions of the experts having drafted this report and representing the main stakeholders from the nuclear field.

This assessment report on Nuclear Energy is structured in 4 different sections, following the expectations and guidelines provided by the EC.

- Section 1 aims at analysing the current situation in the Member States and at EU level covering various aspects such as existing workforces, core occupations, market trends, profiles and skills required by the nuclear sector.
- Section 2 provides an overview about currently ongoing activities, projects and initiatives at Member States and EU level which are targeted at supporting education in the field of Nuclear Energy. The impact of such actions and a brief comparison with other countries is outlined.
- Based on this wide screening, needs and gaps for the nuclear sector are identified in Section 3. The main barriers and bottlenecks currently hindering a smooth development of education, with a good synergy between stakeholders, for a full implementation of the SET Plan goals are identified.
- In Section 4 various common recommendations from the involved experts towards the EC or Member States are drawn, in order to meet the future demands of the nuclear sector in terms of professional skills and competences.

The nuclear science and engineering community in the European Union (EU) is beset with numerous challenges that threaten nuclear power's role as a clean and abundant source of reliable energy. These range from growing disinterest in higher education of young and upcoming scientists and engineers, to a nuclear workforce that is rapidly aging and not being replaced.

It results in a lack of future generations to operate, promote, and expand the nuclear power sector, as well as the loss of trained experts with the necessary knowledge and technical competencies to safely build, operate, and decommission current and future nuclear facilities.

Active nuclear research and education are however of utmost importance to spread knowledge not only in the energy market but also in other very important sectors such as health care and cancer prevention. Therefore they provide qualified and stable employment for mid and long term. Cooperation with other energy sectors is also increasingly important to develop transversal skills and competences oriented to the wellness of society, to analyse globally socio-economic challenges, to create awareness and acceptance for nuclear energy, as part of the whole energy mix.

Smart energy education will be the key to changing behaviour.

In order to create and develop the necessary education, research, and training programmes to ensure nuclear energy's future in the EU, 14 concrete actions are suggested by the experts having contributed to this report. These actions include the following principles:

- Joint education and training programs between the nuclear energy sector and academic institutions should be formed and encouraged to ensure a stable and highly trained workforce.
- New education programs should be developed to address market and societal needs, and improve linkages between nuclear energy and its benefits to society and the economy.
- Private-public partnerships and collaboration with other EU organizations should be encouraged to harmonize nuclear education and training across the EU, as well as support the expansion in E&T programmes in the nuclear sector.
- European initiatives such as EHRO-N, ENEN and JRC databases, (based on input from and cooperation with national organizations), should be reinforced to support and advise different EU strategic actions.
- Key stakeholders in nuclear energy and nuclear safety should develop a common language for employment in nuclear education and training, including a taxonomy of skills and competencies linked to employment opportunities.
- A framework for mutual recognition of qualifications should be further developed with the objective of including non-academic qualifications and related vocational training to help promote nuclear energy. Pilot exercises should apply a 'learning outcomes' approach within ECVET partnerships.

1 Current situation

The nuclear sector is driven by high demands on safety. Such operating environments have traditionally set strong requirements for the training and development of personnel working in the field. Besides basic education and training (E&T), systematic approaches and methods to the training and development of personnel have been developed over the years and this continues. The industry, especially the operators of the NPPs, takes a strong responsibility to ensure that the personnel is competent to carry out their work assignments and maintain and further develop their professional skills. More and more European wide joint actions have also been initiated in the field of E&T and main efforts have been launched to tackle with the challenges of maintaining competence and in its further development due to the main demographic changes in Europe. Within the SET-Plan Education and Training Exercise context, the nuclear sector is thus able to demonstrate several actions that have already been implemented and that could be beneficial also to the other groups in this assessment report.

Market value/size, growth rate, number of companies and research institutes, total employment numbers for the nuclear energy sector.

Today, the EU must import 50% of its energy needs with an annual bill of 240 billion Euros, and its primary energy consumption continues to increase by 2% each year. If no basic changes are made, the imported quantity of primary energies (primarily from fossil origin) could reach 70% in 2030.

At the end of 2010, in computing the shares in *electricity production* in the EU-27 (total of 3370 TWh) by various primary sources, natural gas arrives on top (32 %), followed by nuclear power and (brown)coal (28 % each), oil (2 %), and renewable energy (10 %) - renewable energy includes hydraulic power, biomass and wind + geothermal + solar. Still, that means that more than half of the EU's electricity production (62 %) uses technologies emitting CO_2. At the end of 2010, in computing the shares in *primary energy consumption* in the EU-27 (total of 1850 Mtep) by various primary sources, oil arrives on top (37 %), followed by natural gas (24 %), coal (18 %), nuclear (14 %) and renewable energy (7 %)[1]. Still, that means that more than half of the EU's consumed energy (56 %) comes from abroad (the respective import rates are as follows: 75 % for oil, 60 % for natural gas, 40 % for coal).

Nuclear power is the principal low carbon source of base load electricity in the EU, totalling some 122 GW(e) of installed capacity and accounting for almost one third of current electricity generation (and 15% of the total energy consumed). This translates to a saving in CO_2 emissions of roughly 700 million tons per year and is equivalent to the amount produced by all the cars in Europe. Nuclear power plays therefore a key role in limiting the EU's emissions of greenhouse gases, and makes an important contribution to improving the Union's independence, security and diversity of energy supply.

Nuclear related activities cover a wide range of applications all over Europe, from **energy production by fission** through research and safety activities, radiation protection and medical uses, to the **development of fusion**, as a new energy sector, potentially leading to a fast economic growth and new jobs creation in a wide range of disciplines.

The **scope of the present report** will therefore cover **"fission"** and **"fusion"**, with the aim to develop key issues to maintain and develop the necessary workforce as well as the necessary safety and security in "fusion" activities, while preparing the exploitation of the next "fusion" reactors with a full benefit for Europe.

Some Key figures for the "Nuclear Market": today and at Horizon 2020 - (2050)

Fission:

718 nuclear power plants have been constructed in the world since 1954.

[1] EUROSTAT (2010 edition) "*Panorama of energy – Energy statistics to support EU policies and solutions*" - http://epp.eurostat.ec.europa.eu/portal/page/portal/release_calendars/publications

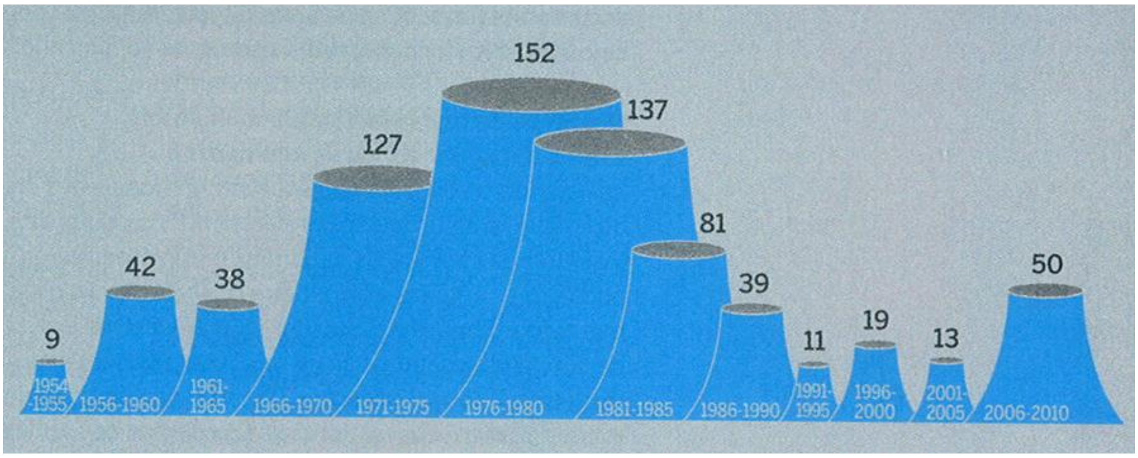


Figure 22. The 718 nuclear power plants constructed in the world since 1954.
Source; Le Monde, January 2012.

Between 1973 and 1986, until the Tchernobyl accident, there was a fast growth of nuclear plant construction, mainly in developed countries (e.g. USA, France, Japan, USSR).

In November 2012, the number of power plants in operation was (Table 1):

- 104 reactors in USA producing 19.3% of the electricity
- 132 reactors in EU-27 producing 28% of the electricity
- 50 in Japan producing 18.1% of the electricity.

The global situation in November 2012 is: 436 reactors operating, ~62 under construction, ~167 projects already planned or on order for construction and 130 closed temporarily or definitively.

These values are updated every two months. The current situation can be found on the World Nuclear Association website [2].

In 2011, despite a continued sluggish world economy and with an update related to the Fukushima Daiishi accident, high expectations for the nuclear technology's future prevailed. This can be seen in the 2012 prevision of the IAEA[ ] (figure 2) where the global capacity of nuclear energy power plants is expected to be between: 501 GW(e) and 746 GW(e), in 2030.

The largest share of this upward shift comes from Asia, a region that not only includes countries which currently possess commercial nuclear power programmes, like China, India, Japan, the Republic of Korea and Pakistan, but also several newcomer countries which can reasonably be expected to have nuclear power plants in operation by 2030 (see Table 1).

In these regions high energy demand, especially for electricity, is driven by continuous population growth, accelerated economic development aspirations and energy security concerns. This high energy demand, coupled with a future most likely characterized by high and volatile fossil fuel prices and environmental considerations, has encouraged a quest for low-carbon energy supplies, of which nuclear power is a part.

---

[2] *World Nuclear Power Reactors & Uranium Requirements* - http://www.world-nuclear.org/info/reactors.html

According to 2011 projections, the rest of the world, except for the countries of the Commonwealth of Independent States (CIS) where the projected increase is more significant, exhibits only a modest projected increase in nuclear generating capacity.

TABLE 21. Nuclear power reactors in operation and under construction in the world (as of November 2012). Source: WNA [2].

World Nuclear Power Reactors & Uranium Requirements

November 2012

This table includes only those future reactors envisaged in specific plans and proposals and expected to be operating by 2030. Longer-range estimates based on national strategies, capabilities and needs may be found in the WNA Nuclear Century Outlook. The WNA country papers linked to this table cover both areas: near-term developments and the prospective long-term role for nuclear power in national energy policies. They also provide more detail of what is tabulated here.

COUNTRY (Click name for Country Profile)	NUCLEAR ELECTRICITY GENERATION 2011		REACTORS OPERABLE Nov 2012		REACTORS UNDER CONSTRUCTION Nov 2012		REACTORS PLANNED Nov 2012		REACTORS PROPOSED Nov 2012		URANIUM REQUIRED 2012
	billion kWh	% e	No.	MWe net	No.	MWe gross	No.	MWe gross	No.	MWe gross	tonnes U
Argentina	5.9	5.0	2	935	1	745	1	33	2	1400	124
Armenia	2.4	33.2	1	376	0	0	1	1060			64
Bangladesh	0	0	0	0	0	0	2	2000	0	0	0
Belarus	0	0	0	0	0	0	2	2400	2	2400	0
Belgium	45.9	54.0	7	5943	0	0	0	0	0	0	995
Brazil	14.8	3.2	2	1901	1	1405	0	0	4	4000	321
Bulgaria	15.3	32.6	2	1906	0	0	1	950	0	0	313
Canada	88.3	15.3	20	14169	0	0	2	1500	3	3800	1694
Chile	0	0	0	0	0	0	0	0	4	4400	0
China	82.6	1.8	15	11881	26	27640	51	57480	120	123000	6550
Czech Republic	26.7	33.0	6	3764	0	0	2	2400	1	1200	583
Egypt	0	0	0	0	0	0	1	1000	1	1000	0
Finland	22.3	31.6	4	2741	1	1700	0	0	2	3000	471
France	423.5	77.7	58	63130	1	1720	1	1720	1	1100	9254
Germany	102.3	17.8	9	12003	0	0	0	0	0	0	1934
Hungary	14.7	43.2	4	1880	0	0	0	0	2	2200	331
India	28.9	3.7	20	4385	7	5300	18	15100	39	45000	937
Indonesia	0	0	0	0	0	0	2	2000	4	4000	0
Iran	0	0	1	915	0	0	2	2000	1	300	170
Israel	0	0	0	0	0	0	0	0	1	1200	0
Italy	0	0	0	0	0	0	0	0	10	17000	0
Japan	156.2	18.1	50	44396	3	3036	10	13772	3	4000	4636
Jordan	0	0	0	0	0	0	1	1000			0
Kazakhstan	0	0	0	0	0	0	2	600	2	600	0
Korea DPR (North)	0	0	0	0	0	0	0	0	1	950	0
Korea RO (South)	147.8	34.6	23	20787	4	5205	5	7000	0	0	3967
Lithuania	0	0	0	0	0	0	1	1350	0	0	0
Malaysia	0	0	0	0	0	0	0	0	2	2000	0
Mexico	9.3	3.6	2	1600	0	0	0	0	2	2000	279
Netherlands	3.9	3.6	1	485	0	0	0	0	1	1000	102
Pakistan	3.8	3.8	3	725	2	680	0	0	2	2000	117
Poland	0	0	0	0	0	0	6	6000	0	0	0
Romania	10.8	19.0	2	1310	0	0	2	1310	1	655	177
Russia	162.0	17.6	33	24164	10	9160	24	24180	20	20000	5488
Saudi Arabia	0	0	0	0	0	0	0	0	16	17000	0
Slovakia	14.3	54.0	4	1816	2	880	0	0	1	1200	307
Slovenia	5.9	41.7	1	696	0	0	0	0	1	1000	137
South Africa	12.9	5.2	2	1800	0	0	0	0	6	9600	304
Spain	55.1	19.5	8	7448	0	0	0	0	0	0	1355
Sweden	58.1	39.6	10	9399	0	0	0	0	0	0	1394
Switzerland	25.7	40.8	5	3252	0	0	0	0	3	4000	527
Thailand	0	0	0	0	0	0	0	0	5	5000	0
Turkey	0	0	0	0	0	0	4	4800	4	5600	0
Ukraine	84.9	47.2	15	13168	0	0	2	1900	11	12000	2348
UAE	0	0	0	0	1	1400	3	4200	10	14400	0
United Kingdom	62.7	17.8	16	10038	0	0	4	6680	9	12000	2096
USA	790.4	19.2	104	102195	1	1218	13	15660	13	21600	19724
Vietnam	0	0	0	0	0	0	4	4000	6	6700	0
WORLD**	2518	c13.5	436	374,135	62	62,789	167	182,095	317	359,655	67,990
	billion kWh	% e	No.	MWe	No.	MWe	No.	MWe	No.	MWe	tonnes U
	NUCLEAR ELECTRICITY GENERATION		REACTORS OPERABLE		REACTORS UNDER CONSTRUCTION		ON ORDER or PLANNED		PROPOSED		URANIUM REQUIRED

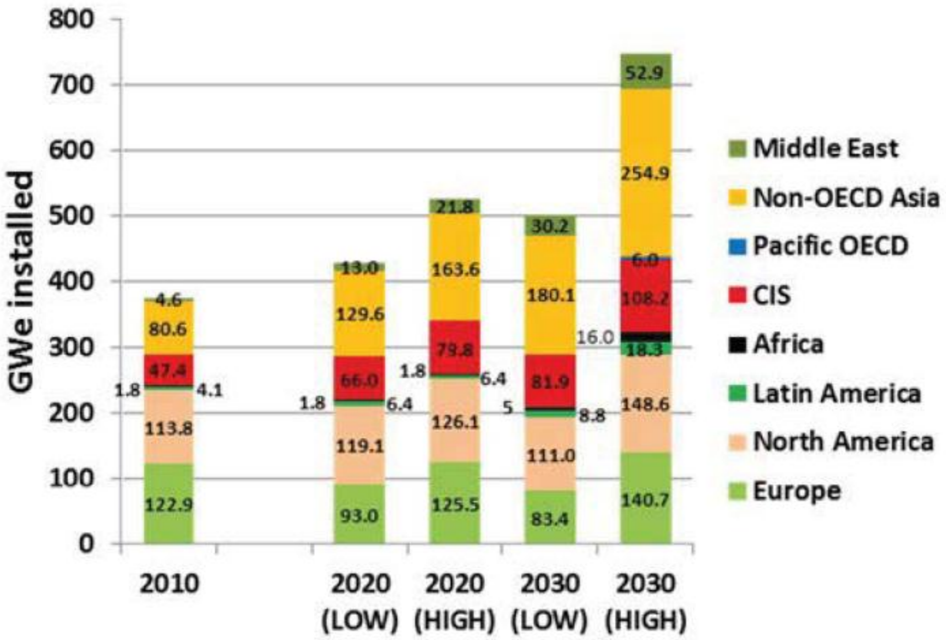


Figure 23. Development of regional nuclear generating capacities 2010-2030, low and high 2011 projections. Source: IAEA 2012. Nuclear technology review 2012[3]. (p. 14)

Currently (after the Fukushima Daiichi NPP accident in Japan on 11 March 2011), there are a total of 132 reactors operating in 14 European Union Member States (total power output of 122 GW(e) net).World-wide information about nuclear policy decisions following the triple disaster in Japan in March 2011 is given in the databases of IAEA[3] and of WNA[2] (also detailed in annexe 1).World-wide, there are 436 reactors in operation in 31 countries plus Taiwan (with a total net installed capacity of 372 000 MWe) and there are 64 reactors under construction (most of them in Asia, notably 26 in China). Of particular interest is what happens in the "emerging nuclear energy countries" (more than 45 according to IAEA). As far as nuclear decommissioning is concerned, a total of 138 civilian nuclear power reactors are shut down in 19 countries. Decommissioning has only been completed for 17 of them. Decommissioning is a complex process that takes years and requires also a considerable amount of multi-disciplinary expertise.

The 2011 events in Japan resulting from the massive earthquake and the resulting Fukushima Daiichi accidents have naturally reinforced the focus of the international nuclear fission community on the continuous need to strengthen and share nuclear safety culture in all nuclear installations.

The operating licenses of some 95 nuclear power reactors in the EU-27 are due to expire by 2025, the bigger part of these, some 53 in total, in the period between 2020 and 2025. In this projection the possible operating life-span extensions of NPPs that are under consideration in some of the nuclear power countries are not taken into account. Namely, the life-span of some 79 nuclear reactors, including all French ones, might be prolonged in the same period by 10 or 20 years.

[3] IAEA *Power Reactor Information System* (PRIS) - dated October 2012 - http://www.iaea.org/pris/

Besides the lifetime extension of NPPs, 6 new reactors with the total capacity of 5 888 MWe are being built in EU-27 and there are plans/proposals for some 37 additional reactors in the medium term with a total capacity of 52 065 MWe. [[4]]

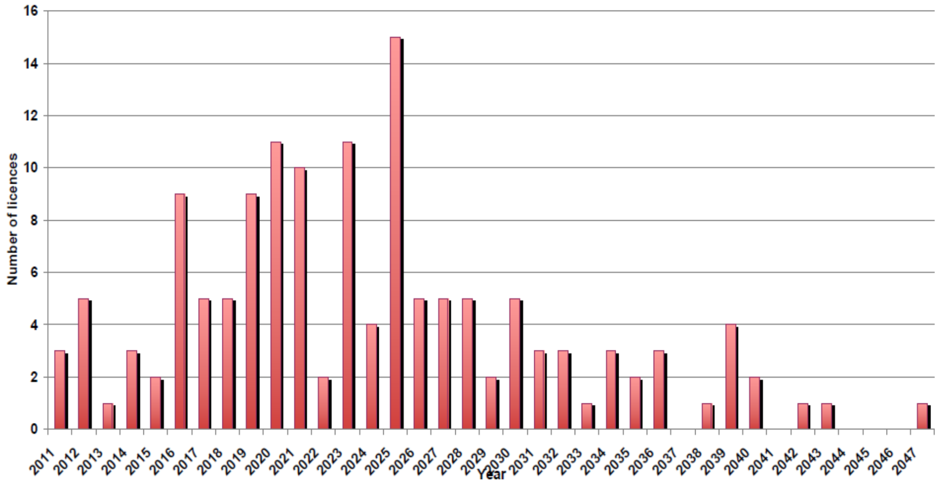


Figure 24.Number of nuclear power reactors' licenses expiring per year in the EU. Source: World Nuclear Association 2012[5] and EHRO-N report (2012 p.35) [5].

Many activities over the full nuclear value chain are directly concerned by the specificity of nuclear energy. These include nuclear fuel production, design & engineering, equipment and component fabrication, construction, operation & exploitation, dismantling, waste management of operating, dismantling, and spent fuel and high-level waste, and cross-cutting activities such as: safety, security and radiation protection, health and the environment, quality and project management, which are becoming nowadays priority actions for the development of nuclear power.

As a consequence, the construction of new NPPs in the EU-27, the operation of the existing ones and the decommissioning of the out of service plants as well as continuing needs for nuclear research, regulation and education and training (E&T) will all require a significant number of experts and technicians in the following decades. These new jobs will especially ensure the efficient and safe operation of present and future nuclear power reactors in the EU-27 and around the world.

Fusion:

Fusion energy is a long-term strategic objective, developed in pan-European collaboration, together with international partners. Europe hosts the flagship project ITER and is leading in technology development, although the Asian countries are catching up fast.

[4] EHRO-N report: Putting into perspective the supply of and demand for nuclear experts by 2020 within the EU-27 nuclear Energy sector : JRC Sientific & policy Report, EUR 25291 EN, ISBN 978-92-79-21276-5, ISSN 1831-9424, doi:10.2790/47738, (Annexe 2 revised with last decisions in Italy declining 10 new PP's)

[5] World Nuclear Association, Public Information Service, Country Briefings, http://www.world-nuclear.org/

The EU roadmap for fusion foresees the construction and operation of ITER, the simultaneous design of DEMO followed by construction and operation in from 2040. ITER gives scientific and technical proof of feasibility, DEMO delivers electricity to the grid at the >0.5 GW level. In parallel to these milestones neutron-hard materials for the reactor vessel will be developed. After DEMO, the first generation of commercial fusion reactors is expected to be deployed quickly. China, South Korea and India follow each similar roadmaps.

In the coming decades the contribution of fusion to world energy production will be negligible, but the development of fusion goes from a science-driven, lab-based exercise to an industry-driven and technology-driven program. Moreover, fusion makes the transition from essentially non-nuclear technology to nuclear technology. ITER is the first step in this triple transition.

The construction of ITER represents a turnover for the European industry of about 0.6 Billion Euro/year. The worldwide fusion programs, including the inertial fusion programme in the USA, and the associated research programs, generate a turnover of about 2 Billion Euros/year. If the roadmap is achieved and several countries build a DEMO reactor in the early 2040s, the worldwide turnover – in industry –may increase by at least a factor 3-4 in the 2030's.

Next to that, several projects of new built research stellerators are run at national level, such as the large Wendelstein 7X project (Greifswald, Germany)[6] with a construction budget of around 1 Billion Euro.

Additionally, the roadmap calls for the construction of a fusion nuclear materials test facility, presently in its early planning phase, representing also a multi-billion Europroject. The fusion materials development program has strong links and synergy with the fission "Gen4" materials development, which is an important element in the research in EU-27. These programs should be considered in conjunction when it comes to training and human resource planning.

ITER employs currently about 5 500 workers in industry (all levels and disciplines) for around 10 years.

Industry, Regulators, Research Institutes and Academia

Fission:

The different industrial sectors related to the management and uses of nuclear energy have been identified for EU-27 within the EHRO-N report (2012)[5]. Within this report, the different stakeholders are identified with respect to their activity related to the nuclear life cycle as:

1. Utilities (i.e. NPPs)
2. Nuclear facility vendors and other big suppliers
3. Fuel fabrication, enrichment and other supply organisations
4. Waste management organisations (WMOs), radioactive waste management

[6] http://www.bmbf.de/en/2272.php

5. (RWM) and decommissioning organisations
6. Design, engineering, equipment and manufacturing, and maintenance organisations
7. Consultancy (including project management and training)
8. Regulatory authorities and TSOs
9. R&D institutes
10. Universities, training organizations

They can also be identified on the EHRO-N website, (http://ehron.jrc.ec.europa.eu/).

Companies established in EU are often world leaders in their category (or among the 6 majors companies in their industry in the world) mainly as vendors or supplier of nuclear facilities and their market extends worldwide. The EHRO-N report has identified 358 organisations in Europe that are active in the nuclear field with specific workforce requirements for the next decade.

Beside industrial organisations, Europe has also developed very strong research institutes and powerful research facilities, which under the European initiative ESFRI [[7]] (European Strategy Forum on Research Infrastructures) aim to develop and facilitate multilateral initiatives leading to the better use and development of research infrastructures, at EU and international level, for both Fission and Fusion. The EHRO-N maps on the website[8] such fission related research institutes and facilities for Europe.

Nuclear fission is discussed in several forums and platforms.

An important contributor to EU energy policy and legislation is the *European Nuclear Forum Energy* (ENEF)[[9]]. With regard to the need for having better knowledge of the skills gaps in the nuclear industry and research organisations, the ENEF created a *European Human Resources Observatory - Nuclear Energy* (EHRO-N)[9], which released its first report on supply and demand on 30 May 2012:" *Putting into perspective the supply of and demand for nuclear experts by 2020 within the EU-27 nuclear Energy sector*."

For European safety enforcement the *European Nuclear Safety Regulators Group* (ENSREG)[10] has been set up. ENSREG is composed of senior officials from national nuclear safety authorities: it focuses on nuclear safety, waste management and spent fuel.

Of the European Technology Platforms, the most notable is the *Sustainable Nuclear Energy Technology Platform* (SNETP)[11]. The SNETP aims at promoting research, development and demonstration that will maintain excellence in fission technology and provide long-term waste-management solutions. The SNETP is composed of over 100 organizations from 21 countries (20 EU Members States and Switzerland).

---

[7] http://ec.europa.eu/research/infrastructures/index_en.cfm?pg=esfri

[8] http://ehron.jrc.ec.europa.eu/

[9] http://ec.europa.eu/energy/nuclear/forum/index_en.htm

[10] http://ec.europa.eu/energy/nuclear/ensreg/ensreg_en.htm

[11] www.snetp.eu

The *Implementing Geological Disposal of Radioactive Waste Technology Platform* (IGD-TP)[12] that was launched in November 2009 provides the necessary focus on RD&D[[13]] that leads to the safe operation of the geological repositories for spent nuclear fuel and high-level nuclear waste in Europe. IGD-TP has 94 participant organisations from 18 European Member States and from Switzerland.

Finally, the EU research strategy for radiation protection is in the hands of the platform *Multidisciplinary European Low Dose Initiative* (MELODI)[14].

The "Vision Reports" of these Technological Platforms are particularly important to understand the long term objectives set up by the respective scientific communities (reactor safety, nuclear waste management, radiation protection) and implementers [[15],[16],[17]]. These vision reports are complemented with the connected Strategic Research Agendas and their Deployment Plans, which also include actions foreseen in the field of E&T.

Fusion:

The FIIF (Fusion Industry Innovation Forum) represents industry that is involved in fusion development. FIIF helps to integrate industry in the development of DEMO and supports the training and education activities.

EFDA (European Fusion Development Agreement) is a Euratom organisation, in which all European fusion laboratories collaborate. EFDA runs a Goal Oriented Training programme and a Fusion Fellowship programme.

F4E (Fusion for Energy) is the legal entity which will realize the EU contribution to ITER. F4E strongly interacts with industry as well as research institutes, but has no direct role in education and training.

Fusenet (the European Fusion Education Network) is the umbrella organization under which all fusion education, from Master (and earlier) to PhD studies, is coordinated. Members of Fusenet are universities with a fusion curriculum, fusion research labs as well as industry that are involved in fusion.

---

[12] http://www.igdtp.eu/

[13] RD&D : research Development and Demonstration

[14] http://www.melodi-online.eu/index.html (formerly called the High Level Group - http://www.hleg.de/)

[15] http://www.snetp.eu/www/snetp/images/stories/Docs-VisionReport/sne-tp_vision_report_eur22842_en.pdf

[16] http://www.igdtp.eu/Documents/VisionDoc_Final_Oct24.pdf

[17] http://www.melodi-online.eu/doc/SRA3.pdf

Market growth forecast in percentile. Forecast on net increase in employment.

Market growth:

According to different studies (e.g. IAEA 2012[3], "*Energy Roadmap 2050*" [18]), the global energy demand over the world will double within the next 50 years and this growth will mainly be concentrated in emerging countries.

From a worldwide perspective, nuclear energy will still have a share of 6% - 7% of the overall global energy mix in 2050. In 2009, the share of nuclear was 13.4% of electricity production.

Even if the total share of nuclear energy is foreseen to be reduced in the energy mix, the total amount of electricity produced by nuclear energy will slowly increase in an absolute value (depending on the scenario; see IAEA 2012[3], Figure 2 this document) and will remain either constant or decrease slowly in EU-27.

Fusion can contribute significantly to the energy mix in the second half of the decade, if it grows exponentially in a same way as other sources like solar PV and wind at present, or fission in the 1960's and 1970's. This scenario is consistent not only with the fusion roadmap of the EU but also with those of China, India and S-Korea, This exponential growth, which would primarily be the concern of the industry, would take place during and after the development of DEMO.

Net increase in Employment:

Fission:

For EU-27 itself the total workforce in the nuclear sector is estimated at some 500 000 people. The total need for nuclear experts by 2020 of the 358 nuclear organizations active in 2010 is nearly 40 000 with the highest share located in France, followed by the United Kingdom (EHRO-N 2012, p.16[5]).

More detailed projections country by country are given in EHRO-N report (2012, p. 48/49)[5] and in the recent OECD/NEA(2012) [19] and IAEA reports. [20]

---

18 "*Energy Roadmap 2050*" (COM(2011) 885 (Brussels, 15.12.2011)
http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2011:0885:FIN:EN:PDF

19 OECD2012/NEA report : Nuclear Education and Training from Concern to Capability.(24 Apr 2012)
ISBN: 9789264176379 OECD Code: 662012011P1,
http://www.oecd-ilibrary.org/nuclear-energy/nuclear-education-and-training_9789264177604-en

20 Human Resources for Nuclear Power Expansion :
http://www.iaea.org/About/Policy/GC/GC54/GC54InfDocuments/English/gc54inf-3-att5_en.pdf

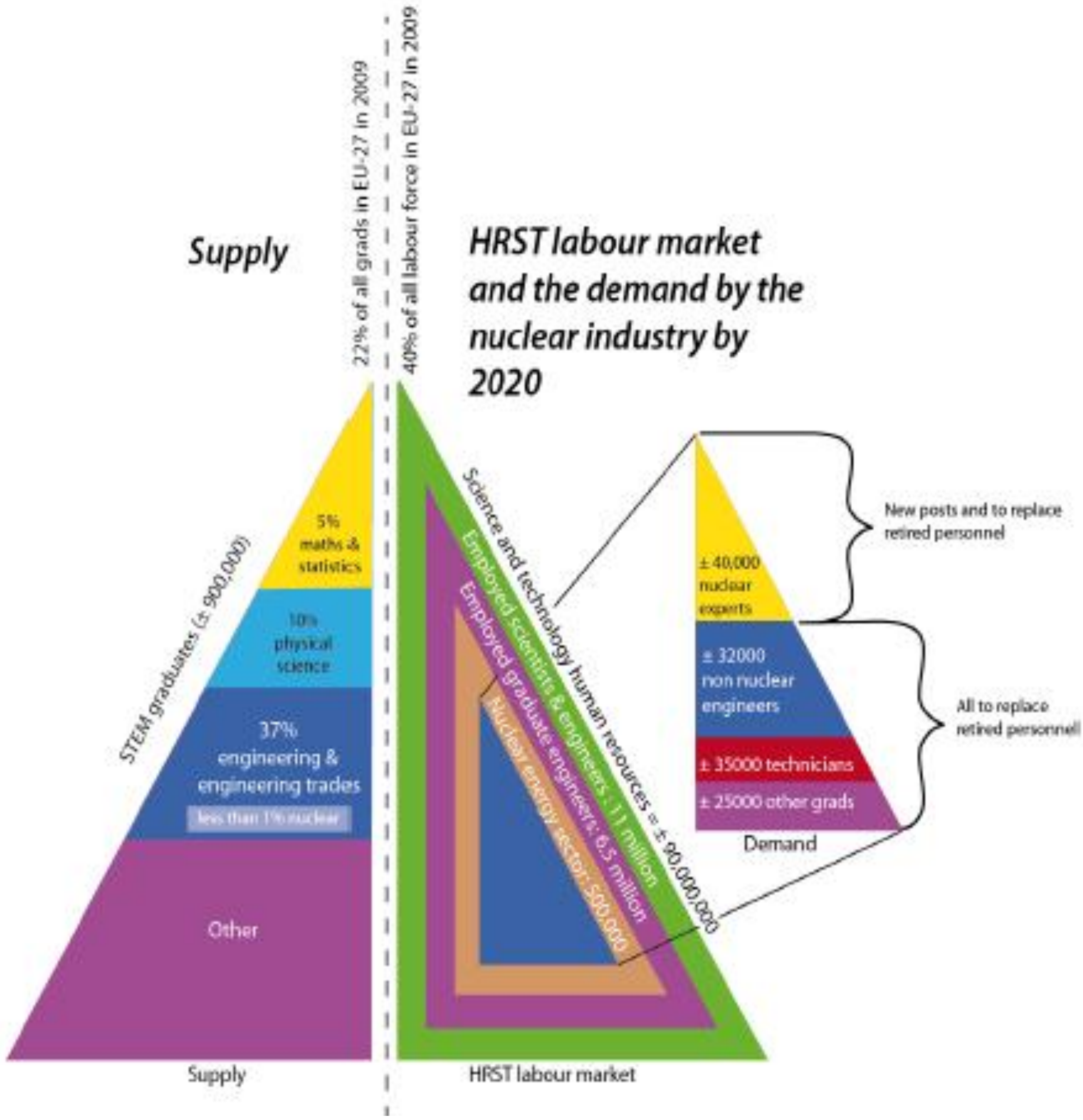


Figure 25. Graphical representation of the supply of Science, Technology, Engineering and mathematics (STEM) graduates in the EU-27 in 2009, the Human Resources in Science and Technology (HRST) workforce in EU-27 in 2009 and the lowest hypothetical demand for nuclear experts, non-nuclear engineers, technicians and other graduates by the nuclear energy sector in the EU-27 by 2020.

Source EHRO-N report (2012, p.65)[5]

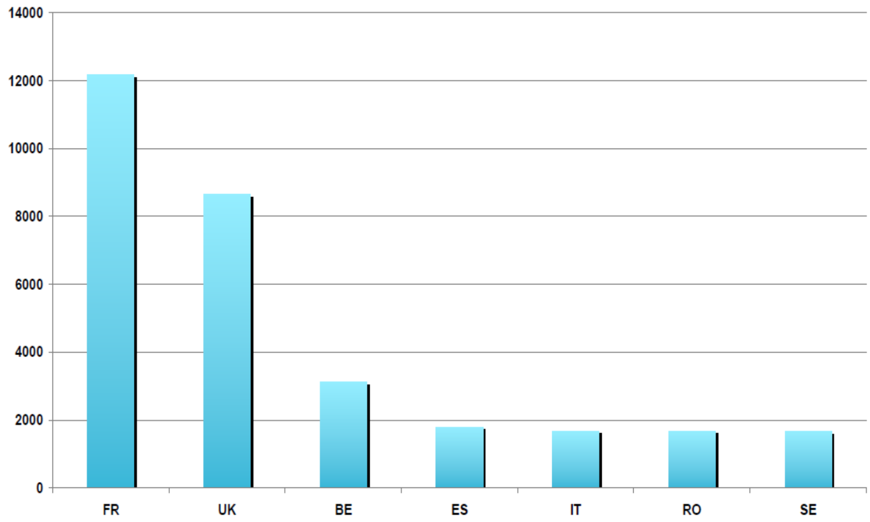


Figure 26. Need for nuclear experts in the next ten years per country in EU-27
Source EHRO-N report (2012, p.49) [5]

This trend is similar to the trend seen in the USA, where by 2030, the staff needed to replace retiring personnel and to cater for additional capacity for NPP operation is evaluated to be approximately 19 000 new positions and in total 63 000 new hires (19 000 + 44 000 to replace retiring employees). (See Figure 5. according to Li & al (2009) in the OECD 2012 report).

This is attributable, to a significant extent, to the age of the workforce and the expected retirement rates.

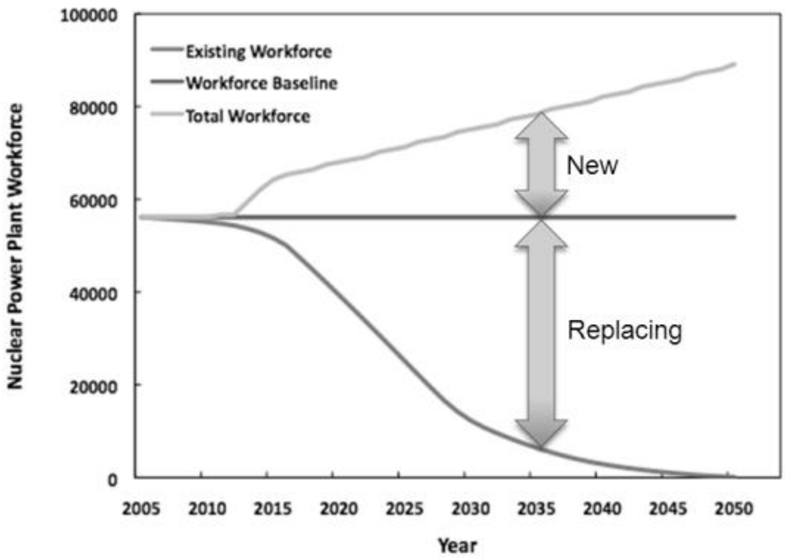


Figure 27. Estimates of the operating personnel needed for retaining market share in nuclear power in the United States. Source: Li, et al. (2009), Los Alamos Nuclear Enterprise Resource and Infrastructure Model (LA-NERIM) in the OECD/NEA report [20].

Skilled workforce has also to be built in Asian countries where the market is growing very fast. EU-27 countries will be called to contribute to educate and to train their workforces (internationalization) where European Stakeholders are selling new plants.

Fusion:

Presently the research community in EU employs around 2 300 professionals, and 4 000 workers in total. Next to that, the European industry for ITER employs a total of about 5 500 workers in industry.

These numbers will grow in the coming decade – in particular in the nuclear technology sector – if the DEMO development is started in agreement with the roadmap.

Important for the education and training programs, which should anticipate the needs of the field by some 10 years, is a good assessment of the changing profile of competences needed in fusion research.

Value chain – core occupations in the nuclear energy sector.

Fission:

The number of experts in the different core occupation in the nuclear sector are given in Figure 6.

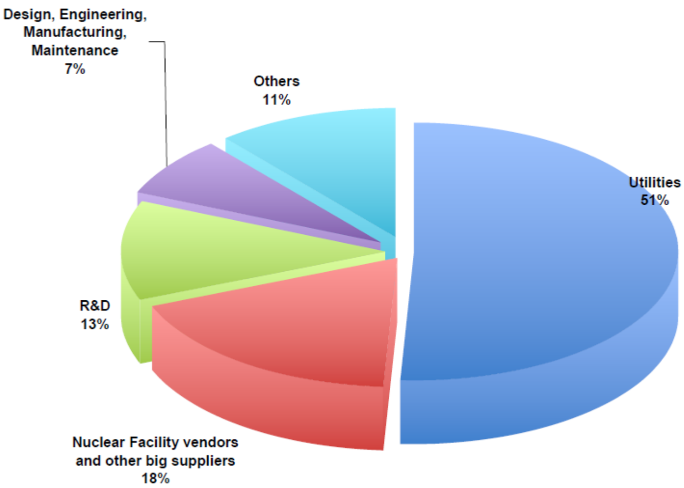


Figure 28. Number of nuclear experts by type of nuclear stakeholder in the EU-27.
Source: EHRO-N (2012, p.46) [5]

Fusion:

The present emphasis is on R&D institutes and universities. This workforce is expected to remain stable (2300 professionals), but gradually shifting emphasis from physics to engineering.

New workforce is needed in: fabrication, manufacturing (wide range of industries, from the huge superconducting coils, vacuum vessel to high power electronics etc., but also nuclear buildings and remote handling technology.) Presently, some 5500 workers mostly with generic engineering competences are involved in ITER manufacturing and construction.

During ITER construction an important expertise that is being build up is the capability to launch and follow up very large and complex industrial contracts.

Other competences to build up for ITER and DEMO:

- Exploitation, maintenance (remote handling)
- Licensing, regulations, oversight and safety
- Nuclear system engineering.

Overall with ITER, fusion moves into the 'nuclear' realm. This brings many commonalities in skills and competences needed between fission and fusion.

Current workforces' profiles/core occupations available in Europe.

Fission

The main sources of information about the current fission related workforce job profiles comes from the OECD (2012)[20] and EHRO-N (2012)[5] reports. It is useful to recognise that there exist various degrees of "nuclearisation" within the industry; that is, the extent to which specific nuclear skills and safety culture training are needed to complement other engineering or management skills. Throughout the workforce, general nuclear awareness is a prerequisite, with more specialised nuclear expertise being required by fewer personnel, depending on the specific job requirements.

Essentially, a threefold categorisation of the competencies necessary to run a nuclear power station can be drawn, which includes:

1. People with a specialised formal education in nuclear subjects (e.g. nuclear engineering, radiochemistry, radiation protection, etc.);
2. People with formal education and training in a relevant (non-nuclear) area (e.g. mechanical, electrical, civil engineering, systems) but who need to acquire knowledge of the nuclear environment in which they have to apply their competencies;
3. People requiring nuclear awareness to work in the industry (e.g. electricians, mechanics, and other crafts and support personnel).

This can be visualised in terms of the pyramid of competence in Figure 8. Generally there will be a larger number of employees from top to bottom.

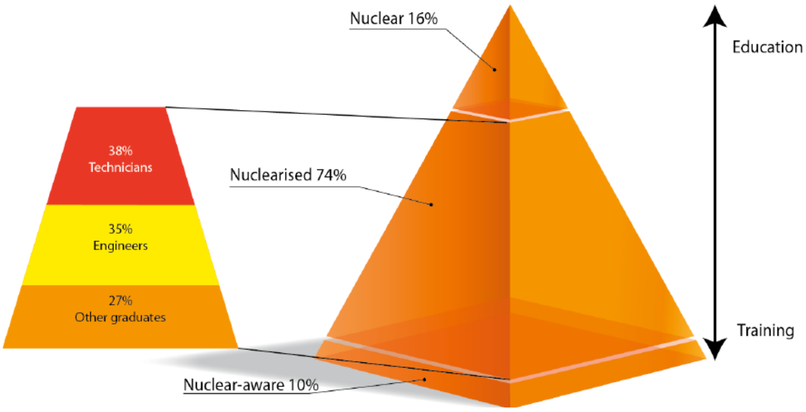


Figure 29. Type of employees in the nuclear sector. Source: EHRO-N (2012, p.63) [5]

Thus in the EU-27, the total workforce in the nuclear energy sector is of some 500 000 people.

This workforce is divided into:

- 16% of nuclear engineers, nuclear physicists, nuclear chemists, radioprotection specialists (or, in short, nuclear experts), which represent the main workforce of 77 000 people.
- 26% of non-nuclear engineers
- 20% of other graduates,
- 28% of technicians, and
- 10% of support and other job profiles.

The non-nuclear engineers, other graduates and technicians were in the EHRO-N report characterized as those that have to be nuclearised.

The family of nuclearised engineers other graduates and technicians (74% of the total workforce), is made up of:

- 38% technicians,
- 35% engineers, and
- 27% are other graduates.

The remaining 10% are employees that perform support and other activities (e.g. commercial, etc.) and are only nuclear-aware. More detailed data is available in EHRO-N(2012)[5].

Both, the nuclearised and nuclear-aware employees need to be trained in order to acquire the competences and skills necessary to perform their activities in the nuclear energy industry.

Fusion

The main industrial effort in fusion is presently that associated with the construction of ITER. Here, an estimated 5500 workers are employed.

- At present, the nuclear competences needed in industry are for a large part generic, not essentially different from those in fission. As such, the needs (for training and education) of nuclear engineers for fusion are a small addition to those for fission.

- There are also nuclear engineering aspects that are fusion specific, for which specialists will have to be educated and trained. This will become much more emphasized when the transition to DEMO is made, which must be anticipated by an adequate training program.

Labour intensity of the nuclear technology value chain and foreseen developments.

Fission:

In EU-27, for 122 GW(e) installed nuclear power capacity we consider to have 16% **(**77 000) nuclear experts. This leads to a figure of 570 nuclear experts per MW(e) unit employed.

The supply of nuclear engineering students and students having had a nuclear energy related subject in their studies (some 2 800 in the EU-27 graduated in 2009) cover only some 70% of the demand for nuclear experts by the nuclear energy sector in the EU-27 (on average 4 000 are needed per year) by 2020.

Fusion:

Given the present stage of development of fusion energy, the labour intensity is not yet of application. In addition to the numbers given before, two considerations can be made:

- To maintain the workforce of 2 300 professionals in EU fusion research programme (research, not industry), the natural replacement needed is about 150 professionals per year. To get those into the field, the number of students that should get a master level education in fusion science and technology should be at least 3 times that, as statistics shows that 75% of the students are employed by the industry (high-tech mostly, and nuclear).

- China is educating an extra 2 000 fusion engineers in the coming years, to create the workforce needed to realize a fusion road map similar to that of EU: DEMO power to the grid in early 2040's.

Different profiles and skills required for the nuclear energy sector.

Fission:

The discussion about the classification of job profiles and Knowledge, Skills and Competence (KSC) has started a few years ago in the nuclear community and a recent approach is proposed in the latest OECD report [20] .Such job taxonomy is an in-depth KSC classification system, which allows the mapping and characterisation of discrete job profiles according to the specific tasks, the responsibilities and activities the role entails, the competencies needed to fulfill them, as well as the associated entry level qualification, training and experience requirements.

The framework of job taxonomy developed in the OECD study adopts a hierarchical approach, categorising job roles first by sector and secondly by function as described in Figure 9.

Sectors are defined by the taxonomy according to the objective for which the workforce is employed, for example, in the nuclear power plant taxonomy, new build, operation, decommissioning and regulation.

Functions are defined by the taxonomy according to the phases or segregated activities within which specific job roles are deployed; for instance maintenance, waste management, safety and environment, operation and control.

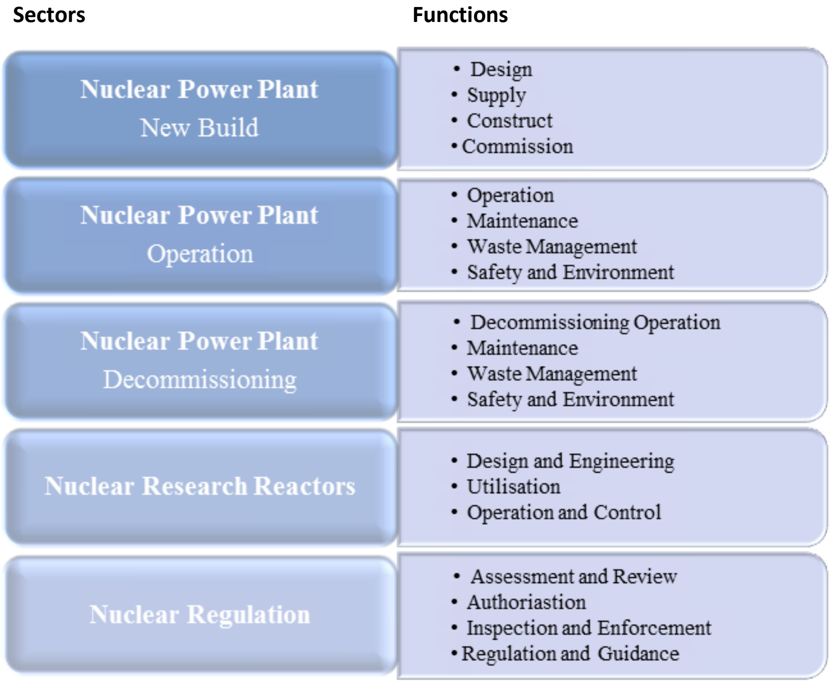


Figure 30. An illustrative job taxonomy – Sectors and functions. Source: OECD/NEA 2012 [20].

The specific needs for each of these functions are not actually available at EU-27 level. A complete collection of such data is very complicated to assemble from the DEMAND side depending on the type of stakeholders, on the countries where they operate, competitiveness considerations and/or on the degree of clarity of their future plans. Such a systematic approach to define the demand side has been made in France (EHRO-N 2012, p.25, 69)[5]. Belgium [21], the UK[22] and Finland (TEM 2012)[23] and should be extended to the other countries for EU-27.

Fusion

The matrix of engineering skills and competences required in industry involved in fusion is, in terms of nuclear engineering, for a large part not essentially different from that in fission. The total volume of fusion-related work in industry is presently 1-2 orders of magnitude smaller than for

---

21 http://www.nuclearforum.be/sites/default/files/Forum%20nucl%C3%A9aire%20-%20Cartographie%20de%20l%20emploi%20dans%20le%20secteur%20nucl%C3%A9aire%20en%20Belgique_23052012_0.pdf

22 COGENT, Next Generation: *Skills for New Build Nuclear, March 2010*

23 Report of the Committee for Nuclear Energy Competence in Finland (2012) Printed publications ISSN 1797-3554, ISBN 978-952-227-599-8 Electronic publications ISSN 1797-3562,ISBN 978-952-227-600-1 http://www.tem.fi/index.phtml?C=98158&l=en&s=2086&xmid=4814

fission. Therefore, in practical terms, the human resources requirements of industry for fusion can presently be approximated as a small increase of those for fission.

According to the fusion road map, a significant increase of this demand will be needed in the coming two decades. As starting point, the same distribution of required knowledge, skills and competences can be used.

The research workforce, presently about 2 300 professionals, 4 000 FTE in total in Europe, should at least stay level during that time. On top that, there is the ITER team while ITER construction calls for an estimated 5500 FTE in industry, adding up to some ten thousand FTE in total.

The industrial engineers involved in fusion work need to acquire some or in some cases extensive knowledge of fusion-specific technology, for which dedicated training – possibly on a commercial basis - needs to be provided. Conversely, a limited number of the fusion specialists need to acquire fusion-specific expertise (see under section 1.7).

Scale

Fission:

As concerns the future demand, there will be a need for **nearly 40 000 nuclear experts by 2020 (4000/year)** in the EU-27 by the nuclear energy sector. **(**EHRO-N 2012, p.65)[5]

In order to estimate the lowest future need for the nuclearised engineers, other graduates, and technicians by the nuclear energy sector in the EU-27, EHRO-N assumed that the retirement rate will be at least 25% in this sector. Thus, the demand by 2020, in order to replace the retired nuclearised workforce, will be (EHRO-N 2012, p. 64) :

- 35 150 technicians or (370 000*38%)*25%,
- 32 375 non-nuclear engineers or (370 000*35%)*25%, which represents ca. 3% (32 375*100/1 204 088) of all engineers needed to be employed because of the retirement of engineers in the EU-27 labour force as a whole (EHRO-N 2012, p.60), and
- 24 975 other graduates or (370 000*27%)*25%.

Fusion:

In first approximation, the nuclear engineering needs of fusion are a small fraction of those for the fission program. In industry: a total of 5500 engineers and technicians (nuclear and non-nuclear) are needed now but the demand is gradually increasing to about 10 000 during DEMO design and construction.

Apart from that, fusion needs specialized fusion-specific nuclear experts. This concerns disciplines such as: nuclear materials, fuel cycle, plant control, system engineering, licensing, regulation, balance of plant. This workforce will need a dedicated training program.

2 On-going actions.

The main education and training activities that support the nuclear sector.

At the EU-27 level:

Since the European Credit Transfer System (ECTS) is formally implemented in most EU countries at the University level according to the Bologna declaration (1999) two recent EU Initiatives provide a great support for training.

- **Europass**[24] launched in **1998.** The European Commission and Cedefop set up the European forum on transparency of vocational qualifications to bring together social partners with representatives of national training authorities around the issue of transparency.
- The European Credit system for Vocational Education and Training **(ECVET).** The objectives of ECVET are transfer, recognition and accumulation of assessed learning outcomes of individuals working in different sectors. ECVET facilitates the mobility and portability of qualifications as well as increase the European cooperation in education and training. [25]

Fission:

The "**European Skills Passport"** is one of the advanced applications of the Europass in the nuclear sector. This passport is to enhance the borderless mobility and lifelong learning of nuclear workforce that could be produced as a result of continuous professional development (CDP) programs across EU, for the benefit of both employees and employers.

A similar arrangement related to radiation protection training is in force in the Nordic countries aiming at reducing overlapping training especially for suppliers working at different nuclear facilities.

To implement all these initiatives, one of the most significant projects on the educational level which was initiated by the European Commission is the **European Nuclear Education Network (ENEN)** Association. It is a network of 64 members and partners including universities, research institutes, industry and regulatory bodies. The main goals of the Association are harmonisation of European Master of Science curricula in nuclear disciplines but also promotion of exchange of students and teachers participating in the frame of ENEN network [26].

In the 7th Euratom Research and Training Framework Programme (2007-2013) ENEN received a financial support for developing the European Fission Training Schemes (EFTS) with the objective of providing the training in some selected domains for professionals working in the nuclear sector,

---

24 Europass : http://europass.cedefop.europa.eu/en/about

25 Recommendation of the EP and the Council of 18 June 2009 on the establishment of a European Credit System for Vocational Education and Training (ECVET) (2009/C 155/02)
http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:C:2009:155:0011:0018:EN:PDF

26 http://www.enen-assoc.org/en/about/new-page-within-about.html

using the ECVET' tools [27]. They are examples of Euratom responses to the need of specific competencies in selected domains, using the above ECVET tools [28]:

- European Network for Education and Training in Radiation Protection – Part II (**ENETRAP-II** (Grant Agreement no. 232620 / March 2009 - December 2012)) is another project which was financially supported by the 7th EU – Framework Programme. ENETRAP-II project is focused on developing European education and training standards in radiation protection domain. The standards and good practices developed under this project can be applied in all sectors where ionising radiation occurs [29].

- **ENEN III**[30] Training schemes - Generation III and IV engineering. (Grant Agreement no. 232629 / May 2009 – April 2013). Here, the focus is on competencies required by nuclear system suppliers. This EFTS is organizing four training schemes:
    - Basic Nuclear Topics for Non-Nuclear Engineers
    - Design Challenges for Generation III NPP (2 professional profiles)
    - Construction Challenges for Generation III NPPs (2 professional profiles)
    - Design Challenges for Generation IV Reactor systems.

  Special attention is devoted to the following competencies: System and Process Engineering, Safety Analysis Evaluation, HVAC Project Implementation, digital I&C Engineering. A number of internships with different stakeholders are organized in order to confront the trainees with the different policies and cultures of employers in various EU countries. The focus is on the acquisition of responsibility and autonomy under the mentorship of employers.

- Further 7th EU – Framework Programme project focusing along with nuclear safety is **TRASNUSAFE**[31]. (Grant Agreement no 249674 / November 2010 - October 2014). The project is focused on competences required by the health physics sector (e.g. ALARA principle). TRANSNUSAFE project is designing, developing and validating two training schemes on nuclear safety culture, with a common basis: industry and installations making use of ionizing radiation.

- **PETRUS II**[32] (Grant Agreement no. 232665) / 15 January 2009 - 14 January 2012) is a specific network working for Education, Training and Research in geological disposal financed as well by the 7th EU-Framework Programme. The partners of the project are developing the Education and Training schemes relevant for radioactive waste disposal for

---

27 http://www.enen-assoc.org/en/training/for-nuclear-community/efts-fp7.html)

28 "1st Situation Report on Education and Training in the Nuclear Energy Field in the EU" http://ec.europa.eu/energy/nuclear/safety/safety_en.htm

29 www.sckcen.be/enetrap2

30 http://www.enen-assoc.org/en/training/for-nuclear-community/efts-fp7/enen-iii.html

31 (http://www.enen-assoc.org/en/training/for-nuclear-community/efts-fp7/trasnusafe-fp7.html)

32 http://www.enen-assoc.org/en/training/for-nuclear-community/efts-fp7/petrus.html,

both Master student and for professional development related to the following competences:

- Site Investigation Design and Management
- Underground Construction
- Repository and Engineered Systems Design
- Long-term safety and performance assessment (Safety Cases)
- Above Ground Waste Handling Facility Design/Operation
- Underground Systems Engineering (Waste Handling)
- Operational and Post-Closure

- The Cooperation in education In Nuclear Chemistry **(CINCH)**, (Grant Agreement no. 249690 / February 2010 - January 2013), financially supported by the Seventh Framework Programme of EURATOM aims to coordinate the education and training activities in nuclear chemistry in Europe. The target groups of the project are both the PhD as well Master students from the EU countries and Russia In the framework of the CINCH project are three courses dedicated to the nuclear chemistry:
  - Chemistry of the Nuclear Fuel Cycle
  - Radioecology
  - Hands-on Training in Nuclear Chemistry (combined e-learning/laboratory course)[[33]].

- The following project, Establishment of a Regional Centre of Competence for VVER Technology and Nuclear Applications - **CORONA**, (Grant Agreement no. 295999 / December 2011 – November 2014), was also developed under the 7th EU - Framework Programme. The CORONA was created with the objective to unify existing Water Power Reactor Technology related training schemes according to IAEA standards and commonly accepted criteria recognized in EU. The partners of the project developed a training scheme for VVER nuclear professionals as well non-nuclear specialists, nuclear subcontractors and students. Very important in this project is knowledge management and knowledge transfer of theory and practice dedicated to VVER technology [[34]].

- **EURECA!** (Grant Agreement no. 295994 / August 2012 – July 2014) is a cooperation between EU and Canada in Education, Training and Knowledge Management on Super-Critical Water Reactors. The EU-Canada collaboration, financially supported by the 7th EU Framework Programme, is focused on competences needed for Generation IV research and training experts. Next to the enhancement the skills of current professionals in the nuclear sector the EURECA's objective is as well the intensification the mobility of nuclear professionals in the EU and Canada.

- **GENTLE** - *Graduate and Executive Nuclear Training and Lifelong Education*: (Grant Agreement no. 323304 / January 2013 – December 2017) focus on synergy between

[33] www.cinch-project.eu

[34] http://www.cvrez.cz/en/trainings-education/projects/corona/

industry and academia. Specifically, the project aims at the implementation of the following joint E&T tools:

- Student research projects to facilitate students from the participating universities to get hands-on experience in Europe's unique and specialised laboratories and student internships) in research and industry, increasing the value of the students' curriculum.
- Intersemester courses for graduate and post graduate students on special industry related topics, which will be provided by academics and specialists from research and industry.
- A series of modular courses, leading to an executive European Master of Science, for young professionals working in, among others, industry, consultancy companies or regulatory bodies, to enhance their knowledge of nuclear reactors and fuel cycles

- **NUSHARE** – *Project for sharing and growing nuclear safety competence*: (Proposal no 335530 - submitted in October 2012)

  NUSHARE is in fact a "*Training and Information programme, drawing the lessons from Fukushima*". This "coordination action" of 4 years, under the leadership of ENEN, is an initiative supported by two Commissioners (Research and Innovation, and Energy) as a consequence of the triple accident in Japan (11 March 2011). The main objective is to share and grow across the EU the nuclear safety culture in all nuclear installations and in all applications of ionizing radiations. Security aspects (in particular, proliferation resistance and physical protection) will also be treated. Therefore an ambitious training and information programme will be conducted in all Member States interested, targeting three types of audience: (1) policy makers (including the radio-medical community); (2) regulatory safety authorities and technical safety organisations (TSO); (3) industry (systems suppliers and energy providers). The synergy with the stakeholders will be ensured through regular contacts with the "European Technological Platforms" and/or specific stakeholders' associations concerned (for example, to discuss mutual recognition across the EU). Collaboration with non-EU countries is welcome (in line with the conclusions of the "stress tests")

Detailed information about these actions are reported during the FISA Conferences[35].

Beside these programs the following initiatives of the Joint Research Centre (JRC) are being adapted to the recent developments in the nuclear industry and regulation for building the necessary competencies in nuclear field: ESARDA, EN3S and EHRO-N.

- **ESARDA** – European Safeguards Research and Development Association is organising academically recognized training courses on nuclear safeguards and non-proliferation.

[35] FISA-2009 - http://cordis.europa.eu/fp7/euratom-fission/fisa2009_en.html,

- **EN3S** –European school for Nuclear Safety and Security is creating a learning programme for graduate and post-graduate, based on JRC's expertise. The education will be developed in close collaboration with academic and other different organisations [[36]].

- **EHRO-N –** European Human Resources Observatory in the Nuclear Energy Sector is exploring the link between supply and demand for nuclear human resources in the 27 European countries. It created a database of nuclear skills needed in the short, medium and long-term perspective which should be periodically reviewed. EHRO-N together with their Senior Advisory Group (SAG) members, being the major nuclear stakeholders, is working also on the identification of gaps and deficiencies in the nuclear educational and training infrastructure in the EU-27 [9].

Although many initiatives in nuclear fission education and training were supported and financed by the EU, there are additional organisations on the European level which are actively involved in the nuclear education and training.

- European Nuclear Society **(ENS)**[37] as a largest society for science and industry in Europe decided to extend its activities to nuclear Education, Training and Knowledge Management (ETKM). Therefore ENS created the Education Training and Career Platform, where information on education training opportunities provided by different stakeholders in 22 European countries is presented. Additionally ENS is organising two specific conferences which are dedicated to education and training - NESTet and ETRAP (E&T in Radiological Protection), gathering the key players of ETKM from all over the world.

- From the industry side – the European Atomic Forum (**FORATOM**)[38] created an ETKM Task Force providing a gateway for industry input to the EU institutions and various EU initiatives in the area of education, training, and knowledge management.

- Four European TSOs, located in France, Germany, Czech Republic and Lithuania, created in 2010 the European Nuclear Safety Training and Tutoring Institute (**ENSTTI**) open to TSOs and nuclear safety authorities that wish to offer their experience and competence; it covers the whole spectrum of competences in nuclear safety. ENSTTI offers short applied training sessions and tutoring periods for university graduates and for those with some professional experience in the nuclear sector, adapted to the profile of each individual.

Europe's aspiration for innovation leadership goes also through the **EIT**. The European Institute of Innovation and Technology established in 2008 by the European Parliament and the Council aims to becoming a flagship for excellence in European innovation. The EIT is the first EU initiative to integrate fully the three sides of the 'Knowledge Triangle' (higher education, research, business/innovation) seeking to stand out as a world-class innovation oriented reference model, inspiring and driving change in existing higher education and research institutions. The EIT consists

[36] http://ec.europa.eu/dgs/jrc/index.cfm?id=1410&obj_id=14320&dt_code=NWS&lang=en

[37] http://www.euronuclear.org/

[38] http://www.foratom.org/

of a number of "Knowledge and Innovation Communities" (KIC), with a proposed funding of € 1360 (+ conditional 1440) million) under Horizon 2020.

Of particular interest for nuclear fission is the current **KIC InnoEnergy [[39]]**, a company, with all its implications: built upon an industrial plan, results and output oriented, commitment from shareholders for a first period of 7 years, financially sustainable in the medium term. The KIC InnoEnergy covers all the SET Plan thematics, shared among 6 Colocation Centres: one of them is "Sustainable nuclear & renewable energy convergence". Business creation activities are coupled with Research & Innovation Projects as well as with Education and Training. As far as education and training towards the needs of industry is concerned, the KIC InnoEnergy launched a European Master in Nuclear energy (MSc EMINE)[[40]] as a partnership between universities (UPC, KTH, Grenoble INP and Paristech), major companies and research institutes (Vattenfall, AREVA, EDF, ENDESA, CEA) which are hosting EMINE students for in-hands sessions at their experimental reactors (EDF & CEA). Dealing with training, another project INEPT [[41]] is aiming as a recognized European platform to maintain and increase the excellence of the nuclear community by proposing access and training on facilities which allows knowledge of nuclear operations. Another objective is to increase the competitiveness by identifying and proposing a set of good practices as an international standard.

Furthermore the EIT provides enhanced opportunities for links and concrete connections with Cohesion policy, since its Knowledge and Innovation Communities (KICs) use the collocation concept where KICS stakeholders share together physical space to spark more innovation through cluster-like interactions. KICS hold a strong potential for effective local and regional spillovers that are able to benefit a lot of potential participants in H2020 across the Union.

At the international level

The European Nuclear Education Network (ENEN) is a partner of the **World Nuclear University (WNU)**, a global public-private partnership committed to enhancing international education and leadership in the peaceful applications of nuclear science and technology.

The **IAEA** has many projects concerning knowledge management on nuclear energy. It offers a selection of information in nuclear energy publications, manages over 20 databases on different nuclear issues as well as an Internet Directory of Nuclear Resources. One significant activity of the IAEA is the International Nuclear Information System – INIS.

The **OECD/NEA** established at the end of 2009 an Ad-hoc expert group on Education and Knowledge Management, involving 23 experts representing 15 countries, EC and IAEA. Its main task is to produce a snapshot of the current situation in nuclear education, facilities and training and provide a "blueprint" for assuring nuclear competence. The OECD/NEA's most recent publication from April 2012 around E&T is entitled "Nuclear Education and Training from Concern to Capability"[20] (OECD/NEA 2012).

---

[39] http://www.kic-innoenergy.com/homepage.html

[40] http://www.kic-innoenergy.com/education/msc-programmes/msc-emine.html

[41] http://www.kic-innoenergy.com/innovation-projects/inept.html

The **International School of Nuclear Law (ISNL),** established in 2001 by the OECD/NEA and the University of Montpellier, benefits from the support of the IAEA. Its objective is to provide a high quality, intensive course in international nuclear law, addressing, in particular, nuclear law students at doctoral or masters level and young professionals in the nuclear sector.

At the Member State level

A number of National Education Networks have been established in several EU Member States and are collaborating under ENEN. Quite a number of big national initiatives increase the number of students and enhance qualifications.

Several EU Member States have ongoing or commencing programmes on the area of national and international nuclear education networks, including the following ones:

BELGIUM	BNEN	http://www.sckcen.be/BNEN/
CZECH REP.	CNEN	http://www.cenen.cz/kontakt.html
DENMARK	NKS	http://www.nks.org/en/welcome.htm
FINLAND	FINNEN and YTERA doctoral programme	http://www.tkk.fi/en/ and http://tfy.tkk.fi/ytera/
FRANCE	INSTN, I2EN, IFCEN	http://www-instn.cea.fr/ http://www.i2en.fr/fr/, http://www.i2en.fr/fr/news/41
GERMANY	Kompetenzverbund Kerntechnik	http://nuklear-server.ka.fzk.de/Kompetenzverbund/start.htm
ITALY	CIRTEN	http://www.cirten.it/
NETHERLAND	KINT	http://www.kint.nl/
ROMANIA	RONEN	http://www.ronen.ro/
SWEDEN	NKS	http://www.nks.org/en/welcome.htm
U.K.	NTEC	http://www.ntec.ac.uk/

While in the past the initiatives often focused mainly on the university level, the new developments lead to a widening or re-orientation of existing approaches and also to new initiatives covering post-graduate programmes as well.

A detailed survey of the overall actions made at the level of MS has been made by EHRO-N: "Mapping of Nuclear Education Possibilities and Nuclear Stakeholders in the EU-27"[[42]]. Visualized data with support of "Google Maps" can be detailed on the "EHRO-N resource maps" http://ehron.jrc.ec.europa.eu .

[42] EHRO-N report: "Mapping of Nuclear Education Possibilities and Nuclear Stakeholders in the EU-27", JRC 67016, EUR 25160 EN, ISBN 978-92-79-22715-8, ISSN 1831-9424, DOI 10.2790/41101

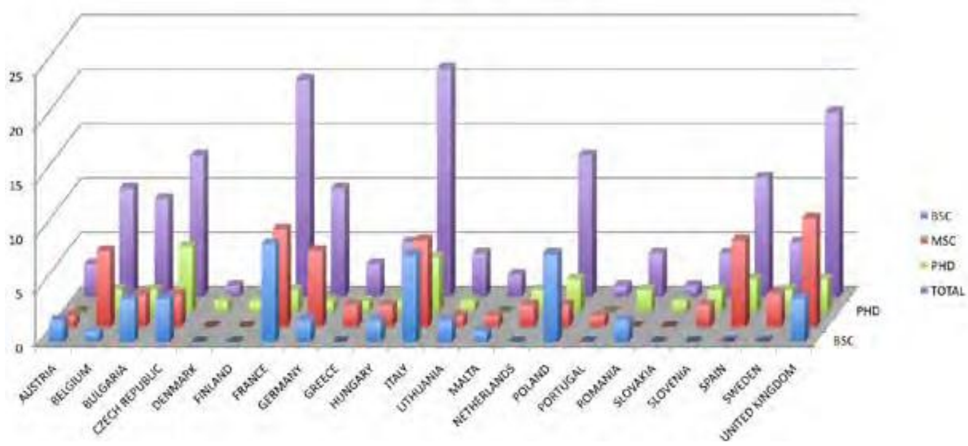
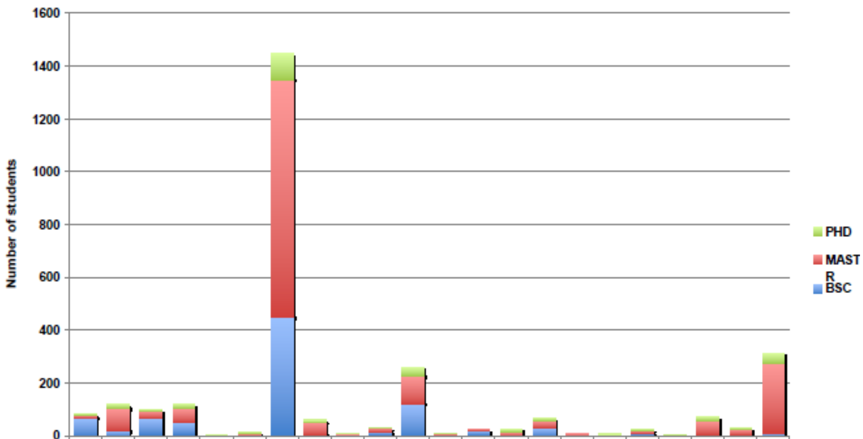


Figure 31. .Degrees per country. Source EHRO-N report (2012 p.12) [41]

Relevant information are also available on the ENS portal[35], which is in tight cooperation with EHRO-N.



	AT	BE	BG	CZ	DK	FI	FR	DE	GR	HU	IT	LT	MT	NL	PL	PT	RO	SK	SI	ES	SE	UK
PHD	5	17	6	17	5	5	100	7	4	1	35	2		12	10		6	7	3	14	6	40
MASTER	10	84	26	53		10	900	48	6	18	105	3	5	14	26	10		11		56	20	263
BSC	67	20	65	50			450	5		12	120	5	17		30			7			5	10

Figure 32. Number of graduates in the nuclear sector in 2009 on BSc, MSc, PhD level (per country). Source EHRO-N report (2012, p.42)[5]

Fusion:

In the Fusion field, there are three actions or organizations that together cover everything concerning education and training at the European level. These are:

- **EFDA**, the European Fusion Development Agreement, which falls under Euratom. [[43]]
- **Fusenet**, the European Fusion Education Network, an FP7 coordination action [[44]]

---

43 http://www.efda.org/

44 http://www.fusenet.eu/

- **FIIF**, the Fusion Industry and Innovation Forum
- **F4E**, the European domestic agency for ITER does not have any direct training actions currently, except for the agencies own staff.

EFDA, Fusenet and FIIF are well harmonized, there is regular contact at board level as well as informal contact at working level. Training is covered by EFDA, with the Goal Oriented Training (GOT) programme, which selects candidates and training proposals and financially contributes to a 3-year training programme. GOT delivers approximately 40 trained engineers per year in targeted fusion technology areas.

EFDA also runs the Fusion Fellowship programme, which promotes excellence among young researchers by competitively making available 10 two-year post doc grants per year.

Education is coordinated by the umbrella organization Fusenet. Under this umbrella, many different actions are found. Fusenet has established joint criteria for the award of the European Fusion Doctorate and Master certificates, which set a high common standard.

At the **PhD-level** the following actions are coordinated under Fusenet :

- The European Fusion Doctoral Network (Universities of Padova, Lisbon, and Munich)
- The Erasmus Mundus Fusion Doctoral School (7 universities, more associated members)
- The UK Fusion Doctoral Training Network (participation of UK universities)
- PhD programmes at Member State or university level
- Furthermore Fusenet offers a harmonized programme of summer schools, annual PhD events, training sessions in hands-on educational labs, etc.

At **Master** level, the joint master criteria bring together various pre-existing actions:

- French Fusion Master track (1 year specialization)
- Eindhoven University of Technology – 2 year fusion Master
- Prague Fusion Master programme.
- The Erasmus Mundus Fusion Master
- Furthermore Fusenet offers a harmonized programme of summer schools, shared access to experimental facilities, web-based learning environments, joint development of education materials etc.

Generic:

- The Fusenet website provides an attractive and transparent interface for students who are interested in fusion. It links them to the various education programs, internship possibilities etc.

Through the **FIIF**, industry is being more strongly involved in these training and education programs, e.g. through internships.

Fusion education and training builds on the very strongly coordinated European Fusion research programme, which includes a large number of different facilities. This research programme has been coordinated by Euratom for decades and is truly integrated at the European scale. The research facilities – naturally the Joint European fusion experiment **JET**, but also the larger experiments in national laboratories – are exploited by European teams. In this context, it is natural that training and education also have a strong multinational European orientation.

The **F4E** agency does, however keep a watching brief on the training actions of EFDA, FUSENET and the FIIF as it has an interest in employment of high quality engineers especially with nuclear and project management expertise. After ITER construction is completed F4E may have a role in E&T.

Result and impact of such actions.

Fission:

High quality nuclear education and training is required to provide the workforce of today and tomorrow. With increased worker mobility it is now emerging that an international approach is required to assure the employer that qualifications demand a similar standard of knowledge and expertise of the employee wherever they are gained.

The different programmes run during the past years **have increased the European cooperation** of national and international programmes and help to interface research and industry. A further integration step is needed to **enhance exchanges and collaboration between key stakeholder from University, Research, Infrastructures or Industry** in key and strategic area for Europe.

Fusion:

The fusion education schemes in Europe, under the Fusenet umbrella, greatly enhance the attractiveness of fusion for students, and make the opportunities for students more transparent and readily accessible.

Support to individual students – for internships outside their country, for participation in summer schools or master classes - is a very cost-effective means of stimulating students. Fusion has the attractions of big science in an international environment, which appeals to good students. With a proper financial support programme these advantages can be effectively played out in order to attract and bind good students.

The European actions – both Goal Oriented Training (GOT) under EFDA and the matchmaking for internships under Fusenet – help to interface education to industry. The link with FIIF is very important here.

The coordination of education through Fusenet is an effective means to increase the general level of fusion education, through joint educational goals and standards, shared resources and shared best practices

The EFDA GOT programme is targeted at expertise areas where shortages are foreseen, and therefore an important and effective tool in the HR planning and management.

Brief comparison with on-going efforts in other developed countries.

On Nuclear Energy the five main international networks are: ANENT (Asia), LANENT (Latin America) and AFRA-NEST (Africa) launched by the IAEA [45], ENEN (Europe), WNU (Worldwide).

There are also good examples of national networks outside EU. In Canada the University Network of Excellence in Nuclear Engineering (UNENE), the Natural Science and Engineering Research Council (NSERC), and the CANDU Owners Group (COG) have come together to focus resources on building capacity in nuclear engineering education in the universities;

In the USA the Nuclear Engineering Department Heads Organization (NEDHO) is composed of the leaders of all the academic programmes in the country;

In Russian Federation the recently established National Research Nuclear University MPhI has united five specialized universities, three regional branches and 13 colleges, with more than 30 thousand students on total to enhance the effectiveness of nuclear education and provide sufficient number of engineers for the nuclear sector needs.

In the USA and Canada, outreach to high schools is very active.

In these countries the use of new media and electronic methods is also developed in nuclear education.

Several projects of distance learning (e-learning, cyber-learning) can be mentioned. Probably the most recent development is the Asian Network for Education in Nuclear Technology (ANENT).

To fill the gap of providing educational experiences with a reactor to universities that do not have their own facilities, North Carolina State University has created a 'virtual' reactor laboratory.

Several databases and teaching materials are also available electronically. The large international networks (ENEN, ANENT etc.) maintain and update their own databases. In Canada CANTEACH is a database of reference and teaching materials on CANDU reactors.

The IAEA has a long tradition of maintaining nuclear databases (e.g. INIS), and other nuclear educational tools (e.g. reactor simulators, video-recorded lecture courses etc.) which are freely available for users of the Member Countries and nuclear educational institutions.

---

[45] http://www.iaea.org/nuclearenergy/nuclearknowledge/networking/About.html

3 Needs and gaps, main barriers or bottlenecks for the nuclear energy sector.

Needs and gaps.

Fission:

A need for human resources:

The distinctive characteristics of nuclear energy and its fuel cycle provide special requirements for education and training. Nuclear plants need to be safely operated, maintained and eventually decommissioned. Specific skills are required for these purposes.

Needs are expressed to maintain an adequate skilled and competent workforce, and to develop a flow of new recruits for long term sustainability.

Policy decisions must anticipate these needs in sustaining an effective workforce pipeline.

A need to match supply and demand:

Actual challenges are in attracting students into specialist nuclear power fields. There is **a big** demand of the industry, in the field of nuclear engineering and technology, for students having had a nuclear energy related subject in their studies, since enrolment covers actually only up to 70% of the demand. (some 2 800 in the EU-27 graduated in 2009 in comparison with 4 000 needed on average by 2020) (EHRO-N 2012, p. 64-66, 69). (This percentage could be even less if one considers the information collected from the supply side without the adjustments done after the benchmarking exercise (45%!))

Moreover, demand for graduates in nuclear chemistry and the fuel cycle is the hardest to fulfil, mainly because the investment needed to establish the necessary faculties. This example stresses out the lack of specific faculties in delimited fields. (i.e.: need of 2% of nuclear chemists, 2% for radioprotection.)

The OECD/NEA reports published in 2000 and 2008[46,47] have also noted that the overall losses of technical competencies and skills varied from one country to another according to the strength of the nuclear power programme. The paradoxical result is that concerns about workforce shortages appear to be expressed less often in countries with faster growing programmes.

The demand for nuclear experts which is not fulfilled by the supply from the higher university institutions in the EU-27 is directed towards the other Science, Technology, Engineering & Mathematics (STEM) graduates (e.g. non-nuclear engineers, physical scientists, etc.).

In a first view, it seems that the number of STEM graduates in EU-27 could fulfil the need of the nuclear energy sector, considering that these are nuclearised to a desired degree of expertise. But one has to take into account that these same STEM graduates are also needed by other (energy)

---

[46] OECD Nuclear Energy Agency, Nuclear Education and Training: Cause for Concern? Paris, France, 2000.

[47] OECD Nuclear Energy Agency, Nuclear Energy Outlook 2008, Paris, France, 2008.

sectors. Besides these considerations the sustainable development of the nuclear technology an important need is expressed for nuclear experts, for professors and researchers by the universities and for trainers by the nuclear training organisations". The rising demands for STEM graduates is moreover crucial, since nearly half (50%) of the nuclear experts employed today in the Nuclear Power Plants in the EU-27 will need to be replaced by 2020 (in comparison with 25% aging population in other relevant fields like engineering).(EHRO-N 2012, Chapter 5 Lessons Learnt, p. 67)[5].

The numbers of STEM graduates can therefore be considered to be inadequate in the EU-27 in general. This situation may be different from one EU-27 country to another depending on its attitude towards nuclear energy (see Annex 1).

Presumably each of the Member State faces different kind of problems in ensuring the availability of a necessary human resource for safe operation and/or dismantling and disposal of their nuclear installations, but the question has to be taken into account globally at the EU-27 level.

A need to attract young students and talents:

There are two main challenges that the EU is facing in the today context:

- Attracting more students to undertake STEM studies;
- Increase the attractiveness of education programmes to foreign talent.

In a world globalised context and a rapidly changing world, the higher education in EU, in the fields of science and technology, is facing nowadays an increasingly growing lack of interest from the young generation. This new generation has new sociological behaviours, is born with internet and fully "connected", is sensitized to ecological aspects and societal challenges (nuclear energy debate as a part), is mobile (ERASMUS) and flexible.

In this context, the nuclear energy sector needs to be more open and aware of the environment in which it operates. It should cooperate, rather than compete, with the other energy sectors, to develop adequately the human resources, skills and competences needed tomorrow by the global energy market (EHRO-N 2012, p. 68) [5].

Europe, which was until now the first "provider" of highly educated graduates is surpassed today (in numbers) by the emerging countries, which have also started to access to the nuclear energy market.

A worldwide cooperation is therefore needed in order to get highly skilled workforce where it is required, but also to give access to world-class programmes to the best students from all around the world.

A need to foster mobility (transnational and trans-sectorial):

With a small number of technology vendors operating worldwide, the context in which nuclear industry operates is becoming progressively more international. Research and development in reactor technology are also increasingly taking place across international borders. This has been accompanied by an internationalisation of the civil nuclear supply chain.

As a result, the needs have emerged for a globally agreed set of nuclear competencies and safety awareness training that are as transferable as the technology they support. This needs also have to be developed within international harmonised programmes and initiatives.

Enhanced mobility of students and personnel raises issues of mutual recognition of qualifications and skills.

The issue of quality assessment and assurance, which is now becoming more prominent, both in relation to training courses and their outcome and the need for accreditation (including peer review of international training programmes open to external entrants). The ability to ascertain the quality of candidate trainees and students in order to make good selections is also becoming a necessity.

A need to adapt continuously Knowledge, Skills and Competencies:

A new **commonly recognized and shared Job Taxonomy** has to be developed between Member States and main stakeholder in the nuclear value chain. (see OECD 2012) and section 3. This Job taxonomy should develop a Competence driven analysis based on Technical, Regulatory, Business and Personal Skills. This is actually in an early stage, with neither a final nor a unique solution, but which is pursuing further. .

In the nuclear industry ensuring a competent workforce is paramount for the safe operation of any nuclear-related activity, and in instilling the confidence of stakeholders. National and international policies and regulations apply to this industry. These require the highest specifications of safety and reliability in both the technology and in the competence of those employed to design, build, operate, maintain and decommission nuclear facilities. Independent non-governmental bodies support and advise here. Undoubtedly, for employees working on a nuclear licensed site or in the supply chain of a nuclear operator, safe behaviours are critical, particularly with increased proximity to the "nuclear island" and controlled areas. This has been further emphasised by the impact of human factors in incidents and accidents, **highlighting the importance of safety culture and safety training in nuclear operations. (in connection with post-Fukushima Daiichi requirements)**

The nuclear industry is therefore characterised by high overall skill levels, in design, construction, operations, research, and management, reflecting the technology and the high degree of safety regulation. Safety is a pre-eminent concern in the nuclear industry overwhelmingly for its own sake, but also its sensitivity in term of public perception and, formally, because of national and regional regulations and international agreements. The importance of training and education in maintaining safety cannot be understated. For all of these reasons, **safe behaviours are regarded as critical skills** that sit in parallel with the specific technical competencies for the job. In turn, comprehensive and sustainable nuclear education and training supported by management and leadership behaviours are required to generate and maintain a robust safety culture.(OECD 2012).

Specific needs are also expressed **in nuclear law experts** and their expertise (i.e.[48]) These experts are relevant in the field of liability, legislation, regulations, etc. Even if they represent a small

[48] http://www.oecd-nea.org/law/isnl/ , http://ola.iaea.org/ola/nli/about.html

percentage of the total nuclear experts population they are needed to complement other engineering or management skills.

Both the utilities and the vendors rely on verifiable levels of competence in the workforce. This is required not only for their own workforces but also for those in the supply chain from whom products and services are contracted, and for whose competence they may ultimately be held responsible. A **framework for competent workforce training** and education at all levels would therefore be useful to comparability and possibly interoperability of standards for training and qualifications, enabling mobility and retention of suitably qualified and experienced personnel and better confidence in the safe and secure development of nuclear in developing countries. It may also provide a robust basis for international labour market research, scenario planning and human resource observatories; the development of "passports" or license to practice for competence assurance; and as guidance for the safe and secure development of nuclear personnel in developing countries. In this range of needs **ECVET should widely be developed** to facilitate the mobility and portability of qualifications.

To face an insufficient supply of STEM graduates, the economic practices might change as well and profiles needed for emerging market for greener products may develop eventually new skills which could be readapted to the specific needs of the nuclear sector.

A need to foster cooperation along the value chain: bridging University, Research institutes and Industry

The integration of national research facilities and academic institutes in international frameworks needs to be improved. It is widely recognised that strong research programmes, increased participation in international initiatives and greater involvement of government, industry and academia in research and training can considerably improve the attraction of high-level students and young researchers.

Co-ordination with universities and other stakeholders needs to be developed through **direct participation in academic curricula**, the promotion and delivery of courses and seminars to a varied audience, the offer of internships, the provision of well-equipped laboratories and guidance to domestic and foreign students for their research, the awarding of prizes, grants and fellowships, and the organisation of visits.

The important interactions among industry, universities and government also in producing a competent workforce with the right mixture of knowledge and skills are reflected in figure 12 below. The IAEA publication *Status and Trends in Nuclear Education*, from which the figure is taken, points out that co-operation is critical in both creating and maintaining education and training programmes and in attracting young people towards nuclear engineering (IAEA, 2010a). Equally importantly, it allows the skills demand to tune educational programmes to provide a better match with industrial needs. With the generic underpinning established, industry is then able to focus on the specific additions required in the work place.

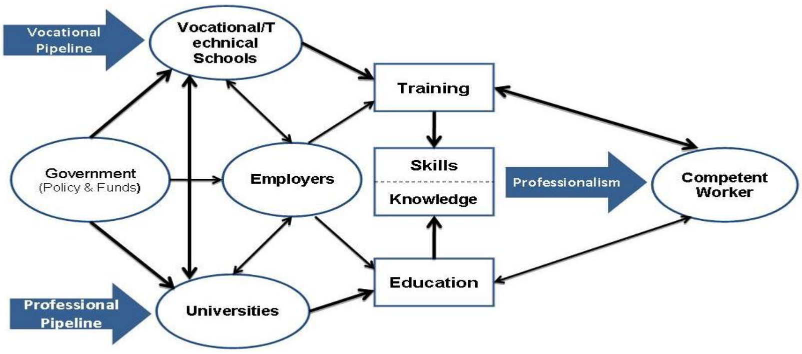


Figure 33. Competence pathways. Source IAEA 2012[49]

A need to introduce Innovative methods for education and training

The spreading of international programmes and networks can benefit from improved technological means such as distance learning. Innovative learning methods are introduced by novel communication systems and means. The use of web-based resources as well as distance learning becomes a widely adopted practice. They are particularly valuable in circumstances where physical or geographical obstacles would prevent the provision of courses or make them significantly more onerous, helping to widely enlarge the pool of prospective students. Several examples of this type can be developed (i.e. Explore Energy [50].)

The nuclear energy sector can also learn from other innovative training solutions (from other sectors):

- Joint initiatives by social partners at sectorial or regional level;
- Collaboration between companies and training providers or universities;
- Research institutes undertaking community-level training;
- Proactive approaches by international professional associations and NGOs involving training of trainers and projects out of reach of formal training provision.

Fusion:

Fusion energy will need an expanding workforce in the coming decades. It is an interdisciplinary field, combining many areas of technology and physics. The challenges of Fusion energy – extreme demands in many respects: e.g. materials, control, advanced measuring techniques, high power microwave technology - make that the development of fusion power is a driver of innovation. Fusion is energy for tomorrow, but innovation today.

In this perspective, the needs for the research work force are quite well charted. The educational programmes coordinated by Fusenet cover this need, provided Fusenet is adequately funded.

[49] Status and Trends in Nuclear Education : IAEA Report : ISBN 978-92-0-109010-2 : http://www-pub.iaea.org/MTCD/publications/PDF/P1475_web.pdf

[50] http://www.exploreenergy.eu/VirtualCampus/tabid/652/language/en-US/Default.aspx

Needs for fusion industry are under development. At this stage in the programme any training has to be targeted at a small but influential group. As the DEMO activities accelerate, training will be broadened to cover all the needs.

Student interest needs to be fostered but the potential is very good. Students perceive fusion as an attractive field, because of the extreme challenges in science and technology, the interdisciplinary character of the field and its international aspect, as well as the fact that it can contribute to saving the long term need for clean energy.

Fusion education is so challenging, broad and interdisciplinary that students have great job opportunities afterwards, also outside fusion. 'Fusion' can be a brand, like aeronautics is a brand. It stands for highly educated, high quality engineers, who find wide employment also outside their field of specialisation.

Main barriers and bottlenecks.

Fission:

The following main barriers have been identified:

- **Lack of clarity** as for the place of nuclear in the energy mix which sends a negative signal to potential students/future workforce in the nuclear sector.
- **A lack of coherent intervention** by governments, industry and universities to avert the risk of severe personnel shortages, and to maintain the stock of a skilled and competent workforce as well as a flow of new recruits. This should be sustainable in the long term and adequate to offset the attrition and impending retirement of ageing workforce countries.
- **National diversity in regulatory practice** and approaches to the supply, demand and accreditation of education and training hinders harmonisation.
- **A deteriorated global context** caused by the persistent financial crisis and the negative sentiments after Fukushima Daiichi's accident create uncertainties and may exacerbate existing shortcomings in workforces.
- **Contradictory energy policies** can have negative effects. Shifting or deferred government decisions act as deterrent mechanisms in investment and employment, and have deleterious repercussions on the interest and engagement of younger people in the industry.
- **Not enough international initiatives** to allow a global answer to the workforce needed.
- **Competition for the Nuclear and STEM students** amongst the different energy fields.

Fusion:

The main barriers and needs identified are:

- A lack of **expertise** on nuclear competences caused by the broad interdisciplinary nature of the field.
- A lack of **funding** to develop oriented training in fusion.

4 Recommendations at EU and Member State level within specific target dates.

The life cycle of new nuclear power plants covers a period of approximately 100 years, from design and construction to dismantling and "green field". Concerns about possible shortage of nuclear experts in the near future could be at risk for the future to ensure the building of new facilities and / or to safely operate installations, and, in particular, to manage radioactive waste and to deal with radiation protection issues.

For these reasons, broad and deeply rooted education, research and training programs, at both national and international levels, are essential to the proper mastering of the many disciplines used in the nuclear domain.

Education nevertheless is one of the competences claimed at the national or regional level in the EU Member States. Higher education is usually under the responsibility of universities, whereas training (in particular, in the nuclear sector) is under the responsibility of industrial or regulatory ad-hoc organisations. As a consequence the EU integrated actions should be concentrated on challenges where the EU added value is clearly demonstrated.

One of the current challenges for knowledge creation and competence building in the EU nuclear sector is to create instruments that meet the requirements of both employers and learners, with emphasis on borderless mobility and lifelong learning.

Changes in nuclear E&T programmes will be influenced, in particular, by requirements such as:

- Development of a common nuclear safety culture world-wide, based on technical and organisational excellence (where public / private research is playing an important role); need to harmonise regulations across the EU; new approaches for human resource development in a multicultural environment; public nuclear debate (understanding and acceptance).
- Need for scientific and technological innovation; increasingly multidisciplinary and international character of the nuclear sector; different national policies regarding nuclear fission in the energy mix; high-level decisions needed over long time scales; trend towards outsourcing of activities.
- Need of a better qualification offered to the next generation of leading European talents, taking advantage of a variety of learning pathways, of the changing multicultural environment (e.g. through increased mobility of workers, trainers and learners), and of networks of competences.

To support these ideas the following recommendations and actions can be proposed:

Filling the skills, competences and knowledge gap

Meeting the skill/competencies gaps

Recommendations:

- **Identify and improve** education and training **in domains with potential shortage/domains needing new competences** (including educators and trainers) and support the internationalisation of these programmes especially on nuclear safety, radiation protection, Knowledge management. Networks such as those developed for educational programmes should be expanded to also cover technical vocational training and all levels of educational programmes should include learning content about the sociological impact of the industry on the society.

- Study the feasibility of networking training institutions into interdisciplinary and multi-company training providers. Co-sponsor the creation of an interdisciplinary and multi-company training organization to share and improve the industry competences especially in nuclear safety and operational excellence.

- Sustain education and develop training in Fusion.

ACTIONS:

A1: Identify and improve education and training in domains with potential shortage/domains needing new competences in nuclear energy

Action: Carry out a more detailed gap analysis based on the survey made by EHRO-N in identifying the needs of specific competences that are potentially in shortage or that need to be developed for the future (applies especially for GEN IV and geological disposal)

The analysis will give a more detailed focus on training activities that need to be prioritized to meet the demand for the future years (2050) in nuclear energy at all stages of the nuclear fuel cycle. **The gap analysis should include the future needs of educators and trainers** (university professors and trainers of professionals) in these areas at a shortage situation, too.

EHRO-N input will promote demand driven education and training that can be implemented in cooperation with public and private funding.

Timeframe: (for analysis): 2012 - 2014

Objectives: Integrate the results of the EHRO-N study with the surveys carried out on national level on competence areas in specific demand and in the EC framework programme surveys (many carried out in cooperation with ENEN association in the field of nuclear engineering, radiation protection and nuclear waste management).

A2: Study the feasibility of supporting creating or networking training institutions into interdisciplinary and multi-company training providers

Action: Study the results the EHRO-N report on education and training needs and of job competences mostly at shortage. Take advantage of the work on the nuclear sector job profiles and make up a feasibility assessment on the volumes needed for self-sustaining interdisciplinary training provision to address the different target groups for training.

Identify the training areas that can be sufficiently covered with normal market driven activities and look at the sectors that cannot be sustained by training markets but are required in the field and provide a sponsoring scheme for these to ensure that the "market prices" of the training would not excluded some European countries from participating.

A funding mechanism for individual or group participation to join such training would also need to be looked at.

Timeframe: 2013 onwards

Objectives/Challenges: Produce a networked model of providing complementary or non-overlapping training for a) large number of personnel having demand in the basic knowledge, skills and competence continuously needed in the nuclear sector and b) addressing the training needs related to the competences at risk (often required in smaller volumes, where cooperation of different providers would be of advantage).

The training institutions should be operating on a commercial basis in an industrial sector as big as the nuclear energy. National regulatory differences can reduce potential of reaching the critical participant numbers for sustainability and interdisciplinary training can easily compromise the specialised content in demand.

A3: Support internationalisation of programmes (for FISSION & FUSION)

Action: Networked educational programmes are needed for all levels of education when aiming at a high European wide safety standard at the nuclear facilities. A major bottleneck in the current internationalisation is the limited sources of support for moving groups of students with their teachers and tutors around in the international programmes and related exchanges. Most support forms are intended for individual students, post-graduates or teachers.

- Support to individual students to take part in joint educational activities or internships in industry or research labs.
- Support to joint educational activities, such as summer schools and annual PhD-event
- Support to joint development of educational materials: hands-on and web-based.
- Maintenance of Interactive website, using web-based techniques bringing new generation of scientists and engineers together.
- Specific set of actions – including support to student mobility – aimed at stimulating the nuclear E&T in the new Member States.

Building up international communities of practice already at the basis educational level is a modern day demand. Other means like videoconferencing via internet and social media can strengthen such networks but the best new practices and innovations that turn into concrete actions are founded on face-to-face interaction and confidence building between individuals. Support forms for moving such student and young (and old) research groups to exchange, to study and work together in practice are needed.

Timeframe: 2014- onwards

Objectives: Set up a support mechanism that is able to provide support for more than single individuals for international mobility. Such a support should provide for multilateral exchange (not only bilateral).

These actions enhance the visibility and attractiveness of nuclear energy to students, are essentially European (as opposed to national), and build on the existing research infrastructure, including large facilities.

A4: Oriented training program in Fusion

Action: The Goal Oriented Training programme (GOT) run under EFDA is an effective tool to target the gaps in the competence profile of the workforce. Now that fusion enters the nuclear arena for real, several hundred engineers will need to be trained in the fusion-specific nuclear area. This fusion-specific GOT programme requires funding, at full cost, of about 13 Million Euros/year.

The fusion field is undergoing a transition, which calls for additional training of existing professionals, in particular in nuclear technology. A training programme and methodology needs to be developed and launched.

Industry is getting involved in fusion, primarily through the ITER project. In-company and/or part-time training schemes and courses must be developed to teach fusion-specific technology to engineers and technicians who work in industry

Timeframe: 2013- onwards

Objectives: enhance the competence of the workforce and build on the existing research infrastructure, including large facilities.

Strengthening and developing existing skills/competencies

Recommendations:

- Appropriate actions at national and union level shall be taken to **strengthen the nuclear safety workforce** profile and to **set up and maintain nuclear knowledge management activities** inside nuclear organizations and to share among organizations relevant knowledge, like on nuclear safety.
- The **fusion** field is undergoing a transition, which calls for **additional training of existing professionals**, in particular in nuclear technology. A training programme and methodology

needs to be developed and launched. In-company and/or part-time training schemes and courses must be developed to **teach fusion-specific technology** to engineers and technicians who work in industry. (not yet covered by Fusenet or EFDA)

- **Collaborate with other energy fields** to drive and share skills and competences and attract more students in science and engineering domains. Support European actions **to raise public knowledge and awareness in nuclear sciences** (e.g. exhibitions, school materials) and to keep attracting talents in nuclear organizations

ACTIONS:

A5: Strengthening nuclear safety, radioprotection and nuclear knowledge management workforce

Action: Aligned with the ECVET principles, European Fission Training Schemes (EFTS) should be further developed in strategic domains of: Safety, Radioprotection and Nuclear Knowledge Management. Proposals should be submitted by networks of organizations of pan-European character, consisting of academic institutions and public or private employers. These EFTS should consist in a variety of learning paths adapted to a variety of profiles in all nuclear sectors with the aim to bridge university knowledge with skills and competences needed in industry.

Timeframe: 2013 onwards

Objectives: Continuous improvement of nuclear safety culture trough public-private partnerships recognized as references at the international level.

Assisting Member States in maintaining and preserving nuclear knowledge.

Maximising the transfer of higher-level competences for young as well for experienced workers.

A6: Skills upgrade towards energy management and entrepreneurial skills.

European wide educational nuclear programmes, but including also learning content related to the sociological impact of nuclear energy Topics like global analyses of the energy market, how to change policy, corporate social responsibility, understanding “acceptance”, energy and environment, markets entrepreneurship, and public awareness should be addressed /developed. The programme should be based on innovative learning approaches and methods (hands on training) and would develop new profiles linking the nuclear sector to the other energy sectors and society. Proposals at the level of MSc &/or PhD networks should be based on a Private-Public partnership and could be taken up e.g. by a group of universities having both nuclear and social sciences in their programme in association with private stakeholder of the nuclear value chain.

Timeframe: 2013 - onwards

Objectives: Develop awareness of the nuclear sector for workforce in society. Increase the attractiveness of nuclear careers in public and private organizations across EU and strengthening links with other sectors in energy.

Fostering involvement, access and up-take by the labour market

Promoting mobility, life-long learning, workforce training

Recommendations for Fission:

- Promote **mutual recognition** of knowledge, skills and competences (ECVET).
- Consideration should be given to carrying over to training the **accreditation and certification** culture that is well established in education and to establishing independent accreditation and certification of training provision and employer schemes. Some countries have competence based qualification (similar to NQA in the UK). Such accreditation bodies need to be national (using ECVET) and need to comprise the academia/training provider, student/labour union representative and an industry/employer representative. This three party evaluation should be included in any proposed action around an accreditation body. At an European level, the TP's need to be involved.

ACTIONS:

A7: Nuclear ECVET Implementation Pilot Project

Action: The JRC/IET has taken over the development of a commonly recognized job taxonomy with requested skills and competences based on the OECD/NEA report[20]. It is being developed for the field of Design, Operation and Decommissioning in co-operation with recognized experts. A pilot project regarding the implementation of the ECVET principle in at least one of the three fields is proposed, including definition of learning outcomes, learning agreements, etc. The successful project will serve as an example for the other fields and will enable not only to improve EU-27 mobility of workers, but also the effective nuclear HR competence analysis, i.e. comparing competence existing with competence needs in the EU-27.

Timeframe: 2013 - 2016

Objectives: The goal is to set up pilot project with a core group of nuclear ECVET experienced stakeholders, who strive for a commonly recognized system. This will be the role-model for further ECVET implementation projects in other nuclear fields.

A8: Nuclear ECVET Certification Bodies Network

Action: In order to make the nuclear ECVET implementation function in the EU-27 a certification system for the ECVET “Learning Outcomes” and the “Learning Passports” has to be implemented. As the certification bodies are under Member States authority and vested in different institutions, a common approach should be prepared. Whenever the nuclear safety authorities are involved, reference should be made to European authoritative bodies such as ENSREG and HERCA to discuss possible commonalities between national nuclear training certification systems. It is clear, however, that the above mentioned "learning passports" do not constitute a license or an official authorisation (in the legal national regulatory sense).An initial analysis of possible National

Certification Bodies for a nuclear ECVET system had already been started by the JRC/IET. The work benefits from linking to the existing structures that are coordinated nationally in cooperation with CEDEFOP[51]. This enables the approval of the national educational authorities to the approach from the outset.

Timeframe: 2013 - 2015

Objectives: Creation of a Network of National Certification Bodies with the objective to harmonize the National approach in the best possible way.

A9: Community of Practice

Action: At the present time the nuclear ECVET team (of JRC) is fostering the creation of communities of practices in order to create informal networks regarding the implementation of ECVET. A community of practice is critical in order to have a specific forum for a nuclear ECVET, in which the participants (no close number of members) discuss, learn and share, taking into account their similar goals, interests, problems and approaches.

Timeframe: 2013 - 2015

Objectives: Creation of nuclear Community of Practice with the objective to share good practices, solve common problems and improve the implementation of ECVET.

Industry involvement and partnerships

Recommendations:

Improve Industry-University (training providers) **synergies**: develop university-industry chairs, promote teaching from industry employees in universities, host students in industry (PhD, internships, etc.), set up industry advisory groups in universities to orientate courses. Industry should be more proactive / flexible in supporting PhD or specific research proposals at universities through means of financial support (funds) or equipment, or to offer internship for a specific job role which may lead to a MS or PhD degree. Examples of successes are the UK's Nuclear Skills Academy working in collaboration with different companies to organize traineeships and apprenticeships. For Fusion: Fusenet, EFDA and FIIF (Fusion Industry Innovation Forum), who work together already, cover this action, as part of the Fusenet package and EFDA GOT program. But both programs need funding to be able to do this task.

Co-ordination of **the access to relevant nuclear instrumentation and critical facilities** suitable for E&T uses should be **internationalised** and efforts should be made by governments to financially support existing structure to perform R&D and enhance education. (need to address non-proliferation, safeguards issues and perform Hands-on experiences or have the organisation of Masters and Bachelor lectures at NPPs). For Fusion: the access to research facilities is well organised by EFDA + Fusenet. Fusenet has also stimulated and sponsored the development of

[51] European Centre for the Development of Vocational Training http://www.cedefop.europa.eu/EN/

educational hands-on laboratories for joint use. These programmes can be run effectively with a mobility fund for students to travel.

ACTIONS:

A10: Mobility through student research projects and internships on R&D facilities or in Industry. (for FISSION & FUSION)

Action:

- Training and teaching of skills in nuclear R&D needs requires access to relevant nuclear instrumentation and critical facilities, including research reactors to perform R&D and enhance education. The main tool for this will be student research projects of 6-36 Months (in different types of format to be defined,: exercise 2-4 weeks, team project 2-4 months, individual research projects 6 months to 3 years..)) in the laboratories of European facilities and other research institutions, to be granted to students from the associated academic partners after evaluation by an Executive Committee. The objective of the common research by means of student research projects (SRPs) is the coupling of expertise in the field of simulation and modelling at the academic partners with the experimental research on (real) nuclear materials, greatly increasing the scientific skills of the students.
- Internships in research and industry (3-6 months) for graduate students from the partner academic institutions are a second tool to be employed in this action. The objective of this tool is to provide students with practical skills needed in the nuclear energy sector and for that reason the stakeholders of the project will be strongly involved in this activity.
- The mobility plans have to include detailed procedures to grading the students (ECTS or ECVET)
- Infrastructure support should be provided to maintain existing nuclear facilities or “simulators” where these can be refurbished, or to replace them, when they are obsolete.

Timeframe: 2013 - 2020

Objectives:

- Stimulate mobility and access to nuclear facilities for graduate students
- Stimulate university-industry relations trough internships
- Effective and fair evaluation of the project proposals.
- Facilitate high quality scientific and applied scientific research.

A11: Development of executive master courses. (for FISSION & FUSION)

Action: Development of executive master courses for (young) researchers and engineers working in, among others, industry, consultancy companies or regulatory bodies, to enhance their knowledge of nuclear technology, with emphasis on issues related to topics for which the nuclear materials issue plays an important role.

- The master course should be typically composed of modules, which together yield a 60 ECVTS Master Degree (i.e.: four class room modules and two practical modules). Apprentice schemes, hands on training…and all types of innovative learning should be promoted.

- This type of program needs a strong connection between university and industry and should be done also together with research facilities. They will involve "trainers" from academic and industry as well as mixed "executive committees" to set up and pilot the program.

- The evaluation of the students outcomes must refer to quality assessment of learning outcomes bridging ECTS and ECVET (Europass).

Timeframe: Prototypes to be developed until 2014.Implementation in 2015.

Objectives: address the recommendation of the ETKM Working group of SNETP*: "Key stakeholders and academic institutions should engage in a joint action to optimise the curricula of academic programmes"..." and to potential synergies between academic and non-academic programmes for graduates, with the overall objective to create a sustainable graduate and vocational education and training programme in the nuclear field that meets the needs of the European stakeholders from industry, research and safety organizations"*

Planning and enabling skills development

Sector skills assessments and observatories

Recommendations:

- **Workforce** supply and demand for the Nuclear Energy Sector **should be monitored** in order to forecast trends and provide information on the demand/supply position. EHRO-N's operation should be long-term secured. EU-27 Member States/Nuclear Stakeholders should contribute to EHRO-N surveys

- Establish an European Nuclear E&T Council

- The staff survey action for fusion should be done regularly, but broader than in the past, covering both research and industry. Human resources planning should be made consistent with the fusion roadmap. The fusion-specific E&T actions should anticipate that planning.

ACTIONS:

A12: Establishment of National EHRO-N Contact Points in the Member States (with a chapter for Fusion)

Action: A Network of National Contact Points should be established with active counterparts from the Member States, in order to strengthen the qualitative outcome of EHRO-N data, analysis and recommendations…

- EHRO-N's operation should be actively supported by the national governments, nuclear safety authorities, nuclear industry and the E&T organisations within the EU-27, in order to provide the authoritative and comprehensive platform for strong interaction between nuclear energy stakeholders in the EU-27 as far as questions of nuclear human resource monitoring is concerned; concretely this could mean devising a commonly agreed methodology and database on the demand/supply situation of nuclear human resource.

- The output information can then be reliably communicated by conventional and electronic means to the Member States' governmental, higher education, and private organisations involved in nuclear E&T that could be used to report to the European Parliament and the Council of the EU and thus influence policy developments

Timeframe: 2013 - 2017

Objectives: The goal is to organize a first EHRO-N EU-27 Conference/Workshop on Nuclear Human Resources Issues and define the above Action and a Road Map

A13: Feasibility Study for a European nuclear sector E&T Council

Action: Based on the experience acquired in the EU in other sectors[52] and the UK example in the nuclear sector[53], a feasibility study for the establishment of a European Nuclear Education & Training Council (derived from the sector skill model) is proposed.

- The Sector Education & Training Council should extend its ambition to higher level of education with the goals to provide a strategic analysis of gaps and shortages, provide innovative paths to improve flexibility of the sector workforces and improve learning & training supply.

- The European nuclear E&T Council should establish the E&T governance in synergy with the EHRO-N and facilitate services related to job qualifications that are based on portfolios of learning outcomes (made of knowledge, skills and competences) in view of their recognition

[52] On EU level feasibility studies had been carried out in five sectors: construction, textile and clothing, ICT, horeca and the hospital sector with positive results : http://ec.europa.eu/social/main.jsp?langId=en&catId=782&newsId=743&furtherNews=yes

[53] COGENT: http://www.cogent-ssc.com/industry/nuclear/index.php

across the EU. This Council should work closely with national and international institutions of E&T concerned with assessment, quality assurance, validation, certification and recognition of the proposed portfolios following, in particular, the ECVET guidelines (see also above action A8). Whenever the nuclear safety authorities are involved, reference should be made to European authoritative bodies such as ENSREG and HERCA to discuss specific governance issues at EU level (in particular, mutual recognition across the EU).

- Coordination with other energy sectors

Timeframe: 2013 - 2014

Objectives: A study to point out the National Nuclear Sector E&T Councils in the EU-27, compare their working methodology and examine the feasibility of a European Nuclear E&T Council in relation with other European Energy Sector E&T Councils.

Online information and other tools

Recommendations:

- Create a centralized information source on nuclear education and training courses. Develop a web based platform with publicly available nuclear engineering lecture. Consideration should be given to disseminating international guidelines for training and competence assurance that would assist employers in choosing or designing appropriate workforce development programmes.

ACTIONS:

A14: "Nuclear Web based platform" NWBP: (for FISSION & FUSION)

Action: This platform is a living lab of Nuclear Energy products. In the same time the NWPB will be a transaction platform where Stakeholder can have access or eventually "sale" or "offer" to the public:

1) education or training materials,
2) virtual lectures,
3) supporting documents, books,
4) webinars (billing based on time and a customer level),
5) other relevant content

The general concept is that NWBP will integrate many heterogeneous systems and modules to give one, with a unified design, information, demonstration and sale channel.

Examples of content offered at NWBP

- Remote controlled experiments - for industrial demonstration or educational purposes
- Remote lectures for students.

- Remote conferences with keynote speakers relevant for industry, researchers, etc.
- Video-streaming of events, such as workshops, contests, awards, etc.
- Simulation and analysis tools.
- IP security guidelines.
- Integrated presentation of LMs.
- Internships offers/requests to channel offer and demand

The tool should be developed according to well investigated boundary conditions with a clear scope and in an up-to-date Informatics environment. A wide and well planned communication campaign should be included at the end, in order to make the tool sufficiently wide known. In strong synergy with existing platforms (ENEN, ANENT, ENS…)

The information security and wide access and constraints to access it should be studied to ensure that the platform is accessible for learners of different types of organisations (including the industry).

Timeframe: 2013 – 2015

Objectives: The goal is:

- To share between education and training as much as possible experience and learning materials, to line up the requests from the industry with the demands from universities, students and learners(and vice versa).
- To speed up the modernisation process for curricula relevant to nuclear energy and in particular to increase the capacity for multidisciplinary education by providing quality controlled educational content at affordable costs to educational institutions.
- To offer on the public side an open portal to create awareness about nuclear energy.

Conclusions.

In conclusion, the supply of nuclear engineering graduates does not sufficiently respond to the demand of the same graduates by the nuclear energy sector. As there is a (growing) demand for STEM graduates from various sectors across the European economy, the nuclear energy stakeholders need to be aware of the wider context in which they operate. It becomes clear that only the joining of forces rather than competition could help in adequately responding to the human resource and skills challenges of the nuclear energy sector.

The E&T actions in the nuclear sector are invited to focus both at MS and EU level in knowledge transfer and competence building.

One of the objectives is to improve the synergy and to develop tools between the world of education and the world of work, while helping universities modernise and enhance quality and innovation. Structured partnerships should be set up between higher education institutions and businesses, which develop innovative ways of producing and sharing knowledge, foster creativity and deliver new curricula and qualifications in a "programmatic" approach where governmental bodies and stakeholders are sharing common objectives:

- Towards a common nuclear safety and security culture world-wide, based on technical and organisational excellence.
- Towards scientific and technological excellence, thereby ensuring a new generation of European highly qualified experts in all nuclear sectors.
- Towards a robust demonstration that the use of nuclear energy is beneficial, responsible and sustainable (thereby renewing the public confidence climate).

ANNEX 1: Nuclear Power Plants in the EU (post-Fukushima situation)

Some facts about nuclear in the EU and world-wide (as of October 2012)

(1) Total of 132 units operable in 14 EU Member States (total power=122 GW(e) net) Go ahead in 12 Member States (MS) and phase-out in 2 MS / New build in 2 MS

Source: World Nuclear Power Reactors & Uranium Requirements (October 2012) [2]

Go ahead in 12 MS and phase-out in 2 MS

(1) France: 58 reactors operable (63 130 MWe net in October 2012, 78 % of total electricity generation in the country in 2011), 1 in construction, 1 planned, 1 proposed

- one EPR in construction in Flamanville-3 to operate by 2016 (one planned in Penly) / AREVA (90 % from State) and EDF (85 % from State) / nuclear in France = 125 000 direct jobs, 300 000 indirect jobs

(2) United Kingdom: 16 reactors operable (10 038 MWe net, 18 %), 4 planned, 9 proposed

- government wants to go "low carbon projects", including nuclear power ("Electricity Market Reform" (EMR), White Paper 2011) - utilities wishing to build new NPPs are still discussing (EDF Energy (EPR); Horizon / Hitachi (ABWR); NuGeneration / Iberdrola + GDF Suez (?))

(3) Sweden: 10 reactors operable (9 399 MWe net, 40 %)

- in 1979, referendum and moratorium against nuclear (phase-out planned by 2010) / in 2009, moratorium cancelled (new NPPs only to replace old ones) / plant upgrading in all utilities (up to 21 % already in place)

(4) Spain: 8 reactors operable (7 448 MWe net, 20 %)

- in 1983, moratorium / the oldest unit (at José Cabrera) was shut down at the end of 2006, 40 years after its construction / plant upgrading in many utilities (519 MWe already in place)

(5) Czech Republic: 6 reactors operable (3 764 MWe net, 33 %), 2 planned, 1 proposed

- Czech state office for nuclear safety said that the country has no immediate plans to review its nuclear expansion plans.

(6) Finland: 4 reactors operable (2 741 MWe net, 32 %), 1 in construction, 2 proposed

- one EPR in construction in Olkiluoto-3 (to operate by 2014, vendors AREVA and Siemens) / in July 2010, ratification from Parliament to build two more NPPs, namely Teollisuuden Voima (TVO) at Olkiluoto, and Fennovoima, a subsidiary of E.ON, at Pyhajoki or Simo)

(7) Hungary: 4 reactors operable (1 880 MWe net 43 %), 2 proposed

(8) Slovak Republic: 4 reactors operable (1 816 MWe net), 2 in construction, 1 proposed

- at Mochovce 3 and 4, Italy's Enel SpA and Slovenske Elektrarne are completing the construction of Units 3 and 4, with commercial operation planned for 2013-2014

(9) Romania: 2 reactors operable (1 310 MWe net, 19 %), 2 planned, 1 proposed

- two CANDU units are planned to operate by 2016-2017 inTransylvania.

(10) Bulgaria: 2 reactors operable (1 906 MWe net, 33 %), 1 planned, namely: a Russian-designed AES-92 VVER-1000 in Belene (stop in March 2012) and now in Kozloduy

(11) Netherlands : 1 reactor operable, (485 MWe net, 4 %), 1 proposed

- new NPP by 2019 (Delta – EDF partnership)

(12) Slovenia: 1 reactor operable (696 MWe net, 42 %), 1 proposed

(13) Germany: 9 reactors operable (12 003 MWe net, 18 %), nuclear phase-out policy since May 2011 – see below

(14) Belgium: 7 reactors operable (5 943 MWe net, 54 %)

- nuclear phase-out law since 1999 and phase-out decision in July 2012 (Doel 1 and 2 closed by 2015; Doel 3 by 2022; Tihange 2 by 2023; Doel 4, Tihange 1 and 3 by 2025) – see below.

Nuclear phase-out in 2 EU MS

Germany: see above (13)

- political landscape has been profoundly marked by the Fukushima events / "A decision has been taken to shut down eight plants before the end of 2011 and they definitely won't be reactivated. The remaining nine will be shut down by the end of the decade." (30 May 2011)

Belgium: see above (14)

- Flaw indications in the reactor pressure vessels of Doel 3 and Tihange 2 (as a result of inspections conducted by the licensee in July and September 2012, respectively). Three subgroups have been formed to assist the Belgian Authorities, namely: (1) Non-destructive Examination techniques (WG1); (2) Metallurgical origin / root causes of the flaw indications (WG2); (3) Structural mechanics & fracture mechanics – Approach for justification file (WG3).

New build: 2 MS

(1) Poland: 0 reactors operable, 6 planned - Poland had four Russian VVER-440 units under construction in the 1980's at Zarnoweic (near Danzig) but they were cancelled in 1990 and the components were sold. Development of shale gas becomes equally important as nuclear.

(2) Lithuania: 0 reactor operable - closure of last NPP in 2009 (Lithuania hosted the two largest Russian reactors of the RBMK type (1500 MWe) designed to provide power for Lithuania and for neighbouring Latvia, Belarus and the Russian exclave of Kaliningrad) - 1 planned: Visaginas NPP project with Baltic States (Latvia, Estonia, Poland) (vendor GE Hitachi, 1350 MWe Advanced Boiling Water Reactor, pending on result of referendum in October 2012).

Other European countries with nuclear phase-out policy

- Italy: in 1987, moratorium on the construction of new NPPs; in 2009, OK for four EPRs by 2018; in 2010, law on return of nuclear; on 13 June 2011, referendum = 95 % against nuclear (in Italy) and against Berlusconi

- Switzerland: 5 reactors operable
  - plant upgrading in many utilities (up to 13 % already in place)
  - no construction of new NPPs (decision in May 2011, latest closure in 2034)

MS with"'no-use of nuclear"

- Austria: in 1999, law for Austria without nuclear "integrated in the Constitution"
- Greece, Ireland, Norway, Denmark: no use of nuclear in their law
- Luxembourg.

(2) Emerging Nuclear Energy Countries (> 45 countries according to IAEA)

(adapted from source [54] , September 2012)

- Over 45 countries are actively considering embarking upon nuclear power programs.
- These range from sophisticated economies to developing nations
- The front runners outside the EU are Iran, UAE, Turkey, Vietnam, Belarus, Jordan.

According to the International Atomic Energy Agency, nuclear power is under serious consideration in over 45 countries which do not currently have it (in a few, consideration is not necessarily at government level).

- In Europe: Poland (6 units planned), Lithuania (1 unit planned), Turkey (4 units planned and 4 proposed), Belarus (2 units planned and 2 proposed), Armenia (1 unit planned), Albania and Croatia, Serbia, Estonia, Latvia
- In the Middle East and North Africa: Iran (2 units planned and 1 proposed), Gulf states including UAE (4 units planned and 10 proposed), Saudi Arabia (16 units proposed), Jordan (1 unit planned), Egypt (1 unit planned and 1 proposed), Qatar & Kuwait, Yemen, Syria, Tunisia, Libya, Algeria, Morocco, Sudan
- In west, central and southern Africa: South Africa (6 proposed), Nigeria, Ghana, Senegal, Kenya, Uganda, Namibia
- In South America: Chile, Ecuador, Venezuela
- In central and southern Asia: Kazakhstan (2 units planned and 2 proposed), Bangladesh (2 units planned), Pakistan (2 proposed), Azerbaijan, Georgia, Mongolia, Sri Lanka
- In SE Asia: Indonesia (2 units planned and 4 proposed), Vietnam (4 units planned and 6 proposed), Thailand (5 proposed), Malaysia (2 proposed), Singapore, Australia, New Zealand.
- In east Asia: North Korea (1 proposed), pending on the outcome of the Six-Party Talks

The IAEA published in 2007 a guidance, with a phased “milestones” approach, for emerging nuclear energy countries (“*Considerations to launch a nuclear power programme*”) [55].

[54] http://www.world-nuclear.org/info/inf102.html

[55] http://www.iaea.org/NuclearPower/Downloads/Launch_NPP/07-11471_Launch_NPP.pdf

SET-Plan Energy Education & Training Photovoltaics

Photovoltaics

Working Group Contributors

Tom Markvart	University of Southampton, UK (Rapporteur)
Gabriella Tranell	NTNU, Norway
Luciano Scaltrito	POLITO, Italy
Daniel Lincot	IRDEP, France
Antonio Martí Vega	Universidad Politécnica de Madrid, Spain
Philippe Malbranche	CEA, France
Martha Lux-Steiner	HZB, Germany
Simona De Iuliis	ENEA, Italy
Hubert Fechner	Technical University of Applied Sciences - Technikum Wien, Austria
Carlos Relancio	Spain
Nicola Pearsall	Northumbria University, UK
Stanislaw Pietruszko	Warsaw University of Technology, Poland

EPUE Mirror Group

Vebjørn Bakken	University of Oslo, Norway
Björn Karlsson	Mälardalen University, Sweden
Jorma Kyyrä	Aalto University, Finland
Stefano Polizzi	Ca' Foscari University Venice, Italy
Olli Pyrhönen	Lappeenranta University of Technology, Finland
Horst-Günter Rubahn	University of Southern Denmark, Denmark
Antonio Urbina	Universidad Politécnica de Cartagena, Spain

Acknowledgements

A. Martí is indebted to Prof. A. Luque, Dr. I. Luque, Dr. A. Bett, Prof. G. Sala, Dr. C. Domínguez and Prof. I. Antón for valuable discussions from which the figures used in this draft have been obtained.

Introduction

Photovoltaics is arguably the youngest of power generating technologies. The first practical solar cells were developed in the early 1950s, finding a ready application on board of satellites. The first terrestrial system began to appear in the 1970s followed by the first grid connected PV power plants some ten years later. Today, the production of solar cells exceeds 20GWp – the peak power of 20 large conventional power stations, with arrays installed predominantly as distributed generation on buildings or as ground mounted arrays (Fig. 1).

The markets, however, remain dependent on government subsidies. Substantial market volatility has been experienced over the last few years, due partly to moving away from dependence on microelectronics for silicon feedstock, and partly to a move towards large scale solar cell manufacture in China. The technology is dominated by crystalline silicon, in the single crystal or multicrystalline form. Production of thin film CdTe solar cells has increased in recent years, accompanied by the increase in production in other thin film technologies such as CIGS, and a steady output in amorphous silicon. There is a small market for GaAs based solar cells for concentrator systems and to provide electrical power to satellites (Fig. 2). These technologies are discussed in more detail below.

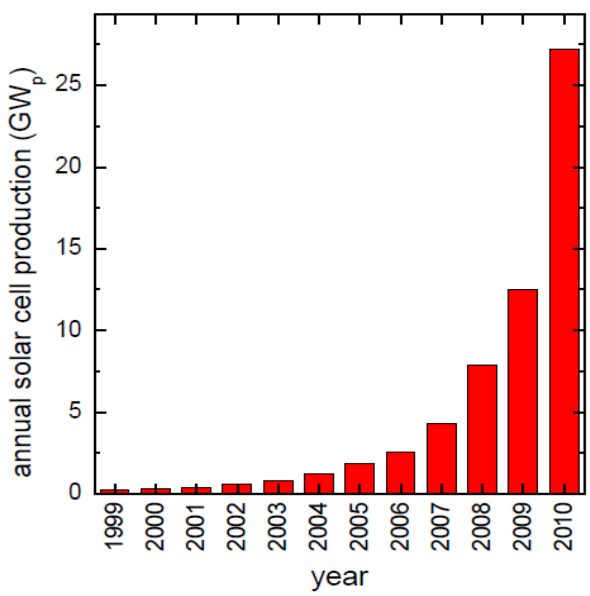


Fig. 1 Annual solar cell production
(Photon 4/2011)

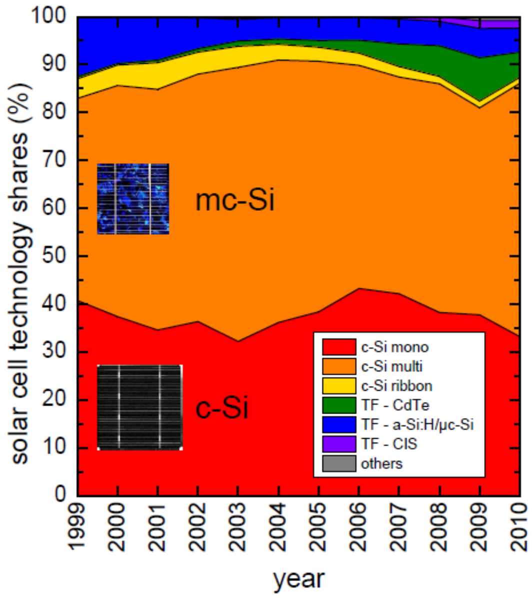


Fig. 2 Photovoltaic technologies
(Photon 4/2011)

Crystalline silicon A typical monocrystalline silicon solar cells in production today has efficiency around 15%. The low absorption coefficient of silicon necessitates relatively thick devices to make good use of the available sunlight. This is most easily achieved by a wafer-based technology, from monocrystalline or multicrystalline ingots. There is a strong move by the leading silicon producers towards a low cost and less energy intensive and more environmentally sustainable silicon production. To avoid kerf loss in ingot slicing, a number of companies are turning to novel slicing techniques as well as non-ingot wafer technologies such edge-defined film-fed growth (EFG), or by the manufacture of thin crystalline silicon solar cells deposited on low-cost substrates.

Thin film solar cells Solar cells in the form of hydrogenated amorphous silicon (a-Si) have traditionally been used principally to power commercial products such as watches and calculators. More modern structures usually involve micro/ nanocrystalline silicon or the combination of amorphous silicon with the wafer based crystalline silicon technology such as the Sanyo HIT cell. The recent growth in thin film solar cell technologies is due to large part to solar cells based on cadmium telluride or other compound semiconductors, principally copper indium diselenide and its derivatives.

Dye-sensitised and organic solar cells These electrochemical solar cells with efficiencies approaching 10% based on molecular dyes were first reported in the early 1990s, followed by considerable research activity into true molecular structures, usually based on mixture of polymers with fulerene derivatives. The feasibility of these cells for power production, however, remains uncertain.

Issues in system design For practical use, solar cells are laminated and encapsulated to form photovoltaic modules. These are combined into arrays and interconnected with other electrical and electronic components (balance of system, BOS) to form a photovoltaic generator. Most photovoltaic arrays are installed at fixed tilt but the amount of solar energy captured can be increased if the modules track the sun. Tracking is particularly important in arrays which use concentrated sunlight. There is a considerable difference between the design of standalone and grid connected systems (where the connection with utility supply is an important consideration). An important issue that is beginning to emerge is the impact of high penetration of photovoltaics on the distribution networks (see Sec. 3).

This report reviews the current photovoltaics market with focus on employment data based on available information and focusing, in more detail, on concentrating photovoltaics and characterization, testing and research (Section 1). Section 2 reviews the available educational courses in photovoltaics, and Sections 3 and 4 provide information about barriers and bottlenecks, and give recommendations for future actions.

Emphasis is given to areas where education bottlenecks are most likely to impede technology progress, and result in shortages in the supply of skilled personnel specifically to photovoltaic industry. It is anticipated that indirect areas or educational issues at a general level (such as language and local issues, the development of legal/ administrative skills, as well as interactions with other critical areas such as construction, architecture and building energy management) will be addressed at a generic level of this initiative or as part of the cross-cutting themes.

1 Current situation

PV Market

According to European Photovoltaic Industry Association (EPIA) [1], the total capacity of photovoltaics connected to the grid rose from 16.8 GWp in 2010 to 29.7 GWp in 2011 (Fig. 3). The number of markets reaching more than 1 GWp of additional capacity during 2011 rose from 3 to 6. In 2010, the top three markets were Germany, Italy and the Czech Republic. In 2011 Italy leads, followed by Germany, China, the USA, France and Japan, each with over 1 GWp of new capacity. The European share remains predominant with more than 75% of new capacity in 2011. The two biggest markets - Italy and Germany - account for nearly 60% of global market growth during last year (Fig. 4).

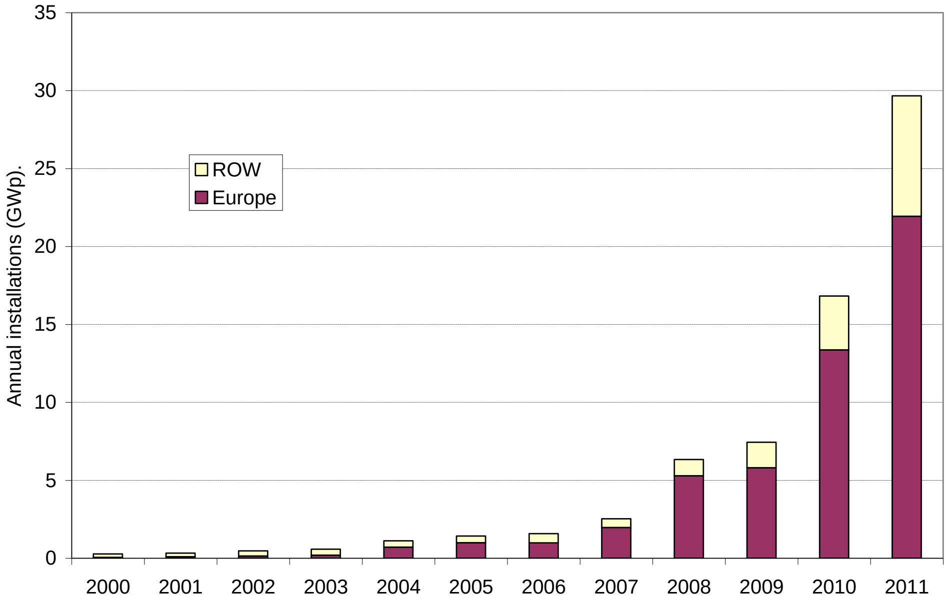


Fig. 3. Annual PV installations (EPIA Global PV Market Outlook, 2012)

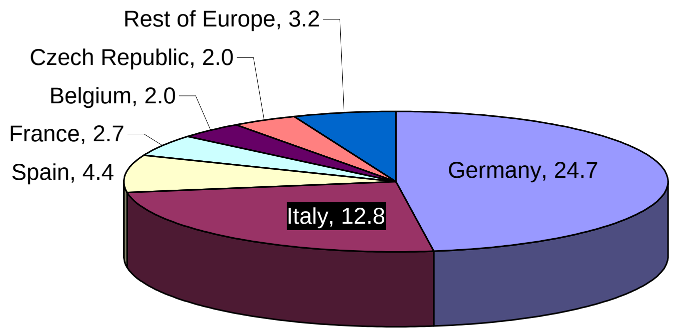


Fig. 4. Cumulative capacity installed per country, in GWp, at the end of 2011
(EPIA Global PV Market Outlook, 2012)

Total installed PV capacity world-wide at the end of 2011 reached over 67.4 GWp (Fig. 5). Photovoltaics is now, after hydro and wind power, the third most important renewable energy in terms of globally installed capacity. The growth rate of PV during 2011 reached almost 70%, an outstanding level among all renewable technologies. The total energy output of the world's PV capacity run over a calendar year is equal to some 80 billion kWh. In Europe, some 51.7GWp of solar arrays were installed at the end of 2011, with annual installations running at the level of 21.9GWp. With growing contributions from Southern European countries, the average load factor of this capacity is increasing and will produce some 60 billion kWh on an annual basis.

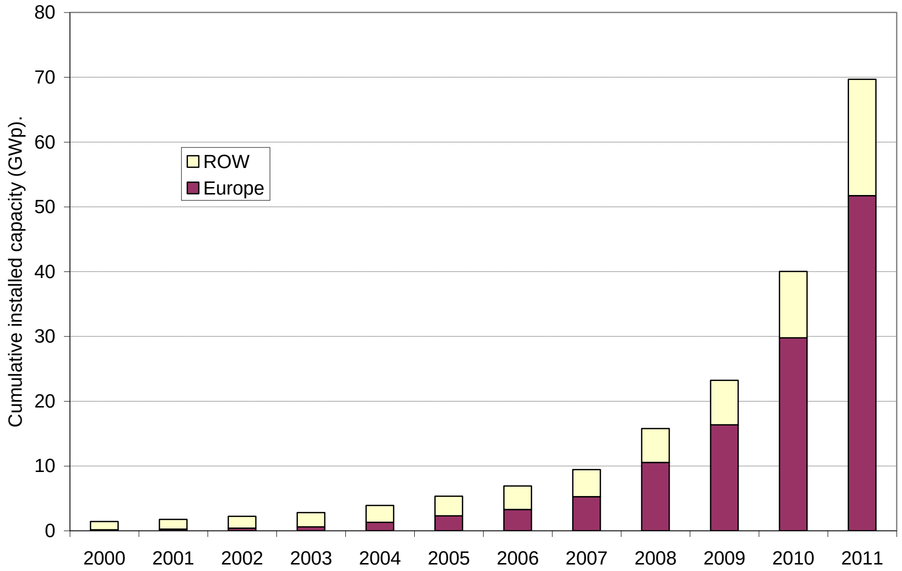


Fig. 5. Total cumulative capacity installed at the end of 2011 (EPIA Global PV Market Outlook, 2012)

Although experiencing rapid market growth, it is difficult to express future growth in precise numerical terms due to large uncertainties which currently exist, and imbalances in market flows which have opened up in recent years (Fig. 6). The situation has been summarised well in the 2011 EPIA Market report [2] which states that *"the PV industry is at a crossroads. Whilst European markets have always outpaced home production, this will presumably no longer be the case in the years to come. At the same time, massive capacity build-up concentrated in Asia has not yet led to a sustainable growth momentum in local markets and is far from being in tune with its enormous production power.*

There may be at least three hints with regard to the future direction of the PV industry. Firstly, large producer countries will need to activate their home markets, placing a larger share of their production locally. Secondly, with enormous potentials still untapped in almost all continents, new markets will have to be opened up to drive PV development in the coming decade just as Europe accounted for it during the last decade. Finally, the principles of open markets and fair competition should be recalled and will certainly require more attention in the future."

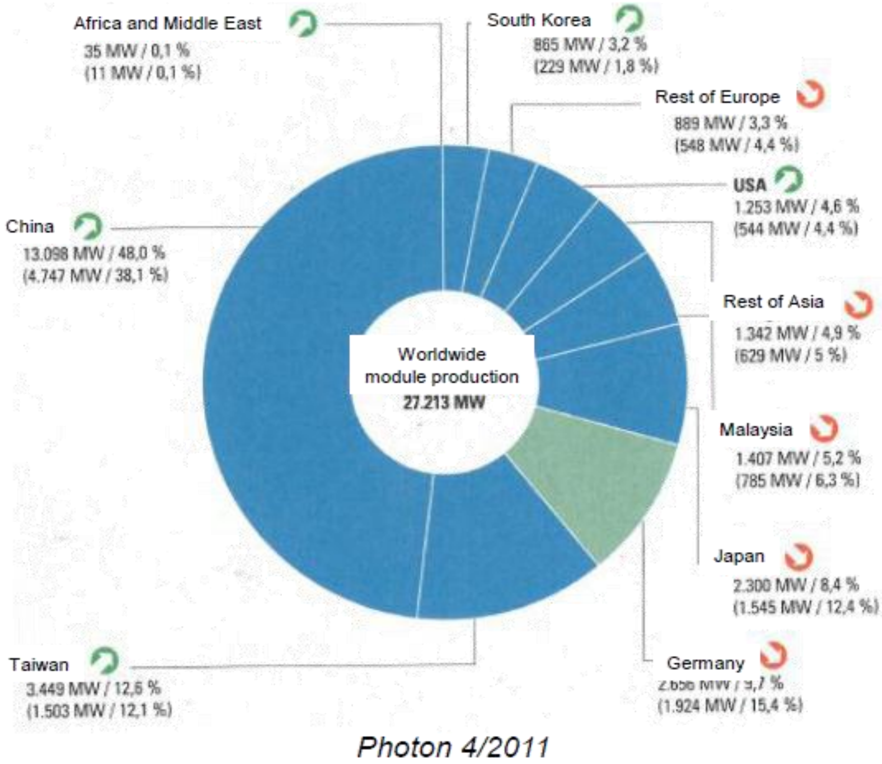


Fig. 6 The photovoltaic markets 2010 (2009)

Concentration Photovoltaics (CPV) is still an emerging market. To give figures such as market value, size, growth rate and the corresponding forecast would be perhaps premature. In concentration photovoltaics we have indeed to distinguish, at least, between two ranges of application. The first is low-medium concentration (up to say 300 suns) and, the second, is the very high concentration range (above 300 suns). The first range is dominated by silicon technology with companies such as Sunpower (US) leading the market. The second is dominated by the technology of III-V triple junction solar cells with companies such as Concentrix-Soitec (Germany-France) leading the market.

In spite of the difficulty because of the lack of data, Fig7. plots the expected growth rate for CPV according to the authors that have risked to give a figure about this technology.

Table1 collects some research centres and industries involved in concentration PV in Europe and other parts of the world for reference. The list is not exhaustive, but likely in this draft includes already some major agents in Europe and is useful to identify the elements that appear in the value chain of CPV. For some of the companies listed (those related to optics and the development of the trackers electronics, for example), CPV is not their main industrial activity but one with apparently increased share in their portfolio.

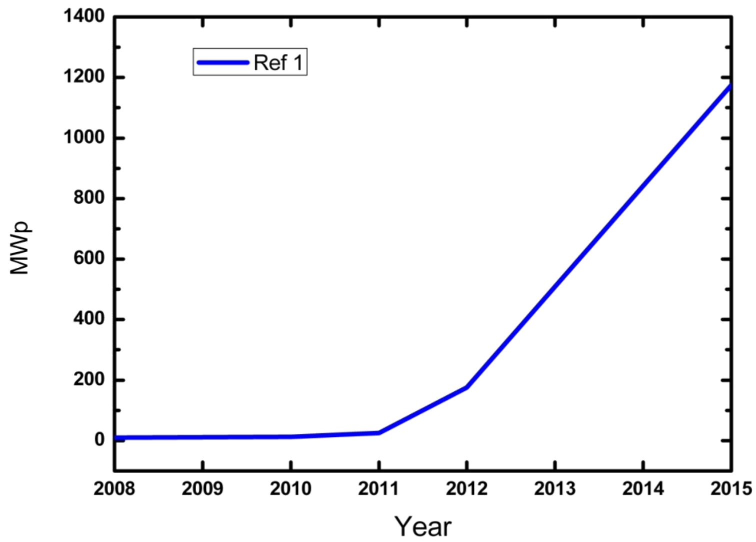


Fig. 7. Expected growth rate for CPV (Elaborated from data in A. Jaeger-Waldau, "PV Status Report 2011," European Commission).

Table 1. Example of Centers and Companies involved in research in concentration photovoltaics (list is not exhaustive).

Centre	Activity	Country
Fraunhofer ISE	Research	Germany
Instituto de Energia Solar – UPM	Research	Spain
Concentrix Solar - Soitech	Turn-key systems	Germany/France
ISOFOTON	Turn-key systems	Spain
Renovalia	Turn-key systems	Spain
BSQ	Trackers,BOS	Spain
Titan Trackers	Trackers	Spain
Suntrack	Tracker controllers	Spain
EKO INSTRUMENTS Europe B.V.	Instrumentation	The Netherlands
Eschenbach Optik GmbH	Optics	Germany
Boschman Technologies/APC	Encapsulation	The Netherlands
Umicore	Substrates	(Europe-USA)
Teknia Manufacting Group, S.L.	R&D -	Spain
Grenzebach Maschinenbau GmbH	CPV modules	Germany
Outside Europe		
Solfocus	Turn key systems	USA
Amonix	Turn key systems	USA
SunPower	Turn key systems	USA
Daido Steel	Turn-key systems	Japan
Axt, Inc.	Substrates	USA
Zhejiang Lante Optics Co., Ltd.	optics	China

The value chain

The value chain differs somewhat from technology to technology. This report focuses on crystalline silicon technology, and on the potentially significant CPV. Due to the availability of data, these two sectors are used as proxy to estimate the workforce required for the PV sectors.

The core elements of the value chain for silicon photovoltaics are shown in Fig. 8 but a more detailed analysis needs to consider further, indirect, components. For example, silicon production and cell and module manufacture requires the input of materials (glass, plastics, aluminium) and process chemical supplies. Employment in the manufacture of equipment (furnaces, printers, etc.) and the maintenance of this equipment also needs to be considered. This part of the value chain is likely to be increasingly important as the process becomes more and more automated. Once manufactured, the cells and modules are tested and sorted for optimum interconnection into arrays – an activity discussed in some detail below. Grid connected photovoltaic generators rely on balance of system components for DC to AC conversion and connection to the utility supply. Standalone systems usually require batteries and charge management electronics. Different types of supports are needed in installation, be it ground based or building integrated. Operation and maintenance is likely to be significant in large scale ground based, flat plate and concentrator, systems. With approaching grid parity, a potentially important aspect may be “grid services” which should be considered in future activities.

Photovoltaics remains an evolving area of power generation technology, and research and development form a highly important component of the supply chain which embraces employers from industry to government institutions and academia.

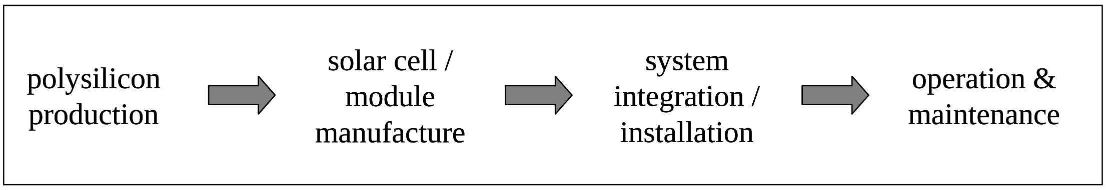


Fig. 8 The value chain for silicon photovoltaics

R&D areas of importance from silicon to wafer include:

- new reduction methods for quarts to Si without C (to lower CO_2 footprint)
- new Si refining methods with low energy consumption and less chemical waste
- continuous crystallisation methods
- use of less pure Si in Cz ingot production
- mono-like multi crystalline ingot production
- thinner wafers and new cutting methods.

In the value chain of CPV the following items can be identified:

- *Research*. Main areas of current research in CPV relate to: Increase the efficiency of multijunction solar cells with the goal of approaching 50 % by attempting to increase the number of cells in the multijunction stack beyond 3 or using novel concepts; development of module technology, including optics, to approach module efficiency to 40 %; develop module aperture higher than 1º; growth on silicon substrates.

- *Substrate growth.* This item compromises the cost of the substrate (typically germanium for the multijunction approach) and the growth or manufacturing of the layer structure that constitute the cell.

- *Cell processing.* This element in the value chain of CPV refers to the manufacturing of an actual solar cell from the prior layer structure. It includes steps such as metallization and cell casting

- *Trackers*. This element in the value chain is specific of CPV since trackers for CPV require of higher accuracy as the concentration factor increases.

- *Optics*. Lenses (primary and secondary) are integrated in the module to produce a concentrator module. Under some approaches the "lenses" consists of mirrors that concentrate the light into the module. The development of low cost, durable and efficient optical elements are also an element of the value chain that are specific to CPV.

- *Module assembly*. Optics and cells are typically integrated to manufacture a CPV module. The efficiency, yield and reliability with which these processes are done impact also to the value chain. The module is the element in CPV in which the optics and the cells are integrated.

- *BOS*. Elements in the balance of systems in CPV are, in their major part, similar to the flat module approach. There are however, a few differences to keep in mind. Concentration aims to high efficiency. Each point of efficiency earned at module level, impacts BOS since less elements needs to be integrated in the system for the same power. CPV is suited for plants; their design rules of the plant aim to maximise the production of energy along the year and not to warrant a minimum of energy production across all the year. Land preparation differs also from flat module since sometimes heavy trackers have to be installed. Also shadowing considerations might differ from one plant to another depending on the tracker design for example.

Current workforce

The range of occupations span metallurgy, chemical engineering and material science in silicon production from quartz, to electronic device process engineers, physicists, electronic engineers, and chemists involved in solar cell manufacture, to roofing workers, electricians and power engineers involved in installation and utility aspects, alongside the administrative, management and distribution personnel. CPV requires further skills in the construction of trackers and light harvesting optics. The need for highly important research personnel should be highlighted if Europe is to regain its leading role in solar cell manufacture.

The time scale and scope of this study has allowed only an analysis of labour input into the various parts of the value chain based on existing studies by REPP [3] and EPIA/ Greenpeace [4]. Other studies (e.g. by Kammen et al [5] and UNEP [6]) use figures which are derived from these sources, albeit presented in different units or in a modified form. The REPP document is particularly detailed and will form the principal source of data in the analysis that follows. Employment data for photovoltaics given in the Solar Generation reports by EPIA/ Greenpeace [4] are similar and will be used to provide additional detail when data from the REPP report are not available.

The principal findings of the REPP study are summarised in Table 1 which shows the hours and skills required to perform 12 different activities to construct, transport, install and service 1 MWp of photovoltaics. The data is based upon interviews with 10 firms engaged in one or more of these activities. The survey specifically examined the labour requirements to create a 2-kW residential photovoltaic system; it is not clear if economy of scale would become relevant for larger installations. The principal source of employment is seen to be the various activities connected with installation (including system integration and BOS components such as inverters) which employs almost 40% of the total. Module assembly requires some 30% of the person time while silicon production and cell manufacture combined with silicon production take up less than 15% of the total. The percentage of person time involved in different activities is shown in Fig. 9.

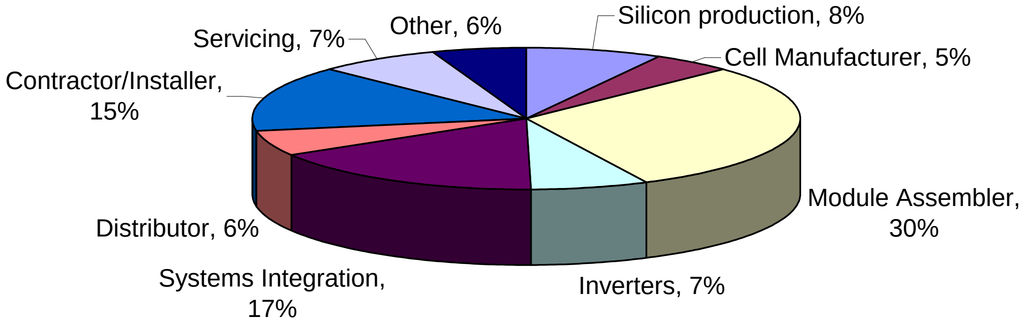


Fig. 9. The percentage of person-years required for the different activities to produce, install and maintain 1MWp of photovoltaics.

We should stress that the employment data pertain to year 2000, and a substantial automation of the silicon production and cell manufacture process as well as improved efficiency of installation mean that the labour requirements for the value chain are likely to be substantially lower at present. In keeping with the Greenpeace/EPIA studies which monitor the evolution of employment in photovoltaics over a comparable time frame we shall assume that the labour workforce required for each segment of the value chain will reduce by 50% in 2020 in comparison with the year 2000; by the same token, the current numbers (2012) will be taken as 66% of the 2000 value. Thus we assume that the complete process, from silicon to installation of 1MWp of a photovoltaic system, currently requires about 23 person-years, reducing to some 18 person-years by the year 2020. The job numbers given by EPIA / Greenpeace [4] and UNEP [6] for 2009 and 2006, respectively, come out somewhat higher but little detail is given of how these numbers are obtained, and what type of activity they include.

Table 1. The breakdown of employment activities in photovoltaics (ref. 2), showing also the assumed reduction of person-years per MWp to current levels (2012) and up to the horizon of the report (2020).

Activity	Professional, Technical and Management	Clerical & sales	Service	Proces-sing	Machine work	Bench-work	Structural work	Misc.	Total hrs per year per activity	Total person-years per activity
Glass	50	-	-	50	50	-	-	50	200	0.1
Plastics	50	-	-	-	250	-	-	-	300	0.2
Silicon	1,550	200	200	3,300	200	200	-	-	5,650	2.9
Cell Manufacturer	800	-	-	1,600	-	600	50	150	3,200	1.6
Module Assembler	3,500	-	-	1,600	-	8,250	750	6,850	20,950	10.7
Wires	150	-	-	-	1,700	-	-	-	1,850	0.9
Inverters	750	-	-	1,000	1,000	1,000	1,000	-	4,750	2.4
Mounting Frame	500	500	-	-	150	100	150	100	1,500	0.8
Systems Integration	8,900	2,850	-	-	-	-	-	-	11,750	6.0
Distributor	1,500	1,500	-	-	-	-	-	1,000	4,000	2.0
Contractor/Installer	2,500	-	-	-	-	-	8,000	-	10,500	5.4
Servicing	5,000	-	-	-	-	-	-	-	5,000	2.6
Total hrs per year	25,250	5,050	200	7,550	3,350	10,150	9,950	8,150	69,650	35.5
Total person-years (2000)	12.9	2.6	0.1	3.9	1.7	5.2	5.1	4.2	35.5	
Person-years (2012)	**8.5**	**1.7**	**0.1**	**2.5**	**1.1**	**3.4**	**3.3**	**2.7**	**23.4**	
Person-years (2020)	**6.4**	**1.3**	**0.1**	**1.9**	**0.9**	**2.6**	**2.5**	**2.1**	**17.8**	

Current workforces in CPV are at present mostly located at research, production of concentrator solar cells and modules as well as the installation of the first CPV plants. Fig 10 lists and quantifies the number of person*month (p*m) estimated to produce 1MWp of concentration photovoltaics with already available technology. For the high concentration range, the estimation has been based on the assumption of a 30 % module efficiency operated at 800 suns. Plant efficiency has been assumed 85 %. The figures do not consider indirect jobs nor the p*m that are necessary to maintain the plant in operation.

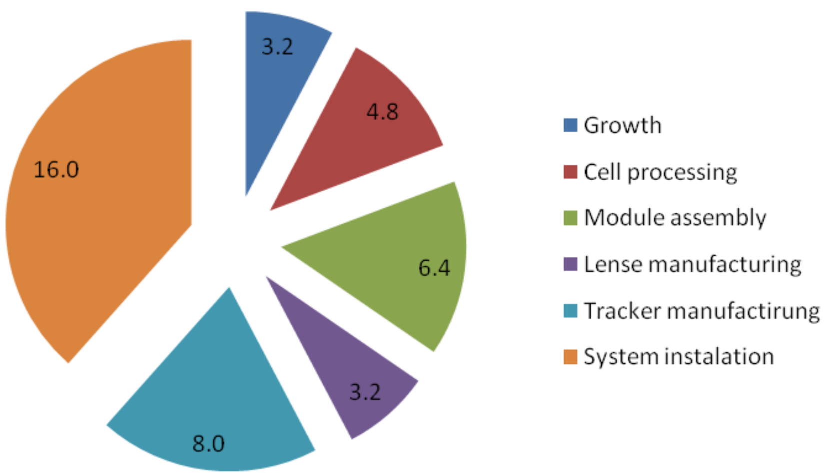


Fig. 10. Estimated number of person-months per MWp installed for a high concentration photovoltaic system.

The CPV total (42 person-months / MWp) is significantly lower than the corresponding figure for flat plate arrays and may signify a considerable reduction in workforce when CPV capacity grows to a level comparable with flat plate arrays. The current rate of growth indicates (Fig. 7) that some 10GWp are likely to be installed by 2020, a rate of 2GWp per annum, and adequate education and training facilities will be needed to ensure that sufficient specialised workforce is available to ensure further growth.

Work-Force Employed In PV Characterization & Testing Industrial Field By analysing employment data of private corporations in fact, referred to 2011, what emerges is that EU companies account for 25% of the global work-force operating in the sector, against for example China's 39%, or an even more surprising Japan's 20% (Source: http://www.enf.cn/database/equipment-cell-tester.html). If compared to the above shown European contribution to the overall production of PV energy, these data are significant: at least in characterization and testing compartment, most of worldwide companies are concentrated in Far East, with a huge number of both large and small companies holding the vast majority of the production lines for PV cells, PV modules, sun simulators and other equipment. Using the global data one can estimate that about 0.4 person-years are involved in the manufacture of 1MWp of photovoltaics.

Some 54 EU companies are involved in PV characterization and testing (Table 2) Figure 11 shows that Germany is by far the leading Country in EU in terms of employees in PV characterization & testing compartment, followed by Italy and Hungary. The other Union's 24 Countries play just a minor role in terms of employment of people in this industrial field.

Table 2. Companies and the number of employees (total 2344) involved in PV characterisation and testing.

2BG	Italy	60	IPTE NV	Belgium	21
Amtec Analysenmesstechnik	Germany	15	Isra Vision	Germany	125
Asys GmbH	Germany	15	JRT Photovoltaics	Germany	15
ATMvision	Germany	27	Manz automation	Germany	90
Aurel Automation	Italy	11	MBJ	Germany	15
Bentham instruments	UK	15	Mondragon Assembly	Spain	38
Berger Lichttechnik	Germany	10	NanoFocus	Germany	15
Buchanan Systems	Germany	15	Neonsee GmbH	Germany	15
Budasolar Technologies	Hungary	15	Op-tection	Germany	15
Dphi DaTarius	Austria	15	Optosolar	Germany	15
Dr. Schenk	Germany	15	P.Energy	Italy	60
Dr. Schwab Inspection	Germany	17	Photonic science	UK	30
Endeas Oy	Finland	5	Pi4_robotics	Germany	25
Energy Equipment testing	UK	8	Precitec optronik	Germany	13
ESCAD automation GmbH	Germany	15	PV-Engineering	Germany	15
ESCAD energy	Germany	150	pv-tools	Germany	15
Fries Research & Technology	Germany	20	Rimas B.V.	Netherlands	33
Gebr. Schmid	Germany	833	Semilab	Hungary	123
Gorosabel Solar Energy	Spain	33	Sensopart	Germany	20
GP solar	Germany	100	Senstech Instruments	Germany	15
GPP Chemnitz GmbH	Germany	4	Sunlab	Netherlands	15
Graphikon	Germany	15	Sunray PV-Tech	UK	15
Greateyes	Germany	15	TWIC	Germany	15
Grenzebach Algoscan	Germany	15	Viscom AG	Germany	15
h.a.l.m. elektronik	Germany	25	Vitronic	Germany	15
Ingenious Power	Italy	25	XYZTec	Netherlands	8
Intego GmbH	Germany	40	Zimmermann & Schilp Han	Germany	15

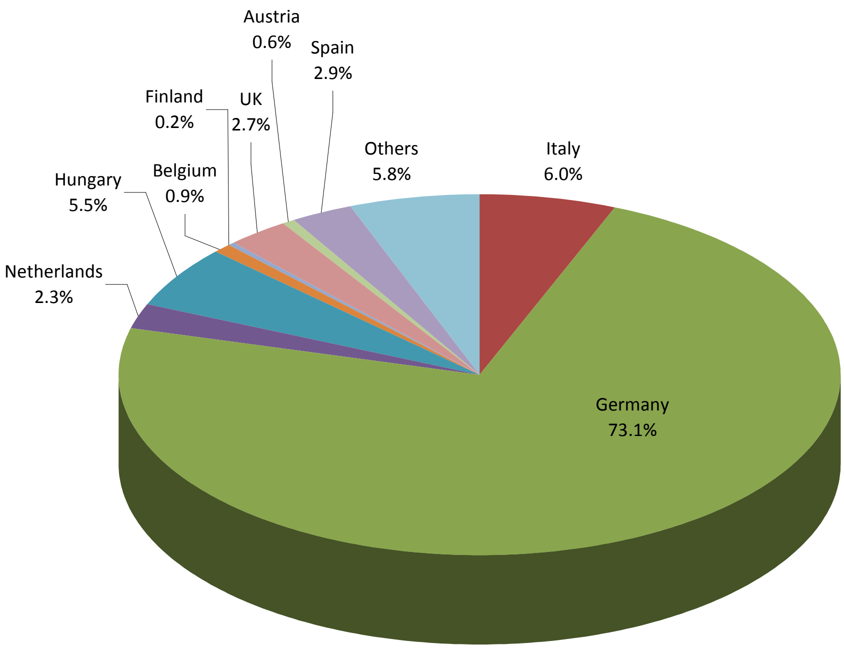


Fig. 11. Percentage of workers in different European countries involved in characterisation and testing.

Work-force employed in PV R&D The research community in photovoltaics in Europe is spread out and growing fast. As an illustration of the size of this community, some 100 European universities have declared interest in photovoltaics in a recent questionnaire carried out by EPUE. More than 5 000 full-time equivalent researchers are working in photovoltaics from 24 Institutes and Research Centres in 17 different Countries, as part of the European Energy Research Alliance (EERA).

Workforce required to achieve SET-Plan targets

To estimate the relevant workforce numbers to achieve the SET-Plan vision we need first to set out clearly the energy production and capacity requirements that this entails. The SET Plan Roadmap [7] gives an industrial sector objective to establish photovoltaics as a clean, competitive and sustainable energy technology providing up to 12% of European electricity demand by 2020 (another Commission document [8], however, gives 15%). The electricity consumption in EU [9] is currently 3,300TWh per annum. Assuming, given current energy saving measures, that this consumption will remain constant up to the year 2020 and using the 12% value, we can thus set the aim for photovoltaics for 2020 to be the production of 400TWh of electricity per annum. Based on the statistics presented in Sections 1 a few percent of this capacity may come from CPV.

The amount of electricity produced by solar cells depends, of course, on the location where the PV array is installed. The energy produced by a PV array can be expressed in terms of the installed capacity (in Wp) as

$$\textit{Electricity produced} = \textit{Installed capacity} * [PR] * PSH$$

where *PSH* denotes Peak Solar Hours and *[PR]* is the Performance Ratio [10]. Values of *PSH* in Europe, determined from average solar irradiation on the plane of the array with optimum inclination, range from some 1150h in Berlin to 2030h in Almeria. Including system losses and inefficiencies associated with imperfect inclination, shading etc., analysis by the International Energy Agency gives an average value of *[PR]* for PV arrays installed in Europe by 2007 approximately as 0.75 [11], increasing steadily over the monitoring period. Data presented in the EPIA Market Report [2] for the cumulative PV arrays installed to-date indicate an average value of the product *[PR]*PSH* of almost 1200h. Based on this value and a small increase in the Performance Ratio we can thus assume that the *[PR]*PSH* product may reach 1300h by the year 2020. Using this value, the cumulative PV capacity required to produce 12% of electricity comes out as 308GWp. These principal assumption of the model are summarised in Table 3.

Table 3

Assumptions / premises of this report	
Percentage of electricity generated by PV	**12%**
Electrical energy to be generated per annum	**400 TWh**
kWh/kWp ratio of the installed PV plant	**1300 h**
Installed capacity required	**308 GWp**
Jobs / MWp (2012 - 2020)	**24 - 19**

To estimate the scale of annual production that will be needed to reach this target requires assumptions to be made about the growth of PV manufacture between now and 2020. Assuming a constant rate of growth, the required cumulative total will be reached with the production growing at the rate of about 8%, with PV manufacture increasing from 24 in 2012 to 46 GWp in 2020. This figure is in keeping with industry predictions of future PV growth at a rate of about 10%. An alternative model can be used where the production between now and 2020 remains constant at 32GWp (Fig. 12).

By using the assumptions discussed above one can readily determine the number of personnel that need to be employed to reach these targets (Fig. 13). Without aiming for spurious accuracy it is seen that achieving the SET-Plan target 12% of electricity generated by photovoltaics in 2020 will require over 500,000 jobs [12]. Of these, over a third will be employed in the professional, management and technical sectors and likely to require higher education. Another, approximately a third of this workforce, will require skills achieved by vocational training. Roughly 13% of this workforce (75,000 jobs) will be required for silicon production and solar cell manufacture; module manufacture will requires some 30% (150,000 jobs) and activities associated with installation about 50% (250,000 jobs). If 8% of the workforce is employed in research, achieving the SET Plan target will require some 40,000 research workers educated to the PhD level.

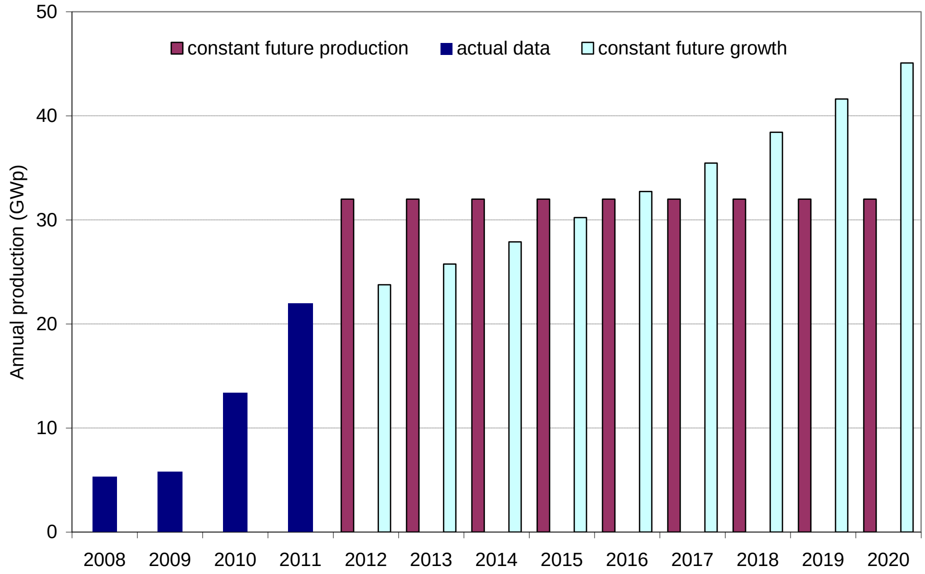


Fig. 12 Two models of future production needed to achieve the SET Plan target PV capacity by 2020

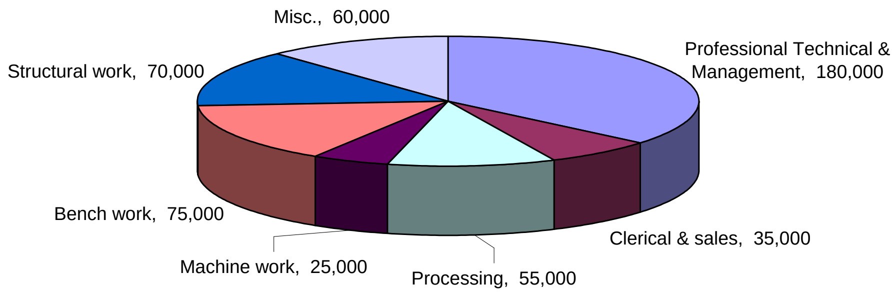


Fig. 13 The number of person-years required to reach the SET Plan target

Some 8,400 jobs are likely to be required in concentration photovoltaics. Some of these (for example, lens and tracker manufacture) will require workforce specialisation somewhat different from flat plate photovoltaics as will R&D that goes into the development of the specialised solar cells and system parts

2 Ongoing actions

Research has been carried out on the availability of courses on photovoltaics within the higher education sector as well as among other education providers. The sources for this search have been the database of energy education courses in European Universities collected by the European Platform of Universities Engaged in Energy (EPUE), and a document published by the PV Technology Platform [13], a paper on PV status in New Member States [14], material presented at several workshops devoted to teaching of photovoltaics [15], and material provided by the publishing house John Wiley & Sons regarding the supply of photovoltaic textbooks to universities. A brief search has been carried out using the internet to corroborate the availability of these courses, and to make a broad comparison between different programmes.

The available information was divided into specialised undergraduate and master courses dedicated to photovoltaics (Table 4), and individual modules as part of undergraduate of master degree programmes (Table 5). Approximately 100 other courses were described in reference 13, principally with a broader orientation (for example, addressing architectural or environmental aspects) or at the vocational level aiming mainly at installers but the number of courses that are actually offered is uncertain. Over the last few years a growing number of intensive courses (often in the form of summer or winter schools) have been organised by universities or research organisations aimed mainly at the research community at the PhD or young researcher level (Table 6).

Dedicated PV Courses at Undergraduate & Master level
Albert-Ludwig Universität Freiburg- Frauenhofer ISE (Part-time Master)
Anhalt University of Applied Sciences (u/g, in German)
Universidad Politecnica de Madrid (Master)
Università di Roma "Tor Vergata" (Master)

Table 4

There is also growing interaction between education and research as exemplified, for example, by the EU Sophia project. This project aims at an increased collaboration and coordination between various European research organisations. One of the Work Packages of this project is about "Exchange of personnel, spreading of good practices, training courses to new users, and summer schools". Its main goal is to disseminate knowledge, mainly within SOPHIA partnering organizations.

Examples of undertaken actions are:

- exchange of personnel for optimization and harmonisation of test procedures
- access of human resources to major research infrastructures in photovoltaic R&D.
- training of human resources at different stages of their career concerning the development of science, technology and use of infrastructures through targeted seminars, webinars, workshops, short courses, summer school.

Table 5. Universities which offer one or more modules in photovoltaics as part of the Undergraduate or Master level curriculum.

Austria
University AS (Applied Sciences) Technikum Vienna
Bulgaria
Technical University of Sofia
Cyprus
University of Cyprus
Czech Republic
Prague Technical University
Finland
Aalto University
France
Ecole Nationale Supérieure d'Arts et Métiers (ENSAM)
Université Paris Sud 11
Universite de Perpignan Via Domitia
Universite Paul Sabatier Toulouse, IUT Tarbes
Germany
Ilmenau University of Technology
Berlin University of Technology
University of Oldenburg
Netherlands
Combined Delft, Eindhoven and Twente Universities

Norway
University of Agder
Oslo University
Norwegian University of Science and Technology
Portugal
University of Lisbon
Spain
University Carlos III of Madrid
Universidad Politecnica de Cartagena
Universita Politecnica de Catalunya
Universidad de Jaen
Universidad Politecnica de Madrid
Universidad de Malaga
Universidad Politecnica de Valencia
Sweden
Dalarna University
Mälardalen University
University of Uppsala
UK
Southampton University
Loughborough University
Several Countries
EUREC Renewable Energy Master (several universities)
PV track in Nordic Master in Sustainable Energy Engineering (NTNU and DTU, from 2013)

Intensive short PV courses (research oriented)	
Course	Comments
Quantsol	One week summer school, organised annually by the European Quantum Solar Energy Society and Helmholtz Centrum Berlin
IDEAL	One week intensive course organised jointly by the Imperial College, London, TU Delft, ETH Zurich, RWTH Aachen and Paris Tech
Aalborg University	Four day course at PhD level of photovoltaics for power system engineers
NTNU	Si summer school. One week course for industry and research personnel on silicon production and refining.

Table 6

Some of the organised events can be open to non-partnering organisations : for instance, some workshops dealing with material characterisation and test procedures have been opened to PhD students and Post-Doc in order to spread best practices, and to teach them about few topics such as "encapsulation", "ageing tests and lifetime prediction" and "solar cell processing and characterization". It would not be useful for the aim of this project, however, to address students below the Master level.

As an exception, we can nevertheless mention a lecture which is periodically given at Northumbria University for students and masters students (European Master in Renewable Energy) by some of the partners.

Based on this information one can make a rough estimate that approximately 80 (40-120) undergraduate and master degrees are awarded annually in specialised PV courses (assuming attendance 10-30 students per course). If a similar attendance can be assumed for university degree modules one can make the rough estimate (based on the 30 courses listed in Table 3) that between 300 and 900 university students receive a general introduction to photovoltaics. A similar reasoning applied to the vocational courses suggests that perhaps one to two thousand personnel are trained every year in broader aspects of photovoltaics, or receive vocational training.

3 Needs and gaps, barriers and bottlenecks

It is clear from the statistics presented in Sections 1 and 2 and from discussions with the industry that the education and training courses available in Europe and the number of trained personnel produced are inadequate to achieve the SET Plan the targets. Using the workforce numbers obtained in Sec. 1 and assuming that 50% of the required workforce already exists and that 50% of the required PV modules will be manufactured within EU we find that, to attain the SET plan targets, 195,000 new jobs will be needed. Of these,

- 50,000 workers will need to have vocational training
- 55,000 should be educated to a degree level, and
- 15,000 should have obtained a PhD.

The timing when these jobs will be required will depend on the profile of how the module production will evolve in the future but in both scenarios discussed in Sec. 1 these jobs will be required well before 2020. Even taking the most optimistic data of Sec. 2 we find that, to reach at least the rudiments of these qualifications by 2020, the number of university courses that offer elements of photovoltaics will need to be increased by a factor of about six, and the number of vocational courses increased by about a factor of three.

A comprehensive plan is therefore required urgently to increase the number of trained personnel across a full range of traditional disciplines. We highlight here one further problem that emerges with respect to system integration of high levels of photovoltaics into utility supply networks.

In early days, PV was primarily seen as “problem” for the electricity grids. First systems operated as “stand alone” systems, the grid interconnection only started in Europe mainly with the “1000 PV-roofs programme” in Germany in 1991, immediately followed by similar programs in other countries.

Harmonics, Grounding, Overvoltage protection, Islanding, EMI of inverter and Array, and some others were main concerns for the network operators. Some research activities, amongst them, the Photovoltaic Power systems program of the International Energy Agency (IEA), started research on grid integration in early times in order to come up with first guidelines for PV grid interconnection. Even though the first concerns of the network operators (mainly harmonics, islanding) are no longer a problem and could be solved generally, some other challenging matters still arise, mainly if the penetration of PV systems connected to the low voltage (LV) grid gets higher. Overvoltage in case of high generation and low consumption, can lead to situations where the maximum tolerance of voltage increase (according mainly to EN 50160) will be reached. Unbalancing of the three phases is still another problem, beside some safety and protection concerns which are coming up in grid interconnection.

Especially in the network operator business, there is a lack of knowledge, mainly since PV in higher penetration is a quite recent development. The rapid development of power-electronics as well as today's and tomorrow's telecommunication and information technologies offer opportunities which needs an on-going trainings process which takes into account the dynamic development of implementing PV to the grid. Smart inverters, taking over more and more tasks of the network operation are essential if Photovoltaics takes over more and more of the generation capacity – at least at certain times of high generation.

Increasing the amount of self-consumption is the next upcoming challenge in order to cope with high PV generation peaks. Home automation systems, demand side management in general and direct coupling of specific devices might be some of the answers.

Anyhow, the dynamic development of PV grid interconnection seems to carry a huge potential for education and training in the PV sector addressing not only the network operators but also the PV installers and planners, electrical engineers as well as the normal building installer, in a later stage also aggregators and other emerging energy businesses might need this know-how as well.

4 Recommendations

It is clear from the information presented in Sections 1 and 2 that there is an acute shortfall of education and training courses to produce personnel that will be adequately equipped to deliver the targets of SET Plan in photovoltaics. The availability of trained personnel at all levels is likely to become key if Europe is to retain its leading role not just in the volume of installed PV capacity but also in the manufacture and innovation activities.

Urgent action is required to rectify this situation and to achieve this aim, this report makes the recommendations set out below.

Heading 1: Filling the skills, competences and knowledge gap

Focus area 1: Meeting the skill/competencies gaps of new and emerging technologies

Action: To develop modern modular teaching materials and joint teaching projects.

This report provides evidence for the need to create a substantial number of up-to-date university Bachelor and Master courses in photovoltaics at a broad range of universities and educational institutions, enabling students trained in traditional disciplines to absorb specialised PV knowledge to be directly employed in industry

It is proposed to progress towards implementation of this action by creating a series of teaching modules that can be adapted by individual universities to suite their particular needs. Modules addressing essential core elements from the value chain, to be created as part of the first step, would be added to and augmented in subsequent years. The principal common feature of the more specialised modules should be to create links between traditional disciplines and photovoltaics, in other words, provide bridges between existing courses and skills needed to manufacture, install and maintain photovoltaic generators (for example, solar cell processing for chemists; optical processes in photovoltaics for electronic engineers, etc.). Although eventually growing into many full scale University Bachelor and Master courses in photovoltaics, this scheme would also help educate and re-train graduates in specialised skills that may be needed for specific parts of the value chain.

The proposed programme can be enacted speedily by building on existing activities at Universities, and taking on board similar existing or past activities by other bodies e.g. the Energy Engineering Programme of UNESCO in the 1990.

Timeframe: Eight core modules to be created by late 2013 / early 2014. Two new specialised modules to be created every year subsequently till 2019 / 2020.

Focus area 2: Strengthening and developing existing skills/competencies

Action: To develop a model through which modern undergraduate and master courses can disseminate the latest research findings in PV and related fields among the potential workforce and student population.

Photovoltaics is one of the newest and most research-intensive energy technologies. To benefit fully from research achievements, the research results should be disseminated effectively and promptly through not only the research community but also among students and the workforce. A suitable framework should be created which allows this to happen, and compels researchers to not only publish their findings in learned journals but to explain them in detail to a wider community that may benefit from them. As an initial move, it is suggested that all future research grants should be awarded under the condition that the holders disseminate the results of the research in a form suitable for incorporation into undergraduate and / or master degree curricula.

Timeframe: To solicit a report from EUA on forging effective links between research education, to be completed by end 2014. Implementation 2015 +.

Heading 2: Fostering involvement, access and up-take by the labour market

Focus area 1: Promoting mobility, life-long learning, workforce training

Action: To establish a European PV summer school

A Summer School is a quick and low-cost manner to encourage interaction between Universities and Industry on the one hand, and research students / early career research workers on the other. Although several summer schools already exist they are heavily oversubscribed (some to the level of three applications for one place) and few offer a genuinely European experience.

Timeframe: To run a pilot one-week Summer School in 2013, with a full Summer School taking place annually from 2014.

Focus area 2: Industry involvement and partnerships

Action: To establish specialised industrial training centres linking industrial and educational institutions where students can master specific skills required in industry.

Although an essential starting point, taught university modules offer broad education and do not specifically focus on the needs of the industry which often needs to either re-train graduates or provide additional (sometimes fairly lengthy) training for new employees. The objective is to create centres as an intermediate step between university education and full-scale employment in industry. The timing for this activity may be propitious as the industry is currently going through a major consolidation process and changing over to education and training activities may be a way forward for some of the smaller - often research oriented - players if this process speedily implemented.

Timeframe: A call to be issued in 2013; first centres to start operation in 2014.

Action: To establish a European program for Industrial PhD

Although the European PV industry has an overall high competence level of its staff, most PhD level graduates are working within research institutes or at universities. This means that there exists a gap between academic and industrial innovation cycles and maybe that the sharpest brains are not in "active service" in the industry, speeding up the level of innovation and boosting Europe's competitive advantage. With an EU sponsored industrial PhD program, BSc/MSc level graduates working in industry can remain employed while pursuing industrially relevant research for a PhD degree and thus being the link in actively working to implement new findings in processes and products. The EU sponsorship would be aimed at supporting both small and large PV companies to be able to afford encouraging suitable employees to pursue a higher degree while remaining employed.

Timeframe: A format to be developed in cooperation with EUA in 2013. First Industrial PhDs to start in 2014.

Action Area: Innovation camps where industry define challenges and PhD/MSc students compete in groups to solve industrial problems/challenges

Fresh perspectives and ideas from students are rarely actively accessed by industry. In an effort to create meeting places for innovation and allow students in-sight into industrial challenges, it is proposed that innovation camps are arranged where groups of students/young scientists can compete to help solve both technical and design (or other cross disciplinary) challenges together with industry, potentially with prize encouragements. Again, this action would create closer ties between industry and education/academia.

Timeframe: A call to be issued in 2013 to solicit interest from industrial partners. First camps to start in 2014.

Heading 3: Planning and enabling skills development

Focus area 1: Sector skills assessments and observatories

Action: To establish a PV education conference

It is proposed to establish a PV education conference, to be held on an annual basis, where teaching contents and emerging trends can be discussed and shared. This conference would also represent a forum for interaction with industry to assess existing and future needs and gaps in education and training, and how these can be filled by the education providers. This conference would also be a forum to report on action under Heading 1, Focus area 1.

Timeframe: Existing format exists in the form of a Workshop on Teaching in Photovoltaics which could be adapted to a new format to run from 2014.

Focus area 2: Online information and other tools

Action: To create a platform based on state-of-art information technology for on-line teaching of interdisciplinary energy subject such as photovoltaics.

Information and communication technologies, alongside e-learning, clearly offer enormous potential for education in new energy technologies. No specific proposals are put forward within the photovoltaics Working Group as this activity is likely to be addressed by the SET Plan Education and Training Initiative as a whole. We only wish to make a link to the Action under Heading 1, Focus area 1 where new modules and educational structures which may initially be created in the traditional format, and be subsequently adapted to the new medium when a suitable format exists. Courses created later (say subsequent to 2015) should be created directly in the new format. To best advantage, this activity should be carried out in cooperation with the publishing / ICT industry.

Timeframe: As soon as practicable, to be decided in discussion with other WGs.

For a speedy implementation it is recommended to run a pilot study which, in cooperation with industry, will highlight interface areas to be targeted in education activities, and produce initial templates which can be followed in a detailed implementation of these recommendations.

References

[1] Global Market Outlook for Photovoltaics until 2016, European Photovoltaic Industry Association, May, 2012. Slightly different figures are given ref. 2.

[2] EPIA Market Report, 2011

[3] The work that goes into renewable energy, Report No. 13 of Renewable Energy Policy Project, 2001

[4] Solar Generation, Greenpeace / European Photovoltaic Industry Association (EPIA). The first Solar Generation Report was published in 2001; the latest available update (2011) is Solar Generation 6.

[5] M. Kammen, K. Kapadia and M. Fripp, Putting Renewables to Work: How Many Jobs Can the Clean Energy Industry Generate ? University of California, Berkeley, 2004.

[6] Green Jobs: Towards decent work in a sustainable, low-carbon world. Produced by the Worldwatch Institute and Cornell University Global Labor Institute for the United Nations Environment Programme (UNEP), 2008.

[7] Commission Staff Working Document: A Technology Roadmap for the Communication on Investing in the Development of Low Carbon Technologies (SET-Plan), 2009.

[8] Communication From The Commission To The European Parliament, The Council, The European Economic And Social Committee And The Committee Of The Regions, Investing in the Development of Low Carbon Technologies (SET-Plan), 2009.

[9] BP Statistical Review of World Energy, June 2011

[10] See, for example, T. Markvart and L. Castañer, Practical Handbook of Photovoltaics: Fundamentals and Applications, Elsevier, Oxford, 2003, Chapter IIIa1, and Chapter IIIe2 by Ulrike Jahn.

[11] Cost And Performance Trends In Grid-Connected Photovoltaic Systems And Case Studies. IEA PVPS Task 2 Report IEA PVPS T2-06:2007, December 2007.

[12] The term "job" is taken to mean in this report the number of persons needed to produce the required number of PV modules at the required time. Different definitions have been used in the past (see, for example, references 5 and 6), leading to some confusion in the results.

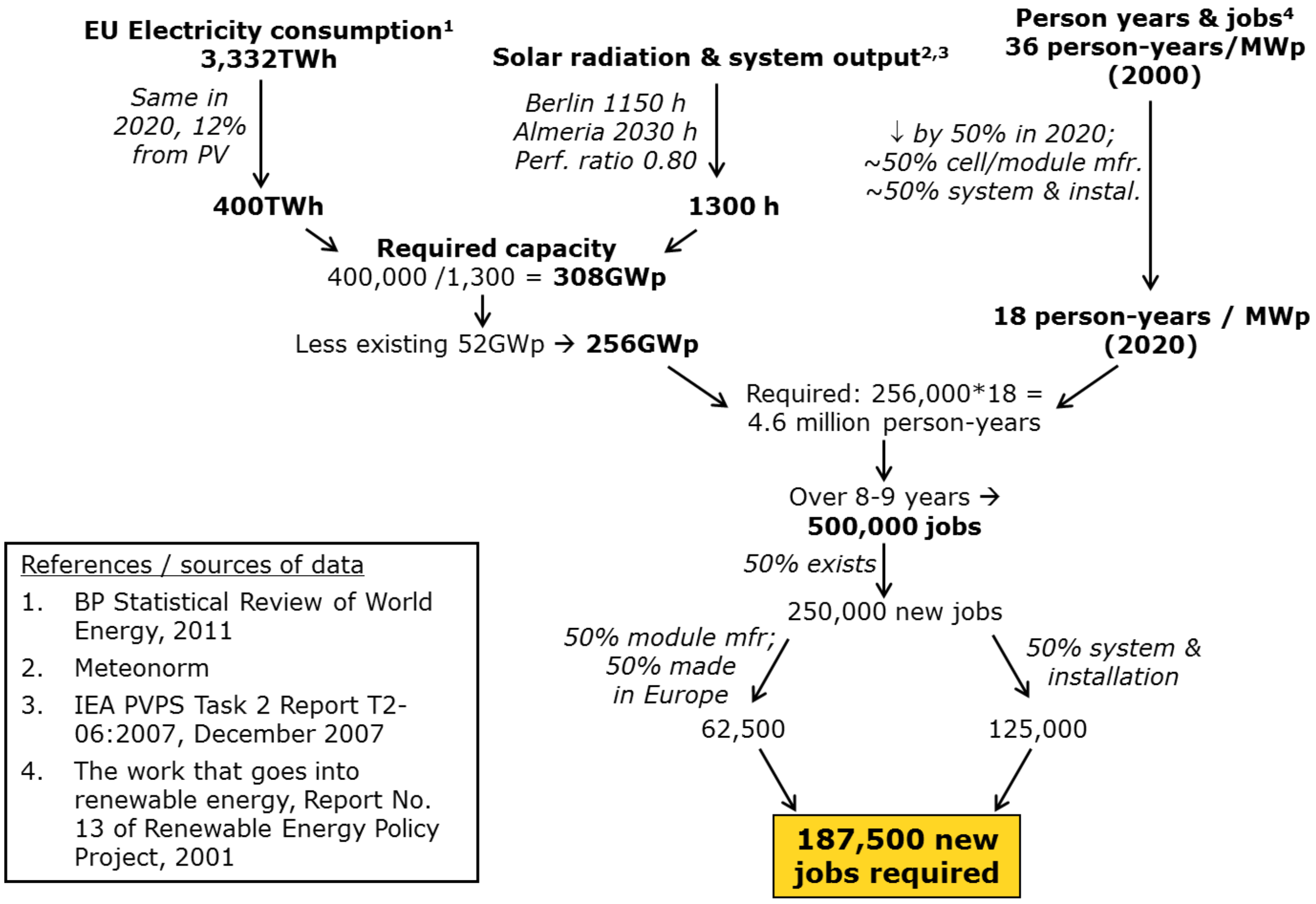
[13] Main PV courses in Europe: University classes and professional trainings, PV Technology Platform, 2009

[14] S. Pietruszko, Status of PV in the EU New Member States: Research, development, education and dissemination (2010

[15] International Workshops on Teaching of Photovoltaics, organised at the Czech Technical University in Prague every two years since 2000.

Appendix

A flow chart and simplified calculation of the required workforce



SET-Plan Energy Education & Training
Smart Cities

Smart Cities

(Energy-efficient buildings, thermal energy networks and Smart Cities integration aspects)

Working Group Contributors

In the course of the elaboration of the here presented report the following European experts listed below have been in involved. Their scientific contributions and teamwork shall be highly appreciated.

Overall responsibility:	Brigitte Bach	AIT
	Reinhard Schütz	AIT
Integrated Urban Energy Planning:	Annemie Wyckmans	NTNU
Thermal Energy Networks:	Henrik Madsen	DTU
Energy-efficient Interactive Buildings:	Peter Franz	University of Applied Science Vienna
Urban Energy Supply:	María Pilar Górriz Ramón	Acciona
Further team members:	Anca Duta	Trans. University of Brasov
	Stefano Carosio	D'Appolonia
	Guy Vekemans	VITO
	Simone Landolina	EUREC
	Luc Bourdeau	CSTB
	Darren Robinson Univ.	Nottingham

Involved countries:

Austria, Belgium, Denmark, France, Italy, Norway, Romania, Spain, UK

Introduction

This report is one part of the SET Plan European Energy Education and Training Initiative launched by the European Commission (EC) in November 2011 and is assessing the educational and training needs of future professionals in the field of Smart Cities. The here presented document has been prepared by a highly-qualified expert group bringing on board their personal expertise and competences relevant for Smart Cities. The contact details of the involved experts are given at the end of the document. It shall be emphasized that the outcome of this report shall be complementary to other specific reports being elaborated under this Initiative of the EC. However, in contrary to the more single technology driven approach in other energy technology fields the current report on Smart Cities focuses on two distinctive issues being of crucial importance in the context of sustainable urban development:

- Multiple energy technology integration in urban environments
- Cross-cutting issues embracing several infrastructure layers of energy systems in cities

A comprehensive literature study on available reports, studies and statistics has been performed over the last months in order to collect relevant information for the elaboration of this report. However, it is important to mention that the list of references given at the end of this document is not exhaustive and shall provide a broad and general overview. This procedure is complemented by personal interviews of stakeholders such as companies, university lecturers or relevant people involved in energy education.

Following the expectations and guidelines provided by the EC the assessment report on Smart Cities is consequently structured in five different sections. Section 1 gives an introduction into the framework of Smart Cities in the context of the European energy landscape and related research areas. Section 2 aims at analysing the current situation in the involved Member States and at EU level covering various aspects such as existing workforces, core occupations, educational levels and market trends. In addition, Section 3 shall provide an overview about currently ongoing activities, projects and initiatives at Member States and EU level which are targeted at supporting the fundamental education in the field of Smart Cities. Such actions shall cover the entire education chain starting from primary school up to university courses and life-long training activities. Based on this Europe wide screening, sectorial needs and gaps shall be identified in Section 4. These barriers and bottlenecks currently hindering the full implementation of the SET Plan goals shall be investigated on the one hand e.g. for the educational sector (specialized high-schools, universities, training centres, etc.) and on the other hand at industry level. In Section 5 some conclusions that can be drawn from this study are given leading to various common recommendations from the involved experts towards the EC or Member States in order to unlock the full potential of Smart Cities and to meet the future demands in terms of professional skills and occupations.

Finally, it shall be emphasized that the here presented report is aimed at analysing the educational needs for Smart Cities in the context of energy only. A detailed extension to further important topics such as mobility or other environmental issues (waste, water, etc.) that are of relevance for future urban development has been neglected or touched to a minor extent for the sake of being focused.

1 The framework of Smart Cities

Following the ongoing international discussions society is facing worldwide climate change which calls for an effective low-carbon policy and highly efficient energy technologies in the very near future. Dramatic CO2 reductions have to be achieved in order to prevent the gradual increase in global average temperature caused by fossil fuel combustion.

According to the International Energy Agency (IEA) energy efficiency is one of the largest influencing factors for improving the critical situation our environment and society are facing. End-use efficiency is the largest contributor to CO2 emissions abatement in the year 2035 compared with the Business as Usual Scenario, accounting for 47% of total savings. In this context energy efficiency offers a powerful and cost-effective tool for building a sustainable energy future based on renewable energy sources. Furthermore, by focusing research on the development of intelligent methods for optimizing energy efficiency the need for investment in new energy infrastructure and upgrading of existing systems can be reduced significantly, fuel costs can be cut, competitiveness is increased and the consumer's welfare improved. However, in order to realize the full potential of energy efficiency the current energy policies and technologies have to be further developed. Substantial steps have been taken over the last years towards the 20% energy efficiency target as outlined in the Europe 2020 Strategy notably in the appliances and building sector. But recent estimates suggest that the EU is on course to achieve only half of the official 20% objective.

Secondly, a change of the worldwide energy mix moving towards a smart integration of renewable energy sources (photovoltaic, geothermal, wind, biomass, solar-thermal, etc.) into our energy networks is of crucial importance for achieving the ambitious targets for CO2 reduction. Based on this measure, the reliance on imported fossil fuels could be decreased enormously leading to improved energy reliability in Europe in the long term. Despite the impressive growth in renewable energy in recent years, most of the world's energy needs and the increase in energy demand since 2000 are still met by fossil fuels. On a European scale, only 10.3% of the gross final energy consumption in 2008 has been based on renewables. This is due to the fact that most renewables are not cost competitive under present market conditions and still rely on various forms of economic incentives within government programmes (World Energy Outlook, IEA, 2010). Hence, policies and national strategies to facilitate the integration of variable renewables into our energy networks are crucial in order to reach the overall 20% target envisaged by the EC by 2020. In addition, cost reductions are essential to large-scale development of renewable energy as the state-of-the-art technologies are still capital-intensive requiring significant upfront investments.

In this context, R&D plays an important role with the scope for further cost reductions for emerging energy technologies and new scientific methods enabling highly efficient energy infrastructure and an intelligent integration of renewable energy sources into urban energy networks complemented by demand-side-management.

Apart from the above described global environmental changes the urbanization of society is another major factor that has to be considered in the context of energy. According to the UNFPA State of World Population 2007 report the majority of people worldwide is already living in urban areas or cities since the year 2008, which is referred to as the "tipping point". These conditions are even more pronounced in Europe with an urbanization rate of 73%. Since about two thirds of the world's energy is consumed in urban areas this has significant implications both for energy security and the global greenhouse-gas emissions brining cities to the forefront of climate change actions.

From these trends it is clear that cities around the world will play a crucial role in the future energy system displaying the large potential of cities for massive energy savings. Following the above mentioned facts it can be concluded that future cities will be involved significantly in such a transition process towards a continuous and efficient energy supply in the long term. The increasing energy demand and its related environmental problems in cities are without doubt huge challenges that have to be faced. However, the overall building density of urban areas reflects itself as well as a chance for significantly increased energy efficiency by optimizing the entire chain covering energy production, distribution and consumption. Furthermore, cities display as well a remarkable innovation potential in R&D for solving such emerging environmental and energy issues at the same time guaranteeing high living standards for their inhabitants and economic competitiveness in a European context.

The framework of Smart Cities provides adequate solutions for future urban challenges through radical innovations and new urban concepts which will have to be developed in the very near future. Integrated planning, design and management of an entire energy system at city level are the key for massive CO2 reductions in urban areas. Furthermore, this particular integrative aspect has to be tackled on two distinctive scales:

- Integrated process level through multiple stakeholder participation
- System approach embracing different infrastructure layers and technologies

State-of-the-art methods and concepts in urban planning often lack the necessary multi-disciplinary aspect for understanding the entire complexity of integrated urban energy systems and the related processes; in general, the latter in fact merely focus on the implementation of single technologies. Hence, a strong demand for innovation and research focusing on distinctive areas combining urban energy technology integration and integrated implementation processes can be identified. These newly developed scientific methodologies and tools shall form a solid basis for enabling the transformation of current urban energy infrastructure towards a more intelligent and sustainable system by linking energy to other environmental and urban issues such as transport, waste, air pollution, etc.

Smart Cities in the context of the European SET Plan

One of the key vehicles of the EU for accelerating the development of large scale deployment of low carbon technologies is the European Strategic Energy Technology Plan (SET Plan). Within this strategy document of the European Commission technology roadmaps serve as a basis for strategic planning and decision making applying a collective approach in research, development and demonstration planning and implementation with a clear focus on large scale programmes, such as the European Industrial Initiatives (EII). Among other industrial initiatives, the "Smart Cities and Communities Initiative" launched in June 2011 highlights the importance of increased energy efficiency, renewable integration and intelligent energy management systems in cities in order to achieve massive reductions of greenhouse gas emissions as outlined in the Energy Strategy 2020 or the Energy Roadmap 2050. One specific object is the sufficient market take-up of energy efficient and low carbon technologies and to effectively spread best practice examples of sustainable energy concepts at city level across Europe. Recently the importance of the topic of Smart Cities has been underlined by the published Communication of the EC (July 2012) on the launch of the European Innovation Partnership on Smart Cities and Communities focusing on the strategic linking of the areas energy, transport and information and communication technologies. The first Smart Cities calls under FP 7 have already been launched in July 2011 with further calls in July 2012 bringing together European cities from various regions and background in various innovative consortia. Another instrument of the EC regarding urban development is the European Smart Cities Stakeholder Platform that is currently being set-up aiming at the Europe wide integration of various stakeholders active in the field of Smart Cities. Within individual working groups specific thematic areas shall be tackled leading to a consistent Smart Cities Roadmap in the future (http://eu-smartcities.eu/).

In parallel to the Industrial Initiatives, the European Energy research Alliance (EERA) as part of the SET Plan brings together key European organizations in the field of applied research to align their individual R&D activities to the needs of the SET Plan priorities and to establish joint programming. In November 2011 a newly formed Joint Programme on Smart Cities under the scientific lead of the Austrian Institute of Technology (AIT) has been launched at the SET Plan Conference in Warsaw (Poland) representing a major contribution for achieving the high ambitions all across Europe by applying an interdisciplinary and integrated approach based on a clear research strategy in the field of urban energy technologies. Within this JP, more than 60 research institutions from 14 European countries are jointly contributing human resources of around 192py/y working on new scientific methods and tools for understanding the complexity of entire urban energy systems.

The role and position of European Member States in the Smart Cities framework is currently not well elaborated enough although national contributions in terms of technology development, financing and policy are of crucial importance for the full implementation of the SET Plan Smart Cities goals. Based on the initiative of the Austrian Federal Ministry for Transport, Innovation and Technology (BMVIT) and AIT a joint European Member States Initiative on the topic Smart Cities has been launched pooling together Member States representatives, national experts, the European Commission and other relevant stakeholders. In this context, the objective is the implementation of a well-structured process aiming at profoundly coordinated programmes, transnational projects and economical instruments all across Europe enabling first lighthouse cities in Europe covering the full spectrum of Smart Cities.

The concept of Smart Cities and related research areas

Following the outline of the Smart Cities and Communities Initiative of the European SET-Plan, “Smart Cities” are clearly characterized by smart energy management based on innovative design and operation of the entire system at city level, combined with the extensive use of low carbon technologies. The International Energy Agency (IEA) states that radical innovations are needed and an “energy revolution” has to be initiated together with dramatic changes in our attitude and investment priorities (World Energy Outlook, IEA, 2008). For achieving these targets, the implementation of CO2 saving technologies shall be complemented by comprehensive stakeholder processes and innovation concepts at city level involving all relevant partners in order to start the transformation of existing cities into “Smart Cities”. A common vision will have to be elaborated at city level leading to individual roadmaps and action plans for research and implementation accompanied by knowledge management and structured monitoring programmes.

Following these indications, a first step for research is the identification and understanding of "Smart Cities" as complex structures involving a continuous interaction between the major parameters and components related to the entire energy system of a city. One important aspect of "Smart Cities" that has not been considered in the past is the switch from single technology applications to a multi-technology perspective combined with energy management in order to make existing energy systems of urban areas more intelligent. International experts from various fields continuously emphasize on the fact that for solving the complex problems of future energy systems old co-operations and state-of-the-art solution patterns in industry and research will not be adequate anymore. The highly complex structure and patterns of energy flows covering the entire chain from energy production, distribution and consumption in cities have to be treated with an integrated system approach heavily supported by research and development.

Therefore, a strong need for smart planning, design and operation of energy systems has been identified that will help to achieve the highly ambitious target of (almost) zero carbon emissions for city areas in the very near future. A broad use of natural resources fully integrated into the energy networks (buildings and grids) will be a crucial part of "Smart Cities". Another key aspect will be the smart management of the energy system by means of Information and Communication Technologies (ICT) in order to support the stochastic energy supply deriving from renewable energy sources. As a consequence, the individual components of the entire energy system, such as the energy distribution grids, buildings, supply technologies and even the consumers, will play a new and important role. The continuous interaction between those users and elements has to be considered in fundamentally new design and operation concepts based on city morphology, intelligent demand side management, energy storage and the potential shift between different energy sources (electric and thermal loads).

From the above mentioned aspects it is clear that the research areas related to the concept of "Smart Cities" cover a broad range. Current trends show that the merging of ICT (information and communication technologies) and energy technologies is of highly beneficial nature for solving the research questions arising in the context of future energy systems serving as a basis for new methods with respect to smart grids and Smart Cities. It shall be emphasized once more that the principal idea behind Smart Cities is to promote smart energy management at city level for achieving the ambitious targets with respect to energy efficiency and CO2 reductions in the long-term as outlined in the 2050 Roadmap of the EC. In order to achieve these targets, we need to foster smart integration of a whole spectrum of various technologies into the urban environment applying an integrated approach. Following the presented framework 4 key research areas can be identified with respect to energy issues which shall be described briefly:

Integrated urban energy planning

Land use, buildings and physical infrastructure change over timescales of decades, so we need to understand the implications of those changes to avoid being saddled with long term problems (Hall et al., 2009). The models, techniques and tools that are required to enable management of the complex coupling of technological, human and natural systems in urban areas do not yet exist. Consequently, engineering and planning decisions are being made without sufficient understanding of long term changes, impacts, interactions and uncertainties. The implications for sustainability within Europe and internationally are critical (COST, 2009). New science-based methods for the analysis of the energy performance of cities have to be developed based on deep knowledge of the urban morphology such as building density, typology and end-use mix. Such methods shall serve at first instance as a decision support for the development of well-tailored energy roadmaps and city action plans taking into account as well social aspects and economic scenario modelling. Furthermore, these new methods will enable a detailed simulation of the time-dependent energy flows within the entire energy system serving as a basis for intelligent energy management on an urban scale. It is clear that research in this particular area requires multi-level competences embracing detailed expertise in various areas among them urban energy planning, energy technology performance, numerical simulation techniques and process design.

Urban energy networks (thermal and electric)

Smart energy grids will allow for an intelligent management and operation of energy networks in cities by utilizing the potential for the shift between thermal and electrical loads. However, at the moment discussions in this area focus merely on the smart distribution of electrical energy lacking the thermal component. Furthermore, the integration of decentralized renewable energy sources into existing energy grids brings up some major technical issues that have to be treated. In this context, the stochastic profile of future energy generation by renewable energy sources calls for an intelligent demand side management of the entire energy networks within cities characterized by a continuous interaction between all involved network components (electrical and thermal grids, buildings, supply technologies, consumer). The interaction between mathematical modelling techniques, numerical simulation environments and advanced communication infrastructure is a powerful tool in this research area. This also holds for analysing the potential for active integration of storage capacities including both electrical and thermal energy within energy networks which can be achieved amongst others by intelligent demand side management.

Energy-efficient interactive buildings

Buildings represent an essential part in the existing energy system of cities being responsible for almost 40% of the entire energy consumption and a third of total CO2 emissions according to European statistics. Thousands of buildings are built or renovated every year. Reducing those emissions is a big challenge and also a tremendous opportunity since a significant contribution to reducing the impacts of climate change and decreasing fossil fuel dependence is possible. Current research focuses on how to reach reduction from existing buildings and to increase the contribution from renewable energies. In literature often the terminus “green building” is associated with these thematic issues and will be referred to as well in this report. The further development of building automation control systems that enable the increase in energy efficiency by including new predictive control strategies (weather, energy prices,…), as well as on the overall energy performance of buildings with respect to new innovative building design concepts (architecture, shape, envelope, …) is an important issue. Moving from successful experimentation to large scale and satisfactory implementation of innovation is always a difficult task in the construction sector, mainly due to a very fragmented market, the fact that the sector is partially made up of a few big companies dominating the market and numerous very small companies and the complex assembly of different techniques. Training of professionals is therefore essential. In the context of a smart city buildings cannot be treated as stand-alone objects but have to be fully integrated into the overall network. Once integrated, they can provide energy storage capacities supporting the smart management of the entire energy system. In addition, buildings can provide energy generation services supporting the overall energy supply of the entire system. This interaction between building and the smart grid is therefore one key aspect for future research where ICT plays a major role. Hence, the transition from single passive building technologies to fully integrated buildings acting as active hubs in the energy system is also one of the main challenges future research has to face.

Urban energy supply

In the field of energy supply technologies research will have to deal with the smart integration of on-site renewable energy sources into buildings and networks, the cascade use of resources or poly-generation. Scientific tools for the optimal use of hybrid supply systems will play a crucial role in this research field combined with large-scale experimental testing and the development of new procedures and standards. Research on new energy storage technologies is complementing this rather complex framework.

Additional areas

Needless to say, in order to capture the full spectrum of Smart Cities various aspects related to transport and mobility play a vital role. Improvement of public transport systems in cities, modal-split and sophisticated passenger and freight logistics shall contribute to reduce CO2 emissions in urban areas based on newly developed smart mobility/transport services. Such measures shall embrace as well the non-motorized transport (walking and cycling) within cities. One topic that is important to consider is the development of alternative fuel vehicles, in particular Electro-Mobility which is of course strongly connected to the core topic of energy as its integration into existing urban energy networks still remains a challenging problem. It shall be highlighted that on a meta-level, the link between new transport concepts and urban energy planning will be a key issue for future cities and has to be addressed by interdisciplinary research teams.

In addition, new business models and innovative investment schemes will be necessary in the future for actually enabling the transformation of European cities into Smart Cities from a financial point of view. This requires to a certain extent new regulations and a new legal framework combined with organizational innovation (stakeholders, companies, institutions, etc.) and social sciences (public awareness, user behaviour, etc.).

Occupational needs for Smart Cities

The above introduced concept clearly shows that although focusing on energy issues Smart Cities is a relatively broad topic embracing many disciplines that are of interlinking and cross-cutting nature. This fact is as well reflected in a first collection of future job profiles summarized in the table below that will potentially be needed in industry and research engaged in Smart Cities projects. Please note that this list is not exhaustive and shall represent a first overview only, whilst extensive descriptions of job profiles dedicated to the specific thematic areas can be found in the literature (ILO reports).

The big challenge for these future professions in the context of Smart Cities is not only being an expert in one particular field or sector but understanding the interplay with other thematic fields by applying a holistic approach. This holds for the entire education chain starting from apprentices up to academic personnel. In addition some entirely new job profiles will appear such as "energy strategy developers" or "city energy managers", where appropriate and dedicated curricula do not exist yet. However, the following sections shall give a more detailed insight into the 4 thematic Smart Cities areas under consideration within this report. It shall be mentioned here that due to the fact that the assessment of education for electric grids will be dealt with in a separate report, the focus in the group on urban energy networks will be on thermal networks only. A similar approach applies to the energy supply group where the here engaged experts dedicated their efforts to the analysis of the challenges regarding technology integration in urban areas.

Table 1: Job profiles in the context of Smart Cities

Integrated urban energy planning	**Thermal energy networks**	**Energy-efficient interactive buildings**	**Urban energy supply**
Urban and regional planners	Network planners	Architects	Process engineers
Architects	Power engineers	Site engineers	Installers / technicians
Land-use planners	Simulation engineers	Structural engineers	Supply design engineers
Landscape planners	Automation engineers	Facility managers	HVAC planners
Energy strategy developers	Component designers	Installers / technicians	Automation engineers
Energy managers	Maintenance engineers	Building physicists	Maintenance engineers
Environmental engineers	ICT engineers	Electro-planners	Authorised/certified consultants
Ecologists	Technicians / installers	HVAC planners	Material scientists
Waste engineers	Welders	Geotechnical engineers	Power engineers
Water engineers	Forecasting experts	Acoustic engineers	Simulation engineers
Logistic planners	Control engineers	Fire protection engineers	System analysts
Mobility engineers	Optimization experts	Facade engineers	Technology developers
Policy advisors	HVAC planners	Developers	Production engineers
Real estate managers		Master-builders	Forecasting experts
Economists		Interior designers	Optimization experts
Climate scientists		Light planners	
Developers		Landscape planners	
System analysts		Building inspectors	

2 Analysis of current situation

Integrated urban energy planning

The need for integrated urban energy planning

Integrated urban energy planning is necessary to achieve long-term urban energy efficiency. Experts in integrated urban energy planning need to be able to identify the co-benefits or trade-offs between different intervention strategies, complex feedbacks and rebound mechanisms. Seldom will they have the opportunity to completely re-engineer a city, or even one component such as the energy network. However, through identification of planning points and the lifecycles of different urban components they will need to be able to devise transition pathways and test the effectiveness of different long term planning methods (such as 'decision pipelines') to support the embedding of energy efficiency measures into existing planning cycles (COST, 2009). The development of a 'Systems Approach' to low carbon design, as opposed to a 'bolt on' component based approach, is essential if the appropriate balance between reduced demand and renewable supply is to be achieved (COST, 2011).

This requires good synergies between national framework plans and local energy plans, including planning and regulation, as well as economic, information and technological instruments (Bernsen, 2012). A common platform for energy planning is provided by the proposal for the Energy Efficiency Directive (to be finalized in autumn 2012): By 1 January 2014, Member States shall establish and notify to the Commission a national heating and cooling plan for developing the potential for the application of high-efficiency cogeneration and efficient district heating and cooling. The plans shall be updated and notified to the Commission every five years. Member States shall ensure by means of their regulatory framework that national heating and cooling plans are taken into account in local and regional development plans, including urban and rural spatial plans, and fulfil the design criteria in Annex VII (Bernsen, 2012).

For the time being, however, the main reserves of Europe's energy efficiency potential remain untapped. Among the three ambitious '202020' objectives adopted by the European Council for 2020, fulfilment of the energy efficiency objectives is falling behind compared to the renewables and emissions objectives. In order to speed up the process, "energy efficiency needs to be mainstreamed into all relevant policy areas, including education and training, to change current behavioural patterns" (COM(2010)639:6).

The COST C23 Action states that "the majority of the European national planning systems covered in our study have not yet produced specific and consistent regulatory frameworks or, at least, clear sets of policy guidelines to support the emergence of a new wave of strategic urban plans or new development control policies to turn our cities into more energy efficient and low carbon built environments" (Jones *et al.* 2009:II-III). According to Droege 2008:7) "severe segregation exists between energy issues and virtually all other urban service dimensions: energy systems and their supply industries, support businesses, finance arrangements and regulatory controls on the one hand and the worlds of urban planning and design, transport infrastructure, building construction, property development and civic life in general on the other." The only exception appears to be the inclusion of solar strategies in urban design practice and education (UP-RES, 2011).

Lack of human resources

A severe lack of human resources and limited understanding of the thematic issues among European stakeholders in public government, industry, research and education makes the threshold for participation in networks and initiatives often inaccessible (Keiner and Kim, 2008). A severe lack of human resources also becomes clear in national studies on capacity and market needs, amongst others in Austria and Norway. Only a few schools offer urban planning and design education (e.g. FH Joanneum, FH Kapfenberg, Donauuniversität Krems, all Austria), mostly as part of architectural education. The interfaces between the architecture, engineering, urban planning and design are not covered in education or practice (BMVIT/WKÖ, 2006; KRD, 2010).

An overview of environmental design in university curricula and architectural training in Europe shows that in most universities, urban planning is offered as part of the architectural curriculum, sometimes from a particular environmental perspective. Only few universities offer courses that can be characterized as integrated urban energy planning. However, due to the mainly elective nature of these topics, not all students possess outstanding knowledge on energy efficiency in architecture and urban planning (EDUCATE, 2010).

A survey by UP-RES (2011), the European project "Urban Planners with Renewable Energy Skills" funded by IEE, shows that bioclimatic design or passive aspects of environmental urban planning (orientation, shading, density, etc.) are the best assimilated in planning practice (57.8 % include it in their planning, almost no need of experts is requested). Thematic areas such as energy sources, production and networks are included in planning with 36%. The habit is mostly of consulting experts on energy issues; 64.5% confirm that they consult experts to keep up to date. The general attitude towards RES, DHC and CHP is overall positive (high potential 40-50%), and there is consensus that urban planning can benefit from these issues. However, general knowledge is related to awareness rather than expertise, and interest is expressed in information (40%) rather than in training. Lack of knowledge exists on both sides, among urban planners as well as energy engineers. For example, few planners have had a chance to use RES or DHC/CHP in their planning, except for solar systems. District Heating directors have not studied urban planning in their degree and have not found the need to study it after their degree; they consider it the responsibility of urban planners to coordinate optimised integration of District Heating and cooling in urban planning. Furthermore, urban planners are not used to working with IT tools. The benefits and planning possibilities of IT-tools will have to be strongly argued, with simple to use and useful tools. Uncertainty about cost-effectiveness strengthens the need for long-term best practices to be able to evaluate real results and cost effectiveness. In the survey, architects (32.5%) and urban planners (31%) were the dominant groups of responders, followed by engineers (11.3%), geographers (6.7%) and environmental planners (5%).

An expert survey performed in the context of Smart Cities and Integrated Urban Energy Planning indicates that respondents overall find it difficult to identify with the topic 'integrated urban energy planning' as a specific competency profile – they more easily relate to conservative topics such as architecture, engineering, construction, and urban planning. In terms of identity, it would therefore be highly useful to create educational programmes with a distinct profile in integrated urban energy planning. Certainly it would be helpful if city planners and architects would learn more energy related issues during their studies, and energy engineers learn more about urban planning and design. This requires cross faculty education. Continuing education and upgrading of existing workforce through vocational training are an absolute must with this respect.

Thermal energy networks

For the sectorial description of the district heating and cooling sector a comprehensive set of literature has been thankfully provided by the European District Heating and Cooling (DHC) Platform.

Given the fact that heating is the largest single energy end-use in Europe being responsible for almost 50% of total final energy consumption, district heating systems represent an efficient and smart solution for delivering heating services to residential (space heating, hot tap water) commercial, public and industrial customers (low to medium temperature industrial processes). Needless to say, the implementation of the Energy Performance of Buildings Directive (EPBD) will play an important factor in this discussion. In contrary, the current total cooling demand is much smaller, showing though exponential growth rates with expectations of about 60% of commercial and public buildings to be equipped with cooling appliances by 2020 (DHC 2012). It's worth noting that cooling demand is not limited to the warm season. Statistics on the actual overall energy demand for cooling on a European or national level are poor. Building owners or tenants are in most cases unaware of the amount of energy they use for cooling because individual electrically-driven chillers meet approximately 98% of cooling demand in the residential sector in Europe, making it difficult to disaggregate cooling demand in an electricity bill. A lack of awareness affects the owners of municipal buildings, too. Electricity consumption for cooling is in the majority of cases underestimated and so are the consequences of the negative environmental and economic implication of the rising power demand for cooling purposes.

Although district heating and cooling networks employ similar principles for their operation, each network develops according to specific local circumstances and the historical developments of the technology in the region making these systems inherently diverse (DHC 2012).

In various European studies it is reported that there are more than 5000 district heating systems in Europe, currently supplying more than 10% of total European heat demands with an annual turnover of € 25 – 30 billion and 2 EJ (556 TWh) heat sales (DHC 2012). The market penetration of district heating in European countries is however unevenly distributed, as indicated in the below given figure 1.

Whilst countries in northern, central and eastern Europe have high penetration rates of up to 65%, in some countries district heating and cooling networks are at present hardly implemented at all. For instance, the UK Committee on Climate Change (CCC) regards district heating drawing heat from low carbon electricity generation as one of the most cost effective carbon abatement measures considered. However, it is stated that "non-financial barriers" are limiting the much broader deployment of district heating in the UK, such as (Heat and the City, 2011):

- Lack of skills and expertise required for systems design and delivery and necessary supply chains
- Lack of experience and absence of routine procedures
- Managing complexity

- Assembling resources (financial, information, human)

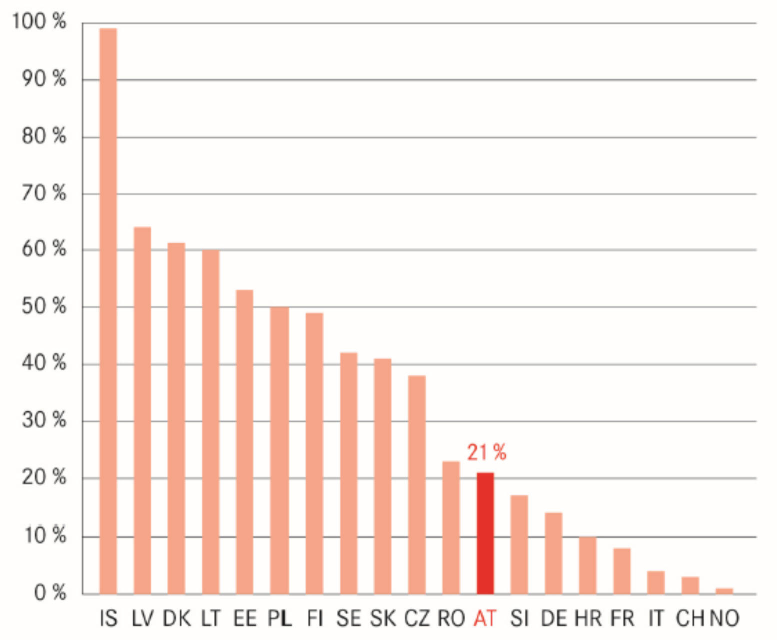


Fig.1: Share of district heating in EU (FGW, 2011) and current share in Austria (21%).

Best practice examples of district heating systems currently in operation in the UK are Southampton, Nottingham, Birmingham and Sheffield. In other European cities such as Copenhagen, Helsinki, Warsaw, Vilnius and Riga as much as 90% of residential heat demands are met by district heating. The highest growth rates for district heating are achieved in Italy and Austria. Some economic indicators for the district heating and cooling market in Austria are summarized in the table given below.

Table 2: Estimates for Austrian district heating & cooling market for period 2011 – 2020.

	Investment (2011 – 2020) [Mio €]	Added value Austria [Mio €]	Employment effect [FTE's]
District heating	1.033	888	1.159
District cooling	412	335	426
Total	1.445	1.223	1.585

On a European level, when moving towards a low carbon society investment in district heating and cooling systems will create a substantial number of new jobs. Studies estimate the job creation to be of about 220.000 new jobs on average for the period 2013 – 2050 (Lund et al. 2012). This job creation is related to substantial investment costs as indicated in the table below (Heat Roadmap Europe 2050).

Investments (Billion €)	EP CPI	HRE	Difference	Lifetime	Adjusted
District heating pipes		146	146	40	146
Industrial excess heat		7	7	30	8
Waste incineration	64	157	93	20	176
Geothermal		24	24	25	37
Solar thermal		22	22	20	42
Individual boilers	254	104	-150	15	-379
CHP2		138	138	22	238
Heat pumps		62	62	20	118
Peak load boilers	17	96	79	20	150
Power plants	582	568	-14	30	-18
Total	***918***	***1324***	***406***		***518***

Fig. 2: Additional investments required in the HRE 2050 RE scenario compared to the reference scenario EP CPI over the 38 year period between 2013 and 2050 (EP CPI refers to the model of the Current Policy Initiatives scenario constructed in the EnergyPLAN tool).

Table 3 gives an overview of some selected key figures of the district heating market in Europe for the year 2009.

Table 3: Key statistics of European district heating market in 2009 (DHC website)

	Austria	Finland	Poland	Sweden
Number of district heating utilities	730	150	499	439
Total investment in 2009	262 Mio €	---	500 Mio €	850 Mio €
Estimated employment figures	2.514	1.700	40.565	5.000

The average European share of district heating in the industrial sector is around 3.5% with slightly higher market shares in individual countries including Hungary, Poland, Finland, Netherlands and Czech Republic (10 – 15%) (DHC 2012).

When looking into the future, in order to achieve its objective of almost zero carbon energy supply by 2050, the EU needs to support the development of integrated, flexible, highly efficient and environmental friendly solutions. District Heating and Cooling (DHC) has all the ingredients to play a central role in achieving both 2020 and longer term EU objectives. Yet, as an interface with many other energy and non-energy processes and with ever-faster changing customer expectations, DHC must continue to evolve within its context to continue representing a smart, sustainable and inclusive solution. By essence, DHC involves a large range of topics, from thermal energy production to its consumption, including customer relations, networks management and integration, etc. (see figure below). The sector must have access to cheap and reliable thermal sources and distribute the resource to consumers, respecting certain qualitative and quantitative aspects, to the benefit of all involved actors. Driven by the ability to provide synergies between local resources and thermal sinks, DHC systems have interfaces with a huge variety of other energy and non-energy sectors.

For these reasons, the DHC industry works in close relation with other stakeholders, like the renewable energy industry (solar, geothermal, biomass, incl. waste), building owners, operators and users, industrial facilities and the service sector, but also with urban planners, local authorities etc.

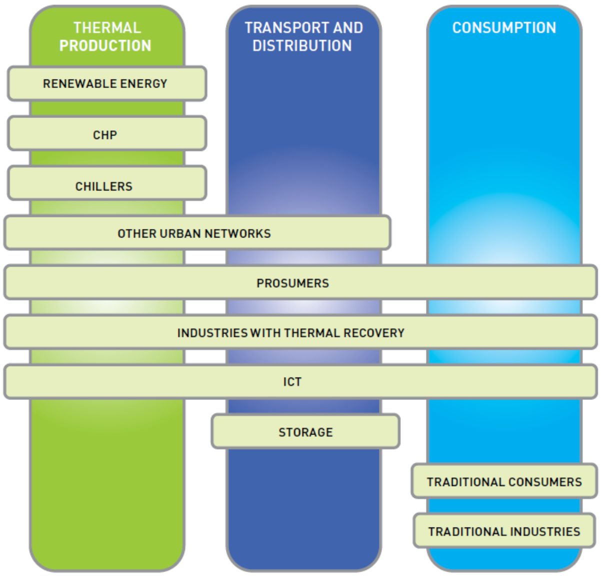


Fig.3: The horizontal nature of DHC involving a large range of topics and stakeholders (DHC Platform)

To enhance DHC's application in a future energy landscape, further research, demonstration and technological development are needed. Modern District Heating and Cooling systems are assumed to play an important role in achieving both 2020 and longer terms EU objectives due to the following reasoning:

- High efficiency energy systems are obtained by combining power and heat production
- DH systems can be used to absorb excess heat from industrial production, waste incineration, etc.,
- DH systems offer relatively large short term storage facilities which will be essential for large scale integration of the highly fluctuating renewable energy sources, like wind and solar energy (similar sized storage facilities are not likely to be offered by power systems within the relevant time horizon), and
- Modern and low energy buildings with floor heating fit perfectly with modern low temperature DH systems.

Until recently DHC has been considered as 'old technology' with very low political interest (Huther and Weidlich, 2011). Also in many countries, the DH of today operates with rather high temperatures which means low efficiency due to increased heat losses. Furthermore the potentials for being used in combined heat and power generation are lower due to the high temperature level. However, in some countries, like Denmark, low temperature DH systems are now implemented in some cities. In such modern DH systems optimized control techniques based on on-line forecasting have been implemented. It is observed that dedicated control techniques are needed for DH/DHC systems since classical control techniques cannot be used for systems like DH networks with time-varying and unknown time delays.

As of today the use of advanced forecasting techniques, like probabilistic forecasting, is limited in the real-life operation of most DH and DHC systems. However, in order achieve high efficient DH systems, advanced forecasting is needed. This is in particular the case for systems in areas with a large penetration of renewables, due to the fluctuating productions and prices originating from the renewable energy production. These forecasts are used as input for the advanced control or optimization needed for modern DH systems.

Modern district heating and cooling can be improved in many ways. Better materials, equipment and processes will boost efficiency, cost-effectiveness and improve the end-customer's experience of the technology. Nonetheless, the development of this sector can be spurred not only through technological advancements, but also by socio-economic and regulatory measures such as those which have stimulated Europe's smart electricity grids.

Despite its huge potential to reduce CO_2 emissions and to allow large scale use of RES, DHC is not always considered as possible solution. This fact is mainly due to the lack of information of the decision makers / planners and to the lack of informative tools about the real potential at local level. Apart from residential demand, DHC can also provide the thermal energy required for industrial processes.

While parameter changes in any of the related sectors may pose challenges in terms of technical and operational adaptations in DHC systems, the huge complexity of the legislative environment as well as ever faster societal changes imply particular challenges for the various business models and their development over time.

Energy-efficient interactive buildings

The building construction sector….

Today the European construction sector accounts for 30% of industrial employment in the EU contributing about 10.4% of the total GDP (E2B Roadmap 2010). Statistics state that out of 3 Mio enterprises 95% are SMEs making the market a very fragmented one. Building construction contributes with about 80% to the total construction output and is therefore the largest economic sector within the construction sector on EU27 level. Similar to many countries in Europe, the construction sector in Austria is as well an important player within the national economy with a total number of about 300.000 employees in 2010. However, innovation activities in the construction field are rather low with only 0.2% of GDP invested in research, aiming for the double over the upcoming years. This fact is as well reflected by a very low share of people with academic degrees working in building construction (3.56% only). Usually innovation in this particular sector is hindered by high risks, the lack of qualified human resources, little research capacities within companies and for instance the low cooperation with suppliers. As another example, in Romania the green building sector is being considered to have a high potential for innovation, however, only less than 100 students are graduating from relevant universities each year. Statistical data from the UK shows that although around 75.000 national vocational certificates have been awarded in construction current skills and training infrastructure is still not providing sufficient support for industry's needs (UK Department for Education DCSF, 2006/07). Table 4 gives an overview about the construction sector including building construction and completion from a European perspective.

Table 4: Structural profile of construction sector EU-27 in 2007 (Eurostat)

	Number of enterprises	Number of persons employed	Turnover	Value added	Apparent labour productivity (per person employed)	Gross operating rate (2)	Invest. rate (2)
	(1 000)		(EUR million)		(EUR 1 000)	(%)	
Construction	**3 090**	**14 793**	**1 665 092**	**562 159**	**38.0**	**12**	**9**
Site preparation	117	460	55 540	19 178	41.7	:	20
General construction	1 270	8 112	1 070 417	325 650	40.1	11	11
Building installation	759	3 483	324 624	125 337	36.0	12	5
Building completion	930	2 637	202 221	86 329	32.7	17	7
Renting of const. equipment	16	89	10 131	4 812	54.0	24	:

(1) Including estimates.
(2) 2006.

Lack of skills….

'Many governments are establishing policies and offering financial incentives to move energy-efficient ("green") buildings forward. However, in many cases these initiatives lack a training component. Lack of skills is a bottleneck which needs to be addressed' (ILO, 2011).

The environmental impact….

The building sector is responsible for 40% of total energy consumption in the EU. The actual, mainly fossil energy mix leads to 8.1 Gigatonnes (Gt) of the total of 29.0 Gt of energy related carbon emissions (IEA, 2007). Due to the fact that the building sector is expanding, the use of energy and therefor CO_2 emissions are increasing if no measures are taken.

To minimize carbon emissions of buildings, main efforts have to be put on energy efficient measures, not only at building level but in an urban context. This can be reached by optimization of passive solar gains (south orientation, etc.), using energy efficient building envelopes (insulation, integrated façade elements, etc.) and installing efficient heating, cooling, ventilation and lighting systems.

The remaining energy supply should be covered by energy from renewable sources produced on site or nearby. Fluctuating energy sources, energy storage and user energy demand interact with intelligent grids by means of information and communication technology (ICT) devices. All efforts have to be focused on veritable user comfort.

New legislation for buildings

Due to the long renovation cycle for existing buildings, new, and existing buildings should meet best energy performance. Measures are needed for increasing the number of so called 'nearly zero-energy buildings'. These types of buildings, new and renovated buildings, are obligatory by 31 December 2020 according to EU Directive 2010/31/EU. All the EU member states have to ensure the realization and detailed application in practice of the definition of 'nearly zero-energy buildings', reflecting their national, regional or local conditions.

Related EU Directives are: Directive 2006/31/EC energy end use efficiency; Directive 2010/31/EU energy performance of buildings; Directive 2009/28/EC promotion of the use of RES.

Core occupations and skills

Many existing occupations will have to be upgraded in terms of skills content. Workers transitioning from traditional construction and from declining sectors will need to be retrained. New emerging occupations will appear in the context of energy-efficient interactive buildings (see for instance www.buildupskills.at).

Early identification of skill needs for "green" buildings, and the timely and adequate provision of skills for the future demand, can make an important contribution to the transition to a sustainable economy. However, the sole provision of education and training possibilities is not enough to reach the ambitious targets throughout Europe. Unlocking the full potential needs to be triggered through adequate incentives based on a standardized and certified manner.

The architectural profession has a pivotal role to play in determining how new innovative buildings will be. Much of the domestic building stock and almost all of the non-domestic stock is planned and designed by architects and civil/structural engineers, with the support of environmental engineers where required. Sometimes they are also involved in the retrofitting of existing buildings. Country level research shows that architecture is a key occupation in energy-efficient interactive building and one of the most difficult in which to fill positions with people who have the right skills and knowledge for building innovation.

A list of core occupations was identified by the ILO research: *Skills and occupational needs in green buildings*, 2011:

- *Conceiving, planning, designing and advising*

  Construction company managers, Architects, Civil Engineers, HVAC, Electrical Mechanical, Sanitary, Building Services Engineers, Energy Analysts, Consultants and Advisors

- *Construction, installation, maintenance*

  Building Site Supervisors, Site Engineers, Insulation, Bricklayers, Carpenters, Plasterers, Roofers, Heating and Cooling Installers, Plumbers, HVAC Installers,..., Conservation of Electric Power, Electricians,...Renewable Energy Systems Installers, Solar Thermal Inst., Biomass Heating System Inst., CHP Sys. Inst., Solar PV Inst., Small scale Wind Energy Systems,..

- *Controlling*

  Energy Auditors, Inspectors, Certifiers, Quality Controllers

- *Enabling*

  Policy Makers, Urban Planners, Financing, Information Providers, Researcher

- *Manufacturing and distribution*

Manufacturers and Distributers of Building Materials and Products, IT Technicians

- *Clients*

  Developers, Energy Managers, Facility Managers, Building Managers, Householders and Tenants

Country level research suggests that architecture is a key occupation in developing "green business". The new occupation of energy efficient analyst is emerging in many countries.

Analysts require an understanding of heating, ventilation and air conditioning systems, solar thermal and photovoltaic technologies, and the energy efficient characteristics of materials.

Knowledge on the part of clients is also very important in ensuring the uptake of energy efficient building projects, since a lack of understanding was identified as a major barrier to the present sector.

Given the rapidity of change, there is a requirement for adaptability to change. There is a need for adequate environmental awareness. Green building also calls for interdisciplinary skills, including the ability to work effectively with people from other disciplines as well as individually having skill sets which cross traditional occupational boundaries. Finally, teamworking, coordination and leadership skills are important core skills in all areas of green building.

Forecast of employment and vocational need in EU and several EU countries 2020

The upcoming analysis refer mainly to the references of

- the European Centre for the Development of Vocational Training – CEDEFOP
- the national reports of BUILD UP Skills – Energy Training for Builders and
- the ILO report – Skills and Occupational Needs in Green Building 2011.

Europe[1]:

The data and results are intended to provide general indications of patterns and trends in skill supply and demand (measured by occupation and qualification) across the whole of Europe. They are based on high level quantitative methodology, using a combination of National Accounts, European Labour Force Survey and other relevant data. Employment trends present the development of the employed persons in 41 sectors which are compatible with NACE classification. In the public area the aggregation to six broad sectors is presented.

It is estimated that the Construction sector grows slightly from 14.619.000 (year 2000) to 15.678.000 (year 2010) to 15.855.000 employees in 2020. This is a rise of approx. 8,5 %.

[1] http://www.cedefop.europa.eu/EN/about-cedefop/projects/forecasting-skill-demand-and-supply/skills-forecasts/main-results.aspx?CountryID=30&case=ETBS

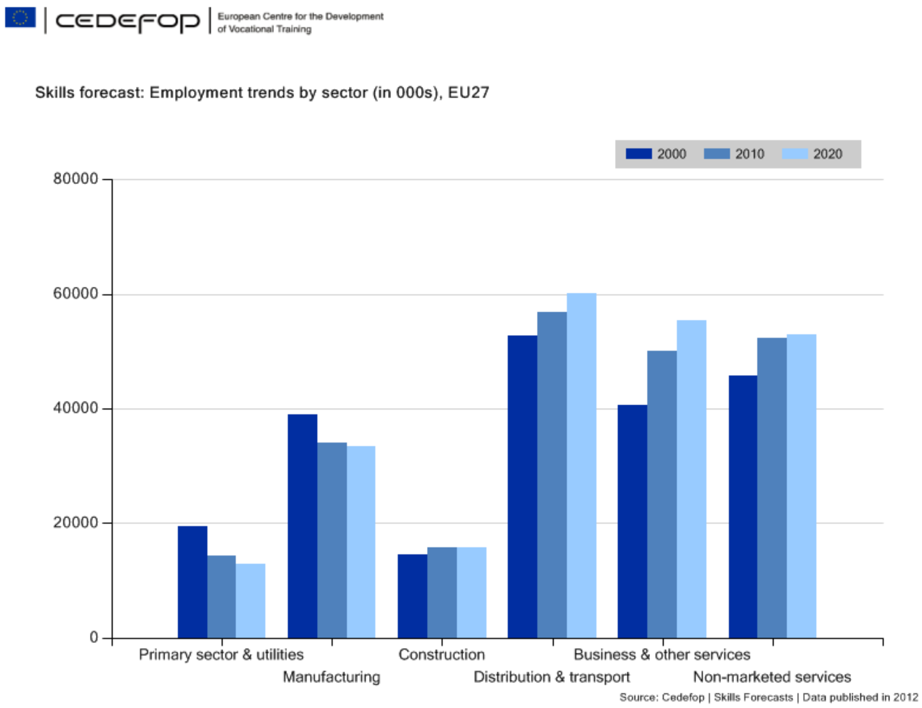


Fig. 4: Skills forecast. Employment trends by sector in EU-27 (CEDEFOP)

Quantitative Methods and Skills Anticipation in EU

It is estimated that a large number of workers will be affected by the changes in skills demand. A European initiative on green building workforce training and qualification estimated that over 2.5 million workers across EU-25 require training between 2006 and 2015 (Williams et al. 2010). The total group of workers is composed by 3 main parts:

- 1.141 Mio in target group as of 2006
- 0.745 Mio from greening of other parts of construction workforce to 2015
- 0.677 Mio from target group's share of demand from the construction sector associated with expansion and with the replacement of people leaving the sector (projected by CEDEFOP) between 2006 and 2015.

According to national and international research data, the ILO study 2011 come to the following assumptions. If the average peak employment in retrofitting per capita for the highest and lowest scenarios is considered and scaled up to the population of the EU -27 countries, this produces a low scenario of *approximately 1 million jobs at peak* and a high scenario of *4 million jobs at peak*. This does not give a reliable indication of the range of possible peak employment levels in retrofitting across the EU -27 countries, but it at least gives a sense of the order of magnitude involved.[2]

[2] International Labour Office, Geneva – Skills and Occupational Needs in Green Building 2011

"Green" building is moving to mainstream. The skills of all those working in the area will have to undergo a transition, minor or substantial. It will therefore affect a much greater number of workers: In the EU-25 about 16.7 million workers in related occupations are estimated to be affected. Eurostat statistical database provides an indication on occupational composition of related sectors (NACE 41, 43 and 71).

- Construction of buildings
- Specialist construction activities
- Architectural and Engineering activities, technical testing

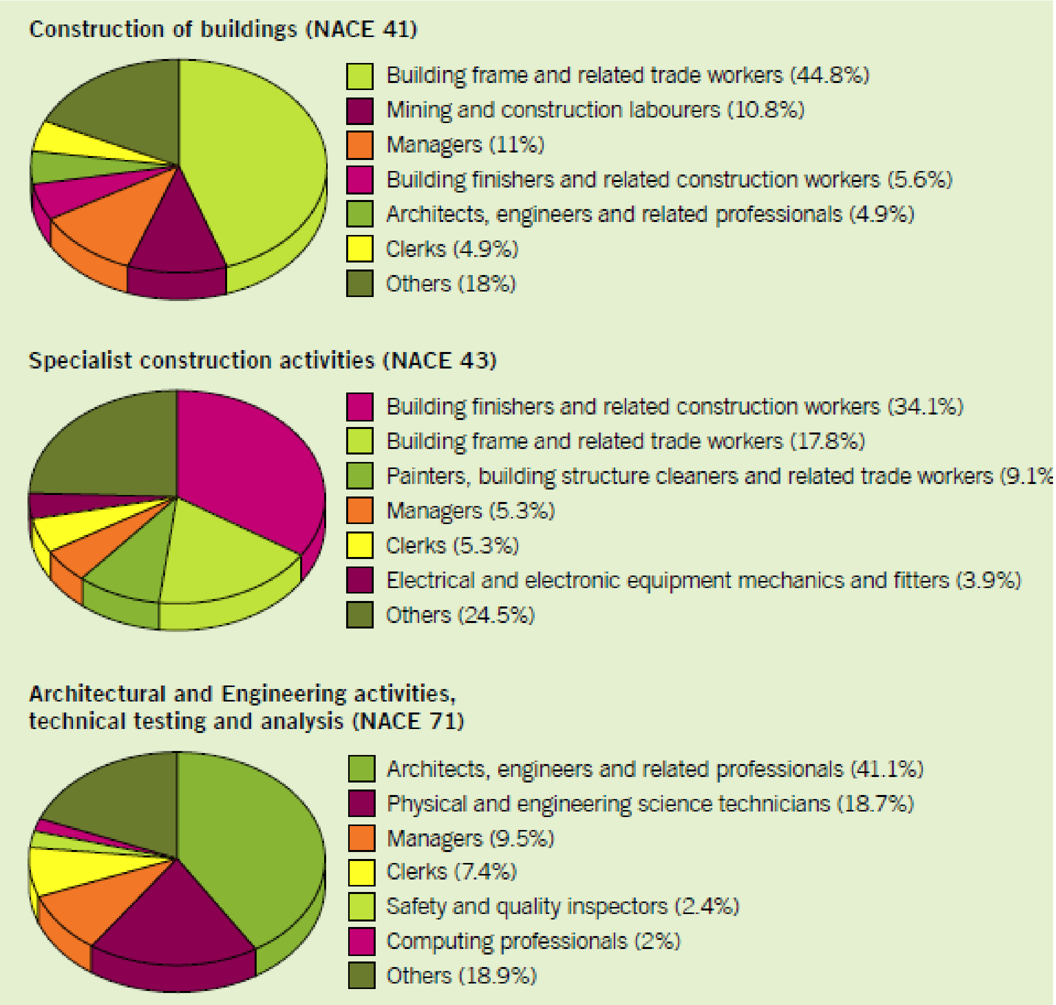


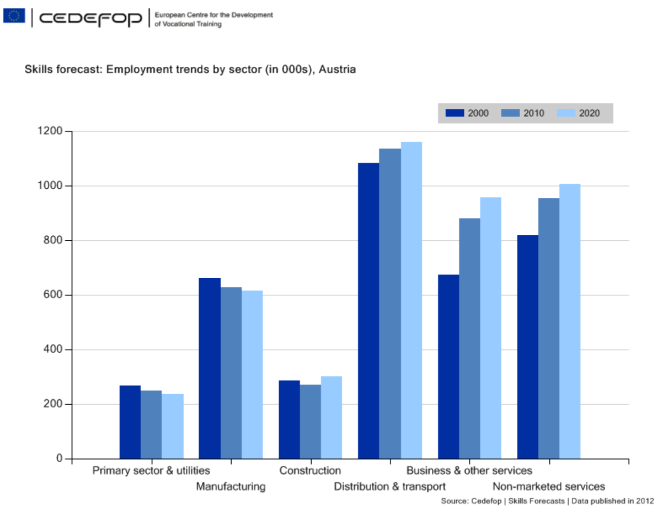
Fig. 5: Most important occupations in sectors most associated with green building in EU 25 (ILO, Research brief, 2011)

Austria[3]:

In 2009 the ÖNACE group F 41-43 (construction of buildings, civil engineering, specialised construction activities) recorded 273.655 employees. Due to the statistical uncertainties (development of indices, other crises that effect the real economy) the past index development of paid employees 2005-2011 can only be estimated roughly for the year 2020.

From 2012 an annual average increase of 3.109 employees can be expected. This means a number of more than 300.000 employees in 2020 in the building construction sector. The scenario thus represents the optimal case, therefore a favourable development of employment in construction (positive economic development and order situation on construction, a constant increase in apprentice).

Skills forecast, Employment trends by sector in Austria 2020, was published by CEDEFOP in 2012 and confirm the trend in the construction sector, an increase of 11.4 % from 2010-2020[4].



Employment trends by sector, Austria

	Levels (000s)			Change (%)	
	2000	2010	2020	2000-2010	2010-2020
Primary sector & utilities	267	249	237	-6.7 %	-4.8 %
Manufacturing	660	628	615	-4.8 %	-2.1 %
Construction	286	271	302	-5.2 %	11.4 %
Distribution & transport	1 082	1 136	1 162	5.0 %	2.3 %
Business & other services	675	881	956	30.5 %	8.5 %
Non-marketed services	818	955	1 006	16.7 %	5.3 %
All industries	3 788	4 120	4 279	8.8 %	3.9 %

Source: Cedefop | Skills Forecasts | Data published in 2012

Fig. 6: Skills forecast: Employment trends by sector in Austria (CEDEFOP)

According to further forecasts for the construction sector an increase of employment can be expected. As part of the Austrian master plan: „green jobs“, the BMLFUW created a catalogue of measures to promote careers in the fields of environment and economy. There was a potential of 100.000 additional „green jobs“ by 2020 estimated.

[3] BUILD UP Skill Austria, August 2012; http://www.buildupskills.eu/national-project/austria

[4] CEDEFOP 2012; http://www.cedefop.europa.eu/EN/about-cedefop/projects/forecasting-skill-demand-and-supply/skills-forecasts/main-results.aspx?CountryID=1&case=ETBS

Hungary[5]

The Centre for Climate Change and Sustainable Energy Policy (3CSEP) at the Central European University in Budapest, Hungary, undertook the most detailed and apparently rigorous national level study on the employment impacts of retrofitting that was reviewed focusing on Hungary (Ürge-Vorsatz et al, 2010). It set out five scenarios based on three different types of retrofitting approach (business as usual, suboptimal and deep) and a range of different rates at which retrofitting progresses (from 60,000 to 250,000 dwellings per annum). The study focused on residential and public buildings, and excluded commercial buildings.

Peak employment under the different scenarios varied from approximately 120,000 full time equivalent (FTE) workers under the fastest deep retrofit scenario to being maintained at less than 10,000 under the business as usual baseline scenario.

Urban energy supply

Without doubt renewable energy sources will play a major role in the transition towards a low carbon society bringing along multiple benefits for the environment, economy and society. At the moment renewables make up only about 13% of the primary energy supply as indicated in Fig. 7, still being far away from the ambitious targets such as the European 2020 targets aiming at a share of 20% from renewables by 2020. However, these figures are constantly increasing enabling an economic boost in various sectors through large-scale investments generating new employment opportunities.

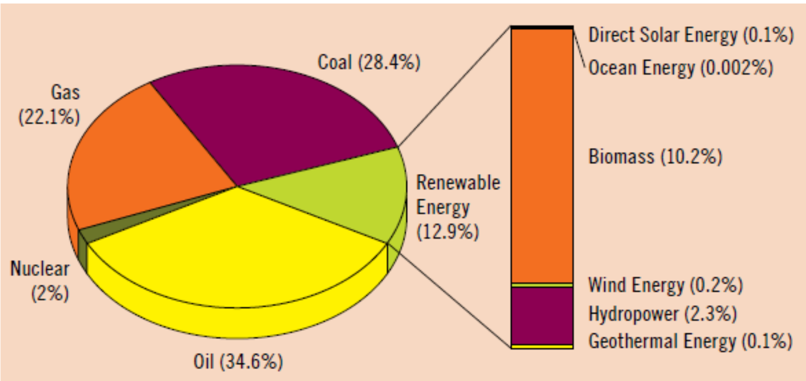


Fig. 7: Shares of energy sources in total global primary energy supply in 2008 (ILO, 2011)

In the last decades, the energy market drastically changed and opened new horizons for the energy consumers. Consumers are more aware of the importance of a good energy management, from economical but also environmental point of view. In some cases, they can themselves be producers of renewable energy and interact with the grids. With the development of low-energy houses, individual heat consumption is expected to decrease. The extent of the reduction needs to be

[5] Ürge-Vorsatz, D. et al. 2010. *Employment Impacts of a large-scale deep building energy retrofit programme in Hungary*. Center for Climate Change and Sustainable Energy Policy of Central European University (3CSEP) (Budapest, Central European University).

understood better, with scenarios making different assumptions on population changes (including the ageing of the population), urbanisation, size of dwelling and reliance on ICT to manage building services.

In 2009, a little over three million people worldwide were estimated to work directly in the renewable energy sector, with additional jobs well beyond this figure and showing an increasing trend. It can be generally stated that these demands will be hard to meet in the future as there is a widespread shortage of engineers and technicians in all parts of the renewable energy industry coming from the broader trend by students away from engineering studies. In Germany, already 10% of available job offers in engineering are somehow related to the topic of energy. Usually, people from universities graduating in civil, mechanical or electrical engineering take over jobs as qualified design engineers in the energy sector. However, the courses offered are still not sufficient to meet the upcoming demands and technical challenges. Statistics from Germany highlight the fact that more students in engineering sciences will be needed with a more adequate set of skills (DNK, 2009) related to new emerging job profiles.

The below given table summarizes current employment figures for Austria, where in 2009 around 37.000 jobs have been available in the energy sector showing an increase of 4.8% compared to 2008. Current statistics estimate a total of 185.000 “green jobs” displaying a significant increase compared to 2008 (+9.8%).

Table 5: Employment in renewable energy technologies in Austria in 2010 (WKO, 2010)

	FTE's (2010)
Solarthermal	4.700
Biomass	17.400
Biogas	1.500
Biofuels	1.869
PV	4.414
Heat pumps	1.101
Hydro Power	6.857

These indicators are even more elaborated in the case of UK, where in 2010, employment in the energy industries stood at around 173.000 representing an increase of 13.8% over the previous year. Around 6.500 companies are working in renewable energy and its supply chains across the UK in 2010 contributing about 3.4% to UK GDP. In addition, around 400.000 jobs will be needed to deliver the legally binding target of 15% of UK energy from renewable sources in 2020. These numbers are strongly supported by the fact that for achieving legally binding targets for renewable energy production in the UK extensive vocational training will be needed in order to fill current and projected skills shortages (total number of learning opportunities required summing up to 813.514 (Environmental Technologies LMI, 2010)). Nowadays, almost a third of Building Services Engineering companies are now involved in installing renewable energy technologies.

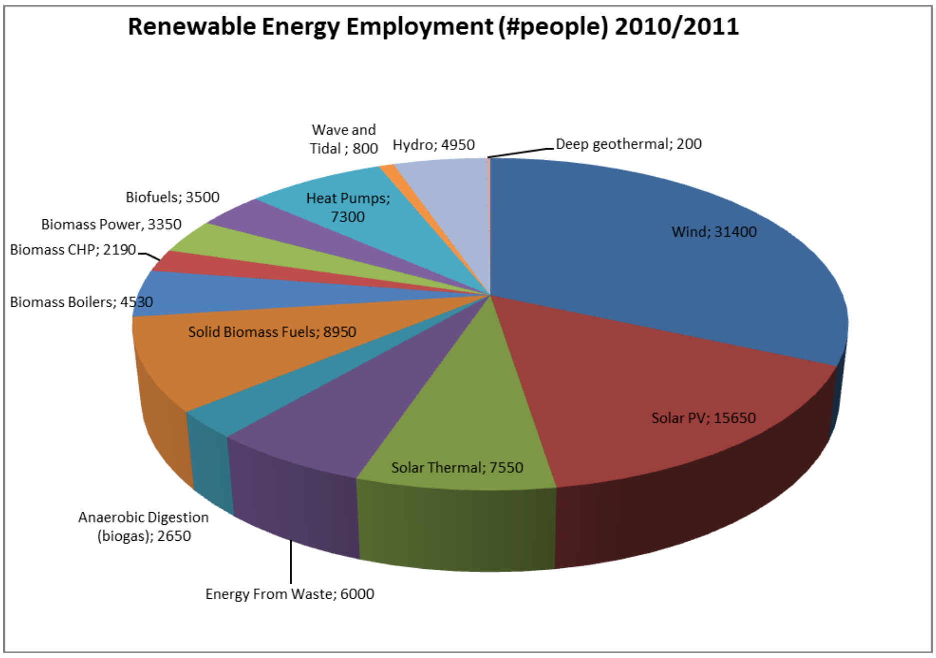


Fig. 8: Employment in renewable energy technologies in UK in 2010 (Renewable Energy Association, 2012)

Table 6: National market growth rates in UK per technology (Renewable Energy Association, 2012)

Technology	*Growth from 2009-2010*	*Technology*	*Growth from 2009-2010*
Hydro	2.8%	Solar thermal	6.2%
Wave & tidal	5.5%	Solar power	56.0%
Heat pumps	5.2%	Wind	7.1%
Biofuels	3.9%	Anaerobic Digestion	3.0%
Biomass power	4.6%	Energy From Waste	2.6%
Stoves & boilers	5.0%	Solid biomass fuels	5.4%

In other countries such as Spain, the job market in the renewable energy sector has been hit hard by the economic crisis during 2008 – 2010. Although the contribution of the renewable energy sector to the national GDP has increased in 2010 up to 8.2% compared to 2009, around 4.400 jobs were lost with a total employment number of 54.925 directly in the renewable energy market. Despite these job losses on a general level, the employment in concentrated solar power has increased significantly (from 978 in 2009 up to 1.810 in 2010, see table below).

Employment	2005	2006	2007	2008	2009	2010
Biofuels	3,179	3,246	3,487	3,598	3,767	3,153
Biomass	17,583	19,416	20,457	21,238	21,620	20,122
Wind	18,562	19,698	20,781	22,970	20,092	17,898
Geothermal High Temperature	42	61	76	99	152	156
Geothermal Low Temperature	13	14	24	44	77	100
Small Hydro	934	1,023	1,028	1,101	1,110	1,094
Marine	30	49	56	62	76	85
Small Wind	449	445	501	530	542	555
Solar Photovoltaic	5,547	5,778	6,414	25,063	10,889	9,952
Concentrated Solar Power	0	57	398	761	978	1,810
Direct employment	**46,339**	**49,785**	**53,222**	**75,466**	**59,303**	**54,925**

Table 7: Breakdown for technologies of direct employment in the renewable energy sector in Spain (APPA, 2010)

In contrary, national efforts in Romania to promote renewable energies focus strongly on wind energy and small hydropower systems with approximately 2500 employees active in this field.

In France, the renewable energy sector has been consistently identified as having the highest potential in terms of job creation with an estimated number of 200.000 jobs for the upcoming years making up for job losses in the conventional energy sector and automobile industry (ILO 2011). In addition, through national strategies, such as the Grenelle Round Table, France has committed to a "factor four" reduction in GHG by 2050.

In terms of labour-intensity, the below given table indicates that PV is the most labour-intensive technology in terms of jobs required for each megawatt of energy generated, followed by wind and biomass.

	Manufacturing, construction, installation	**Operating & maintenance/ fuel processing**	**Total**
Solar Photovoltaic	5.76–6.21	1.20–4.80	6.96–11.01
Wind Power	0.43–2.51	0.27	0.70–2.78
Biomass	0.40	0.38–2.44	0.78–2.84
Coal Fired	0.27	0.74	1.01
Natural Gas Fired	0.25	0.70	0.95

Table 8: Average employment (jobs per megawatt of average capacity) over life of facility (ILO, 2011)

Data from Germany shows that women are still underrepresented in employment in renewable energies (23.6% against 45% in the whole economy) leading to the conclusion that the new sector replicates existing gender patterns (ILO 2011, DNK 2009). This largely derives from the fact that enrolments of women in education and training related to energy engineering and other technical occupations are still low (in contrary e.g. to India). Similar observations have been made in Spain where only 26% of the employees in the renewable energy sector were women (APPA, 2010)

In general the renewable energy sector has 4 major elements to its value chain (ILO 2011) all showing different employment patterns and skills demands:

- Equipment manufacture and distribution
- Project development
- Construction and installation
- Operation and maintenance

Depending on the size of individual projects employment patterns are either stable or are being subject to unsteady conditions when a significant new installation is commissioned. Unfortunately, green jobs are not as such necessarily “decent” jobs as working conditions are often poor or risks to occupational health and safety are high.

It shall be stated that the integration of renewable energy sources in urban areas is an important issue to be considered as it will bring along new and very specific questions to be tackled from an engineering and scientific point of view. For the implementation of renewable energy sources into existing urban infrastructure a rather different approach has to be adopted in contrast to large-scale plants installed on green field. That includes different government regulations and standards issues to be applied and different plant management ways due to the different plants nature.

New concepts have to be considered in urban energy supply in reference to Smart City definition. The concept of smart grids integrates energy services but not only consumption and production but also energy storage and communication exchange. At this respect the energy generation technologies from renewable sources have to be integrated with storage technologies, like the use of Phase Change Material for storage, and advanced ICT-technologies like new communication Protocols.

All of this makes that some of the renewable technologies applied in urban energy supply are more mature than others and this all results in a continuous training needed added to very specific capabilities in the engineering and building field.

The sector has created significant employment in manufacturing, research and development, consultancy, engineering services, finance and planning, sales, government and education. Many of the professional profiles needed are originate from the more traditional science and engineering but also other profiles can be transferable to and from other sectors with specific retraining. In the Earthcare handbook (www.idec.gr/earthcare) are described the job profiles for the emerging renewable energy occupations. It constitutes a reference for occupational counsellors and career advisor in order to address the shortage of skilled personnel in urban energy supply.

Apart from that, the integration of on-site renewable energy sources into buildings and thermal energy networks and into the grid in a smart way it is necessary to adequate the different technologies each other, combining capabilities in different fields. This integration requires substantial R&D activities including the development of individual technologies for the use of renewable energies, added to the improvement of existing, conventional technologies the development of new building materials, house energy management concepts, lighting, planning tools and so on. But also appropriate building concepts taking into consideration not only reduced energy losses but also the specific requirements of renewable energy technologies, such as storage not only thermal but also electrical.

Currently, there is a lack of qualified and skilled workers in urban energy supply. This lack is more focused on renewable energy topics being included in other fields, such as electrical or mechanical engineering and other traditional technical studies, than on specific studies for urban energy supply as a course topic itself.

In the context of Smart City the technologies involved in the integration of RES in the grid are more focused on the managing a smart grid where distributed generation plants are connected and different energy demand profiles are supplied with the addition of thermal and electrical storages. That requires managing all the information about production, demands and resources viabilities in order to do not overload the grid and to deliver energy to the citizens when it is required. In this kind of grid it is used smart equipment and control technologies that allow the energy supplier to control the production in order to adjust it to the demand in the most efficient way. It is known as smartmetering.

The above mentioned issues give us the idea that it is needed knowledge about Information and Communication Technologies (ICTs) in relationship with energy management in order to be more efficient and intelligent in the use of resources and the handling of specific electrical equipment where high specialist in electricity field are required.

3 Overview of ongoing initiatives and actions

The following sections provide a short overview of currently ongoing initiatives, actions and programs both on a national or European level. A more detailed summary of such actions is provided in the table given in the Appendix to this report.

Integrated urban energy planning

There exists a wide range of initiatives, programmes, commitments and declared goals with focus on urban climate and energy in Europe and internationally. They typically facilitate pooled resources and knowledge, and heighten dissemination of interests towards policy and funding bodies. Benchmarking and exchange of best energy practices and policy is also highly valued. Examples of successful initiatives are ICLEI Local Governments for Sustainability, European Green Capitals, CONCERTO Eco-City projects, Covenant of Mayors committed to local sustainable energy, EcoCities (the Bruntwood initiative for sustainable cities), the Climate Alliance, the Green Cities Network, and North Sea Sustainable Energy Planning, the Kyoto Protocol (1997/ 2009), Agenda 21 (1992), the Leipzig Charter on Sustainable European Cities (2007), the Territorial Agenda of the European Union (2007), and the Energy Efficiency Action Plan (EEAP), the Energy and Climate Change Policy “20-20-20”, the Energy Performance of Buildings Directive 2002/91/EC, and the Energy End-use Efficiency and Energy Services Directive 2006/32/EC. Examples of EU financing instruments including energy efficiency and integrated urban development planning include European Investment Bank (EIB), European Local Energy Assistance (ELENA), Joint European

Support for Sustainable Investment in City Areas (JESSICA), and Joint Assistance to Support Projects in European Regions (JASPER) (Bernsen, 2012; Keiner and Kim, 2008; UrbEnergy, 2012).

Education and Training (EU level)

KIC InnoEnergy is one of the three KICs (together with EIT ICT labs and Climate-KIC) created under the leadership of the European Institute of Innovation and Technology. They are a commercial company, incorporated as Societas Europea, with 29 shareholders, all of them key players in the energy field, with top rank industries, research centres and universities. One of their 6 thematic areas is 'Intelligent, energy-efficient buildings and cities' focusing as well on urban development aspects. KIC InnoEnergy delivers among others MSc, PhDs and PostDoctorate engineers, with strong entrepreneurship and hands on capabilities. In the first 5 years of the industrial plan, the KIC InnoEnergy aims to deliver 1200 students, PhD and midcareer professionals trained in InnoEnergy Education programs (across all 6 thematic areas) (KIC InnoEnergy, 2012).

IEE project UP-RES "Urban Planners with Renewable Energy Skills" has performed a Competence and Training Needs Analysis, defining current knowledge and further needs of urban planners in renewable energy skills, with emphasis on DHC (District Heating and Cooling) and CHP (Combined Heat and Power). This will help determine student potential and profile, and highlight important issues for the UP-RES training program (UP-RES, 2011).

IEE project IDES-EDU Master and Post Graduate Education and Training in Multi-Disciplinary Teams gathers 15 European universities to educate, train and deliver specialists in Integral Sustainable Energy Design of the Built Environment. In a further stage, this project could be extended with integration of urban planning and RES (IDES-EDU, 2012).

Projects and Databases (both EU and national level)

Energy Cities, the European Association of local authorities inventing their energy future, organises conferences, education, training and projects (EnergyCities, 2012).

REAP Rotterdam Energy Approach and Planning project incorporates CO2 and energy directly into the development process towards CO2 neutral planning. It aims to make better use of a city's own energy potential by reducing consumption (using intelligent and bioclimatic design), reusing waste energy streams, and using renewable energy sources. In order to achieve this, design and planning of clusters of buildings are optimised to facilitate that energy is exchanged, stored or cascaded amongst them. Scientific staff at TU Delft are actively engaged in the development and implementation of this project (REAP, 2012).

The International Initiative for a Sustainable Built Environment features a Working Group on Synergy Zones for provision of technical services to small urban areas. It outlines a "system model for the development or redevelopment of small urban zones to maximise operational efficiencies by optimising supply, demand and storage functions of energy, potable water, grey water, materials and local transportation systems associated with multiple buildings and community services" (iiSBE, internal working document, 2012).

The SURBAN database on sustainable urban development in Europe contains access to detailed information on city case studies of good practise in European urban development, including integrated urban energy planning. The European Academy of the Urban Environment has developed the system with the support of Land Berlin Ministry for Urban Development, Environmental Protection and Technology and the European Commission Directorate General Environment, on behalf of the Expert Group on the Urban Environment, which was set up by the Commission in 1991 (EAUE, 2012).

The Urban Morphology Lab is part of CSTB in France. It studies the relationships between urban forms, networks, energy consumption and economics. Quantitative tools and models are developed to measure the structural impact of urban morphology on energy consumption and economic value creation. Case studies around the world measure and evaluate morphological parameters. Urban indicators for sustainability are implemented, and a new typology of urban forms is created, associated with their structural energy consumption. An urban sustainability assessment system is developed, aiming at providing decision makers with robust and quantitative tools for urban policy. It aims at forecasting long term impact of policy measures that structurally improve urban energy efficiency as well as economic value creation on the neighbourhood, district and city scales (UrbanMorphologyLab, 2012). Master students and PhD researchers participate in the research.

The Urb.Energy project Energy Efficient and Integrated Urban Development Action is a European transnational cooperation project part-financed by the European Union within the framework of the Baltic Sea Region Programme 2007 – 2013. Urb.Energy combines energy efficient refurbishment of residential buildings with integrated urban development concepts, modernization of energy supply infrastructure, revaluation of residential environment and identification of innovative financing instruments. The project started in January 2009, has a duration of three years, and builds on the results of the BSR Interreg III B project BEEN - Baltic Energy Efficiency Network for the Building Stock (Urb.Energy, 2012). The project has published, amongst others, an extensive overview of urban planning principles and energy policies that impact on energy efficient and integrated urban development planning, on a national and international scale (Urb.Energy, 2010).

COST TU0902 Action 'Integrated Assessment of Cities' aims to develop better representations of urban systems interactions and dynamics as well as new configurations of urban areas so that they consume fewer resources, emit less pollution (including greenhouse gases), are more resilient to the impacts of climate change and are more sustainable in general. This objective is supported by a holistic approach taking into account the integration of subjects traditionally analysed independently e.g. water resources, transport, waste management and health as well as the strong collaboration between academics and urban decision-makers (COST, 2009). The Action includes more than 20 European universities as its members, integrating Action results in their educational practice; the Action also plans to organise a Summer School in 2013. While the scope of this Action extends beyond energy, it covers policy analysis, geographical information science, resource management, eco efficiency, urban development, planning and transportation, life cycle thinking and decision-making processes needed to achieve integrated urban energy planning.

Conferences (International level)

- *SASBE Conference series on Smart and Sustainable Built Environments*. SASBE2012 is the fourth in a global conferences series, being the previous editions organized in Australia (2003), China (2006) and The Netherlands (2009). At global level, organization is hosted by CIB (International

Council for Research and Innovation in Building and Construction) Work Commission 116, which shares the conference name (SASBE, 2012).

- *SB conference series on Sustainable Buildings* is organized by iiSBE International Initiative for a Sustainable Built Environment, an international non-profit organization whose overall aim is to actively facilitate and promote the adoption of policies, methods and tools to accelerate the movement towards a global sustainable built environment, including energy, synergy grids and urban morphology. The conference series is organised in co-operation with CIB and UNEP (iiSBE, 2012).

- *ECEEE Summer Study* is a series of conferences organized by ECEEE, the European Council for an Energy-Efficient Economy. The Summer Studies are the backbone of ECEEE's ambition to deliver comprehensive evidence-based information on all aspects of energy efficiency, in areas such as energy efficiency policy, transportation and spatial planning, appliances and buildings policy and technology, dynamics of consumption, local action and much more (ECEEE, 2012).

Thermal energy networks

DHC is a local business, but most DHC systems face similar issues and developers of one system could learn from the experiences of others. Moreover, as DHC development varies largely between EU Member States, studies[6] distinguish between consolidation, expansion, modernization and emerging countries with each of these categories having particular research possibilities and needs.

Future low temperature DH (and high temperature DC) systems will meet a challenge in the need for ***I**CT, advanced forecasting, control and optimization*. These subjects are interrelated and in some countries a few national research and demonstration projects, on e.g. 4 Generation District Heating, are focusing on these issues. However, these initiatives must be raised to European level in order to achieve the objectives with respect to near zero energy buildings and the share of the renewable energy.

Some of the initiatives and projects found in the course of the literature research and expert consultation shall be summarized briefly:

Ecoheat4Cities (EU level):

This project has been initiated by the DHC Platform with support from Intelligent Energy Europe and aims at promoting district heating and cooling systems by customers through the establishment of a voluntary green energy labelling scheme. By establishing a label that recognizes the energy efficiency, use of renewables, and CO2 emission savings by DHC companies, the project enables local decision-makers, citizens, and interested investors to make renewable energy and energy efficiency based choices.

Project partners: Euroheat & Power, Delft University of Technology, Danish Technological Institute, AGFW Germany, Swedish District Heating Association, Building Research Establishment, Lithuanian Energy Institute

[6] www.ecoheat4.eu

Website: www.ecoheat4cities.eu

Ecoheat4EU (EU level):

This project was devised with the aim to support the creation of well-balanced and effective legislative mechanisms to foster the development of modern district heating and cooling throughout Europe, and more specifically, in the fourteen countries targeted by the project. Some of the specific project objectives include:

- Achieve transformations in the legislative/ policy frameworks
- Provide DHC stakeholders in Europe with relevant information and analytical tools to assist them in their interactions with national policy-makers and to provide input for drawing up company strategies to boost the development of modern DHC systems.
- Increase understanding among EU policy-makers

Website: www.ecoheat4EU.org

Solar-District-Heating-Take-off (EU level):

In this project the market conditions and barriers of solar district heating (SDH) plants were analysed leading to recommendations to policy and support scheme decision makers. District heating experts and industries together at one table with experts and industries of the solar thermal sector have elaborated industry standards and guidelines for SDH, necessary for commercial activities on this sector. Capacity on the supply side is built up by training and support structures. Targeted dissemination activities aim at disseminating the project results in 18 European countries, motivate and support new market actors in more European countries to start activities on this field. Project results include the following aspects:

- Reliable knowledge about the market conditions and barriers for SDH, translated into recommendations for regulations, support schemes, policy.
- Standard state-of-the-art industry standards and guidelines
- Capacity on the supply side through training and support structures.
- Targeted dissemination activities reaching market actors in 18 EU countries.

Website: www.solar-district-heating.eu

Summer PhD Course in DHC (national level):

In summer 2012 (August) Halmstad University (Sweden) will organize an international summer PhD school on district heating and cooling systems. The courses are targeted at European PhD students and will contain a profound programme with lectures, working exercises and study visits. This activity is being organized in collaboration with the DHC Platform, currently setting up a working group on education and training issues.

Energy-efficient interactive buildings

New initiatives and research programs (EU level)

There are two challenges of new initiatives and further activities. On the one hand there is an increasing number of flagship projects for new green buildings – often plus energy buildings. On the other hand there are efforts to raise the number of renovated energy-efficient buildings substantially.

Although first building standards like Passivhaus (Germany and Austria), Minergie (Switzerland) and Zero Carbon Hub (UK) are successfully introduced, the widespread implementation, especially of large scale buildings in urban areas, has not happened yet.

BUILD UP Skills, the EU Sustainable Building Workforce Initiative (EU level)

With BUILD UP Skills, the Intelligent Energy Europe (IEE) program is offering funding opportunities to unite forces and increase the number of qualified workers in Europe's building workforce, focusing on the continuing education of craftsmen and on-site workers.

In a first step the initiative will gather European stakeholders from the construction, energy, education and training sector to start a strategic process (2011-2012). In a second step national roadmaps have to be designed where concrete measures to improve the skills and qualifications of workers have to be announced (2012-2013).

Regarding the Austrian build-up skills project, a first comprehensive report on the status-quo of the education and training field in the construction sector has been published in June 2012. (www.buildupskills.at)

Energy Strategy Austria - Building Sector (national level)

The Energy Strategy Austria (BMWFJ und BMLFUW, 2010) contains a comprehensive set of measures aiming to achieve ambitious energy efficiency and saving targets in all relevant sectors. Stabilising the final energy consumption is one of the key targets. In the Building Sector (space heating & cooling in residential buildings, offices and factories) the efficiency target for 2020 is minus 10 % of end energy consumption referred to 2005.

To increase the energy efficiency of buildings, the reduction of heating and cooling energy by improving the building standard, the installation of 'nearly zero energy buildings', is proclaimed. Increase of energy consultants and the installation of energy management systems focus on electricity efficiency and waste heat use. The remaining energy should be supported by renewables. There is a focus on district heating and combined energy systems supported by solar energy, biomass and geothermal energy.

OIB guideline 6, 2011 (national level)

The building regulatory system is currently in the process of being changed. Detailed requirements will be set in so called 'OIB-guidelines', issued by the Austrian Institute of Construction Engineering (OIB). Most of the 9 federal provinces will in their ordinances refer directly to these OIB-guidelines, which will also be made compulsory by the ordinances.

The OIB 6, where topics of energy savings and heat insulation are treated, was passed in October 2011 and is the national implementation of the EBPD recast 2010. OIB 6 refers to:

- requirements on the useful energy demand for heating of new and major renovated residential and non-residential buildings,
- requirements for the final energy demand of buildings,
- requirements for specific construction elements and on energy supply components,
- energy performance certificate,
- calculation methodologies
- calculation of primary energy demand, CO_2 emissions, efficiency factor, electricity demand
- certification of the total energy performance of buildings

Overall, the Energy Strategy Austria does not only provide a realistic opportunity for reaching energy and emission reduction targets adopted on the EU level, but also provides a strong stimulus for the country's economy. It should thus secure and create "green jobs".

The Energy Strategy Austria should be regarded as a long-term process. A controlling mechanism will be set up in order to evaluate the effects of implemented measures and adapt them if necessary.

Masterplan green jobs (national level)

The Austrian Federal Ministry of Agriculture, Forestry, Environment and Water Management (BMLFUW) started an initiative to create 100.000 green jobs until 2020. Actions are planned in the field of job qualification initiative, increase and support of the innovation potential, networking and cooperation, export initiative of green technologies, stimulate investments in sustainable technologies, awareness raising.

CONSTRUCTYS fund in France (national level)

In France, the legislative framework of continuous vocational training is established by different laws with the latest of 24th November relating to “life-long orientation and vocational training.” These laws made it mandatory for each employer to contribute to the development of continuous vocational training of their employees by paying an annual contribution to an” Accredited Collecting Fund for Training” (“Organisme Paritaire Collecteur Agréé” - OPCA). The amounts collected enable the OPCA to fund training actions for company employees.

From 1 January 2012, the Construction industry OPCA, “CONSTRUCTYS,” is the only fund in the building sector responsible for collecting the contributions from all construction companies regardless of their size. Its aim is to develop and maintain industry policy and improve services to companies, employees and future employees of the sector. It has 3 professional sections: one for companies with 10 or more employees, one for companies from the public works sector with 10 or more employees and a section for companies of the construction sector with less than 10 employees. In addition, 24 CONSTRUCTYS regional associations have also been created. Their mission is to provide training, advice and to support the development of skills among companies and their employees in the region.

The European Energy Award (EU level)

The European Energy Award (eea®) supports communities that want to contribute to a sustainable energy policy and urban development through the rational use of energy and an increased use of renewable energies.

The European Energy Award is a qualified instrument for steering and controlling communal energy policy in order to review systematically all energy-related activities. The European Energy Award allows municipalities to identify strengths, weaknesses and potential for improvement and, above all, implement effectively energy efficient measures. The success of a municipality's efforts is made visible by an award, namely the European Energy Award. The standardised assessment permits a benchmarking between the eea® communities. It allows member cities to share their experiences and expertise.

The European Energy Award® consists of two main elements:

- A quality management system for communal energy-related services and activities
- Certification and award for energy-related achievements and control of success through regular audits

More information can be found under http://www.european-energy-award.org

COST Action "Smart Energy Regions" (EU level)

COST TU1104 Action 'Smart Energy Regions' investigates drivers and barriers towards large scale implementation of low carbon technologies and processes, focussing on built environment in relation to long term development programme of smart regions. WG2 aims to identify skills, knowledge and training requirements to support regional implementation of a low carbon built environment, and implications for up-skilled supply chains (COST, 2011).

Energy-efficient buildings PPP (EU level)

Energy-efficient buildings (EeB) is a consists of a financial envelope of € 1 billion to boost the construction sector, and aims at promoting green technologies and the development of energy efficient systems and materials in new and renovated buildings - this, with a view to radically reducing their energy consumption and CO2 emissions.

The programme is financed jointly by industry and the European Commission under the Seventh Framework Programme for Research (FP7). The research programme has started in July 2009 with coordinated calls for research proposals, jointly implemented by DG Research and Innovation, DG Energy and DG Information Society and Media.

Urban energy supply

Like any other energy systems, urban energy supply systems, have to be adapted continuously to the new environmental requirements and savings set out in the European Directives and then incorporated into national law and technical regulations such as the RITE and the CTE, in the case of Spain.

These adaptations involve the use of new distribution systems that add new technologies and innovative techniques to existing ones, the use of new materials, new generation systems and energy as well as new cost-saving measures and new concepts of consumption.

The implementation of these new systems requires an adaptation in the working methods not only in the implementation phase but also in the design one in order to incorporate new technologies to the existing systems.

For covering these energy sector needs the labour market requires professionals with the demanded skills in order to perform actions of design, execution and maintenance in urban energy supply. (system)

Many kind of professionals like process engineers, installers / technicians, supply design engineers, HVAC planners, automation engineers, maintenance engineers, authorised/certified consultants, material scientists, power engineers, simulation engineers, system analysts, technology developers, production engineers require a retraining that enable them to be competitive in the market and at the same time to generate new business opportunities, thus contributing to the establishment of more efficient urban energy supply.

But not only the existing occupations require retraining but also it is necessary to accommodate in the market new occupations that are focused on developing techniques that help to the establishment of efficient urban energy supply.

This retraining in the labour market must be raised at all levels, so it involves all the market actors including all categories: technicians, engineers and scientists in the developed proceedings.

Currently, there are several concepts of performance carrying out the achievement of a common goal, namely ”to provide the market of qualified professionals in urban energy supply “ depending on the action level: EU, MS or Regional

China-EU Institute for clean and renewable energy (International level)

The ICARE, which is located in the Chinese province of Hubei, is to become the top-quality education institute on energy efficiency and renewable energy in China, focusing on the following specific objectives:

- Producing qualified candidates to fill the gap between the growing industry demand for specialised clean and/or renewable energy experts, and the skills currently available on the Chinese job market.
- Promoting education in the field of energy efficiency and renewable energy at all levels.

- Fostering scientific cooperation between EU and Chinese top researchers, through the research platform.
- Providing an increasing access to specialised clean and renewable energy education and professional training activities for women, members of minority groups and persons with limited economic means

The main program activities include offering a Master Programme, vocational training activities for existing energy professionals, the establishment of a research support platform, communication and visibility activities, alumni/membership activities and institutional development activities

EU-Level

At this level the support is focused on establishing an appropriated legislative framework for the development and promotion of measures that promote the creation and consolidation of a labour market according to real needs through the publication of Recommendations and Directives that force EU-Members to incorporate into their own national law.

European Social Fund

Besides, funding proposals submitted by different Member Status. It should be emphasized at this measure the disposal of the European Social Fund. In Spain, the Biodiversity Foundation for the improvement of the employment and the environment (www.fundacion-biodiversidad.es), as "gestor" del Fondo social Europeo through the "Emplea Verde" (Green Employment) program provides alliances between different organizations and institutions in order to develop training projects focused on the supply of specialized technical staff for the labour market.

EUCERT:

As one of the best practice examples on the European level, the European Certified Heat Pump installer program (EUCERT) aims at implementing a training program for heat pump installers, establishing a certification program for this target group and disseminating the trademark „certified heat pump installer". Key element of the program initiated by the European Heat Pump Association (EHPA) is identical training material (in local language) for all trainings throughout Europe to enable the development of a comparable qualification and an easy mutual acceptance of certificate by different participating countries.

EUREC Master in Renewable Energy

The European Master in Renewable Energy is an initiative proposed and developed by the European Renewable Energy Centres (EUREC) Agency and a consortium of Universities. The programme has been run since 2002 by a network of ten European Universities and research centres who are leading the way in renewable energy research, development and demonstration. It is coordinated by EUREC Agency EEIG, a consortium of European renewable energy research centres, which has its headquarters in Brussels. In 2010 the European Master of Renewable Energy received record number of applicants and is now host to 45 students wishing to further their careers in renewable energy. Students now have the choice of six renewable energy technologies to specialise in, those being: Photovoltaics, Wind Energy, Hybrid Systems, Grid Integration, Solar Thermal and Ocean Energy.

Website: www.master.eurec.be

Enterprise level:

Companies themselves have a continuous training system where they are formed and retrained their own technicians developing their own products and providing a stable position in the market to the company itself.

In case of SMEs, they team up in associations and through these partnerships is how they provide the skills training. That is the case of FENIE (the Biodiversity Foundation and Telecommunications Installations Businessmen Association), in the field of solar energy who has provided a skills training programme to the retrain of electrical installers in the field of photovoltaic solar energy in the programme called "Programa Sol"

Regional and State level:

In the public sector, there are many actions carried out to provide specific and qualified training for the professionals:

As regional or state programmes, focused on boosting renewable energy, actions of training professionals are developed where courses are offered. That is the case of programs such as “Emplea Verde” (Green Employment) that, through small courses, it offers the necessary training in the sector.

From Universities the contribution to this situation is the offer of new specific degrees, normally as MASTER and Post-graduate degree.

That is the case of UNED (Open National University) where the Master “Energías Renovables y Sistema Eléctrico” and the postgraduate course “Gestor energético en la Edificación” are offered as also different courses in other categories as professional expert.

There is also another kind of funding for the training of the professionals in energy supply like programs that are developed from state institutions as “Fundación tripartite para la Formación y el Empleo” “El Ministerio de Trabajo y Asuntos Sociales” or “Servicio Público de Empleo” among others.

In the “Masterplan Human Resources for Renewable Energy Technologies” project, the Austrian institution ÖGUT develops a scenario based model for calculating the number of employees needed in each branch of renewable energy technologies in 2020-2030 for Austria. The model is quite detailed and will give numbers per branch, per value creation level and per job profile / qualification level. In Autumn 2012 a stakeholder process will take place to discuss results and recommendations with representatives from research, industry, education and public authorities (ÖGUT, 2012).

In France, the Grenelle Round Table is a major government initiative launched in 2007 to address energy efficiency improvements (built environment, energy, transport, etc.) and a range of other environmental issues. Following this national initiative a fully-fledged skills development strategy has been launched in September 2009 with the Mobilisation Plan for Green Jobs, a plan to mobilize relevant sectors of the economy and the regions to develop occupations for green growth. The objective is to adapt existing training programmes and qualifications and create new ones where necessary, articulated along four themes: identification of the relevant occupations, definition of training needs, recruitment for sustainable development-related jobs and promotion of the professions for green growth.

Romania developed an Action Plan for implementing the 2020 EU Directive, and most of the regions and cities formulated the Sustainable development Strategy, therefore certain steps forward were done. Most the actions are the result of various legal instruments (as it is the "Green House" program launched by the Ministry for Environment, decision no. 950/2010 that supports built integrated renewables or the program developed by Ministry of Public Works for buildings refurbishing aiming at energy efficiency and energy savings) but concerted actions, at community level are seldom are limited by a set of barriers being of technical, economic or social nature.

4 Sectorial needs and gap analysis

Integrated urban energy planning

New skills, roles and profiles – the need for system integrators

There is a lack of understanding of how to implement the technologies in a holistic way, how they can be introduced over an appropriate time period through building regulations and other government lead incentives, cost, the skills needed, and what their value added is in relation to quality of life (COST, 2011). City managers need to understand the value and logistics of successful community participation, in relation to the changing organisation and ownership of urban energy supply and demand (Houghton, 2000). Integrated energy modelling can help bring together different stakeholders to develop a common understanding

of processes and consequences of long term change (Hall *et al.*, 2009). It is clear that fostering experts with this type of understanding requires a broadening of the roles and responsibilities of all those involved in the built environment supply chain, with the possibility of a group of professionals emerging in a new overarching project management role, e.g., "*urban energy strategy developers, urban energy coordinators, urban energy policy experts*, *and urban energy advisors*" (to assist builders and designers). Integrated urban energy planning requires built environment professionals with less emphasis on single discipline solutions and a greater understanding of holistic solutions. However, such knowledge needs to be based on a deep and solid understanding of basic technical and engineering principles. Education and (vocational) training will need to foster experts with a broader awareness of the interrelationship between their own profession and others, so called 'system integrators' operating on the cross section between the different disciplines. Such experts can place more emphasis on overall quality control and commissioning of the total system, not in a fragmented approach on components. Various aspects of urban energy expertise would have to be mandatory in the curricula of certain engineering and urban planning degrees. Actions that encourage young people (maybe starting even in kindergarten) to engage in technical subjects are highly recommended.

Table 9: Different profiles and necessary competences for "system integrators"

Necessary competences	**Profile (activities, tasks, positions, clients, etc.)**
System integrators at the management and communication level **Complex urban process management** Communication between the varying levels of urban actors, different disciplines and stakeholder (administrative, financial, political, academic and expert layers)	Experts in communication and project management also trained in energy field. The tasks: integrating the appropriate actors at appropriate time in the planning process, ensuring the efficient transfer of information between the different involved levels (political, administrative, academic, other experts) • Managing complex and transdisciplinary energy planning projects, • Enabling efficient communication between different disciplines and actors, • Detecting and filling the gaps in information and communication, • Determining appropriate information formats that are suitable for each level of development and each group of stakeholders
System Integrators at social and cultural level **Socio-cultural integration of energy education and awareness.** Mainstreaming the urban energy subject in the humanistic sciences.	Socio-cultural development experts with know-how in energy topics, capable of coupling and mainstreaming the knowledge about the impact of energy in societal transformation topics. • Linking human behaviour and energy topics, • Addressing urban areas that face energy poverty • Developing innovative methods and concepts for bottom up actions, communication and integration of local energy deployment and building up of local skills (community energy management, energy-art-social media) • Mainstreaming the energy, life style and individual impact topics in the society
System Integrators at Regional Level	Transnational Knowledge of political, legislative, regulatory and administrative framework conditions coupled with understanding of energy

Regional Energy Planning Experts Many regions in Europe are connected by given geographical/climatic conditions (Baltic Sea Region, Danube Region, and Rhein Region) that trespass the national borders, regulative frameworks and strategies. However, the most expertise is contained either in specific national context or on the EU level. The Regional level in Europe is very weak at present. At the same time urban Regions contain the greatest potential for deploying energy sources, supplying and exchanging energy between the cities. For that to happen, the regional energy planning experts (system integrators) are necessary.	market and good knowledge about energy technologies. • Analysing regional development trends, strengths, risks and shortcomings, • Analysing national and transnational energy related strategies and matching them with regional capacity building, • Developing new transnational funding and investment models (beyond EU funding), • Coordination of cross-border energy planning activities, trans-national negotiations.
System Integrators in Education Energy Topic Integration in Education Curricula in Schools	Teachers, education experts capable of introducing urban environment and energy discipline in schools • Developing the teaching methods and curricula for the urban built environment and energy topics, • Conducting experiments in energy, built environment and technologies in schools, • Implementing local energy saving solutions together with the pupils in schools, • Teaching about the waste, transport and other energy and environment related topics
System Integrators in Urban Design Fields Integration of energy planning in Urban Landscape and Public Space planning and design Integration of energy planning in urban design and master planning Integration of energy and transport planning	Linking creative industries with energy planning and engineering: • Design of urban master plans that couple high quality design with deployment of local energy sources and application of smart technologies, • Urban landscape design and regeneration, taking into account urban climate, resilience and quality of the built environment, • Linking energy supply, storage and planning of urban mobility systems.
System Integrators in Social Media and ICT	Using available social media and ICT to communicate and to mainstream the energy and environment topic:

	• Setting up local community networks that pick up the energy in the neighbourhood topics • Mainstreaming the living lab demonstration and information exchange
System Integrators in Business Development *Systems Integrators in Property Development*	Innovative green business development models for Smart Cities: • Development of financing and marketing models for renewable energy exploitation technologies, • Development of new business models for sustainable energy integration and feasibility in the property development and real estate market, • new business models for renewable energy integration in the residential rental sector

In addition, the experts involved in the elaboration of this report have identified a strong need for the following skills, roles and profiles:

- *Solid understanding of basic technical and engineering principles*
- *Interdisciplinary curricula, training, integrated practices*: teaching to search for innovative solutions from changing, dynamic perspectives; Exchange platforms within universities and other research institutions, which would enable to detect the overlaps, synergies and potentials for interdisciplinary research projects as well as development of new research methods and tools.
- *Integration between urban planning and energy systems engineering:* Experts with a broader awareness of the interrelationship between their own profession and others, 'system integrators' operating across the different disciplines; Interdisciplinary thinking and working; ability to work in increasingly international, cross-cultural environments.
- *A holistic approach:* Experts who can place more emphasis on overall quality control and commissioning of the total system, not in a fragmented approach on components; combining various solutions and methods of managing human resources, design processes, building physics, engineering, energy strategy developments, land-use planning, materials, climate and environmental issues, economy and policy analysis; Energy experts will to a larger degree need to become familiar with the latest developments in low carbon city living, including the socio-political, sociotechnical and economic issues that will need to be addressed if cities are to be managed towards a low carbon future. The real problem is integrating technology with human behaviour / expectations
- *Strategic Energy Planning and Management:* A group of professionals emerging in an overarching project management role, with capacity to address the increasing complexity of

cities e.g., urban energy strategy developers, urban energy coordinators, urban energy policy experts, and urban energy advisors (to assist builders and designers); Municipal staff and economists with additional energy and environment related understanding, capable to set up new business models and financing structures for a true integration of already available technologies; Energy economy and financial schemes

- *Science-policy interface*: Ability to translate the outcomes of scientific findings for municipalities, politicians, industries; Fostering dialogue between the different stakeholders
- *GIS:* Geographic Information Systems for energy planning; GIS experts in 3D modelling of energy databases for cities
- *Technicians:* containing the capacity to implement higher required energy performance standards
- *School teachers,* capable to understand and educate school pupils about the importance and interrelations between energy, our built environment and impact on the eco-systems; Actions that encourage young people (maybe starting even in kindergarten) to engage in technical subjects are highly recommended
- *Awareness disseminators* to the general public (e.g., energy journalists, energy media)
- *Energy policy coordinators:* City Halls should be advised to include at least two experts that could work as urban energy policy coordinators (production, consumption, links to service provision and construction, procurement etc.); International competitions of planners and universities with ambitious goals related to transformation of existing buildings / neighbourhoods / cities, to developing energy management tools specifically aimed at urban planners; Land use planning and building acts should include requirements for how energy strategies are incorporated into regional and more local land use / zoning plans

Quality framework for education and training

Integrated urban energy planning is in its infancy, and research, education and innovation in this field urgently need to be strengthened throughout Europe. This can be achieved through co-operation between European institutes and stakeholders, ensuring quality through extensive dialogue, reflection and interaction. As described in the previous chapters, several activities already exist today; however, they are strongly fragmented and mainly depending on the efforts of individuals. With financial and human resources becoming more stringent, this effort cannot be maintained. External support and institutionalization are needed to mainstream integrated urban energy planning in research, education and innovation, and ensure that best practice becomes standard throughout Europe. One potential manner in which to develop this further is with the support of the Intelligent Energy Europe programme, which has already financed many educational projects on energy in buildings.

Experience shows that education and training on new subjects tends to grow around proficient research groups, as the concentration of large capacity of expertise makes it possible to deal with new problems and emerging themes (EDUCATE, 2010). Incentives should be made available to leapfrog this development in a coherent manner throughout Europe, to facilitate the pressing need for high-quality factual information packages, databases and guidelines for good practice. Co-operation of educational institutions with proficient research groups, industry and public government ensures exchange of experiences and knowledge development relevant for integrated urban energy planning practice, including evaluation and improvement of curriculum, pedagogic methods, and relevant assessment criteria for student performance. Learning platforms can be developed to spread quality-ensured databases of student projects as well as activities developed by or accessible to students. It is recommended to involve student organizations in this platform.

Mainstreaming in planning and engineering education

Education and (vocational) training in integrated urban energy planning should aim to create enlightened, innovative and independent experts, with critical distance and reflection of the new theories and solutions that increasingly arise in the context of smart cities. Creative design and planning methods need to be combined with innovative technologies to provide high-quality, energy-efficient, resilient urban areas.

In order to ensure a necessary minimal level of knowledge and skills among all future professionals, it is recommended that integrated urban energy planning be an integral and explicit part of urban planning and design as well as energy engineering education, with optional possibilities for further specialization and training. While previously regarded as 'expert knowledge' for few specialists, basic knowledge of integrated urban energy planning has now become absolute necessity for any urban planner, architect and energy engineer.

Experience shows that while students start with ambitious energy and environmental goals in their projects, translating theoretical knowledge into actual energy efficiency in a practical project is a large obstacle. The transition from facts to engineering and planning practice must be designed through small analysis tasks, case studies and reflection to make sense. This type of problem-based learning requires close cooperation between education, research and industry in the design studio (Wyckmans and Wiberg, 2011).

Interdisciplinary collaboration between urban planners, architects and engineers needs to be in focus to promote understanding, communication and a positive attitude among disciplines. Such collaboration in educational practice is very labour-intensive for staff and students. Extensive guidance and facilitation is required in order to make the experience positive for the students involved, and to avoid confirmation of the conservative prejudice that continues to exist between disciplines. In addition, educational collaboration between different faculties and with industry, public organizations and research institutions requires good administrative support in order to be viable in the long term (Wyckmans, 2008).

In addition, the Competence and Training Needs Analysis (UP-RES, 2011) defines the future needs of urban planners in renewable energy skills in three main categories:

- Information and training needs:
    - Strengthening vocational training activities
    - Consciousness and implication of urban planners: to recognize the benefits of RES, DHC and CHP and to be able to communicate them

- The importance of preparing one unified document to aid planners in tackling the energy related issues rather than having various guidance documents
- Show detailed examples of planning from other countries
- Very practical courses, with real examples, and professional specialists from urban planning and energy companies
- Useful, competent and realizable skills
- Interactive (workshops, site visits of best practices, etc.)
- Strong demand for practical guidelines applicable within the current rules and regulations – implementable concepts, checklists.
- Covering of various scales of planning
- Providing a certification that proves learning success during participation

• Practises and challenges:

- Consider the heritage and patrimonial complexity, show examples of energy saving at building and urban scale that respect and preserve architectural heritage
- Consider the post-planning issues : management and maintenance of various sustainable energy systems and consumer's habits
- Consider bio-climatic design for urban planning: density, shadings, green spaces, winds, etc.
- Concerned about cost, performance, convincing economic arguments for implementation such as benefits/risks. Also mentioned underperformance, results analysis, and maintenance issues.
- Include renovation in training program: planning DHC and renewable energies in existing districts/ buildings (small scale micro-renewables).

• Competences to be developed:

- Need of persons trained to coordinate and do networking between urban planning and energy planning, on the technical but also economic and regulatory level
- Provide detailed training of RES and/or DHC/CHP in urban renovation/regeneration programs as well as in new developments
- Economic control : knowledge on investment costs and operation costs at long range
- Need of economical and financially sustainable projects: balance between investment and returns
- Disdain in wind energy and micro and conventional hydropower, probably because they are considered as engineering infrastructures, emphasis must be made in the UP-RES to show their integration in urban planning.
- Need for new tools and instruments supporting urban transitions

Thermal energy networks

On a very general level it shall be stated that the transfer of knowledge is crucial in the European environment for ensuring long-term sustainability. It is important to teach younger generations about district heating and cooling technologies in order to be capable of dealing with upcoming challenges regarding urban development. Nowadays, there is almost no specific academic formation on district heating and cooling as the topic is only dealt with in university careers such as mechanical engineering to a very limited extent. Currently training of technicians and engineers is mostly done within the responsibility of companies themselves without any standardised education courses and training programmes. It is the responsibility of the district heating and cooling sector to ensure that relevant knowledge is passed on to a new generation of not only engineers, but as well architects, planners, etc. in a unified way (DHC 2012).

Furthermore, a lack of tools and instruments to improve knowledge, acceptance and planning of district heating and cooling systems can be identified that makes it difficult for decision makers to select the right thermal technologies according to local framework conditions. Specific dissemination and education campaigns and projects shall be put in place in order to tackle these issues on a decision making level.

There are many good examples of measures to support the development and deployment of smart thermal energy networks and thereby attain both economic and environmental benefits. Unfortunately, few of the regulatory approaches that theory predicts and practice has shown to be effective in promoting DH networks are currently in force. Research is needed to understand why. The answer may lie in a conflict between the needs of local, regional and national energy systems. In the same way it is of great importance to study how policy frameworks and instruments should be designed to stimulate and support an extension of sustainable thermal systems.

To realise the full potential of DHC as a tool to decarbonise EU energy supply, investment in higher education and vocational training for DHC technology is essential. Nowadays, there is almost no education programme devoted solely to DHC. Engineers, urban planners and architects would be the targets. The new generation should be ready to develop smarter cities presenting integrated solutions using renewable energy. The development of a Master Degree in District Heating and Cooling such as proposed by the DHC platform in their Strategic Research Agenda covering all these topics would be an important step to ensure the long term sustainability of the European energy system.

There is a need for further education on advanced forecasting, control and optimization in relation to modern district heating and cooling applications. This is due to the challenges observed in terms of time varying time delays, non-linearity, non-stationarity for low temperature DH systems with a complicated fuel mix, and last but not least the highly fluctuating energy production from renewable energy sources (like wind and solar) (see Pinson et.al., 2008 for more information).

In addition, on the industrial level there is a need to integrate new ICT, forecasting, control and optimization procedures, and this calls for new training and education also for the existing industry. It is expected that 4 generation DH systems will call for new industrial and business areas where Europe can take the lead if the adequate priorities are acknowledged in time and on a European level.

Finally, new technologies in pipeline construction are the key to a catalytic effect on the safe and economic expansion of district heating and cooling as there is little experience with flowable filling materials, trenchless laying and recycling of filling materials (Huther 2011).

Energy-efficient interactive buildings

Skills development plays a strategic role in promoting the development of energy efficient buildings. Following fields of activities are identified...

- Include skills development in green building initiatives: Many initiatives to promote the greening of buildings are being held back because of shortages of skills; green building programs and projects should be established with strategies to address skill issues, including appropriate training components

- Consider skills-led strategies for green building policy: People with the right skills can act as drivers

- Provide broad skills for manual occupations: Training of skilled construction trades workers in a certain type of building technology through its lifecycle (installation, maintenance, removal, disposal, recycling)

- Look at skills beyond the building sector: A wide range of occupational groups are effected, including trainers, urban planners, investors, etc.

Focus on developing the understanding of green building among clients and potential clients, consider how clients get reliable advice

- Prioritize energy-efficient building in the provision of construction related training and education: Providers of training and education that develop skills for construction related industries should prioritize skills for energy-efficient buildings. Both, initial and continuing education and training

- More and better training in assessment, advice and quality assurance

- Engage social partners: A large number of temporary workers find it difficult to participate in the institutions of ongoing social dialogue, and find them excludes from training opportunities

- Boost incentives for training in energy-efficient buildings: There is a need to ensure that those working in the sector receive sufficient training to develop skills; it also helps to break gender barriers and occupational segregation

Urban energy supply

The use of Renewable Energy source like solar thermal, photovoltaic, biomass, cogeneration, geothermal, etc…in urban energy supply, requires a sort of skills that professionals have to acquire.

Most of them, depending of technical knowledge of the technician, can be easily acquired through short-timed courses to adapt to the particular technical specifications of the technology used, install procedures, control methods, maintenance tasks and management in urban energy supply.

In the efficiency urban energy supply field is essential the use of a good control and management system for that reason is very important the implementation of ICTs. That requires additional training in this field.

University level:

The most affected degrees are those related in engineering and building.

At this level the actions to carrying on are focused on the introduction, in existing degrees, related urban energy supply, like engineering and building, of subjects in the technologies applied in renewable energies. Another measure were the establishment of new degrees and specialized master like "Maintenance in Energy supply systems Engineer".

A more important aspect at this level to take in account is the research in this field, specially the investigation of new materials for thermal storage (both heat and cold), like Phase Change Materials (PCMs) or new energy generation systems adapted to the building functionality, like little-scaled cogeneration systems, or the integration of photovoltaic systems in structural elements of the building like roofs, facades and even windows. For that reason the creation of Specialized Technological Centres where research were done but also disseminated is crucial.

Training is necessary not only for graduated workers. There are methodologies and systems relatively easy to be learnt by green collar workers. Seminars and part-time courses could improve urban energy supply skills of these workers. These could create new positions and help to reduce the unemployment via re-training routes.

ICTs systems are other field where measures will have to be taken. Training in these subjects is necessary in order to use new control (domotic) and management (monitoring) specific systems.

A technical high specialized training and continuous retraining becomes increasingly necessary due to the complexity and the continuously change of these technologies. This training would be addressed to staff with high degree that should be provided by specialized technical institutions or specialized centres of vocational training (technician institution/specialized high school.)

Everything that has been stated above must be followed by training focused on installers, who should be experts for energy supply applicable utilities. This kind of training has to be managed in specific training centres.

Industry level:

The current educational system put in the labour market a lot of high qualified people but with a limited knowledge about the latest technologies in urban energy supply. However specialized professionals are limited to enter in the urban energy supply sector, being this one of the most important gaps in the sector.

Regarding to the content in current training programs, they are characterized by their extremely theoretical and very focused on economic vision content, driving off the reality of the technical needs of engineers and technicians developing energy supply systems. What they really need is a mainly technical training, showing the equipment and their problems, how they are inside, how they work, their operate mode and maintenance, etc..

It is common, in urban energy supply, that the maintenance concept is associated to crisis management limiting the maintenance concept to emergency maintenance and not taking into account concepts like RCM (Reliability Centred Maintenance), TPM, (Total Productive Maintenance) CMMS (Computer Maintenance Management Software), preventive maintenance, maintenance audits, etc…The market would be more productive, efficient and secure if maintenance management is considered one of the key points in training.

The measures will have to be taken would be the organization of highly specialized technical courses. It would be offered a kind of time-short courses that involves specific training to professionals with a certain qualification that requires a specialization, thus giving them the possibility of cover the professional skills gap existing in specific fields, as for example, showing the equipment inside, analysis of the equipment problems, working mode, and knowing the solutions of every possible problem.

Another proposal would be fleeing from the organization of generalists congresses and fairs and direct efforts towards specialized congresses and fairs about urban energy supply. These congresses and fair would help experts and professionals to discover new challengers in urban energy supply.

Quantified needs of future job market

As stated in the above sections for the 4 individual thematic areas a certain amount of new jobs and upgrading of existing skills will be needed in order to fully implement and realize Smart Cities on a European scale ("roll-out"). However, such numbers are difficult to estimate and are usually based on relatively crude assumptions. It shall be stated here that for the field of Smart Cities basic calculations to estimate future job needs as they might be valid for single technology fields (e.g. jobs per kW-installed power) are almost impossible to perform. The below given table somewhat summarizes the information that could be found in the literature for some of the involved areas. However, it shall be mentioned that even those numbers shall be treated with care in the context of the current economic environment in Europe where unemployment rates are on the rising in some countries.

Table 10: Estimated quantification of future job needs

Thematic area	**Quantified job needs**	**Timeframe**	**Source of information**
Integrated urban energy planning	No numbers to be found	none	none
Thermal energy grids	220.000 new jobs (multiplier effects excluded)	2050	*Heat Roadmap Europe 2050*, Aalborg University and Halmstad University for Euroheat & Power
Smart (electricity) grids	See other group within SET Plan Education & Training Initiative		
Energy-efficient interactive buildings	280.000 – 450.000 new jobs by the recast EPBD	2020	EeB PPP – Longterm research roadmap and multiannual implementation plan
	2.5 Mio workers require training across EU-27	2015	Williams et al. (2010): IEE Programme, TREN/A2/143-2007 (ECORYS)
Urban energy supply			
Solar thermal	More than 200.000 new jobs	2030	Solar Thermal Vision 2030, ESTTP
PV	See other group within SET Plan Education & Training Initiative		
Bioenergy	See other group within SET Plan Education & Training Initiative		
Heat Pumps	No numbers to be found	none	none
Geothermal	See other group within SET Plan Education & Training Initiative		
Energy Storage	See other group within SET Plan Education & Training Initiative		

5 Recommended actions

Besides the specific recommendations and field of activities of the individual thematic areas given in the previous sections of the report, the following actions related to Smart Cities, embracing a much broader and general spectrum, can be recommended. It is important to mention that these recommendations are still valid and appropriate for all the four thematic areas related to Smart Cities. As a time wise prioritization of actions is sometimes difficult to perform a general timeframe shall be proposed, given as:

1) Initiating relevant processes at EU and national level by mid 2013 (upon completion of Education Roadmap by EC)

2) Start of dedicated projects by 2014

3) Full implementation of recommended actions by 2015

A part from very concrete actions to be implemented in a rather easy and straightforward manner it shall be stated that radical innovations and shifts in the education sector can only be achieved through European-wide strategic processes involving the European Commission, relevant ministries at national level and representatives from educational institutions, research and industry. Appropriate governance in the education sector is the key success factor for a sustainable future job market where people with the right skills can lead the necessary boost in the energy sector. Such strategic processes require a close coordination and streamlining of the relevant actors (EC, ministries, educational institutions, social partners, industry) based on a deep joint understanding of the current situation and of ways to overcome existing barriers. European processes need to be translated into national environments taking into account the individual national strengths, weaknesses and boundary conditions in general. The EC is clearly in the position for kicking-off and steering such initiatives and processes together with key experts in the field.

In addition, many of the below proposed actions are targeted towards the higher educational sector (universities, research institutions, etc.) as the topic of Smart Cities will need to be tackled firstly from a research point of view. However, it shall not be forgotten to provide as well adequate working environments for people with lower education or even no professional education whatsoever. Due to various reasons (nationalities, religion, social classes, political conditions, etc.) many people in Europe still do not have an appropriate access to educational services that fit their talents and aspirations in the future. The current weak economic framework in Europe is another factor that needs to be taken into account. Such bottlenecks need to be overcome through social balancing and turned into a European added value in order to fully exploit the potential of the available workforces all over Europe.

Finally, it can be summarized that identifying and elaborating concrete measures and actions that can trigger new governance processes are key for enabling a paradigm shift in the educational sector.

Filling the skills, competences and knowledge gap

Focus area 1: Meeting the skill/competencies gaps of new and emerging technologies

Title	*1. Strengthening vocational training*
Description	Providing and strengthening education and training for existing workforce is of utmost importance for meeting the ambitious energy targets in 2020 and 2050. Current state-of-the-art skills shall be updated for all levels of education (apprentices, academics, etc.) according to latest technology and innovation trends in order to unlock the full potential of people already on the job market. Therefore well-defined education and training packages shall be elaborated on EU-level in a standardized and unified manner.
Actions	Call for proposal: development of education and training packages according to specific thematic areas and different EQF levels (mid 2013) Education and training packages publicly available (beginning 2015)
EQF levels	1 - 8
Title	*2. Adoption of "skills-led" strategies in education*
Description	It is of crucial importance to provide students and apprentices currently undergoing their education with the latest technology trends in order to be ahead of current practice once entering the job market. People with the right skills can act as drivers of change and facilitate new investment. Innovation should be transferred into industry through adequate "skills-led" strategies in education and training. This radical shift in the education sector shall be triggered by the EC and initiated through a strategic EU-wide process amongst relevant ministries and decision makers in the education sector. The proposed education network (see action 7) shall serve a key instrument in such a process.
Actions	Initiation of EU-wide strategy process with relevant national stakeholders (ministries, social partners, "education competence network", etc.) (mid 2013)
EQF levels	3 - 8
Title	*3. Upgrading of existing curricula*
Description	Current university curricula are often not up to date anymore with regards to contents and teaching methodologies. A radical upgrading of existing curricula according to the complex skill-demands and new job profiles arising from research in the context of Smart Cities is absolutely necessary. In addition, a better embedding of the topic "energy" in various curricula (natural-, legal-, economic sciences), not only engineering sciences, is highly desirable. Finally, enriching current education courses with soft skills needed in the course of Smart Cities implementation projects (stakeholder engagement, communication, cultural understanding, leadership of innovation processes, integrative approaches etc.) shall be envisaged.

Actions	Initiate dialogue with national universities and educational institutions, this action is strongly linked to action 7 and 11 (mid 2013) Upgrading to be implemented by 2015
EQF levels	6 - 8

Focus area 2: Strengthening and developing existing skills/competencies

Title	*4. Shift towards methods oriented courses*
Description	Adopting appropriate methodologies and concepts in upcoming urban development projects is the key to Smart Cities. Current courses are often lacking such method oriented education focusing only on skills development for a very narrow and specialized technology field without providing the overall picture. The emphasis shall be put in the future on portable skills, where training courses are built around a core qualification and a set of methods that will be useful and applicable in a much broader range of related sectors. Needless to say, such skills will have to be based on a deep and solid understanding of technical and engineering principles.
Actions	Elaboration of “core qualifications” for different thematic areas and EQF levels Development of action plan for implementation
EQF levels	3 - 8
Title	*5. Implications of energy scenarios, trends and policy documents on education sector*
Description	Scenario modelling and trend analyses in the energy sector (e.g. Energy Roadmap 2050) are necessary instruments for preparing strategic guidelines for industry, policy makers and research. However, such activities often do not consider the implications of the analysed scenarios and trends on the education sector with regards to workforce needed, skills demand, etc. leading to a certain mismatch in the project landscape. The immediate and on-time reaction to global trends is of crucial importance for being prepared for upcoming challenges with regards to education and training. The EC should fully exploit the potential of these instruments by considering the implications of energy scenarios and trends on the education sector and consequently guaranteeing a better coordination between policy making, investment and skills provision.
Actions	Inclusion of education scenarios in EC strategy documents on regular basis
EQF levels	6 - 8

Fostering involvement, access and up-take by the labour market

Focus area 1: Promoting mobility, life-long learning, workforce training

Title	*6. Increasing mobility of young researchers and professionals*
Description	Although many mobility programmes have already been installed over the last years (e.g. Erasmus), young researchers and professionals are still not exploiting the full potential of such opportunities. International education and job experiences beyond Europe shall be further supported by light and flexible procedures (working permits, pension schemes, social insurance, etc.) and particular incentives for going abroad.
Actions	Further extension and promotion of mobility programmes on international level (mid 2013) Awareness raising on EU + national levels (in collaboration with ministries and social partners) Coordination with national authorities beyond Europe (to be started mid 2013)
EQF levels	3 - 8

Focus area 2: Industry involvement and partnerships

Title	*7. Creation of European "education competence network"*
Description	Providers of education and training shall collaborate more closely on a European level by creating an "education competence network" (similar to the framework of EERA) focusing strongly on typical Smart Cities topics such as integrated urban energy planning, urban energy networks, green buildings, urban energy supply, etc. This shall ultimately lead to an appropriate "quality framework" and regular exchange of experiences for the education and training sector.
Actions	Call for tenders: Installation of a EU education competence network (mid 2013) Network in full operation by mid 2014
EQF levels	1 - 8
Title	***8. Benefits of vocational training for industries***
Description	Industrial companies often do not recognize the broad range of benefits that are brought along by vocational training activities for their existing workforce. Dedicated campaigns shall increase the awareness in industry for such training activities and ultimately lead to a stronger engagement of companies in education issues. For such activities it is highly desirable to recruit industrial employees with broad experience for vocational training purposes. The inclusion of social partners is key for such processes.
Actions	Call for proposals: companies can apply with detailed course programme and

	vocational training packages, EC provides financial support (mid 2013)
EQF levels	3 - 8
Title	*9. Get trained on "real objects"*
Description	Smart Cities are complex systems that are difficult to understand through written teaching material and in class rooms only. Cities should be considered as living labs, giving students the chance to get educated in "real life" on "real objects" such as showcase cities, highly innovative buildings or other cutting-edge energy projects. Making the topic of Smart Cities a more tangible one will raise the interest of young people in the subject.
Actions	Call for proposals: development of "living lab objects" with maximum potential for training purposes/facilities (=key requirement). Development of training modules in conjunction with "real objects" according to thematic areas and different EQF levels
EQF levels	6 - 8
Title	*10. Smart Cities Summer School*
Description	A dedicated Smart Cities summer school for European students on Master and PhD-level shall be envisaged in collaboration with industry and EERA. Experts from the EERA JP Smart Cities shall be involved in this activity as lecturers providing insight into the latest research trends in the context of Smart Cities. Such an event shall be organized once a year.
Actions	Yearly call for proposals: organization of Smart Cities Summer School (on a yearly basis), foreseen duration: 3 weeks, transnational collaborations
EQF levels	6 - 8
Title	*11. Smart Cities EU Education & Training Conference*
Description	Creation of a forum for relevant Smart Cities stakeholders coming from research, universities, industry and the public sector to exchange educational needs and share knowledge and experiences. Such an event should be of high-level quality, highly visible and to be hold once a year. Transfer of innovation throughout the various sectors on EU-level is of crucial importance.
Actions	Pilot financing of first conference through EC, later co-funding through EC, engagement of "EU education competence network" in event organization.
EQF levels	4 - 8
Title	*12. Attract young people to energy sector*
Description	Young people are the key for transforming our society towards a sustainable future. Dedicated activities should focus on the following issues/barriers currently encountered:

	• Overcome gender barriers and occupational segregation • Diversity and inclusion • Enabling the enhancement of quality of employment in energy sector through adequate policies • Incentivize innovation boost in traditional industry sectors • Support the role of social partners facilitating the interaction between industry and trade associations
Actions	Call for proposals: High quality marketing campaigns in collaboration with industry and educational institutions dedicated at different age groups, additional: scholarships for apprentices and students (all to be started by mid 2013)
EQF levels	1 - 8
Title	*13. Smart Cities research and training infrastructure*
Description	The topic of Smart Cities is raising radically new research questions which will have to be answered with the help of adequate research infrastructure. An extension of already existing infrastructure on EU-level shall be envisaged (ESFRI) focusing in particular on the highly interdisciplinary nature of Smart Cities. It shall be highlighted that new laboratories (both hardware + software environments for simulation/modelling activities) etc. will have to go beyond the classical use for single-technology applications with a much broader range of facilities for system analysis. Such research infrastructure shall then be combined as well with training purposes for engineers and technicians in order to directly transfer innovation and newly gained knowledge to the education sector.
Actions	Call for proposals: Set up of Smart Cities research and training infrastructure based on upcoming ESFRI Roadmap (mid 2014)
EQF levels	6 - 8
Title	*14. Smart Cities Trainee Programmes*
Description	Development and promotion of well-defined “Smart Cities Trainee Programmes” in relevant industry and the public sector (city authorities) for young graduates in order to facilitate and increase the efficiency when entering the job market. Experienced professionals acting as “mentors” for these young people shall be provided with specialized training courses providing the necessary basis with regards to didactic methods.
Actions	Call for proposals: Development of Smart Cities Trainee Programmes in relevant industries for different thematic areas and EQF levels including transnational cooperations (companies, educational institutions, etc.)
EQF levels	3 - 8

Planning and enabling skills development

Focus area 1: sector skills assessments and observatories

Title	*15. Strong engagement of European Technology Platforms in education*
Description	European Technology Platforms shall be encouraged to provide valuable input for the educational sector with regards to upcoming skill-needs for the implementation of energy technologies. Dedicated responsibles/contact persons, working-groups and task forces shall be installed within the platforms taking care of educational issues (see already ongoing actions of the DHC platform). Regular updates of technology roadmaps provided by the platforms shall include the according needs and the necessary measures for education and training.
Actions	Initiate process and close dialogue with all EU technology platforms, set up of specific working groups, strongly linked to "education network" (see action 7) (mid 2013)
EQF levels	6 - 8

Focus area 2: Development of teaching materials and courses

Title	*16. Promotion of European "double-degrees"*
Description	Support for better coordination and streamlining of university curricula on EU-level. The promotion of "double-degrees" will ultimately lead to transparent and aligned curricula over Europe and enhance mobility of students
Actions	EC to initiate dialogue amongst European universities for setting up new "double-degrees" (mid 2013), involvement of European University Association (EUA) desirable
EQF levels	6 - 8
Title	*17. New Smart Cities related curricula*
Description	Development of new module-based curricula within university networks for Smart Cities related thematic areas meeting the demand of new job profiles. Such curricula should be based on a rotational principle and overcome the current sectorial thinking by focusing strongly on interdisciplinary education across various engineering disciplines (see job profiles for "system integrators")
Actions	Call for proposals: Development of new Smart Cities based curricula (mid 2013) Implementation by 2015
EQF levels	6 - 8
Title	*18. New Smart Cities related professorships*
Description	Teaching and training in the field of Smart Cities will require a new generation of

	academics being specialized on the interfaces between the different energy topics and urban infrastructure layers (building-to-grid, multi-source energy networks, buildings as storage, large-scale RES integration in urban environments etc.). The introduction of newly specialized professor- and lectureships related to Smart Cities shall enable students to receive the necessary education and opportunities to focus their studies on Smart Cities topics accompanied by the appropriate academic supervision (e.g. for Master or Doctoral thesis, etc.)
Actions	Call for proposals: funding for establishment of new professorships related to Smart Cities targeting highly potential young scientists/lecturers
EQF levels	6 - 8

Focus area 3: "Train the trainer"

Title	*19. Establishment of platform for trainers*
Description	A European platform for trainers shall be put in place for continuing their education and sharing of knowledge. Such a platform shall be embedded within the proposed "education competence network" (see action 7). In addition, representative offices at national level shall be installed too.
Actions	See action 7
EQF levels	3 - 8
Title	*20. European "Train-the-Trainer" Academy for Smart Cities related thematic areas*
Description	Development of adequate courses, seminars and materials for trainers at ALL education (EQF) levels (apprentices, students, professionals, etc.) according to the thematic areas related to Smart Cities. Quality control is of utmost importance for this action.
Actions	Call for proposals: Set-up of European "Train-the-Trainer" Academy for Smart Cities related thematic areas (link to "education network", action 7)
EQF levels	1 - 8

Focus area 4: Online information and other tools

Title	***21. European education database***
Action	Information on how to access education and training for Smart Cities is a key issue to be considered. The creation of a European database providing information for ALL levels of education (apprentices, students, professionals, etc.) shall enable young people to find appropriate education and training courses from a European perspective. In addition, relevant information on scholarships or a job-portal shall complete such an education database. Job offerings from companies/industries on this platform shall be considered to be free of charge.
Actions	Call for tender: Set-up of European education database including job portal
EQF levels	1 - 8
Title	*22. European Smart Cities Roadshow*
Description	Better and transparent information of careers in the field of energy at national level is urgently needed with a strong focus on additional elements such as gender and diversity. A European-wide Smart Cities Roadshow dedicated at particular age-groups shall improve the current situation and should be installed in combination with other ongoing Member States initiatives. In addition, the development of specific Smart Cities lectures at primary- and secondary schools shall support the early engagement of young people in the field of energy.
Actions	Call for tender: Development of European Smart Cities Roadshow (incl. dedicated events, project weeks, exhibitions, etc.) according to thematic areas and different EQF levels. (this action shall be strongly linked to action 12)
EQF levels	1 - 8

The following figure given below shall highlight once more the strong need for bringing together different stakeholders being active in the education sector through adequate processes and governance. The proposed “EU Education and Training Conference” for Smart Cities under action 11) is a key element for such a dialogue enabling the elaboration of further concrete actions to be implemented at various levels.

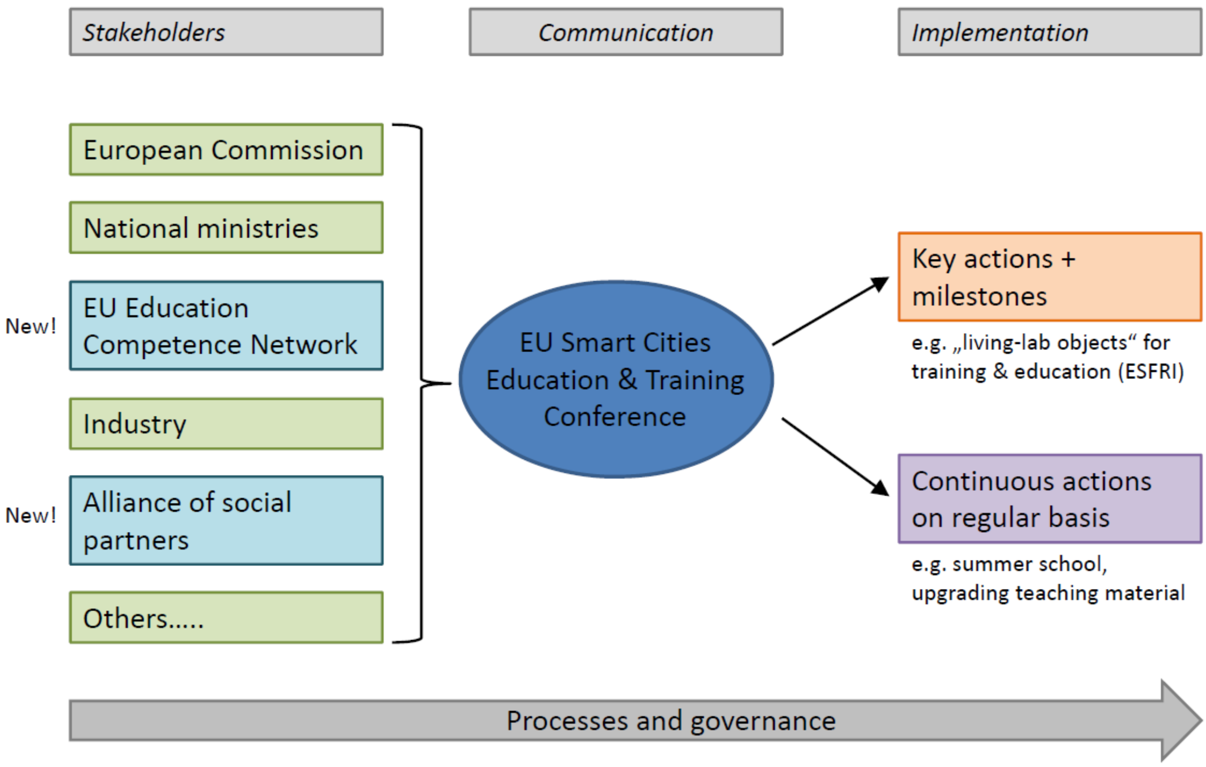


Fig. 9: Overview of relevant stakeholders, communication and governance processes and implementation strategies.

References

1) Statistics Austria, www.statistik.at

2) Eurostat, www.ec.europa.eu/eurostat

3) Schneeberger, A. Petanovitsch, S. Novak; *Techniker/innenmangel trotz Hochschulexpansion*, Institut für Bildung der Wirtschaft, September 2006.

4) A.Schneeberger, A. Petanovitsch, S. Novak; *Requirement for skilled labour and qualification strategies oft he Lower Austrian Economy*, ibw research brief, Institut für Bildung der Wirtschaft, September 2006.

5) W. Amann, St. Ramaseder; *Forschungsbedarf in der Bauwirtschaft – eine Potentialanalyse*, Forschungsgesellschaft für Wohnen, Bauen und Planen Wien, January 2006.

6) DNK (WEC); *Fachkräftemangel in der Energiebranche*, Stellungnahme des DNK-Nachwuchsforums Energie, March 2009.

7) S. Mader; *Wirtschaftsfaktor Fernwärme und Fernkälte – Arbeitsplätze und Wertschöpfung in Österreich*, Final report, Austrian Energy Agency, November 2010.

8) CEDEFOP; *A strategy for green skills*, Briefing note, European Centre for the Development of Vocational Training, February 2012.

9) CEDEFOP; *Europe's skills challenge*, Briefing note, European Centre for the Development of Vocational Training, March 2012.

10) ILO; *Investment in renewable energy generates jobs. Supply of skilled workforce needs to catch up*, Research brief, International Labour Office Geneva, 2011.

11) ILO; *Skills and occupational needs in renewable energy*, International Labour Office Geneva, 2011.

12) ILO; *Greening of the building sector is held back. Skills-led strategies can drive green building forward*, Research brief, International Labour Office Geneva, 2011.

13) ILO; *Skills for Green Jobs. A Global View*, International Labour Office Geneva, 2011

14) Dachverband Energie-Klima; *Erneuerbare Energie – Technologische Kompetenz aus Österreich*, in collaboration with Austrian Economic Chambers, October 2011.

15) WKO; *Plattform Technik*, Austrian Economic Chambers, www.wko.at

16) M. Haas; *Humaresourcen in Österreich. Eine vergleichende Studie im Auftrag des Rates für Forschung und Technologieentwicklung*, University of Vienna, February 2008.

17) Austrian Federal Ministry of Agriculture, Forestry, Environment and Water; *Österreichischer Masterplan Green Jobs*, www.lebensministerium.at, October 2010

18) R. Gaubitsch, M. Luger; *Zum Fachkräftemangel in Österreich*, Public Employment Service Austria, April 2011.

19) EHP; *Recommendation for Education, Training and Examination of Fitter and PE-Welder and Certification of Fitter Companies*, Euroheat & Power, June 2010.

20) T. Bühler, H. Klemisch, K. Ostenrath; *Ausbildung und Arbeit für Erneuerbare Energien*, Wissenschaftsladen Bonn, Germany, 2007.

21) St. Humpl, S. Nindl, M. Prokopp, F. Rainer; *Bedarfs-, Kohärenz- und Akzeptanzanalyse für den FH-Bakkallaureats- sowie FH-Masterstudiengang Erneuerbare Urbane Energiesysteme in Wien*, 3s Unternehmungsberatung GmbH, June 2006

22) H.Huther, I. Weidlich; *The Future of District Heat in Germany*, 17th Urban Energy Conference, Debrecen, Hungary, October 2011.

23) P. Pinson, H. Madsen, H. Aa. Nielsen, T.S. Nielsen, N.K. Poulsen; *Modeling the nonlinear temperature reponse of district heating systems for model predictive control applications*, 11th Annual Symposium on District Heating and Cooling, Reykjarvik, Iceland, August 2008.

24) Williams et al. 2010. *Ex-ante evaluation of the initiative on building workforce training and qualification in the field of energy efficiency and renewable energy within the Intelligence Energy Europe Programme*, TREN/A2/143-2007.

25) FGW, *Fernwärme in Österreich - Zahlenspiegel 2011*, Fachverband der Gas- und Wärmeversorgungsunternehmungen, 2011.

26) Heat and the City, *Developing District Heating in the UK: What works?*, 2011.

27) DHC Platform, *District Heating & Cooling, A Vision towards 2020 – 2030 – 2050*, March 2012.

28) DHC Platform, *District Heating & Cooling – A Strategic Research Agenda*, March 2012.

29) RHC Platform, *Common vision for the Renewable Heating & Cooling sector in Europe*, 2011.

30) H.Lund et al., *Heat Roadmap Europe 2050*, First pre-study for EU27 performed by Aalborg University and Halmstad University, May 2012.

31) Código técnico de edificación, CTE, www.codigotecnico.org

32) Reglamenro de instalaciones térmicas en Edificios. RITE . Real Decreto 1027/2007

33) Instituto para la Diversificación y el Ahorro de Energía. www.idae.es

34) Instituto Nacional de estadística www.INE.es

35) Plan de Energías Renovables 2011-2020 (PER 2011-2020). Instituto para la Diversificación y Ahorro de Energía (IDAE)

36) Impacto económico de las energías renovables en el sistema productivo español. Estudio técnico PER 2011-2020. Madrid 2011

37) Empleo asociado al impulso de las energías renovables. Estudio Técnico PER 2011-2020.Madrid 2011

38) Francisco Pérez García (Dir.).Trayectoria y perspectivas de la economía española, Fundación BBVA e Instituto Valenciano de Investigaciones Económicas. España 2011

39) Francisco Pérez García (Dir.). Universidad, universitarios y productividad en España, Fundación BBVA e Instituto Valenciano de Investigaciones Económicas. España 2012

40) Observatorio de la Formación para el Empleo. Informe nacional de formación en las empresas en 2010.

41) Instituto para la Diversificación y el Ahorro de Energía. Guías técnicas

42) MINISTERIO DE EDUCACIÓN, CULTURA Y DEPORTE. Datos y cifras del sistema universitario español. Curso 2011-2012. España 2011

43) Asociación de Productores de Energías Renovables. Estudio del Impacto Macroeconómico de las Eenrgías Renovables en España.. España 2010

44) Observatorio de las ocupaciones del Servico Público de Empleo Estatal. Estudio Prospectivo de als Energías Renovables.España 2009

45) Department of Energy and Climate Change; UK Energy Sector Indicators 2011, URN11D/193, 2011

46) Renewable Energy Association/Innovas; Renewable energy: Made in Britain, 2012

47) RenewableUK/Energy & Utilities Skills; Working for a Green Britain: Employment and Skills in the UK Wind & Marine Industries, February 2011

48) Department of Energy and Climate Change; Digest of United Kingdom Energy Statistics (DUKES) 2011, National Statistics, London TSO, ISBN 9780115155277

49) Higher Education Funding Council for England (HEFCE) /UCAS; Unistats from universities and colleges in the UK [online] available at http://unistats.direct.gov.uk/

50) Higher Education Statistics Agency (HESA); Statistics - Students and qualifiers at UK HE institutions [online] available at http://www.hesa.ac.uk/content/view/1897/239/

51) Chartered Institute of Building Services Engineers (CIBSE); Accreditation of rogrammes [online] available at http://www.cibse.org/index.cfm?go=page.view&item=1774

52) National Statistics; Vocational Qualifications in the UK: 2006/07, 26 Feb 2008 [online] available at http://www.education.gov.uk/rsgateway/DB/SFR/s000773/sfr03-2008.pdf

53) RenewableUK / Energy & Utilities Skills; Working for a Green Britain: Future Employment and Skills in the UK Wind & Marine Industries Vol. 2, July 2011

54) SummitSkills; Potential Training Demand in Environmental Technologies in Building Services Engineering Indicative Training Needs Analysis Using a Scenario-Based Approach (Stage 2), October 2010

55) UK District Energy Association (ukDEA). UKDEA Key Facts [online] available at http://www.ukdea.org.uk/en/home/introduction

56) E2B Roadmap, Energy-efficient Buildings PPP – Multi-annual roadmap and longer term strategy, Ad-hoc Industrial Advisory Group, 2010.

57) NRDC, Smarter Cities, A project of the Natural Resources Defense Council, <http://smartercities.nrdc.org/sustainability-factors>, last accessed 11 July 2012.

58) COST Secretariat; Memorandum of Understanding for the implementation of a European Concerted Research Action designated as COST Action TU0902: Integrated assessment technologies to support the sustainable development of urban areas, COST 243/09, 2009.

59) COST Secretariat; Memorandum of Understanding for the implementation of a European Concerted Research Action designated as COST Action TU1104: Smart Energy Regions, 2011.

60) A.Bernsen; Integrated Urban Energy Planning Success Stories throughout Europe, presented at the EHP 2012 Euroheat & Power Conference in Copenhagen, 26-27 April 2012, Teaming up for renewable heating and cooling, Session F Urban Planning.

61) COM(2010)639; Energy 2020. A strategy for competitive, sustainable and secure energy. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions.

62) P. Jones, P. Pinho, J. Patterson, C. Tweed (eds); Low Carbon Urban Built Environment. European Carbon Atlas, summarising the results of the COST C23 Action, Cardiff, Welsh School of Architecture, 2009.

63) P. Droege; Urban Energy Transition: An Introduction; in: P. Droege (ed); Urban Energy Transition. From Fossil Fuels to Renewable Power, University of Newcastle, NSW, Australia, World Council for Renewable Energy, Elsevier, Amsterdam, 2008, pp.1-14.

64) UP-RES; Deliverable 2.1. Competence and Training Needs Analysis for RES H/C integration in urban planning, results of comparative studies and survey. Report of the IEE project UP-RES Urban Planners with Renewable Energy Skills, 2011, <http://aaltopro2.aalto.fi/projects/up-res/products.html>, last accessed 13 July 2012.

65) M. Keiner, A. Kim; City energy networking in Europe; in: P. Droege (ed); Urban Energy Transition. From Fossil Fuels to Renewable Power, University of Newcastle, NSW, Australia, World Council for Renewable Energy, Elsevier, Amsterdam, 2008, pp.193-209.

66) Urb.Energy; website of the Urb.Energy project, <http://www.urbenergy.eu>, last accessed 18 July 2012.

67) BMVIT/WKÖ; Forschungsbedarf in der Bauwirtschaft – eine Potentialanalyse, 2006 (in German)

68) KRD; Norwegian market needs regarding education on energy in buildings, Working group for energy efficient buildings, Ministry of local government and regional development, 2010 (in Norwegian)

69) EDUCATE; Framework for Curriculum Development. Report authored by the IEE project EDUCATE Environmental Design in University Curricula and Architectural Training in Europe, 2010. Available online at <www.educate-sustainability.eu>, last accessed 13 July 2012.

70) KIC InnoEnergy website, <http://www.kic-innoenergy.com/about-us/key-facts.html>, last accessed 16 July 2012.

71) ÖGUT; website of the Masterplan Human Resources for Renewable Energy Technologies, <http://www.masterplan-energie2020.at/ziele/> (in German), last accessed 23 July 2012.

72) IDES-EDU website, <http://www.ides-edu.eu>, last accessed 13 July 2012.

73) EnergyCities; website of the EnergyCities initiative, <www.energy-cities.eu>, last accessed 23 July 2012.

74) REAP website, <http://aiany.aiany.org/files/REAP-UK.pdf>, last accessed 16 July 2012.

75) iiSBE; website of the International Initiative for Sustainable Built Environment, <http://www.iisbe.org>, last accessed 19 July 2012.

76) EAUE; website of the European Academy of the Urban Environment, <http://www.eaue.de/winuwd/default.htm>, last accessed 18 July 2012.

77) Urban Morphology Lab; website <http://www.urbanmorphologylab.com>, last accessed 23 July 2012.

78) SASBE2012 conference website; <http://www.fec.unicamp.br/~sasbe2012/index.html>, last accessed 19 July 2012.

79) ECEEE; website of the European Council on Energy-Efficient Economy, <http://www.eceee.org>, last accessed 19 July 2012.

80) A.Wyckmans; Environmental learning in architecture. From individual choice to collective responsibility, Nordic Journal of Architectural Research, Vol. 20, No. 3, pp.73-87.

81) I.Wyckmans and A. H. Wiberg; Industry- and research driven education in sustainable architecture: Transitioning towards a professional M.Sc programme on zero emission built environments, International Journal of Sustainable Building Technology and Urban Development, December 2011, pp.267-275.

82) S. A. Hammer; Renewable Energy Policymaking in New York and London: Lessons for other 'World Cities'?; in: P. Droege (ed); Urban Energy Transition. From Fossil Fuels to Renewable Power, University of Newcastle, NSW, Australia, World Council for Renewable Energy, Elsevier, Amsterdam, 2008, pp.143-172.

83) Build-up Skill Austria, Status quo der Aus- und Weiterbildung in der Bauwirtschaft, Austrian Energy Agency, 2012. www.buildupskills.at

Annex I

Table about ongoing initiatives (Excel sheet): Please note that this list only gives a partial country overview due to the lack of detailed data.

List of national Initiatives/Programmes/Actions

Area	**Name**	**Country**	**Website (link)**	**Target group**					**Further descriptions**
				Primary -school	**High-school**	**Apprentice-trainees**	**University students**	**Professionals (vocational-training, life-long learning)**	
Integrated Urban Energy Planning	UNICA Euromaster in Urban Studies	EU	www.4cities.eu				X		International and interdisciplinary collaboration programme between universities in Vienna, Madrid, Brussels and Copenhagen
	Association of European Schools of Planning	EU	www.aesop-planning.eu				X	X	Platform with excellent overview about European wide educational courses in urban planning (summer schools, master courses, PhD programmes, etc.)
	UP-RES	EU	www.aaltopro2.aalto.fi/projects/up-res					X	Urban Planners with Renewable Energy Skills, organizing training for urban and regional planners in the five partner countries (FI,HU, GER, SP, UK), supported by IEE
	Association of Energy Cities Romania, OER	Romania	www.oer.ro					X	Promoting sustainable energy concepts in Romanian communities; training for energy managers in the city hall structures, able to develop and implement sustainable energy action plans
	Urban planning and territorial administration	Romania	www.uauim.ro/departamente/ut				x		Faculty of Urbanism, University for Architecture and Urban Planning, Bucharest, specific B.Sc. and M.Sc programs
	Enercities	EU	www.enercities.eu	X	X				Online game for young people to experience energy-related implications. The goal of the game is to create and expand virtual cities dealing with pollution, energy shortages, renewable energy etc. The game is web-based and suitable to play on low-budget computers.

	EDUCATE Prize	EU	www.educate-sustainability.eu				X		EDUCATE Prize was launched in July 2011 to celebrate outstanding student work that creatively investigates and reflects on the various dimensions of sustainability in architecture and urban design
Thermal energy networks	Euroheat & Power Recommdentions	EU	www.euroheat.org			X		X	Education, Training and Examination of Fitter and PE-welder and Certification of Fitter companies
	Fachverband Gas Wärme	Austria	www.gaswaerme.at					X	platform providing specific training activities
	Ecoheat4Cities	EU	www.ecoheat4cities.org					X	Voluntary green labelling scheme (by DHC Platform + IEE)
	Ecoheat4EU	EU	www.ecoheat4.eu					X	Creation of well-balanced and effective legislative mechanisms to foster the development of modern district heating and cooling throughout Europe
	Solar-District-Heating-Take-off	EU	www.solar-district-heating.eu					X	Market conditions and barriers of solar district heating (SDH) plants were analysed leading to recommendations to policy and support scheme decision makers
	COGEN	Romania	www.cogen.ro					X	association providing support for developing the legal frame for thermal energy co-generation in Romania and for the support actions, including training
	Green energy cluster	Romania	www.greenenergy.org.ro					x	Cluster focusing on the use of biomass in sustainable energy projects; short term training sessions on technical aspects related to thermal installations
	Installation Engineers' Association AIIR	Romania	www.aiir.ro			x	x	x	training courses on: built integrated renewables (solar-thermal and heat pump systems), energy certification in buildings; it also mediates practical placement or the students in companies
	Ecoheatcool	EU	www.euroheat.org/ecoheatcool					X	Analysing the heating and cooling demands in Europe with a view to provide comprehensive, aggregate information about the whole heating and cooling market and its dynamics in Europe
Energy-efficient Interactive Buildings	Klimaaktiv	Austria	www.klimaaktiv.at					X	klima:aktiv is the Austrian climate protection initiative launched by the "Federal Ministry of Agriculture, Forestry, Environment and Water Management", embedded in the Austrian federal climate strategy. Educational courses focus strongly on sustainability in the building sector

	Build-up Skills	EU	www.buildup.eu			X		X	European programme focusing on the continuing education of craftsmen and on-site workers
	Award "Timber Construction"	Austria	www.proholz-noe.at				X		Promoting timber construction in the building sector
	Building Academy	Austria	www.bauakademie.at			X		X	Platform providing training courses for building sector
	Green Skills	Austria	www.greenskills.at					X	Training courses for the use of sustainable building materials
	Green Academy	Austria	www.green-academy.at						Training courses for sustainability in the building sector
	Gas Natural Fenosa	Spain	www.empresaeficiente.com					X	Workshops & events to promote efficiency in SMEs
	Fundación ATECYR	Spain	www.atecyr.org					x	Training courses on building efficiency standards, building certification, energy audit.
	Romanian Green Building Porfessional	Romania	www.rogbc.org/ro/romania-green-building-professional-certification-training-program					X	Training and certification programme for increasing competencies in green buildings for professionals active in civil engineering and in related fields for developing a sustainable built environment
	ROFMA	Romania	www.rofma.ro					X	Association for Property and Facilities Management in the built environment aiming to contribute in aligning the Romanian legislation to EU and to provide training and consultancy in the field
	Romanian Green Building Council	Romania	www.rogbc.org					x	Short term various courses for green buildings development: Energy Management & Integration with Renewable Energy Sources
	Grenelle Building Plan	France	www.legrenelle-environnement.fr/			X	X	X	Launched in 2009, national French strategy for reducing energy consumption in building sector
	ADEME	France	www.ademe.fr			X		X	French Agency for Energy, providing info on the current training offer, the required competence of trainers, and a set of recommendations for the setting up of a system for the remote training of trainers
	CSTB	France	www.cstb.fr						Independent public institution dedicated to innovation in buildings
	FEEBat	France	www.feebat.org			X		X	Partnership between French public organisations, professional associations, SMEs and energy companies, which aims to train 120.000 people by 2020 mainly in retrofitting

	GRETA	France	www.edoucation.gouv.fr						French public education continuous training organisation, providing training for job seekers and employees.
	AFPA	France	www.afpa.fr			X		X	French training organisation providing training for 168.000 adults per year, 30.000 in the building sector
	Effinergie	France	www.effinergie.org					X	French association with the objective of creating a supportive dynamic within the construction market that makes it conducive to building comfortable and energy efficient buildings
	CONSTRUCTYS	France	www.constructys.fr					X	Accredited Collecting Fund for Training in the building sector contributing to the development of continuous vocational training of employees
	CAPEB	France	http://www.capeb.fr/			X		X	French building craftsmen professional association
	Amavis Project	Romania	www.amavis.ro					X	Training Centre KNX Romania, Basic training short term courses on intelligent buildings control, design and installation of intelligent buildings equipment
	Certified European Passive House Designer	EU	www.eu.passivehousedesigner.de					X	Promoting Passive House Standard in Europe (supported by IEE)
Urban energy supply Technologies	Austria Solar	Austria	www.solarwaerme.at					X	Training courses for certified solar thermal installers
	Leistungsgemeinschaft Wärmepumpe Austria	Austria	www.lgwa.at			X		X	Training courses for certified heat pump installers under the umbrella of EHPA
	European Master in Renewable Energy	EU	www.master.eurec.be				X		A European Master Programme on Renewable Energy organised by EUREC in collaboration with 10 EU partner universities
	EUCERT	EU	www.ehpa.org					X	European Certified Heat Pump Installer
	Asefosam	Spain	www.asefosam.com					X	Training courses for installers
	Prosol	Spain	www.agenciaandaluzadelaenergia.es					X	Certification programme for professionals
	PVTRIN	EU	www.pvtrin.eu				X	X	A project aiming at training photovoltaic installers and European certification
	PANER 2011-2020	Spain	www.minetur.gob.es/energia/desarrollo/EnergiaRenovable/Paginas/paner.aspx	x	x	x	x	x	Promote of use of RES

	IDEA	Spain	www.idae.es					X	Several training programme in RES and to promote the employment and use in RES
	PANER 2011-2020	Spain	www.minetur.gob.es/energia/desarrollo/EnergiaRenovable/Paginas/paner.aspx	x	x	x	x	x	Promote of use of RES
	FFER	Spain	www.cenifer.com				x	x	Promote of training in renewable energy
	Empres	EU	www.empres.eu/project/				x	x	Program for management in Renewables Energies
	Qualit'ENR	France	www.qualit-enr.org					X	Training for craftsmen for the installation of RES. In 2011 more than 5.000 adults have received training
	Empleatec	Spain	www.empleatec.es			x	x	x	Online courses on RES
	Censolar	Spain	www.censolar.es				X	X	Solar Energy training centre

General	MINT	Austria	www.mint.at				X		Attracting students to natural and engineering sciences
	IT Offensive 2020	Austria	www.ubit.at			X	X		Promoting jobs in ICT
	Technik - Berufe.Geld.Zukunft	Austria	www.wko.at			X	X	X	Awareness activity of the Austrian Economic Chambers for promoting engineering professions
	Berufs Informations Computer	Austria	www.bic.at			X	X	X	Platform of descriptions of different job profiles /professions in engineering field
	Green Jobs	Austria	www.lebensministerium.at/umwelt/green-jobs			X	X	X	Web-portal of the Austrian Federal Ministry of Agriculture, Forestry, Environment and Water Management for any activities related to jobs/professions in environmental technologies
	FIT-Initiative of BMUKK	Austria	www.fitwien.at		X				Increase the number of women in engineering and science professions
	Sparkling Science	Austria	www.sparklingscience.at		X				Collaborations between scientists and teenagers
	Project Green Chemistry at TU Vienna	Austria	www.tuwien.ac.at		X				Attracting teenagers to sustainable chemistry
	BMVIT - Generation Innovation	Austria	www.generation-innovation.at		X				Internships for teenagers at research institutions and innovative companies

	Das Schulportal	Austria	www.schule.at	X	X				Providing overview about projects for attracting teenagers to technical professions
	Tech Woman	Austria	www.techwoman.at		X	X	X	X	National and international projects for supporting women in technical professions
	IMST - Innovations in Matehmatics, Science and Technology Teaching	Austria	www.imst.uni-klu@ac.at	X	X				Projects for improving the quality of teaching in maths, science and technology
	FEMtech - BMVIT	Austria	www.femtech.at				X	X	Financial support for raising awareness about women in science and engineering
	Take Tech Weeks	Austria	www.sft.at/taketech		X	X			Open days at technology oriented companies for attracting teenagers to technical professions
	Kuratorium Elektrotechnik	Austria	www.kfe.at			X			Training courses on the basics of electrical engineering
	Traumberuf Industrie (WKÖ)	Austria	www.traumberuf-industrie.at			X			Database of job profiles / professions in industry
	Technik on Tour	Austria	studnitzka@at.festo.com	X	X				Attracting teenagers to technical professions
	Emplea Verde	Spain	www.empleaverde.org			X	X	X	Programme that provides alliances between different organizations and institutions in order to develop training projects focused on the supply of specialized technical staff for the labour market
	Fundación tripartita para formación en el empleo	Spain	www.fundaciontripartita.org			x		x	Promote training courses in different sectors
	APEA- Energía para escolares	Spain	www.apea.com.es	x	x				Programme to improve the schoolchildren awareness on the efficient use of energy and renewable energy.
	Avanza en tu carrera	Spain	www.avanzaentucarrera.com		x	x	x	x	Platform for looking for training, degree, masters, etc…
	oapee	Spain	www.oaapee.es	x	x	x	x	x	Management of different training programmes: Erasmus, Comenius, Grundtvig, Leonardo da vinci
	educ@emplea	Spain	educaemplea.feria-alicante.com			x	x	x	

	Earthcare	EU	www.idec.gr/earthcare			x	x	x	Tool for occupational counsellors and career advisors in Greece, UK, France, Italy and Spain
	Red emprende verde	Spain	www.redemprendeverde.es			x	x	x	Platform to promote and support for green entrepreneurs
	Enjoined	EU	http://www.enjoined.edupolicy.net/index.php/en/about.html?showall=1		x	x	x	x	ESdPI aims to challenge the lack of information and appropriate models for future adaptation to climatic diversity in the Caucasus and South-Eastern Europe , Region. It will tackle the issue by making information available and by developing simple educational modules implemented through the new network of established and competent partners and guided by the environmental aspects of the EU acquis (Bosnia Herzegovine, Croatia, Estonia, Georgia, Kosovo, MAcedonia, Romania, Slovenia)
	Association for Energy Efficiency and Renewable Energy Systems	Romania	www.ae3r-ploiesti.ro					X	NGO promoting projects, experience exchange and training on energy efficiency and renewables, for professionals in urban development
	Sustainable Energy - High school teaching	Romania	www.unitbv.ro	x	x			x	in-service training course (provided by Transilvania University of Brasov) for primary and high-school teacher teaching on how to introduce sustainable energy concepts in the regular curricula; practical activities are developed in the teachers' classroom
	Engineering of Renewable Energy Systems	Romania	http://www.unitbv.ro/LinkClick.aspx?fileticket=r8FHtOdn_wc%3d&tabid=7312&language=en-US				X		B.Sc. programme, including specific courses on Sustainable Development - Smart Cities and on Integrating renewables in the built environment. The program, initiated by the Transilvania University of Brasov is now running also in the Politechnical University of Timisoara
	Wetenschapsweek	Belgium	http://www.wetenschapsweek.be/	X	X				Initiative by universities to promote studying science and technology; energy and smart cities is a returning subject
	Kinderuniversiteit	Belgium	http://www.kuleuven.be/kinderuniversiteit/ and http://www.kinderuniversiteit.be/	X					Initiative by universities to promote studying science to young children (8-year olds); 2011 theme was energy

	KVIV and VIK: "de wereld aan je voeten"	Belgium	http://www.dewereldaanjevoeten.be/		x				2 engineering societies who jointly promote to study engineering with a dedicated campaign
	Vlaanderen in Actie	Belgium	http://vlaanderenInactie.be/doorbraken/de-lerende-vlaming/		x	x	x	x	government campaign to promote studying (including LLL) technology
	Agoria	Belgium	www.agoria.be		x	x	x	x	industry association promoting to study technology (this year focus on IT)
	Open Bedrijven Dag	Belgium	www.openbedrijvendag.be	x	x	x	x	x	companies opening to the general public, a.o. to promote studying technology
	ODE Vlaanderen	Belgium	www.ode.be					x	platforms
	Grenelle Round Table	France	http://www.legrenelle-environnement.fr/			x	x	x	Major government initiative launched in 2007 to address energy efficiency improvements and a range of other environmental issues
	Alliance Villes Emploi	France	http://www.ville-emploi.asso.fr/					x	French national association of elected representatives acting for employment, inclusion and training policies
	FPSPP	France	www.fpspp.org/					x	French fund aiming to qualify or re-qualify employees or job seekers through actions adapted to the beneficiaries and their professional projects
	Product Design for Sustainable Development and Environment	Romania	http://www.unitbv.ro/LinkClick.aspx?fileticket=DOEW_dLgZJk%3d&tabid=7312&language=en-US				x		M.Sc. programme, with specific courses on Integrating Renewables in the Built Environment, Passive Solar solutions and Solar-thermal hybrid and co-generation systems. The program is running in The Transilvania University of Brasov, Romania; over 30 Ph.D. programs are developed in the field of renewables integrated in the built environment each year
	AMS - FIT Programme	Austria	www.ams.at/fit			x			Attracting women to technical-manual professions

Please note that this list gives a partial country overview due to the lack of more detailed data.

Annex II

European SET Plan Education & Training Initiative

EUROPEAN COMMISSION

Questionnaire for expert/industry feedback

In view of the progressing worldwide urbanization and the potential risks of climate change, cities are at the forefront of policy, industry and research playing an important role in the shaping of future societies and sustainable systems. This fact is well reflected in the field of energy, where ambitious targets regarding energy efficiency and CO_2 reductions, as outlined in the European Strategy 2020 and the Energy Roadmap 2050, are forcing new challenges upon our society related to future development of urban areas.

One of the key vehicles of the EU for accelerating the development of large scale deployment of low carbon technologies is the European Strategic Energy Technology Plan (SET Plan). Within this strategy document of the European Commission (EC) technology roadmaps serve as a basis for strategic planning and decision making applying a collective approach in research, development and demonstration planning and implementation with a clear focus on large scale programmes, such as the European Industrial Initiatives (EII). Among other industrial initiatives, the “Smart Cities and Communities Initiative” launched in June 2011 highlights the importance of intelligent energy management systems in cities in order to achieve massive reductions of greenhouse gas emissions by 2020 (the “20-20-20 targets”) and 2050 (up to -85%). One specific object is the sufficient market take-up of energy efficient and low carbon technologies and to effectively spread best practice examples of sustainable energy concepts at city level across Europe.

When defining the concept of Smart Cities innovative design and intelligent operation of an entire energy system at city level are two of the main topics under consideration. On a general level, 4 major thematic areas related to energy technology integration can be identified in the context of Smart Cities:

1) *Integrated urban energy planning* and city transformation processes based on a deep understanding of energy performance and energy flows within entire cities

2) Intelligent *urban energy networks* (thermal and electric) including the underlying ICT infrastructure for enabling an effective and smart operation of the city-wide energy distribution

3) *Energy-efficient buildings* as interactive elements of the urban energy system (e.g. “building-to-grid”)

4) *Renewable energy supply technologies* integrated into urban infrastructure (hybrid systems)

In addition, highly relevant topics in the field of transport and mobility have to be taken into account, complemented by new business models and complex stakeholder processes. The stochastic profile of future energy generation by renewable energy sources calls for an intelligent demand side management of the entire energy networks within cities, characterized by a continuous interaction between all involved network components (electrical and thermal grids, buildings, energy supply technologies, consumer). Current state-of-the-art projects focus merely on the implementation of single energy technologies lacking the holistic approach necessary for a complete understanding of the extensive energy system of an entire city. In this context, the concept of "Smart Cities" plays an important role, which can only be analyzed and investigated through an integrated system approach in industry and R&D. The first calls for Smart Cities have already been launched within FP7 in July 2011 bringing together European cities from various regions and background in various innovative consortia.

Due to the complexity of the Smart Cities concept pooling together various technical disciplines in the field of energy the question arises if the current educational framework in Europe covering the entire education chain from primary school up to apprenticeships, universities and vocational training is capable of delivering the necessary skills of engineers, technicians and scientists for coping with the upcoming urban challenges. Therefore, the European Commission has launched the *SET Plan Education & Training Initiative* in late 2011 in order to identify the barriers and needs of industries, educational institutions, policy makers etc. with regards to "education" for enabling a full implementation of the SET Plan goals. Various expert groups have been established around individual technology fields, one of them the group led by Dr. Brigitte Bach (AIT Energy Department) working on Smart Cities. The results of this working group shall be summarized in an assessment report analysing the current status in the 4 thematic areas, listing current ongoing initiatives and coming up with concrete recommendations and actions to be taken by the EC for improving the education framework in Europe. Apart from available literature, studies and statistics, experts and industry feedback is an essential part of this report. Hence, this questionnaire has been set-up to capture your opinions, statements and views.

It shall be mentioned that due to the fact that the assessment of education for electric networks ("smart grids") will be dealt with in a separate report, the focus of the working group on Smart Cities will be on thermal networks only.

Basic facts about your company/institution:

Name of company/institution:	
Branche/sector:	
Nr. of employees:	
Contact person:	Name + email
Company/institution address:	

Survey:

1) Do you see in your field/sector an increasing demand for skilled workmen over the upcoming years? If yes, can you provide rough numbers?	
Integrated urban energy planning:	
Thermal energy networks	
Energy-efficient interactive buildings:	
Urban energy supply:	

2) According to your experience, what will be the concrete skills needed in the near future in order to tackle future challenges related to "Smart Cities" (see 4 topics)?	
Integrated urban energy planning:	
Thermal energy networks	
Energy-efficient interactive buildings:	
Urban energy supply:	

3) Do you expect new job profiles arising in the near future in the context of "Smart Cities"? If yes, can you provide examples?
e.g. energy strategy developers for cities

4) What kind of concrete actions would you like to see to be taken with regards to education that will have a potential positive impact for the implementation of the SET Plan goals?

SET-Plan Energy Education & Training
Wind and Ocean Energy

Wind and Ocean Energy

Working Group Contributors

Rapporteur: Jørgen Kjems	SEEIT	DTU/ Kjems R&D Consult, DK
Thierry Maitre	KIC InnoEnergy	Grenoble-INP, FR
G.J.W. (Gerard) van Bussel	EERA Wind + SEEIT	TU Delft, NL
Jens Nørkær Sørensen	EERA Wind	DTU, DK
Olav Fosso	EERA Wind	NTNU, NO
Moses Kärn	EERA Wind	FORWIND, DE
David Ingram	EERA Ocean	Edinburgh University, UK
Joachim Peinke	SEEIT	University of Oldenburg, DE
Philippe Chatelain	EUA-EPUE	Université catholique de Louvain, BE
Torgeir Moan	EUA-EPUE	NTNU, NO
Tony Lewis		University College Cork, IE
Antonio Sarmento		Instituto Superior Técnico, PT
Gareth Davis		Aquatera, UK
Dorina Iuga (Filippo Gagliardi)	*EWEA, TP Wind*	EWEA Project Manager (TPWind Secretary General)
Allan MacAskill	*EWEA, TP Wind*	MacAskill Associates / TPWind Executive Committee Member
Jaco Nies	*EWEA, TP Wind*	GE / co-chair of WG2 “Power Systems” in TPWind
Nathalie Rousseau	*European Ocean Energy Association*	Executive Director
The working group has had one physical meeting in March 2012 in Brussels, and have since then communicated via e-mails, a common electronic document folder, and telephone conferences		

Members of the EPUE Mirror Group

Name	***Country***	***Institution***
Philippe Chatelain	Belgium	Université catholique de Louvain
Torgeir Moan	Norway	Norwegian University of Science and Technology
Olli Pyrhönen	Finland	Lappeenranta University of Technology
Joachim Reuder	Norway	University of Bergen
Thomas Schrefl	Austria	St Pölten University of Applied Sciences
Almerindo Ferreira	Portugal	University of Coimbra
Morten Nymand	Denmark	University of Southern Denmark

Executive summary

Wind energy is already a global, well-established sector with an annual capacity increase of 45 GW (2012) and more than 282 GW installed capacity (end 2012). The corresponding figures for EU are 11.6 GW and 106 GW. The most recent estimates of the current employment in the sector in the EU correspond to about 270.000 full-time equivalent (FTE)[1] of which about 2/3 is directly employed in the industry and 1/3 is indirectly employed.

The IEA outlook scenarios until 2050 show a steady growth in the installed wind power capacity worldwide to a level of 2500 GW of which 500 GW in Europe. Offshore installations are expected to cover more than half of the new capacity in EU by 2020. According to the Windskill study this scenario will require an increase of the work force in Europe by 2020 to about 328.000 FTE and a further increase by about 50.000 in 2030. In the coming decade this translates to an annual need for about 20.000 new, trained persons distributed over a range of skills and qualification.

Compared to wind energy the development of ocean energy in its different forms is still in very early stages. The ocean energy roadmap[2] indicates at least a 30 year time-lack behind wind energy in expected installed capacity, investment and employment impact, and the resulting need for education and training. The roadmap indicates that ocean energy generation in the EU has a potential to reach 2.3 GW[3] of installed capacity by 2020 and close to 188 GW by 2050. These scenarios would generate job opportunities at a rate similar to that experienced in the wind energy industry over the last 30 years. In the coming decade the annual educational need will amount to about 200 - 400 persons growing to about 2000 - 3000 in the following decade.

Education and training in wind energy has been mostly "on-the-job", and it is now necessary to supplement these efforts with a new European education and training platform in wind energy in order to secure the supply and to achieve common quality standards. For ocean energy the education and training effort in the coming decade will be coupled to technology development, pilot project and the emerging up-scaling. The ocean energy education and training activities can take advantage of the emerging European platforms and networks among the relevant institutions and industries.

There is a special need for launching vocational training programs aimed at the needs in those EU member states and regions, which are in the early phases of development of wind and ocean energy. The industry is here met with demands for local production contributions and has recognised a clear need for local expertise and skills in the new markets. Meeting these needs can be done most effectively through partnerships with the existing knowledge centres in other regions.

Like in the other areas of the SET Plan, the development of a common strategic agenda and road maps are excellent tools to guide actions at many levels and by many actors. This will also hold true for education and training. At the EU level this should be supported by monitoring and evidence-based policy analysis combined with support to joint actions by key stakeholders to

[1] EurObserv'ER 2012

[2] Oceans of Energy – European Ocean Energy Roadmap 2010-2050. (EU-OEA), 2010

[3] NREAP plans has been revised in 2012

promote strategic cooperation towards the common goals. The outcome will be joint development and implementation of educational programs, mobility of learners, teachers and researchers and support to the interaction with the world outside the EU.

At the university and college level this new platform should stimulate:

- Increase exchange of students, scientists, and teaching staff
- Increase number of interdisciplinary programmes on Master level
- Support interdisciplinary and international PhD-level education
- Increase number of wind energy research facilities and laboratories at universities
- Increase staff (professors and lecturers) at universities
- Enable career changes between university and industry
- Allow senior experts to become professors and enrich education
- Increase number of life-long learning opportunities
- Create/increase support or funding schemes for professionals for part-time continuing education

The educational institutions working in networks should also be encouraged to introduce more flexibility with greater variety of study modes like part-time, distance and modular learning as well as continuing education for adult returners and others already in the labour market. This should be followed by mechanisms to ensure both quality and relevance. The institutions and the relevant authorities should create/increase support or funding schemes for professionals for part-time continuing education.

The specific, recommended actions are listed below:

Heading 1: Filling the skills, competences and knowledge gap

Meeting the skill/competencies gaps of new and emerging technologies, and strengthening and developing existing skills/competencies

Action 1.1: Breeding of European clusters of excellence like the EERA, EWAA, KIC-InnoEnergy and SEEIT alliances with focus on SET Plan and wind and ocean energy needs in both R&D and education and training

Action 1.2: Support to networks of universities for joint development of flexible master programs with modular building blocks also suited for life-long learning tuned to the industrial needs in wind and ocean energy

Action 1.3: Support to strategic networks of vocational training centres in association with leading knowledge institutions, focus on EQF levels 4-6 in order to strengthen local qualifications and skills in wind and ocean energy

Action 1.4: Train the trainers programs with focus on new markets and vocational training

Heading 2: Fostering involvement, access and up-take by the labour market

Promoting mobility, life-long learning, work force training based on industry involvement and interdisciplinary partnerships

Action 2.1**:** Development of a European model for industrial doctorates programs jointly sponsored and executed in industry/university collaborations

Action2.2: European program for access to research and pilot facilities for higher level education and training in wind and ocean energy

Action 2.3: Industry-endowed chairs (industry pooling) at the leading universities in wind and ocean energy

Action 2.4*:* Support to networks of regional, vocational training centres with focus on the special local needs in wind and ocean energy

Action 2.5: Student and researcher grants to expand the impact of European Knowledge alliances and other types of strategic partnerships involving both academia and industry

Heading 3: Planning and enabling skills development

Sector skills assessments and observatories, “Train the Trainers”, and Online information and other tools

Action3.1: Pilot actions to boost the use and impact of e-learning and virtual training facilities in wind and ocean energy combined with platforms and library systems for the development and exchange of teaching material (e-books, e-lectures) at research universities and university colleges

Action 3.2: Platform and library system for the development and exchange of teaching material (e-books; e-lectures) at research universities and university colleges

Action 3.3: Drive further harmonisation of the educational systems in the Member States and stimulate mutual skills recognition in order to enhance mobility of the work force in wind and ocean energy

Action 3.4: Establish a Wind and Ocean Energy Skills Observatory with focus on offshore and new markets needs and the shift towards O&M

Background and Introduction

The Working Group in Wind and Ocean Energy was established as part of the SET-Plan Education and Training Initiative launched by the European Commission in the fall of 2011. Twelve other WGs were established by the Core Group covering the different SET-Plan energy technologies as well as cross-cutting issues.

The Working Groups were given the assignment to address the state of play and needs per job categories (technicians, engineers, scientists) as well as describe the actions required (in relation to undergraduate, graduate, post-graduate education, life-long training, reconversion schemes, professional training) within priority energy technology sectors.

The limited time available for the work of the group have made it necessary to base the work on available data and reports and to refrain from attempts to make independent data collection and analysis. The working group also agreed to aim for a report that followed the outline presented by the Core Group.

The European Union is committed to reducing greenhouse gas emissions to 80-95% below 1990 levels by 2050. This requires a complete transformation of the European energy system towards low-carbon energy sources. The change is currently taking place indicated by the fact that renewable energy sources accounts for a 70% share of the new installed electricity generating capacity in 2011. The share of renewable energy in the gross final energy consumption is growing steadily towards to the 2020 20% target reaching 12-14% in 2011. Wind and solar energy are the dominating the current investment portfolio with ocean energy as a potential attractive large-scale investment object beyond 2025-2030.

The EU "Roadmap for moving to a competitive low-carbon economy in 2050" implies massive investments in transformation of the energy systems from production to end-use. All scenarios point to a strong role for renewable energy sources, which has to become cost effective through research and development, scaling-up, and world market exposure. The clear message is that the investments will pay off**,** in terms of growth, employment, greater energy security and lower fuel costs. History also shows a relation between a country's stability and magnitude of the subsidy scheme on one hand and the size of the industry and the installed base at the other hand: countries with stable and substantial subsidy schemes have the lion share of the industrial activity and energy produced. The transformation creates a new landscape for European industry and can increase competitiveness. It will create massive job opportunities, many with new skills requirements. Jobs will be created at many levels, and their skill profiles will change over time as the industry and the sectors are maturing. Education and training is key to enable an optimal match between job opportunities and skills requirements. The grand challenge for the stakeholders in education and training is to provide the best odds for the match to happen - anywhere in Europe.

The present assessment report takes stock of the current situation and attempts to project the employment opportunities and skills requirements in the wind and ocean energy sectors in the 2030-2050 timeframe. The point of departure is the IEA and EU scenarios for the global and European development of the wind and ocean energy sectors. The wind energy sector is already well established with a well-documented database, whereas ocean energy exploitation is still in its infancy with fewer amounts of data and empirical evidence. Both sectors are projected to grow with close to double digits in the next decade(s), but the impact on employment will be largest in the wind energy sector in the short to medium term.

1 Outlook

Wind

The European Union's Renewable Energy Directive sets ambitious targets for all Member States, such that the EU will reach a 20% share of energy and 34% of electricity generation from renewable sources by 2020. It also requires national action plans to achieve their declared objectives. The development has in fact been faster than foreseen in 2008. Annual installations of wind power have increased steadily over the last 17 years from 814 MW in 1995 to 9,616 MW in 2011, an annual average market growth of 15.6%. A total of 106 GW is ultimo 2012 installed in the European Union, an increase in installed cumulative capacity of 11% compared to the previous year. Germany remains the EU country with the largest installed capacity, followed by Spain, France, Italy and the UK. Growth in onshore installations in Germany and Sweden, and offshore in the UK – together with continuing strong performance from some emerging onshore markets in Eastern Europe – have more than offset the fall in installations in more mature markets such as France and Spain. The wind capacity installed by the end of 2012 would, in a normal year, produce 224 TWh of electricity, representing close to 7% of electricity consumption.[4]

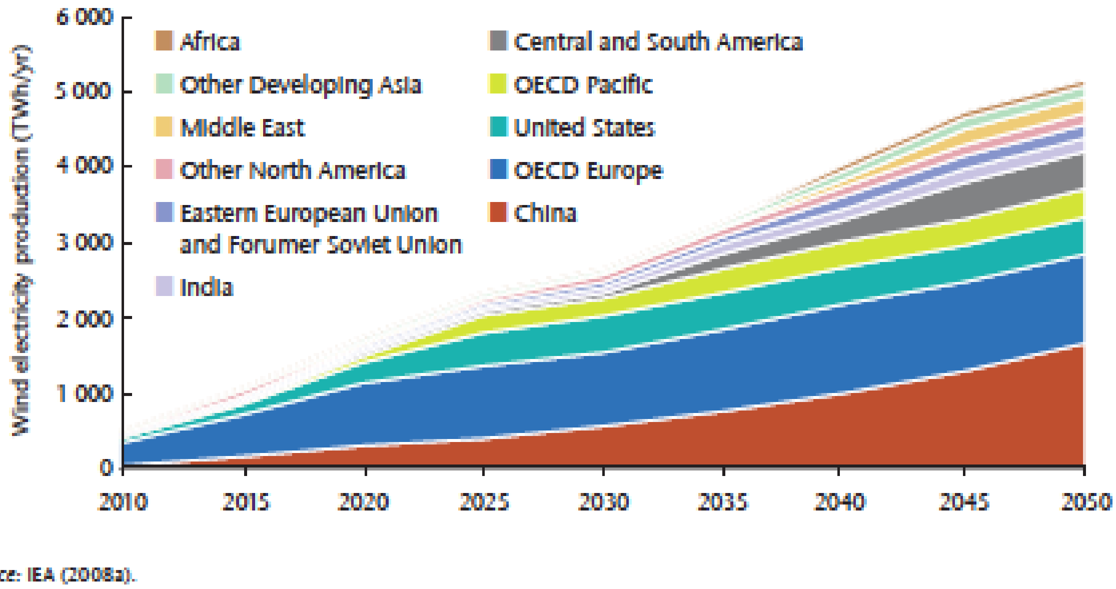


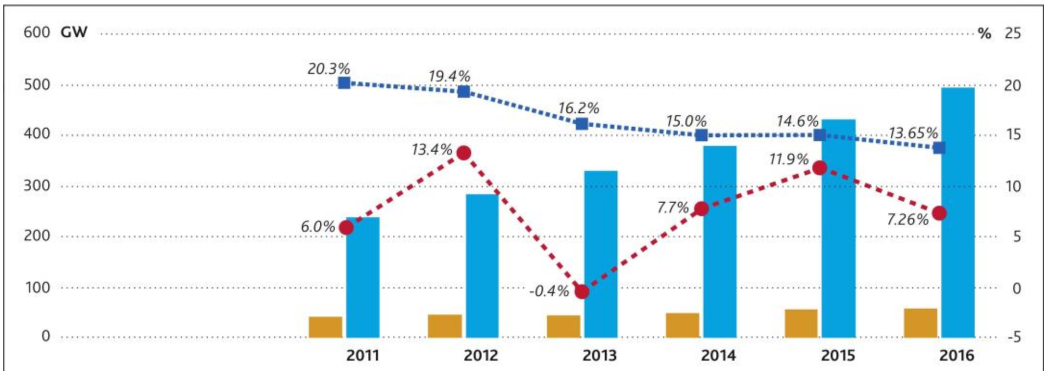
Fig. 1 Regional production of wind electricity in the ETP 2008 BLUE Map scenario.

[4] Wind in Power, EWEA, 2012

In 2008 EWEA's market predictions foresaw a rise in the offshore segment from 1.5 GW to 40 GW cumulative installed capacity by 2020 thereby increasing the contribution of wind energy alone to 15% of the EU total EU electricity demand by 2020. By 2020 the most recent forecasts indicate 220 GW of installed wind energy capacity in the European Union and about 450 TWh annual energy production.[5] The EA Technology Roadmap (2008) describes different global scenarios for the production of electricity from renewable sources. In the BLUE Map scenario the global wind energy production increases ten-fold by 2030 (about 2600 TWh) and 20-fold in 2050 over the 2008 level (about 5100 TWh or 12% of global electricity). The expected global distribution of the production over the years until 2050 is shown in the figure above. The global development in cumulative installed capacity has roughly followed this scenario since 2008 and reached 282 GW by the end of 2012, a third of which was found in Europe.

Every year, GWEC (Global Wind Energy Council) undertakes the difficult task of forecasting global wind market developments for the coming five years, and this exercise has become a fixture in the GWEC annual report.[6] Overall, GWEC predicts that at the end of 2015, three years from now, global wind capacity will stand at 459 GW, up from 282 GW at the end of 2012. During 2015, 55.2 GW of new capacity is expected to be added to the global total, compared to 38.3 GW in 2010. In money value the investment in new capacity reached a record level of 70.4 b€ in 2010. This corresponds to an average cost of 1.84 €/Watt installed power.

Market Forecast 2012-2016



	2011	2012	2013	2014	2015	2016
Annual installed capacity [GW]	40.6	46.0	45.8	49.4	55.2	59.24
Cumulative capacity [GW]	237.7	283.7	329.5	378.9	434.1	493.33
Annual installed capacity growth rate [%]	6.0%	13.4%	-0.4%	7.7%	11.9%	7.26%
Cumulative capacity growth rate [%]	20.3%	19.4%	16.2%	15.0%	14.6%	13.65%

Source: GWEC

Fig.2: Global market forecast from GWEC Annual market update 2011.

The very recent Global Wind Energy Council annual market statistics published in February 2013 show that the wind industry installed just over 46 GW of new wind power in 2012, bringing the total installed capacity globally to more than 280 GW at the end of last year. This represents an increase of 19%, with an increase in the size of the annual global market of just over 6%. In line with the last 5 year forecast quoted above. In the EU, 11.56 GW of wind energy capacity was

[5] EurObserv'ER Barometer, 2013

[6] GWEC- Global Wind 2012 Report

installed in 2012, for a total installed capacity of 105.7 MW - enough to supply about 7.% of the EU's electricity, according to the European Wind Energy Association (EWEA). Today, about 75 countries worldwide have commercial wind power installations, with 22 of them already passing the 1 GW level. The global annual market for offshore wind in 2012 is estimated at some € 4.5 billion and is expected to increase to the range € 20-30 billion by 2020. As an example: the UK Government is committed to generating 15% of all its electricity from renewable sources by 2020. Offshore wind is expected to be a key contributor to these targets. Presently, the UK accounts for 40% of the global offshore market.

Eastern Europe also has untapped potential for wind power. At the end of 2012 there was more than 7.7 GW installed wind energy capacity in Poland, Romania, Bulgaria, Hungary, Czech Republic and Slovenia. As an example Romania a high wind energy potential of 14,000 MW, and investors already have connection requests of 12,000 MW. As of 2012, wind power in Romania has an installed capacity of 1942 MW; up from the 14.1 MW installed capacity in 2009. Another study made by the Romanian Energy Institute (REI) said that wind farms could contribute with 13 GW to the national power generation capacity by 2020. [7]

GWEC has also carried out analysis of the work force needed to build new wind power capacity and finds the relation to be approximately 105 jobs (man years) per MW installed. This number is in line with the findings in the Windskill project, which quote a total work force directly employed in the wind power industry of 108.600 in EU (2007) and the number of indirectly employed to be 42.700. The average installed capacity (2006-8) was 8100 MW resulting in a job factor of 13.4 direct jobs and 5.3 indirect jobs per MW installed. By applying the GWEC factor to EWEA's growth scenario for the period up till 2030 European employment in the sector is expected to double by 2020 (approx. 328.000 jobs) with a further 48.500 expected in the decade to follow. By 2030 employment expectations reflect the expected growth of the offshore sector: 160,000 jobs onshore and 215,000 offshore.

The Windskill study was based on job figures/estimates for the different EU member states, and the distribution is shown in the table above. The "Wind at Work" report also provides an overview of the employment areas within the sector (2007 figures) without however allocating these accumulated figures to the education and job profiles also listed in the report. more recent study[8] (2011) from the German Ministry for Environment (Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (BMU)), which includes a broader spectrum of indirect employment, finds even higher numbers for the total employment in wind power in Germany. The production and direct operation is concentrated in the north, but the indirect employment in production and operation is spread over the country. The forecast for 2030 is a net growth in export driven employment for the entire renewable energy field of 180.000- 250.000, with wind accounting for 25-30%.

[7] Wikipedia

[8] www.bmu.de ,· www.erneuerbare-energien.de

Tables from the Windskill Project with wind energy employment in Europe in 2009 (left) and employment profile along the value chain, 2007 (right)

Wind energy employment EU	
Country	***No. of directJobs***
Austria	700
Belgium	2,000
Bulgaria	100
Czech Republic	100
Denmark	23,500
Finland	800
France	7,000
Germany	38,000
Greece	1,800
Hungary	100
Ireland	1,500
Italy	2,500
Netherlands	2,000
Poland	800
Portugal	800
Spain	20,500
Sweden	2,000
United Kingdom	4,000
Rest of EU	400
Total	108,600

	Share of direct employment	Direct employment	Indirect employment	
Component manufacture	22.0%	23,892.0	42,716.0	
Wind farm development	16.0%	17,376.0		
Installation, operation and maintenance	11.0%	11,946.0		
IPP/utilities	9.0%	9,774.0		
Consultants	3.0%	3,258.0		
R&D/universities	1.0%	1,086.0		
Financial	0.3%	325.8		
Others	0.7%	760.2		
Total	100.0%	108,600.0	42,716.0	151,316.0

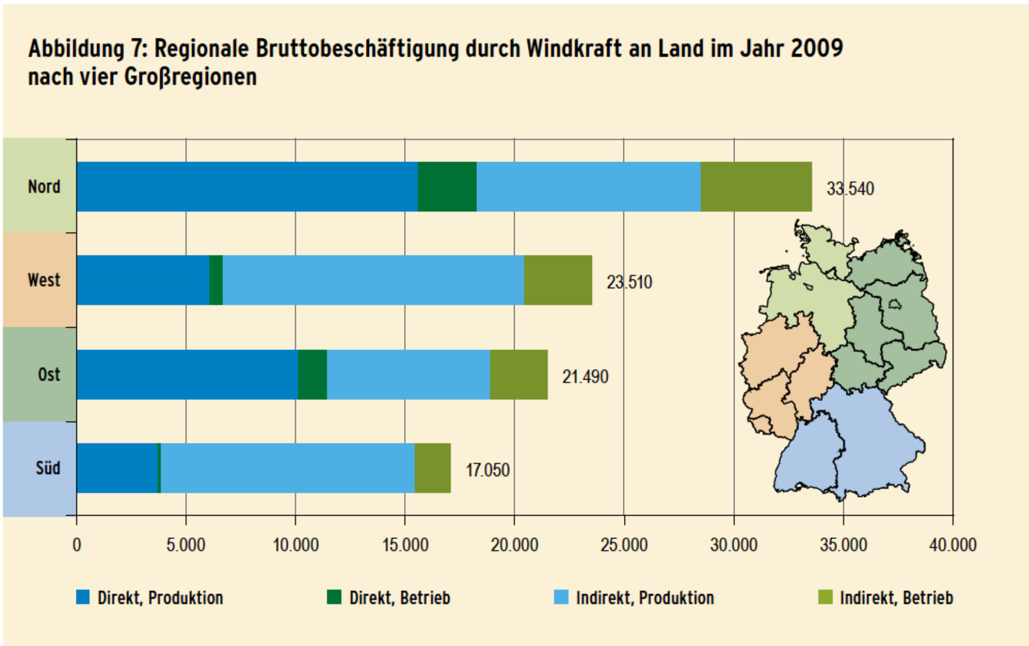


Fig. 3 Geographical distribution of wind energy employment in Germany

A national study in the UK designated the South West region as the first Low Carbon Economic Area and the job growths scenario for 2020 indicated an increase by 15.000-40.000 in the off shore wind sector[9] distributed over all the NQF level 1 – 5+ with about 33% in the 5 and 5+ levels 50%- 60% in the 2-4 levels and quite limited (below 10%) in low skill categories. As the installed capacity grow the employment impact of operation and maintenance will also grow. The Windskill study found that - irrespective of company structure - the deployment of O&M staff to be a team of two service technicians in order to service 20 turbines with an average performance of 1 MW rated power. This conservative ratio of 0,1 technician per MW has since been revised in the GWEC prognosis cited above, showing a demand for 0.33 technicians per MW. The IEA quote O&M prices at € 22 per MWh for turbines built in the 1990ies and € 8/MWh for turbines erected in the 2000nds. If converted to technical salaries at € 60 k/year this would correspond to a lower number of about 0,033 technician year/MW or 33 FTE per GW. Another approach is to look at the service business of a big manufacturer like VESTAS which amounted to M€ 705 in 2011 with a growth rate of 13% per annum and corresponds to 13% of the revenue in 2011. VESTAS provides this service with an estimated staff of 3-4000 people.

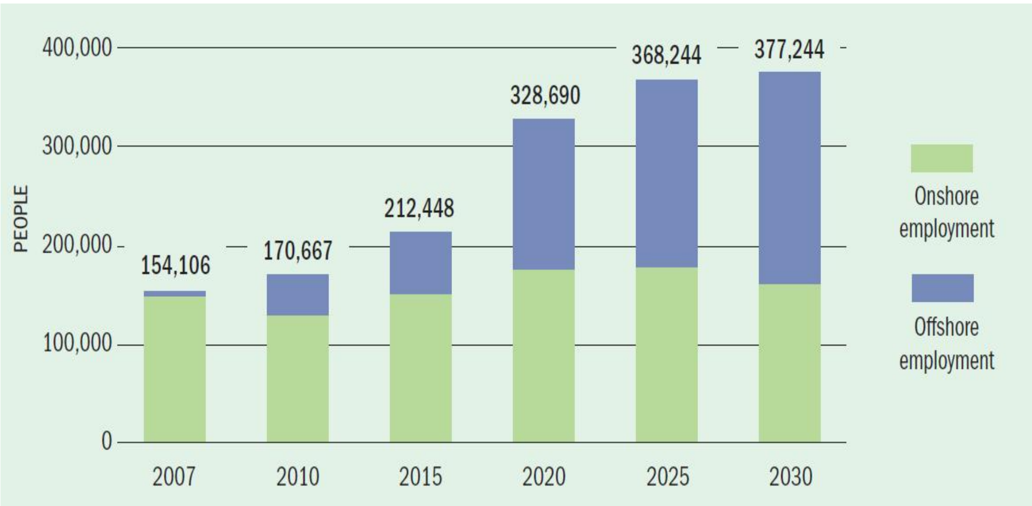


Fig. 4 Forecast of employment in wind energy (Windskill project, 2009)

The Windskill project also analysed the profiles of the activities giving rise to the employment and type of work force needed in the different business sectors as shown in the figures below.

[9] South West Regional Employment and Skills Board, info@swrsp.org.uk

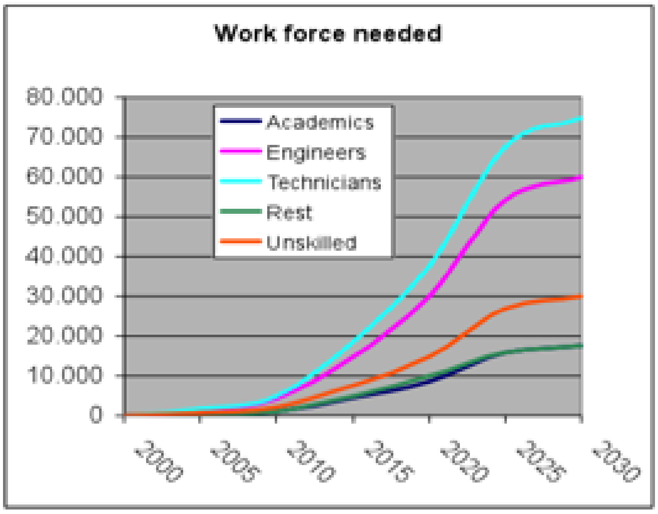


Fig. 5 Employment and type of work force needed in the different business sectors

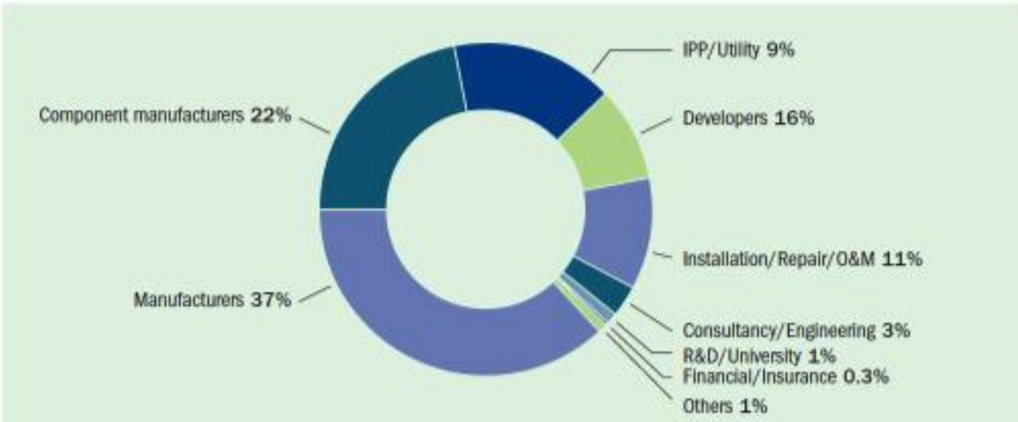


Fig. 6 Type of work force needed in the different business sectors

The development of offshore wind energy will requires skills like[10]:

- Strategic planning
- Project development and implementation support
- Offshore geotechnics and foundation design
- Technology assessment
- Wind resource and energy yield
- Electrical interconnection planning and design
- Commercial management and procurement
- Health and Safety
- Acquisition due diligence
- Lender due diligence

[10] Mott MacDonald, Presentation by Simon Harrison, 2009

The skills requirements are further detailed in the key messages in a UK study from the South West region[11]:

Table : Key messages from the South West Regional Employment and Skills Board ,UK, 2009

Value Chain	Job Function	National Jobs Growth Scenarios to 2020	Timing for SW projects		Occupation	NQF Level
			Atlantic Array	West of Isle of Wight		
Developers	Planning and Development	1,800-4,600	2010-2013	2010-2014	Specialist consultants/scientists – Marine, ecology, geology, ornithology, environmental, archaeology Specialist Engineers – GIS, Building Services Directors[1], Project managers, Planners	5+
Component Suppliers and Manufacturers	Design and Manufacturing	2,700-8,200	2014-2018	2015-2018	Engineers – Aeronautical, Civil, Electrical, Environmental, Mechanical, Mechanical Design, Structural, Production, Sub sea structures design, Quality Manager, Systems Control, Systems design, Control Systems design, Control Systems, Sub sea structures design engineer, Test	5+
					Technicians - CAD, Engineering Craft Technician, Refrigeration and/or Air Conditioning Technician	3+
System Integration and installation	Construction and installation	4,800-12,400	2014-2018	2015-2018	Engineers – inc Control System, Environmental, Building Services	5+
					Construction Project manager/engineer, Construction Site manager	4-5
					Installation Technician, Control Systems Technician, Fabrication Engineers, Project Controller	3
					Cable Jointer, Linesperson, Plant Operator, Concrete Operative, Site Logistics Operative, Welder	2-3
Servicing. Maintenance and Owners/Operators	Operations and maintenance	4,200-10,900	2015-2040	2016-2066	Professional Engineers, Strategic Facilities Manager	5
					Business Development Managers, Managers[2], Supervisors[3], Project development Engineers, Estate Manager/Project manager	4-5
					Maintenance technician (Electrical, Mechanical) Facilities Manager, Production Control Engineer, Manufacturing Buyer	3-4
					Cable Jointer, Linesperson	2-3
Wind renewables /services	Technical, financial and legal services	1,500-3,900	2010-	2010-	Lawyer, Accountants, Forecasting/Taxation Specialists, Health and Safety Specialists, HR professionals	4-5
					Craneage, Divers, Construction Diving Operative, Specialist marine roles	2-3
					Clerical and admin staff, Administrative assistants, IT specialists	1-3

Ocean Energy

The oceans contain a huge amount of energy. Changes in salinity, thermal gradients, tidal currents or ocean waves can be used to generate electricity using a range of different technologies. These could in principle provide reliable, sustainable and cost-competitive energy. An estimate of the total technical potential for the different forms of ocean energy is shown in the figure below.

Capturing ocean energy at competitive costs could have substantial benefits. Compared to wind energy the developments of ocean energy in its different forms are still in very early stages. The ocean energy road map[12] indicate at least a 30 year time lag between the realized cumulative wind energy capacity and the forecast for ocean energy. This therefore also holds for the forecast for investments and employment impact and hence for the need for education and training.

[11] South West Regional Employment and Skills Board ,UK, 2009

[12] Oceans of Energy – European Ocean Energy Roadmap 2010-2050. (EU-OEA), 2010

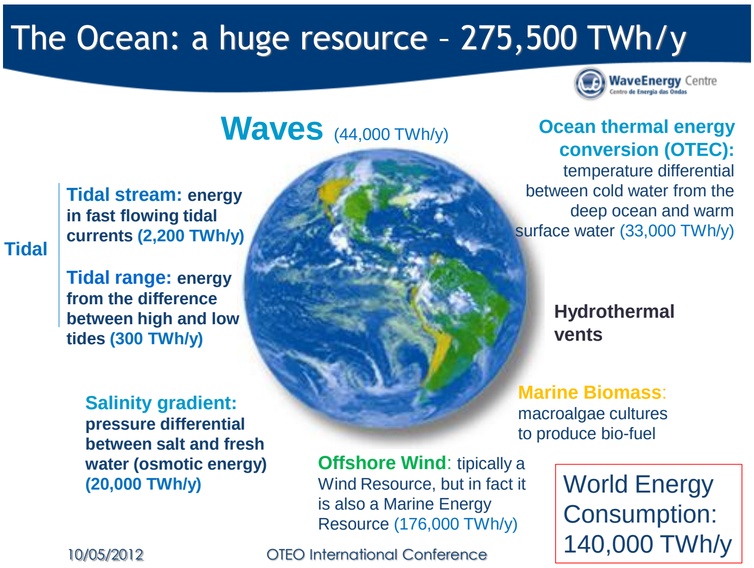


Fig. 7 Estimated technical potential for ocean energy[13].

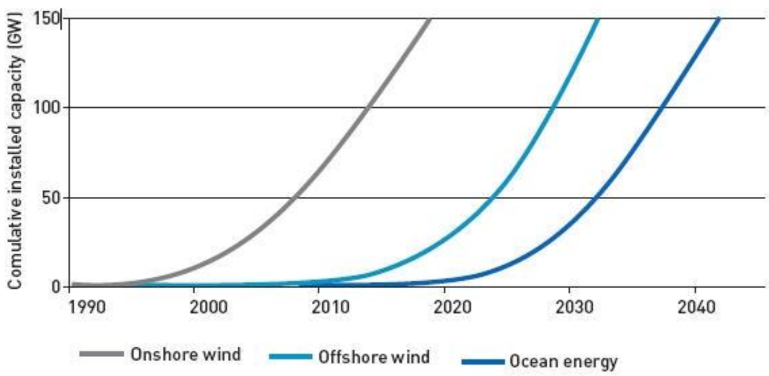


Fig. 8 Forecast for cumulative ocean energy capacity. (EU-OEA), 2010

The road map indicates that ocean energy generation has a potential to reach 3.6 GW of installed capacity by 2020 and close to 188 GW by 2050. This represents an electricity production over 9 TWh/year by 2020 and over 645 TWh/year by 2050, amounting to 0.3% and 15% of the projected EU-27 electricity demand by 2020 and 2050, respectively. The numbers presented are regarded as achievable targets for ocean energy at the European level. The scientific basis for the road map are studies aiming at the characterization of the wave energy resource, having in view its utilization, started naturally in those countries where the wave energy technology was developed first. The WERATLAS, a European Wave Energy Atlas, whose preparation was funded by the European Commission in the mid-1990s, remains a basic tool for wave energy planning in Europe. More detailed wave energy atlases (including the near-shore and shoreline resources) were produced later in several countries for national purposes. The wave energy level is usually expressed as power per unit length (along the wave crest); typical values for "good" offshore locations (annual average) range between 20 and 70 kW/m and occur mostly in moderate to high latitudes.

[13] "An overview of Offshore Renewable Energy", TEO International Conference, Porto, May 2012 – António Sarmento

Seasonal variations are in general considerably larger in the northern than in the southern hemisphere, which makes the southern coasts of South America, Africa and Australia particularly attractive for wave energy exploitation. The main disadvantage of wave power, as with the wind from which is originates, is its (largely random) variability in several time-scales: from wave to wave, with sea state, and from month to month (although patterns of seasonal variation can be recognized). However, being an integrated form of wind energy, both spatially and temporarily, wave power is much more stable than wind or solar power (3 days are the typical time-scale to attain statistically independent wave conditions in the North Atlantic) and can be forecasted with good accuracy up to 5 days in advance.

The development of ocean energy and in particular wave energy has been going on for several decades. The British Government started in 1975 an ambitious research and development program in wave energy (followed shortly afterwards by the Norwegian Government), but its funding came almost to a halt by 1982. In Norway the activity went on to the construction, in 1985, of two full-sized (350 and 500kW rated power) shoreline prototypes near Bergen. In the following years, until the early 1990s, the activity in Europe remained mainly at the academic level, the most visible achievement being a small (75 kW) OWC shoreline prototype deployed at the island of Islay, Scotland (commissioned in 1991). At about the same time, two OWC prototypes were constructed in Asia: a 60 kW converter integrated into a breakwater at the port of Sakata, Japan and a bottom-standing 125 kW plant at Trivandrum, India. The situation in Europe was changed by the decision made in 1991 by the European Commission of including wave energy in their R&D program on renewable energies. Since then, the European Commission involving a large number of teams active in Europe funded about thirty projects on wave energy. In the last few years, growing interest in wave energy is taking place in USA, Canada, South Korea, Australia, New Zealand, Brazil, Chile, Mexico and other countries. Two grid connected shoreline OWC plants built in 1999 (Azores) and 2000 (Scotland) are still in operation as demonstration plants.

National targets have been set in most European countries for renewable energy in general, and in many countries also with wave energy specific targets. The UK has the highest wave energy target for 2020, at 2GW (see figure below). This is double that of France and 4 times that of Ireland, Portugal and Denmark. However, it must be remembered that the UK has 10 times the population of these countries, so for per head of population perspective, Ireland, Portugal and Denmark are setting very high targets[14]. Compared with the Offshore Wind sector, the Marine Energy (Wave and Tidal) sector is in its infancy but it could still install 1-2GW of schemes by 2020. It is estimated that the global market for Marine Energy could be € 0.7 billion by 2020.

[14] Market Drivers, Ocean Energy Systems Report (2010)

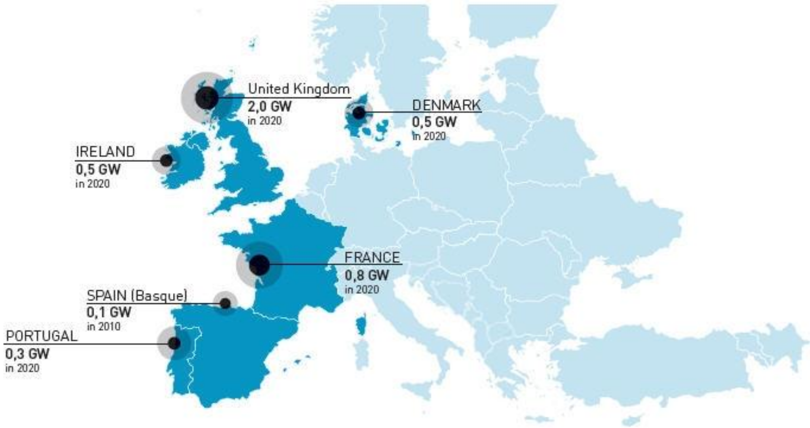


Fig. 9 Countries with specific wave energy targets

In the following, the historic development and actual energy target are given for wave energy and for tidal hydrokinetic energy. Though its potential is smaller, it is likely that tidal energy will be harnessed before wave energy at an industrial scale because the technology seems to be more accessible. The main reason is that marine turbines can operate on the seabed, far from violent ocean conditions that can occur at the sea surface (wave, wind, storm…). However to be economic attractive tidal stream turbines needs to be deployed in very high currents usually with very intense turbulence. This may result in severe fatigue mainly in turbine blades. The very high stream velocity also poses difficulties for deployment and recovery. Hydrokinetic energy can also be developed for river applications, which seems to be easier due to the proximity of the electric network and of easier environmental conditions.

Concerning the current kinetic energy, a wide range of stream turbines (under-water wind turbines whose rotor is turned by the currents) is being developed.[15] Favourable areas have water depths of at least 20m for sufficiently powerful (big) machine and currents speeds greater than 2m/s that can be found in straits, headlands, narrows…). In Europe, stream energy resources are mainly found in United Kingdom (2004-2005 Black et Veatch study: 13-23 TWh/year, 4.5 GW installed capacity) and in France (2006 EDF study: 5-14 TWh/year, about 3 GW installed capacity). The energy source is located between shallow (<40m) and deeper water for the most part. Therefore, immersed designs will probably have the major share of the market in the long term, following an initial phase (present time) during which above-water machines in shallow water and below-water machines will coexist.

The first trials were made by IT Power and studies with Aberdeen. Growing mobilization in the United Kingdom started in 2001. Significant investments have been made since then, for example the Carbon Trust, Supergen programmes (EPSRC), deployment funding (£50 million), etc. Dynamic development in the United Kingdom took place: the EMEC (European Marine Energy Center) was created between 2001 and 2003 in the Orkney Islands with European and Scottish funding, where stream turbines (and wave power) prototypes can be set up and connected to the grid. The Energy

[15] Michel Paillard, Denis Lacroix, Véronique Lamblin " Marine Renewabme Energies" Prospective Forsight Study for 2030, Edition Quae, 2009

Technology Institute made calls for tenders in 2007 on marine energies projects.

Projects were launched in France, between 1999 and 2001, by Hydrohélix Energies (now called Marénergie and which received the Brittany Marine Cluster label in 2005), EDF (Marine Current Turbines) and G-INP laboratories (the Harvest project, awarded the Tenerrdis cluster label in 2005). Support from the Agency for the Environment and Energy Management (ADEME) for these initiatives. The zoning process for marine renewable energy sources was launched by CIADT in 2004.

There was growing interest in Canada (OREG), USA (EPRI), and at an international level (IEA-OES: International Energy Agency-Ocean Energy Source). A European network called CA-OE was created in 2003 under FP6 and the European Ocean Energy Association (EU-OEA) was created in 2005.

Interest for stream energy has emerged from several factors: The will of the United Kingdom to revitalize the offshore industry in view of declining fossil resources in the North Sea, the hope of taking advantage of synergies with offshore wind and the oil related sector. The field has not yet reached the industrial phase: the first marine turbines farm is in deployment in the north coast of France at the Brehat Paimpol site.

Costs

Wave energy is predicted to have a high Capex, ranging from a low of € 1400/MW to a high of € 8-10,000 by Dalton [9] and Cameron [10]. These very high Capex costs will require substantial support mechanisms to make wave farm ventures viable. It would also be assumed that learning curve and market demand would help reduce the Capex over time to similar levels of onshore wind. The table below gives a recent comparison of Capex costs for wave energy compared to offshore wind energy.

Table : Comparison of Capex costs for wave energy compared to those of offshore wind energy

Technology	Author	Year	Reference	Turbine or farm size	€/kW
Offshore wind	Snyder and Kaiser	2009	[12]	1-2MW turbines	1500-3000
				2-5MW turbines	2000- 3000
				1 – 50MW farms	1500-3000
				50 – 200MW farms	2000-3000
	Fingersh et al	2006	[13]	3MW	1500 ($2100)
	DETI	2002	[14]	Not quoted	1400-2000
	Horns Reef	2002		160MW	1700
	Barthelmie et al.	2008	[15]	Not quoted	1650
	Luypert et al	2008	[16]	Not quoted	2500
		2010		5MW	3500-4500
Wave energy	Weiss	2007	[17]	90MW	1800 ($2600)
	Carbon trust	2006	[18]	commercial	1400-3500
	Previsic (calculated from report)	2004	[19]	1MW	5350 ($7500)
				105MW farm	1900 ($2600)
	Dunnett	2009	[20]	Not quoted	2500 ($3500)
	Aquamarine	2010	[10]	1MW	90001
	Dalton	2010	[9]	1MW	8000
				20MW	5800

Cost of electricity (COE) is measured in €/kWh or €/MWh. This metric is most useful for providing an economic relationship between the cost of the project and the electricity output. COE is location specific and does not factor in revenue. The levelised annual average costs of the project includes all annual OPEX costs in the estimate. This figure provides the most accurate metric for developers.

COE for wave energy is the highest amongst other renewable energy compared, as displayed in Figure below. However, caution must be exercised in using COE for the following reasons: COE for the same technology can vary from location to location; and COE will vary from report to report for each device. Some reports include revenue support in the COE calculation, thus lowering the reported COE.

In conclusion, COE must be used with care when comparing technologies. Capex/MW can be more reliable. In general, wave energy will involve high costs, which need to be supported by mechanisms, such as grants or feed-in tariffs.

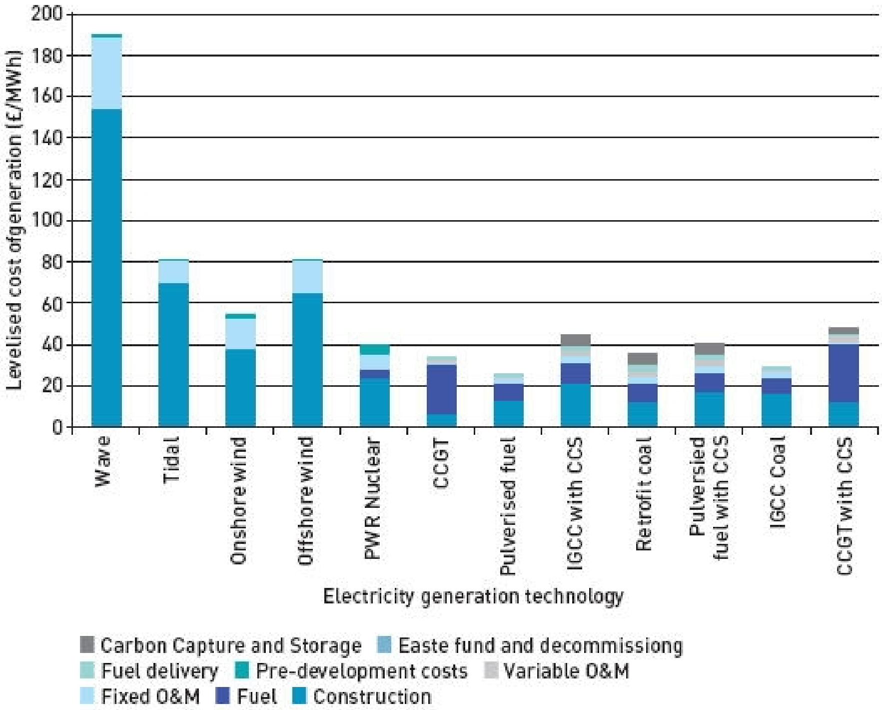


Fig 10 Comparison of the levelised cost of electricity for different technologies

Ocean energy is well positioned to contribute to regional development in Europe, especially in remote and coastal areas. The manufacturing, transportation, installation, operation and maintenance of ocean energy facilities will generate revenue and employment. Studies suggest that ocean energy has a significant potential for positive economic impact and job creation. Parallels can also be drawn with the growth of the wind industry. Clean technology now account for € 7.1 billion annually in Denmark, while in Germany, wind technology exports alone are worth over € 5.1 billion. Based on the projections for installed capacity, by 2020, the ocean energy sector could generate over 26,000 direct and 13,000 indirect jobs. By 2050 these numbers would increase to 314,000 and 157,000 jobs respectively.

In order to meet the Irish inspirational 500 MW target by 2020, the Irish wave energy industry could produce 1,400 additional full time employment jobs and a net present value (NPV) of € 0.25 billion, rising to 17,000-52,000 FTE jobs and an NPV of between € 4-10 billion by 2030.

Scotland has published several roadmaps for the development of marine energy. The latest roadmap developed by the FREDS Marine Energy Group estimates an overall expenditure of £2.4 billion to achieve 1,000 MW installed in Scotland by 2020, generating 5,000 direct jobs.

In conclusion, the wave energy industry has considerable potential in indigenous job creation. Also, as O&M is expected to represent as much of 40% of the total cost of energy, ocean energy is expected to have a significant impact in the local economy.

Summary of employment outlook

Wind energy is already a global, well-established sector with an annual capacity increase of 46.5 GW (2012) and more than 286 GW installed capacity (ult. 2012). The corresponding figures for EU are 11.56 GW and 105.7 GW. The most recent estimates of the current employment in the sector in the EU correspond to about 270.000 FTE of which about 2/3 is directly employed in the industry and 1/3 is indirectly employed.

The outlook scenarios (IEA) until 2050 shows a steady growth in the installed wind power capacity worldwide to a level of 2500 GW of which 500 GW in Europe. Offshore installations are expected to cover more the half of the new capacity in EU by 2020. According to the Windskill study this scenario will require a doubling of the work force in Europe by 2020 to about 328.000 FTE and a further increase by about 50.000 in 2030.

The wind energy sector has quite a broad skills base of with a rough distribution shown below:

EQF levels 6-8: R&D, Engineering, Developers, Others	~ 5 - 10%
EQF levels 4-6 (engineers): Manufacturing, Installation, O&M etc.	~ 30 %
EQF levels 3-5 (technicians): Manufacturing, Installation, O&M etc.	~ 30 - 35 %
EQF levels 1-2 ("unskilled"): Support: assistance, production, transport	~ 20 %
EQF levels 3-8: Management, Finance/insurance, Developer, IPP/Utility	~ 10%

The present employment has a geographical distribution that follows the regional installed capacity with additional employment at the major manufacturing regions. The growth in offshore installations are expected to create significant new employment in the coastal regions closest to the offshore sites and take advantages of skills and man-power available from the oil and gas exploitation.

Ocean energy is still in the early phases of development with considerable potential for energy production, and with scenarios for the installed capacity on the scale of 100-200 GW by 2050. This could provide as much as 10- 15% of the EU electricity supply. A global market of about € 700 million in 2020 would correspond to 26.000 FTE directly employed in the industry and about half that number indirectly employed. This could increase with an order of magnitude by 2050 if ocean energy follows the same kind of industrial development as has been observed for wind - with a delay of about 30 years.

The skills profiles in ocean energy are similar to those for offshore wind energy as far as the more generic type of skills concerning planning, installation and O&M, whereas the specialized skills in connection with design and construction of the machinery will be ocean energy specific.

2 Ongoing Actions

Wind energy (academic education)

The upcoming interest in wind energy and the accompanying demand in training experts in wind energy have promoted wind energy research in European member states. In some countries national centres for wind energy research were established which also organized training programs (like in DK an NL). In others places research and teaching developed as niches (D), but remained very often as initiatives of single persons or small institutions.

An overview of existing academic programmes on wind energy has been compiled by desktop research and can be found in the appendix to this report. Looking at the various university course offers one can identify five different ways of on-going activities:

Specializations in existing (traditional) programmes:

Courses carrying the label "wind energy" have become increasingly popular in the last few years. There are a number of programmes where students can chose a specialization in wind energy but the final degree is in "renewable energies" or the like. Some of these programmes have their roots in special courses (modules) which were already started during the late 1970s, e.g. TU Delft (Aerospace Engineering), University of Oldenburg (Physics, Renewable Energies). There is also the European master programme offered by EUREC, which is operated by a consortium of European universities. By now "renewable energy" programmes are established at many places, their number is growing fast, and their profiles are confusingly different. The level and quality of their courses in wind energy is not always easy to find out, which especially for students planning their career is a big inconvenience.

Dedicated wind energy programmes: DTU was most likely the first university in the world to offer a full two-year Master of Science programme in wind energy. But it is not the only one anymore: during recent years an increasing interest in university programmes, mostly on Master level, bearing "Wind Energy" in their title can be seen: "Wind Energy Engineering" at the Leibniz University of Hannover, "Wind Energy Technology" at the University of Applied Sciences Bremerhaven (all in Germany), "Wind Engineering" at the University of Applied Sciences Flensburg, or "Wind Power Project Management" at Gotland University (SE).

International dedicated joint programme: Only recently the first international joint wind energy programme has been established: the "European Wind Energy Master (EWEM)". The consortium of TUDelft, DTU, University of Oldenburg, and NTNU Trondheim joined forces to design this master programme as the currently best practice offer.

International PhD programmes: International PhD programmes provide interdisciplinary training for researchers who are on the way to become the new generation of leading academics in wind and ocean energy. They will be able to take management positions in industry, or become the future academic teachers at universities who will have the task of establishing this new academic field. The Initial Training Network (ITN) "WAUDIT Wind Resource Assessment Audit and Standardization" should be mentioned as one of the first EU Marie Curie schools.

Academic continuing education: Reacting to the needs of a quickly growing market, postgraduate programmes on academic level have been designed as part-time studies for professionals: the "Continuing Studies Programme Wind Energy Technology and Management" (since 2006) and the "Continuing Studies Programme Offshore Wind Energy" (starting 2012) by ForWind/University of Oldenburg.

Vocational training: The rapid growth of the wind energy sector is making an important area for future development and offering manufacturers, subcontractors and service providers significant potential. At the same time, the wind energy sector is suffering from a lack of highly skilled workers, and the competition with the automobile and aircraft industry. The successful development of the wind energy sector is closely tied to the availability of training and professional certification opportunities. In spite of the above-mentioned activities there are still not enough full-time programmes at universities to cover the increasing demand for experts with high-level qualifications. This requires immediate action to qualify professionals.

Example: Continuing Studies Programme Wind Energy Technology and Management

The *Continuing Studies Programme Wind Energy Technology and Management* is especially designed to support companies and professionals in the wind energy sector in their development. The programme is directed equally to specialists and executive staff in the wind energy sector, as well as to recent graduates and those who wish to enter this field. It offers comprehensive systematic understanding of wind energy projects from scientific grounds to technical, legal and economic realization, as well as skills in planning and project management.

The programme is especially designed to fit the requirements of professionals. It offers a mix of learning methods: self-study of reading materials, a two-day seminar once every month, and project work in teams. The total duration of the programme is eleven months. It is intended to be short but intensive. The University of Oldenburg upon successfully passing of the examinations issues a certificate.

The realization of wind energy projects requires that experts from a variety of differently disciplines work closely together. This program fosters a 'know-how-transfer' from acknowledged experts in the field and from Universities thus, providing current and expert knowledge. The interdisciplinary approach is the central theme that the program is based upon and is represented by the following special characteristics: multi-disciplinary expertise; management experience; international perspectives; case study work; and expert and alumni network.

The program is in its sixth year of existence the *Continuing Studies Programme Wind Energy Technology and Management* ("Windstudium"), and has been developed in close cooperation between ForWind and WAB. Numerous partners from research, education, industry, and businesses in the field of wind energy supported the realization of this continuing academic education for professionals, and evaluate the development of the programme through its advisory board. GE Wind Energy, Bremer Landesbank, and WSB Service GmbH sponsor the programme.

Ocean Energy

A very extensive inquire on existing and forecasted education and training in ocean energy was requested at European level, both directly to universities (IST and UBI, Portugal; Universidade de Cantábria and UPC, Spain; Ecole Central de Nantes, France; Universities of Southampton, Strathclyde, Edinburgh, Exeter, Lancaster and QUB in the UK; NTNU, Norway; Gent University, Belgium; Aalborg University, Denmark; Dresden University, Germany; Universidade di Nápoli, Italy; Chalmers and Uppsala universities, Sweden; UCC, Ireland) and other bodies (EUREC, EU-OEA, KIC-InnoEnergy). Whilst only a very limited number of replies were obtained, it is obvious that no dedicated university or other type of education or training programs exists specific for ocean energy. Only at IST (Lisbon) an Advanced Diploma on Ocean Energy to be offered from 2012 onwards could be identified, as well as a specialization module in ocean energy in the EUREC Master on Renewable Energy also to be offered from 2012 (to be delivered by IST). However several courses on ocean and coastal engineering, renewable energy or other topics offer some education and training in ocean energy and in several of these cases there is an indication that ocean energy modules will be expanding in the future.

EUREC renewable energy European master has several specializations, including wind and ocean energy. KIC InnoEnergy has several generic masters and doctoral programs in energy and even renewable energy but no one specially dedicated educational programs in wind or ocean energy.

EUREC has developed a course in ocean energy. The course is part of the EUREC master degree on Renewable Energy and also offered by IST (Instituto Superior Técnico, Lisbon Technical University) as a post-graduation course. EUREC Master on Renewable Energy has a core semester where a wide background on different aspects of renewable energy is offered at the core universities and a second semester dedicated to the different renewable energy sources and technologies offered by the specialized universities. IST is responsible for offering the ocean energy specialization, which will start in 2012-2013 academic year. Typically 5 to 10 students are expected to follow the ocean energy specialization. A similar number of students are expected to follow the post-graduation course offered independently by IST. The third semester is dedicated to develop the thesis in an ocean energy subject.

The specialization semester is organized to provide the students with sufficient technical knowledge on Ocean Renewable Energy while also providing them with a good grounding in the role of marine renewables in the energy sector and an understanding of the industry approach to offshore renewable energy projects. The course is designed to provide the students with the following background:

- Sound understanding of the role of marine renewable energy technologies in the energy sector
- Basic technical knowledge on the different marine renewable energy technologies, including the enabling technologies, that are and will be contributing to energy supply covering the following aspects:
    - Evaluation of the resource
    - Conversion process
    - Performance of systems in operation

- Tools for simulation, design and operation
- Offshore operations relevant for deployment and O&M of ocean energy farms
- Environmental impacts, conflict of uses and licensing of offshore farms
- Ability to make an economic evaluation of the profitability and competitiveness of marine renewable energy projects

Wavetrain2, Marie Curie ITN

Wavetrain2 (2008-2012) is a Marie Curie Initial Training Network designed to provide 3 years training in wave energy to 20 young researchers to support the growth of a wave energy industry. Wavetrain2 follows the very successful Wavetrain MC RTN (2004-2008). Almost all of the 15 Wavetrain research fellows are now hired by the industry, from engineering consultant companies to utilities, technology developers to supply chain industry or research centres and universities. The two training networks are designed in a similar way: they are intended to provide research capabilities to young professionals to be integrated by industry. The research background is offered through long term research projects, many of which lead to PhD thesis. On top of this a wide background is offered through summer schools (typical 13) that cover all the technological and non-technological aspects relevant to develop the technology or wave farm, including economic and finance aspects, environmental impacts and legislation, wave farm licensing, H&S, grid connection, etc. Secondments to industrial partners are encouraged to facilitate the trainees' integration in the work market. Supergen Marine is a UK initiative similar in size, organization and objectives to the Wavetrain MC RTN.

FRANCE ENERGIES MARINES

The research institute "FRANCE ENERGIES MARINES[16] has been launched in March 2012. This centre will gather a staff of 70 people on 3 sites (Brest, Nantes and Toulon). Funding of M€ 133 is provided for ten years from the French government, local authorities and private-public investments. The company EDF is in charge of the management of this institute. It is intended to boost the competitiveness in the marine renewable energies (MRE) industry, by providing its support to the sectors of **fixed and floating offshore wind, tidal current energy, and wave energy and ocean thermal energy conversion**. The objective is to ensure the qualification of technologies supported by the industrial firms and will pool means and facilities for simulation, experimentation and especially the test sites, which should be operational as of **2013**. The aim is also to construct an industrial supply chain fed by exports to the global market and contribute to complying with the commitment for 6 installed GW from marine energy sources in 2020.

The institute will define the needs for initial and further training and will disseminate educational tools to fulfil requirements for the job creation perspectives generated by the sector. This is the spirit in which Master's degree courses in "Marine energy sources" began in September 2010 in Brest (the only French academic program fully dedicated to ocean energy).

---

[16] http://www.france-energies-marines.org/

3 Needs and Gaps

The working group has made the following general observations concerning the needs and gaps:

- Wind energy is a cyclical energy business dominated by big global companies (producers, developers, operators)
- Ocean energy and offshore wind projects provide local job opportunities
- Strong need for continuing education also for regulators, lawyers and business people
- Universities could learn from each other and in some case develop and use common educational platforms
- Some universities have long time experience (more than 10 years) and many are newcomers in the wind and ocean energy areas
- Teaching resources and student grants are important barriers
- Industry shapes the labour market but students, universities and local/national authorities shape the market for training and education; how to match these markets
- Public understanding and acceptance (NIMBY) are important issues

Skills need in the energy industry

A study by the Deloitte Energy Institute of the skills need in the energy industry[17] identified a set of issues, which still holds true in the wind energy and ocean energy industries:

– Steadily decreasing pool of new entrants to the labour market
– Accompanying decline in scientific, engineering and technical (SET) skills by these new entrants
– Increasing competition from other industries for these shortage skills
– Decreasing numbers of SET graduates choosing to enter a SET career
– Rapid strides towards larger scale retirement year on year
– Lack of experienced hires for key roles in an expanding industry

The report also identified a set of needs that the industry needed to consider carefully:

- **Better attraction of the industry as an employer to combat a steadily decreasing pool of new entrants to the labour market**
  This may require consideration of a wider range of potential employees than their traditional market, including more diversification of the workforce. This is also likely to require attracting those considering a return to the industry, making better use of those about to leave or those who have recently left the industry and recruitment from countries

[17] Skills needs in the energy industry report- jan 2008, Deloitte Energy Institute

- **Re-skilling and cross-training to combat the accompanying decline in scientific, engineering and technical (SET) skills possessed by these new entrants**
  Re-skilling or cross-training of existing or new staff is necessary, particularly in parts of the industry that have rapidly changing technology requirements. Support for training organisations, particularly universities, is critical if those organisations are to meet industry needs on high-level skills. This may be in the form of practical help such as sharing of cutting edge technology and IT solutions or in building relationships and supporting the development of potential future employees;

- **Higher profile for the industry as one of the most exciting to work in to combat increasing competition from other industries for these shortage skills**
  The energy industry is an exciting career option for young people and offers some of the biggest challenges – to individuals and the world – that lead to a valuable and worthwhile job offering real responsibility to young engineers and others. The industry needs to be well presented to young people as a prime career choice;

- **Getting the rewards right for engineers and technical specialists in order to combat decreasing numbers of SET graduates choosing to enter a SET career**
  SET careers need to be seen as attractive and financially rewarding in order to compete with careers for high-flying SET graduates in finance, management and law. During their studies students need to be presented with positive role models and have the opportunity for practical experience of what a future SET career might entail. Role models, placements, job finding services, training and development opportunities can all assist in enhancing the profile of such careers but employers also have a commitment to recognising energy professionals, offering suitable development opportunities and rewarding technical specialists in line with management staff;

- **More creative use by employers of the experienced workforce and prospective returners to combat the rapid strides towards larger scale retirement year on year**
  Employers need to be aware of the potential for major loss of staff, not just from retirement, which is largely predictable, but also from loss of younger staff to competitors and other industries, particularly as SET specialists become more marketable and can command ever-higher salaries. Where loss of experienced staff to retirement is inevitable, employers need to manage their exit in order to consolidate their skills and value to the business and invest them in new and existing staff. This may involve the use of mentoring schemes, use of 'garden leave' or part-time re-hire options or continuation of their employment on a consultancy basis;

- **Greater involvement by the industry in developing its new and potential graduates at an early stage to combat lack of experienced hires for key roles in an expanding industry**
  There is no magic formula for turning a fresh graduate into a skilled technician with ten years' experience. Such development requires time, investment and ability to retain them once trained to that level. This will require employers to be more innovative in their methods of training and development, looking for efficient and effective ways of benchmarking employees'

competence, and giving them the experiences and support to develop those skills. It will also require closer cooperation between industry and academia to develop such skills during their early training.

The present WG finds that these needs and suggested solutions still are very relevant also for the wind energy and ocean energy industry and other stakeholders, where SET skills are in demand.

Needs in Wind energy education and training

Coherent definition of wind energy modules and curricula

A few individual researchers and experts in wind energy have been the pioneers to establish training activities in the past. Because of this the landscape of education and training is still fragmented in Europe and there is no common understanding about the content of a programme devoted to wind energy, but the activities are very strongly dominated by the personal profiles of the founders (being electrical or mechanical engineer, physicist or material scientist).

Local expertise is in almost all cases limited and thus one university alone is not able to deliver a "complete", research based wind energy curriculum. Even the leading universities in the field, DTU and TU Delft, have joined forces with two other universities, Univ. of Oldenburg and NTNU, Trondheim, in order to offer the "European Master Wind Energy (EWEM)". Cooperation is necessary to integrate the various disciplinary approaches to wind energy into reliable and coherent programmes that are oriented towards different job profiles in the sector.

Besides the exchange of knowledge between universities there is also a common need to get a better understanding of these job profiles, of what skills and competences are needed in different fields of wind energy.

Given the still incoherent understanding of wind energy modules and curricula and the urgent need to offer a growing number of students a systematic university education in the field of wind energy, the development at universities has to be considered on all academic levels:

- Bachelor, Master, PhD;
- Research and applied orientation;
- Full-time and part-time.

Currently, there is no university that can master all wind energy programmes on all levels and specific orientations. Cooperation and exchange in European network and alliances would be very helpful for universities (for designing their modules and programmes) and students (looking for orientation for their career choices) and industry (looking for experts and qualification programmes).

Experienced and interdisciplinary scientific staff is lacking on advanced levels

Scientific staff in research and education is still the "first generation": they are trained in traditional disciplines like physics, electrical or mechanical engineering and other disciplines, and have learned wind energy relevant know-how through application of their specific discipline to wind energy. They are still experts in their "home" field, and lack interdisciplinary expertise on advanced levels. While they can teach wind energy with all its interdisciplinary aspects on – let's say – Bachelor level, they cannot necessarily master the interdisciplinarity or multidisciplinarity needed on Master level. So, current Master programmes are typically adding up different disciplines to achieve the broad training. There is a need for exchange and cooperation among universities engaged in wind energy in order to improve the interdisciplinary level of advanced courses, and to thereby bring wind energy education to the next level of integrated programmes on Master and PhD level (PhD graduate schools). Graduates from these programmes could then become the "second generation" scientists and teachers with interdisciplinary skills and competences on advanced level.

Increased research and teaching resources at universities

There is already a sufficient (and rising) number of research institutions in Europe, e.g.: DTU, TU Delft, ForWind, Fraunhofer, DLR, Cener, Sintef,... (see EAWE). But, in order to deliver research based education to more students and at higher levels it is necessary to intensify the cooperation of research institutions, industry, and universities (the "knowledge triangle").

In order to reach the SET plan goals it is necessary to work out a new consistent Wind Energy training programme – which does not exist up to now. To achieve this an increase of the resources at universities: more laboratories, professors, and lecturers in all fields contributing to wind energy research and teaching. Important measures are e.g.:

- support cooperation and exchange of wind energy faculty
- common (in the sense of triangle) training program for students
    - exchange on BA, internships, practical works at partners
    - common MA courses
    - common international PhD schools
    - summer schools and PhD seminars
- involve industry in university support
- operate research facilities so that universities have real data available for research and teaching...

Applied education

Apart from research based education there is a need to educate large numbers of academics with a focus on jobs application for applied education in order to train skilled experts in all areas of industry and commerce.

Increased access to continuing education

Because the demand for education exceeds the supply with graduates there is a need to develop flexible and demand side oriented qualification programmes that are available quickly. There are some programmes offered commercially (see above), but there is potential for more, especially for re-skilling programmes for career changers, or programmes to secure labour for the aging workforce. But the economic basis for these programmes is not easy to achieve. A lack of support schemes for lifelong learning – at least in Germany – makes it difficult for many people to invest their private money in continuing education for a career change.

While continuing education is increasingly supported by the big enterprises that have entered the wind energy market during the last years, it is still much more difficult for employees at small and medium-sized enterprises (SME) to get funding or other support from their employer. External funding schemes would be of great help in these cases.

Needs in Ocean energy education and training

The discussion about the required skills is particularly difficult for ocean energy, in particular for wave energy, since the technology is still very open in what concerns the final configuration of the technology. It is still unclear if the devices will be floating or underwater, if they will use as power take-off equipment air turbines, water turbines, electrical linear generators, hydraulic rams or rack and pinion systems. Fixed foundation offshore wind energy is now a commercial activity, which may experience a significant development along the forthcoming years according to the SET Plan. The experience in fixed foundation offshore wind development is very relevant for floating offshore wind (now in an early demonstration phase) and ocean energy (also in an early demonstration phase) in terms of required skills and their need per unit of installed power, etc. However one should try to anticipate in what aspects these two early stage technologies may be different from the much more mature fixed foundation offshore wind and how this affect the required skills both in quality and quantity.

Operation and management skills required

Tidal turbines, wave devices and floating wind turbines will be deployed in deeper waters than fixed foundation wind and this will require a larger use of ROVs in their maintenance and in the maintenance of the underwater electrical connectors. Tidal turbines are deployed in sites with very strong currents, thus requiring special trained crews to operate under these conditions. Both wave energy devices and floating wind turbines require extensive mooring lines and dynamic electrical cables. The maintenance of these systems may require specific skills and possibly a large number of people. Platforms for wave energy and floating wind may experience large accelerations and drift motions, thus resulting in more difficult access for O&M and so specific training. The deployment and O&M vessels may also be different, maybe also requiring special training.

Use of prototypes in education and training

Ocean energy like tidal current and wave raise very difficult issues both with respect to electric and mechanical design and performance of the devices, and this calls for research in laboratories must be accompanied by the development of prototypes in a structured collaborative frame at a European level. Because of the high cost of prototypes the research has to be conducted in a complementary way between several universities with a clever combination of specialties and competences. EU programs could facilitate the cooperation between existing prototypes developers and universities. Further research and actions for the 10 coming years must concern themes like: (1) material for large scale machines and for robustness, (2) issues concerning medium and large scale farm (hydro-mechanical-electric), (3) the interaction between the ocean medium (wave, wind, storm, currents), and (4) the machine and (a fortiori) the farm for large scale interaction.

Environmental impact and regulation training

Environmental impacts may be different and so training in these aspects may be needed for people to be employed in regulators and licensing bodies. Deep offshore wind, wave and tidal resource characterization is different from shallow water wind resource characterization. The design of floating wind, wave or stream turbine farms is in some aspects different from fixed foundation wind farms and the industry will need people with these skills.

The procedures for licensing and consenting, economic assessment may be similar to fixed foundation offshore wind, but the increase of deep water projects of any kind will require an increasing number of professionals.

Floating offshore wind foundations and wave energy devices have a size, which is intermediate in relation to typical structures built in shipyards and metalwork contractors, i.e., they are small for shipyards and usually large for metalwork contractors. The firsts are not prepared in general to develop serial construction methods, while the seconds are not aware of ship regulations and standards. This may imply dedicated training actions for both shipyards and metalwork contractors.

4 Infrastructures and synergies

Infrastructures

Wind and ocean energy requires large-scale installations to harvest power from the flows of air and water. The trend is up scaling towards bigger and bigger machines for both offshore wind and wave and tidal power. These big machines are installed in farms in the 100-1000 MW scale, which requires development of electric power infrastructure and seaside infrastructure both in the building/installation phases and for operation and maintenance.

For ocean energy installations grid infrastructure and connections will be important for further development. Grid connections to onshore grids can also be problematic, as in some cases the grid is too weak to absorb the electricity production from wave energy power stations. Except for coastal countries, such as Portugal and the SW region of the UK that have high voltage transmission lines available close to shore, coastal communities lack sufficient power transmission capacity to provide grid access for any significant amount of electricity that can be generated from marine energy.

The trend towards larger wind turbines, which slowed in recent years, has resumed. The largest wind turbine now in commercial operation has a capacity of 7.5 MW, and most manufacturers have introduced designs of turbines in the 4.5 – 10 MW range (up to a total of 42 different designs) mostly for off shore use. Both industry and academia see even larger turbines (10 – 20 MW) as the future of off shore machines [TPWind, 2010].

Synergies

Wind energy depends on other sectors including: the electricity grid which is a fundamental enabler for higher wind penetration and is currently underdeveloped in particular regarding international interconnections; electricity storage (pumped or reservoir hydropower, compressed air, etc.); and manufacture of subsea HVAC/HVDC cables. The European installed capacity of hydro-pumping storage, currently at 40 GW, should be increased in order to allow for more system flexibility. More reservoir-hydro capacity would contribute to grid support and this would enable more wind and other non-firm renewables into the system.

Synergies exist between the offshore sector and the oil and gas (O&G) industry in areas such as the manufacture of installation vessels. This sector can bring in experience and know-how to the off shore wind sector, in particular on substructure installations and on operation and maintenance issues.

Some ocean energy projects share grid-related issues with off shore wind and even with onshore at a lower level. Exchange of technological knowhow with the aeronautics industry might result from the entry of EADS in the wind sector. Other sectors that have possible synergies with wind are the grid components, in particular for off shore installations, and electricity storage sectors. The latter, along with the auto industry for electric cars, and with the support of smart grids/metering, would create a demand-management scenario able to adapt and assimilate surplus wind electricity.[18]

Research infrastructures

The R&D priorities suggested by the Wind Technology Platform [TPWind, 2010] include new turbines and components for on- and off shore deployment, large turbines, testing facilities; development and testing of new off shore foundations, and its mass manufacturing; grid integration including long distance HVDCs, connections off shore to at least two countries and multi-terminal solutions; and resource assessment including a new European wind atlas and spatial planning instruments. While R&D programmes run by the European Commission are already adapting to these priorities, Member States are expected as well to align their R&D funding in the near future.

For the marine technologies to succeed, much attention needs to be paid to technical risks in design, construction, installation and operation. Importing knowledge and experience from other industry sectors, such as off shore oil and gas, including risk assessment procedures and engineering standards is of great importance. Rigorous and extensive testing, including single components, sub-assemblies and complete functional prototypes are still necessary to establish the new technologies. Large deployment can be successful with the convergence of technologies, thus reducing the number of isolated actors and allowing technology development to accelerate. Industrial R&D should be moving in parallel with continuing academic R&D.

RD&D in advanced materials offers synergies with a number of low-carbon industries (non-exhaustive): fibre-reinforced composites with the nuclear and solar energy; coatings with the solar power, biomass and electricity storage industries; special concretes with building and nuclear; high-temperature superconductors with the electricity transmission and storage sectors, etc. [European Commission, 2011b].

Apart from the national test facilities for both turbines and component there is a European (ESFRI) project under development in wind energy called Windscanner. The WindScanner facility is a unique new and distributed infrastructure for research in the large-volume wind fields engulfing today's and tomorrow's huge on- and offshore wind turbines. It can be described as a “wind tunnel without walls” for renewable energy research spurred from recent advances within mobile laser Doppler wind measurement techniques. It is based on 3-dimensional scanning with wind lidars to determine

[18] SETIS: 2011 Technology Map of the European Strategic Energy Technology Plan (SET-Plan), JRC

the instantaneous flow and turbulence fields. The project is to be implemented by the EERA joint program on wind energy by the EERA participants: Risø DTU, CENER, ECN, CRES, Fraunhofer IWES, SINTEF & LNEG, (FORWIND)

The Irish government allocated a financial package for marine energy administered by a new ocean Energy Development Unit (OEDU) based within the Sustainable Energy Authority of Ireland (SEAI), covering support for device developers, enhancement of test facilities and development of grid-connected test facilities.

Whilst very desirable, it is not easy to see how students and trainees may have access to real data and physical access to the equipment from the ongoing operation of wind farms. At least three reasons converge as barrier for this to happen: confidentiality, costs and risks. Confidentiality may prevent owners of the technology or farms to provide access to critical data, as for instance data related to the reliability of some components or cost of energy. This could be solved if pilot plants or demonstration farms were deployed for the specific purpose of education, training and research; however the cost of this and the complexity of running these facilities is possibly beyond the capability of universities or research centres to dealt with – except possibly if a single or a very limited number of infrastructures of this type were built under a common organization or umbrella.

5 Recommendations

General recommendations for the wind and ocean energy sector:

The expected growth in the wind and ocean energy sectors will require continued expansion of the corresponding education and training activities in the EU roughly with a doubling of the effort and output by 2020 if it is to scale with the expected growth in the sector. The needed skills base is quite broad and ranges from design, component manufacturing, wind farm development, installation, operation and maintenance, utilities, consulting, R&D in industry, universities and research centres as well as financial and legal services, and government regulation. The spectrum of skills covers the whole range from EQF level 1 to EQF level 8 (Ph.D.). Similarly, it will require a broad spectrum of activities to meet the education and training needs including undergraduate, graduate, post-graduate education, life-long training, reconversion schemes, professional training schemes, market uptake measures, etc.

It will require actions by a broad range of stakeholders in European Commission, national government bodies, regional authorities, industry as well as in educational institutions and students including professionals seeking further education. The driver for this development will be the employment opportunities and their attractiveness for the employees.

The working group finds that the Commission's proposal "Supporting growth and jobs – an agenda for the modernisation of Europe's higher education systems" (COM(2011)567 final) contains many of the elements needed to support the education and training needs in wind and ocean energy.

Like in the other areas of the SET Plan, **the development of a common strategic agenda and road maps** for the desired development are excellent tools to guide actions at many levels and by many actors. This will also hold true for education and training. At the EU level this should be supported by **monitoring and evidence based policy analysis combined with support to**

joint actions by key stakeholders to promote strategic cooperation with joint development and implementation of educational programs, mobility of learners, teachers and researchers and support to the interaction with the world outside the EU.

As the training in wind and ocean energy has been grown in a bottom up process it is now necessary to guarantee a common quality by establishing a new independent training field called Wind Energy on all levels in a European wide top down process.

- **Increase exchange of students, scientists, and teaching staff**
- **Increase number of interdisciplinary programmes on Master level**
- **Support interdisciplinary and international PhD-schools**
- **Increase number of wind energy research facilities and laboratories at universities**
- **Increase staff (professors and lecturers) at universities**
- **Enable career changes between university and industry**
- **Allow senior experts to become professors and enrich education**
- **Increase number of lifelong learning opportunities**
- **Invent/increase support or funding schemes for professionals for part-time continuing education**

The educational institutions and their networks should also **encourage flexibility greater variety of study modes** like part-time, distance and modular learning as well as continuing education for adult returners and others already in the labour market. This should be followed by mechanisms to ensure quality and relevance. The institutions and the relevant authorities should invent/increase support or funding schemes for professionals for part-time continuing education

The **universities should liaise with professional membership bodies** to assist students in getting a head start towards their recognition as energy professionals and use of such bodies as sources of useful information and contacts.
It is obvious that the development of strategic partnerships and networks of learning should take full advantage of the **potential of ICT to enable more effective and personalised learning experiences like e-Learning and blended learning and increase the use of virtual learning platforms.** This will require continuous professional development of the university and college staff, recruitment of new staff to develop emerging fields and the ICT based learning methods.

The industries and other employers will also have to contribute actively to meet the education and training needs in the wind and ocean energy sectors. In a recent analysis by the Deloitte Energy Institute the actions were listed as:

- **Upgrade skills of existing and future workforce** including investment in in-house training and development programmes;
- **Consider alternative sources of employment** including overseas workers, returners, women, consultants and the retaining of 'retired' staff;
- **Engage with universities to offer technical support, student placements and allow**

recruits to return to university to promote the industry to future graduates;

- **Overhaul the appearance of the industry** to potential recruits making it clear that the energy industry as a whole offers a worthwhile and fulfilling long-term career.

Finally the energy profession itself has a role to play in **developing younger members of the workforce and supporting the future skills growth of the next generation.** The partners in this piece of research propose a number of developments that will be of assistance in achieving this aim.

These general goals can be pursued by the following recommended actions listed below.

Specific proposals for concrete actions:

Heading 1: Filling the skills, competences and knowledge gap

Meeting the skill/competencies gaps of new and emerging technologies, and strengthening and developing existing skills/competencies

Action 1.1: Breeding of European clusters of excellence like the EERA, EWAA, KIC-InnoEnergy and SEEIT alliances with focus on SET Plan and Wind and Ocean Energy needs in both R&D and education and training

Why: Currently, there is no university that can master all wind and ocean energy research and educational programmes on all levels and specific orientations. Specialized and specific training in wind and ocean energy is currently concentrated in relatively few institutions across EU and is not always supported by a solid research base. Cooperation and exchange in European research network and alliances would be very helpful for universities (for designing their modules and programmes) and students (looking for orientation for their career choices) and industry (looking for experts and qualification programmes).

What: The growing educational and training efforts should take advantage of the newly formed strategic alliances and the emerging joint program in wind and ocean energy. The research based experiences and competences at the most prominent centres should be used to strengthen knowledge alliances, cooperative programs, and strategic networking to ensure the quality, capacity and speed the development of new educational programs. Activities includes

- Joint R&D project that includes student activities
- Setting-up and operate research and training sites mainly for education
- Sharing of labs and research infrastructure

How: New European Knowledge Alliances would increase the number of interdisciplinary program at master level, and should include industrial partners. They should be closely linked to the SET Plan activities in the technology platforms, the EIIs and EERA. The well-established industry–university relations could be used for pilot traineeships to improve the quality and relevance of new educational programs.

When: The ongoing efforts to strengthen joint research programming should be supplemented with efforts do engage more universities with matching educational and training programs that would can make rapid use the research results. Call in 2014 aimed at creating five new educational initiatives associated with the joint programming efforts in wind and ocean energy.

Action 1.2: Support to networks of universities for joint development of flexible master programs with modular building blocks also suited for lifelong learning tuned to the industrial needs in wind and ocean energy

Why: The demand for education and training exceeds the current supply, and there is a need to develop flexible and demand side oriented qualification programmes that are quickly available. There are some programmes offered commercially, but there is potential for more, especially for re-skilling programmes for career changers, or programmes to secure labour opportunities for the aging workforce. There is also a need to secure and support the economic basis for such programmes both for the development of the programs, and for supporting their attendance. A lack of support schemes for lifelong learning in many countries makes it difficult for many people to invest their private money in continuing education for a career change.

What: The energy industry has pointed to the need for re-skilling and cross-training to combat the accompanying decline in scientific, engineering and technical skills in their work force. This is necessary particularly in parts of the industry that have rapidly changing technology requirements. Support for training organisations, particularly universities, is critical if those organisations are to meet industry needs on high-level skills. This may be in the form of practical help such as sharing of cutting edge technology and IT solutions or in building relationships and supporting the development of potential future employees. The industries and other employers will also have to contribute actively to meet the education and training needs in order to develop the younger members of the workforce and supporting the future skills growth of the next generation. The outcome will be development of joint (international) programmes on bachelor, master and Ph.D. level as well as part-time programmes on advanced academic level issuing a university certificate to be used as building blocks in life-long modular education.

How: The leading universities in the wind and ocean energy fields should develop and offer specialized short (1 year concentrated or stretched over several years) professional “master” programs for continued education. This should be combined with a certified lifelong learning CV/diploma and accreditation of such programs leading to a new concept of cumulated masters in Lifelong learning. Such programs could be developed effectively as part of European strategic alliances.

When: University partners should start developing such programs immediately in parallel with the launching of a European dialogue to gain accept of the concept and to attract sponsors and students as well as necessary national accreditations. Call for EU support should be launched in 2014

Action 1.3: Support to strategic networks of vocational training centres in association with leading knowledge institutions; focus on EQF levels 4-6 in order to strengthen local qualifications and skills in wind and ocean energy

Why: Vocational training in the regions of emerging market is in high demand, particularly in the wind energy industry. In Europe these regions include the eastern parts of EU, where interest in wind energy is growing and the coastal regions, where off shore activities are growing. The suppliers of turbines and other equipment are often met with demands for local co-production from the customers and the local authorities. The vocational training centres in these regions have insufficient expertise in these the specific wind and ocean energy technologies.

What: A program should be launched to couple the vocational training centres in regions of the EU where wind energy is emerging but less developed to similar centres in regions with long experience with these technologies.

How: The program should consist of guest teacher secondment, supply and exchange of teaching material, and visiting programs for students at the leading teaching and training facilities. It could include new markets in the neighbouring regions to the EU in the east and south, where there is a potential for European industry.

When: A supporting program should be prepared through workshops and expert analysis, but should be launched as soon as possible with 2-5 pilot project called for in 2014.

Action 1.4: Train the trainers programs with focus on new markets and vocational training

Why: Scientific staff in research and education is still the “first generation”: they are trained in traditional disciplines like physics, electrical or mechanical engineering and other disciplines, and have learned wind energy relevant know-how through application of their specific discipline to wind energy. There is a need for exchange and cooperation among universities engaged in wind energy in order to improve the interdisciplinary level of advanced courses, and to thereby bring wind energy education to the next level of integrated programmes on Master and PhD level (PhD graduate schools). Graduates from these programmes could then become the “second generation” scientists and teachers with interdisciplinary skills and competences on advanced level. These needs are general but there are special needs to help creating a sufficient numbers of qualified “trainers” in the regions with emerging markets (see above under 1.3) and to include those involved in vocational training.

What: Special short to medium term courses should be developed in collaboration between the knowledge centres and /or knowledge alliances in wind and ocean energy and the universities and other teaching and training institutions in the EU regions with emerging markets for these technologies. The aim is to rapidly increase the number of qualified teachers and the effort should be closely linked to the development of the local teaching curricula in the regions with emerging markets.

How: The realization of wind energy projects requires that experts from a variety of differently disciplines work closely together. This program fosters a ‘know-how-transfer’ from acknowledged experts in the field and from Universities thus, providing current and expert knowledge. The interdisciplinary approach should be the central theme that the program is based upon and is represented by the following special characteristics: multi-disciplinary expertise; management experience; international perspectives; case study work; and expert and alumni network. The support should include both the development of the courses and support to attendance of “trainers” from the focus region.

When: The train the trainers program should be prepared with workshops and conferences to bring the potential collaborating together, and these efforts could be carried out jointly with the preparations of action 1.3 above. Call for pilot project should be made in 2014.

Heading 2: Fostering involvement, access and up-take by the labour market

Promoting mobility, life-long learning, work force training based on industry involvement and interdisciplinary partnerships

Action 2.1: Development of a European model for Industrial Doctorates programs jointly sponsored and executed in industry/university collaborations

Why: Several EU members states have national Industrial Doctorate programs, where the doctoral projects are carried out in close collaboration between a university and an industrial partner. These programs have proven very effective in technology transfer, and they have in many cases led to research based innovation in the participating industries with promising results. However, they are typically limited to partners in the respective member states. The programs have been particularly successful in areas, which require a broader research base and cross-disciplinary activities such as wind and ocean energy.

What: Development of a European platform and practise for industrial doctorates using the common elements from the national schemes and introducing best practices in the European platform. EUA and EPUE or similar university consortia could offer to host the framing of this new initiative.

How: The European Academy of Wind Energy has a good track record for organizing summer schools and PhD-workshops, and this organisation could form the basis for new European doctoral schools and be a facilitator for the proposed new European Industrial Doctorates in this field. Together with other consortia in the field they could be responsible for matchmaking between industries, universities and the potential student as well as specific industrial doctorate projects to be supported by European grants.

When: The ideas should be developed through European workshops followed by calls for applications in 2013 within national and European programs.

Action2.2: European program for access to research and pilot facilities for higher level education and training in Wind and Ocean Energy

Why: In any field of science, technology and engineering access of students and trainees to laboratory and real scale data and equipment is of foremost importance to complement the more theoretical learning related to the conceptual description and understanding of complex systems. If this is true in general and also in onshore wind, it particularly applies to offshore wind and ocean energy, as here students have also to become familiar with a very aggressive environment, which most do not know at all or only very superficially.

Ocean environment has an enormous impact in technology and market development due to a number of facts: cost, risk and logistics of any maritime operation; increased fatigue and corrosion; access difficulties; extended complexity of the equipment due dynamic electrical cables, extensive mooring lines; underwater connections, etc.; environmental impacts and conflict of uses; marine legislation; etc.

What: A EU education and training action is proposed to expose students and trainees to pilot plants and demonstration offshore farms, through (1) access to real data (related to their performance, environmental impacts, and O&M), (2) physical access to the sites with visits and if possible (3) involvement in deployment and O&M operations, so that they experience the size and complexity of the logistics involved in these operations and the difficulty and risks in accessing the equipment.

Access to laboratory data and equipment is a standard in most universities and more practical training institutions, but not so much the access to real data and equipment. This however is important to enhance the size and complexity of many of industrial equipment, as well as the challenges related their design, deployment and O&M. On the other hand, it is also fundamental to foster innovative ideas for technology and systems improvements.

How: The proposed action could be coupled to the SET Plan for wind energy: under the action "New Turbines and Components" the SET Plan proposes a "network of 5 – 10 European testing facilities to test and assess efficiency and reliability of wind turbine systems". It would be relatively easy to extend the purpose of these 5 – 10 European testing facilities to testing and training facilities, possibly with an additional fund to cover extra costs associated with it. Further alternatives include: i) to increase the grant for demo projects funded by Horizon 2020 to allow access for education and training; ii) to give a grant to existing or planned production farms to allow access for education, training and research purposes.

Pilot plants and demonstration farms could be run as Explore-Houses, where students and trainees would have access to real data of very different type, but could be also involved in their O&M and also possibly in the control of the equipment. This would also be a means to increase the participation of industry and research in the education and training activities.

When: The action should be launched in 2013 as 3-year projects included in FP7 calls; each project should aim at 3-500 student with total budget in the range 3-5 M€; from 2014 the action could be part of new calls in Horizon 2020

Action 2.3: Industry endowed chairs (industry pooling) at the universities in wind and ocean energy

Why: Scientific staff in research and education is still the "first generation" in the fields of wind and ocean energy. The staffs are typically trained in traditional disciplines like physics, electrical or mechanical engineering and other disciplines, and have learned wind energy relevant know-how through application of their specific discipline to wind energy. They are still experts in their "home" field, and often lack interdisciplinary expertise and industrial experience on advanced levels. There is a need for exchange and cooperation wind energy industry in order to improve the interdisciplinary level of advanced courses, and to thereby bring wind energy education to the next level of integrated programmes on Master and PhD level (PhD graduate schools).

What: Individual industries and/or industrial association should consider sponsorships for new chairs for research based education at the leading universities within the fields of wind and ocean energy in order to promote interdisciplinary and industry inspired research and education at the highest level. Such a program would be a logic element to promote education and training in conjunction with the development of the technology platforms and the more specific EII and EERA projects. EPUE would be a natural organisation to host the effort to develop and promote such an European endowed chairs program.

How: Five-year grants should be established for externally sponsored professorships to be filled in open European competition. Sponsorships should be solicited from individual large companies or from association of companies. Co-founding by the EU would be an attractive option to spread such a scheme to regions where wind and ocean energy is less developed by where there is a big potential.

When: EPUE could initiate the preparations for such a program with industrial sponsors could at very short notice, whereas an EU sponsored scheme could follow the schedule for the annual work program in energy.

Action 2.4: Support to networks of regional, vocational training centres with focus on the special local needs in wind and ocean energy

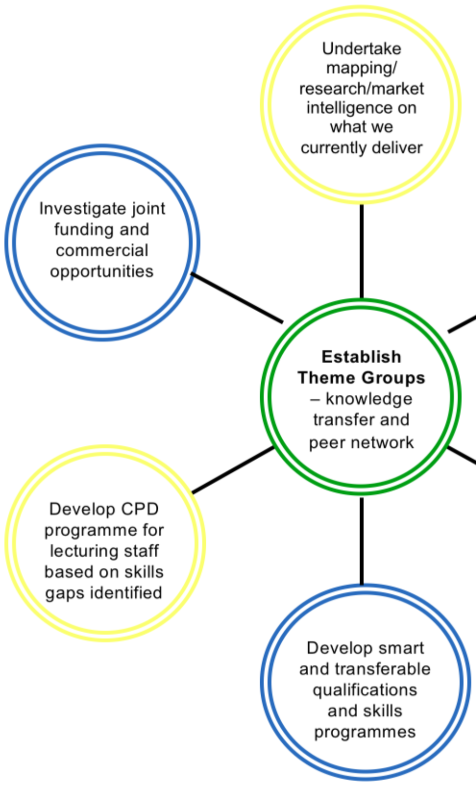
Why: The educational institutions should develop individual and collective strategies to deliver the right skills, in the right place at the right time to satisfy the needs of the growing wind and ocean energy sector. This should be done in local, regional and European networks matched to the required level of competence, capacity, research experience and facilities. Such networks can (1) exploit the synergies between the partners to develop wider capabilities and capacity through collaboration, (2) work with industry to contextualise existing qualification and training interventions and develop new programs that are recognized by industry, (3) identify bottlenecks and work with partners to develop appropriate interventions, and (4) establish key centres of excellence to support the sector. The lack of experts also hits research institutions and universities. While universities are increasingly designing dedicated programmes they themselves suffer from the lack of dedicated professorships and lecturers. In order to increase the number of experts and support technological innovations new forms of academic education should be designed and operated in close cooperation between universities, research institutions, and industry.

What: Actions are proposed to support initiatives in wind and ocean energy that create innovative forms of enhanced networking (in the MS and Europe) between regional universities, research institutions, and industry, in order to develop innovative forms of education, transfer of know-how, and life-long learning on all levels (vocational training, Bachelor, Master, PhD). The actions should promote strategic partnerships between institutions and national networks with the scope of enhancing the exchange of knowledge and experience between research and application.

How: By developing educational models in partnerships of universities, research institutions, and industry, especially develop curricula and teaching formats together by:

- Sharing experiences and lessons learned; and organize cooperative ways to find efficient solutions
- Giving priority to personal and exclusive networks built on trust as opposed to only virtual ones; and
- Promoting joint life-long learning activities for professional experts
- Creating buddy programmes for students, young researchers and alumni in industry that provide guidance for students and help industry, research institutions, and universities to find new staff
- Designing additional support with social media and web 2.0 technologies adjusted accordingly
- Creating exchange or visiting programmes for staff at universities, research institutions, and industry.

An example of such a strategic network is the energy skills partnership in Scotland whose strategy is illustrated below:



Action 2.5: Student and researcher grants to expand the impact of European Knowledge alliances and other types of strategic partnerships involving both academia and industry

Why: Joint programming initiatives are underway in several areas of the SET Plan Road Map including wind and ocean energy. These initiatives will link the foremost competence centres to each other forming new European Knowledge alliances and speed-up research and technology development at competitive levels globally. Special efforts are needed to secure knowledge and technology transfer to regions and areas in the EU, which have not yet been able to join the knowledge alliances.

What: A Marie Curie like competitive fellowship program to enable student and researcher from regions to join research teams at one of the Knowledge Alliance Centre institutions for periods between 3 months and one year and to obtain a suitable credit to be used at their home base education/training institution.

How: The exchange program should be competitive with a minimum of bureaucracy. It should be administered by the Knowledge Alliances and funded by a combination of host contribution (for visiting researchers), local/national support schemes (tuition waivers and visiting student programs) and block grants to the Knowledge Alliance. The activity level should correspond to about 10% of the research staff and student enrolment in the given program

When: This type of block grants should be included in the call for joint programming as soon as possible.

Heading 3: Planning and enabling skills development

Sector skills assessments and observatories, “Train the Trainers”, and On-line information and other tools

Action 3.1: Pilot actions to boost the use and impact of e-learning and virtual training facilities in wind and ocean energy combined with platforms and library systems for the development and exchange of teaching material (e-books, e-lectures) at research universities and university colleges

Why: ICT technology and platform for e-learning are developing fast, and most universities have in-house activities to incorporate these tools in their education and training programs. FP7 is sponsoring several collaborative projects to develop the concepts of the ”virtual campus” and the ”virtual laboratory”, which will enable student to follow lectures at different universities and to obtain remote access to unique laboratory facilities. EIT KIC’s are developing virtual university platforms to strengthen networking between the knowledge centres. While the technology is developing fast there is a need to engage more teachers and to develop their skills and experiences with these new tools.

Education and training in wind and ocean energy is an ideal area for pilot actions to boost the use of the ICT tools and the teachers' abilities to take advantage of the new opportunities for ICT based teaching and learning:

- Key competences are concentrated at relatively few universities, while the education and training needs are quite wide spread
- Remote research infrastructures, test facilities and data banks can be made valuable components in education and training via the distant learning tools
- Programs for continued education, especially “train the trainers”-programs, could grow quickly in response to the need

What: Actions are proposed to support pilot actions in wind and ocean energy for joint e-learning programs in European university consortia with the scope to

- Building joint e-learning platforms to support bachelor, master and doctoral education including common e-learning material,
- Focus on the development of teachers skills and creativity in ICT based teaching and learning
- Jointly develop tools for remote access to research and test facilities for education and training purposes
- Create a network to support universities and colleges outside the consortium to enhance their educational programs in wind and ocean energy
- Liaise with industry to ensure program relevance and coupling to trouble shooting as well innovation projects

How: Calls for 4-year pilot projects with the scope above directed at the leading universities in wind and ocean energy research and education to form e-learning consortia with partner universities in areas of growing need for wind and ocean energy education and training. The proposed total budget is 10-15 M€ for 2 – 4 projects. Support should be given to joint development of e-learning tools, -material, -courses, teacher training and networking, implementation at associated institution and other forms of dissemination.

When: Universities should immediately complement their internal development of e-learning with multilateral efforts within their strategic alliances. National and European programs should support this via calls in 2012 or early 2013.

Action 3.2: Platform and library system for the development and exchange of teaching material (e-books; e-lectures) at research universities and university colleges

Why: The development in wind and ocean energy has the potential to create massive job opportunities, many with new skills requirements. Jobs will be created at many levels, and their skill profiles will change over time as the industry and the sectors are maturing. Education and training is key to enable an optimal match between job opportunities and skills requirements. The grand challenge for the stakeholders in education and training is to provide the best odds for the match to happen - anywhere in Europe. This creates a need to broaden the base for wind and ocean energy. ILO[19] quote: "There is plenty of scope for continuing and deepening exchanges of knowledge and experience among countries on training and skills development policies and systems. It is particularly valuable for countries to share their experiences in dealing with the more difficult challenges of maintaining the relevance of education and training to the world of work, and in moving from policy principles to application."

What: More instruments are needed to convince/help existing teachers to include wind and ocean energy in their curricula and teaching material. A program of open access to e-based learning material on an exchange basis should be created as a form of common library for teachers from college to university level based on a reasonable level of standardisation of both the platforms and the presentations. The scope would be to make learning material readily available to teachers and institutions at institutions new to the advanced fields of wind and ocean energy technology. It is obvious that such development would be helped by more formal strategic partnerships and networks of learning that could take full advantage of jointly developed virtual learning platforms.

How: A 3-year European pilot program in wind and ocean energy should be initiated to

- Survey the field of open access e-based learning material
- Build a European virtual pilot library for e-based learning material based on a combination of exchange and open access
- Develop the procedures for contribution, quality assurance and use of the library material
- Assess the different technology platforms in order to develop flexible standards
- Develop and report on best practices for a more permanent virtual

When: EPUE and/or other European Consortia together with the Commission should jointly organise workshops and seminars to develop this idea with the view to a funding call in 2013.

---

[19] A Skilled Workforce for Strong, Sustainable and Balanced Growth: A G20 Training Strategy, International Labour Office – Geneva, 2010

Action 3.3: Drive further harmonisation of the educational systems in the Member States and stimulate mutual skills recognition in order to enhance mobility of the work force in Wind and Ocean energy

Why: The overall quality and agility of the European system for education in training would be enhanced if the European universities were encouraged to build learning mobility more systematically into their curricula, and if the national governments continued the efforts to eliminate unnecessary barriers to switching institutions between bachelor and master levels and to cross-border co-operation and exchanges. It would also require more readily recognition of credits gained abroad through more effective collaboration on quality assurance based on comparable and consistent use of ECTS and the Diploma Supplement. Linking qualifications to the European Qualifications Framework would be another important element. Vigilant harmonisation of the educational systems in the Member States with focus on the transferability of credits and transparency in the description of learning outcomes is a prerequisite for increased mobility of students and graduates. The ocean and wind energy sector is already very international, but cross-border recruitment in the sector is essential and would benefit from further development of the ECTS and ECVET schemes and from the linkages between the EQF and the national qualification schemes for continued education and life-long learning programs.

What: The development of education and training opportunities in the wind and ocean energy sector should be facilitated by more transparency, better databases, and more readily accessible information on the internet covering both the educational and training programs combined with performance-based ranking and information tools that profiles the higher education institutions.

How: National governments should use the wind and ocean energy sector a pilot area for the development standardised information platforms combined with clear progression routes from vocational and other education to higher education and to encourage outreach to students from underrepresented groups and "non-traditional" learners, and to develop national strategies to train and retrain researchers and higher education teachers to meet the national demands in the sector. Harmonisation and European accreditation should be accompanied by more student and researcher grants to promote mobility and excellence to allow the best talent to gain the optimal education and training.

When: Should start immediately and be a key element in the development of a road map for SET-Plan education and training.

Action3.3: Establish a Wind and Ocean Energy Skills observatories with focus on offshore and new markets needs and the shift towards O&M

Why: The landscape of education and training is still fragmented in Europe and there is no common understanding about the content of a programme devoted to wind energy, but the activities are very strongly dominated by the personal profiles of the founders (being electrical or mechanical engineer, physicist or material scientist). Cooperation is necessary to integrate the various disciplinary approaches to wind energy into reliable and coherent programmes that are oriented towards different job profiles in the sector. Given the still incoherent understanding of wind energy modules and curricula, and the urgent need to offer a growing number of students access a systematic university education in the field of wind energy, and a way to overlook the educational opportunities in EU. Besides the exchange of knowledge between universities there is also a common need to get a better understanding of these job profiles, of what skills and competences are needed in different fields of wind energy.

What: An education observatory should be established either to serve the needs in Wind and Ocean Energy alone or in combination with other SET Plan technology fields. The observatory should:

- Provide overview of educational programs in Wind and Ocean Energy in Europe combined with information on how to join such programs
- Engage with educational institutions to harmonize their templates and vocabulary in the description education programs and learning objectives
- Work with MS governments, national institutions and industries to assess the training needs and identify
- Organise workshops, conferences at EU level for the education and training stakeholders
- Publish status reports regularly with clear recommendations for the stakeholders
- focus initially on the emerging market and the offshore needs

How: The observatory function and status should be awarded for periods of 5 years following competitive tendering. Potential candidates to perform such tasks are national agencies with similar remits, European associations with legal entity status, and private consulting service companies.

When: ASAP, the establishment of such observatories will be a logical next step in the development of the SET Plan Education and Training Road Map.

6 Action Template

Heading 1: Filling the skills, competences and knowledge gap

Meeting the skill/competencies gaps of new and emerging technologies, and strengthening and developing existing skills/competencies

Action 1.1: Breeding of European clusters of excellence like the EERA, EWAA, KIC-InnoEnergy and SEEIT alliances with focus on SET Plan and Wind and Ocean Energy needs in both R&D and education and training

Action 1.2: Support to networks of universities for joint development of flexible master programs with modular building blocks also suited for lifelong learning tuned to the industrial needs in wind and ocean energy

Action 1.3: Support to strategic networks of vocational training centres in association with leading knowledge institutions; focus on EQF levels 4-6 in order to strengthen local qualifications and skills in wind and ocean energy

Action 1.4: Train the trainers programs with focus on new markets and vocational training

Heading 2: Fostering involvement, access and up-take by the labour market

Promoting mobility, life-long learning, work force training based on industry involvement and interdisciplinary partnerships

Action 2.1: Development of a European model for Industrial Doctorates programs jointly sponsored and executed in industry/university collaborations

Action2.2: European program for access to research and pilot facilities for higher level education and training in Wind and Ocean Energy

Action 2.3: Industry-endowed chairs (industry pooling) at the leading universities in wind and ocean energy

Action 2.4: Support to networks of regional, vocational training centres with focus on the special local needs in wind and ocean energy

Action 2.5: Student and researcher grants to expand the impact of European Knowledge alliances and other types of strategic partnerships involving both academia and industry

Heading 3: Planning and enabling skills development

Sector skills assessments and observatories, "Train the Trainers", and On-line information and other tools

Action3.1: Pilot actions to boost the use and impact of e-learning and virtual training facilities in wind and ocean energy combined with platforms and library systems for the development and exchange of teaching material (e-books, e-lectures) at research universities and university colleges

Action 3.2: Platform and library system for the development and exchange of teaching material (e-books; e-lectures) at research universities and university colleges

Action 3.3: Drive further harmonisation of the educational systems in the Member States and stimulate mutual skills recognition in order to enhance mobility of the work force in Wind and Ocean energy

Action 3.4: Establish a Wind and Ocean Energy Skills observatories with focus on offshore and new markets needs and the shift towards O&M

European Commission
EUR 26725 EN– Joint Research Centre – Institute for Energy and Transport

Title: Strategic Energy Technology Plan European Energy Education and Training Initiative

JRC Coordination: A.Georgakaki, U.von Estorff, S.D.Peteves

Luxembourg: Publications Office of the European Union

2014 – 616 pp. – 21.0 x 29.7 cm

EUR – Scientific and Technical Research series – ISSN 1831-9424 (online)

ISBN 978-92-79-39145-3 (PDF)

doi10.2790/30422

LD-NA-26725-EN-N

JRC Mission

As the Commission's
in-house science service,
the Joint Research Centre's
mission is to provide EU
policies with independent,
evidence-based scientific
and technical support
throughout the whole
policy cycle.

Working in close
cooperation with policy
Directorates-General,
the JRC addresses key
societal challenges while
stimulating innovation
through developing
new methods, tools
and standards, and sharing
its know-how with
the Member States,
the scientific community
and international partners.

Serving society
Stimulating innovation
Supporting legislation

doi:10.2790/30422

ISBN 978-92-79-39145-3

Publications Office