The Geothermal ERA NET suggestions and input on the ISSUES PAPER on DEEP GEOTHERMAL ENERGY

This document will summarise the view and input of the Geothermal ERA NET to the Issue Paper on Geothermal Energy. In addition to this specific input, the Geothermal ERA NET have been consulted in the input from ETIP on Deep Geothermal and the consortium supports in general the view of ETIP.

It is the view of the Geothermal ERA NET that the proposed Issue Paper does not cover well enough the vast opportunities laying in the utilisation of geothermal for smart heat and as a part of community integrated energy systems. There is great potential for the increased utilization of geothermal energy for heating in Europe, including many countries that currently rely on fossil fuels for their heating needs and thus have high greenhouse gas emissions. As an example, in many cities in Eastern Europe there exist district heating systems that can easily be adapted to use local geothermal resources instead of imported fossil fuels. This would increase both energy security and price stability, in addition to curbing greenhouse gas emissions. Several cities in Hungary and Romania have implemented geothermal district heating systems, as well as in other countries in the region. Besides, there is also a potential for an increased use of geothermal heat in industry and agriculture. Unlocking all of this potential will be enabled by research and innovation that leads to improvement of the technology and its incorporation into the energy system. Smart integration of geothermal (together with underground heat and cold storage) into our energy system is one of the key options for the transition towards a 100% renewable heat supply in our communities (for heating our buildings, food production, and industries).

Therefore, the Geothermal ERA NET would like to emphasize innovative smart integration of geothermal into the European energy system, as a key towards carbon-neutral concepts for heating and cooling, by using heat for different applications and combining it with (underground) heat storage

In line with stronger focus on heating and energy system integration the following additional target is proposed by the Geothermal ERA NET

> ***Target related to integration into the energy system and widespread roll-out:***
> Enhance an affordable and widespread roll-out of geothermal by 2025, by developing at least 25 large scale projects, demonstrating innovative integrated concepts in which geothermal energy plays a central role towards a carbon-neutral energy system, creating added value to their communities.

And subsequent action

> ***Action: Launch a ComInGeo flagship programme (Community Integrated Geothermal)***
> ***Scope:*** *Geothermal Energy is one of the few options for a transition towards 100% renewable heat supply. It is crucial to develop innovative concepts that demonstrate this potential, and pave the way for a widespread roll-out. The goal of this action is to develop at least 25 large scale integrated demo projects in different settings, where geothermal energy (possibly in combination with geological heat storage) plays a central role towards a carbon-neutral energy system. The projects should demonstrate smart integration of geothermal energy into the energy system, addressing themes such as space heating and cooling, greenhouse heating, industrial heating and cooling, low-exergy solutions ("Smart Heat"), additional benefits, and increased generation of revenues.*
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> ***Deliverables:*** *25 Demonstration sites in different geological plays and community settings, including cooling versus heating-only, and hybrid combinations of carbon-neutral sources of heating and cooling.*

EUROPEAN COMMISSION
RTD - Energy
ENER - Renewables, R&I, Energy
Efficiency JRC – Institute for Energy and
Transport **SET Plan Secretariat**

Geothermal ERA NET suggested version of the

ISSUES PAPER on DEEP GEOTHERMAL ENERGY

Introduction – Geothermal Energy

Geothermal energy is a valuable and local source of energy that can cost-effectively provide base-load/dispatchable electricity, heat or a combination of both. Geothermal reservoirs may also act as sites for energy storage as well as CO_2 storage. Geothermal energy has great potential as a renewable source not only in Europe but also globally, in particular in many developing countries. It is convenient and accepted to divide the geothermal sector into "deep" and "shallow" geothermal sectors. The actual depth that marks the boundary between "deep" and "shallow" differs highly across regions and is to most extent dependent on the local geothermal gradient, i.e. the temperature of the resource. The distinction between the two usually corresponds to whether or not primary use of the energy requires the use of heat-pumps. Nevertheless, the reference to the deep/shallow terminology provides a general understanding of the technologies needed and of the possible applications of the geothermal energy harnessed from the Earth. This issues paper focuses on deep geothermal energy[1], which can be directly used as heat or converted into electricity.

Geothermal energy for direct use (e.g. hot water and space heating) is probably the oldest use of renewable energy. The first geothermal plant for electricity production started operations in Italy as early as 1904. Since then, the technology to use and transform geothermal heat coming from the Earth's subsurface, and knowledge of the geological and physical processes involved have greatly increased. However, geothermal energy is still only utilized in choice regions, that are well-explored and with known high-quality reserves.

Deep geothermal energy can technically be extracted for power, heat or cogeneration from a variety of geological media although the effort and cost related to this extraction can vary greatly. A geological formation with natural fractures and/or a porous structure where water can move readily is termed a hydrothermal reservoir. The technologies associated with hydrothermal power and heat production are available and the large majority of existing geothermal energy systems exploit hydrothermal resources. Nevertheless, further innovations are needed to reduce the uncertainty of finding reserves, and costs to unlock the vast European geothermal potential that has not yet been utilised. Moreover, new technologies should be developed to improve the environmental performance of high-temperature geothermal power generation systems, minimizing the release into the biosphere and atmosphere of potentially hazardous chemical compounds as well as non-condensable gases (NCGs) like alkanes, carbon dioxide, hydrogen sulphide, nitrous and sulphurous

[1] The shallow geothermal sector will be covered in a separate issues paper

oxides, some of which contribute to global warming.

In many geological formations there is no natural hydrothermal reservoir to be utilized because there is insufficient or little natural permeability or fluid saturation; in such systems heat transfer occurs almost exclusively by conduction. Through application of EGS (Enhanced or Engineered Geothermal Systems) techniques, it is possible to create or improve a hot water reservoir by increasing the permeability by injecting water at sufficient pressure into the subsurface to extract heat. The hot water is pumped to the surface and used to produce power and heat, before being recycled and re-injected into the subsurface. The origins of EGS technologies date back several decades, and have been regarded as proven in Europe at meso-scale since the commissioning of a successful pilot plant at Soultz-sous-Forêts in 2007, now in the hands of private industry and producing power since 2010; nevertheless, EGS technologies remain in development.

Nowadays **geothermal heat** is directly used, depending on its temperature, in a number of sectors: from bathing and swimming to industry, agriculture and district heating. The latter are the most promising sectors for large-scale uptake of geothermal heat. For example, there are currently 257 geothermal district heating systems in Europe, with a total installed capacity of 4.6 GW_{th} (EGEC[2] 2015 data). Data on direct use are difficult to find and variable in quality, making statistically robust comparisons difficult. Nevertheless, the growing importance of geothermal heat as a local source of energy is evident. There is great potential for the increased utilization of geothermal energy for heating in Europe, including many countries that currently rely on fossil fuels for their heating needs and thus have high greenhouse gas emissions. As an example, in many cities in Eastern Europe there exist district heating systems that can easily be adapted to use local geothermal resources instead of imported fossil fuels. This would increase both energy security and price stability, in addition to curbing greenhouse gas emissions. Several cities in Hungary and Romania have implemented geothermal district heating systems, as have other countries in the region. Importantly, there is also a potential for an increased use of geothermal heat in industry and agriculture. Unlocking all of this potential will be enabled by research and innovation that leads to improvement of the technology and its incorporation into the energy system. Smart integration of geothermal (together with underground heat and cold storage) into our energy system is one of the key options for the transition towards a 100% renewable heat supply in our communities (for heating our buildings, food production, and industries). The importance of decarbonization of Europe's heating systems is underlined by the EU Strategy on Heating and Cooling[3].

According to the EGEC Market Report Update, in 2015 the total capacity for **geothermal electricity** generation in Europe was about 2.2 GW_e, installed in 84 power plants (of which there are 0.95 GW_e in 51 plants in EU28). The total installed capacity is expected to reach 3.5 GW_e by 2018 including the rapidly growing Turkish market. In the world, the total installed capacity in 2013 was 12 GW_e producing 76 TWh/y and, according to IEA-GIA projections, there are readily available resources for a supply of 1,400 TWh/y (equal to 3.5% of global electricity production) by 2050[4], half of it produced by EGS (Enhanced Geothermal System) plants. The geothermal power market is particularly dynamic in the USA, Philippines, Indonesia, Mexico and Kenya and could be invigorated in the near future in the EU if unconventional geothermal resources (supercritical, magmatic, geopressurized, off-shore… etc) and EGS systems can be commercialised successfully under a wide range of geological and thermodynamical conditions, if power markets were better interconnected and if social acceptance were higher.

[2] EGEC, Market Report 2015.

[3] An EU Strategy on Heating and Cooling, COM(2016)51, 16.02.2016

[4] IEA-GIA, Trends in Geothermal Applications 2013 and IEA, Technology Roadmaps - Geothermal Heat and Power, 2011

Recent JRC-EU_TIMES modelling results[5] predict geothermal power production of 540 TWh in 2050 under a long-term decarbonisation scenario. This would mean that geothermal power could provide 12.5 % of the EU electricity demand while exploiting about 20 % of the available geothermal technical potential[6]. This market share might be increased significantly if reductions in upstream development costs can be realised. On volcanic islands geothermal energy could provide the highest share of renewable heat and power.

Even when a geothermal play – a geological setting where heat source, heat migration, heat storage and technical options to produce the heat to surface – has been understood, installations are characterized by low OPEX but high CAPEX, used mostly to cover the costs of exploration and drilling, and the plant construction. In addition, financing costs are high due to high risks associated with proving reserves during early-stage exploration. However, high capacity factors (far higher than most other renewables) and low OPEX result in an LCOE very similar to those of other renewable and low-carbon technologies[7].

<u>Why taking action now on geothermal energy?</u>

The European Commission moves ahead with its goals for decarbonization of the economy. The target reduction of greenhouse gases is 40% by 2030, which would double the achievement of 20% by 2020 in just 10 years. Recognizing the excellent potential for geothermal energy in Europe a number of NREAPs (National Renewable Energy Action Plans) have declared ambitious targets for development. Continued technological developments (binary plants) have made it possible to cost-effectively produce electricity with fluids at ever-lower temperatures; there is also an increasing awareness of the potential for geothermal heat use. In order to stimulate the uptake of geothermal energy the following issues need to be addressed to improve performance and reduce unit costs, and make widespread implementation possible:

- Reduce exploration risk and subsurface development costs, to increase success rates at lower CAPEX;
- Improve the overall efficiency of geothermal installations primarily by ensuring sufficient mass circulation flow with low pressure drop covering high sweep area across the reservoirs, by enabling high heat transfer to the surface installations and by optimizing reservoir management;
- Improve the environmental performance applying “closed-loop” power generation systems, including the total reinjection of geothermal fluids (liquids and non-condensable gases) in high NCGs content reservoirs;
- Demonstrate innovative smart integration of geothermal into the energy system, as a key towards carbon-neutral concepts for heating and cooling, by using heat for different applications and combining it with (underground) heat storage.

These are enabling steps to bring geothermal technologies to full commercial scale in many more locations across Europe and to allow for widespread harnessing of geothermal energy. Additional research for use of geothermal energy in hybrid systems together with other renewables as well as the development of unconventional resources (e.g. supercritical, magmatic, geopressurized, off-shore…) should facilitate expansion of the range of applications of geothermal energy utilization in Europe, extending the resource base both geographically and economically.

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[5] 2015 JRC Geothermal Energy Status Report. The JRC-EU-TIMES[7] - a system cost optimization model for technology deployment - is used to assess how different exogenous policy-driven decarbonisation pathways affect the power sector's technological deployment until 2050

[6] Highly energy efficient scenario with constrained total primary energy consumption of 1319 Mtoe in 2050 and a full decarbonisation of the power sector.

[7] 2014 JRC Geothermal Energy Status Report.

Targets

Building on the Integrated Roadmap of the SET Plan, public (EC and Member States/Regions) and private investment must focus on targeted R&I actions to achieve the following goals in terms of performance and cost-reductions. The proposed targets are as follows:

Related to unit cost reduction – references are first-of-a-kind projects in a particular play:

1. Reduce the exploration costs and improve success rates of finding reserves by 10% in 2020, 30% in 2030 and by 50% in 2050.
2. Reduce the unit cost of drilling (€/MWh) by 30% in 2030 and by 50% in 2050.

Related to performance improvements:

3. Improve reservoir management and performance (included stimulation) mitigating unwanted side effects (induced seismicity, emissions to the environment) and ensure sustainable yield.
4. Improve the overall conversion efficiency of geothermal installations at different thermodynamical conditions by at least 5% in 2030 and 10% in 2050, and enhancement of economics through cascading and system integration.

Related to integration into the energy system and widespread roll-out:

5. Enhance an affordable and widespread roll-out of geothermal by 2025, by developing at least 25 large scale projects, demonstrating innovative integrated concepts in which geothermal energy plays a central role towards a carbon-neutral energy system, creating added value to their communities.

Related to EGS and Unconventional Resources:

6. Reduce production costs from EGS and Unconventional Resources below 10 €ct/kWh_e for electricity and 3 €ct/kWh_{th} for heat by 2030 in well-established plays and embark on a cost reduction path for other play systems via a suite of pilot and demonstration projects.

Annex: Targeted R&I actions for geothermal energy development

A. Proposed targeted R&I actions

Advanced Research Programme for improving deep geothermal production technologies

Action 1: Enhanced reservoir exploration and characterization from surface and subsurface

Scope: Exploration technologies for subsurface imaging and resource characterization are crucial prior to exploration drilling. The goals are delineation of the geologic structure and characterization of bulk properties of the reservoir to assess its performance. Process understanding of the heat transfer processes, the stress field and fracture patterns related to fluid flow in the reservoir are important. Full-scale investigations of the basic hydraulic, mechanical and chemical processes are required. Advanced reprocessing and modelling of existing data for new depth targets of exploration for EGS are required to reduce exploration risk. Such advanced workflows will need to incorporate tectono-structural modelling, which in turn improve successful targeting of natural fracture permeability. Full-scale investigations of the basic hydraulic, mechanical and chemical processes are required to successfully engineer reservoirs to design specifications.

Deliverables: *Innovative, cost-effective, subsurface imaging, processing and modelling tools to characterize reservoirs including application of new integrated geological, geochemical and geophysical methods.*

Action 2: Completion technologies, wellbore integrity and novel drilling technologies

Scope: Reliable drilling performance and well completions, which not only optimize in- and outflow of wells, but also ensure well integrity are crucial to optimize performance and manage environmental hazards from the reservoir wells. This is particularly the case for unconventional geothermal systems. Novel drilling concepts at the technological frontier may lead to dramatic reductions in unit development cost (€/MWh), albeit not in the immediate future. Having a lower technology maturation level, support for applied basic research is necessary to ensure availability of novel drilling concepts to the geothermal industry on a medium/long term timeframe. Solutions to remediate operational issues such as scaling and corrosion are needed to secure long-term well/equipment integrities. New technical materials may lead to cost reductions in all of these fields.

Deliverables: *Completion technologies fit for optimal well performance and well integrity; maturation of a range of novel drilling technologies; Geothermal technical system components constructed from novel materials; Cost-effective methods to prevent corrosion and scaling in various geological and geochemical circumstances.*

Action 3: Enhanced reservoir engineering

Scope: Existing reservoir stimulation methods need to be further refined to increase project economics (improving well inflow, maximizing reservoir sweep efficiency, minimizing reservoir impedance). This applies also for removal of well and formation damage, for developing and propping over fracture networks, for developing and testing stimulation designs and for managing environmental hazards (e.g. aquifer pollution, exposure to naturally occurring radioactive materials (NORMs), induced seismicity). Research should focus on understanding the underlying processes leading to optimal well and reservoir impedance, and develop concepts to minimise unwanted side effects. These concepts include the use of non-hazardous materials and stimulation approaches. Hydro-thermo-mechanical and geochemical modelling developments are necessary to optimize the reservoir management and manage its long-term evolution.

Deliverables: *Design and field implementation of hydraulic, chemical, thermal stimulation techniques in various play settings (sedimentary/stratified, volcano/tectonic, crystalline/metamorphic). Improved prediction and monitoring of chemical, mineralogical, and hydraulic developments.*

Action 4: Efficient use of geothermal resources and system integration

Scope: Reservoir management leads to a sustainable operation which includes successfully managing corrosion and/or scaling as well as managing environmental impacts (measurement, monitoring and verification). The utilization of geothermal systems depends critically on the temperature range being harnessed to meet demand, as well as load factors for the various applications as well as efficiencies in energy conversion processes. The useful temperature range can be extended by innovations in cascading designs; energy conversion efficiency can be improved by binary plant improvements. In combined heat and power designs, load factors for heat can be significantly enhanced by incorporation of seasonal heat storage, and energy system integration with other renewable energy sources and technologies. Environmental performance of geothermal systems can be continuously improved by zero emissions in the thermal loop. Monitoring technologies are required to assure environmental safety. In general, research infrastructures are required for test and validation of the robustness of novel techniques for exploration, drilling, stimulation, and production at laboratory to field scales, i.e. multi-scale (natural) laboratories, accessible to research & industry.

Deliverables: *development and testing of enhanced designs for thermal loops, conversion and system integration, "closed-loop" power generation systems, resulting in reduction of levelized costs of energy and higher energy output with improved environmental characteristics; multi-scale test and validation facilities for exploration, drilling, stimulation, and sustainable production*

Action 5: Availability and networking of geothermal energy research infrastructures of pan-European interest

Scope: The maturation of a number of innovative research actions requires field piloting and testing in carefully designed and monitored research infrastructure sites. Throughout Europe, a number of national research infrastructure sites exist, currently owned and operated with a view towards meeting national demands and needs. This action aims to truly open up the research infrastructures and complement them on an as needed basis with additional ones.

Deliverables: *Development of a strategy and plan for pan-European research infrastructures for geothermal energy research with a view towards incorporating them in national research infrastructure roadmaps and ultimately uptake in the European Strategy Forum on Research Infrastructures.*

Industrial Pilot and Demonstration Programme

Action 1: Improving deep geothermal field management by closed loop field management and monitoring

Scope: Downhole instrumentation is required to improve performance, reduce environmental impact and increase public acceptance. A reliable and expanded monitoring system should be developed and installed at geothermal sites under development and in operation. That way, hazards such as induced seismicity, exposure to naturally-occurring radioactive materials found in many deep thermal waters, and the protection of fresh water can be better monitored and measures to mitigate unwanted side effects of geothermal development and operations can be defined. For the successful operation of most geothermal projects in non-volcanic environments, there is a need to improve efficiency and longevity of artificial lift systems, to secure production reliability, to develop tools for suppressing two-phase flow in wells, in order to upgrade project economics. Closed loop approaches in which monitoring data are continuously used to update reservoir characterization and predictive models for reservoir and geothermal well and plant performance, and in turn steer decisions in field management

Deliverables: *Application of new monitoring networks including surface installations to measure seismic and other physical properties of the subsurface. Development of high temperature resistant, high efficiency pumps and instrumentation, and advanced high T tracer technology. Measures to predict and reduce corrosion and scaling in operating geothermal plants inclusive new developed inhibitors.*

Action 2: Launch a ComInGeo flagship programme (<u>Com</u>munity <u>In</u>tegrated <u>Geo</u>thermal)

Scope: Geothermal Energy is one of the few options for a transition towards 100% renewable heat supply. It is crucial to develop innovative concepts that demonstrate this potential, and pave the way for a widespread roll-out. The goal of this action is to develop at least 25 large scale integrated demonstration projects in different settings, where geothermal energy (possibly in combination with geological heat storage) plays a central role towards a carbon-neutral energy system. The projects should demonstrate smart integration of geothermal energy into the energy system, addressing themes such as space heating and cooling, greenhouse heating, industrial heating and cooling, low-exergy solutions ("Smart Heat"), additional benefits, and increased generation of revenues.

Deliverables*: 25 Demonstration sites in different geological plays and community settings, including cooling versus heating-only, and hybrid combinations of carbon-neutral sources of heating and cooling.*

Action 3: Develop an EGS flagship programme

Scope: EGS is a technology for accessing heat in hot but low-permeability basement and sedimentary rocks. Once fully developed it will provide a major increase in the geothermal resource base, both for heat and electric power. At each stage of EGS development, proven methodologies can be applied and bottlenecks identified. The expected outcome will be the development of cost-effective and reliable large EGS plants to make geothermal power fully competitive. Upscaling projects often lead to the development of better or less expensive applications (economies of scale and scope). Such a flagship programme will include the demonstration of public acceptability, which itself required a number of specific actions.

Deliverables: *Demonstration sites in different geological settings (3 plants of 5 MWe-10MWth) and upscaling to10 MWe-20MWth (one plant) and 20 MWe-40MWth (one plant) and establish a network of European EGS test laboratories, a sub-set of which may be part of a pan-European research infrastructure (see Action 7 Research Programme)*.

Action 4: Develop Unconventional Resources programme

Scope: Unconventional Resources (supercritical, magmatic, geopressurized, off-shore, high temperature – high non-condensable gas - hydrothermal), are still in initial development phase, and no pilot plants have been realized so far. It will be necessary to achieve a proof-of-feasibility for each advanced concept in some test site, like – for instance – Italy, Turkey or Iceland for supercritical/high pressure/temperature conditions and launch a pilot plant phase.

Deliverables: *Up to 10 different pilot and demonstration sites in different geological settings and unconventional resource category. Some of them may be part of a network of a pan-European Research Infrastructure.*

B. Framework conditions – policy measures

Innovative and Market-uptake Programme

Action 1: Aiding decision making in a complex and uncertain subsurface world

Scope: Project developers face very complex and highly uncertain decision-making processes in the early stages of field development until the reservoir has been proven. The subsurface model for a given resource remains poorly constrained, reserves are not proven and development scenarios are highly uncertain. The principle technical barrier with a major economic down-side is the risk of drilling "dry wells" during early exploration for new reservoirs. Additional technical risks that derive from a poor understanding of subsurface dynamics are for example, seismic risks associated with EGS projects and ground deformation associated with exploitation of shallow reservoirs. To date industry has only a rudimentary knowledge on the success of mitigation actions identified accordingly in, for example, stimulation planning. Since a number of technical risks with significant adverse financial consequences derive from poor knowledge of Europe's subsurface, risks may be transferred to the general public. One effective transfer mechanism is an insurance or guarantee scheme, which offsets exploration and development risk until technological solutions are available to manage these technical risks. The scheme should act as a stimulus until the initial high level risk have been mastered and developers are able to carry out exploration/development without having to transfer these technical risks that result from the lack of knowledge of the subsurface.

Deliverables: *Standards and methods for those technical risks that can be transferred to the public (e.g. European Geothermal Risk Insurance for transferring geological risk to the public). Harmonized resource reporting for valuation purposes.*

Action 2: Subsurface data information systems and catalogues, resource potential awareness

Scope: A wealth of subsurface information of geothermal prospects is available from exploration and production of the hydrocarbon exploration and production. For hydrocarbon exploration it is estimated that at least 1000 billion euro has been invested in exploring oil and gas reservoir in the past 50 years – or about one year's worth of total capital expenditures in the worldwide hydrocarbon industry. Data include well bore cores and logs, geophysical surveys including seismic images, and other geophysical dataset, temperature and stress measurement. These are all of great relevance for identifying potential prospects and reducing exploration risk in site development. In many EU countries data are not publically accessible, and/or not harnessed in information systems and rock physics catalogues. Doing so enables stakeholders to identify geothermal prospectivity and access at low cost critical parameters for (predictive models for) resource characterization. It augments to awareness of the resource potential to a variety of stakeholders, increases exploration efficiency and furthermore the datasets and catalogues are key for R&D development. Finally, it helps permitting and regulatory authorities to perform their duties.

Deliverables. *References maps and rocks physics catalogues for the EU geothermal resource base, harmonized access to underlying catalogues (data base systems), information systems. Evaluation of the EU EGS potential; European Information Platform for Geothermal Energy.*