European Technology
Deep Geothermal
& Innovation Platform

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Subject: Input paper - consolidated response to European Commission's Issues Paper on DEEP GEOTHERMAL ENERGY

Integrated SET Plan Actions Nr.1&2

Dear Sir or Madam,

The newly created ETIP on deep geothermal welcomes the publication of the Issues Paper for deep geothermal

The Geothermal ETIP is an open stakeholder group, including representatives from industry, academia, research centres, and sectoral associations, covering the entire deep geothermal energy exploration, production and utilisation value chain.

Its mission is to provide a framework for stakeholders to define and implement an innovation strategy to increase the use of geothermal and to foster the growth and the market uptake of the relevant European industries.

Since the opening of the consultation of the issues paper on 26th of May 2016, the ETIP has consulted its members, the European geothermal industry: EGEC, the EERA-JPGE and the ERANET-geothermal.

A consolidated response is provided here, following approval from the Steering Committee of the ETIP on deep geothermal.

The ETIP supports the ambition set in the Issues Paper for deep geothermal but wishes to propose new targets and further actions.

We are available for any further clarification and we look forward to the working meeting with the SET Plan Steering Group.

Yours faithfully,

Ruggero Bertani

Enel Green Power

Chairman ETIP deep geothermal

List of Attachments:

- Comments to the Issues paper on deep geothermal

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

Integrated SET Plan Actions Nr.1&2

ISSUES PAPER on DEEP GEOTHERMAL ENERGY

Purpose of this document

This document[1] is intended to progress the implementation of the actions contained in the SET-Plan Communication[2] and specifically the actions concerned with the priority "Number 1 in renewable energy". It is part of a series of Issues Papers jointly prepared by the services of the European Commission and discussed with the representatives of EU member states and countries part of the SET Plan, working together in the SET Plan Steering Group.

The Issues Papers propose strategic targets in different areas of the energy sector to stakeholders. The input from, and positions of, stakeholders for each area will be used to come to an agreement on targets in a dedicated meeting of the SET Plan Steering Group in which key stakeholders are represented.

Stakeholders are invited to take position on the proposed targets in accordance with the guidelines set out in the paper "The SET Plan actions: implementation process and expected outcomes" and submit their positions to SET-PLAN-SECRETARIAT@ec.europa.eu by **17 June 2016** at the latest. All relevant documents and material are available on the SETIS website https://setis.ec.europa.eu/ .

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. With these features, it has the potential to provide real alternatives to replace fossil fuel based power plants. In addition, it has great potential as a renewable source not only in Europe but also globally, in particular in many developing countries. It is convenient to divide the geothermal sector into "deep" and "shallow" geothermal sectors- a commonly accepted segregation. 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

[1] This document is a working document of the European Commission services for consultation and does not prejudge the final form of any future decisions by the Commission

[2] Towards an Integrated Strategic Energy Technology (SET) Plan: Accelerating the European Energy System Transformation" (C(2015)6317)

energy harnessed from the earth. This issues paper focuses on deep geothermal energy[3], 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 beneath the Earth's surface and knowledge of the geological and physical processes involved has greatly increased.

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 within which water can move 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 costs and risks to realise 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, avoiding the release of steam and potentially hazardous chemical compounds into the atmosphere from the cooling tower, as well as non-condensable gases (NCGs) like carbon dioxide which have a negative impact on global warming.

In many geological formations there is no natural hydrothermal reservoir because there is insufficient or little natural permeability or fluid saturation; in such systems heat transfer occurs almost exclusively by conduction. Through EGS (Enhanced or Engineered Geothermal Systems) techniques it is possible to create or improve a hot water reservoir by increasing the permeability and injecting water at sufficient pressure into the subsurface where it is heated up. 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 at meso-scale since the commissioning of a successful pilot plant at Soultz-sous-Forêts in 2007, in the power production phase since 2010; nevertheless, EGS remains a technology in development.

Today **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} (2015 data published by EGEC[4]). Data on direct use is 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 utilization of geothermal energy for heating in Europe, including many countries that currently rely on fossil fuels for their heating needs. As an example, there are many cities in Eastern Europe with district heating systems that can easily be adapted to use local geothermal resources instead of imported fossil fuels. This would increase energy security and price stability as well as independence from fossil fuel sources. This has been implemented in several cities in Hungary and Romania, amongst other countries in the region. In addition, there is also a potential for an increased use of geothermal heat in industry and agriculture. The unlocking of all of this potential will be enabled by research and innovation which leads to the improvement of technology and its incorporation into the energy system. Smart integration of geothermal (together with

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

[4] EGEC, Market Report 2015.

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 decarbonising our heating systems is underlined by the EU Strategy on Heating and Cooling[5].

According to the EGEC Market Report Update, in 2015 the total installed capacity for **geothermal electricity** generation in Europe was about 2.2 GW_e, generated by 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 in 2018 including the promising 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, it could increase to reach 1,400 TWh/y (equal to 3.5% of global electricity production) by 2050[6], 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 EGS can be commercialised successfully under a wider range of geological conditions.

Recent modelling results[7] by the JRC-EU-TIMES model 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[8]. This market share might be increased significantly if reductions in drilling costs can be realised. On volcanic islands geothermal energy could provide the highest share of renewable heat and power.

Geothermal installations are characterised 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 costly drilling during early-stage exploration. Market financiers generally are unwilling to take up these early stage risks and costs, which represents one of the major barriers for geothermal project developers. However, high capacity factors (far higher than most other renewables) and low OPEX result in LCOE very similar to those of other renewable and low-carbon technologies[9].

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

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

[7] 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

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

[9] 2014 JRC Geothermal Energy Status Report.

Why take action now on geothermal energy?

Geothermal energy has excellent potential in Europe, and there are ambitious targets for it in a number of NREAPs (National Renewable Energy Action Plans). The European Union has set a target of having 40% of its energy supply coming from renewables in 2030, doubling its planned achievement of 20% for 2020 in just 10 years. Recent technological developments (binary plants) have made it possible to cost-effectively produce electricity with fluids at 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 tackled to improve performance and reduce costs, and make widespread implementation possible:

- improve the overall efficiency of geothermal installations primarily by ensuring sufficient mass circulation flow through the reservoirs, enabling high heat transfer to the surface installations and by succeeding in optimal reservoir management;
- improve the overall efficiency by bottoming steam turbine with binary cycles;
- Improve the environmental performance applying "closed-loop" power generation systems, including the total reinjection of geothermal fluids (liquid and non-condensable gases) in high temperature – high NCGs content reservoirs;
- Reduce exploration and drilling costs, to lower CAPEX and the risk of project failure;
- Demonstrate innovative smart integration of geothermal energy 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 the steps to bring geothermal technologies to full commercial scale and to allow for widespread use of geothermal energy. Additional research for use of geothermal energy in hybrid systems together with other renewables (biomass, solar thermal and photovoltaic etc.) as well as the development of unconventional resources (e.g. supercritical, magmatic, geopressurised, off-shore etc.) should facilitate expansion of the range of applications of geothermal energy utilisation in Europe, extending the resource base both geographically and economically.

In addition, setting up a European wide or national geothermal insurance schemes to cover the early-stage geological and drilling risks of geothermal developments would significantly contribute to a major increase in the number of geothermal projects.

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 cost reduction:

1. Reduce the exploration costs and pre-drill mining risk by improved success rates of exploration drilling by 10% in 2020, 30% in 2030 and by 50% in 2050.
2. Reduce the drilling costs by 30% in 2030 and by 50% in 2050.
3. Transparent and harmonised methods and instruments for technical and financial risk management.

Related to performance improvements:

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, system integration and bottoming of geothermal steam plants.
5. Improve reservoir management (included stimulation) mitigating unsolicited side effects (induced seismicity, emissions to the environment) and ensure sustainable yield.
6. Improve performance of stimulated reservoirs by 50% in 2020.

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

7. Enable an affordable and widespread roll-out of geothermal by 2025, by developing 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:

8. Reduce EGS production costs below 10 €ct/kWh_e for electricity and 3 €ct/kWh_{th} for heat by 2025 establish five EGS plants (can be part of above mentioned geothermal development) in different geological situations, of which at least one with large capacity, for the technology to reach commercial-scale stage.
9. Develop 10 pilot plants in 2030 (can be part of above mentioned geothermal development) in different geological settings, harnessing unconventional resources (supercritical, magmatic, geopressurized, off-shore, high temperature – high NGGs hydrothermal), and / or hybrid solutions which couple geothermal with other energy sources.

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, surface and bottom-hole

Scope: Exploration technologies for subsurface imaging and resource characterisation are crucial prior to locating drilling targets. Advanced geophysical exploration technology and integration of new methods are needed, in order to increase the exploration drilling success rate and effectively reduce mining risk The goals are delineation of the geologic structure and characterisation of bulk properties of the reservoir to assess its performance. Processes 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. Targeting natural fracture permeability by application of accurate tectono-structural modelling approaches has to be improved. Advanced reprocessing and modelling of existing data for new depth targets of exploration for EGS are required to enhance reduction of pre-drill mining risk. Full-scale investigations of the basic hydraulic, mechanical and chemical processes are required.

Deliverables: *Innovative, cost-effective, subsurface imaging, processing and modelling tools capable of investigating down to reservoir depth including application of new integrated geological, geochemical and geophysical methods, surface and bottom-hole.*

Action 2: Wellbore integrity and novel drilling technologies

Scope: Reliable drilling performance and completion which ensures well integrity are crucial to mitigate environmental effects from the utilised wells. Novel drilling concepts at the technological frontier are expected to allow for dramatic drilling time and cost reductions in the future. The concepts should be investigated and applied research supported in order to have these techniques available for geothermal drilling in the medium/long term timeframe. Advanced drilling and completion techniques have to be developed also for very high temperature resources, as currently under investigation in several places worldwide. A non-exhaustive list of concepts comprises: millimetre wave deep drilling, water jet drilling, hydrothermal and instant steam spallation drilling, robotic, ultra-deep, high temperature/pressure drilling technologies. Other technologies such as laser drilling and fusion drilling should first be analysed by reliable assessment studies to prove their basic viability.

Deliverables: *Concepts for well integrity; selected prospective drilling technologies.*

Action 3: Enhanced reservoir engineering

Scope: Existing reservoir stimulation methods need to be further refined to increase rate of success, to improve predictability of results, to remove well and formation damage, to develop and prop open fracture networks, and to reduce potential 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 improved permeability and develop concepts to minimise unwanted side effects. Hydro-thermo-mechanical and geochemical modelling developments are necessary to optimise reservoir management and predict its long-term evolution. These concepts include the use of non-hazardous materials and soft stimulation approaches.

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

Action 4: Corrosion and scaling processes and new material solutions

Scope: Corrosion and scaling are among the main problems during operation of deep geothermal plants, jeopardising plant efficiency and longevity. Corrosion and scaling are not isolated processes but an aspect of the entire system. Therefore, the interaction of terrestrial fluids with reservoir rocks and with technical materials with has to be systematically investigated by basic research to prevent design shortcomings and secure well/equipment integrities.

Deliverables: *Design and testing of low cost, high temperature / high pressure mechanically-resistant metals, alloys, and composite materials. Study of interaction of geothermal fluids from different geological environments with standard and newly developed specific alloys and composite materials as technical system components of the geothermal cycle (e.g. tubing, cements, sealants, well head designs, heat exchangers etc).*

Action 5: Efficient use of geothermal resources and system integration

Scope: Reservoir management leads to a sustainable operation including control of corrosion and/or scaling issues as well as environmental impact monitoring. Performance of geothermal systems is critically dependent on the temperature range being used for energy production, load factor and the energy conversion process. The temperature range can be extended by innovations in cascading designs and energy conversion efficiency can be improved by binary plant improvements. In combined heat and power designs, load factor for heat can be significantly enhanced by incorporation of seasonal heat storage, and energy system integration with other renewable energy sources and technologies. In addition, environmental performance of geothermal systems can be improved by zero emissions in the thermal loop. Monitoring technologies have to be available to ensure environmental safety. A key requirement for the long-term improvement of reservoir management and sustainable geothermal operations is the availability of and access to research infrastructures, i.e. multi-scale (natural) laboratories for testing and validating of the robustness of novel techniques for exploration, drilling, stimulation, and production at laboratory to field scales, accessible to research & industry.

Deliverables: *development and testing of enhanced designs for thermal loop, conversion and system integration, resulting in reduction of levelised costs of energy and higher energy output; multi-scale test and validation facilities for exploration, drilling, stimulation, and sustainable production*

Action 6: Improve environmental performance of power generation systems

Scope: The improvement of the environmental performance of power generation systems is crucial to increase social acceptance. The goal is to avoid the emission into the atmosphere of steam and potentially hazardous chemical compounds from the cooling towers as well as non-condensable gases (NCGs) like carbon dioxide which have a negative impact on global warming.

Deliverables: *Development of innovative, cost-effective, “closed loop” power generation systems by different types of geothermal resources capable to ensure the total reinjection and avoiding the emission of hazardous chemical compounds in the environment.*

Industrial Research 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 controlled 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 pump efficiency and longevity, to secure production reliability, to develop tools for suppressing two-phase flow in wells, etc., in order to upgrade exploitation economics. The harsh geological environment of geothermal installations can lead to corrosion and precipitation from thermal waters, which can accelerate a decline in productivity if left unchecked. Closed loop approaches in which monitoring data is continuously used to update reservoir characterisation 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 (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 up to 25 large scale integrated demo projects in different settings, where geothermal energy (possibly in combination with geological heat storage, cogeneration, multi-purpose use, and with cascade uses including power generation) 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 the 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 (cascading effect for drilling). Such flagship programme has to include the demonstration of public acceptability, which itself required a number of specific actions.

Deliverables: *Five demonstration sites in different geological settings (3 plants of 5 MWe-10MWth) and upscale (1 plant=10 MWe-20MWth and 1 plant=20 MWe-40MWth) and establish a network of European EGS test laboratories*.

Action 4: Develop Unconventional Resources programme

Scope: Unconventional Resources (supercritical, magmatic, geopressurised, off-shore, high temperature – high NGGs hydrothermal), a hybrid utilization of geothermal brine with binary cycle) and of the fossil fuel content in the geothermal resource with total re-injection of the produced CO2) are technologies still at an initial development phase. No pilot plants have been developed so far. It will be necessary to achieve a proof-of-feasibility in some test sites, in for instance Italy or Iceland for supercritical/high pressure/ high temperature conditions and launch a pilot plant phase. Moreover it is important also to improve the overall efficiency of the traditional plants with bottoming steam turbines with binary cycles.

Deliverables: *Up to 10 different Demonstration sites in different geological settings and unconventional resource category, and establish a network of European Research laboratories*.

B. Framework conditions – policy measures

Innovation and Market-uptake Programme

Action 1: Technical and financial risk management

Scope: Several risk factors (e.g. technical, financial, and environmental) need to be carefully evaluated during the exploration phase while the subsurface model for a given reservoir remains poorly constrained, the resource is not yet completely proven and the development scenarios are not yet clearly defined. The principle economic barrier is the risk of "dry wells" during early exploration stages of new reservoirs. As pilot production commences, seismic risks associated with EGS projects and ground deformation associated with exploitation of shallow reservoirs should be addressed and mitigation actions identified accordingly in stimulation planning. It is assumed that in early exploratory stages a framework insurance policy would be promoted to mitigate the exploration risk. It should act as a stimulus until, after the initial high level risk be mastered, developers carry out exploration/development issues under their own responsibility and resources.

Deliverables: *Standards and methods for technical and financial risk management, including resource reporting, performance assessment, and a European Geothermal Risk Insurance for reducing the geological risk*.

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 exploration it is estimated that at least 1000 billion euro has been invested in exploring oil and gas reservoirs in the past 50 years. Data includes well bore cores and logs, geophysical surveys including seismic images, and other geophysical datasets, temperature and stress measurement. These are all of great relevance for identifying potential prospects and reducing pre-drill mining risk in site development. In many EU countries data is not publically accessible, and/or not harnessed in information systems and rock physics catalogues. Making this data available by law will remove one of the major obstacles in geothermal project development and unleash a wave of activity and investment in the sector, as it would enable stakeholders to identify geothermal prospects. It will also allow access, at low cost, to critical parameters for resource characterisation. Datasets and catalogues are key for R&D activities.

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

Action 3: Public acceptance of geothermal technologies

Scope: The public will increasingly come in contact with geothermal technology as it becomes more widely used. General awareness and understanding of the technology will need to increase in parallel with scientific innovation and deployment. The public and policy makers must become more familiar with the technology and effective policy options in order for the industry to develop. In particular, issues such as microseismicity, stimulation, environmental impact, and emissions should be considered in any attempts to ensure socio-political acceptance. In turn, consumers and investors should become more aware of the potential opportunities and challenges inherent in participating in geothermal projects. The development of strong communication methodologies and strategies which address the interests of all stakeholders is a requirement for acceptance and sustainability.

Deliverable: *Impact guidelines for social acceptance of geothermal installations. Protocol for collecting technical, economic, environmental and social information about geothermal projects; Stakeholder identification, classification and mapping; Integrated model for managing social acceptance.*