Deep GEOTHERMAL IWG

SET-Plan - Deep Geothermal IWG Implementation Plan

SET-Plan
Implementation Working Group
Deep Geothermal

Implementation Plan

Revision 1 of the Implementation Plan
endorsed on 24 January 2018
by the SET-Plan Steering Group

28 August 2020

Table of content

DG IWG 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. Today, geothermal heat is directly used depending on its temperature in a number of sectors: from balneology to industry, and in agriculture to district heating. There is great potential for the utilization of geothermal energy for heating in Europe. Many locations in Europe with district heating systems can easily be adapted to make use of local geothermal resources instead of relying on fossil fuels, imported or otherwise. The substitution will increase energy security and price stability, help achieve climate neutrality as well as independence from fossil fuel sources. There is also a potential for an increased use of geothermal heat in industry and agriculture. Unlocking this potential will come through research and innovation focused on the improvement of the technology and the incorporation of geothermal energy 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 about 80 TWh worldwide and over 12 TWh in Europe. The total installed capacity in Europe is expected to reach 3GWel in 2020 including the rapidly growing Turkish market.

The geothermal electricity market is particularly dynamic in the USA, Philippines, Indonesia, Mexico and Kenya, and could be invigorated in the near future in the EU, if a larger extent of new geothermal resources (e.g. EGS, supercritical, magmatic, geo-pressurized, off-shore), can be successfully commercialized under a wide range of geological conditions.

Recent modelling results indicate that EU geothermal power production could reach up to 540 TWh per year 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 or commercial production from a larger extent of geothermal resources (as mentioned above) are realized. On volcanic islands geothermal energy could provide the highest share of renewable heat and electricity.

Geothermal installations are characterized by low OPEX but high CAPEX, used mostly to cover the cost of exploration and drilling, as well as plant construction. In addition, financing costs are high due to high geological risks associated with costly drilling with uncertain outcomes during early-stage exploration. Market financers generally are unwilling to carry 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 under which technologies can be applied and to develop technologies bring a larger extent of geothermal resources, including EGS, to 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. Furthermore, 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 (GGA) at COP21. The GGA is a coalition of 46 countries and 40 development and industry partners that have joined political forces to increase the share of geothermal energy in the global energy mix. The GGA aspires to achieve a 500% increase in global installed capacity for geothermal power generation and a 200% 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. Establish procedures to ensure that the Public and societal benefits are identified and pursued, communities (and/or citizens at large or stakeholders) concerns are evaluated and managed and progresses in the licensing procedure are achieved. This also includes the acceptability of all stakeholders, through engagement processes.
2. Increase reservoir performance* in sustainable yield predicted for at least 30 years and reduce the power demand of operating facilities to below 10% of gross energy generation by 2030;
3. Improve the overall geothermal energy conversion efficiency, including bottoming cycle, of geothermal installations at different thermodynamic conditions by 10% in 2030 and 20% in 2050;
4. Ensure production costs (CAPEX and OPEX) of geothermal energy (including from currently not exploited unconventional resources, such as superhot, 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**;
5. Demonstrate the technical and economic ability of innovative exploration approaches and tools to increase the drilling success rate by 20% in 2025 and 50% in 2030 compared to 2015*;*
6. Reduce the unit cost of drilling (€/MWh) by 15% in 2025, 30% in 2030 and by 50% in 2050 compared to 2015;
7. 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 or heat production;
8. Demonstrate the technical and economic feasibility of geothermal heating, cooling and high-temperature storage in a flexible heating system; cover 5% of demand in Europe by 2030 and 25% by 2050.

** Reservoir performance includes underground heat storage.*

*** Costs must be confirmed by establishing at least 5 plants in different geological situations, of which at least one has a large capacity (10 MWel or, if for direct use only, 20 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 the widely present low and high temperature geothermal resource in 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 be a major contributor to balancing local effects resulting from the dependence on non-dispatchable renewables, such as wind and PV and solar thermal; 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 related to 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 geothermal 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 heating applications, is steadily increasing across Europe. The growth of geothermal electricity is mainly due to rapid expansion in Turkey, which is set to continue. Italy, France, Germany and The Netherlands are implementing their geothermal strategies, and other countries have portfolios of new and innovative projects that are expected to be realised in the near future.

Among renewables, electricity from geothermal resources is today fully competitive with fossil fuels in choice locations, with costs of about 0.07 EUR/kWh including systems and operation for large-scale systems. 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. In 2019, there were 5,5 GWth of installed geothermal district heating and cooling capacity in 25 European countries, corresponding to 327 systems. With about 200 new plants in in the pipeline, 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 electric 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 a further boost from the adoption of the implementation plan.

R&I ACTIVITIES

A. Geothermal heat in urban areas

B. Integration of geothermal electricity and heating & cooling in the energy system responding to grid and network demands

C. Improvement of overall geothermal energy conversion performance for electricity and heating & cooling generation

D. Closed loop electric and heating & cooling plants integrated in the circular economy

E. Sustainable and efficient production technologies

F. Development and exploitation of geothermal resources in a wider range of geological settings

G. Advanced drilling/well completion techniques

H. Innovative exploration techniques for resource assessment and drilling target definition

NON-TECHNICAL BARRIERS/ENABLERS (NTBE)

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 Implementation Working Group stresses the relevance of two cross-cutting issues which are crucial for gaining more widespread support for all research and innovation actions while addressing non-technical barriers/enablers:

Knowledge transfer + training (including peer-to-peer learning and research infrastructures)

It is important that the EC demonstrates capacity building, industrial technology transfer and science & academic partnerships via transfer of know-how. The development of high quality, competitive and sustainable geothermal energy projects is the shared goal that underpins this issue. This includes the continued development of European Research Infrastructure Consortia (ERIC). Of particular relevance is the European Plate Observing System (EPOS) – ERIC, which supports 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-energytest-beds-low-carbon-energy) and allows for their efficient and coordinated use.

Important for this cross-cutting action is training and educating new geothermal professionals. Among the necessary actions, is a much-needed 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 the workforce of declining industries; and to promote the mobility of workers in Europe.

Support to these actions should be sought nationally, in Horizon Europe (and subsequent framework programs) Coordination and Support Actions, and in existing EC programs or support of knowledge transfer and human mobility, such as Marie Curie, Erasmus+ or 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 linkage of and development of information platforms, and the creation of standard and common data models at EU level. Progressive coordination of national data to facilitate data discovery and mining is an important step to provide scientists, stakeholders, investors, and geothermal developers with information, which will also serve as a basis for resource assessment and feasibility studies.

Resources for this action are likely to be provided by national geological services of European countries and regions. A general commitment to open access to relevant data is recommended through a user-friendly interface with different levels for professionals and the general public seeking information. An example of a successful and existing infrastructure is the EPOS-ERIC's Thematic Core Service on Anthropogenic Hazards (TCS-AH). The TCS-AH coordinates the provision of services for open-access data harvesting, data mining and data management.

Next Steps

The Deep Geothermal Implementation Working Group (IWG) is composed of representatives of relevant countries and stakeholders, representing both the industry and the academia. The IWG is responsible for revision of the Deep Geothermal IP. Throughout 2020 the Implementation Plan was revised.

Of the eight research and innovation (R&I) activities, four are considered to be flagship activities. Common to the latter R&I activities are interdisciplinary, sector-coupling projects (flagship projects) that demonstrate efficient implementation. Furthermore, five R&I activities envisage projects with low initial TRL where feedback loops with basic and/or fundamental research is of particular importance (R&I activities B, C, D, E and H have initial TRLs between 3 and 4). R&I activity E is related to cross-cutting technologies necessary for several parts of the geothermal value chain. For the flagship projects, the TRL refers to the main technology, but sub-technologies on lower initial TRL related to the cross-cutting R&I activity E is necessary to exploit the potential of linking of more basic research to large demonstration projects. 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. The proposed activities are characterised by different levels of maturity. For the implementation of R&I activities as well as NTBE-A and NTBE-B considerable efforts and funding will be required over the coming years to meet the goals of the Declaration of Intent.

All actions of the Implementation Plan are crucial to meet the SET-Plan targets for geothermal energy listed in the Declaration of Intent. To ensure their proper implementation, an estimated overall investment of €936,5 mln needs be mobilised over the next 5-8 years, sourced as follows:

- €456 mln from the industry (private funds - 49% of the total);
- €342 mln coming from national programmes (36,5% of the total);
- €138,5 mln coming from EU funds (14,5% of the total).

There are potential synergies with several other IWGs, namely:

- Carbon capture and use (CCU) and carbon capture and storage/use (CCS) where one may combine CCS/U with geothermal energy extraction; data availability for CO_2 saline equilibria at high pressures and temperature; reservoir modelling; equipment for drilling and NCG reinjection)
- Concentrated Solar Power with particular attention on advanced power cycles based on, for example, supercritical CO2

  Energy consumers (rebound effect of geothermal energy on non-dispatchable renewables, with significant effects on the cost of electricity)

- Integrated and flexible energy systems covering topics such as energy storage, sector coupling, as well as grid flexibility and dispatchability.

ENABLING FRAMEWORK FOR THE DEEP GEOTHERMAL IMPLEMENTATION WORKING GROUP'S EFFORTS ON THE IMPLEMENTATION PLAN

The Support Unit for the DG-IWG

Supported by a Horizon 2020 Coordination and Support Action, a so-called "Support Unit" to the Deep Geothermal IWG has been set up to. The task of the Support Unit is to facilitate the execution/realisation of the Implementation Plan and to ensure that the DG-IWG has the requisite data, tools and procedures in place to have evidence based facts for well-grounded discussions at its disposal. In this manner, the DG-IWG may make strategic decisions to accelerate the uptake of geothermal energy in Europe in an efficient way.

The workstreams of the Support Unite are three:

1. To provide the DG-IWG with relevant data about the IP execution, from the various stakeholder groups as well as providing strategy support for the DG-IWG in their decision-making process and actions;
2. To promote and organise initiatives that mobilise the geothermal community to implement the actions identified in the implementation plan, e.g. workshops, brokerages, consortium building and exploitation of RD&I results.
3. To provide a secretariat for the DG-IWG to assist on administrative issues and strategy support.

With two years into the implementation of the plan, which was endorsed by the SET-Plan Steering Group on 24 January 2018, the Deep Geothermal Implementation Working Group has initiated a review, an update and a revision of the plan. The Support Unit has undertaken the coordination of this process. The Deep Geothermal Implementation Working Group expects the revision to be approved by the fourth quarter of 2020 and will submit the revised implementation plan for endorsement by the SET-Plan Steering Group towards the end of the fourth quarter 2020.

The Clean Energy Transition Partnership

The European Commission has successfully encouraged a number of European SET-Plan countries (and beyond) and their geothermal research and innovation funding organisations to collaborate and pool resources across the innovation cycle. The current transnational collaboration the (ERANET GEOTHERMICA) builds on a common understanding of the research and innovation needs in GEOTHERMICA countries, the identification of common challenges and resulting from this realization a comprehensive set of activities that serve to address the common challenges for the geothermal sector. A cornerstone are joint calls for transnational research and innovation projects and a number of additional activities. The first such call has been co-funded by the European Commission with subsequent calls being supported only by GEOTHERMICA countries.

Building on the success of a number of such ERANETs across energy technologies, EU member states and associated countries together with the European Commission envisage a next stage in the cooperation: the establishment of a co-funded “Clean Energy Transition” partnership (CETP). The Deep Geothermal Implementation Working Group expects that this challenge driven CETP will provide ample opportunities to launch calls and additional activities that are not only driven by technology needs but are more appropriately framed in the context of challenges that Europe faces on her journey to carbon neutrality and beyond. The DG-IWG expects the continued operation of GEOTHERMICA Implementation Plan.

Ongoing and planned R&I Activities

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

A - GEOTHERMAL HEAT IN URBAN AREAS

R&I Activity A	**Targets: DOI 1, 2, 4, 8 & NTBE A, B:**
TRL at start: 3-5 (for simulation and monitoring and research on social acceptance), 7	**TRL at end: 9**
Total budget required: €73,3mln	**Flagship: Yes**

Scope:

To enhance the European heat transition to renewable energy by providing safe and reliable geothermal based solutions for urban areas. To contribute to decarbonising energy use for heating and cooling in cities and to improve air quality.

Description:

The activity will aim to demonstrate new heating concepts for urban areas and/converting conventional district heating networks of urban areas into renewable heating systems. R&I will be geared towards enabling the smart use of thermal grids with emphasis on flexible supply of resources (sector coupling), adapted to different source temperatures (cascading uses) and varying demand. Geothermal utilization (including underground storage) will be positioned as a crucial pillar for the (heat) transition of the energy system. Attention will be paid to assessing potential risks of such developments, such as pollution of groundwater, and social concerns should be considered and studied to ensure the acceptance of the technology. Activities include geothermal heat for industry and agriculture, underground thermal energy storage (UTES) including high-temperature storage, innovative and multiple uses for geothermal energy (sector coupling and cascading use) and side-products, balneological systems, and design and operation of geothermal doublets.

Several demonstration projects will showcase the broad potential of geothermal energy in urban areas, 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. sector coupling, 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. This includes the development of modelling or simulation tools to account for cascading use and balanced resource management.

Monitoring mechanism:

Progress will be reported with respect to deliverables of each specific project.

Expected deliverables:	Timeline:
Portfolio (expected at least one per country involved) of SET Pland country demonstration projects: number of realized project will be listed, pointing out best practices and successes. Minewater Heerlen, Greater Munich, Ruch Area, Frankfurt, Paris, Milan, Geneva, Bern …	2020 on
Examples of combining Renewable Technologies for a Renewable District Heating System, might include H2020 demonstration case.	2019 on

Party/Parties	Implementation Instruments	Indicative financing contribution
Industry, BE, CH, DE, FR, IT, NL, PT, EU	Dedicated industry investment (private funds)	€30mln
	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): €40,5mln Italy: €0,7mln
		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
	GEOTHERMICA CFA	€8,5mln of EU funds[1]
	Horizon 2020 calls".	

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

B - INTEGRATION OF GEOTHERMAL HEAT AND POWER IN THE ENERGY SYSTEM AND GRID FLEXIBILITY

R&I Activity B	**Targets: DOI 1, 4, 7 & NTBE B**
TRL at start: 4-5	**TRL at end: 7-9**
Total budget required: €11,5mln	**Flagship: Yes**

Scope:

The activity covers the integration and optimization of flexible energy supply from geothermal energy resources in such a way that sector coupling strategies and their implementation are enabled

Description:

In order to cope with fluctuations of heat demand, flexible supply units are necessary that are not designed for one specific optimal condition, but in a way that optimizes the use of the heat source. Such systems should also consider hybridization with various sources of renewable heat, such as biomass or solar thermal supply options. 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 (sector coupling) should be able to provide additional services to the grid such as peak power, role in electricity balancing/reserve market. At any time economic feasibility and the environmental impact needs to be monitored and assessed in comparison to other renewable alternatives.

- Specifically the activity will have the following impacts:
- Demonstrating the technical, economic and financial feasibility of responding to commands from a grid or network operator, at any time, to increase or decrease output ramp up and down.
- Demonstrating automatic generation control (load following / ride-through capabilities to grid specifications) and ancillary services of geothermal power plants.
- Demonstrate flexible heating and cooling and electricity supply from binary cycles and EGS plants, including (sector-) coupling with renewable energy sources.
- Providing solutions to specific problems of geothermal power production in isolated energy networks (islands).
- Showcasing geothermal 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 heating, cooling, and electricity.

The expected impact will comprise a number of tests that demonstrate automatic generation control (load following / ride-through capabilities to grid specifications) including heating and cooling options by sector coupling.

Monitoring mechanism:

H2020 and GEOTHERMICA project monitoring Annual round-check on advances made in operational flexibility of geothermal plants connected to the electric grid and heating and cooling networks with different technologies.

Expected deliverables:	Timeline:
Tests to demonstrate automatic generation control (load following / ride-through capabilities to grid specifications) including heating and cooling options by sector coupling	2019-22

Party/Parties	Implementation Instruments	Indicative financing contribution
Industry, CH, IS, IT, PT, TR, EU	Dedicated industry investment (private funds)	€10mln
	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): €1,5mln

C - IMPROVEMENT OF OVERALL GEOTHERMAL ENERGY CONVERSION PERFORMANCE FOR ELECTRICITY GENERATION, AND HEATING & COOLING

R&I Activity C	**Targets: DOI 1, 3, 4 & NTBE A**
TRL at start: 5-6	**TRL at end: 7-8**
Total budget required: €21mln	**Flagship: No**

Scope:

The activity covers all measures that improve the overall conversion efficiency and reduce the cost of geothermal energy utilization, developing a 'best-practice' European technology solution with a perspective to become a worldwide standard.

Description:

The overall geothermal energy conversion efficiency will be improved by the development of higher performance of power plants able to supply both heat and electric power.

Specifically the increase of system efficiency will be demonstrated by:

- Improved design of improved heat exchangers and pumps,
- Optimized selection of materials, new working fluids with very small GWP (Global Warming Potential)
- Increases in expander efficiency
- Improved efficiency of the cooling system by enhancement of the air-cooler condenser and matching to the cycle, or avoiding the loss of useful heat into the environment by promoting the low-enthalpy industrial use of the circulating fluid
- Utilizing geothermal fluids at high temperature (> 175°C) and with high content of non-condensable gases (>2%) with suitably designed binary power plants
- Introduction of bottoming/hybridization units on existing or new power plants and development of new concepts for thermodynamic cycles (working media).
- Deployment of methods that lower the potential of scale formation in pipes, especially radioactive scales.

Technical solutions need to 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 new and innovative business models that account for multiple uses of geothermal resources.

Ultimately, the overall impact will be an improved general performance of systems that enable the generation of electricity and heating and cooling 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. There will be a number of associated impacts that result in a significantly improved efficiency of surface systems equipment/components encompassing heat recovery equipment, turbines for power only and for combined heat & power generation, and cooling generation (via heat absorption).

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.

Expected deliverables:	Timeline:
Piloting and demonstration of performance improvement of systems that enable the generation of electricity and heating and cooling from geothermal energy resources with medium and low enthalpy	2030
Improving operational performance, efficiency, and availability of surface systems equipment/components: heat recovery equipment, turbines for power only and for combined heat & power generation, cooling generation (via heat absorption)	2030

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): €4,5mln Italy: €1,5mln
	Transnational calls in Horizon Europe and CETP/GEOTHERMICA	€8-10mln – shared with Grid Flexibility demonstration)- Research from private manufacturers Cooperation with other energy sectors Support potential involvement of private research.

D - FULL REINJECTION ELECTRIC AND HEATING & COOLING PLANTS INTEGRATED IN THE CIRCULAR ECONOMY

R&I Activity D	**Targets: DOI 1, 3, 4 & NTBE B**
TRL at start: 5-6	**TRL at end: 6-7**
Total budget required: €123,4mln	**Flagship: Yes**

Scope:

Demonstrating the feasibility of power and heating & cooling plants that are integrated in the framework of a circular economy. Specifically, cradle to cradle concepts need to be piloted and demonstrated for the application of the total reinjection of the geothermal fluids including the capture of non-condensable gases (zero emission plants), to eliminate 'waste' by finding alternative usage options and ensure long term stability of the geothermal resources or even extend their lifetime by heat storage. Essential is the demonstration of such expected impacts by way of laboratory and field tests related to full reinjection in test circuits and/or geothermal reservoirs at different resource conditions.

Description:

The expected impact is to operate geothermal zero emission plants with capture of greenhouse gases, storage and reinjection schemes for the development and exploitation of geothermal reservoirs, in particular those with high content of non-condensable gases (NCGs).

An associated impact is the validation of the feasibility and reliability of closed-loop reinjection of geothermal fluids at high temperature (> 175°C) and with high (>5%) NCG content, which will require systems for capture and re-injection, and the use of chemical compounds and additives to manage the chemistry of produced fluids.

A further impact of such solutions will be an improved matching of the subsurface reservoir to the power cycle and the development of new equipment (intelligent well completions, compressors, pumps, intercoolers, mixing nozzles and possibly refrigeration equipment).

Additionally, following the cradle-to-cradle concept of a circular economy, 'waste' produced during the construction and installation of the geothermal systems will be converted to 'value', e.g. drill cuttings that can be used as construction material (buildings, roads etc.).

Furthermore, the re-use of abandoned oil and gas wells for geothermal heat production or heat storage as well as co-production of e.g. Lithium or other materials present in the geothermal fluid is also in the scope of this activity.

Monitoring mechanism:

Information on new plants (realized or under construction) will be gathered in partner countries involved in these activities with a stock-take every 3 years.

Benchmarking with respect to specific project deliverables. The information collected will be organized in a report taking into account the initial baseline and, if accessible and available, supplemented with data coming from countries not represented in the IWG.

Expected deliverables:	Timeline:
Lab and field tests demonstrating possibility of full reinjection in test circuits and/or geothermal reservoirs with different resource conditions as well as the possible re-use of drilling materials (drill cuttings) or abandoned oil- and gas wells	2025
Pilot/demonstrative geothermal plants to experiment high-performance closed loop technologies	2030

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 €40mln (5 MW_{el} 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): €7,5mln Italy: €0,4mln Turkey: €0,5mln
	Technology specific calls for solutions that significantly reduce the cost of renewable power generation (Type of action: R&IA)	€15-20mln (contribution from the EU expected per proposal)
	Call for the demonstration of highly performant renewable technologies for heat and power generation and their integration in the EU's energy system (Type of action: R&IA)	€15-20mln (contribution from the EU expected per proposal)

E - SUSTAINABLE AND EFFICIENT PRODUCTION TECHNOLOGIES

R&I Activity E	**Targets: DOI 1, 2, 3, 4 & NTBE B**
TRL at start: 2-4 (Methods and equipment 4 (Materials)	**TRL at end: 6 (Methods); 9 (Equipment); 6 (Materials)**
Total budget required: €25,6mln	**Flagship: No**

Scope:

The development of new methods, processes, equipment and materials suitable to solve problems commonly encountered in geothermal resources development and exploitation (e.g. corrosion and scaling) at low and high temperatures. Such developments need to lead to a lower power demand of operating facilities and include the application of advanced well architectures and innovative technologies and materials, which will lower the unit technical cost of heat, power and storage.

Description:

Expected impacts include the demonstration of major innovations that increase operational availability (e.g. artificial lift techniques, heat exchangers, materials). Specifically, sustainable and reliable production from deep geothermal resources situated in a high temperature, high pressure environment, and characterized by variable geothermal fluid composition as well as dynamic reservoir response to stimulation and/or fluid production/reinjection. Major innovations include novel materials and equipment required need to cope not only with hostile and aggressive reservoir environments but also thermochemical and -physical fluid properties with the ultimate the goal is to improve equipment reliability and to increase plant utilization factor. Materials and/or methods and/or equipment such as production pumps for artificial lift, and heat exchangers need to demonstrate their suitability for the application in all parts of a geothermal plant to minimize operational issues related to high temperatures, scaling, corrosion, and gas content. It is to be demonstrated that the development and utilization of machine learning technology in analysis of geothermal data has significant potential in improving exploitation and operation of geothermal systems. Similarly, stable and uninterrupted operating conditions, improved performance and mitigation of risk need to be demonstrated by the integration of improved monitoring techniques, advanced dynamic reservoir simulation and an improved understanding of coupled thermal, hydraulic, chemical and mechanical processes operative in the reservoir during fluid production and reinjection.

Monitoring mechanism:

Checking of deliverables for each specific project with respect to the targets of the Declaration of Intent

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)	€10mln
	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): €4,5mln Italy: €1,5mln
	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.	€8-10mln – shared with Grid Flexibility demonstration)- Research from private manufacturers Cooperation with other energy sectors Support potential involvement of private research.
	CETP/GEOTHERMICA	€8,5mln of EU funds
	Calls for the development of the next generation of renewable energy technologies	€2-5mln

F - DEVELOPMENT OF GEOTHERMAL RESOURCES IN A WIDER RANGE OF GEOLOGICAL SETTINGS

R&I Activity F	**Targets: DOI 1, 3, 4 & NTBE A, B**
TRL at start: 4	**TRL at end: 8**
Total budget required: €382,5 mln	**Flagship: Yes**

Scope:

Demonstration of innovative methods and techniques for reservoir development and exploitation in a wider range of geological settings, including complex and/or untested geological conditions.

Description:

The expected impact is the demonstration of energy efficient, environmentally sound and economically viable generation of electricity, and/or heating and cooling from geothermal resources in a wide range of geological settings, enabling geothermal energy development in new regions and supporting application concepts for local energy supply.

In addition, new geological environments, which require additional techniques to improve reservoir performance, need to demonstrate their suitability for geothermal use, enabling an unprecedented development of geothermal energy at European level (including countries with little known or presently absent resources suitable for direct use geothermal energy). This includes developing low-temperature resources, EGS, “super-hot” reservoirs in excess of 350-400°C, as well as off shore geothermal development, and hybrid solutions which couple geothermal with other renewable energy sources, e.g. in combination with subsurface seasonal storage.

Monitoring mechanism:

Checking of deliverables for each specific project with respect to the targets of the Declaration of Intent

Expected deliverables:	Timeline:
Portfolio of existing/planned projects Soultz, Deep EGS, Hungary, Mol, Gardanne, MEET	2020
1 plant=10 MW_{el}-20MW_{th}	2022
1 plant=20 MW_{el}-40MW_{th}	2025

Party/Parties	Implementation Instruments	Indicative financing contribution
Industry, CH, DE, FR, IS, IT, PT, EU	Dedicated industry investment (private funds)	€30mln
	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): €33m
	Calls on: demonstration of geothermal systems in different geological conditions; deep geothermal demonstration of cost efficient technologies ; on the development of technical solutions that reflect an improved knowledge of the impact of chemical and physical properties of geothermal fluids (including hot and super-hot fluids)	€10mln per call

G - ADVANCED DRILLING/WELL COMPLETION TECHNIQUES

R&I Activity G	**Targets: DOI 1, 4, 6**
TRL at start: 5 (improvement), 4 (novel)	**TRL at end:7 (improvement), 6 (novel)**
Total budget required: €52,1mln	**Flagship: No**

Scope:

Research and innovation activities that lead to a reduction in drilling/well completion costs leading to reduced cost of energy (€/MWh). Specifically, the demonstration of 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).

Description:

The overall expected impact is the reduction of cost for drilling and subsurface installations by at least 25% compared to the situation today.

Novel and advanced drilling technologies, currently not used in geothermal well construction, have to be adapted, optimized and field-tested in a variety of project settings. Technologies to be demonstrated include the introduction of drilling process automatization, of novel drilling fluids to compensate unwanted loss of circulation zones whilst minimizing reservoir damage as well as the introduction of improved cementing procedures and well cladding. The demonstration has to go hand in hand with adapted risk assessments, life cycle and social impact analysis resulting from the introduction of new technologies and methodologies. Innovative system need to be demonstrated to avoid/reduce the discharge of geothermal fluid into the environment while drilling and flow testing. This demonstration includes horizontal - multilateral wells clusters.

Advanced drilling technologies using compact, lightweight and low-noise equipment and the use of horizontal and multilateral well cluster, as well as completion techniques have to be demonstrated that minimize the impact of well construction in urban environments.

The expected impact is the validation and benchmarking of new drilling and well completion techniques by field-testing in a range of geological formations. Such technologies are expected to be developed using principles of a circular economy and include percussive drilling for deep/hot wells (e.g. fluid hammers) and non-mechanical drilling technologies (such as laser, plasma, hydrothermal flame drilling).

Monitoring mechanism:

Where available information (often protected by strong acts on trade and manufacturing secrets) will be gathered on new wells in partner countries drilled and completed with advanced techniques involved in these activities. Benchmarking with respect to specific project deliverables.

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)	€20mln
	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
	CETP/GEOTHERMICA	€8,5mln of EU funds
	Calls focused on developing solution to reduce the cost and increase performance of renewable technologies	€8-10mln

H - INNOVATIVE EXPLORATION TECHNIQUES FOR RESOURCE ASSESSMENT AND DRILLING TARGET DEFINITION

R&I Activity H	**Targets: DOI 1, 4, 5**
TRL at start: 5-6	**TRL at end: 7-8**
Total budget required: €49mln	**Flagship: No**

Scope:

The scope covers innovative, high-resolution exploration methods and tools to increase the precision for resource assessment, target definition of exploratory drilling and prediction of long-term reservoir performance. In particular, digitalization offers unparalleled opportunities owing to improved software, computing power, and big data management, machine learning and knowledge discovery. Interdisciplinary approaches are considered paramount to integrate a broad range of exploration methods to identify promising geothermal provinces and to optimize resource assessment.

Description:

The expected impact is an increase in the likelihood of successful exploration wells that prove the existence of geothermal reservoirs by 20% in 2025 and 50% in 2030 thereby reducing the exploration costs. Cost reduction should also be achieved through markedly faster times required for exploration data acquisition, processing, analysis and interpretation. Specifically:

- Piloting and demonstrating the added value of identification, access, and sharing of existing data and knowledge that aim to capitalize and build on previous projects and studies. Machine-learning algorithms will to demonstrate a positive impact on approaches to knowledge discovery and the optimized use of big data sets.
- Demonstrating the suitability and cost reduction potential of exploration techniques to a wide range of geothermal play types tailored to the specificity of the site.
- Developing and demonstrating new tools and techniques coupled with innovative modelling techniques, increasing measurement precision and acquisition rates, and applying faster analysis, processing, inversion and integration of acquired data to achieve useful yet accurate models of potential subsurface reservoirs..

Monitoring mechanism:

Information will be gathered periodically on new wells and exploration campaigns in IWG partner countries involved in these activities. Benchmarking with respect to specific project deliverables in terms of unit finding cost. The information collected will be organized in a report taking into account the initial baseline and, where available and accessible, also data from countries currently not involved in the DG-IWG.

Expected deliverables:	Timeline:
Improved subsurface images and characterization, cost reduction, higher resolution, faster results, new algorithms for machine learning on big data sets	2030
Develop and pilot new generation exploration techniques and integration of these techniques	2030

Party/Parties	Implementation Instruments	Indicative financing contribution
Industry, CH, DE, FR, IS, IT, PT, EU	Dedicated industry investment (private funds)	€15mln
	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): €22,5mln Italy: €0,4lnm
	CETP/GEOTHERMICA transnational calls	€8,5mln
	Dedicated Horizon Europe calls on exploration (and digitization).	€8-10mln

NTBE A - INVOLVING THE PUBLIC IN SUSTAINABLE GEOTHERMAL DEVELOPMENT

NTBE-A	**Targets: DOI 1**
TRL at start: not applicable	**TRL at end: not applicable**
Total budget required: €21mln	**Flagship: No**

Scope:

A: Public engagement: improve awareness of community affected (and citizens at large and stakeholders) and dissemination of the environmental, social and economic effects of geothermal energy.

B: Coordination of national and regional regulatory oversight practices for health, safety and environmental aspects of geothermal projects (also potentially referring to ISO standards). 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:

The expected impact is the availability of a continuously expanding data sets and approaches to addressing environmental and social concerns. Activities under that scope will result in lower barriers that will improve the awareness and knowledge regarding the contribution of geothermal energy to the energy mix. Suitable measures will be based on narratives and discourse styles regarding the nature of public concerns and the elements that influence individual and group perceptions of geothermal installations. Another impact will be an increased level of understanding and ability to communicate the socio-economic dimension of geothermal energy, and, where needed, to promote change in community's perceptions and responses to new and existing geothermal installations.

Education and outreach activities are expected which enhance social benefits and an improved ability of operators to adopt solutions for risk management. Such risk management strategies and adequate technology selection will, for example, demonstrate operator's capabilities to manage the risk of induced seismicity or to achieve emission reductions.

Activities need to be geared towards greater engagement and participation of local communities in decision-making processes on the development of geothermal energy (on new plants, new technologies adopted, new scientific and technical results, etc.) are deemed particularly important.

Monitoring mechanism:

Periodical, location-specific surveys that monitor changes in perception of people. Periodical information will be gathered about the perception of local communities in regard to near-by geothermal plants (built or under construction).

The information collected (from surveys, media, public reporting, etc.) will be organized in a repository of case studies, taking into account the initial situation. If available and accessible, data and analysis from countries currently not in the IWG will be gathered.

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)	€1mln
	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): €4,5mln Italy: €8mln
	CETP/GEOTHERMICA and transnational calls	€8,5mln of EU funds
	Calls that center al Social Sciences and Humanities (SSH) aspects of the CleanEnergy Transition	€1-3mln (contribution per funded transnational project)
	Calls that have a user-centric focus for the decarbonisation of SET-Plan country building stock: innovative approaches and affordable solutions changing the market for buildings renovation.	€3-4mln (contribution per funded transnational project)
	Calls that centre on market uptake support financed by end users and pro/consumers	€1-3mln (contribution per funded transnational project)

NTBE B - RISK MITIGATION (FINANCIAL/PROJECT)

NTBE-B	**Targets: DOI 1, 2, 4**
TRL at start: not applicable	**TRL at end: not applicable**
Total budget required: €177mln	**Flagship: No**

Scope:

Adapting and expanding of national geological risk mitigation methods and financial schemes (e.g. exploration grants, geothermal guarantee schemes) to enhance accountability for potential drawback of the production towards stakeholders (e.g. communities).

Description:

The expected impact is a more widespread deployment of geothermal energy enabled by fit-for-purpose, well understood financial risk management tools. The result will be an understanding of the different types of risks (e.g. financial, geological, etc.) that geothermal developers and operators face and a shared understanding of the similarities across national borders and a common approach to managing those risks. Of course, countries are expected to then derive tailored solutions depending on market maturity and subsurface conditions. A major impact for a successful implementation of such schemes will derive from the collation and identification of good practices across SET-Plan countries with regards to nationally differing rationales, set-up, financing, coverage, procedural aspects, mode of pay-out, fee structure and so on. A much-improved investment value and an optimized allocation of such funds that help offset technical and financial risks is expected from advanced approaches and guidelines.

Monitoring mechanism:

Via monitoring of national policy instruments; at EGRIF level via EGEC.

Expected deliverables:	Timeline:
Improved national and/or European project risk mitigation schemes	2025

Party/Parties	Implementation Instruments	Indicative financing contribution
Industry, CH, FR, IT, NL, PT, EU	Dedicated industry investment (private funds)	€1mln
	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): €176mln (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*
	Calls that address the development, implementation and refinement of market uptake support measures.	€1-3 m (contribution per funded transnational project)

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: A, C
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: A, C, E
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.	NTBE: 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 knowhow 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

6	EERA Geothermal	EERA Geothermal is a Joint Programme in the European Energy Research Alliance (EERA) that provides research to • expand the type, number and size of geothermal resources suitable for increasing power and heat generation; • improve efficiency, sustainability and flexibility in production of geothermal resources; and • improve integration of geothermal heat and power in the energy system. EERA Geothermal incorporates experiences from several plants in operation under different geological environments. Combining the forces of the major European geothermal R&D institutions and considering the strategic goals of the SET-Plan, EERA Geothermal aims at facilitating a significant acceleration of the development for providing reliable and highly efficient technology for the use of deep geothermal resources for heat and power. This is achived through integration and coordination activities, knowledge sharing and sharing of facilities. EERA Geothermal has 37 research institutions across Europe as Full or Associate Participants and has organised its work in eight sub-programmes.	Transverse
7	ETIP Deep Geothermal	The ETIP-DG (European Technology & Innovation Platform on Deep Geothermal) is an open stakeholder group, endorsed by the European Commission under the Strategic Energy Technology Plan (SET-Plan), with the overarching objective to enable deep geothermal technology to proliferate and reach its full potential everywhere in Europe. The primary objective is overall cost reduction, including social, environmental, and technological costs. The ETIP-DG brings together representatives from industry, academia, research centres, and sectoral associations, covering the entire deep geothermal energy exploration, production, and utilization value chain.	Transverse

Contacts

Deep Geothermal IWG Chair:

Gunter Siddiqi (gunter.siddiqi@bfe.admin.ch)

Deep Geothermal IWG Vice-chairs:

Gerdi Breembroek (gerdi.breembroek@rvo.nl)

Inga Berre (inga.berre@uib.no)

Fausto Batini (fausto.batini@magmaenergyitalia.it)

Support unit

Harpa Pétursdóttir (harpa.petursdottir@os.is)

Hjalti Páll Ingólfsson (hpi@georg.cluster.is)