The Deep Geothermal Implementation Plan

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On behalf of Implementaion Working Group-DG, Chairing Pool

Declaration of Intent Deep Geothermal Energy: Targets

Action 1 — *Performant renewable technologies integrated in system*

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;

Improve the overall conversion efficiency, including bottoming cycle, of geothermal installations at different thermodynamic conditions by 10% in 2030 and 20% in 2050;

Action 2 — *Reduce costs of technologies*

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/kWhe for electricity and 5 €ct/kWhth for heat by 2025**;

Reduce the exploration costs by 25% in 2025, and by 50% in 2050 compared to 2015;

Reduce the unit cost of drilling (€/MWh) by 15% in 2020, 30% in 2030 and by 50% in 2050 compared to 2015;

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 MWe or, if for direct use only, 40 MWth).*

IP R&I Activities

R&I Activities:

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

NTB/Enablers:

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

IMPLEMENTATION PLAN deep geothermal – expected budget

- **Total investment required**
  - **€ 936.500.000,** *which includes investments by the industry alone as well as with the support of either national and/or EU funds (e.g. NER 300 or Horizon 2020)*
- **Sources**
  - **€ 456.000.000 from the industry** (49% of the total);
  - **€ 342.000.000** from national programmes (36.5% of the total);
  - **€ 138.500.000** from EU funds (14.5% of the total – from both NER 300, which awarded 3 geothermal energy project, and Horizon 2020, including the ongoing Geothermica ERA NET project)

Title: Geothermal heat in urban areas	R&I Activity.1
Targets: DOI 3, NTB A, B	**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.

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.

TRL at start: 7	**TRL at end**: 9		
Total budget required: €73.3m		**Flagship:**	Yes

Title: Materials, methods and equipment to improve operational availability (high temperatures, corrosion, scaling)	R&I Activity.2
Targets: DOI 3, 2, 1 NTB A	**Monitoring mechanism:** 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

Title: Enhancement of conventional reservoirs and development of unconventional reservoirs	R&I Activity.3
Targets: DOI 3, 2 NTB A, B	**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.

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 (including EGS, 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 geothermal use, fostering an unprecedented development of geothermal energy at European level (including Member States with low-quality or presently absent resources). 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.

TRL at start: 4	**TRL at end**: 8	
Total budget required: €382.5	**Flagship**	Yes

Title: Improvement of performance (conversion to electricity and direct use of heat)	R&I Activity.4
Targets: DOI 3, 2 NTB A	**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.

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 behaviour 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.

TRL at start: 5-6	**TRL at end**: 7-8	
Total budget required: €21m	**Flagship:**	No

Title: Exploration techniques (including resource prediction and exploratory drilling)	R&I Activity.5
Targets: **DOI 3, 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).

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.

TRL at start:5-6	**TRL at end**: 7-8	
Total budget required: €49m	**Flagship:**	No

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

Title: Integration of geothermal heat and power in the energy system and grid flexibility	R&I Activity.7

Targets: DOI 6, 3; NTB B	**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.

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.

TRL at start:4-5	**TRL at end**:7-9	
Total budget required: €11.5	**Flagship:**	Yes

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

Title: Increasing awareness of local communities and involvement of stakeholders in sustainable geothermal solutions	NTBE-A

Targets:	**Monitoring mechanism:**
NTB A NTB B	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

Title: Risk mitigation (financial/project)	NTBE.B

Targets: DOI 3,1 NTB A	**Monitoring mechanism:** Via monitoring of national policy instruments; at EGRIF level via EGEC.

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).

TRL at start: NA	**TRL at end**: NA	
Total budget required: €177m	**Flagship:**	No

Nuts & bolts of IP execution

Deep Geothermal Implementation Working Group established:

- **SET-Plan Country Representatives (mostly funding agencies):**

  BE (Wallon), **CH**, CY, **DE**, **ES**, **FR**, **IE**, **IS**, **NL**, **PT**, SE, **TR***

  Indirect via (GEOTHERMICA): **DK**; **BE** (Flanders); **IT**; **RO**; **SI**; **NO**

  (Sorely missing are Austria, Bulgaria, Croatia, Czech Republic, Estonia, Finland, Greece, Hungary, Latvia, Lithuania, Luxembourg, Malta, Poland, Slovakia & UK)
- **European Commission:** DG Research and Innovation
- **European Energy Research Alliance:** Coordinator of the EERA Joint Program on Geothermal Energy, representing the Scientific sector
- **European Technology and Innovation Platforms (ETIPs):** ETIP-DG and Renewable Heating and Cooling (RH&C)-ETIP
- **European Geothermal Energy Council (EGEC):** representing the Industry

With a working cabinet (NL & CH co-chairs; Support Unit; EC; EERA & EGEC)

* bold are GEOTHERMICA countries

Deep Geothermal IP execution

- At the national, regional and European scale (EC, SET-Plan Countries) growing agreement and alignment on 8 research and innovation activities (R&I) and 2 areas of non-technical barriers and enablers (NTBE):
  - National geothermal energy research & innovation strategies and plans increasingly aligned with Deep Geothermal Implementation Plan.
  - At European scale: 2019 Implementation Roadmap of European Technology and Innovation Platform on Deep Geothermal (ETIP-DG) specifically designed to complement the Deep Geothermal IP.
  - Pan-European (2 calls of ERANET GEOTHERMICA & number of H2020 calls) align on 8 R&I activities.
  - European Commission's Coordination and Support Action enables the establishment of a Support Unit to the Deep Geothermal Implementation Working Group (1 Feb 2019 – 31 Jan 2022; € 1 mln).

(WP4) Industry

Task	Description	Due date
T4.1	Analyse private financing of geothermal research and innovation	Feb 2020
T4.2	Gain commitment to execute the IP	Feb 2022
T4.3	Execute & Monitor the IP for the industry part	Feb 2022

Deliverable	Description	Due date
D4.1	Map of geothermal market actors	September 2019
D4.2	A report on private stakeholders´ engagement	Feb 2022
D4.3	Support tools to ensure private stakeholders´ engagement	Dec 2019
D4.4	Annual report on execution of the IP by companies	Feb 2020-2021-2022