European Commission

The Strategic Energy Technology (SET) Plan

At the heart of
Energy Research and Innovation
in Europe

2007-2017
SET PLAN 10TH ANNIVERSARY

Research and Innovation

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The Strategic Energy Technology (SET) Plan

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Coordinators

DG RESEARCH AND INNOVATION
Nuno QUENTAL, Dermot BUTTLE, Sandya ABRAR,
Karina FIRKAVICIUTÉ, Jose JIMENEZ MINGO

DG ENERGY
Dimitrios SOFIANOPOULOS, Andy KONTOUDAKIS

JOINT RESEARCH CENTRE
Cristian SALES AGUT

Acknowledgements

AUTHORS

DG Research and Innovation
Sandya ABRAR
Piero DE BONIS
Dermot BUTTLE
Filippo GAGLIARDI
Jose JIMENEZ MINGO
Karina FIRKAVICIUTÉ
Nuno QUENTAL
Jeroen SCHUPPERS

DG Energy
Jens BARTHOLMES
Remy DENOS
Andy KONTOUDAKIS
Alexandros KOTRONAROS
Eric LECOMTE
Pietro MENNA
Dimitrios SOFIANOPOULOS
Mark VAN STIPHOUT

Joint Research Centre
Lois BRETT
Franco DI PERSIO
Natalia LEBEDEVA
Heinz OSSENBRINK
Cristian SALES AGUT

CONTRIBUTORS

DG Research and Innovation
Fabio BELLONI
José COTTA
Roger GARBIL
Christopher IBBOTT
Gwennaël JOLIFF-BOTREL
Vassilios KOUGIONAS
Frederick MARIEN
Leila PAGNINI
Maria Josefa SABO PAEZ
Matthijs SOEDE
Piotr TULEJ
Philippe TULKENS

DG Energy
Mario DIONISIO
Roberto GAMBI
Aleksandra KRONBERGA
Margot PINAUT
Andreea STRACHINESCU OLTEANU

Joint Research Centre
Johan CARLSSON
Aliki GEORGAKAKI
Arnulf JAEGER-WALDA
Zoi KAPETAKI
Maria KOTTARI
Davide MAGAGNA
Edesio MIRANDA BARBOSA
Jose MOYA
Wouter NIJS
Efstathios PETEVES
Ruth SHORTALL
Marc STEEN
Nigel TAYLOR
Thomas TELSNIG
Evangelos TZIMAS
Cristina VAZQUEZ HERNANDEZ

Programme Office of the Fuel Cells and Hydrogen Joint Undertaking
Enrique GIRON
Nikolaos LYMPEROPOULOS

Table of Contents

1

SET Plan: 10 years at the heart of EU clean energy R&I policies

Ten years ago, when the Strategic Energy Technology (SET) Plan was launched, the energy transition was in the making but still looked distant. While the challenge of successfully transforming our energy system still lies ahead of us, few would deny that the chances of success seem today much brighter than a decade ago.

A radical transformation is underway in the way energy is produced and used to fulfil societal needs. Clean renewables gradually replace fossil fuels. Rotating wind turbines generate power onshore and offshore. The sunlight is converted into electricity by increasingly efficient photovoltaic (PV) cells. Biofuels can already be produced from sources that used to be incinerated. Many other examples could be given – and this publication features some of the most important.

What is perhaps less obvious, but certainly not less important, is the employment re-structuring effect at the heart of this energy transition. **By 2015, the European Union (EU) had 1.6 million people working on renewables and energy efficiency[1]. This represents a growth of 13 % since 2010 – more than seven times greater when compared to the 1.7 % employment increase for the whole EU economy.** Given the potential for job creation, growth and exports, the EU industry needs to remain globally competitive in the low-carbon energy sector. Strengthened research and innovation (R&I) is indispensable for that endeavour.

The energy transition is motivated by the decisive challenge facing humankind – to protect our planet and its inhabitants from catastrophic climate change. The landmark Paris Agreement of the United Nations Framework Convention on Climate Change in 2015 was a real breakthrough in the worldwide efforts to keep global warming well below 2 °C above pre-industrial levels. As the energy sector produces at least two-thirds of the total greenhouse-gas (GHG) emissions, the clean energy transition, also powered by consumers, is essential to reach the objectives of the Agreement.

There are numerous signs to suggest that the energy sector is heading in the right direction. Remarkable technological and deployment progress has been driving renewable energy costs down – often drastically, as in the case of wind, PV and batteries – and their performance up. Thanks to this, onshore wind and the top-performing utility-scale PV are already cost competitive against newly built fossil fuel power generation in Europe[2]. **The EU-wide share of renewable energy use increased from 9.7 % in 2007 to 16.4 % in 2015[3]**. In 2016, newly installed renewables' capacity excluding large-scale hydropower amounted to 55 % of all the generating capacity added globally – the highest proportion in any year to date – while investment in 'new renewables' was roughly double that in fossil fuel generation for the fifth successive year[4].

1 Eurostat (2017), *Employment in the environmental goods and services sector.*
2 Bloomberg New Energy Finance (2017), *New energy outlook 2016 – Europe.*
3 European Environment Agency (2017), *Indicator assessment: share of renewable energy in gross final energy consumption.*
4 Frankfurt School-UNEP Centre/BNEF (2017), *Global trends in renewable energy investment* 2017.

These positive trends are likely to continue in the future, strengthening further the economic case for renewables. **A tipping point will probably be reached by the mid-2020s, when building a new wind farm is expected to become cheaper than running an existing gas plant[5]. And it will mean faster, more widespread renewables' deployment.** By 2040, projections indicate that renewable energy sources will represent 60% of the European electricity mix, up from 24% in 2015, with solar representing half of the additional installed capacity and wind receiving half of all power capacity investment[6]. The consumers' role will be enhanced, with small-scale PV deployed on rooftops of households and businesses (often combined with battery storage) making-up around half of Europe's solar capacity. On the transport sector there are also reasons to be optimistic, as it is estimated that by 2030 low-emission mobility will represent 15-17% of transport energy demand[7] and by 2040 electric vehicles will make up to 25% of the global car fleet[8].

Notwithstanding all the above, national commitments under the Paris Agreement so far are not commensurate with limiting global warming to well below 2ºC. Attaining this target would require around double the current levels of investment in the energy sector – as much as $3.5 trillion on average each year until 2050[9]. Market diffusion investments need to be complemented by a very ambitious technology push effort. For instance, under the Mission Innovation initiative, members have pledged to double their clean energy R&I expenditures. This means that the impressive progress made so far will be stepped-up.

Financing availability must therefore adapt to the future needs of clean energy R&I. **Although not a funding mechanism per se, the SET Plan can be instrumental in that regard by promoting a more targeted and efficient spending, and mobilising additional finance both from national and private sources.** More *targeted* because it focuses on those technologies with the greatest potential for future development; and more *efficient* because it leverages impact through increased R&I agenda alignment and implementation of joint R&I activities in SET Plan countries (EU Member States, Norway, Iceland, Switzerland and Turkey). EU funds are also key in supporting R&I activities with a high European added value.

5 Bloomberg New Energy Finance (2017), *New energy outlook 2016 – Europe*.
6 *Ibidem*.
7 European Commission (2016), *Communication 'A European strategy for low-emission mobility*, COM/2016/0501.
8 Bloomberg New Energy Finance (2017), *New energy outlook 2016 – Europe*.
9 International Energy Agency and International Renewable Energy Agency (2017), *Perspectives for the energy transition: investment needs for a low-carbon energy system*.

Emerging opportunities in the energy system must also be exploited. Consumers, empowered by numerous innovations, will influence the system dramatically. The flexibility they can bring by responding to price signals via demand response and by producing their own energy will likely contribute to a better grid management, enabling the grid to cope with rising shares of renewable energy. Other measures such as increased energy storage capacity, strengthened interconnections and smart grids will further support that.

Furthermore, widespread deployment of energy efficiency solutions across the European building and industry sectors is needed. While the goal is first and foremost to reduce carbon emissions, efficiency also brings about enhanced competitiveness and export potential. For both sectors, the European industry needs result-oriented research that provides innovative answers to challenges such as accelerating the refurbishment rates of buildings and the adoption of more performing technologies and processes.

2017 marks the 10th anniversary of the SET Plan, born out of acknowledging the dire need to reshape Europe's energy future. **In the long run, new-generation technologies must be developed through breakthroughs in research if we are to meet the greater ambition of reducing EU GHG emissions by 80% by 2050**. Further cost reductions in clean energy generation will be required, and the EU industry will feed on that progress to keep the forefront position it enjoys globally in most clean energy sectors. The SET Plan, within the overarching Energy Union strategy and the 'Clean Energy for all Europeans' legislative package, aspires to make the European energy system fit for the next decades.

The remainder of this chapter outlines the SET Plan milestones since its birth in 2007. Chapter 2 illustrates the key role of R&I in the energy transition by presenting relevant examples of technological progress achieved over the last decade across the 14 low-carbon energy technology sectors the SET Plan covers. Chapter 3 presents the first three implementation plans which identify R&I activities to achieve strategic targets endorsed by the SET Plan community in 2016. The final chapter concludes this publication with the envisioned way forward.

PRIVATE AND PUBLIC FUNDING IN ENERGY UNION / SET PLAN R&I PRIORITIES

In 2015, an estimated €23 billion were invested in the R&I priorities identified by the Energy Union / SET Plan[10]. As much as 77% originated from the private sector, while the remainder came from Member States' public funding (18%) and the EU (5%) (Figure 1). The private sector is the major source of R&I investment in all but one Energy Union / SET Plan R&I priorities. The exception is for nuclear safety, which is primarily funded through public (national) investments.

R&I investment grew by almost 8% in the period 2010-2015 mostly due to increased spending by the private sector and, to a smaller extent, the EU. By contrast, public (national) funding decreased slightly over the same period. R&I investment in sustainable transport has nearly doubled, again driven by the private sector, and that in efficient and smart systems has increased but at a slower pace. Renewables experienced a slight R&I investment decrease. The latter trend may be explained by the higher degree of maturity of mainstream renewable energy technologies, while smart systems and system integration are comparatively less developed and therefore require more resources.

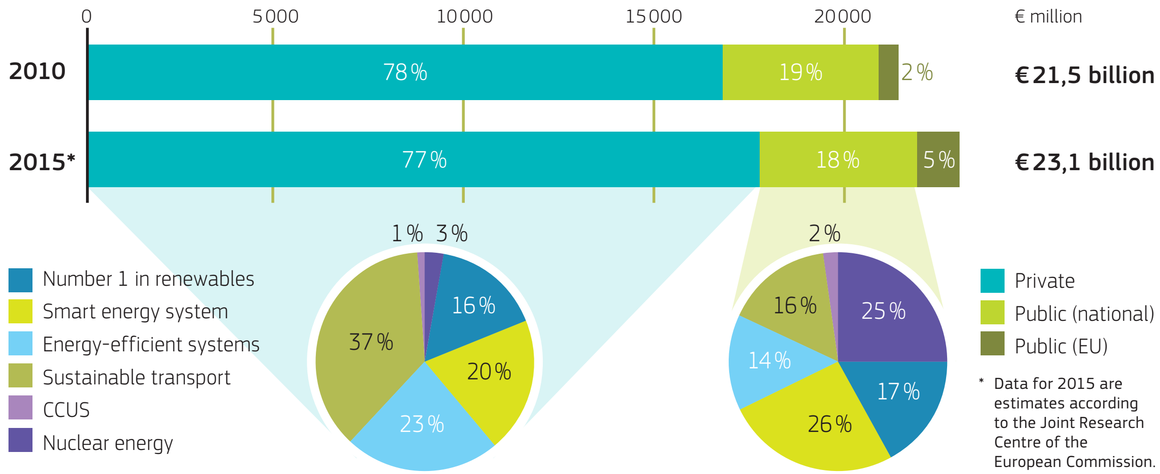


Figure 1: Investment in the Energy Union / SET Plan R&I priorities in the EU (2010-2015).
Data sources: Public (national) investment: International Energy Agency RD&D online data service; Private investment: as estimated by SETIS/Joint Research Centre (detailed methodology available[11]); EU investment: Directorate-General for Research & Innovation. Note: public (national) and private data for 2015 are estimates.

10 Source: cf. caption of Figure 1.
11 Fiorini, Georgakaki, Pasimeni, and Tzimas (2017), *Monitoring R&I in low-carbon energy technologies: methodology for the R&I indicators in the State of the Energy Union Report – 2016 edition*. Joint Research Centre, European Commission.

Key SET Plan milestones

Key SET Plan milestones

10 JANUARY **2007**

European Commission Communications: 'Towards a European Strategic Energy Technology Plan' [COM(2006) 847]; and 'An energy policy for Europe' [COM(2007) 1]

2007

Proposes the creation of the SET Plan: 'Europe has two key objectives for energy technology: to lower the cost of clean energy and to put EU industry at the forefront of the rapidly growing low-carbon technology sector.'

8 AND 9 MARCH **2007**

European Council conclusions

2007

Adopts an 'Energy Policy for Europe' endorsing the 2020 climate and energy targets and welcomes the Commission intention to table the SET Plan. The Council recognized 'the need to strengthen energy research in particular to accelerate the competitiveness of sustainable energies (...) and the further development of energy efficiency technologies.' The headline 20-20-20 targets were later incorporated in the wide-ranging 'Europe 2020 strategy' (COM/2010/2020).

22 NOVEMBER **2007**

Communication 'A European Strategic Energy Technology Plan: Towards a low-carbon future' [COM(2007) 723]

2007

Presents the SET Plan structure and main goals: 'The vision is of a Europe with a thriving and sustainable economy, with world leadership in a diverse portfolio of clean, efficient and low-carbon energy technologies as a motor for prosperity and a key contributor to growth and jobs.'

28 FEBRUARY **2008**

Conclusions of the Council on Transport, Telecommunications and Energy

2008

Welcomes the Commission proposal for a SET Plan and agrees on its fundamental principles: 'accelerated development and wide-scale application of clean, sustainable and efficient energy technologies [as] an essential element for the achievement of the EU's ambitious energy and climate goals for 2020 and [the] transition to a low-carbon economy by 2050.'

26 JUNE **2008**

SET Plan Steering Group

2008

First meeting of the SET Plan Steering Group. It includes official representatives from all EU Member States, Norway, Switzerland, Iceland and Turkey.

2008

European Energy Research Alliance

2008

The European Energy Research Alliance (EERA) becomes the public research pillar of the SET Plan by bringing together 175 public research organisations from 27 countries.

7 OCTOBER **2009**

Communication 'Investing in the development of low-carbon technologies (SET Plan)' [COM(2009) 519]

2009

Puts forward technology roadmaps for the development of low-carbon technologies and an initiative on smart cities and communities. Implementing these decade-long roadmaps would require an investment of €60-70 billion.

12 MARCH **2010**

Conclusions of the Council on Transport, Telecommunications and Energy

2010

Requests the Commission to 'develop to its full capability the SET Plan Information System (SETIS) to provide a robust technology-neutral planning tool, which reflects the current state of the art of the individual technologies and their anticipated technological development and market potential. It should make it possible to assess performance and cost-effectiveness and to monitor the progress of the SET Plan activities towards their objectives in a transparent and objective way.'

3 AND 4 JUNE **2010**

European Industrial Initiatives and the Smart Cities and Communities European Innovation Partnership

2010

European Industrial Initiatives as well as a public-private partnership on smart cities and communities are launched to implement the technology roadmaps.

10 NOVEMBER **2010**

European Commission Communication 'Energy 2020 – a strategy for competitive, sustainable and secure energy' [COM(2010) 639]*

2010

Defines the EU energy strategy towards 2020 to meet the 2020 climate and energy targets. It also grounds the SET Plan to renewed and concrete targets to aspire to, and calls for speeding-up its implementation.

2 MAY **2013**

Communication 'Energy technologies and innovation' [COM(2013) 253]

2013

Provides a stock-taking exercise of the SET Plan and the European Industrial Initiatives. The consequences of the 2008/2009 gas supply crises and the shale gas revolution led to a reflection on the role of innovative energy technologies.

* Not directly part of the SET Plan process

2014

Energy ERA-NETs under Horizon 2020

2014

Ten energy Horizon 2020 ERA-NET Cofund joint programming networks are launched. ERA-NETs have been the most used instrument by Member States for the coordination of their activities in the context of the SET Plan. They represent €217 million in public funding commitments and €68 million from the EU, and mobilised almost €80 million from the private sector.

DECEMBER 2014

SET Plan report 'Towards an integrated roadmap: research and innovation challenges and needs of the EU energy system'

2014

Releases the so-called 'Integrated Roadmap'. The need to provide a larger share of renewable energy, to promote further efficiency gains and to enable the active participation of consumers in the energy system requires an approach that goes beyond technology silos. The roadmap proposes R&I actions integrated along the innovation chain, the value chain and the energy system – the first effort of such kind in Europe. More than 150 stakeholders actively contributed with inputs.

2015-2016

European Technology and Innovation Platforms

2015

Establishes nine European Technology and Innovation Platforms (ETIPs) as the industrial pillar of the SET Plan – the outcome of merging eight pre-existing European Technological Platforms with the six European Industrial Initiatives. ETIPs are industry-led fora covering through their members the whole innovation chain (including research). Seven ETIPs are technology oriented (wind, PV, ocean, bioenergy, deep geothermal, zero emissions and sustainable nuclear energy) and two favour technological or system integration: renewable heating and cooling, and smart networks for energy transition.

25 FEBRUARY 2015

'Energy Union strategy'

2015

Adopts the Energy Union strategy setting the decarbonisation ambition towards 2030, and revising targets for renewable energy sources and energy efficiency. It highlights the critical role of energy R&I for the EU's competitiveness and identifies the SET Plan as the framework *par excellence* to foster it. Four core priorities for energy R&I are set: becoming world leader in renewable energy technologies, facilitating consumer participation in smart energy systems, developing efficient energy systems, and developing sustainable transport systems. Carbon capture and storage and nuclear energy are added as additional research priorities.

JUNE **2015**

InnovFin Energy Demonstration Projects

2015

Creates the InnovFin Energy Demonstration Projects risk finance instrument to support first-of-a-kind, innovative, low-carbon energy projects reaching the market. Available funds amount to € 300 million from Horizon 2020 and will be further increased thanks to part of NER300's[12] undisbursed revenues (€ 450 million). The facility is managed by the European Investment Bank.

15 SEPTEMBER **2015**

Communication 'Towards an integrated Strategic Energy Technology Plan: accelerating the European energy system trans-formation' [C(2015) 6317]

2015

Revises the SET Plan to align it with the Energy Union R&I priorities (and reflect its system integration vision), and to further prioritise activities. This results in the identification of 10 SET Plan key actions.

12 DECEMBER **2015**

Paris climate agreement*

2015

Pledges a global commitment to reduce GHG emissions to keep the global temperature rise well below 2 °C above pre-industrial levels and to pursue efforts to limit the temperature increase even further to 1.5 °C.

1 JUNE **2016**

Mission Innovation*

2016

The EU joins Mission Innovation. This international initiative was launched at the 2015 Paris United Nations Climate Change Conference (COP21) and represents a major effort by 22 countries and the European Commission to double their government investment in clean energy R&I over the next five years. The SET Plan can be seen as the facilitator for the EU's participation in the initiative.

12 NER300 stands for 'New Entrants' Reserve' and is a grant instrument financed with the sale of 300 million allowances of the EU emissions trading system.

* Not directly part of the SET Plan process

30 NOVEMBER **2016**

'Clean Energy for All Europeans' package*

2016

Puts forth a major EU legislative package that includes the revision of legislation on renewables' and energy efficiency, as well as new market design and Energy Union governance proposals that are expected to drive low-carbon R&I developments (see next point) and the EU energy system towards the achievement of the 2030 climate and energy targets.

* Not directly part of the SET Plan process

30 NOVEMBER **2016**

Communication 'Accelerating Clean Energy Innovation' [COM(2016) 763]

2016

Adopts a comprehensive strategy to boost public and private investment in clean energy innovation. SET Plan's instrumental role in aligning Member States' investments and in exploring opportunities to develop relevant Projects of Common European Interest is recognised.

2016-2017

Strategic targets

2016

Adoption of strategic targets[13] to be reached by 2020-2030 in all SET Plan areas through the so-called 'Declarations of Intent.' They follow a highly participative and scientifically-grounded process involving 154 umbrella organisations.

13 SET Plan Declarations of Intent and the respective targets can be found in SETIS at https://setis.ec.europa.eu/actions-towards-implementing-integrated-set-plan

2017-2018

Implementation plans

2017

Preparation and endorsement of implementation plans which identify R&I activities and demonstration projects required to achieve the targets (see previous point), and setting the basis to mobilise the corresponding private and public resources. The plans are developed by working groups chaired by one or more SET Plan countries and co-chaired by the industry, and include representatives of other relevant stakeholders such as ETIPs and EERA. By September 2017, three out of 14 plans had been endorsed by the SET Plan Steering Group. Their execution would mobilise up to €7 billion until 2030 (chapter 3 for details).

2

Research & Innovation achievements

The world is undergoing a radical transformation in the way energy is produced and used, shifting to a cleaner, consumer-centric and more efficient energy system. European countries, the industry, research organisations and the European Commission are working together to speed up this transformation through the SET Plan. The goal is to facilitate the achievement of the EU climate and energy goals and to strengthen industrial competitiveness. This is being done by better coordinating national R&I agendas on low-carbon energy and mobilising the associated resources required. The present chapter illustrates the SET Plan's role in the energy transition through examples of important R&I advances over the last decade across the 14 energy sectors it covers[14].

14 SET Plan Declarations of Intent and the respective targets can be found in SETIS at https://setis.ec.europa.eu/actions-towards-implementing-integrated-set-plan

Becoming world number one in renewables

The EU has the ambition to become the world number one in renewable energy. To meet this goal, the EU must lead the development of the next generation of renewable energy technologies. And efforts so far are paying off: fuelled by R&I and large-scale deployment, the cost of mainstream technologies like wind and photovoltaics is going down as their performance improves. Meanwhile, technologies not yet at the commercial stage are making their way to the market and will likely have an expanded role in the years ahead. To help accelerate the pace of these positive trends, the SET Plan has set ambitious R&I targets for the five renewable energy technologies covered in this section.

Photovoltaic energy

Photovoltaic energy (PV) has seen exponential growth over the last decade: at the end of 2016 its installed capacity exceeded 100 GW in the EU alone and produced around 4 % of the EU electricity demand. Germany has been leading this growth worldwide, followed by China, Japan, Italy and the United States[15]. Europe is also a leader in PV research and technology development. Coupled with deployment on a large scale, this resulted in PV module prices falling by around 80 % between 2009 and 2015[16]. The SET Plan intends to contribute to further cost reductions and to relaunch PV cell and module manufacturing in the EU.

In line with the general clean energy R&I trends, industry provides most of the R&I investments in the PV sector, an estimated € 1 095 million in 2015, followed by funding from EU countries, who contributed with € 346 million. European funding, which is allocated to technology areas with stronger EU added value, amounted to € 73 million[17].

15 World Energy Council data (2017), https://www.worldenergy.org/data/resources
16 Taylor and Jäger-Waldau (2016), *Photovoltaics technology development report 2016.* Joint Research Centre, European Commission.
17 Data sources: cf. caption of Figure 1. Note: the figure for Member States' and EU R&I funding concerns the entire solar sector, i.e., it includes both PV and concentrating solar power.

MAJOR ADVANCES IN PHOTOVOLTAIC MODULE EFFICIENCY

The mainstream technology for PV is wafer-based crystalline silicon (Figure 2). Between 1990 and 2015, wafer thickness was reduced from 400 μm to 180 μm or less, and the cell area has increased from 100 cm^2 to over 200 cm^2. Overall, silicon material usage for cells has fallen over the last 10 years from 16 g/W to less than 6 g/W. Module efficiency increased from about 10 % in 1990 to typically 15.5 % for polycrystalline silicon, 16.5 % for p-type monocrystalline silicon and 20.5 % for n-type monocrystalline silicon at the end of 2015[18].

Thin film technologies first emerged 35 years ago, thanks to new deposition methods and concepts. Developments over the past 3-4 years have seen efficiencies in the laboratory matching those of polycrystalline silicon. In March 2016, the Baden-Württemberg Center for Solar Energy and Hydrogen Research set a new European record of 22.0 % efficiency for copper indium (gallium) diselenide cells, also thanks to an innovative vacuum deposition process. By contrast, the efficiency of commercial modules is currently just over 14 %[19].

Organic solar cells use carbon-based materials to convert solar energy into electric energy. In 2016, German firm Heliatek claimed a record efficiency of 13.2 %. The focus is on low-cost printing (roll-to-roll processes) or coating of the electrodes, charge transport layers and active layers on flexible substrates[20]. Recently much research attention has focussed on hybrid-organic-inorganic perovskite materials. These claim efficiencies of over 20 %[21] in the laboratory but stability issues need to be addressed.

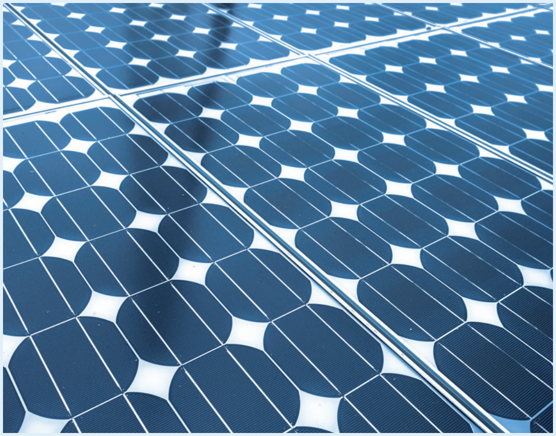


Figure 2: Wafer-based PV modules.
© Bohbeh/Shutterstock.com

18 Taylor and Jäger-Waldau (2016), *Photovoltaics technology development report 2016.* Joint Research Centre, European Commission.
19 *Ibidem.*
20 *Ibidem.*
21 Saliba, Matsui, Seo, Domanski, Correa-Baena, Nazeeruddin, Zakeeruddin, Tress, Abate, Hagfeldt and Grätzel (2016), *Cesium-containing triple cation perovskite solar cells: improved stability, reproducibility and high efficiency.* Energy and Environmental Science 16, pp. 1989-1997.

SIGNIFICANT COST REDUCTIONS

From 2008 to the second quarter of 2016, residential PV electricity system prices fell by over 80 % in the most competitive markets. In an increasing number of markets, the cost of PV-generated electricity is already lower than residential electricity retail prices. This drop is explained by a steep learning curve for PV module prices (Figure 3): 42 years of data show that every time the installed capacity doubled, the price fell by 28 %[22]. This dramatic cost reduction has been led by 'p-type' wafer-based crystalline silicon devices, which represent over 90 % of the market. Both efficiency and material usage are critical parameters affecting costs.

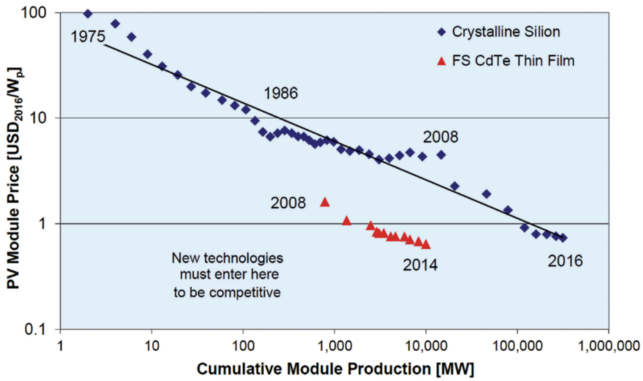


Figure 3: Price-experience curve for solar modules.
Source: Jäger-Waldau (2016), PV Status Report 2016.
Joint Research Centre, European Commission

22 Wang (2017), *Solar modules to get even cheaper and more efficient.* Bloomberg New Energy Finance.

R2M-SI AND NEXWAFE: EFFICIENT AND COST EFFECTIVE SOLAR ENERGY CONVERSION

With EU funding, the Fraunhofer Institute for Solar Energy Systems led a project to deliver a process and manufacturing concept for highly efficient crystalline silicon thin-film PV modules. The project, entitled 'R2M-Si' (Roll to module processed crystalline silicon thin-films for higher than 20 % efficient modules) uses an approach called 'lift-off', which consumes considerably less silicon and potentially leads to 20 % more efficient solar cells and to strong cost reductions. It achieves this by reducing wafer thickness (3-4 times thinner than today's wafers) and by eliminating the need to wire-saw silicon ingots (the reason why the process is known as 'kerfless' wafer production).

NEXWAFE, a spin-off of the institute, is attempting to commercially exploit this technology by building a 250 MW manufacturing plant with support from the InnovFin Energy Demonstration Projects risk-finance instrument.

ENABLING MASS REALISATION OF BUILDING INTEGRATED PV

Buildings account for 40 % of the energy demand. Building integrated PV offers huge potential to exploit roofs and facades as a local energy source, also enabling the electrification of heating and cooling, and transport. R&I efforts focus on (a) glazing, in particular 'smart windows' which can adjust the level of light transmission; (b) shells, i.e. concepts for coverings of buildings; and (c) different components such as roofs, facades and curtain walls. While several projects produced successful demos, mass production has yet to take off.

Concentrating solar power/solar thermal electricity

Concentrating solar power/solar thermal electricity (CSP/STE) currently represents a minor part of renewable energy generation in Europe. However, the potential for growth is significant given the capability of CSP/STE to provide renewable electricity when needed – unlike other technologies, which are dependent on the availability of the energy source. This dispatchability is possible thanks to in-built energy storage and enables plants to respond to peaks in demand, continue production even in the absence of sunlight, and provide ancillary services to the grid.

Despite its advantages, CSP/STE has considerably lagged behind the development of PV in terms of costs and deployment. Currently only approximately 5 GW are installed globally (of which 2.3 GW in Europe, concentrated in Spain). However, the technology seems to finally be gaining traction with the current wave of new projects in different countries (Morocco, South Africa, China, Chile and the Middle East, where a recent tender was the cheapest ever for CSP/STE). As the technological leader in the sector, the EU has much to gain from such expansion.

The CSP/STE implementation plan, endorsed in September 2017, aims to re-launch innovation and deployment of that technology in Europe (cf. chapter 3 for additional details).

DEVELOPMENT OF TWO MAINSTREAM CSP/STE TECHNOLOGIES

• Parabolic trough power plants

The CSP/STE market is dominated by parabolic trough power plants: they comprise more than 80 % of the facilities in operation or under construction worldwide. In these plants solar radiation is collected in rows or loops of parabolic trough-shaped mirrors and then concentrated onto a receiver tube, where a heat transfer fluid is heated to approximately 400 °C (Figure 4). The fluid is then pumped through a series of heat exchangers to produce superheated steam which is converted to electricity in a turbine. The heat transfer fluid can also be used to heat a thermal energy storage system. The commercial viability of a system with storage was demonstrated back in 2008 in the EU-supported Spanish Andasol I plant (50 MW).

• Central receiver plants

The EU was also strongly involved in the development of central receiver plants (also known as 'solar tower' plants). These use a field of large mirrors with sun-tracking motion, known as heliostats, to concentrate solar radiation onto a central receiver mounted at the top of a tower (Figure 5). A heat transfer fluid in this central receiver heats up and is used to generate superheated steam and then electricity in a conventional steam turbine. These are generally more efficient than parabolic trough plants because fluid temperatures are higher. Demonstration plants were built in 1981 in the US and Spain, but 15 years went by before commercial-scale operations began – again in Spain[23]. Currently, only a total of 0.9 GW are in operation or under construction worldwide.

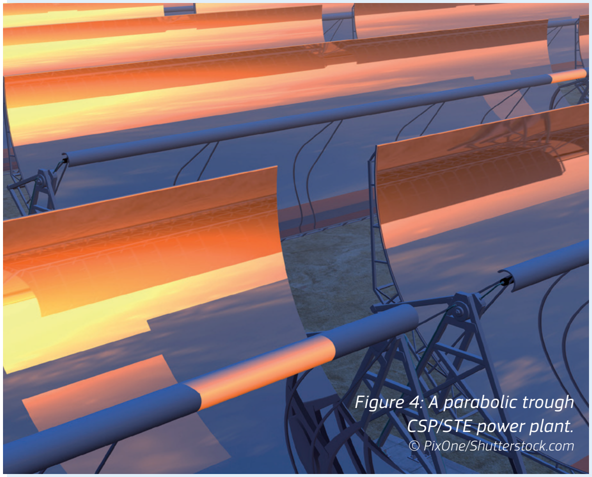


Figure 4: A parabolic trough CSP/STE power plant.
© PixOne/Shutterstock.com

Figure 5: A central receiver CSP/STE power plant.
© paulrommer/Shutterstock.com

23 Ho (2017), *Advances in central receivers for concentrating solar applications.* Solar Energy 152, pp. 38-56.

OPPORTUNITIES FOR HIGHER EFFICIENCIES AND FURTHER COST REDUCTION

- **Heat transfer fluid**

For tower systems, the emerging options for increasing efficiency from the current 18 % to above 23 % include using supercritical steam or carbon dioxide as heat transfer fluid, or pressurised air at high temperatures. In such cases, the gas or air can be used to directly replace natural gas in a high efficiency (>60 %) gas and steam combined-cycle plant. As temperatures could exceed 1 000 ºC, the use of newly developed receivers would make such plants easier to operate.

- **Thermal energy storage**

Two types of storage systems offer great potential and are being researched for increased plant efficiency: latent heat systems make use of the high amounts of energy released and absorbed in phase change materials when they undergo a phase change; and thermochemical storage systems profit from the energy absorbed and released in chemical reactions (e.g. the reduction and oxidation of metal oxides). Energy densities are typically much higher than in comparable sensible heat systems, which are currently the only ones used in commercial plants.

RESEARCH COOPERATION UNDER THE STAGE-STE INTEGRATED RESEARCH PROGRAMME

Under the auspices of EERA, the CSP/STE community was successful in establishing an integrated research programme entitled 'Scientific and Technological Alliance for Guaranteeing the European Excellence in Concentrating Solar Thermal Energy', also known as STAGE-STE. The programme has received € 10 million funding from the EU and a slightly higher amount from research performers and industrial players. There are 41 partners in the consortium, including nine non-European partners from those regions of the world with the highest potential to deploy CSP/STE. STAGE-STE has so far contributed to critical technological achievements such as developing five typologies of low-cost heliostats, testing receiver tubes and validating simulation models to assess the performance of CSP/STE plants using field data.

PLATAFORMA SOLAR DE ALMERÍA: AN EXAMPLE OF A CSP/STE RESEARCH INFRASTRUCTURE

'Plataforma Solar de Almería' is one of the largest and most advanced R&I centres in the world devoted to CSP/STE, with over 30 years of experience (Figure 6). The centre is located on a plot of 103 hectares in southeast Spain, in the Tabernas Desert, which provides ideal conditions for CSP/STE research: a direct annual insolation of more than 1 900 kWh/(m^2 year) and an average temperature of around 17 ºC. Several test facilities are available at the 'Plataforma', including an experimental tower and heliostat field. A wide range of EU framework programme projects have made use of these facilities.

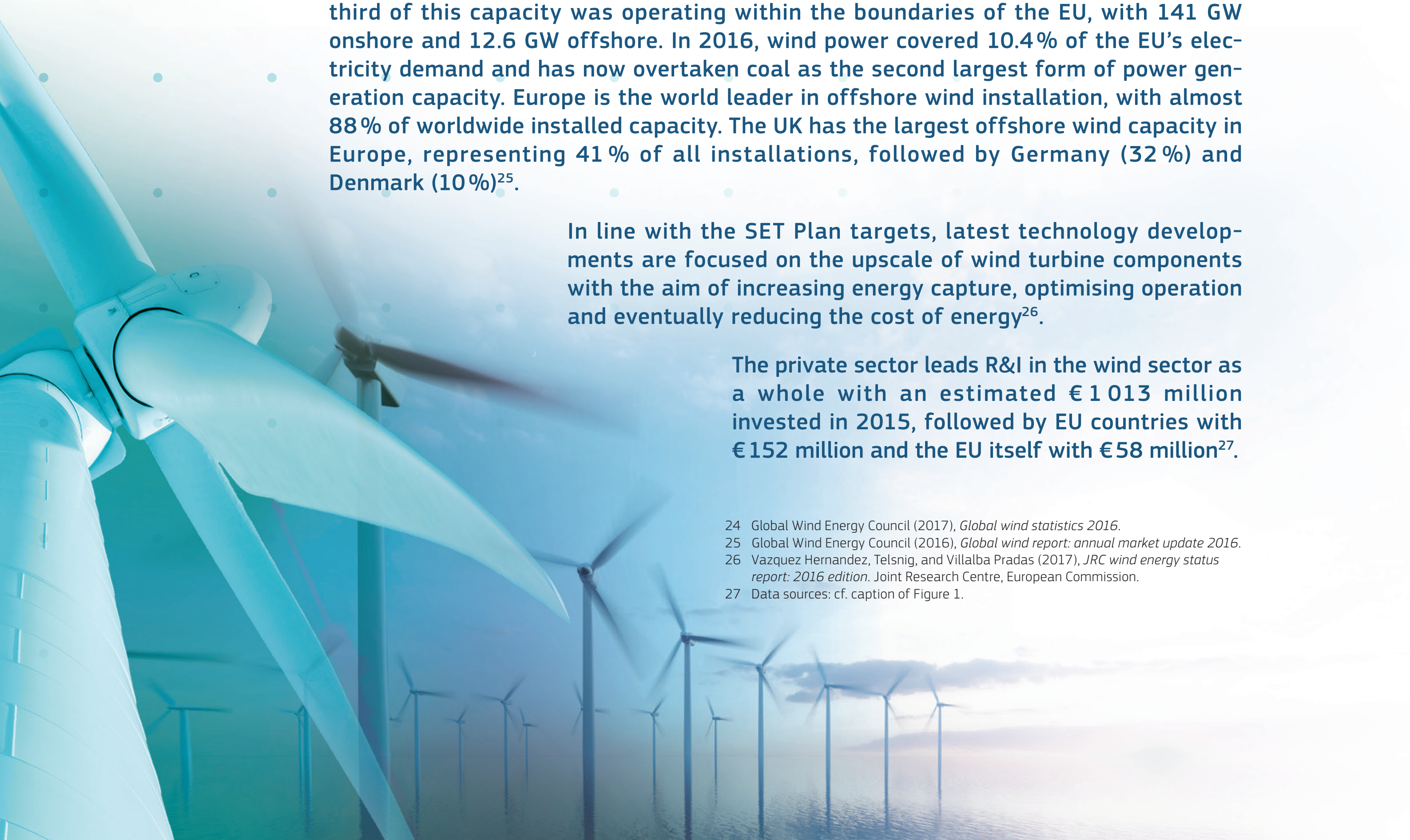
Figure 6: Aerial view of Plataforma Solar de Almería, in Spain.
© CIEMAT-PSA

Offshore wind energy

At the end of 2016, global cumulative installed wind power capacity reached approximately 486 GW, over four times the capacity installed in 2007[24]. Approximately one third of this capacity was operating within the boundaries of the EU, with 141 GW onshore and 12.6 GW offshore. In 2016, wind power covered 10.4 % of the EU's electricity demand and has now overtaken coal as the second largest form of power generation capacity. Europe is the world leader in offshore wind installation, with almost 88 % of worldwide installed capacity. The UK has the largest offshore wind capacity in Europe, representing 41 % of all installations, followed by Germany (32 %) and Denmark (10 %)[25].

In line with the SET Plan targets, latest technology developments are focused on the upscale of wind turbine components with the aim of increasing energy capture, optimising operation and eventually reducing the cost of energy[26].

The private sector leads R&I in the wind sector as a whole with an estimated € 1 013 million invested in 2015, followed by EU countries with € 152 million and the EU itself with € 58 million[27].



24 Global Wind Energy Council (2017), *Global wind statistics 2016*.
25 Global Wind Energy Council (2016), *Global wind report: annual market update 2016*.
26 Vazquez Hernandez, Telsnig, and Villalba Pradas (2017), *JRC wind energy status report: 2016 edition*. Joint Research Centre, European Commission.
27 Data sources: cf. caption of Figure 1.

MORE POWERFUL WIND TURBINES

Technological advances in wind turbine components in the last 10 years have made wind power more efficient and affordable than ever before. The installation of larger turbines (Figure 7) results in fewer foundations per MW, bringing installation costs down as a result[28]. Research continues to push the boundaries of scale in the development of blades.

Energy capture is rising thanks to the use of longer blades and the resultant increase in swept rotor area. From 2007 to 2016, the average rotor diameter of blades grew from 98 m to 164 m, an increase of 68 %; over the same period, the swept rotor area increased 2.8 times[29].

On drive train configuration, the offshore wind market has evolved from the 'leading configuration' (a geared high-speed doubly fed induction generator) towards both direct drive and hybrid arrangements[30].

The rated capacity of offshore wind turbines has grown 20 % over the past decade (2006-2015)[31]. The average rated capacity of turbines installed in 2016 was 4.8 MW, 15.4 % larger than 2015. Offshore wind turbines of 8 MW were recently installed for the first time, reflecting the rapid pace of technological development[32]. In addition, a 9.5 MW wind energy converter was launched[33].

28 International Energy Agency (2017), *Renewables 2017 market report*.
29 JRC wind energy database.
30 Hybrid arrangements refer to geared turbines with synchronous generator and full power converter.
31 Vazquez Hernandez, Telsnig, and Villalba Pradas (2017), *JRC wind energy status report: 2016 edition*. Joint Research Centre, European Commission.
32 WindEurope (2017), *The European offshore wind industry: key trends and statistics 2016*.
33 http://www.mhivestasoffshore.com/#/Our-Story/2017

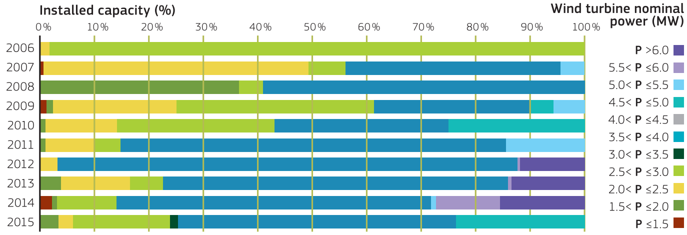


Figure 7: Change in nominal power of offshore wind turbines in the world.
Source: JRC wind energy database.

SIGNIFICANT COST REDUCTIONS

Cost reductions are driven by increasing economies of scale, more competitive supply chains and a variety of technology improvements – the latter also leading to higher capacity factors. These developments make wind energy highly competitive in medium and low-wind speed sites, expanding opportunities in new markets. Today, turbine supply accounts for about 33-40 % of total project costs, followed by installation costs (20-25 %) and foundation supply (15-18 %). Transmission expenditure outside the plant's boundary, which usually includes offshore and onshore transformers, export cable(s) and onshore connection, is estimated to represent 10-20 % of total investment costs[34]. Costs were expected to gradually decrease towards a target of €100/MWh by 2020[35], but in 2017 a dramatic development took place thanks to reverse auctions (Figure 8). Leading energy companies won three projects in such auctions in Germany by placing bids of zero euro per MWh, meaning they will not receive any subsidy on top of the wholesale electricity price. The projects are planned to be commissioned in 2024 and 2025, although the final investment decision is pending in 2021. One of the cost drivers enabling these zero subsidy bids is the expectation of significantly bigger turbines by 2024.

34 International Energy Agency (2017), *Renewables 2017 market report*.
35 Global Wind Energy Council (2017), *Global wind statistics 2016*.

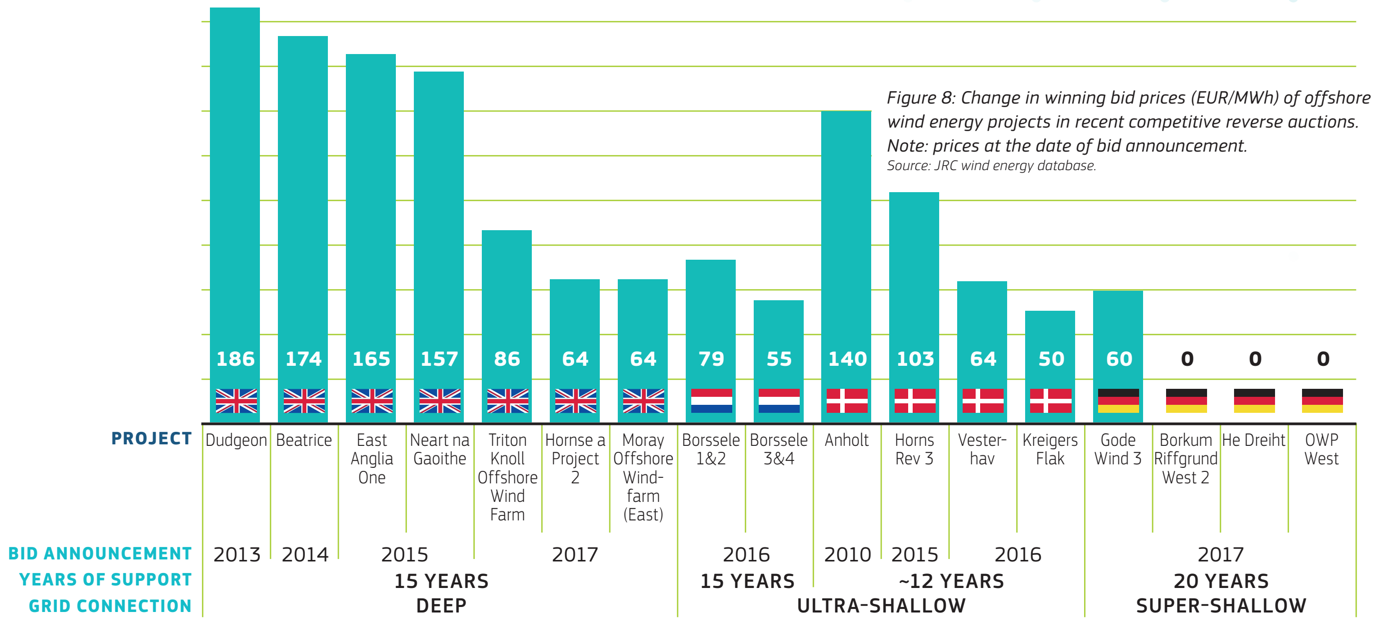


Figure 8: Change in winning bid prices (EUR/MWh) of offshore wind energy projects in recent competitive reverse auctions. Note: prices at the date of bid announcement.
Source: JRC wind energy database.

INNWIND.EU: INNOVATIVE WIND CONVERSIONS SYSTEMS (10-20 MW) FOR OFFSHORE APPLICATIONS

INNWIND.EU (Innovative wind conversion systems for off-shore applications) is a EU-funded project led by the Technical University of Denmark focusing on the design of large-scale 10-20 MW wind turbines. It follows the previous project UPWIND (2006-2011) that developed turbines of up to 10 MW. Both projects have had a major impact on the offshore wind industry, generating the knowledge to design large wind turbines and paving the way for the 10-MW ones. INNWIND.EU is also designing other concepts for large-scale harvesting of wind.

ERA-NET DEMOWIND: SUPPORTING STRONG COLLABORATION BETWEEN MEMBER STATES

DemoWind is a project that enables industry to form partnerships to push technologies to higher technology readiness levels[36] (from 5-6 to 6-7) in transnationally funded projects. The aim is to connect existing and new European offshore wind demonstration opportunities, exchange knowledge and help cost-reducing innovative technologies to reach the market faster – in line with the SET Plan targets. This in turn supports the economic development of the European offshore wind sector and helps it maintain its internationally leading position. Belgium, Denmark, the Netherlands, Portugal, Spain, and the UK have pooled national resources of up to €21.2 million, matched with €10.4 million from the EU.

36 For more on this concept, see https://en.wikipedia.org/wiki/Technology_readiness_level

Ocean energy

The EU is at the forefront of ocean energy technology development, being home to approximately half of the world's tidal energy developers and 60% of wave energy developers. Over the last decade, more than 20 MW of tidal stream and wave devices have been tested on different scales in European waters[37]. By 2050, installed capacity in the EU could grow to 100 GW, feeding around 350 TWh of power to the grid[38]. This is the equivalent of bringing electricity to 230 million people – almost half of EU households – or replacing 90 average coal power plants, i.e. as much as a third of Europe's coal fleet[39]. For this to happen, the SET Plan aims to demonstrate deployment of ocean energy at commercial scale in order to kick-start market deployment and drive down costs. Consolidation of the supply chain is also considered critical in this regard.

As with other sectors, most R&I investment originates from the private sector, with an estimated € 171 million going into ocean energy in 2015. Public funding amounted to € 58 million at national level and to € 70 million at EU level[40].

37 Magagna, Monfardini and Uihlein (2017), *JRC ocean energy status report: 2016 edition*. Joint Research Centre, European Commission.
38 Ocean Energy Forum (2016), *Ocean energy strategic roadmap 2016: building ocean energy for Europe*.
39 Ocean Energy Europe (2017), *Ocean energy project spotlight* (March 2017).
40 Data sources: cf. caption of Figure 1.

Figure 9: Installation of the 1.5 MW AR1500 Atlantis tidal turbine on the MeyGen project.
© Atlantis Resources Ltd

TIDAL TECHNOLOGIES AT THE PRE-COMMERCIAL STAGE

By the end of 2016, 21 tidal turbines of over 100 kW totalling 13 MW were deployed in European waters. Three tidal energy farms were deployed in 2016: in France (Paimpol-Bréhat) and in Scotland (Shetlands and Pentland Firth – Figure 9). The Scottish tidal farm is the biggest tidal stream energy farm to date. Tidal energy has reached a high level of technological maturity, as borne out by the increasing number of deployment projects. As the technology becomes more mature, we are seeing convergence towards certain types of technology solutions, with horizontal axis turbines being used by three quarters of the companies currently developing full-scale tidal devices. Today, horizontal axis turbines have reached a technology readiness level of 8, meaning that the technology has been completed and qualified through test and demonstration. For example, an innovative 2 MW floating device with two tidal turbines is operational in the island of Orkney, where it was able to generate nearly 7 % of its electricity demand in September 2017[41].

41 http://tidalenergytoday.com/2017/09/13/orkney-isles-light-up-with-scotrenewables-tidal-power.

PROGRESS TOWARDS COMMERCIALISATION IN WAVE ENERGY SOLUTIONS

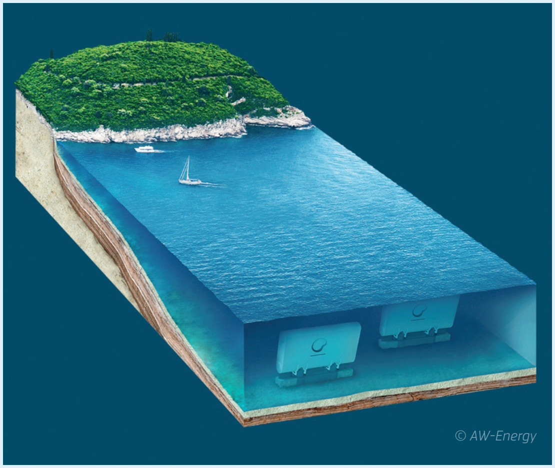
Although wave energy is at an advanced phase of technological development, it still lies a few years behind tidal stream energy. The diverse nature of wave resources in deep and shallow waters and the complexity involved in harvesting energy from waves have meant that there has always been a wide range of technology solutions under development. Only a handful of devices had their system qualified through test and demonstration and even in these cases improvements are needed to make them commercially viable. From a technological point of view, the most advanced device types are 'oscillating water columns' and 'point absorbers.'

Over the past years, 13 wave energy devices (totalling 5 MW) were deployed at sea, of which more than 76 % was installed in the last three years alone. Even if most of these devices are experimental or are down-scaled versions of the final concept, six further projects totalling 17 MW are under construction and another 15 MW of wave energy capacity have already been permitted.

WAVEROLLER: WAVE ENERGY TECHNOLOGY NEARLY AT THE COMMERCIAL STAGE IN EUROPE

The WaveRoller, a commercial-scale demonstrator under construction near Peniche (Portugal), is based on a 1993 invention by a professional diver (Figure 10). It took a decade for a Finnish company (set up by the inventor with support from the Finnish Technology Fund) to perform thorough tests and get the device to the prototype stage. In 2012, the European Commission co-funded prototype demonstrators of this technology in an operational environment as part of the SURGE project. Using the experience of the research project, the company decided to go ahead with a demonstration on a higher scale. WaveRoller is running a first-of-its-kind 350 kW wave energy demonstration project, thanks to the first loan provided by the InnovFin Energy Demonstration Projects facility (€ 10 million put towards project costs of € 19 million). If the demonstration project proves successful, the global market potential for the technology is high.

Figure 10: Production of a WaveRoller blade for a 350kW demonstrator.
© AW-Energy



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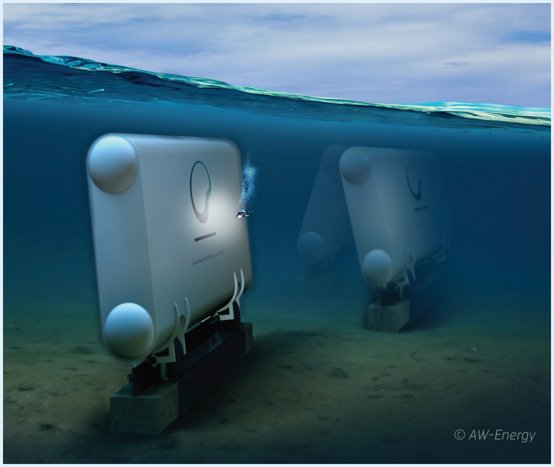

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Geothermal energy

Geothermal energy is a reliable, flexible and indigenous energy source with a low levelised cost and high capacity factor. This makes it an attractive option for the EU's energy mix in terms of energy security and better grid management.

In 2015, geothermal energy represented 3.1 % of the EU's total primary renewable energy production[42]. The installed capacity in the EU is divided into: 16 GW in ground source heat pumps; around 3.8 GW in direct use[43]; and 1 GW in geothermal power plants[44]. Geothermal resources are currently being exploited to only a limited degree, especially considering the enormous technical potential, estimated at about 2 600 TWh by 2050[45].

However, there are signs that this is changing. Geothermal energy is increasingly exploited for heating and cooling applications: between 2012 and 2016, 51 new geothermal district heating plants entered into operation in the EU, increasing the total number to 190 plants (including co-generation systems). Over 200 projects are planned and capacity is estimated to grow by up to 6.5 GW by the end of this decade, with the main markets being France, the Netherlands, Germany and Hungary[46]. It is also estimated that more than 3 GW of geothermal energy are potentially available in abandoned coal or other mines and could be used in applications such as district heating in Europe[47]. As for power production, the future role of geothermal energy will depend on the roll-out of enhanced geothermal systems (EGS). If EGS are successfully developed and deployed, as advocated by the SET Plan targets, the EU could reach a total installed capacity of 80 GW by 2050.

42 Eurostat (2017), *Supply, transformation and consumption of renewable energies*.
43 Statistics on direct heat systems are difficult to obtain and often not reliable.
44 Joint Research Centre (2016), *Technology market report: geothermal energy*; and Joint Research Centre (2016), *Technology development report: geothermal energy*.
45 *Ididem*.
46 International Energy Agency (2017), *Renewables 2017: analysis and forecasts to 2022*.
47 Díez and Díaz-Aguado (2014), *Estimating limits for the geothermal energy potential of abandoned underground coal mines: a simple methodology. Energies* 7(7), pp. 4241-4260.

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LOWER RISKS AND COSTS IN THE EXPLOITATION OF GEOTHERMAL RESERVOIRS

The riskiest part of geothermal exploration is reliably assessing the targeted reservoirs and achieving an acceptable level of confidence about the conditions in them. The problem is that the deeper a well goes, the higher the uncertainty over those conditions (see on the right for the associated benefit of drilling deeper). There has recently been some very promising R&I tackling this issue, which will increase the success rate of future projects. This is crucial to reduce costs and create the conditions for wider deployment of geothermal power in Europe in different geological conditions. Of particular note in this context is the IMAGE project. The methods it explored include geophysical techniques (e.g. seismic measurements), fibre-optics installed in wells (to assess subsurface structure, temperature and physical rock properties), and new tracers and geothermometers. The project has received over €10 million from the EU.

EU DEEPEGS PROJECT REACHES A MILESTONE BY DRILLING TO A DEPTH OF 4659 METERS

DEEPEGS aims to demonstrate the feasibility of EGS technologies in deep wells and different geological conditions. This will facilitate widespread deployment of EGS in Europe. The project focuses also on volcanic environments such as those found in Iceland, where the drilling process led to a well reaching a depth of 4659 meters in the Reykjanes peninsula (the deepest casing in the country) – see also Figure 11. Drilling so deep and in temperatures as high as 427 °C is extremely challenging and conventional techniques cannot be applied. DEEPEGS managed to tackle all challenges and reach what is now considered a milestone in the geothermal energy sector. Deep wells such as the one developed by the project can produce more energy than conventional ones. If successfully replicated, more geothermal plants could be deployed across Europe in different geological conditions. The project has received almost €20 million from Horizon 2020.

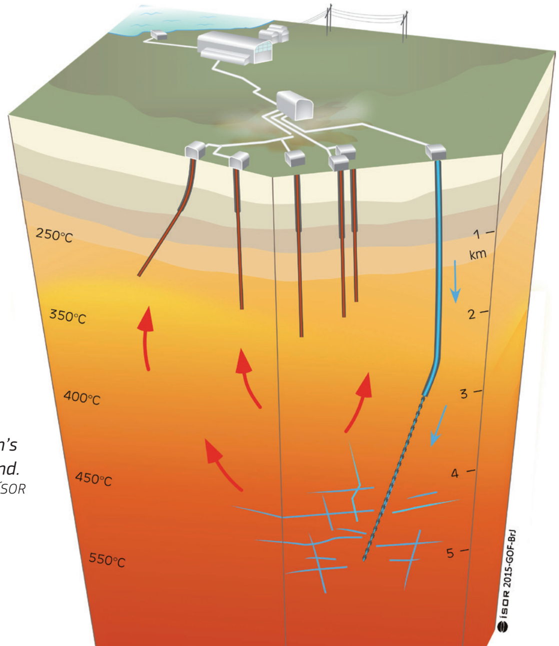


Figure 11: The DEEPEGS project drilled 4.6 km below the earth's surface into the heart of a volcano in the Reykjanes peninsula, Iceland.

© DEEPEGS/ÍSOR

Delivering a smart consumer-centric energy system

One of the aims of the Energy Union is to increase the number of citizens as active players in a decentralised and digitalised energy system – with a direct role in a cleaner energy production and adjusting their consumption patterns to market signals. Buildings, districts and cities will also need to become smarter to reach 'zero energy' levels. The overall goal is to have a more flexible and highly-efficient energy system that incorporates storage capabilities, is better integrated with local heating and cooling networks and that puts consumers at the centre. These challenges call for innovative R&I solutions as the SET Plan sets out to achieve.

Energy consumers

In addition to making progress on specific clean energy technologies, a major R&I challenge lies in designing innovative services, business models and ways of engaging consumers in the energy system. Interoperable information and communication technologies (ICT) will play the most important role in meeting this challenge. This is because our energy system is undergoing an important transformation, both with the deployment of smart meters and controls, and with the emergence of smart appliances and their inclusion in home networks. Smart technologies and services allow energy consumers to benefit from a more comfortable, more convenient and healthier living environment, while also consuming less energy and paving the way for their role as 'prosumers'[48].

For this reason, both the 'Clean Energy for All Europeans' legislation package and the SET Plan place consumers at the centre. The SET Plan includes targets to speed up the penetration of smart energy services and applications. The aim is for at least 80 % of electricity consumption and at least 80 % of energy consumption to be controllable through ICT in 80 % of European homes by 2030. Cooperation with the industry and research institutes is needed to perform the R&I that will deliver these targets.

In 2015, the private sector clearly led R&I investment in the sector, with nearly €2.4 billion. Public funding at national level was much lower, at €98 million. EU support via Horizon 2020 was granted to 42 projects (a contribution of €260 million to the €318 million in overall project costs[49]).

48 Active energy consumers are often called 'prosumers' because they both consume and produce electricity.
49 Data sources: cf. caption of Figure 1.

INNOVATION ECOSYSTEM FOR SMART CONSUMER TECHNOLOGIES AND SERVICES

The EU is leading a world-class industrial research effort that embraces digitalisation, including robotics, the Internet of Things and smart connected objects[50]. However, it needs to step up its efforts to turn technologies into innovative services that create new markets. Europe has also spearheaded the creation of an interoperable language called SAREF (Smart Appliances REFerence ontology), which became a standard for the European Telecommunications Standards Institute and OneM2M (the Global initiative for Internet of Things standardisation) in 2015[51]. SAREF enables smart home appliances to communicate with any management system as part of the demand-response mechanism of smart grids.

Significant progress is expected from the revision of both the Directive and Regulation on the electricity market. They will enhance the market for demand response and innovative energy services, and provide incentives for consumers to contribute to an efficient operation of the electricity system. Furthermore, the revision of the Energy Performance of Buildings Directive will: (a) introduce building automation and control systems as an alternative to physical inspections; (b) deploy smart readiness indicators for buildings to enhance their energy efficiency and other performance characteristics – namely by assessing their ability to interact with occupants and the grid; and (c) use building codes to support the roll-out of recharging infrastructure for e-mobility.

50 Such as the FIWARE platform on cyber-physical systems.
51 SAREF was demonstrated in commercial products (such as washing machines, tumble dryers, PV systems, etc.) at the 'Internationale Funkausstellung Berlin' in 2016. A second version of the standard has since emerged.

SIGNIFICANT COST REDUCTIONS IN SENSORS

Smart homes depend on robust and advanced energy-related sensors and controllers that can be easily integrated into energy management systems using widespread, upgradable software and application programming interfaces (e.g. plug-and-play, self-configuring, maintenance-free and easy to reuse). Over recent decades, sensor technology has become significantly cheaper and improved considerably, to the point that it is now ready for use in smart appliances. Additional work is nonetheless needed for sensors and controllers to be more easily installed and maintained, and to reduce the payback period for consumers. Europe is also maintaining its global strength in chip research, but manufacturing needs support. As such, the joint undertaking 'Electronic Components and Systems for European Leadership' focuses on reducing the cost of chips and linking research with new applications. Further consumer engagement and the guarantee that new services will benefit them are equally important. In this context, the SET Plan has set a target to measure consumer benefits and the success of tools and appliances available on the market.

ECOGRID-EU AND POWERMATCHING CITY: ACTIVE CONSUMER PARTICIPATION IN THE ENERGY MARKET

ECOGRID-EU is a large-scale demonstration project promoting consumer engagement on the island of Bornholm, Denmark. The project has demonstrated the potential of providing access for thousands of small-scale participants to a competitive marketplace where, by responding to real-time price signals, they can procure and sell energy services and optimise the electricity produced from nearby wind parks.

PowerMatching City – a smart grid pilot project in Groningen, the Netherlands – has enabled 40 participants to become energy prosumers. A number of stakeholders have worked together to balance the demand and supply of energy to the grid, combining energy flexibility from individual homes. The lessons learned have been implemented in the Universal Smart Energy Framework, an example of best practice for the design of a market coordination mechanism for demand-side flexibility.

© ECOGRID-EU, Bornholm, Denmark

NOVICE: DESIGNING BUSINESS MODELS TO REDUCE THE PAYBACK TIME OF ENERGY EFFICIENCY MEASURES

In the NOVICE project stakeholders have come together to create an innovative business model that can provide a faster payback on energy efficiency investments. They include energy service companies to implement energy upgrade renovations; aggregators to help bring demand response to the grid; energy investment funders; and building operators and owners. This model combines revenue streams from energy savings and grid services alike.

Smart cities and communities

Cities and their surrounding areas consume around 80% of the world's energy production and account for roughly the same proportion of global GHG emissions, stemming increasingly from the energy services required for lighting, heating and cooling[52].

The smart cities and communities focal area of the SET Plan addresses the decarbonisation of the city energy system as a whole and more specifically through promoting positive energy blocks and districts. This is in line with Horizon 2020, which has provided smart cities and communities' lighthouse projects with approximately €500 million in funding for 2014-2020; some of these projects will unlock up to 20 times more in investment[53].

The 'smart city' concept is also at the core of a rather new and important global growth market – estimated to be worth up to €1.3 trillion in 2020[54]. It offers great export possibilities for European business, specifically in providing cutting edge solutions that significantly increase cities' overall energy and resource efficiency.

52 The International Bank for Reconstruction and Development/ The World Bank (2010), *Cities and climate change: an urgent agenda.*
53 http://www.sharingcities.eu/
54 https://ww2.frost.com/news/press-releases/frost-sullivan-global-smart-cities-market-reach-us156-trillion-2020

ADVANCES IN SYSTEMS INTEGRATION AT CITY LEVEL

Over recent decades many 'smart city'-related projects have successfully demonstrated solutions to specific, isolated technical challenges. These solutions are all essential, but can only achieve their full potential if allied with the smart integration of renewable energies, demand response, energy efficiency, heating and cooling, and mobility. Tackling all these sectors simultaneously requires new and highly complex systems thinking.

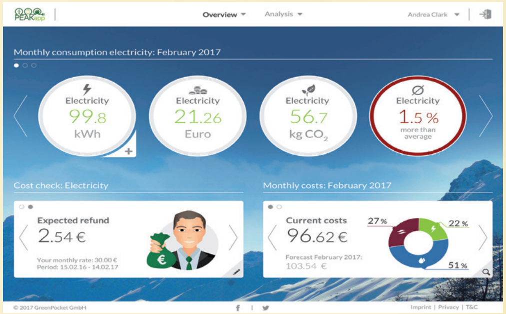
The European Commission has been strongly supporting this systems integration approach at city level since 2004, starting with FP6 R&I funding of the CONCERTO projects.

Figure 12: Smart city lighthouse projects funded by Horizon 2020.
© Google Maps image: 2017 Landsat/Copernicus, Data SIO, NOAA, US Navy, NGA, GEBCO. Project data: European Commission

These drew on renewable energy sources in paving the way for low-energy buildings and relevant infrastructures; they also provided a solid data monitoring base to better understand system performance. A good example for FP7 is the CITY-zen project, which achieved a CO_2 reduction of 59 000 tonnes/year with its people-friendly solutions, including fully functional smartgrid development, electricity storage demonstrators, innovative cooling schemes and higher district heating efficiency. The Smart City lighthouse projects (Figure 12) under Horizon 2020 followed.

The Energy Performance of Buildings Directive stipulates that from 2020 all new buildings will have to be nearly zero-energy in nature. This is a great step in the right direction, but to reach the Paris Agreement targets we will have to aim even higher. The next step will be to further exploit synergies between buildings and to increase their integration in the energy system to achieve zero-energy and emission districts and cities.

Going a step further, the SET Plain aims to roll-out positive energy blocks/districts (having a positive impact on the energy system). They consist of buildings that actively manage the energy flow between them and the broader energy (electricity, heating and cooling) and mobility systems by making optimal use of advanced materials, local renewables, storage, demand response, electric vehicle smart-charging and ICT.



ERA-NET 'SMART CITIES AND COMMUNITIES'

Smart cities and communities have been identified as pivotal to achieving the energy efficiency targets for 2020 and 2050. This ERA-NET seeks a technological shift in the current energy system and provides smart and integrated solutions for technology, government and society. Putting forward smart cities measures requires vast and pooled investment volumes. In line with the European Commission's new 'smart specialisation' strategy, the proposed ERA-NET activities should encourage Member States, regions and their managing authorities to align their national R&I funding schemes with the Structural Funds. In a similar vein, 'Global Urban Challenges – Joint European Solutions' seeks to develop a European R&I hub on urban matters and create European solutions through coordinated research.

EUROPEAN INNOVATION PARTNERSHIP ON SMART CITIES AND COMMUNITIES

The European Innovation Partnership on Smart Cities and Communities brings together more than 5000 stakeholders. It promotes the take-up of successful solutions – including those developed in EU-funded smart city projects – and continues to support market creation for integrated smart city solutions.

Energy systems

The energy sector – and the electricity sector in particular – has dramatically evolved since the turn of the century. In its 2020 and 2030 climate-energy packages the EU has committed itself to lower GHG emissions and to higher shares of renewables and interconnection levels. These goals are being achieved (e.g. almost 30 % share of renewable electricity in gross electricity consumption in 2015, up from 16 % in 2007[55]) and continued growth is expected. Particularly the increased production from intermittent sources such as wind and PV (12.6 % of net electricity generation[56]) poses difficulties for grid management and highlights the need for flexibility. This encompasses storage, demand response and sector coupling, such as power-to-heat and power-to-electric vehicles.

The SET Plan has recently set forward-looking targets to address these challenges and it now attempts to identify actions that will deliver on them. The current European Commission reference scenario[57] projects a renewables generation share of 43 % in the power sector by 2030, with a quarter coming from variable renewables. Clearly, the future energy transition will be based mainly on dispersed sustainable electricity generation and distributed load controls.

55 Eurostat (2017), *Electricity generated from renewable sources.*
56 Eurostat (2017), *Electricity production and supply statistics.*
57 European Commission (2016), *EU reference scenario 2016: energy, transport and GHG emissions – trends to 2050.*

FROM SMART GRIDS TO INTEGRATED ENERGY SYSTEMS

Initially, EU research efforts focused on smartening the grid. They looked at introducing smart metering and innovative architectures for active distribution networks, capable of balancing power generation and demand in real time. Other important research areas tackled better grid monitoring and network observability for optimum maintenance, as well as efforts for more integration of renewables into future infrastructures.

This smartening of the grid led to the development of standards and protocols to improve the interoperability of innovative smart devices. R&I is now needed on the best way of handling massive amounts of data while striking the right balance between privacy and security, and coping with the need to exchange data to improve real-time grid operation.

Energy storage assets are currently being tested in all parts of the energy network, from households to distribution and transmission networks. The integration of electrical vehicles also presents both a challenge and an opportunity for the energy system. It combines high levels of power consumption for short charging periods with opportunities to use vehicle batteries when they are idle (typically more than 90 % of the time).

Demand-response schemes, featuring new players such as aggregators and energy communities, are also being trialled in a number of places across Europe. And several sector coupling tests are underway, e.g. involving power-to-heat.

These demonstration projects, clustered under the BRIDGE initiative, are now delivering their first results. While in many instances the technological demonstration is commendable, the key for successful innovation depends on the capacity to

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solve technological problems; to adapt the regulatory environment; to develop business cases and models; and, of course, to engage stakeholders, starting with consumers.

ERA-NET ‘SMART GRIDS PLUS’: LEVERAGING NATIONAL RESEARCH PROGRAMMES

The ERA-Net ‘Smart Grids Plus’ brings together owners and managers of national and regional funding programmes in research, technical development and demonstration from 21 EU Member States and regions. The aim is to build a sustainable cooperation structure between national and regional smart grids programmes so that relevant initiatives can work together on a European level. € 13 million in EU funding tops up more than € 26 million in national funding, creating a sizeable leveraging effect.


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Develop and strengthen energy-efficient systems

Increased deployment of energy efficiency solutions in Europe's buildings and industry is a means to reduce carbon emissions while making the EU more competitive and boosting its exports. There is a need to encourage results-oriented research to find innovative answers to a number of challenges that affect both individual buildings and entire sectors of industry. These include accelerating the refurbishment rates of buildings, incentivising and empowering industry to adopt better performing technologies and processes, and ultimately creating new business opportunities, jobs and growth. The SET Plan sets out to focus R&I efforts on achieving these goals.

Energy efficiency in buildings

The overall EU building renovation market is worth about € 500 billion per year, higher than that of new builds which are valued at about € 400 billion a year[58]. The construction sector and its extended value chain (including equipment manufacturers) accounts for 9.6 % of the EU GDP and employs 14.6 million people directly and 43.8 million indirectly[59].

The EU built environment's significant economic clout is matched by its impact on Europeans' quality of life: as much as 40 % of the EU's energy is consumed in buildings[60], which also emit 36 % of the EU's GHGs. This high figure is being compensated by an increasingly energy efficiency household sector (one third improvement between 1990 and 2014), in great part thanks to more efficient new and renovated buildings resulting from the obligations under the Energy Performance of Buildings and the Energy Efficiency Directives. The SET Plan seeks to stimulate technology development to help bring down energy consumption in buildings even further.

Drie Hofsteden IV-V-VI_Kortrijk
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58 European Commission (2016), *Commission staff working document: impact assessment accompanying the document 'Proposal for a Directive of the European Parliament and of the Council amending Directive 2010/31/EU on the energy performance of buildings,'* [SWD(2016) 414].
59 European Commission (2013), *Energy-efficient buildings: multi-annual roadmap for the contractual PPP under Horizon 2020.*
60 European Construction Technology Platform (2017), *EeB PPP project review 2017.*

Venning Kortrijk – The ECO Life project used innovative low-energy architectural approaches in renovating and building social housing in Kortrijk (Belgium).
© B2Ai – Gerald Van Rafelghem.

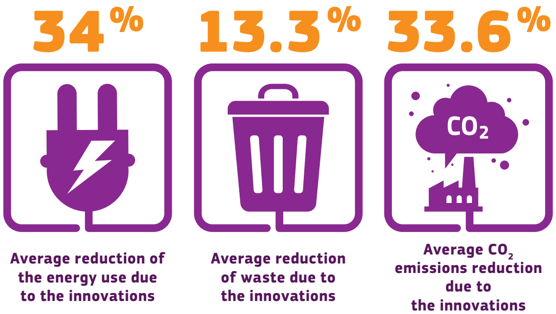


Figure 13 : Operational results from the 155 EU-funded R&I demonstration projects.
Source: European Construction Technology Platform (2017), EeB PPP project review 2017.

DEVELOPMENT OF NEW MATERIALS AND TECHNOLOGIES FOR BUILDINGS

Over the last decade, 155 demonstration projects representing a total investment of € 1.1 billion have been launched as part of the EU's R&I programmes to implement innovative solutions for better energy efficiency in buildings[61]. Succinct results are presented in Figure 13.

61 European Construction Technology Platform (2017), *EeB PPP project review 2017.*

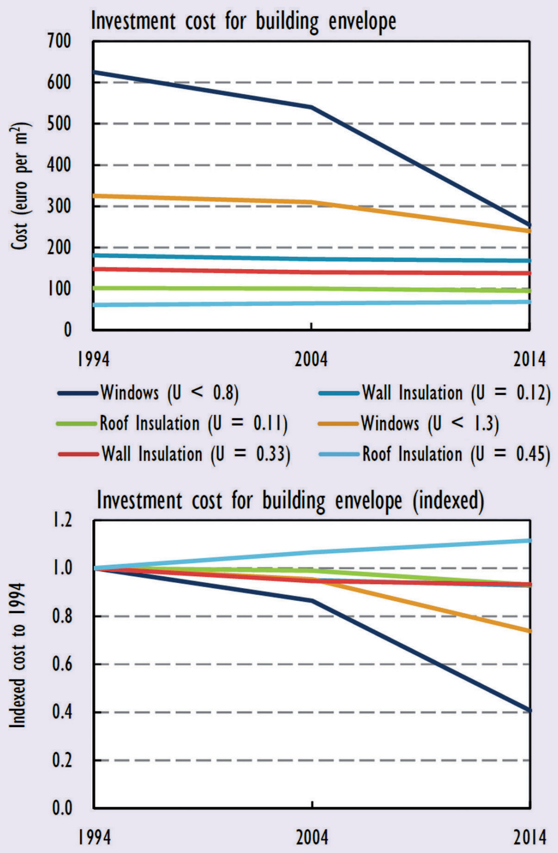


Figure 14: Cost of building envelope measures in Germany, 1994-2014.
Source: International Energy Agency (2015), Energy efficiency market report 2015.

DECREASING BUILDING ENVELOPE COST AND ENERGY CONSUMPTION IN RESIDENTIAL BUILDINGS

The adoption of the Energy Performance of Buildings Directive in 2010 has spurred a number of technological innovations, leading in turn to sizeable benefits. Average final energy consumption in the residential sector fell by 2.1 kWh/(m^2 year) up to 2006, and by 3.8 kWh/(m^2 year) from 2007 to 2013. Consumption appears to have stabilised since then[62]. This can be partially explained by a gradual decline in building envelope costs, with the cost of windows falling most dramatically (as depicted in Figure 14 for Germany).

In general, advanced materials and innovative technologies (including nanotechnologies) have been developed over the last few years. They are swiftly reaching the commercial deployment phase and contributing to continuous cost reductions. Examples include the development of super-insulating materials and components; the improved technical properties of organic materials; advanced, low-CO_2 cement-based technologies; modular, mass customised envelope solutions; and full-scale demonstrations of adaptable envelope integrations.

MORE EFFICIENT HEATING AND COOLING SOLUTIONS

Heating and cooling technologies have their own important role to play in a building's overall energy efficiency. For instance, geothermal heat pumps and solar technologies are becoming cheaper and more efficient (Figure 15). Heat pumps now combine high energy conversion with the capability of utilising aerothermal, geothermal or hydrothermal heat at useful temperature levels, depending on the local climate and weather conditions.

62 Sebi and Lapillonne (2017), *Energy efficiency trends of final consumers in the EU*. Odyssee-Mure project.

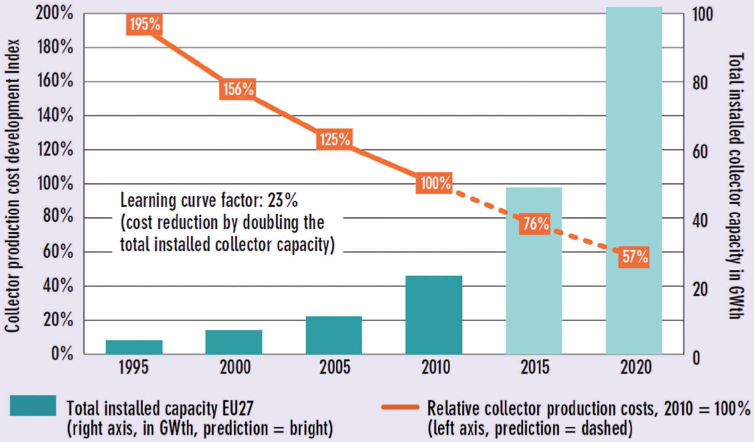


Figure 15: Production costs for a high-efficiency flat-plate solar thermal collector panel with a gross collector area of about 2.2 to 2.5 m², manufactured in Europe[63].
Source: European Technology Platform on Renewable Heating and Cooling (2012), Strategic research priorities for solar thermal technology.

CELSIUS PROJECT: DEMONSTRATING MODERN HEATING AND COOLING SYSTEMS IN FIVE CITIES

An intelligent district heating and cooling system approach has been adopted in the CELSIUS project, which demonstrates ten applications in five cities: Cologne, Genoa, London, Gothenburg and Rotterdam. These include the use of washing machines and electricity savings. Noteworthy, the district heating network has been connected to a ship in a harbour for the first time, thereby avoiding burning bunker oil and the associated emissions and noise.

LOW-ENERGY CONSUMPTION BUILDINGS DEMONSTRATED THROUGH THE NEED4B PROJECT

The 'New Energy Efficient Demonstration for Buildings' (NEED4B) project has set out to demonstrate highly energy-efficient and cost-effective technologies and measures in the building sector on five sites (in Spain, Italy, Germany, Sweden and Turkey). These would result in very low-energy newly constructed buildings and aim for a larger market take-up thanks to an easily replicable design, construction and operation methodology. The project is considered best practice in implementing the Energy Performance of Buildings Directive, which states that all new buildings must be nearly zero-energy by the end of 2020. Actual (primary) energy consumption achieved by NEED4B was lower than 60 kWh/(m² year), or about half of the figure for current regular practice and regulation requirements.

63 Based on a learning factor of 23% derived from historical data, cost reduction projections are calculated up to 2020 based on market expectations of the National Renewable Energy Action Plans.

Energy efficiency in industry

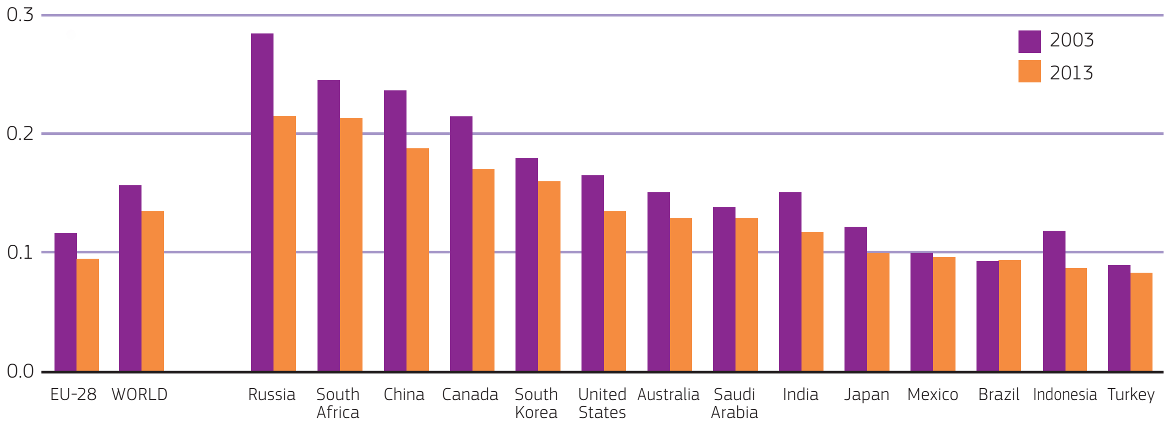
The industrial sector in the EU has significantly improved its energy efficiency: final energy consumption in industry decreased by 17 % between 2003 and 2013[64], with CO_2 emissions falling by almost a quarter over the same period[65]. Globally, the EU outperforms its peers on energy intensity (Figure 16).

Energy efficiency, low GHG emissions and competitiveness go hand-in-hand with resource efficiency, industrial symbiosis and the circular economy. Energy efficiency is particularly important for energy-intensive industries, as they are subject to the EU Emissions Trading System Directive. The overall number of free allowances is currently set to decline at an annual rate of 1.74 % from 2013 to 2020. The Commission has proposed[66] increasing the rate of reductions to 2.2 % from 2021 onwards, so the EU can meet its Paris Agreement commitments and reduce CO_2 emissions by 40 % by 2030.

A systems approach is needed to derive maximum benefit from all aspects of industrial sustainability. This is the scope and aim of the implementation plan on 'energy efficiency in industry' which was endorsed in September 2017 (cf. details in chapter 3).

64 European Environment Agency (2017), *Final energy consumption by sector and fuel*.
65 European Commission (2016), *EU energy in figures 2016*.
66 https://ec.europa.eu/clima/policies/ets/revision_en.

Figure 16: Energy intensity country comparison (2003-2013).
Note: energy intensity is the ratio between the gross inland consumption of energy and the gross domestic product (GDP).
The GDP figures are at 2011 constant prices expressed in United States dollars converted using international power parities. Data not available for Argentina.
Source: Eurostat, International Energy Agency and the World Bank (2017), International Comparison Program database.



ADVANCES IN RESOURCE AND ENERGY EFFICIENCY – PUBLIC-PRIVATE PARTNERSHIP

SPIRE is a contractual public-private partnership covering sustainable process industry through resource and energy efficiency. The partnership created an alliance between the European Commission and eight European industry sectors (cement, ceramics, chemicals, engineering, minerals and ore, non-ferrous metals, steel and water). They are at the core of most industrial value chains, but also face challenges due to their high dependence on resources (energy, materials and water).

The technologies developed by SPIRE should lead to a 30 % decrease in fossil energy intensity and a 20 % decrease in the use of non-renewable resources; achieving these targets will in turn bring CO_2-equivalent footprints down by 40 %.

To make all this happen, European R&I funding of € 900 million has been set aside for the period 2014-2020, with an expected investment leverage factor of up to five. The first projects started in 2014 and 75 have been launched so far. Altogether, these 75 initial projects should develop 173 new technologies or systems and reduce their time-to-market by 24 months on average.

NIWE PROJECT: REDUCING ENERGY CONSUMPTION AND EMISSIONS THROUGH WIRELESS POWER TRANSFER

The EU-supported NIWE project has demonstrated a new production process that can cut the embodied energy of aluminium, iron and steel foundry products by over a quarter, drastically reducing its carbon footprint.

The expected energy efficiency gains come from a new mobile furnace with a wireless power transmission system based on electromagnetic coupling that can keep the liquid metal at a constant and lower temperature after its transfer from the melting furnace to the casting facility (Figure 17). The process also offers highly flexible production that can cope with highly variable demand in terms of quantity and diversity.

Figure 17: NIWE: melted iron poured into the mobile furnace.
© NIWE project.

STEELANOL: CIRCULAR REUSE OF STEEL MILL FLUE GAS TO PRODUCE ETHANOL

The Steelanol project's aims are twofold: (a) to demonstrate the cost-effective production of low-carbon ethanol using unavoidable steelmaking production gases as a resource, by means of novel gas fermentation technology; and (b) to assess the valorisation of the ethanol produced for diverse applications, mostly in the transport sector (Figure 18). A demonstration plant capable of producing approximately 65 000 tonnes of ethanol per year is currently under construction. It will be the first-of-its-kind in Europe, and the largest facility in the world built to use this technology. Life-cycle analysis has revealed that this highly efficient bio-fermentation process has the potential to reduce the electricity required to make ethanol and, when ethanol is used as a fuel, to reduce GHG emissions in transport by up to 85 %.

HISARNA: COMBINED EU AND NATIONAL PROJECT TO CUT CO_2 EMISSIONS IN THE STEEL INDUSTRY

The HIsarna process reduces ironmaking, presently consisting of three steps, to a single step: hot liquid metal is produced from iron ore fines using (non-coking) coal as a reductant, so there is no need for ore agglomeration or coking. The technologies associated with HIsarna were shown to work on a small scale in the ultra-low-carbon dioxide steelmaking (ULCOS) project. The work continued at a pilot plant in the Netherlands, with a budget of € 25 m, including € 7.4 m funding from Horizon 2020. The testing period has now been extended, thanks to a grant from the Netherlands to further demonstrate and confirm the CO_2 reduction target of 35 %.

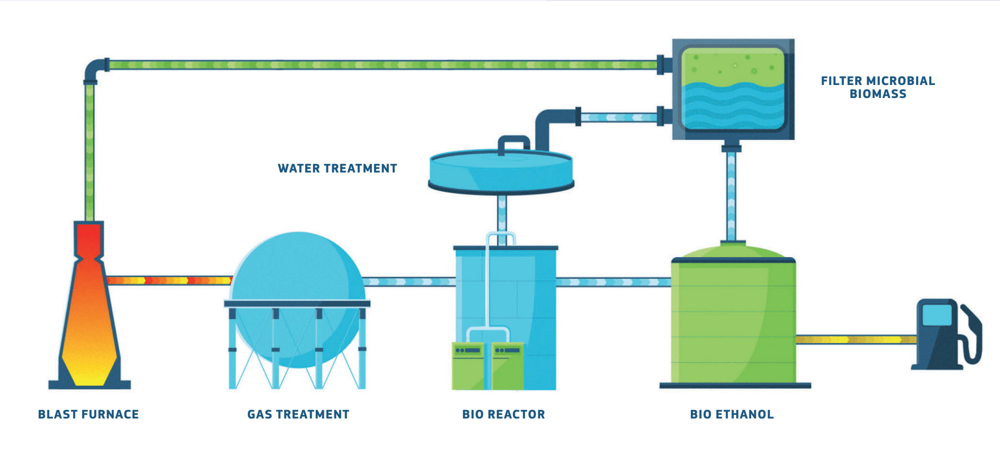


Figure 18: Steelanol – production of sustainable biofuel through an innovative gas fermentation process using exhaust gases emitted in the steel industry.
© Steelanol project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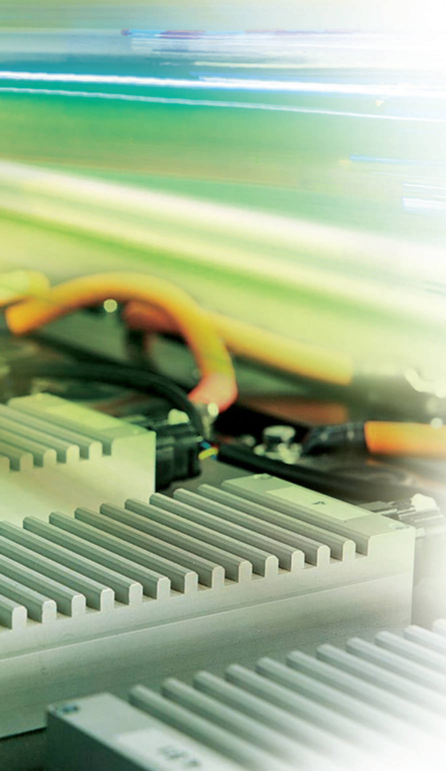
Diversify

and strengthen energy options for sustainable transport



Increasing energy efficiency and speeding up the decarbonisation of the transport sector feature among the Energy Union priorities. To achieve this goal, the SET Plan seeks to boost R&I in two specific areas: (a) becoming competitive in the global battery sector to drive e-mobility and stationary storage forward; and (b) generating significant volumes of advanced biofuels which can be sustainably produced, so that internal combustion vehicles can contribute to low emission mobility. Progress during the last 10 years might seem modest, but EU action in these sectors has been constant and is poised to grow.

Batteries for e-mobility and stationary storage

© Joint Research Centre, European Commission

The market value for lithium-ion batteries (cell level) increased from $5.5 billion in 2007 to almost $16 billion in 2015. This massive growth in market value is projected to continue, topping $35 billion by 2025[67]. This is because of the take-off in electro-mobility, combined with the rapid increase in stationary energy storage capacities. There are unprecedented opportunities for Europe to share in this global boom[68].

Over the past decade the SET Plan has been instrumental in creating a favourable integrated R&I environment in Europe, also benefiting battery technology development. Between 2007 and 2016, the EU R&I framework programmes supported 135 battery-related research projects covering a wide technology spectrum; these involved more than a thousand participants and received EU funding of € 375 million, along with € 180 million in private co-financing. A comprehensive overview of the results achieved by these projects was recently presented in a 'Projects for Policy' report[69]. Despite the achievements so far, further support for R&I is required to meet the ambitious targets in the SET Plan and make Europe competitive in the global battery sector.

67 Pillot (2016), The rechargeable battery market 2015-2025. Avicenne Energy.
68 Joint Research Centre (2017), *EU competitiveness in advanced Li-ion batteries for e-mobility and stationary storage applications: opportunities and actions*. JRC science for policy report. European Commission.
69 European Commission (2017), *Batteries: a major opportunity for a sustainable society.*

MAJOR ADVANCES IN CELL ENERGY DENSITY

Energy density is highly relevant to cell performance. In the last decade energy densities have increased; nowadays, lithium-ion (Li-ion) cells are extensively employed in battery vehicles and stationary energy storage systems. However, energy density – together with other relevant parameters such as power density, recharging time and cyclability – will need further improvement to meet the increasingly stringent performance demanded by various applications (Figure 19). While batteries for grid-connected and residential stationary energy storage applications may have different requirements than those for electric vehicles, the energy storage sector can benefit hugely from progress in the e-mobility sector.

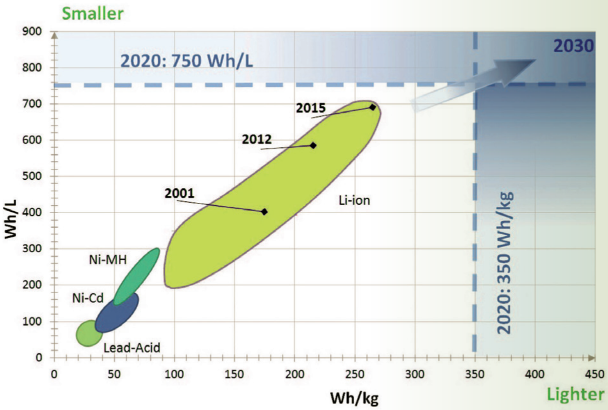


Figure 19: The energy density of Li-ion batteries has been increasing steadily over recent years.
Source: Joint Research Centre, European Commission.

SHARP DROP IN LITHIUM-ION BATTERY PACK COSTS

The costs of Li-ion batteries are continuously decreasing and will soon reach a level that triggers the widespread and faster deployment of both battery electric vehicles and energy storage applications. Li-ion battery pack costs have fallen dramatically by 80 % in the last 10 years to below $ 250/kWh (Figure 20). While the cost of the battery pack for electric vehicles is seldom revealed by vehicle manufacturers, projections indicate that it will fall further to under $ 100/kWh by 2030, making electric vehicle costs competitive with those of internal combustion engine vehicles. Sustained R&I, economies of scale and vertical integration along the battery value chain are all contributing to the falling costs. Stationary battery energy storage systems are also benefiting from this trend and will do much to help the integration of renewable energy and smart grids.

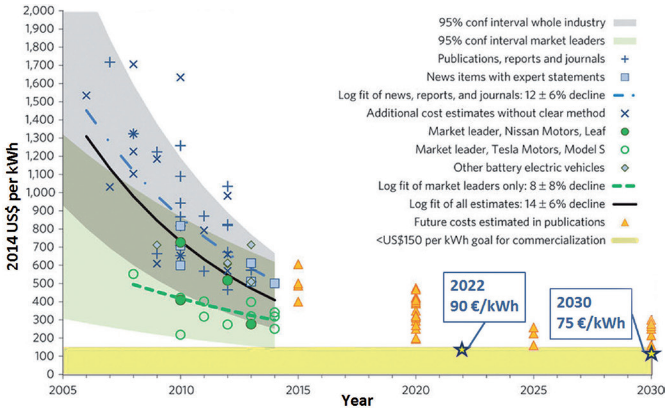
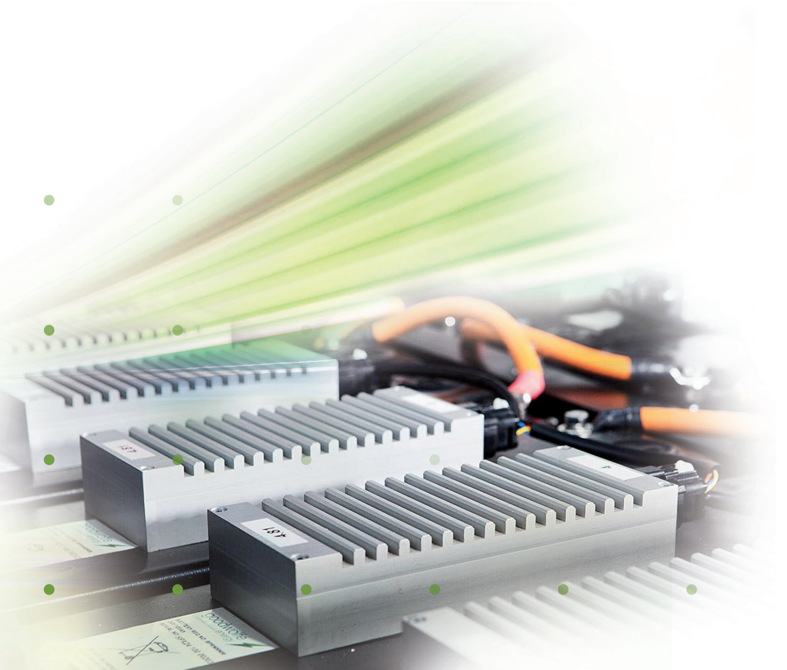


Figure 20: The cost of Li-ion battery packs in battery electric vehicles has fallen dramatically over recent years.
Source: Nykvist and Nilsson (2015), Rapidly falling costs of battery packs for electric vehicles, Nature Climate Change 5, pp. 329-332.

PROJECTS ADVANCING BATTERY PERFORMANCE

The FiveVB project focuses on the development of the next generation high voltage Li-ion battery in a consortium of industrial partners dealing in the major components for industrial cell production in Europe. Pouch cells containing a silicon anode, a high Ni-content in the lithium-manganese-cobalt-oxide cathode and a specifically tailored electrolyte have been successfully developed during the project. In a final step, production of next generation automotive metal cells utilising the same materials will be demonstrated on a pilot production facility.

The NAIADES project aims to develop and demonstrate the ambient sodium-ion battery as an effective alternative to Li-ion batteries for stationary electric energy storage applications. The overall aim is to develop a battery technology for sustainable electric energy storage that would bring costs down sharply while delivering sustainability and performance in terms of safety, cycle life and energy density.

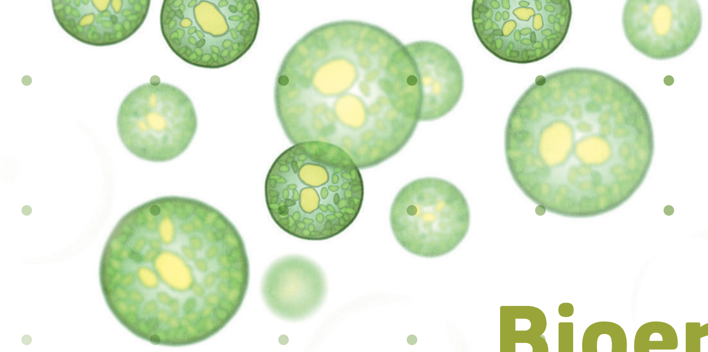


CHALLENGES AND OPPORTUNITIES AHEAD

While EU industry is well established in the lead acid battery value chain, the EU is lacking mass-production capabilities in the Li-ion battery sector, where its strength is currently limited to high-quality superior performance cells for high-tech niche markets. To enable EU industry to share in the global boom in the batteries' market, large-scale investment to establish domestic Li-ion manufacturing capabilities is required along the whole value chain, but most importantly for cell manufacturing. Future research, together with other measures to be agreed within the recently formed EU Battery Alliance, should help the EU in that regard and, subsequently, on post-Li-ion battery markets as well. These may *inter alia* include sodium-ion, metal-air, molten-salt and redox flow batteries.

Research efforts should also help the EU industry develop its well-proven track record in recycling. For example, it can profit from cost-effective recycling of different lithium battery chemistries used in different types of electric vehicles according to their specific needs for energy, power, safety, lifespan and cost. Furthermore, the development of second use options for automotive batteries which are no longer suitable for use in vehicles offers new opportunities to improve the economic and environmental performance of battery systems.

In an approach advocated by the SET Plan, strong joint European efforts in the coming years, drawing on fruitful collaboration between all interested stakeholders, including public and private players, will be needed to create a competitive and sustainable European battery ecosystem for the future.



Bioenergy and renewable fuels

Transport represented more than 30 % of EU final energy consumption[70] and 23.5 % of GHG emissions in 2015, and relies on oil for 94 % of its energy needs. Decarbonising the transport sector to support climate and energy goals depends critically on fuel production and use (as part of a 'well-to-wheel' approach). The development of biofuels from sustainable feedstocks and renewable fuels can play an important role in this regard, supporting fuel security and the EU objective of having at least 10 % of transport fuels derived from renewable sources by 2020. R&I needs therefore to focus on the efficient production of advanced biofuels, renewable fuels, hydrogen from renewable sources and carbon capture and utilisation fuels.

Biorefineries for example are improving the cost-effectiveness of biomass conversion into advanced biofuels and enlarging the range of other useful products. This maximises resource efficiency while improving sustainability in the sense of the Renewable Energy Directive.

Hydrogen may also contribute to decarbonising the transport sector. It has the highest mass energy density of any fuel, which makes it an extremely effective medium for energy storage and distribution (Figure 21).

70 European Commission (2015), *A framework strategy for a resilient Energy Union with a forward-looking climate change policy* [COM(2015) 80].

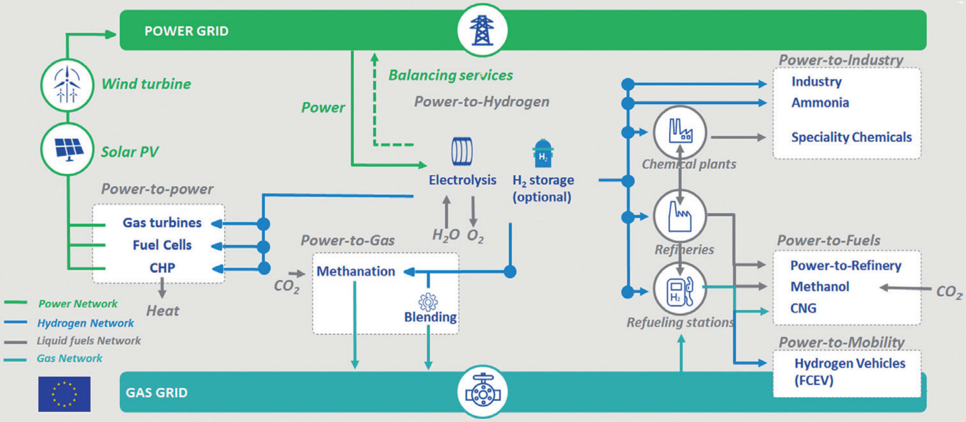


Figure 21: Potential uses of hydrogen.
© Fuel Cells and Hydrogen Joint Undertaking

IMPROVED ELECTROLYSIS TECHNOLOGY FOR COMPETITIVE HYDROGEN PRODUCTION

Scientific developments have led to increasing energy density and efficiency of proton exchange membrane (PEM) electrolysers. The 2014 HYBALANCE project, for example, is developing and installing a hydrogen production, storage and dispensing facility that utilises a 1.2 MW electrolyser, feeding light industry and transport clients. The BIGHIT project, in turn, produces hydrogen from curtailed wind, wave and tidal electricity in two electrolysers of 1.5MW combined power for a small fleet of vehicles, among other applications (Figure 21).

DEMONSTRATION OF 2ND GENERATION LIQUID BIOFUELS

According to the International Energy Agency, biochemical conversion demonstration plants in operation today have yearly capacities at or below 5 kt[71]. The situation might change if the first-of-a-kind, commercial scale plant built in Italy with 40 kt annual production capacity is successfully demonstrated.

Several large-scale thermochemical conversion demonstration plants – have been planned but the projects were cancelled or put on-hold before reaching – operation. As of today, only one large-scale Fischer-Tropsch plant of 200 kt capacity is under construction[72]. Two pyrolysis plants are in operation with a total annual production capacity of around 75 kt[73] but the bio-oil is used on site for power and heat production (the oil could be refined to viable transport fuel in future). The process of hydrothermal liquefaction produces bio-oils of higher density than pyrolysis oil. These plants do not yet approach demonstration scale, with yields in continuous flow-type reactors producing bio-crude reaching 38-64 % with microalgae[74]. Despite continuing work required to commercialise these technologies, there is large scale biofuel production using over 2.3 million tonnes of feedstock per annum from used cooking oil, and some further production from waste animal fats[75].

Processes for 2nd generation biofuels have estimated costs ranging from 60-80 €/MWh (0.60-0.80 €/L) up to 140 €/MWh, depending on feedstock price and type of final fuel[76].

71 Kilotonne (1000 tonnes).

72 http://demoplants.bioenergy2020.eu
73 http://www.pyroknown.eu
74 Elliott, Biller, Ross, Schmidt, and Jones (2015), *Hydrothermal liquefaction of biomass: developments from batch to continuous process.* Bioresource technology 178, pp. 147-156.
75 Flach, Lieberz and Rossetti (2017), *EU biofuels annual 2017.* USDA Foreign Agricultural Service.
76 Maniatis, Landälv, Waldheim, Van den Heuvel, and Kalligeros (2017), *Sub-group of advanced biofuels of the sustainable transport forum: positions & recommendations – final report.* European Commission.

DECREASING COSTS FOR COMBINED HEAT AND POWER BASED ON BIOENERGY

The situation is more positive in what concerns other end-use of biomass beyond fuels for transport: the use of biomass in a variety of solid or gaseous forms in combined heat and power plants is increasing, in particular to compensate the intermittence of other renewable energy carriers and to provide balancing services to the grid. As overall efficiency for combined heat and power and biogas plants (using agricultural residues as feedstock) improved to more than 60 %, electricity production costs have fallen to below 120 €/MWh.

ADVANCEMENT IN PRODUCING BIOFUELS USING RENEWABLE SOURCES

The EU-funded project 'Photofuel' seeks to advance biocatalytic production of alternative liquid drop-in transportation fuels using only sunlight, CO_2 and water. The goal is to engineer microbial cells to directly excrete hydrocarbon and long chain alcohol fuel compounds, sparing the need to harvest biomass. Whilst it is still in an early development stage, it could become a new carbon-capture system and an innovative way of producing synthetic biomass for energy use.

Within the EU-funded project ITAKA, 900 tonnes of aviation compliant biofuels have been produced and tested in the real aviation logistics and aircrafts. Lignocellulosic feedstocks and hydrogenated lipid fuels are currently considered the only short-term solution to reduce the emissions of fossil aviation fuel.

ELECTROCHAEA: A POWER-TO-GAS SYSTEM TO INTEGRATE INTERMITTENT RENEWABLES IN THE GRID

In order to address Europe's energy storage and decarbonisation needs, the BioCat project will design, engineer, construct, and test a 1 MW power-to-gas plant based on Electrochaea's biological methanation technology. The unique feature of this innovative technology lies in the ability of the archaea's methanogenic strains to self-replicate with no need for periodic replacement. The project, still in demonstration phase, will provide both frequency regulation services to the Danish power grid and inject renewable natural gas into Copenhagen's energy grid (Figure 22). If successful, it will be a competitive pathway to produce clean energy and an additional carbon-sink.

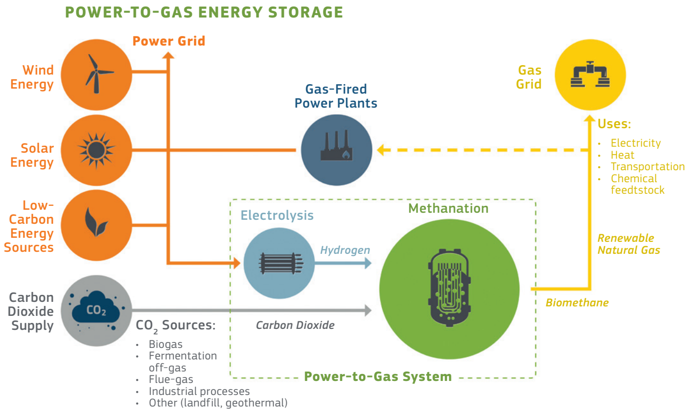
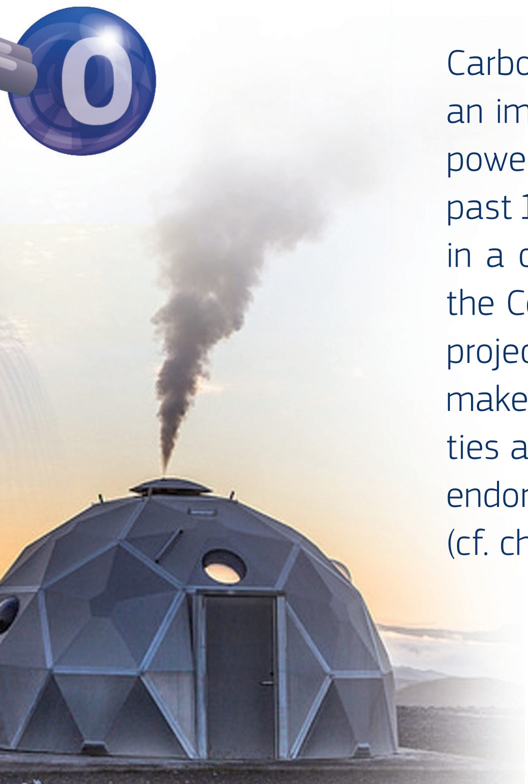


Figure 22: Electrochaea power-to-gas system.
Source: Electrochaea project

© Reuters
© CardFix

Driving ambition in carbon capture, utilisation and storage



Carbon capture, utilisation and storage (CCUS) represents an important set of technologies for the decarbonisation of power generation and energy-intensive industries. Over the past 10 years, the SET Plan has united European stakeholders in a common R&I agenda involving countries, industry and the Commission, combined with international outreach. Pilot projects and other R&I activities are under way aiming to make CCUS cost-effective. These and additional R&I activities are identified in detail in the CCUS implementation plan endorsed by the SET Plan Steering Group in September 2017 (cf. chapter 3 for additional details).

MAJOR ADVANCES IN CO_2 CAPTURE EFFICIENCY

Capturing CO_2 is an energy-intensive process which results in a loss of overall energy output within a power or industrial plant. This represents a high cost as the plant needs to make up for this efficiency loss by burning additional fuel. EU-funded research has contributed to reducing the energy penalty and cost of capture. A consecutive series of pilot plant tests using solvent-based and calcium looping capture technologies have gradually reduced thermal energy consumption from a reference value of 4 GJ/tonne to 2.4 GJ/tonne, and reduced the cost from a reference value of 40-50 €/tonne of avoided CO_2 to 20-25 €/tonne. Capture rates of more than 90 % have been achieved.

SAFE GEOLOGICAL STORAGE OF CO_2

Safe and permanent geological storage is a crucial segment in the CCUS chain to attain drastic global CO_2 emission reductions (Figure 23). Countries and the EU have supported a series of storage pilot projects throughout Europe in different geological settings and investigating different aspects of the storage cycle. Remedying the problem of leakage has also been extensively tested, both in the lab and in subsurface pilot projects. For example, the CarbFix project in Iceland has developed a method that reduces that risk of leakage by dissolving CO_2 in water during its injection into basalt rocks. The CO_2-charged water accelerates the release of metals contained in the basalt, which then reacts with the gas to form carbonate minerals. More than 80 % of CO_2 injected into the CarbFix injection site – at 20-50 °C and 500-800 m depth – was carbonated within a year, compared to tens of thousands of years or more expected when the injection takes place in sedimentary basins.

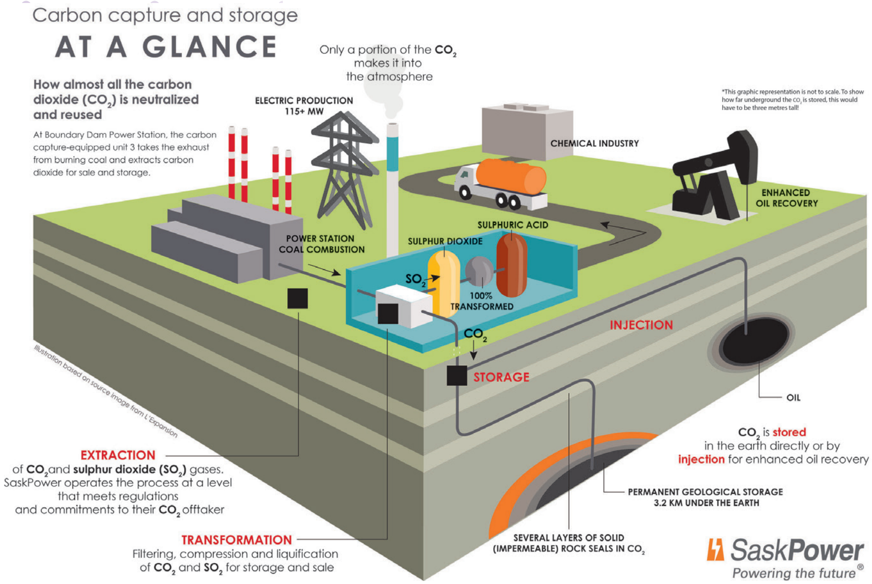


Figure 23: Carbon Capture and Storage at a glance. At the Boundary Dam power station, in Canada, the carbon capture-equipped unit will emit 100 000 tonnes of CO_2 into the atmosphere per year, as opposed to 1.1 million tonnes before.
© SaskPower. Licensed under CC BY-NC-SA 2.0

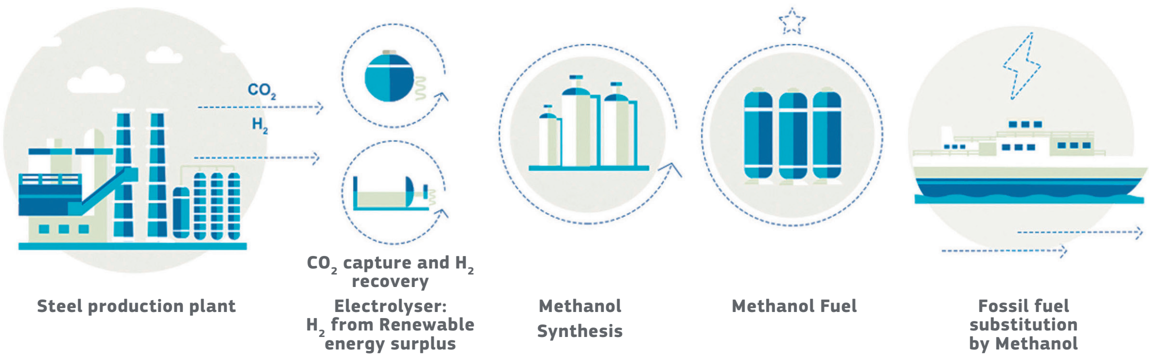


Figure 24: Example of a CCU process producing methanol based on carbon captured in a steel plant.
© FresMe project

DECARBONISING CARBON-INTENSIVE INDUSTRY

CCUS in industry is a new development and a key technology that can lead to CO_2 emission reductions in sectors such as iron and steel, cement and refineries (Figure 24). R&I efforts are currently ongoing at EU and national levels to accelerate use of this technology. Norway, for example, plans to develop an industrial CCUS portfolio consisting up to three capture demonstrators by 2020: an ammonia plant, a waste incinerator and a cement plant.

CONVERSION AND UTILISATION OF CAPTURED CO_2

New solutions for the conversion of captured CO_2 to products such as fuels or chemicals will create new markets for innovative industrial sectors. They can also play a role in supporting the deployment of CCUS by offsetting the high costs of capture and storage. The EU finances R&I on CO_2 utilisation options that have the potential to result in a net reduction of CO_2 emissions in high enough volumes to yield a meaningful contribution to climate change objectives.

EUROPEAN CARBON DIOXIDE CAPTURE AND STORAGE LABORATORY INFRASTRUCTURE (ECCSEL)

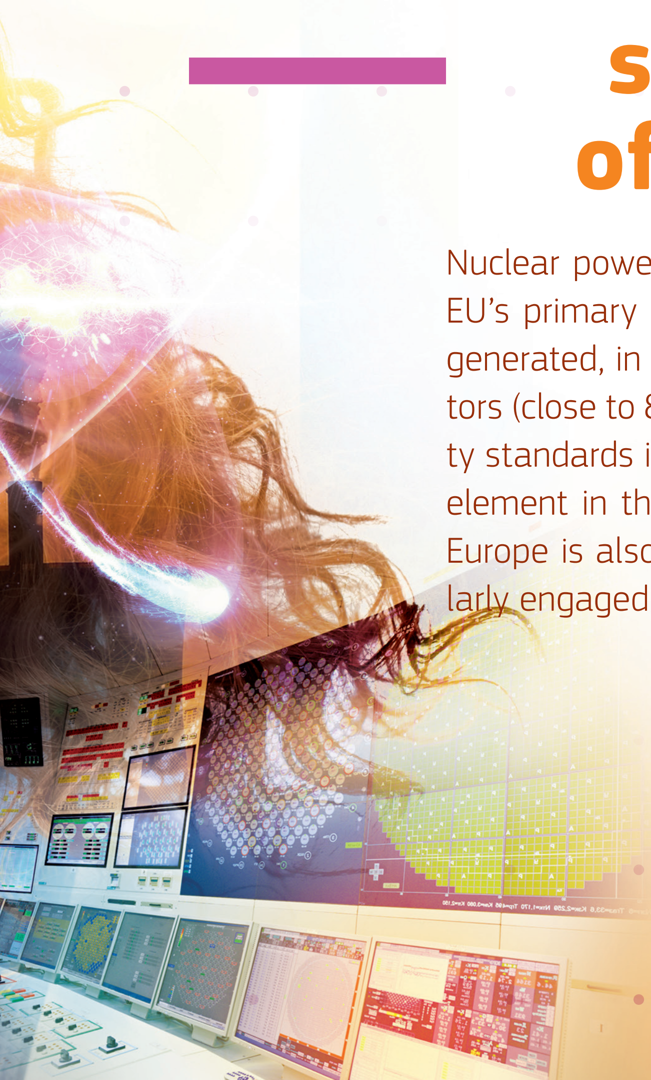
ECCSEL was established in June 2017 to provide researchers with access to top quality Pan-European research infrastructures devoted to CCUS technologies. Norway, France, Italy, the Netherlands and the UK are the founding members of ECCSEL's European Research Infrastructure Consortium, with more countries expected to join in the near future.

ERA-NETS: SUPPORTING FIRM COLLABORATION BETWEEN SET PLAN COUNTRIES

The ERA-NET Cofund 'GeoERA' brings together 48 national and regional geological survey organisations in Europe to support the sustainable use of surface and subsurface resources, including the permanent storage of CO_2 resulting from energy production. A related network is the ERA-NET 'Accelerating CCS Technologies' Cofund, which launches transnational calls for CCUS R&I projects. Most of the € 42.8 million budget is secured by the nine countries involved, with € 12.8 million provided by the EU.

Increase

safety in the use of nuclear energy



Nuclear power plants currently provide around 15 % of the EU's primary energy production and 28 % of the electricity generated, in part due to their high and stable capacity factors (close to 85 %). The implementation of the highest safety standards is vital as nuclear fission remains an important element in the energy mix in a number of Member States. Europe is also a key player in nuclear fusion and is particularly engaged in the construction of ITER.

Saint-Laurent EDF power plant, France.
© EDF – Marc Didier

A SECTOR FACING SEVERAL CHANGES

Nuclear energy production has been decreasing since 2005 at an average rate of 1.4 % per year and certain countries such as Belgium, Germany and Switzerland are considering excluding, or have already excluded, nuclear energy from their energy mix. At the same time, several countries plan to extend the lifetime of their plants. Today, six nuclear reactors are under construction (in Finland, France, Slovakia and the UK) and others are planned.

Significant improvements on nuclear safety, reliability and competitiveness have been made over the last decade in the context of the long-term operation of existing power plants. With support from the industry and interested countries, new reactor designs with improved productivity and higher levels of safety are also being proposed.

INCREASED NUCLEAR ENERGY SAFETY

Under the SET Plan, and since its inception in 2007, enhanced coordination of national programmes is stimulated as well as joint R&I actions involving public and private funding – always in view of increasing safety in the use of nuclear energy. Current priority areas for this coordination relate to: (a) safety to help securing the long-term operation of existing nuclear reactors; (b) safe management of radioactive waste and decommissioning; and (c) efficiency and competitiveness of current and innovative technologies (of interest only to countries wishing to maintain nuclear in their low-carbon energy mix over the long-term, thereby allowing innovation in safety systems).

As set out by the Council[77] and in line with the EU's Nuclear Safety Directive[78], R&I funded through Euratom managed by the European Commission is restricted to nuclear safety, management of radioactive waste, radiation protection, as well as education and training in these fields. Therefore, eventual joint R&I actions in other areas shall be funded by interested member states and industry.

FUSION TECHNOLOGY: A HIGH POTENTIAL ATTRACTIVE LONG-TERM LOW-CARBON ENERGY SOLUTION

The EU is a key financer of the construction of ITER. One of the most important industrial research projects in the world, ITER aims to demonstrate the feasibility of fusion power and show that it can work without negative impacts (Figure 25).

Figure 25: Construction of ITER's coils winding facility in Cadarache, France.
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77 Council Regulation (Euratom) No 1314/2013 of 16 December 2013 on the Research and Training Programme of the European Atomic Energy Community (2014-2018) complementing the Horizon 2020 Framework Programme for Research and Innovation.
78 Council Directive 2014/87/Euratom of 8 July 2014 establishing a Community framework for the nuclear safety of nuclear installations.

3

Implementation plans

This year, the SET Plan has embarked upon preparing implementation plans for each of the 14 low-carbon energy sectors presented in the previous chapter. They take stock of the R&I progress achieved so far and identify specific technological R&I activities, demonstration projects and other general actions that are needed to meet the SET Plan targets[79]. The plans were prepared by working groups that brought together interested SET Plan countries, research and industrial stakeholders, and the European Commission. By September 2017, implementation plans on (a) concentrated solar power/solar thermal electricity; (b) carbon capture utilisation and storage; and (c) energy efficiency in industry had been endorsed and are ready to be put into practice.

This chapter summarises the R&I activities and demonstration projects proposed as well as their expected impact. Execution would mobilise € 7 billion of public and private funding into R&I by 2030. Some 11 additional implementation plans, covering the remaining technological areas of the SET Plan and representing a much higher investment volume, shall be endorsed by the first half of 2018.

79 SET Plan Declarations of Intent and the respective targets can be found in SETIS at https://setis.ec.europa.eu/actions-towards-implementing-integrated-set-plan.

Concentrating solar power/ solar thermal electricity

Concentrating solar power/solar thermal electricity (CSP/STE) can make a significant contribution to transforming the energy system, particularly because it can provide 'dispatchable' renewable electricity (i.e. electricity that is available on demand). By delivering services that enhance grid flexibility, CSP/STE can make it easier to integrate renewable energy sources with a variable output, such as PV and wind energy. This in turn contributes to making energy supply more reliable.

The goal of the CSP/STE implementation plan is to achieve significant cost reductions for existing technologies in the short term and to work towards developing the next generation of technologies in the longer term. This will create the conditions to reactivate CSP/STE innovation in Europe and keep the EU's technological leadership in the sector. Given the significant potential to export to other regions of the world, it will also strengthen the EU's industrial base. The plan has been drafted in a working group composed of interested SET Plan countries, stakeholders[80] and the European Commission.

80 EERA, the European Solar Thermal Electricity Association and the European Association of Gas and Steam Turbine Manufacturers.

COUNTRIES PARTICIPATING IN THE WORKING GROUP

Spain (Chair), Belgium, Cyprus, France, Germany, Italy, Portugal and Turkey.

OVERVIEW OF TARGETS AND R&I ACTIVITIES

The plan identifies five strands of action: 12 R&I activities, one to three first-of-a-kind demonstration projects on a commercial scale, financing aspects, regulatory framework and support to internationalisation. The plan identifies the parties interested in carrying out each R&I activity and potential financing sources. In this way it takes advantage of the strong synergies between research performers, industrial players, national funding agencies and the European Commission.

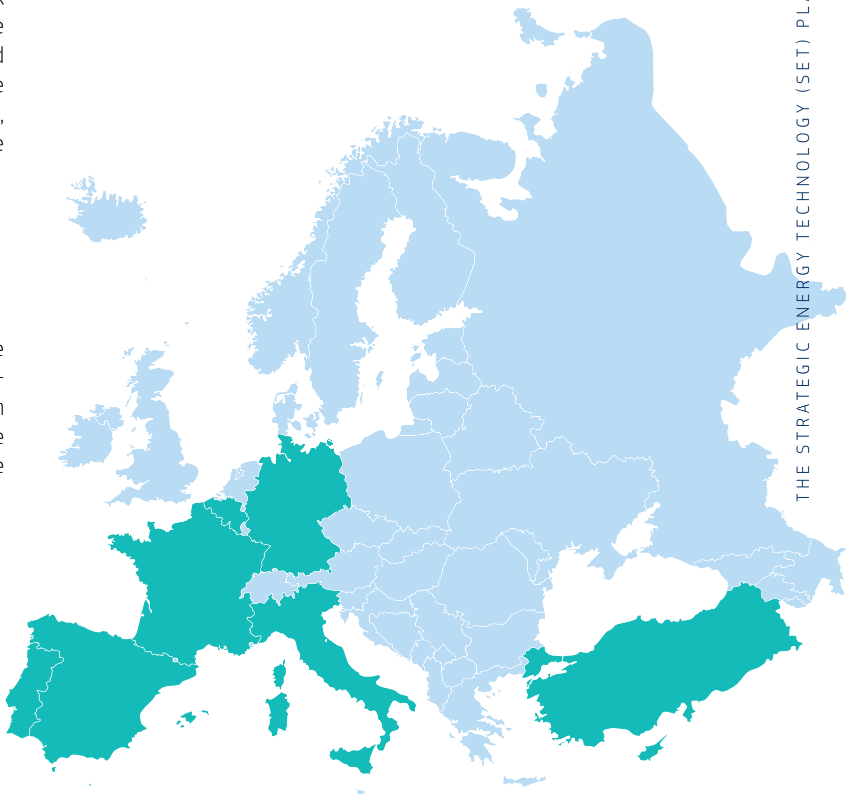
VOLUME OF INVESTMENT TO BE MOBILISED

Investments under the 12 R&I activities set out in the implementation plan amount to €200 million. The first-of-a-kind demonstration projects require up to €1 billion in addition. Funding should mainly originate from private and public sources at national level, with EU funding made available where there is a clear EU added value.

R&I ACTIVITIES HELPING TO LOWER COSTS

- **Advanced linear concentrator Fresnel technology with direct molten salt circulation as heat transfer fluid for high temperature thermal energy storage**

New optical designs for higher concentration and the use of salts as heat transfer fluid at elevated temperatures will be demonstrated (565°C).



- **Parabolic trough with molten salt**

Using molten salt as a heat transfer fluid in parabolic trough systems is an attractive option. This is because it can: (a) increase solar-to-electric efficiency; (b) reduce storage costs; (c) simplify the control system by separating the solar harvest from electricity production; and (d) have a lower environmental impact than state-of-the-art oil plants.

Parabolic trough with silicon oil

The operating temperature limit of silicon oil is 430 °C, which is more than 30 ºC higher than current state-of-the-art synthetic oil. This additional temperature spread between inlet and outlet leads to higher solar field output and higher system efficiencies at the power block side.

- **Solar tower power plant to commercially scale-up and optimise the core components of the open volumetric air receiver technology**

The open volumetric receiver technology in solar towers uses an open ceramic honeycomb structure to absorb the concentrated solar radiation and heat up ambient air. The technology combines a superior receiver behaviour with a very inexpensive fixed bed thermal storage.

- **Improved central receiver molten salt technology**

This R&I activity is concerned with a complete set of items aimed at improving the molten salt central receiver technology currently available in solar towers. This will achieve significant cost reduction in a short time frame.

R&I ACTIVITIES HELPING DEVELOP NEW CSP CYCLES (SELECTED)

- **Next generation of central receiver power plants**

This R&I activity aims to contribute to the development of the next generation of solar towers. It focuses on central receiver technology using molten salts, the one with the greatest potential for reducing costs in the short and medium term.

- **Multi-tower central receiver beam down system**

An alternative solution to the classic solar system with the receiver on the top of a tower is the 'beam down' solution. This solution simplifies the construction of both the receiver and the tower, with a very positive impact on costs. This concept opens the door to the use of several heat transfer fluids and heat storage solutions for high efficiency systems, even for a medium-size plant.

- **Thermal energy storage**

This R&I activity aims to develop innovative thermal storage media at either an affordable cost or using outstanding volumetric energy density or higher working temperatures. Special attention will be paid to the reliability of the systems, the associated subsystems and the materials available.

FIRST-OF-A-KIND PROJECTS

At present, new CSP/STE technologies face a serious market failure in Europe which impedes them from reaching the market. As a result, these are being deployed in other continents that offer better finance and enabling conditions. It is crucial to reverse this trend and demonstrate CSP/STE innovations in the EU so that Europe can maintain its position as industrial leader in the sector.

The implementation plan intends to demonstrate one to three first-of-a-kind projects to break the current deadlock. The projects will be primarily implemented by industry, but public support will also be sought (e.g. via InnovFin Energy Demonstration Projects).

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Energy efficiency in industry

R&I in industrial energy and resources efficiency is needed to ensure that industry contributes to climate change targets and increases its export competitiveness. This is especially important in a situation where manufacturing companies from across the globe have easier access to the same energy-saving technologies. R&I investment is therefore necessary to further boost the EU's technological leadership and innovation know-how as a way to maintain competitive production in the EU. To maximise the impact of R&I, there is a need to prioritise action in the sectors and technologies with the highest potential. Steel (including iron) and chemicals (including pharma) were the two industrial sectors selected for inclusion in the implementation plan by the SET Plan working group[81]. These sectors were selected based on their high potential for energy savings and their socioeconomic importance given the added value and employment they generate. Other sectors are covered by two cross-cutting priorities: heat and cold recovery, and system integration.

81 Stakeholders represented in the working group: Association – Sustainable Process Industry through Resource and Energy Efficiency (A.SPIRE, Co-Chair), EERA, Euroheat & Power, the European Association for the Promotion of Cogeneration (COGEN Europe), the European Chemical Industry Council (CEFIC), the European Confederation of Iron and Steel Industries (Eurofer), the European Geothermal Energy Council, the European Turbine Network – EUTurbines, the European University Association and the Fuel Cells and Hydrogen Joint Undertaking.

COUNTRIES PARTICIPATING IN THE WORKING GROUP

Finland (Chair), Austria, Belgium, Cyprus, the Czech Republic, France, Germany, Ireland, Italy, Latvia, Norway, Poland, Portugal, Slovakia, Spain, Sweden, Switzerland, the Netherlands, Turkey and the UK.

OVERVIEW OF TARGETS AND R&I ACTIVITIES

The energy efficiency in the industry implementation plan identifies the R&I activities required to deliver the targets agreed in the respective industry's Declaration of Intent. In the iron/steel and chemical sectors, the aim by 2030 is to improve the cost effectiveness of one third of the existing technologies (with a payback lower than 3 years) and to increase the technology readiness level of one third of the emerging technologies to level 8. For the cross-cutting priorities, the aim by 2025 is to: (a) demonstrate cost-effective heat and cold recovery solutions; and (b) reduce energy consumption by 20 % through system integration, optimal design and intelligent operation, including industrial symbiosis and digitisation.

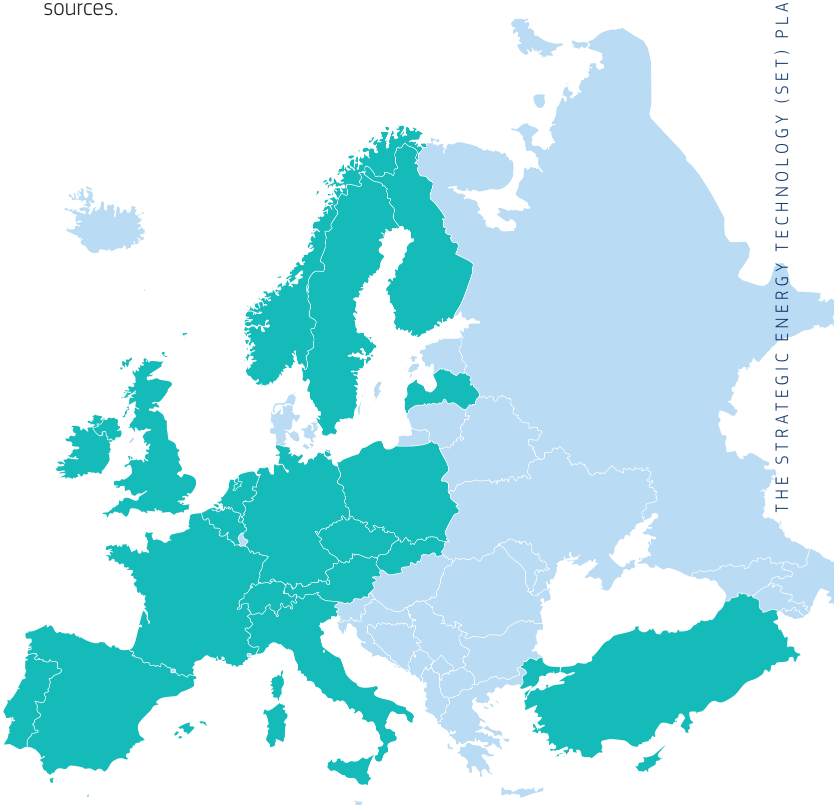
VOLUME OF INVESTMENT TO BE MOBILISED

Some 14 R&I activities have been identified, representing an estimated investment of € 3-4 billion. All activities are new projects, and their duration ranges from 3-5 years to 17 years. The funding sources and instruments will be a mix of public (national) and private funding, plus EU funding where the activity has demonstrable European added value.

R&I ACTIVITIES

- **Steel sector**

In the steel sector, the proposed R&I activities aim to make a full-scale demonstration of steel-making using hydrogen instead of coke to reduce iron ore. This method reduces CO_2 emissions thanks to the switch to greener energy sources. Unlike coke, the use of hydrogen as a reductant does not produce point CO_2 emissions and produces almost no life-cycle emissions if it is generated using renewable electricity sources.



This is particularly important given the expected reduction of free EU emissions trading system allowances and consequently the rise in allowances costs. Financing these industrial scale first-of-a-kind demonstrations remains a challenge given the technical and financial risks.

- **Chemical sector**

R&I in this area is more open and tackles the following challenges: (a) design optimisation for more intensive processes and more flexible and modular plants; (b) development of more efficient separation technologies; and (c) use of unconventional energy sources and electrification. These are crucial in enabling decentralised plants to use variable and renewable feedstocks/energy sources.

- **Heat and cold**

R&I in this area concentrates on: (i) industrial heat pumps converting low-grade heat into higher-grade heat (higher temperature); and (ii) refrigeration cycles converting low-grade cooling into higher-grade cooling. These are vital for intra-plant optimisation and inter-plant integration (industrial symbiosis) by enabling the cascading use of heat (or cold) in industrial parks and in district heating/cooling networks. Poly-generation (i.e. of heat, cold and electricity) and heat-to-(electrical) power conversion technologies are also addressed.

- **Industrial symbiosis**

R&I in this area includes: (a) developing quantification methodologies to enable price setting for the traded commodities; and (b) identifying, assessing and testing opportunities of symbiosis between different industries. These are crucial for the exchange of material and/or energy flows between two or more production sites or sectors and can save energy and materials.

- **Digitalisation**

R&I in this area addresses further integration in process and plant management, including the plant/process design phase and plant retrofitting. Digital technologies and process automation can significantly boost energy efficiency by finding new ways to increase plants' flexibility, optimise consumption and reduce GHG emissions.

- **Capacity building and dissemination**

Capacity building and dissemination activities include: (i) the mapping of methodological approaches, tools, best practices and business models used in industrial pilot plants; and (i) improving the level of awareness and the overall 'sustainable energy management culture' in industrial companies and small businesses.

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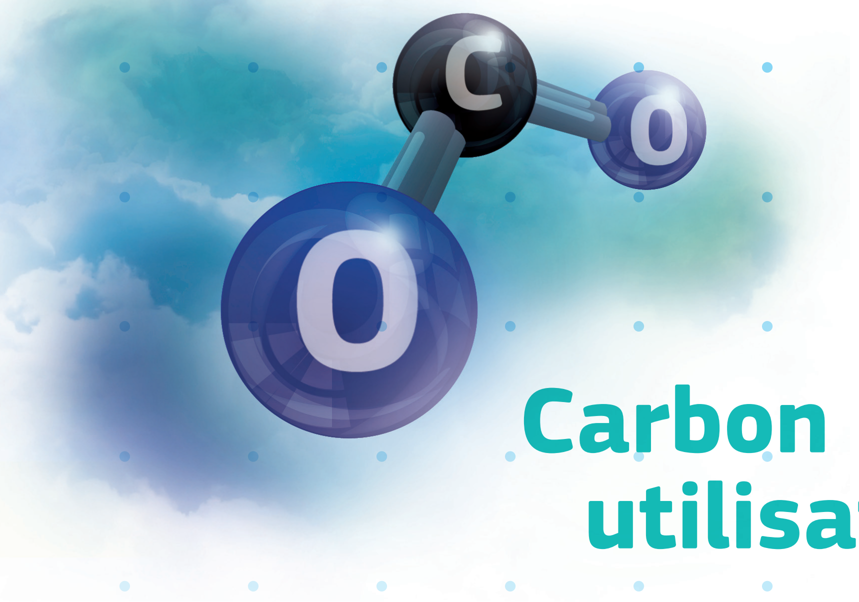


Carbon capture, utilisation and storage

The SET Plan's key R&I objectives for carbon capture, utilisation and storage (CCUS) are: (a) to demonstrate and to deploy on a commercial scale the full CCUS value chain; (b) to reduce the costs of CO_2 capture; and (c) to demonstrate safe CO_2 storage.

The CCUS implementation plan identifies eight R&I priorities. Where ongoing projects are seen to be insufficient to achieve the SET Plan targets by 2020 and 2030, the plan proposes new actions to address such gaps. For example, it identifies ongoing demonstration activities at national level which, due to their importance, can be classified as 'flagships'. It also tackles the problem of insufficient finance to put ongoing and new projects into operation. The implementation plan was drafted in a working group composed of interested SET Plan countries, stakeholders[82] and the European Commission.

82 The European Technology Platform for Zero Emission Fossil Fuel Power Plants (Co-Chair), Actys-BEE, ArcelorMittal, Bellona, the British Geological Survey, BP, EERA, the European Chemical Industry Council (CEFIC), the European Steel Technology Platform, the European Turbine Network, the European Steel Association (Eurofer), Gassnova, the Global CCS Institute, General Electric, the German Aerospace Center, Greenwin, Heidelberg Cement, the International Energy Agency, IFP Energies Nouvelles, the International Association of Oil and Gas Producers, Mitsubishi Hitachi Power Systems, Port of Rotterdam Authority, the Research Council of Norway, Scinnov, Shell, Sintef, Sotocarbo, Taqa Global and the Netherlands Organisation for Applied Scientific Research (TNO).

COUNTRIES PARTICIPATING IN THE WORKING GROUP

The Netherlands (Chair), Norway (Chair), the Czech Republic, France, Germany, Hungary, Italy, Spain, Sweden, Turkey and the UK.

OVERVIEW OF TARGETS AND R&I ACTIVITIES

The CCUS implementation plan identifies eight R&I activities required to deliver the following SET Plan targets: (a) reduce the cost of CO_2 capture; (b) complete the detailed appraisal of cost-effective and bankable storage capacity; (c) initiate CO_2 hubs and clusters and a cross-border CO_2 transport infrastructure; (d) initiate piloting and demonstration of CO_2 re-use technologies. The plan also includes an action with a socioeconomic focus, which relates to the role of CCUS in meeting European and national climate and energy objectives.

VOLUME OF INVESTMENT TO BE MOBILISED

It is estimated that executing the identified R&I activities requires the mobilisation of around €2 billion. Considerable additional investment will be necessary post-2020 to keep the implementation plan on track in the years up to 2030. Funding is expected to come mainly from public (national) and private sources, while EU funding will be considered for actions (or parts of actions) with a significant EU added value.

R&I ACTIVITIES

- **Delivery of a whole chain carbon capture and storage (CCS) project operating in the power sector**

The successful delivery of a large scale, full chain CO_2 capture, transport and storage project would provide visibility about the costs of CCS, provide experience of the use of this technology and promote cost reduction. This in turn would support subsequent phases of CCS[83].

- **Delivery of regional CCS and carbon capture utilisation (CCU) clusters, including feasibility for a European hydrogen infrastructure**

Industrial CO_2 sources are often relatively small. The successful delivery of several such CCUS projects as part of a 'cluster' will make it possible to share infrastructure and achieve economies of scale. A cluster can also support a range of different CCU technologies using either chemical or biological transformation to produce chemicals, material and fuels.

- **Cross-border CO_2 transport infrastructure**

The development of a cross-border CO_2 transport infrastructure will provide a solution for CO_2 sources in countries that do not have their own storage capacities. This will mean that more countries can benefit from the development of CCS.

- **European CO_2 storage atlas**

The creation of a European CO_2 storage atlas will identify and characterise all recognised prospective onshore and

83 Given the decision not to progress with the 'ROAD' CCS project in the Netherlands, this activity can no longer be implemented by 2020, contrary to what was originally planned.

offshore CO_2 storage sites. This will make it easier to compare and rank sites, and will greatly help project developers and permitting authorities to prioritise the areas with the greatest potential. The storage atlas will help identify potential storage locations to be further evaluated for possible future commercial deployment (see next R&I activity).

- **Unlocking European storage capacity**

To be able to store large enough quantities of CO_2 and thus make a meaningful contribution to the Paris Agreement targets, new storage sites need to be characterised and assessed every year for the next 30 years. The first step is to demonstrate safe and effective CO_2 storage technologies at pilot scale. This is needed to increase the confidence of the public and stakeholders in CCS.

- **Developing next-generation CO_2 capture technologies**

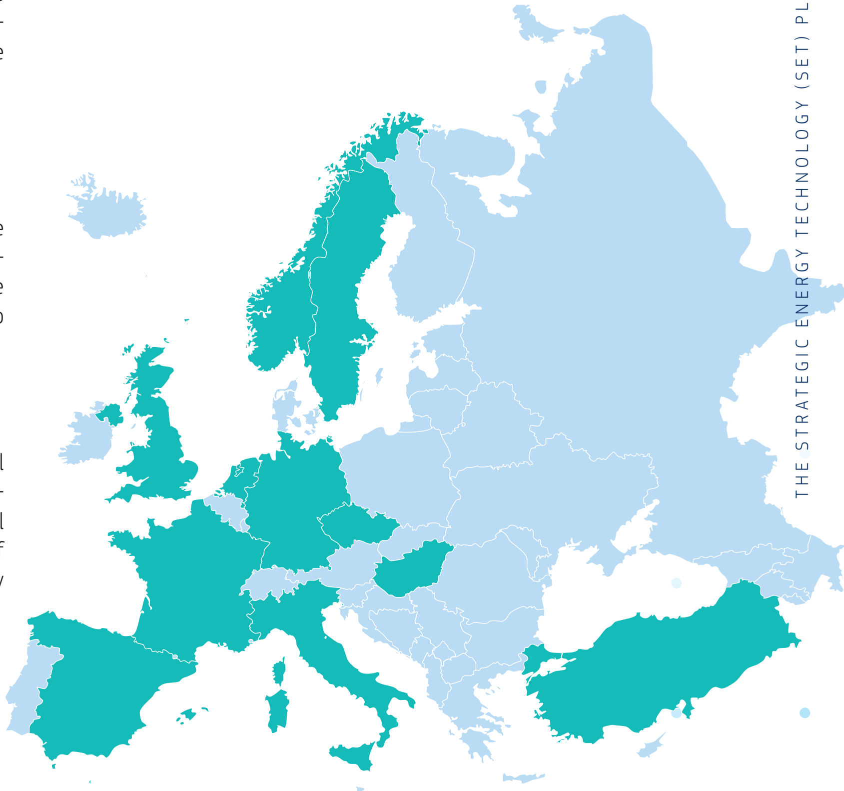
CCS needs to become a cost-competitive technology before it can start to be commercially deployed. A key R&I challenge is to reduce the energy penalty and cost of capture associated with CCS. Therefore pilot projects are needed to demonstrate solutions responding to this issue.

- **CCU action**

New solutions for the conversion of captured CO_2 to useful products such as fuels or chemicals will create new markets for innovative industrial sectors. Such solutions will also play an important role in supporting the deployment of CCS by making early CO_2 capture projects economically viable.

- **Understanding and communicating the role of CCS and CCU in meeting European and national energy and climate change goals**

Successful deployment of CCS and CCU requires technology and policy to progress in parallel. This activity will help with the preparation of policy actions to meet this goal. The work will draw on a better understanding of the potential role of CCUS in the coming decades through advanced energy systems and economic modelling. Such analysis will also be useful in the context of the integrated national energy and climate plans.



4

The way forward: implementation

Ten years have passed since the emergence of the SET Plan. During this period, the plan contributed to boosting clean energy innovation by triggering increased alignment between public and private, European and national research agendas. Technological roadmaps and targets helped to focus on priorities, while inclusive governance structures and processes stimulated cooperation and pooling of resources. During these ten years, the SET Plan has been a reference for Europe's R&I policies both at national and at EU levels – or even wider, as recently proved by the Mission Innovation Initiative.

In September 2015, the SET Plan underwent a major transformation in a quest to integrate R&I actions along the energy system while highlighting the role of consumers, the need to make cities smarter, and to promote energy efficiency. Above all, the focus shifted to producing tangible results: the Integrated SET Plan was born and represents a new way of collaborating. SET Plan countries, together with the relevant industrial and research stakeholders and the European Commission, have defined a clear path by endorsing strategic targets in all SET Plan areas to accelerate the energy transition and keep Europe at the forefront of the next generation of low-carbon energy technologies. The SET Plan community is now preparing implementation plans to identify the R&I activities and demonstration projects required to achieve those targets.

This means that the SET Plan is entering its most critical (and at the same time most complex) phase: it is moving from a planning phase into a real 'implementation phase'. The million-euro question is 'how to turn this joint vision for clean energy R&I into reality?' **Translating the plans into real projects will require a strong commitment from all actors**.

In this sense, it became clear during the last 10 years that more agile cooperation instruments are required if we are to succeed in mobilising the investments required to execute the implementation plans. The SET Plan is therefore analysing all existing cooperation instruments in order to identify those that can lead to a step-change when it comes to pooling additional public and private resources.

Take as an example the first three approved implementation plans: CSP/STE, CCUS, and energy efficiency in industry: they require up to €7 billion until 2030 from both public and private sectors. A much higher investment volume should be needed if the remaining 11 implementation plans still under preparation are also accounted for.

The key player is and will continue to be the private sector – which accounts for as much as 77 % of all clean energy R&I investments (recall Figure 1). But mobilising additional private funds may prove difficult as R&I is inherently risky. For this reason, the European Commission Communication 'Accelerating Clean Energy Innovation' foresees the use of public support to lower investors' risks and boost private investment. It also intends to create the right business environment through targeted policies, standards and regulations.

Still, the leverage role of EU funds cannot be underestimated, and the linkages with Horizon 2020, the next framework programme and InnovFin Energy Demonstration Projects must be strengthened. It goes without saying that the multi-billion-euro Innovation Fund[84] will also be critical for the successful implementation of the SET Plan. No less importance should be given to reinforcing the links between the existing SET Plan Steering Group, the national R&I authorities and funding bodies and stakeholder structures such as ETIPs and EERA. In fact, while the European Commission is certainly a crucial actor, we should keep in mind that the SET Plan is an initiative of all the participating countries. Their governments and administrations are in the driving seat and their joint efforts are the basis for the SET Plan's success.

The SET Plan was designed to increase synergies in Europe whilst avoiding the duplication of efforts in energy technology research, development, demonstration and deployment. **The mobilisation of public and private resources in a coordinated and targeted way (focusing on concrete activities), is and will continue to be at the SET Plan's centre.** In this sense, the SET Plan can play a major role in assessing progress on the R&I pillar of the Energy Union strategy, namely by providing relevant inputs to the integrated national energy and climate plans foreseen under the Energy Union governance model recently proposed. The SET Plan also needs to underpin other EU initiatives under development such as the Clean Energy Industrial Competitiveness Forum and feed into the discussions for the post-2020 EU clean energy R&I financial framework.

Through the SET Plan, these ten years of partnership between countries, industry, research organisations and the European Commission have undoubtedly contributed to numerous breakthrough innovations that are leading to a cleaner, more sustainable and smarter energy system. This partnership needs to become even stronger to accelerate clean energy innovation for the benefit of our citizens and to place the European industry at the forefront of a fair and competitive low-carbon economy.

84 The Innovation Fund will follow NER300 during the period 2021-2030 (cf. footnote 12) as an important EU instrument supporting innovative projects in the fields of renewable energy, CCUS and energy efficiency in industry.

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