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 to stakeholders strategic targets in different areas of the energy sector. 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 with a representation of key stakeholders.
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. It has great potential as a renewable source not only in Europe but also globally, in particular in some developing countries. It is convenient and accepted to divide the geothermal sector into "deep" geothermal 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, ie. the temperature of the resource. Nevertheless, the reference to the deep/shallow terminology provides a general understanding of the technologies needed

[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).

and of the possible applications of the geothermal 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 source of renewable energy, and the first geothermal plant for electricity production started operations in Italy already in 1904. Since then, the technology to use and transform geothermal heat coming from beneath the Earth's surface, the knowledge of the geology and also the understanding of the physical processes involved have 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 where water can move is termed hydrothermal reservoir. The technologies associated with hydrothermal power and heat production may be considered as mature and the large majority of geothermal energy stems from hydrothermal resources.

In many geological formations there is no natural hydrothermal reservoir because there is insufficient or little natural permeability or fluid saturation, in such cases heat is distributed by conduction. Through EGS (Enhanced or Engineered Geothermal Systems) 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 then pumped back to the surface and used to produce power and heat, before being recycled and re-injected back into the subsurface. The EGS technologies are proven on small scale since 2007 but they are still in the development process.

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. This latter being the most promising sector for geothermal heat. In Europe there are 257 geothermal district heating systems, with total installed capacity of 4.6 GWth (2015 data published by EGEC[4]). Data on direct use is difficult to find and statistically not homogenous[5], yet the growing importance of geothermal heat as a local source of energy is evident.

According to the EGEC Market Report Update, in 2015 the total installed capacity for **geothermal electricity** generation in Europe was about 2.2 GWe, generated by 84 power plants (thereof, 0.95 GWe in 51 plants in EU28). The total installed capacity is expected to reach 3.5 GWe in 2018, mainly thanks to the very promising Turkish market. In the world, the total installed capacity in 2013 was 12 GWe 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 interesting in the USA, Philippines, Indonesia, Mexico, Kenya and can be made interesting in the near future in the EU if EGS will be commercialised under various geological conditions.

[3] The shallow geothermal sector will be covered in a separate issues paper.
[4] EGEC, Market Report 2015.
[5] According to the IEA-GIA 2013 report geothermal heat production reached about 150 TWh/yr in 2013 and it is projected to reach about 1,600 TWh/yr in 2050.
[6] IEA-GIA, Trends in Geothermal Applications 2013 and IEA, Technology Roadmaps - Geothermal Heat and Power, 2011.

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 cost reductions associated with drilling will be realised. In volcanic islands geothermal energy could provide the highest share of renewable heat and power.

Geothermal installations are characterized by low OPEX and 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 during exploration. High capacity factors and low OPEX result in LCOE very similar to other renewable technologies[9].

Power, heat or a combination of both are traditionally generated in areas where hydrothermal, high temperature, resources are available. However, recent technological developments are now allowing the valorisation of resources with lower temperatures. In order for geothermal energy to fully meet its potential in the renewable energy mix it is necessary for EGS technology to be commercially available to allow the exploitation of so far untapped geothermal resources[10].

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

Geothermal energy has an excellent potential in Europe, and in a number of NREAP (National Renewable Energy Action Plan) there are ambitious, yet far to be reached, targets for it. Recent technological developments (binary plants) have made possible to cost-effectively produce electricity with fluids at lower temperatures and there is an increasing awareness of the potential of geothermal heat. In order to allow the widespread diffusion of geothermal energy the following issues need to be tackled to improve performance and reduce costs:

- 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;
- reduce exploration and drilling costs <u>in order to </u>to lower CAPEX~~ and the risk of project failure~~.
- <u>reduce exploration risk to improve the success rate of deep geothermal projects</u>
- <u>develop innovative geothermal DH systems in dense urban areas: lower temperature, more efficient, cooling; development towards and integration into smart thermal grids</u>
- <u>provide competitive solutions to provide H&C for the industry (high temperature, storage)</u>

In addition it is necessary to bring EGS at commercial scale, reduce its costs<u>,</u>~~ and~~ increase its performance<u> and upscale plant size</u>, to allow for widespread harnessing of geothermal energy.

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[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.

[10] 2015 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 cost reduction:

1. Reduce the exploration costs by at least 25% in 2020, and by 50% in 2050, expressed as reduced number of abandoned projects;
2. Reduce the drilling costs by 15% in 2020, 30% in 2030 and by 50% in 2050.

Related to performance improvements:

3. Improve the overall efficiency of geothermal installations, increase reservoir management and ensure sustainable yield predicted for a given period +/- 20 years by 2030.

Related to cost reduction and to performance improvements:

4. Reduce EGS production costs below 12 €ct/kWh by 2020; establish 5 EGS plants in different geological situations, of which at least one plant of capacity 20 MWe or 40 MWth, for the technology to reach commercial-scale stage.

5. Develop 10 flexible, efficient, multifunctional and cost-effective smart thermal grids based on geothermal heat: Smart Thermal grids can play an important role in the future Smart Cities by ensuring a reliable and affordable heating and cooling supply to various customers

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Annex: Relevant actions of the document 'Towards an Integrated Roadmap ' needed to achieve the targets

Concrete targeted R&I actions for the long, medium and short term for geothermal energy development in general are proposed in the Annex 2 of the 'Towards an Integrated Roadmap' document. Action 1 from the Advance Research Programme, Action 1 and 2 of the Industrial Research and Demonstration programme and Action 1 of the Innovative and Market-uptake Programme seem to be the most relevant for realising the targets defined in the Issues Paper.

A. Proposed targeted R&I actions

Advanced Research Programme

Action 2: Improving deep geothermal production technologies: reservoir stimulation and management

Scope: Natural permeability of reservoirs is one of the key factors to determine the energy output of geothermal systems by controlling the productivity of a well. Existing stimulation methods need to be refined to increase rate of success, to improve predictability of results, to remove well and formation damage, to develop and prop fracture networks, and to reduce environmental hazard (pollution of aquifer, induced seismicity). Research should focus on understanding the underlying processes leading to improved permeability and develop concepts to minimise unwanted side effects. 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 and hydraulic developments.

Action 3: Improving deep geothermal production technologies: New materials

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 stand alone processes but a matter of the system. Therefore, the interaction of technical materials with terrestrial fluids 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 metal, 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 thermal cycle (e.g. Tubing, cements, sealing, well head, heat exchanger).

Action 4: Costs reduction of deep geothermal drilling technologies: develop novel drilling technologies

Scope: Novel drilling concepts at the technological frontier are expected to allow for dramatic drilling time/cost breakthroughs in an unforeseeable future. The concepts should be investigated today (2014-2016), and basic (and later applied: 2016-2020) research supported in order to have these techniques available for geothermal drilling in the medium/long term timeframe. A non-exhaustive list of concepts comprises: millimetre wave deep drilling, hydrothermal and instant steam spallation drilling, robotic, ultradeep, high temperature/pressure drilling technologies. Other technologies as laser drilling and fusion drilling should first be analysed by reliable assessment studies to prove their basic viability.

Deliverables: selected prospective drilling technologies.

Action 5: Improve exploration technologies

Scope: Exploration technologies for subsurface imaging are crucial prior to locating drilling targets. The goals are delineation of the geologic structure and characterization of bulk properties of the reservoir. 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.

Deliverables: Development of innovative, cost-effective, subsurface imaging tools capable of investigating down to reservoir depth including application of new geological and geophysical methods. Evaluation of the EU EGS potential.

Industrial Research and Demonstration Programme

Action 2: Improving deep geothermal production technologies: innovation in monitoring and operation

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 of induced seismicity, of radioactivity from the deep thermal waters and the protection of drinking 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 avoiding 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, processes accelerating the decline in productivity.

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. Measures to reduce corrosion and scaling in operating geothermal plants inclusive new developed inhibitors.

Action 3: Launch an EGS flagship programme

Scope: EGS is a technology for accessing the heat in hot but impermeable basement rock. 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).

Deliverables: 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 7 Heat and cold underground storage

scope: The ground could also be used for heat or cold storage, UTES (Underground Thermal Energy Storage). Underground Thermal Energy Storage (UTES) can offer leveling of seasonal unbalances in supply and demand. Inter-seasonal heat storage means sustaining deep geothermal reservoir life either as a result of injecting residual heat (hot water) from cooling in summer, thus recharging the resource prior to the next winter heating cycle, or in combination (hybrid mode) with other renewable sources (chiefly solar thermal) or industrial residual heat. Such systems, similar in principle to shallow aquifer thermal energy storage (ATES), require a careful assessment and monitoring of their thermo-chemical (e.g. scaling) and environmental (biochemical, water quality) impacts,

Deliverable: New generation of sensible Thermal Energy Storages: water, be it in tanks, pits, aquifers (groundwater), caverns, abandoned mines, or solid like soil or rock in borehole stores. Demonstration projects of ATES and BTES for temperatures in the range of 40-90 °C to above 90 °C. Improving the efficiency of combined thermal energy transfer and storage: reliable and efficient system performance of thermal storage; more efficient storage through improved heat transfer and heat transport; increased storage density using phase change materials and thermochemical materials. Investigation of behaviour and energy losses of high temperature heat storage in the reservoir

Action 8 Decarbonize the industrial sector with geothermal

scope: Main issues comprise reliability (no stops of production!) and competitiveness. Clean energy is only a budgetary item, arising from emission limits, ETS, etc. The industrial sector is an area of high demand and yet little RES supply and efficiency measures. Innovative solutions and substantial basic research are required in particular in the high temperature ranges from ca 250 °C upwards, to temperatures in excess of 1000 °C. Hybridisation, different system stages, storage, etc. need to be investigated. For the low to medium temperatures, applied research, development and demonstration is crucial to convert known technological solution into practical installations and marketable products. Different renewable energy technologies can provide heat at Low and Medium temperature levels. In the short term, few renewable energy technologies can provide heat at temperatures above 250 ºC at costs competitive with fossil fuel alternatives. In future, deep geothermal technology may effectively supply these needs.

Deliverable: High temperature: CHP installations at high temperature, suitable for energy intensive industry. Low temperature: UTES at 40-90 °C can directly supply heat for low temperature industrial needs such as batch processes or seasonal industries (e.g. sugar refineries), where periods of heat (and/or cold) demand are followed by phases of inactivity. Application of innovative concepts for geothermal energy use in agriculture, aquaculture, drying processes, desalination, industrial uses, snow melting and road de-icing, etc

B. Framework conditions – policy measures

Innovative and Market-uptake Programme

SET Plan Secretariat – 26 May 2016

Action 2: Public acceptance of geothermal technologies

scope: Socio-political acceptance: Of technologies and policies by the public, by key stakeholders, by policy makers market acceptance: Consumers, Investors, Intra-firm community acceptance: communication and information, Integration and involvement, balance of interests and conflict resolution.
it can concern microseismicity, stimulation, environmental impact, emissions.
Development of methodology and strategies with regard to system interaction is a requirement for acceptance and sustainability.

Deliverable: Impact guidelines for social acceptance of geothermal installations

Action 3: Mitigate geological risk associated with geothermal

Scope: Several risk factors (e.g. technical, financial, and environmental) need to be carefully evaluated during the exploration phase while the subsurface model is not well understood, the resource not completely proven and the development scenarios not yet clearly defined. In particular, 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: a European and/or National Geothermal Risk Insurance Funds for reducing the geological risk.

Action 4 Geothermal for Smart cities and rural communities

scope: Smart Thermal grids can play an important role in the future Smart Cities by ensuring a reliable and affordable heating and cooling supply to various customers with renewable energy carrier like solar thermal, biomass and geothermal energy. Smart thermal grids have the following characteristics to make this possible: Flexible, Intelligent, Integrated, Efficient, Competitive, Sizable. They allow increasing the security of supply at a local level using local sources of energy for heating & cooling

Deliverables: the development of smart thermal grids (1st generation) with the building of new district heating & cooling networks, optimization of existing networks, 2nd generation of smart thermal grids with new geothermal combined heat and power plants with low temperature installations and Enhanced Geothermal Systems.

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