SET-Plan Temporary Working Group
<u>Deep Geothermal</u>

Implementation Plan

Approved by TWG members

January 2018

DG TWG Implementation Plan

Main Key Action/Declaration of Intent:

Geothermal energy is a valuable and local source of energy that can cost-effectively provide baseload/dispatchable electricity, heat or a combination of both. With these features, it has the potential to provide real alternatives to replace power plants and heating systems emitting greenhouse gases, not only in Europe but also globally, in particular in some developing countries. In addition, geothermal reservoirs may also act as sites for storage of energy as well as CO_2.

This document focuses on deep geothermal energy, which can be directly used as heat or converted into electricity or used for cooling purposes.

Nowadays geothermal heat is directly used, depending on its temperature, in a number of sectors: from balneology to industry, agriculture to district heating. There is great potential for the utilization of geothermal energy for heating in Europe. There are many locations in Europe with district heating systems that can easily be adapted to make use of local geothermal resources instead of relying on imported fossil fuels. This can increase energy security and price stability as well as independence from fossil fuel sources. In addition, there is also a potential for an increased use of geothermal heat in industry and agriculture. Unlocking of this potential will be enabled through research and innovation focused on the improvement of technology and its incorporation into the energy system. In this way, geothermal energy (together with underground heat storage) will become one of the key options for the transition towards a 100% renewable heat supply in Europe.

According to the EGEC Market Report Update (2017), as of 2016, there exist 102 operating geothermal power plants in Europe, with a total installed capacity of around 2.5 GWel, of which 1 GWel in the European Union. Altogether, there is an estimated total annual electric production of 15 TWh. The total installed capacity is expected to reach $3GW_{el}$ in 2020 including the rapidly growing Turkish market.

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 (e.g. supercritical, magmatic, geo-pressurized, off-shore), including EGS, can be successfully commercialized under a wider range of geological conditions.

Recent modelling results indicate that geothermal power production could reach up to 540 TWh in 2050 under a long-term decarbonisation scenario provided that EGS can be deployed on a large scale. In other words, geothermal power could provide 12.5% of electricity demand in EU and neighbouring countries, while exploiting about 20% of the available geothermal technical potential. This market share might be increased significantly if cost reductions associated with drilling are realized. On volcanic islands geothermal energy could provide the highest share of renewable heat and power.

Geothermal installations are characterized by low OPEX but high CAPEX, used mostly to cover the costs of exploration and drilling, and of the plant construction. In addition, financing costs are high due to high geological risks associated with costly drilling during early-stage exploration. Market financers 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 for most other renewables) and low OPEX, near zero system costs and externalities, result in costs very similar to those of other renewable and low-carbon technologies.

EU industries and operators experience and leadership, as well as European scientific excellence are recognized worldwide. In order to stimulate the uptake of geothermal energy it is necessary to reduce costs and to improve performance. It is also necessary to widen the geological conditions in which technologies can be applied and make technologies to harness

unconventional resources, including EGS, available for the market. In addition, hybrid systems able to integrate energy production from different renewable sources and flexible systems that smooth the geothermal electricity load profile need to be demonstrated.
Environmental performance and social acceptability must be improved.
The worldwide importance of geothermal energy has recently become acknowledged at the political level with the launch of the Geothermal Global Alliance at COP21. This is a coalition of 42 countries and over 29 development and industry partners that have joined political forces to increase the share of geothermal energy in the global energy mix. The Geothermal Global Alliance aspires to achieve a 500 per cent increase in global installed capacity for geothermal power generation and a 200 per cent increase in geothermal heating by 2030. The opportunity for Europe and the European industries, with their knowledge and leadership, in reaching these goals should not be missed.

Targets of the Declaration of Intents (DOI):

1. Increase reservoir performance* resulting in power demand of reservoir pumps to below 10% of gross energy generation and in sustainable yield predicted for at least 30 years by 2030;
2. Improve the overall conversion efficiency, including bottoming cycle, of geothermal installations at different thermodynamic conditions by 10% in 2030 and 20% in 2050;
3. Reduce production costs of geothermal energy (including from unconventional resources, EGS, and/or from hybrid solutions which couple geothermal with other renewable energy sources) below 10 €ct/kWh_{el} for electricity and 5 €ct/kWh_{th} for heat by 2025**;
4. Reduce the exploration costs by 25% in 2025, and by 50% in 2050 compared to 2015;
5. Reduce the unit cost of drilling (€/MWh) by 15% in 2020, 30% in 2030 and by 50% in 2050 compared to 2015;
6. Demonstrate the technical and economic feasibility of responding to commands from a grid operator, at any time, to increase or decrease output ramp up and down from 60% - 110% of nominal power.

** Reservoir performance includes underground heat storage.*
*** Costs have to be confirmed establishing at least 5 plants in different geological situations, of which at least one with large capacity (20 MWel or, if for direct use only, 40 MWth).*

Summary:

The research and innovation (R&I) Actions envisaged in the Deep Geothermal Implementation Plan address relevant issues crucial for the development of the use of geothermal energy resources, both as heat and electricity. The implementation plan (IP) pays due attention to low-enthalpy resources, which are widely present in the Europe and whose development, together with that of urban district heating networks fed by geothermal, represents a key opportunity to increase renewable heat supply. Geothermal electricity can represent a major contributor to balancing local effects resulting from the dependence on non-dispatchable renewables, such as wind and PV and solar thermal; relevant attention is paid to developing this capability, with a specific key action in the IP. Other key actions are related to development of materials which can be effective in reducing problems connected with scaling and corrosion, both for low- and high-temperature applications; and new exploration technologies and advanced drilling techniques. Strongly connected to the DOI targets of cost decrease, and to issues of social acceptance, are the key actions dedicated to performance improvement and to the development of zero-emission power plants. Knowledge transfer and data unification issues are also relevant measures of the IP. Non-technical barriers/enablers were finally identified: Social acceptance, in support of a wide-spread and accepted development of geothermal energy; and risk management, with the objective of establishing a European scheme for the management of risk in geothermal projects, which is considerable as exploration and field development represent a major investment.

State of the Art:

The use of geothermal energy, particularly for heat, is steadily increasing across Europe. The growth of geothermal power is mainly due to rapid expansion in Turkey, which is set to continue. Italy, France, Germany and The Netherlands are focusing their geothermal strategies, and further new and innovative projects are also expected in other countries in the near future.

Among renewables, electricity from geothermal resources is today fully competitive in choice locations with fossil fuels, with costs of about 0.07 EUR/kWh including systems and operation for large scale systems, referring to specific locations or high-quality resources. The European industry performs excellently in the geothermal sector.

District heating and cooling has been a real success story for geothermal, since it is still expanding into new markets. Deep geothermal for heating and cooling encompasses supply to industrial and service sectors. There are 280 such plants in Europe with a total installed capacity of about 5 GW_{th}. With about 200 new plants in planning, the installed capacity is set to grow up to 6,5 GW_{th} by 2020.

Geothermal energy can represent a relevant contribution to the transition towards a more sustainable energy system. Combined heat and power, hybridization with other renewables (solar, biomass), and support to local and sustainable economic development, security of supply and load flexibility are already recognized qualities of geothermal energy, which will find further boost from the adoption of the implementation plan.

R&I Activities:

1. Geothermal heat in urban areas
2. Materials, methods and equipment to improve operational availability (high temperatures, corrosion, scaling)
3. Enhancement of conventional reservoirs and deployment of unconventional reservoirs
4. Improvement of performance (conversion to electricity and direct use of heat)
5. Exploration techniques (including resource prediction and exploratory drilling)
6. Advanced drilling/well completion techniques
7. Integration of geothermal heat and power in the energy system and grid flexibility
8. Zero emissions power plants

Non-technical barriers/Enablers:

A. Increasing awareness of local communities and involvement of stakeholders in sustainable geothermal solutions
B. Risk mitigation (financial/project)

Cross-cutting Issues:

The Deep Geothermal Temporary Working Group stresses the relevance of two cross-cutting issues which are crucial for support to all research and innovation actions as well as non-technical barriers/enablers:

- Knowledge transfer + training (including peer-to-peer learning and research infrastructures)
It is important that the EC demonstrates throughout Europe capacity building, industrial technology transfer and science & academic partnerships via know-how, with the shared goal to develop high quality, competitive and sustainable geothermal energy projects. This includes supporting the existing pan-European infrastructure of experimental test and monitoring facilities and infrastructures (Geo Energy Test Beds, GETB - see also https://www.epos-ip.org/data-services/community-services-tcs/geo-energy-test-beds-low-carbon-energy) and making efficient and coordinated use of them. This cross-cutting action also aims at training and educating new geothermal professionals. Among the necessary actions, a key issue is represented by cooperation between education and training institutes and companies, creating networks for education and training involving industrial platforms, universities and research centres. Further ideas are to develop courses on geothermal energy within existing university courses and to launch new courses; to absorb workforce of declining industries; and to promote mobility of workers in Europe. Support to these actions should be sought nationally, in H2020 (and subsequent framework programs) Concertation and Support Actions, and in existing EC programs or support of knowledge transfer and human mobility, such as (Marie Curie, Erasmus +, ERC grants).

- Recommendation of an open-access policy to geothermal information (including standard exchange formats)
The scope of this cross-cutting action is to facilitate access to geothermal information at the European level via the development of an information platform, creation of standard and common data models at EU level. This should be achieved through progressive harmonization of national data to facilitate data discovery and mining. This is an important step to help scientists, stakeholders, investors and geothermal developers, and the basis for resource assessment and feasibility studies. Resources for this actions should be mainly guaranteed by national geological services within European countries. A general commitment to open-access to relevant data is recommended through a user-friendly interface with different levels for professionals and general public seeking information. In the frame of the Geothermal ERA-NET the concept of a European Geothermal Information Platform was developed and principal features suggested. Such a platform is envisaged as a web tool gathering data and knowledge from national and scientific

providers in agreement with the European INSPIRE directive. The platform needs to be interoperable with other pan-European data platforms, e.g. EGDI. Activities include:

- Definition of standards (e.g. for database format, services which make automatic uses of data) and data models.
- Data preparation, harmonization and publication through national web-services.
- Development of the geothermal information platform, providing services for open-access data harvesting, data mining and data management (e.g. graphs, statistical tools etc.)
- Continuing support to ERA-NET/GEOTHERMICA though Concertation and Support Actions or other initiatives is recommended.

Next Steps:

The Deep Geothermal Temporary Working Group is composed of representatives of relevant countries and stakeholders, representing both the industry and the academia. Throughout 2017 it identified 8 research and innovation (R&I) activities as well as 2 non-technical barriers/enablers, which were included in this Implementation Plan.

All these actions are crucial to meet the SET-Plan targets for geothermal energy listed in the relevant Declaration of Intent. To ensure their proper implementation, an estimated overall investment of €936.5m shall be mobilised, to be covered as follows:

- €456m coming from the industry (private funds - 49% of the total);
- €342m coming from national programmes (36.5% of the total);
- €138.5m coming from EU funds (14.5% of the total – from both NER 300 and Horizon 2020, including the ongoing Geothermica ERA NET project)

Of the 8 R&I activities identified, 4 are considered to be flagship. Furthermore, 4 target projects with low initial TRL, hence requiring basic and/or fundamental research endeavours (activities 2, 3, 6 and 7 have initial TRLs between 3 and 4). Finally, the main non-technological barriers to the development of deep geothermal, i.e. public acceptance, dissemination of best practices, coordination of geological risk mitigation methods and development of ad-hoc financial schemes, are targeted by separate, dedicated activities.

For these reasons, the proposed activities are characterised by different levels of maturity. Although the implementation of some activities has already started (see for example activities 1, 2, 5, 6 and 7, as well as NTB-A and NTB-B, which are partially covered by the ongoing Geothermica ERA NET project), considerable extra efforts and funding will be required over the coming months and years to meet the goals of the Declaration of Intent. Continuous work on this IP is therefore expected.

Having finalised the IP, the work of the Deep Geothermal TWG is completed. However, the execution of the IP would need to be coordinated by a new dedicated structure and the TWG could either contribute to it or represent a starting point for its design. Ad-hoc meetings could be organised as necessary to move the IP into the execution phase.

In the following, prioritized research and innovation activities are identified and completed with a discussion on non-technical barriers and enablers.

Ongoing and planned R&I Activities

<table>
<tr><th colspan="4">Description of Research and Innovation Activity</th><th colspan="2">DG TWG</th></tr>
<tr><td colspan="4">Title: Geothermal heat in urban areas</td><td colspan="2">R&I Activity.1</td></tr>
<tr><td>Targets:
DOI 3,
NTB A, B</td><td colspan="5">Monitoring mechanism:
A subject should be decided for reporting at member states/EC level.
Progress will be reported with respect to deliverables of each specific project.
Quantitative check on energy delivered to connected users with respect to targets declared in the flagship project.</td></tr>
<tr><td colspan="6">Scope: To enhance the European heat transition to renewable energy by providing geothermal based solutions for urban areas. To contribute to decarbonising energy use for heating and cooling in cities and to improve air quality.

Description: Demonstrate new heating concepts for urban areas based on geothermal energy and/converting conventional district heating networks of urban areas into renewable heating systems based on geothermal energy; enable the smart use of thermal grids with emphasis on flexible supply of resources, adapted to different source temperatures and varying demand; and position geothermal utilization (including underground storage) as a crucial pillar for the (heat) transition of the energy system.
Activities include geothermal heat for industry and agriculture, underground thermal energy storage (UTES), innovative and multiple uses for geothermal energy and side-products, balneological systems, and design and operation of geothermal doublets.
Several demonstration projects will showcase the broad potential of geothermal energy, providing an overall justification for a Flagship in terms of relevant contribution to conservation of energy resource and together with geothermal energy storage to a large scale transition towards renewable heat in Europe. Integrated innovative concepts will be demonstrated including smart integration into the energy system (e.g. cascading, matching supply with demand, heat and cold exchange, using a LowEx approach which minimizes exergy losses by matching the energy quality of heat (or cold) demand and supply) and possible integration of other renewables in the geothermal heat supply.</td></tr>
<tr><td colspan="3">TRL at start: 7</td><td colspan="3">TRL at end: 9</td></tr>
<tr><td colspan="4">Total budget required: €73.3m</td><td>Flagship:</td><td>Yes</td></tr>
<tr><td colspan="4">Expected deliverables:</td><td colspan="2">Timeline:</td></tr>
<tr><td colspan="4">Portfolio (expected at least one per country involved) of Member state demonstration projects: number of realized project will be listed, pointing out best practices and successes.
Minewater Heerlen , Greater Munich, Paris, Milan, Geneva, Bern …</td><td colspan="2">2020 on</td></tr>
<tr><td colspan="4">Examples of combining Renewable Technologies for a Renewable District Heating System, might include H2020 demonstration case.</td><td colspan="2">2019 on</td></tr>
<tr><td>Party/Parties</td><td>Implementation Instruments</td><td colspan="4">Indicative financing contribution</td></tr>
<tr><td rowspan="2">Industry, BE, CH, DE, FR, IT, NL, PT, EU</td><td>Dedicated industry investment (private funds)</td><td colspan="4">€30m</td></tr>
<tr><td>National funding programs (incl. public & private contributions) possibly combined in bi- or multilateral projects.</td><td colspan="4">Germany, Portugal, Switzerland, Netherlands, France and Iceland (all involved in GEOTHERMICA – cumulative allocation): €40.5m
Italy: €0.7m
Structural funds could play a role as well, based for example on the pilot experience in Tuscany, which builds on the interregional platform on energy</td></tr>
</table>

	GEOTHERMICA CFA	€8.5m of EU funds[1]
	LCE-17-2017 “Easier to install and more efficient geothermal systems for retrofitting buildings”.	Projects, and relevant EU and private budget, to be announced in the first half of 2018

[1] Total GEOTHERMICA budget, relevant to various IP activities (see the rest of this document)

Description of Research and Innovation Activity	DG TWG
Title: Materials, methods and equipment to improve operational availability (high temperatures, corrosion, scaling)	R&I Activity.2

Targets:	**Monitoring mechanism:**
DOI 3, 2, 1 NTB A	Checking of deliverables for each specific project with respect to advancement plan.

Scope: Developing new materials, methods and equipment suitable to solve problems commonly encountered in geothermal applications (resistance to corrosion and scaling) for low and high temperatures; decreasing the overall cost of a geothermal project. **Description:** The major advantage of geothermal energy over other renewable energy sources is the time and site independent availability of the geothermal resource. To use this advantage, the operational availability of geothermal energy installations has to be stable on a high level. Sustainable and reliable production from deep geothermal resources is associated with various challenges, mainly related to the high temperature, high pressure environment, and geothermal fluid composition. The materials and equipment required need to cope with hostile and aggressive reservoir environments and thermo-chemical fluid properties; the goal is to improve equipment reliability and to increase the plant utilization factor. Developing materials and/or methods and/or equipment such as pumps and heat exchangers for the application in all parts of a geothermal plant to minimize operational issues related to high temperatures, scaling, corrosion, and gas content.

TRL at start: 5 (Equipment); 4 (Materials)	**TRL at end**: 9 (Equipment); 6 (Materials)

Total budget required: €25.6m	**Flagship:**	No

Expected deliverables:	**Timeline:**
Status report on improvement of operational availability in the Geothermal sector	2022
Demonstration of major innovations that bring operational availability to a higher level (e.g. pump, heat exchanger, materials)	2030

Party/Parties	**Implementation Instruments**	**Indicative financing contribution**
Industry, DE, IS, IT, NL, PT, EU	Dedicated industry investment (private funds)	€10m
	National funding programs (incl. public & private contributions) possibly combined in bi- or multilateral projects.	Germany, Portugal, Switzerland, Netherlands, France and Iceland (all involved in GEOTHERMICA – cumulative allocation): €10.5m
	GEOTHERMICA CFA	€8.5m of EU funds
	LC-SC3-RES-1-2019: Developing the next generation of renewable energy technologies	€2-5m

<table>
<tr><td colspan="3">Description of Research and Innovation Activity</td><td>DG TWG</td></tr>
<tr><td colspan="3">Title: Enhancement of conventional reservoirs and development of unconventional reservoirs</td><td>R&I Activity.3</td></tr>
<tr><td>Targets:
DOI 3, 2
NTB A, B</td><td colspan="3">Monitoring mechanism: Annual round-check on advancement. Every year information on new plants will be gathered (realized or under construction) in countries involved in this activity. Benchmarking with respect to deliverables. The information collected every year will be organized in a report which also accounts for the initial baseline and captures data from countries not directly involved in this activity or current TWG composition. Quantitative check on power/heat targets declared in the flagship project. A particular focus will be on activities in connection with flagship projects and the implementation of monitoring systems.</td></tr>
<tr><td colspan="4">Scope: Demonstration of techniques for reservoir improvement in different geological settings and up-scaling of power plants, and/or (industrial) heat production. Development of reservoirs (incl. ultra-deep hydrothermal and petro-thermal) in untested geological conditions with innovative methods for reservoir exploitation.

Description: This action covers the development and demonstration of energy efficient, environmentally sound and economically viable generation of electricity, and/or heating and cooling from enhanced conventional reservoirs and the integration in a flexible energy supply and delivery system. In addition new geological environments which require additional reservoir improvement techniques shall be developed for the geothermal use. The expected outcome will be geothermal energy in a form that can be widely deployed and competitively priced, underpinned with reduced capital, operational and maintenance costs.</td></tr>
<tr><td colspan="2">TRL at start: 4</td><td colspan="2">TRL at end: 8</td></tr>
<tr><td colspan="2">Total budget required: €382.5</td><td>Flagship</td><td>Yes</td></tr>
<tr><td colspan="2">Expected deliverables:</td><td colspan="2">Timeline:</td></tr>
<tr><td colspan="2">Portfolio of existing/planned projects Soultz, Deep EGS, Hungary, Mol, Gardanne</td><td colspan="2">2020</td></tr>
<tr><td colspan="2">1 plant=10 MW_{el}-20MW_{th}</td><td colspan="2">2022</td></tr>
<tr><td colspan="2">1 plant=20 MW_{el}-40MW_{th}</td><td colspan="2">2025</td></tr>
<tr><td>Party/Parties</td><td>Implementation Instruments</td><td colspan="2">Indicative financing contribution</td></tr>
<tr><td rowspan="3">Industry, CH, DE, FR, IS, IT, PT, EU</td><td>Dedicated industry investment (private funds)</td><td colspan="2">€30m</td></tr>
<tr><td>National funding programs (incl. public & private contributions) possibly combined in bi- or multilateral projects.</td><td colspan="2">Germany, Portugal, Switzerland, Netherlands, France and Iceland (all involved in GEOTHERMICA – cumulative allocation): €33m</td></tr>
<tr><td>LCE 18 2017 EGS in different geological conditions
LC-SC3-RES-12-2018: Demonstrate highly performant renewable technologies for heat and power generation and their integration in the EU's energy system
LC-SC3-RES-13-2018: Deep geothermal demonstration of cost efficient technologies to limit emissions and/or to condense and re-inject gases
LC-SC3-RES-14-2019: Develop a better understanding of the chemical and physical properties of geothermal fluids (including hot and super-hot fluids)</td><td colspan="2">€8-10m
€8-10m – shared with Grid Flexibility demonstration

€15-20m

€3-5m</td></tr>
</table>

	South Hungarian EGS Demonstration NER 300 project in Hungary GEOSTRAS NER 300 project in France and Germany	€39m €17m *The private contribution can be estimated as being roughly 4 times as high as the NER 300 one.*

<table>
<tr><td colspan="3">Description of Research and Innovation Activity</td><td>DG TWG</td></tr>
<tr><td colspan="3">Title: Improvement of performance (conversion to electricity and direct use of heat)</td><td>R&I Activity.4</td></tr>
<tr><td>Targets:
DOI 3, 2
NTB A</td><td colspan="3">Monitoring mechanism:
Annual round-check on advances in performance of energy conversion including information on new plants (commissioned or under construction) in the partner' countries involved in these activities.
Benchmarking with respect to specific project deliverables and reference plants.</td></tr>
<tr><td colspan="4">Scope: To improve the overall conversion efficiency and reduce the cost of geothermal energy utilization. To develop an EU technology solution with a perspective to become a worldwide standard. To improve the efficiency of binary cycle power plants, including application to high temperatures, use as bottoming cycle and the capability of dealing efficiently with variable heat and electricity supply.

Description: This action shall focus on specific components with considerable potential for an increase of system efficiency e.g. design of improved heat exchangers and pumps, selection of materials, new working fluids with very small GWP (Global Warming Potential), increase in expander efficiency, improved efficiency of the cooling system by enhancement of the air-cooler/condenser and matching to the cycle, or avoiding the dumping of useful heat into the environment by promoting the low-enthalpy industrial use of the circulating fluid. Utilizing high temperature/enthalpy geothermal fluids through a binary power plant can solve some of the material challenges. Bottoming/hybridization of existing or new power plants and development of new cycle concepts is also matter of interest.
In order to cope with fluctuations of the heat demand, flexible supply units are necessary that are not designed for one specific optimal condition, but in a way that maximizes the use of the heat source. Such systems should also consider hybridization with various sources of renewable heat, such as biomass or solar thermal. Technical solutions should be tested and their applicability demonstrated, promoting the flexible use of the geothermal heat source depending on demand (electricity and heat). This implies an optimization of partial load behavior and flexible control strategies for the operation of the whole system. Activities are also directed to facilitating the direct use of heat for industry and/or municipality by finding new innovative and multiple uses for the geothermal resource.</td></tr>
<tr><td colspan="2">TRL at start: 5-6</td><td colspan="2">TRL at end: 7-8</td></tr>
<tr><td colspan="2">Total budget required: €21m</td><td>Flagship:</td><td>No</td></tr>
<tr><td colspan="2">Expected deliverables:</td><td colspan="2">Timeline:</td></tr>
<tr><td colspan="2">General performance improvement of systems that enable the generation of electricity from geothermal energy resources with medium and low enthalpy, including double flash and complex/hybrid cycle systems, organic Rankine Cycles (ORC), Kalina and supercritical CO_2 cycles.</td><td colspan="2">2022</td></tr>
<tr><td colspan="2">Improving efficiency of surface systems equipment/components: heat recovery equipment, turbines for power only and for combined heat & power generation, cooling generation (via heat absorption)</td><td colspan="2">2022</td></tr>
</table>

Party/Parties	Implementation Instruments	Indicative financing contribution
Industry, FR, IT, FR, IS, PT, TR, EU	Dedicated industry investment (private funds)	€15m
	National funding programs (incl. public & private contributions) possibly combined in bi- or multilateral projects.	Germany, Portugal, Switzerland, Netherlands, France and Iceland (all involved in GEOTHERMICA – cumulative allocation): €4.5m Italy: €1.5m

	LC-SC3-RES-12-2018: Demonstrate highly performant renewable technologies for heat and power generation and their integration in the EU's energy system National funding programs (incl. public & private contributions) possibly combined in bi- or multilateral projects.	€8-10m – shared with Grid Flexibility demonstration)- Research from private manufacturers Cooperation with other energy sectors Support potential involvement of private research.

<table>
<tr><td colspan="4">Description of Research and Innovation Activity</td><td>DG TWG</td></tr>
<tr><td colspan="4">Title: Exploration techniques (including resource prediction and exploratory drilling)</td><td>R&I Activity.5</td></tr>
<tr><td>Targets:
DOI 3, 4</td><td colspan="4">Monitoring mechanism:
Annual round-check on advancement. Each year information will be gathered on new wells in the partner countries involved in these activities
Benchmarking with respect to specific project deliverables in terms of unit finding cost. The information collected every year will be organized in a report taking into account the initial baseline and also data coming from countries not directly involved in this activity (i.e. countries not represented in the TWG).</td></tr>
<tr><td colspan="5">Scope: Improving the precision of pre-drilling exploration and performance prediction by regularly updating methodological approaches. Moving beyond the state of the art by testing new tools, developing new approaches and taking advantage of improved software and computing power, thereby reducing uncertainty and bringing down exploration costs.

Description: To ensure a reliable pre-drilling assessment of geothermal resources, high resolution exploration methods and approaches are essential to minimize exploration risks. This will be achieved by

a) The development of new tools and techniques coupled with innovative modeling techniques, increasing measurement precision and applying faster analysis of acquired data to achieve a precise predictive model of the reservoir.

b) The update and improvement of state-of-the-art exploration techniques and methods to reduce the average cost for exploration while increasing the quality of the used method. Such progress must address in increasing detail the geological complexity of resources, and increasing target depths.</td></tr>
<tr><td colspan="2">TRL at start:5-6</td><td colspan="3">TRL at end: 7-8</td></tr>
<tr><td colspan="3">Total budget required: €49m</td><td>Flagship:</td><td>No</td></tr>
<tr><td colspan="3">Expected deliverables:</td><td colspan="2">Timeline:</td></tr>
<tr><td colspan="3">Improved subsurface images, cost reduction, higher resolution, faster results</td><td colspan="2">2022</td></tr>
<tr><td colspan="3">Develop and apply new generation exploration techniques</td><td colspan="2">2024</td></tr>
<tr><td>Party/Parties</td><td colspan="2">Implementation Instruments</td><td colspan="2">Indicative financing contribution</td></tr>
<tr><td rowspan="4">Industry, CH, DE, FR, IS, IT, PT, EU</td><td colspan="2">Dedicated industry investment (private funds)</td><td colspan="2">€15m</td></tr>
<tr><td colspan="2">National funding programs (incl. public & private contributions) possibly combined in bi- or multilateral projects</td><td colspan="2">Germany, Portugal, Switzerland, Netherlands, France and Iceland (all involved in GEOTHERMICA – cumulative allocation): €22.5m
Italy: €0.4m</td></tr>
<tr><td colspan="2">GEOTHERMICA CFA</td><td colspan="2">€8.5m</td></tr>
<tr><td colspan="2">LC-SC3-RES-11-2018: Developing solutions to reduce the cost and increase performance of renewable technologies</td><td colspan="2">€8-10m</td></tr>
</table>

Description of Research and Innovation Activity	DG TWG
Title: Advanced drilling/well completion techniques	R&I Activity.6

Targets: **DOI 3, 5**	**Monitoring mechanism** Annual round-check on advances: Information will be gathered on new operating wells in partner countries involved in these activities Benchmarking with respect to specific project deliverables. The information collected every year will be organized in a report with reference to the initial baseline and also including data from countries not directly involved in this activity (i.e. countries not represented in the TWG).

Scope: Reduction in drilling/well completion costs. Demonstrate concepts that can significantly reduce drilling/well completion costs (reduce drilling time and non-productive time, reduce costs, mitigate risks) or enhance reservoir performance (including directional and horizontal multilateral drilling). The target is to reduce cost for drilling and underground installations by at least 25% compared to the situation today.

Description: Well construction represents a major share of the necessary investment in geothermal projects. Hence, reductions in specific well cost (€/MWh) will substantially influence the overall economics of a deep geothermal plant. To increase the economic viability of a geothermal development, advanced drilling technologies, currently not used in geothermal well construction, have to be adapted and optimized for the specific project requirements. Implementation of advanced technologies includes, but is not limited to, process automatization, drilling fluids to compensate unwanted loss of circulation zones as well as improved cementing procedures and well cladding, and stimulation methods improvement for deep wells. Risk assessment and lifetime analysis of the new technologies and approaches must be part of the work. Innovative system to avoid/reduce the discharge of geothermal fluid into the environment while drilling and flow tests will be considered. Horizontal - multilateral wells clusters in various geological formations will be also considered. Targeted (e.g. compact and lightweight) equipment and techniques for drilling and well completion in urban areas is another challenge in this area. Increased technology transfer from the oil and gas industry on horizontal well drilling and completion is needed. The proposed procedures should result in a significant reduction of overall costs over the lifetime of the installations.
New methods for drilling and well completion in the various geological formations relevant for geothermal energy with the potential to accelerate the process, reducing costs and risks shall be tested in realistic settings. Such methods include percussive drilling for deep/hot wells (fluid hammers etc.) and non-mechanical drilling method development (such as laser, plasma, hydrothermal flame drilling). Benchmark testing in boreholes should be attempted. The efforts will be directed to demanding environments (e.g. >5000 m depth and T>250ºC) and all relevant geological formations.

TRL at start:5 (improvement), 3 (novel)	**TRL at end**:7 (improvement), 5 (novel)

Total budget required:€52.1m	**Flagship:**	No
Expected deliverables:	**Timeline:**	
Developed (new) and demonstrated concepts that significantly reduce drilling/well completion costs (reduce drilling time, reduce costs, or mitigate risks) or enhance reservoir performance	2022	
New technologies (non-mechanical methods) will be ready for testing at the real scale in deep wells. Reduction in drill time or non-productive time ~20% by 2025 with the potential to reduce by 50% in 2040.	2022	

Party/Parties	**Implementation Instruments**	**Indicative financing contribution**
Industry, CH, DE, IS, IT, NL, PT, EU	Dedicated industry investment (private funds)	€20m
	National funding programs (incl. public & private contributions) possibly combined in bi- or multilateral projects.	Germany, Portugal, Switzerland, Netherlands, France and Iceland (all involved in GEOTHERMICA – cumulative allocation): €30m
	GEOTHERMICA CFA	€8.5 of EU
	LC-SC3-RES-11-2018: Developing solution to reduce the cost and increase performance of renewable technologies	€8-10m

<table>
<tr><td colspan="5">Description of Research and Innovation Activity</td><td>DG TWG</td></tr>
<tr><td colspan="5">Title: Integration of geothermal heat and power in the energy system and grid flexibility</td><td>R&I Activity.7</td></tr>
<tr><td>Targets:
DOI 6, 3;
NTB B</td><td colspan="5">Monitoring mechanism:
H2020 and GEOTHERMICA project monitoring
Annual round-check on advances made in operational flexibility of geothermal power plants connected to the grid with different grid technologies.</td></tr>
<tr><td colspan="6">Scope: Integration of flexible generation from geothermal power in the energy sector

Description: Demonstrate the technical and economic feasibility of responding to commands from a grid operator, at any time, to increase or decrease output ramp up and down. Demonstrating the automatic generation control (load following / ride-through capabilities to grid specifications) and ancillary services of geothermal power plants. Addressing flexible heat/cold and electricity supply from binary cycles and EGS power plants, including coupling with renewable energy sources; addressing specific problems of geothermal power production in isolated energy networks (islands). Thermoelectric energy storage integrated with district heating networks and dedicated equipment (heat pumps, ORC turbo-expanders, and heat exchanger networks, with hot and cold reservoirs able to cover variable demand of heat, cold and electricity.
Activities will include impact on the development of transmission and distribution infrastructure and the interplay with other flexibility options (e.g. demand-side management and storage), and test on dispatchability. Furthermore, the flexible generation should be able to provide additional services to the grid such as peak power, role in electricity balancing/reserve market.</td></tr>
<tr><td colspan="3">TRL at start:4-5</td><td colspan="3">TRL at end:7-9</td></tr>
<tr><td colspan="3">Total budget required: €11.5</td><td colspan="2">Flagship:</td><td>Yes</td></tr>
<tr><td colspan="3">Expected deliverables:</td><td colspan="3">Timeline:</td></tr>
<tr><td colspan="3">Tests demonstrating automatic generation control (load following / ride-through capabilities to grid specifications)</td><td colspan="3">2019-22</td></tr>
<tr><td colspan="3">Demonstrations of load following in binary cycles coupled to RES</td><td colspan="3">2019-2022</td></tr>
<tr><td colspan="3">Demonstration of flexible electricity production from EGS plants</td><td colspan="3">2022-2025</td></tr>
<tr><td colspan="2">Party/Parties</td><td>Implementation Instruments</td><td colspan="3">Indicative financing contribution</td></tr>
<tr><td colspan="2" rowspan="2">Industry, CH, IS, IT, PT, TR, EU</td><td>Dedicated industry investment (private funds)</td><td colspan="3">€10m</td></tr>
<tr><td>National funding programs (incl. public & private contributions) possibly combined in bi- or multilateral projects</td><td colspan="3">Germany, Portugal, Switzerland, Netherlands, France and Iceland (all involved in GEOTHERMICA – cumulative allocation): €1.5m</td></tr>
</table>

Description of Research and Innovation Activity	DG TWG
Title: Zero emissions power plants	R&I Activity.8

Targets:	**Monitoring mechanism:**
DOI 2, 3 NTB B	Annual checks on advances. Every year information on new plants (realized or under construction) will be gathered in partner countries involved in these activities. Benchmarking with respect to specific project deliverables. The information collected every year will be organized in a report taking into account the initial baseline and also data coming from countries not represented in the TWG. Quantitative check on power connected with respect to targets declared in the flagship project.

Scope:
Increasing the feasibility of closed-loop reinjection and demonstrating the capture of non-condensable gases (Zero emission power plants).

Description:
Zero emission power plants and development of CO_2 capture, storage and reinjection schemes for reservoirs with high CO2-content.
Increasing the feasibility and reliability of closed-loop reinjection and demonstrating the capture of non-condensable gases (NCGs). Development of systems for capture and re-injection of chemical compounds associated with produced geothermal fluids.
NCGs are often present in geothermal brines, and may contain contaminants requiring chemical processing. Depending on reservoir conditions (thermodynamics and composition, including saline equilibria) the challenge can in some cases be addressed avoiding flashing of the resource, or maintaining a high flash pressure, possibly using hybrid solutions. Solutions for complete reinjection into the reservoir are targeted, with NCGs in gaseous or liquid state. These solutions imply correct matching to the power cycle and development of new equipment (compressors, pumps, intercoolers, mixing nozzles, and possibly refrigeration equipment). Research will deal both with whole process optimization, and new equipment. The first power plants of this type are expected within 2025 and may represent a worldwide flagship, with relevant market fallouts for many countries (IT, TR, IS, Kenya…).

TRL at start: 5-6	**TRL at end**: 6-7	
Total budget required: €123.4m	**Flagship:**	Yes

Expected deliverables:	**Timeline:**
Lab and field tests demonstrating possibility of full reinjection in test circuits and/or geothermal reservoirs with different resource conditions	2020
Pilot/demonstrative geothermal plants to experiment high-performant closed loop technologies	2025

Party/Parties	**Implementation Instruments**	**Indicative financing contribution**
Industry, FR, IS, IT, PT, TR, EU	Dedicated industry investment (private funds)	An industrial project is under authorization procedure in Italy, for an expected investment of €40m (5 MWel demonstration pilot).
	National funding programs (incl. public & private contributions) possibly combined in bi- or multilateral projects	Germany, Portugal, Switzerland, Netherlands, France and Iceland (all involved in GEOTHERMICA – cumulative allocation): €7.5m Italy: €0.4m Turkey: €0.5m

	LC-SC3-RES-13-2018: Demonstrate solutions that significantly reduce the cost of renewable power generation (Type of action: R&IA)	€15-20m (contribution from the EU expected per proposal)
	LC-SC3-RES-12-2018: Demonstrate highly-performant renewable technologies for heat and power generation and their integration in the EU's energy system (Type of action: R&IA)	€15-20m (contribution from the EU expected per proposal)
	Geothermae NER 300 project in Croatia	€15m *The private contribution can be estimated as being roughly 4 times as high as the NER 300 one.*

Description of Research and Innovation Activity	DG TWG
Title: Increasing awareness of local communities and involvement of stakeholders in sustainable geothermal solutions	NTBE-A

Targets: NTB A NTB B	**Monitoring mechanism:** Annual surveys that monitor changes in perception of people. Every year information will be gathered regarding the perception of local communities in regards to near-by geothermal plants (built or under construction). Benchmarking with respect to deliverables. The information collected (from surveys, media, public reporting, etc.) every year will be organized in a report taking into account the initial situation and also capturing data coming from countries not directly involved in this activity (i.e. countries not represented in the TWG)

Scope:

A: Public acceptance: improve community perceptions about non-condensable gas emissions, micro-seismicity, stimulation, and other environmental effects. Coordination of national and regional regulatory oversight practices for health, safety and environmental aspects of geothermal projects.

B: Best practices for managing health, safety and environmental aspects of geothermal projects. Seismic monitoring and mapping of seismic events, guidelines for stimulation indicators in order to prevent surface impacts.

Description:

To address environmental and social concerns that pose barriers limiting the contribution of geothermal energy to the energy mix, the challenge is to assess the nature of public concerns and the elements that influence individual and group perceptions of geothermal installations, to increase the understanding of the socio-economic dimension of geothermal energy, and, where needed, to promote change in community responses to new and existing geothermal installations.

Different technologies and possible technological solutions, for reducing environmental effects and enhance societal benefits, including reinjection of incondensable gases in deep geothermal plants, and seismicity control, are key elements of the socio-environmental assessment. Risk management strategies and adequate technology selection, for example induced seismicity or emission reduction should be addressed.

TRL at start: not applicable	**TRL at end**: not applicable	
Total budget required: €21m	**Flagship:**	No
Expected deliverables:	**Timeline:**	
Guidelines/Best Practice documents for environmental performance of geothermal projects	2022	
Guidelines for correct monitoring and mapping of seismic events	2025	
Compendium of national and regional practices related to concessions	2025	
Participative social methodologies implemented in geothermal sites or regions to improve social acceptability of deployment of geo-plants. New pilot projects testing participative methodologies for socially responsible market uptake of DG	2022	

Party/Parties	**Implementation Instruments**	**Indicative financing contribution**

Industry, FR, IS, IT, PT, EU	Dedicated industry investment (private funds)	€1m
	National funding programs (incl. public & private contributions) possibly combined in bi- or multilateral projects.	Germany, Portugal, Switzerland, Netherlands, France and Iceland (all involved in GEOTHERMICA – cumulative allocation): €4.5m Italy: €8m
	GEOTHERMICA CFA	€8.5m of EU funds
	LC-SC3-CC-1-2018-2019-2020: Social Sciences and Humanities (SSH) aspects of the Clean-Energy Transition Type of Action: R&IA	€1-3m (contribution from the EU expected per proposal)
	LC-SC3-EE-1-2018-2019-2020: Decarbonisation of the EU building stock: innovative approaches and affordable solutions changing the market for buildings renovation Type of action: R&IA	€3-4m (contribution from the EU expected per proposal)
	LC-SC3-RES-27-2018-2019-2020: Market Uptake support Type of Action: CSA	€1-3m (contribution from the EU expected per proposal)

<table>
<tr><td colspan="5">Description of Research and Innovation Activity</td><td>DG
TWG</td></tr>
<tr><td colspan="5">Title: Risk mitigation (financial/project)</td><td>NTBE.B</td></tr>
<tr><td>Targets:
DOI 3,1
NTB A</td><td colspan="5">Monitoring mechanism:
Via monitoring of national policy instruments; at EGRIF level via EGEC.</td></tr>
<tr><td colspan="6">Scope: Coordination of national geological risk mitigation methods and financial schemes (e.g. exploration grants, geothermal guarantee schemes).

Description: Risk mitigation is crucial for widespread deployment of geothermal energy. The Netherlands, France, or Switzerland are examples of European countries that offer geothermal guarantee schemes. The schemes differ widely in the rationale, set-up, financing, coverage, procedural aspects, mode of pay-out, fee structure and so on. The activity will collate good practices (worth replicating) and lessons learnt. Advanced approaches and guidelines on how to address and quantify exploration risk, and financial tools that help mitigate such risks will be developed and paths towards a Europe-wide system will be explored (additional stakeholder consultation, creation of a «task force / working group», development of European concepts).</td></tr>
<tr><td colspan="3">TRL at start: NA</td><td colspan="3">TRL at end: NA</td></tr>
<tr><td colspan="3">Total budget required: €177m</td><td>Flagship:</td><td colspan="2">No</td></tr>
<tr><td colspan="3">Expected deliverables:</td><td colspan="3">Timeline:</td></tr>
<tr><td colspan="3">Improved national and/or European project risk mitigation schemes</td><td colspan="3">2025</td></tr>
<tr><td colspan="2">Party/Parties</td><td colspan="2">Implementation Instruments</td><td colspan="2">Indicative financing contribution</td></tr>
<tr><td colspan="2" rowspan="3">Industry, CH, FR, IT, NL, PT, EU</td><td colspan="2">Dedicated industry investment (private funds)</td><td colspan="2">€1m</td></tr>
<tr><td colspan="2">National funding programs (incl. public & private contributions) possibly combined in bi- or multilateral projects.</td><td colspan="2">Germany, Portugal, Switzerland, Netherlands, France and Iceland (all involved in GEOTHERMICA – cumulative allocation): €176m (due to the presence of financial instruments)
EEA grants could also play a role. Furthermore, a European Geothermal Risk Insurance Fund (EGRIF) could be conceived, as proposed by GEOELEC</td></tr>
<tr><td colspan="2">LC-SC3-RES-27-2018-2019-2020: Market Uptake support
Type of Action: CSA</td><td colspan="2">€1-3m</td></tr>
</table>

International Cooperation:

N.	Title	Short description	DOI /NTBE LINK
1	GEMex	International Cooperation with Mexico on geothermal energy. The GEMex project is a Cooperation in Geothermal energy research Europe-Mexico for development of Enhanced Geothermal Systems and Superhot Geothermal Systems. Co funded by EC.	DOI 1 3
2	IEA-Geothermal TCP	The International Energy Agency's Geothermal Technology Collaboration Program or IEA Geothermal, provides an important framework for wide-ranging international cooperation in geothermal R&D. Efforts concentrate on encouraging, supporting and advancing the sustainable development and use of geothermal energy worldwide both for power generation and direct-heat applications.	DOI 1 3 5
3	GGDP	The Global Geothermal Development Plan (GGDP) is an ambitious initiative by the World Bank's Energy Sector Management Assistance Program (ESMAP) and other multilateral and bilateral development partners to transform the energy sector of developing countries by scaling up the use of geothermal power. The GGDP differs from previous efforts in that it focuses on the primary obstacle to geothermal expansion: the cost and risk of exploratory drilling.	NTB A
4	Global Geothermal Alliance	Global Geothermal Alliance, coordinated by IRENA, is a platform for enhanced dialogue and knowledge-sharing within the constituency as well as for coordinated action to increase the share of installed geothermal electricity and heat generation worldwide.	Transverse
5	GEOTHERMICA	GEOTHERMICA combines financial resources and know-how of 17 geothermal energy research and innovation programme owners and managers from 14 European countries and their regions. Together with financial support from the European Commission GEOTHERMICA launches joint projects that demonstrate and validate novel concepts of geothermal energy deployment within the energy system, and that identify paths to commercial large-scale implementation. GEOTHERMICA regularly calls for innovative demonstration projects and technology development projects that accelerate geothermal energy deployment.	Transverse

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