



# Implementation Roadmap for Deep Geothermal



**ETIP-DG**

European Technology & Innovation  
Platform on **Deep Geothermal**

[www.etip-dg.eu](http://www.etip-dg.eu)

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# EXECUTIVE SUMMARY

Geothermal energy has the characteristics required to play a crucial role in our future energy mix: it is decarbonised, capable of providing affordable energy for society, and allows for the competitiveness of European industry.

Geothermal is a renewable energy source which is local, manageable and flexible. It should be integrated using a regional approach which both reduces costs for society (including system costs, such as infrastructure and storage facilities, as well as externalities, such as greenhouse gas emissions) and improves local security of supply.

Geothermal will be a key energy source both in smart cities and smart rural communities, in addition to supplying energy for industry, services and agricultural sectors. This is thanks to its ability to supply both Heating and Cooling (H&C) and electricity, as well as solutions for smart thermal and electricity grids via underground thermal storage.

Research and Innovation are two of the cornerstones for the further development of deep geothermal technologies and their market uptake.

A new generation of deep geothermal systems and technologies, the adaptation of existing technologies for new applications and markets, novel applications to be demonstrated, standardised and combined in hybrid systems, and the promotion of pre-existing technologies will all contribute to an accelerated deployment of geothermal in the EU in the context of the 2030 milestones.

Chapter A introduces the missions, the objectives and the timeframe of Research and Innovation (R&I) actions. The targets and the expected performance of the European Technology and Innovation Platform on Deep geothermal (ETIP-DG) have been set during recent years of activity and are summarised in Chapter B, along with Key Performance Indicators (KPI).

As regards the Implementation plan in Chapter C, three main aspects are considered: the identification of R&I actions which ought to be developed as a priority (based on the work of the ETIP-DG Working Groups), the objectives of the research actions, and finally, its targets and measurable performance indicators.

Finally, Chapter D addresses the funding of these research and innovation activities for deep geothermal. A key message here is that it is not only necessary to strengthen R&I private investments and increase the public funding budget for R&I projects at European, national and regional levels. A strengthening of the market deployment policy and knowledge sharing for deep geothermal are also required.



# INTRODUCTION

This Implementation Roadmap on Deep Geothermal identifies a path forward, developing high-performance, cost-effective and sustainable deep geothermal technologies that can expand the production of electricity, heating and cooling while reinforcing EU industrial capacity and leadership in the sector. It continues the work of the 2014 Geothermal Technology Roadmap created by the ETIP on Renewable Heating and Cooling (RHC Platform<sup>1</sup>), which launched the 2020 objectives and the related Implementation Plan. The mission, goals and actions described here for 2030 and the future date of 2050 build upon the Vision<sup>2</sup> and the Strategic Research and Innovation Agenda for Deep Geothermal (SRIA<sup>3</sup>). The selection of topics has been established via a stakeholder consultation process which prioritised goals and further needs for action.

This document is complementary to the one provided by the Deep Geothermal Implementation Working Group active within the Strategic Energy Technology Plan<sup>4</sup>, as it ranks short to medium-term challenges and actions, tracks long-term strategy, and offers a description of topics and goals, providing performance indicators.

The Roadmap is intended for policy makers, funding institutions, manufacturers and energy market actors, research institutions and other stakeholders.

## DEEP GEOTHERMAL ENERGY FOR EUROPE

In its Vision for the development of deep geothermal, the European Technology and Innovation Platform on Deep Geothermal presents its view on the City of the Future: a place where it is good to live and citizens play an active role in as “prosumers” in a smart, clean and 100% renewable energy system. Geothermal is a cornerstone of this energy system. It covers most of the demand for domestic heat and much of the demand for electrical power in Europe. This includes fully exploiting the flexibility of the geothermal supply, providing large centralised options as well as domestic and decentralised small-scale alternatives.

In 2050 the energy landscape will consist of interconnected local energy grids that are fed by a variety of local (renewable) energy sources. Due to the intermittent character of various renewable energy sources and the actions of prosumers, energy flowing within the grids is highly variable. Geothermal is widely used to balance the flows as it can be used for baseload supply or adjusted to deal with imbalances in demand and supply. Furthermore, deep geothermal bridges different energy sectors:

- Geothermal Combined Heat and Power plants create flexibility to supply heat/cold or electricity depending on demand

<sup>1</sup>RHC Platform Technology Roadmap, 2014

<sup>2</sup>ETIP-DG Vision, 2018

<sup>3</sup>ETIP-DG SRIA, 2019

<sup>4</sup>Agreed set of targets in Declaration of Intent (2017) and Implementation plan endorsed in 2018.

- By linking geothermal sources to efficient heat pumps, the heat supply increases during periods of high heat demand
- Excess heat from other sources is stored underground by geothermal wells
- Electricity supply can be stored underground as heat for later use
- Fuels (e.g. gas, methanol) produced by geothermal fluids and heat can be used to store energy or for transportation purposes

Due to its flexibility, geothermal holds a unique position in the future energy landscape. It creates a bridge between the heating and cooling sector and the electricity market. Furthermore, new production processes allow the conversion of CO<sub>2</sub> and hydrogen into synthetic fuels using excess heat from high-temperature geothermal resources. As such, geothermal interlinks the three energy sectors (i.e., electricity, heating and cooling and transport) and provides resilience to the energy system. This adds to the attractiveness of geothermal as an indigenous, locally available, environmentally benign, clean, renewable and sustainable energy source.

Geothermal is already a well-established market covering different technologies. Electricity production using geothermal resources started in Larderello in Tuscany, Italy in the first decade of the 20th century. Today, there are 102 geothermal power plants in Europe with a total installed capacity amounting to around 2.5 GWe, producing some 14.6 terawatt-hours (TWh) of electric power every year. Geothermal district heating dates back to the 1930s. The first geothermal district heating was installed in Reykjavik, Iceland. Since then, the direct use of geothermal heat has grown continuously, with peaks in development shortly after the first oil crisis and over the last decade. Today, Europe counts 288 geothermal district heating systems. The plants are spread over 24 countries and represent a total heating capacity of about 5 GWth. In 2017, they supplied about 11.7 GWh of heat.

In all these cases, geothermal has proven to be a reliable and affordable source of energy. Capacity factor for geothermal power plants ranges from 58 to 85%. Values are typically in excess of 70% and some binary plants are operating at almost 100%. The Levelized Cost of Energy (LCoE) for electricity production varies between 30 and 150 €/MWh. It should be noted that deep geothermal projects have low systems costs and negligible externalities, meaning that the LCoE accounts for almost the full costs for the project.

The higher values are typical for binary plants tapping into medium temperature resources. The LCoE for flash plants is typically lower and has an average value of about 40 €/MWh.

The selling price for heat in existing geothermal district heating systems is usually around 60 €/MWh, and within a range of 20 to 80 €/MWh. The price depends on the local geothermal situation, socio-economic conditions and pricing policies. In addition, district heating networks account for a significant share of the total costs for a geothermal district heating system. The main challenge for the development of new geothermal district heating systems most often concerns the financing and the development of new heat grid infrastructures.



Despite positive experiences with geothermal energy, there remains a considerable amount of untapped potential for new projects all over Europe. The economic potential for geothermal electricity generation in Europe in 2030 and 2050 has been estimated in the context of the GEOELEC project using an LCoE value of less than 150 €/MWh for 2030 and less than 100 €/MWh for 2050. The geothermal electricity potential in the EU is estimated, given current knowledge of resource assessment, at more than 34 TWh in the EU in 2030. Economies of scale, innovative concepts for accessing underground resources and substantial cost reductions should lead to a coverage by 2050 of as much as 50% of projected electricity supplied in the EU, including Iceland, Turkey and Switzerland.

The GeoDH project investigated the potential of geothermal district heating. A mapping of geothermal resources showed that over 25% of the EU population lives in areas directly suitable for geothermal district heating. Adding geothermal heat sources to existing grids can contribute significantly to the decarbonisation of the district heating sector, for which a considerable expansion is expected in Europe by 2050. A large part of these new district heating grids can be powered by geothermal sources. Innovations with respect to geothermal technologies and their integration into the district heating system should result in a reduction of the selling price of heat to about 40 €/MWh by 2030.



## MISSIONS, OBJECTIVES AND TIMEFRAME

### **MISSION 1: CONTRIBUTE TO CLEAN ENERGY PRODUCTION IN EUROPE BY FURTHER UNLOCKING THE POTENTIAL OF GEOTHERMAL ENERGY**

RD&I is required to achieve the ambition of deep geothermal covering up to 50% of projected electricity demand and 80% of heating supplied in Europe by 2050.

In areas with well-known, high geothermal potential, the use of optimised and new technologies may improve the utilisation of resources, helping to make a shift to emission-free production of the heat below our feet. The development of geothermal's full potential also means drilling into hotter and deeper resources that are much less known, as well as exploring and developing areas with less favourable geological conditions. New exploration approaches and technologies are needed in order to de-risk geothermal projects in these areas. In addition, the high temperatures and pressures and aggressive fluid composition will place new requirements upon the technologies and materials used to access and manage resources.

In the Strategic Research and Innovation Agenda, the members of the ETIP-DG defined 26 topics for technological progress. The identified topics address all stages of a geothermal project:

- Exploring and assessing the resource: Topics defined under exploration relate to the development of new approaches and technologies to locate and characterise geothermal resources. The overall objective of R&I in exploration is to reduce the costs of exploration technologies, increase the probability of successfully characterising geothermal resources prior to drilling and during geothermal development, and assess European geothermal potential including cutting-edge resources.
- Accessing the resource: Topics relating to the development of improved well designs, drilling and stimulation technologies, measurement tools and monitoring techniques to guarantee safe and cost-effective access to the resource and to prolong the lifetime of the well field. The overall objective is a reduction of the costs of drilling and maintaining the wells and to optimise the output of the well field.
- Using the resource: Topics related to utilisation of the resource include the development of new geothermal plant surface systems and the integration of geothermal heating, cooling and electricity supply into the energy system. The overall objective is to reduce the LCoE by maximising energy output while keeping costs as low as possible.
- Integrating geothermal into energy systems: This includes addressing the specific problems of geothermal power production in isolated energy networks (islands) such as grid infrastructure and demand-side management. In order to enable the achievement of this stage's potential, it is also necessary to develop adequate transmission and distribution infrastructure and to interconnect this with other flexibility options (e.g. demand-side management and storage), in addition to testing dispatchability.

## MISSION 2: IMPROVING SOCIAL WELFARE THROUGH THE RESPONSIBLE DEPLOYMENT OF DEEP GEOTHERMAL ENERGY

Introducing and deploying deep geothermal technologies at large scales entails a number of technical and non-technical challenges, notably as regards their initial high investment cost, the acceptance of technologies in the developing areas, the involvement of consumers in the production chain so as to enhance the role of prosumers, and the lowering of legal and financial barriers. Barriers to the deployment of geothermal are diverse. They include:

- Financial, economic and market barriers (including access to finance, ability to access market etc.)
- Political and governance barriers
- Barriers regarding consent and environmental barriers (including positive and negative impacts)
- Social barriers (including social concern and resource conflict)

On the other hand, the development of technology to harness geothermal potential offers opportunities for Europe to reinforce industrial leadership, create jobs, cultivate significant export opportunities, and secure energy provision using a resource, such as geothermal, which is resilient to changes in climate while itself fighting against climate change by reducing greenhouse gas (GHG) emissions.

Geothermal energy can leverage extra value by exploiting synergies and knowledge transfer across subsurface-related sectors. Currently companies from the oil and gas, nuclear (waste) and mining sectors are leading players in subsurface technologies, and these may create extra value from their knowledge by using it to exploit new growth opportunities and more sustainable technologies in the geothermal industry.

The ETIP-DG members identified two non-technological challenges:

- The shift from R&I to deployment: The aim is to develop regulatory, financial, political and social solutions that can be implemented in order to overcome the barriers obstructing the deployment of innovation in the sector while increasing market uptake all over Europe, reinforcing technology leadership, creating jobs, and capitalising on its status in order to cultivate significant export opportunities.
- Knowledge sharing: Establishing an open-access policy for geothermal information (including standard exchange formats) to ensure easy access to data and information, as well as a pan-European hub of scientific excellence and research infrastructures.



Furthermore, a broader Mission regarding the approach of an energy system should consider two priorities:

- Integration of geothermal into the circular economy, notably by:
  - Adopting geothermal standardisation procedures and quality branding
  - Improving the applicability and use of recycled/secondary materials/ waste in geothermal plants
- Human deployment and outreach through:
  - Enhancement of the educational and training process, which should also call upon a coordinated effort (networking)
  - Development of an Employment Action Plan in order to transfer knowledge and absorb the workforce of declining industries promoting the mobility of workers in Europe
  - Launching international cooperation schemes, especially for EGS

The present Roadmap lays out the path for reaching the mission objectives stated above. The ultimate goal is the development of deep geothermal as a cornerstone of the energy system that will drive the city of the future and supply electrical and thermal energy wherever it is required in Europe. This is a long-term vision that lies beyond the timescale of the Roadmap. In order to make the Roadmap clear and tangible, its timescale extends to 2030. The identified actions were set along a timeline stretching from 2020 until 2030, based on input from the members of the ETIP-DG Steering Committee, priority considerations, and TRL.

## THE TARGETS

In order to embrace the considerable geothermal potential of Europe in a coordinated and responsible way and maintain global leadership in the sector, the SET-Plan<sup>5</sup> stakeholders from the European geothermal sector came together in 2016 to agree to six ambitious targets (T) and two transversal goals (G) with respect to efficiency, system integration, cost reduction, transparency and societal inclusion :

- T1: Increase reservoir performance [including underground heat storage], reducing the power demand of reservoir pumps to below 10% of gross energy generation and achieving a predicted 30-year or greater sustainable yield by 2030
- T2: Improve the overall conversion efficiency, including the bottoming cycle, of geothermal installations at different thermodynamic conditions by 10% by 2030 and 20% by 2050
- T3: Reduce the production costs of geothermal energy (including from unconventional resources, EGS, and/or from hybrid solutions which couple geothermal with other renewable energy sources) to below €0.10/kWhe for electricity and €0.05/kWhth for heat by 2030
- T4: Reduce exploration costs by 25% in 2025 and by 50% in 2050 compared to 2015
- T5: Reduce the unit cost of drilling (€/MWh) by 15% in 2020, 30% in 2030 and by 50% in 2050 compared to 2015
- T6: Demonstrate the technical and economic feasibility of responding at any time to commands from a grid operator to increase or decrease output ramp up and down from 60% to 110% of nominal power
- G1: Develop transparent and harmonised methods and instruments for technical and financial risk management
- G2: Pursue increased social acceptability and mitigation of unsolicited side effects (induced seismicity, emissions into the environment).

These strategic targets and goals were taken into account during the preparation of the ETIP-DG SRIA and served as a foundation for the definition of the main targets for technological and non-technological progress. During the consultation process upon which the Roadmap is based, these target statements were ranked with respect to relevance and priority, providing a basis to define the KPIs for the actions described in Chapter C: Implementation plan

The objective for all deep geothermal energy applications is to become widely distributed energy sources. As technologies are developed, their costs will decrease and their performance will increase, while risks will reduce and more plants will be deployed, meaning that the cost of producing energy (both electricity and heat) will further decrease due the market expansion of devices, tools and components. The overall objective of unlocking deep geothermal energy requires targets in the three main stages of geothermal project development.

<sup>5</sup>SET Plan Declaration of Intent Deep Geothermal



## TECHNOLOGICAL TARGETS AND INDICATORS

### BETTER PREDICTION AND ASSESSMENT OF GEOTHERMAL RESOURCES

Innovative exploration techniques at surface and borehole level are required to reduce the cost of geothermal exploration, a benefit obtained by reducing the risk of not finding the expected resource and reducing the survey-based and down-hole exploration costs. Innovation is also required to increase the probability of successfully characterising geothermal resources both prior to drilling and during geothermal development, which contributes to the sustainable management of geothermal projects. Another main priority is the provision of public and transparent performance analysis tools for resource potential and site assessment which can be used for energy planning, comparison and combination with other energy sources and energy applications, and for market uptake and sustainable and responsible development.

The overarching targets are:

- TA-1: Improve accuracy and reliability and reduce the cost of survey-based and down-hole exploration technologies
- TA-2: Improve analytical models and energy production forecasting and enhance the ability to image and characterise underground geological, physical and chemical properties throughout the life of geothermal projects
- TA-3: Minimise the uncertainty associated with geothermal energy by increasing the probability of discovering productive (i.e. fluid-filled) fractures and faults to be used as drilling targets
- TA-4: Improve resource and uncertainty reporting protocols, contributing to transparent and harmonised methods and instruments for technical and financial risk management, increased transparency for stakeholders, better and harmonised assessment of energy stocks across Europe and direct comparison with other RES projects
- TA-5: Investigate and characterise cutting-edge geothermal resources, enlarging the resource portfolio.

The two major KPIs on assessing geothermal resources are those related to:

- Increasing reservoir performance and achieving a predicted 30-year or greater sustainable yield by 2030 as a result of improved control, understanding and management of underground geological processes
- Reducing exploration costs by 25% in 2025, including the cost of exploratory drilling, and by 50% in 2050 compared to 2015.

## EFFICIENT RESOURCE ACCESS AND DEVELOPMENT

The strategic targets of the SET-plan Declaration served as a basis to define the KPIs for the actions on resource access and development. Members of the ETIP-DG steering committee were asked to rank 7 target statements with respect to relevance and priority. The statements were related to cost reduction as regards drilling, workovers and maintenance, increasing the efficiency of stimulation, prolonging the lifetime of pumps and other equipment, standardisation, and improving environmental performance and mitigating unsolicited side effects (induced seismicity, emissions into the environment);

Setting aside the technological solutions mentioned in the statements, the three priority targets were translated into 3 overarching KPIs:

- TD1: Reducing costs related to workovers and maintenance: The overarching performance indicator to evaluate the impact of actions relating to workovers and the maintenance of production pumps and the transfer piping/steam network is the production cost of geothermal energy. This KPI is linked to strategic target no. 3 of the SET-Plan Declaration.
- TD2: Reducing the costs of accessing and developing the resource: The overarching performance indicator used to evaluate the effectiveness of the actions affecting the way geothermal resources are accessed and developed is the total investment in the well-field (encompassing the costs of drilling and completing the injection, production and monitoring wells) divided by the energy output (€/MWh). The situation in 2016 is used as a basis for cost comparison. In order to reduce the investment costs of developing the well-field it will be crucial to improve the efficiency of the drilling process. The most straightforward way to lower these costs is by reducing the number of days needed to drill, complete and test the wells. As costs related to the daily drilling rate make up about 30 – 40% of the total costs of a geothermal well, the relative cost reduction that can result from a shorter drilling time is limited, but the impact on the total budget for the field can run into the millions of euros. Drilling faster is one option to shorten the time needed to complete a well. However, overspending due to unforeseen geological conditions, wellbore instability and/or unpredicted operational events such as lost-in-hole have a larger impact on the economics of a geothermal project than rate of penetration. Technological developments that can help to avoid or mitigate such unforeseen costs, as well as technology transfer and experience exchanges, are equally as important to achieving the overarching objective as the development of fast drilling technologies. For low-permeability resources, reaching the overall objective will also strongly depend upon the development of cost-effective stimulation techniques.
- TD3: Reducing the impact of deep geothermal by improving environmental performance and avoiding unsolicited side effects: The third priority target is improving the environmental performance of geothermal plants and mitigating unsolicited side effects (e.g., induced seismicity, emissions to the environment).



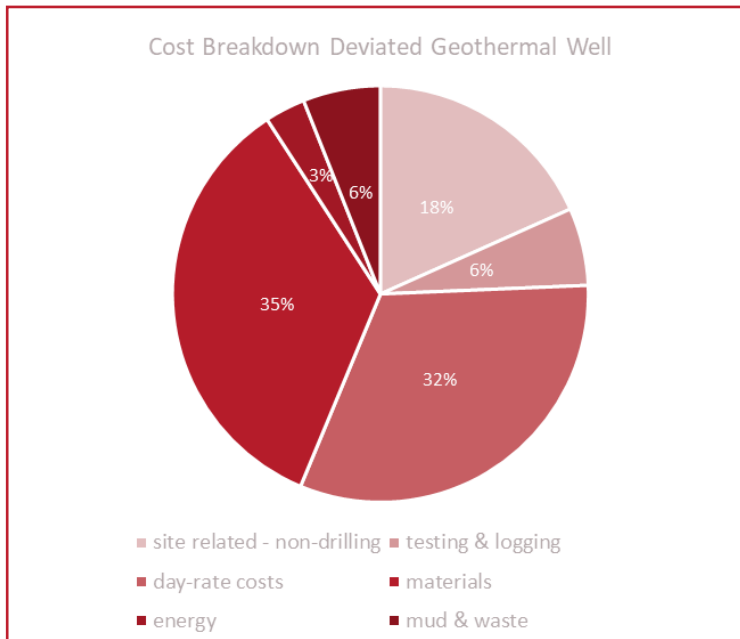


Figure 1: Cost breakdown for a deviated geothermal well

The graph above represents the relative cost breakdown for a 4000 m deep, deviated geothermal well (based on the costs for drilling well MOL-GT-02 in Mol – Belgium).

## DEPLOYING HEAT AND ELECTRICITY GENERATION AND SYSTEM INTEGRATION

The challenge here is to maximise generation while keeping costs as low as possible. Novel technologies should focus on enabling total exploitation of geothermal energy while reinjecting the fluid and balancing the mass underground, thus reducing reservoir geofluid depletion.

A critical priority is also to go beyond conventional generation by exploiting the vast and deep superhot geothermal resources, which are estimated to be 10 times greater than hydrothermal resources and on the same order of magnitude as EGS resources. One potential means of cost reduction for geothermal resources is also the co-production of metal and non-metallic material contained in the geothermal fluids in addition to thermal and electrical energy.

The four targets are the following:

- TS-1: Increase efficiency and reduce losses and internal consumption during energy conversion processes
- TS-2: Improve the reliability and durability (resistance to corrosion, abrasion) of surface system equipment
- TS-3: Reduce the overall cost of heat and power generation
- TS-4: Adapt plants to be baseload and dispatchable in order to facilitate larger shares of renewables in the energy system and improve the integration of geothermal energy through enhanced interaction with energy storage, demand response and smart interconnection with other technologies.



The major KPIs are those related to:

- Increasing electrical and thermal generation and subsurface storage efficiency by 10% by 2030
- Reducing the production costs of various applications by 15% (with respect to specific technologies) by 2030
- Demonstrating the technical and economic feasibility of responding at any time to commands from a grid operator to increase or decrease output and ramp up and down from at least 60% to 100% of nominal power

## NON-TECHNOLOGICAL TARGETS AND INDICATORS

### MOVE FROM R&I TO DEPLOYMENT

The aim is to develop regulatory, financial, political and social solutions that can be implemented in order to overcome barriers to deploying innovation in the sector, as well as barriers to the broader deployment of geothermal energy solutions and their increased uptake all over Europe. This must be done in parallel to the technological research described above if geothermal energy is to be one of the main contributors to European climate and energy targets, by:

- TM-1: Setting ambitious policies at EU and national levels to allow the development of the geothermal market and the penetration of innovation in the sector
- TM-2: Adapting policies and markets. Research and assess the economic incentives and support mechanisms for geothermal (as well as the legal and regulatory frameworks) that will enable fast deployment at a low price
- TM-3: Minimising the uncertainty associated with geothermal energy by addressing and quantifying exploration risk, while developing financial tools to help mitigate such risks
- TM-4: Integrating geothermal into the natural environment
- TM-5: Complying with the European concept of the "circular economy"
- TM-6: Ensuring public engagement and acceptance. Further research is needed to understand the drivers of public engagement and develop a more effective way to communicate key aspects for public acceptance such as environmental and economic elements
- TM-7: Ensuring access to first-class skills and human resources and consolidating the scientific base for geothermal energy in order to cement progress and educate the next generation of geothermal pioneers.

The two major KPIs on market uptake are to:

- Reach more than 5 GWe installed capacity in 2030 (from 3 GWe in 2019);
- Reach more than 15 GWth installed capacity in 2030 (from 5 GWth in 2019).



## KNOWLEDGE SHARING

The main aim here is to improve access to data, information, laboratories and demo sites, improve the accuracy of research and accelerate its progress, and strengthen collaborations while also reinforcing trust in data through the use of open and shared data access. Successful market introduction of developed technologies will be improved by achieving two main targets:

- TK-1: Improving access to relevant data and derived models in order to reduce exploration costs and manage technical and financial risks
- TK-2: Large scale demonstration and deployment in order to provide proof of innovative concepts and their integration in the energy system

This cross-cutting action also aims to train and educate new geothermal professionals.

The overall KPI related to the number of Research Infrastructures (RI) established at European level in the field of Deep Geothermal is evaluated using the following specific KPIs:

- Achieving 100% of geothermal datasets in national databases being harmonised at European level
- Creating a pan-European geothermal information platform
- Creating shared facilities for testing and developing innovative deep geothermal concepts
- Doubling the quantity of geothermal information shared

## POTENTIAL COST REDUCTION: BEYOND THE LCoE APPROACH

The competitiveness of the deep geothermal sector must be consolidated by first developing a fair basis of cost comparison between energy sources which goes beyond a limited LCoE approach, taking into account actual system costs and external factors. It should be noted that deep geothermal projects have low systems costs and negligible externalities, which means that the LCoE accounts for almost the full costs for the project.

This potential cost reduction is linked to the third strategic target of the SET-Plan Declaration. The target is set at a maximum production cost of 15 €/kWh for electricity and 6 €/kWh for heat by 2023, and 10 €/kWh for electricity and 5 €/kWh for heat by 2026. These cost targets apply to all types of deep geothermal projects, including EGS and super-hot geothermal systems (> 350°C).

As of 2019 the levelized cost of energy (LCoE) for electricity production varies between 30 and 150 €/MWh. The higher values are typical for binary plants tapping into medium temperature resources. The LCoE for flash plants typically is lower and has an average value of about 40 €/MWh.

The selling price for heat in existing geothermal district heating systems is usually around 60 €/MWh, and within a range of 20 to 80 €/MWh. The price depends on the local geothermal situation, socio-economic conditions and pricing policies. In addition, district heating networks account for a significant share of the total costs for a geothermal district heating system.

The economic potential for geothermal electricity generation in Europe in 2030 and 2050 has been estimated as part of the GEOELEC project, using an LCoE value of less than 150 €/MWh for 2030 and less than 100 €/MWh for 2050.

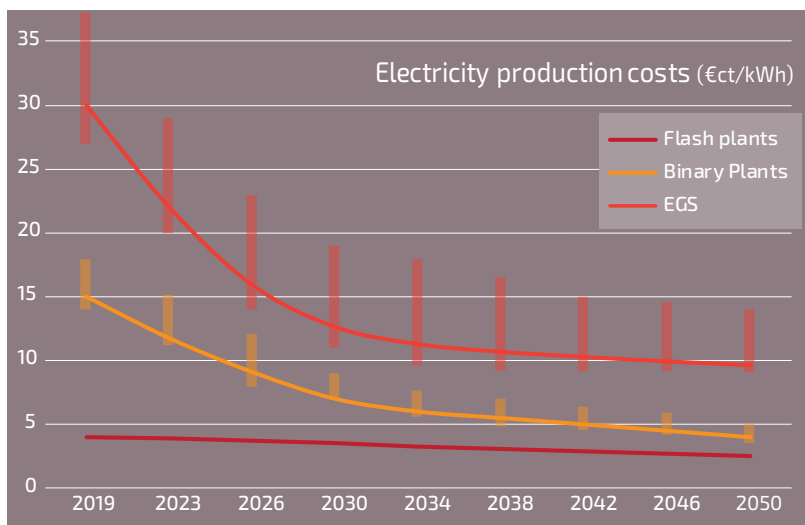


Figure 2: Potential costs reduction for electricity production

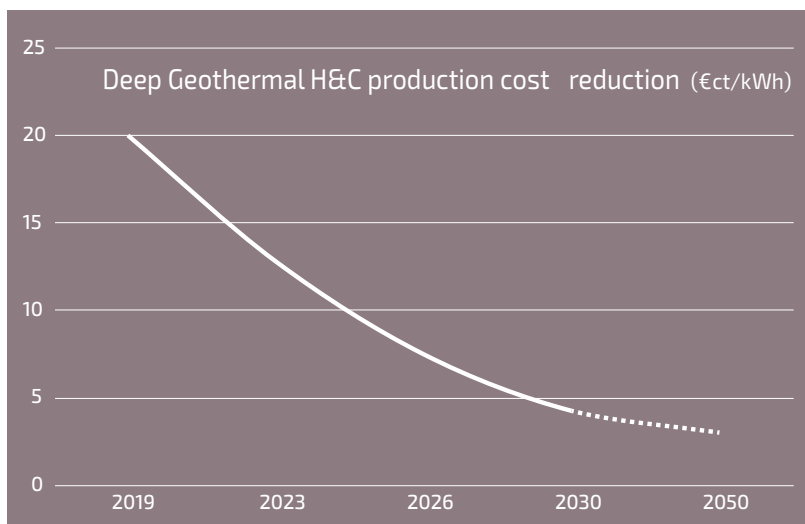


Figure 3: Potential cost reduction for h&c production

# IMPLEMENTATION PLAN

## INTRODUCTION OF DEEP INTO THE ENERGY SYSTEM

### PRIORITY TIMELINE 2020-2030

PRIORITIES		2020-2023	2023-2026	2026-2030	Budget
Prediction and assessment of geothermal resources	PA-1 Assessing Deep Geothermal resource potential		2025		€ 250 m
	PA-2 Improved exploration prior to, during and after drilling				€ 50 m
	PA-3 Exploration workflows and cataloguing		2025		€ 50 m
	PA-4 Cutting edge geothermal resources				€ 100 m
Efficient resource access and development	PD-1 Total reinjection and greener power plants				€ 150 m
	PD-2 Reduce the impact of scaling and corrosion while improving equipment and component lifetime				€ 75 m
	PD-3 Efficient resource development				€ 200 m
	PD-4 Improved rate of penetration technology for accessing the resource				€ 165 m
	PD-5 New electronics to monitor and operate geothermal wells				€ 60 m
Heat and electricity generation and system integration	PS-1 Developments in turbines				€ 100 m
	PS-2 Flexible production of heat and power and integration with smart grids				€ 150 m
	PS-3 High-Temperature Underground Thermal Energy Storage				€ 100 m
	PS-4 Developing hybrid plants and exploiting mineral production from geothermal sources				€ 200 m
Non technical priorities	From R&I to deployment				€ 40 m
	Knowledge Sharing				€ 40 m
Next generation of technologies					€ 120 m

Figure 4: Priorities of the ETIP-DG Roadmap and timeline 2020-2030

T= Target

P= Priority

A= Better prediction and assessment of geothermal resources

D= Efficient resource access and development

S= Deploying heat and electricity generation and system integration

M= Move from R&I to deployment

K= Knowledge sharing

TA= Target for Better prediction and assessment of geothermal resources

PA= Priority for Better prediction and assessment of geothermal resources



## MISSION 1: CONTRIBUTE TO CLEAN ENERGY PRODUCTION IN EUROPE BY FURTHER UNLOCKING GEOTHERMAL ENERGY POTENTIAL

### BETTER PREDICTION AND ASSESSMENT OF GEOTHERMAL RESOURCES



*Vibroseis fleet in operation during an active seismic survey for the DESCRAMBLE project*

The RD&I topics in the SRIA are:

- Topic 1: Improved exploration prior to drilling
- Topic 2: Advanced investigation and monitoring technology
- Topic 3: Exploration workflows - Conceptual models, reservoir characterisation, performance and decision models
- Topic 4: Exploration catalogues – Reservoir analogues, rock properties and model constraints
- Topic 5: Assessing resource potential
- Topic 6: Beyond conventional resources

The priority ranking of these 6 topics in the produced four actions for improving the prediction and assessment of geothermal resources.

Total budget= € 450 million

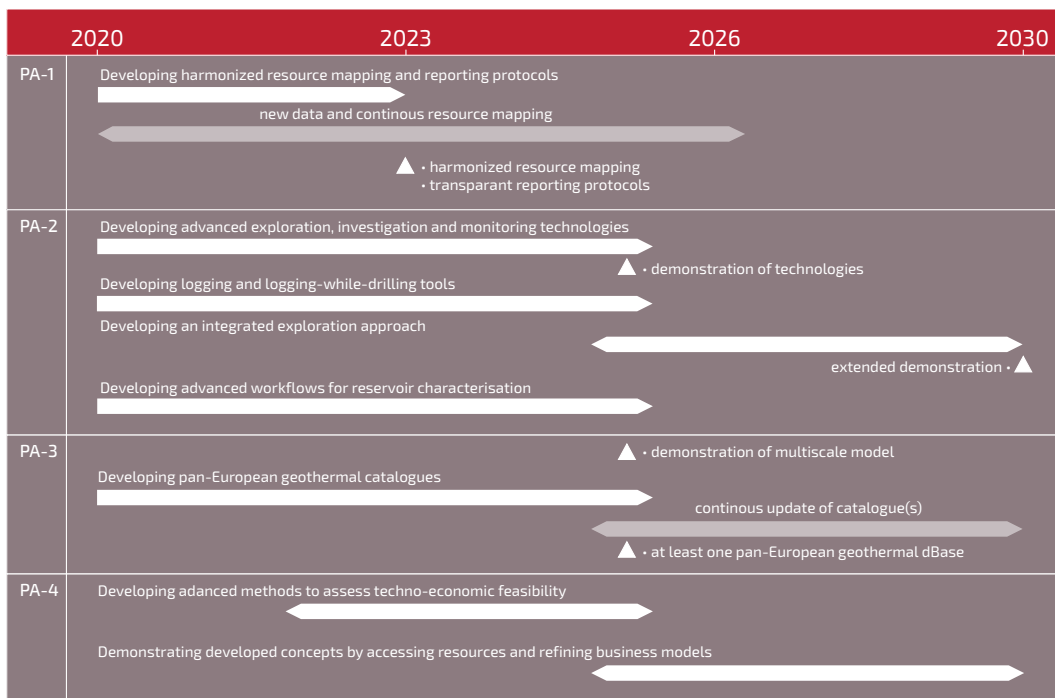


Figure 5: Timeline 2020-2030 Prediction and Assessment of geothermal resources.

### Priority PA-1: Assessing deep geothermal resource potential

**Budget: € 250 m**

#### State of play

Although geothermal reporting codes have been developed in a few countries (Canada and Australia) for their specific stock exchange markets, and a scheme for the classification, reporting and management of energy and mineral resources is available, these are essentially dedicated to particular market aspects and lack the elements necessary for the consistent comparison of geothermal resources to other energy sectors.

#### Objectives

Produce a comprehensive European overview of current and future geothermal energy sustainability scenarios at project, company, national, regional or global level, to be used by investors, regulators, governments and consumers, and which can also be compared with other RES projects. In order to achieve this main objective, it is necessary that European countries agree and adopt harmonised protocols and pursue the assessment of geothermal energy stocks across Europe. This main objective is to be achieved via intermediate actions:

- Develop a methodology to compute the geothermal potential of different applications and develop a resource-reserve and uncertainty reporting protocol for technical and financial risk management (by 2022, TRL from 2 to 4).
- Calibrate reporting protocols in developed areas (green field) and areas under development (brown fields) (by 2023, TRL from 5 to 7).
- Acquire new data (by drilling and accessing available but not currently accessible data) and further develop resource maps to be harmonised at European level.

Two main goals, the promotion of basic research and a European drilling campaign (in addition to geophysical campaigns), will be proposed. The aim of the drilling campaign is to further reduce risk and thus promote commercial initiatives by supporting secondary exploration through the drilling of characterisation wells in prospective regions based on commercial initiatives. Data will be collected in high-quality public databases.

### Targets and KPIs

- Produce a comprehensive mapping and reporting of geothermal resources for different applications in Europe in 2025, to be continuously updated.
- Contribute to transparent and harmonised methods and instruments for technical and financial risk management
- Demonstrate reporting protocols which can provide public and transparent performance analysis tools for resource potential and site assessment for different applications.
- In the future, not a single project should need to be abandoned after the decision to go ahead with drilling. The chapter on knowledge sharing provides further details on the upscaling of products.

The two major KPIs on assessing geothermal resources are to:

- Increase reservoir performance and achieve a predicted 30-year or greater sustainable yield by 2030 as a result of improved control, understanding and management of underground geological processes
- Reduce exploration costs by 25% by 2025 (including the costs of exploratory drilling) compared to the current situation :
  - The cost of identifying a resource is estimated to fall between € 350,000 – € 1,000,000
  - Cost estimates for resource exploration range from one to ten million euros
  - The contribution to LCoE is estimated at €3.5 per megawatt hour.

A specific KPI for this action is to:

- Provide and demonstrate reporting codes in at least 5 regions with differing geological and technical applications by 2025
- See adoption of a common reporting protocol by at least three European Member States.

### Scope

Partnerships with public (geological surveys, research institutes) and/or private (drilling companies, specialised engineering and project developers) initiatives are required, as are synergies with the oil and gas sector.

<sup>6</sup>United Nations Economic Commission (UNFC)



## Priority PA-2: Improved exploration prior to, during and after drilling

**Budget: € 50 m**

### State of play

Numerous exploration techniques are used to characterise resources before, during and after the first wells are drilled in order to predict the resource, test the existence of a geothermal reservoir capable of sustaining commercial rates of fluid production and injection, and provide necessary data for sustainable management. Continuous effort as well as periodic RD&I opportunities are required in order to test and optimise developed technologies.

### Objectives

Mitigation of risks during the feasibility and operational phases of a geothermal project by maximising the probability of predicting physical (T, P, permeability, stress, thermal capacity, etc.) and chemical parameters as well as detecting fluid-bearing fractures and faults. This action includes the following:

- Developing advanced exploration, investigation and monitoring technologies to reduce the cost of surveys and improve the resolution of underground imaging by 2025 (from TRL 3 to 6)
- Developing an integrated approach by improving the multidisciplinary aspect of exploration methods, using joint modelling, specialised data and computationally advanced exploration, investigation and monitoring technologies by 2030 (from TRL 3 to 6 with an extended demo)
- Improving logging and logging-while-drilling tools and methods, building upon those used in geothermal and the oil and gas sectors so as to withstand harsh geothermal conditions (in particular, high temperatures) (from TRL 3 to 6).

### Targets and KPIs

The two major KPIs on assessing geothermal resources are to:

- Increase reservoir performance and achieve a predicted 30-year or greater sustainable yield by 2030 as a result of improved control, understanding and management of underground geological processes
- Reduce exploration costs by 25% by 2025, including the cost of exploratory drilling.

A specific KPI for this action is to:

- Demonstrate cost reductions for survey, monitoring and down-hole tools of at least 10%
- Demonstrate at least one productive well following the application of novel exploration tools
- Demonstrate at least one each of novel logging, exploratory and monitoring tools.

<sup>7</sup>*The renewables cost challenge: Levelized cost of geothermal electric energy compared to other sources of primary energy – Review and case study* by Christoph Clauser & Markus Ewert (2017)



### Priority PA-3: Exploration workflows and catalogues

**Budget: € 50 m**

#### State of play

An integrated approach focused towards multi-disciplinary complementarity, including geological, geophysical and geochemical techniques as well as numerical models, was employed to predict the geothermal target (productive resources) and to design the well. Various geological processes and conceptual play models are slowly progressing thanks to different projects and the data collection and applications involved. Continuous improvement of multiscale (tens of kilometres to metres) and multi-disciplinary regional and site-based conceptual models and reservoir characterisation capabilities is required, improvement which can result from the adoption and optimisation of techniques used in other (e.g. oil and gas, mining) sectors.

#### Objectives

This action aims at improving reservoir characterisation and knowledge of underground processes and properties by:

- Demonstrating advanced workflows for reservoir characterisation for different reservoir types and portfolio approaches (by 2025, TRL from 3 to 6). This action builds upon action PA-2 for advanced exploration methods
- Building harmonised, pan-European catalogues of rock properties and fluid-rock interactions, multiscale reference models and maps supplying constraints for regional and site models (implementation by 2025 with continuous updates thereafter, TRL from 3 to 5).

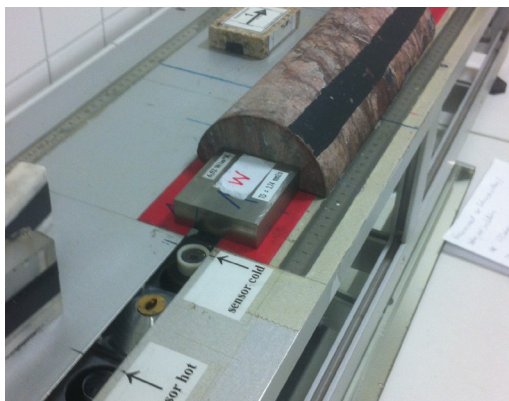
#### Targets and KPIs

The two major KPIs on assessing geothermal resources are to:

- Increase reservoir performance and achieve a predicted 30-year or greater sustainable yield by 2030 as a result of improved control, understanding and management of underground geological processes
- Reduce exploration costs by 25% by 2025 (including the cost of exploratory drilling).

A specific KPI for this action is to:

- Demonstrate at least one multiscale reference map and model which provides constraints for regional and site models, integrating geophysical, lab and structural models by 2025
- Demonstrate at least one relevant database on fluid-rock interaction, providing constraints on the variation of rock properties in the presence of hydrocarbon/geothermal fluids by 2025.



*Measuring physical parameters on a rock sample for the DESCRAMBLE project*

## Priority PA-4: Cutting edge geothermal resources

**Budget: € 100 m**

### State of play

RD&I for cutting edge resources, studied at both national level and in FP7 and H2020 projects (e.g. super-hot geothermal systems in IMAGE GEMEX, DESCRAMBLE DEEPEGS projects, Enhanced Geothermal Systems in GEISER and DESTRESS projects, mineral extraction from geothermal fluids in the CHPM2030 project) provided insights into coupled geological processes as well as performance under varying physical conditions and various rock and fluid geochemical compositions in investigated areas. A comprehensive view of achieved results and the available data, which is of interest for developing geothermal resources beyond the current level of technology, is currently unavailable.

### Objectives

Enhanced Geothermal Systems (EGS), super-hot and deep resources, offshore systems including remote islands, abandoned mines and exhausted water, and oil and gas wells can significantly contribute to geothermal energy growth in the future. That being said, their potential in various applications (e.g. innovative heat and fluid extraction for electricity and mineral production, combined and hybrid heat and power production, thermal and water storage) has yet to be established. The main aim here is to characterise these resources and develop novel ways to use them, by:

- Developing advanced methods to estimate and predict properties and processes deep underground, and defining the abundance and techno-economic feasibility of resources in view of different applications by 2025 (TRL from 3 to 5)
- Demonstrating developed concepts by accessing resources and refining business models by 2030 (TRL 5 to 6).

### Targets and KPIs

The two major KPIs on assessing geothermal resources are to:

- Increase reservoir performance and achieve a predicted 30-year or greater sustainable yield by 2030 as a result of improved control, understanding and management of underground geological processes
- Reduce exploration costs by 25% by 2025 (including the cost of exploratory drilling) .

A specific KPI for this action is to:

- Increase installed geothermal capacity by more than 200 MWe and 400 MWth by 2030 through the use of cutting-edge resources.



## EFFICIENT RESOURCE ACCESS AND DEVELOPMENT

In the SRIA, 11 RD&I topics leading to more efficient access and development of geothermal resources were defined. The RD&I topics in question are:

- Topic 1: Advancement towards robot drilling technologies
- Topic 2: Rapid penetration rate technologies
- Topic 3: Green drilling fluids
- Topic 4: Reliable materials for casing and cementing
- Topic 5: Monitoring and logging while drilling (incl. 'looking ahead' of the bit)
- Topic 6: High-temperature electronics for geothermal wells
- Topic 7: Effective and safe technologies for enhancing energy extraction
- Topic 8: Total reinjection and greener power plants
- Topic 9: Reducing corrosion and scaling and optimising equipment and component lifetime
- Topic 10: Efficient resource development
- Topic 11: Enhanced production pumps

In the process of defining the Roadmap, these topics were ranked with respect to priority and urgency. This exercise resulted in the definition of five actions for the period 2020 – 2030. The actions include targets corresponding to one or several of the RD&I topics and they are spread across the Roadmap timeline depending on their priority and current TRL.

Total budget= € 650 million

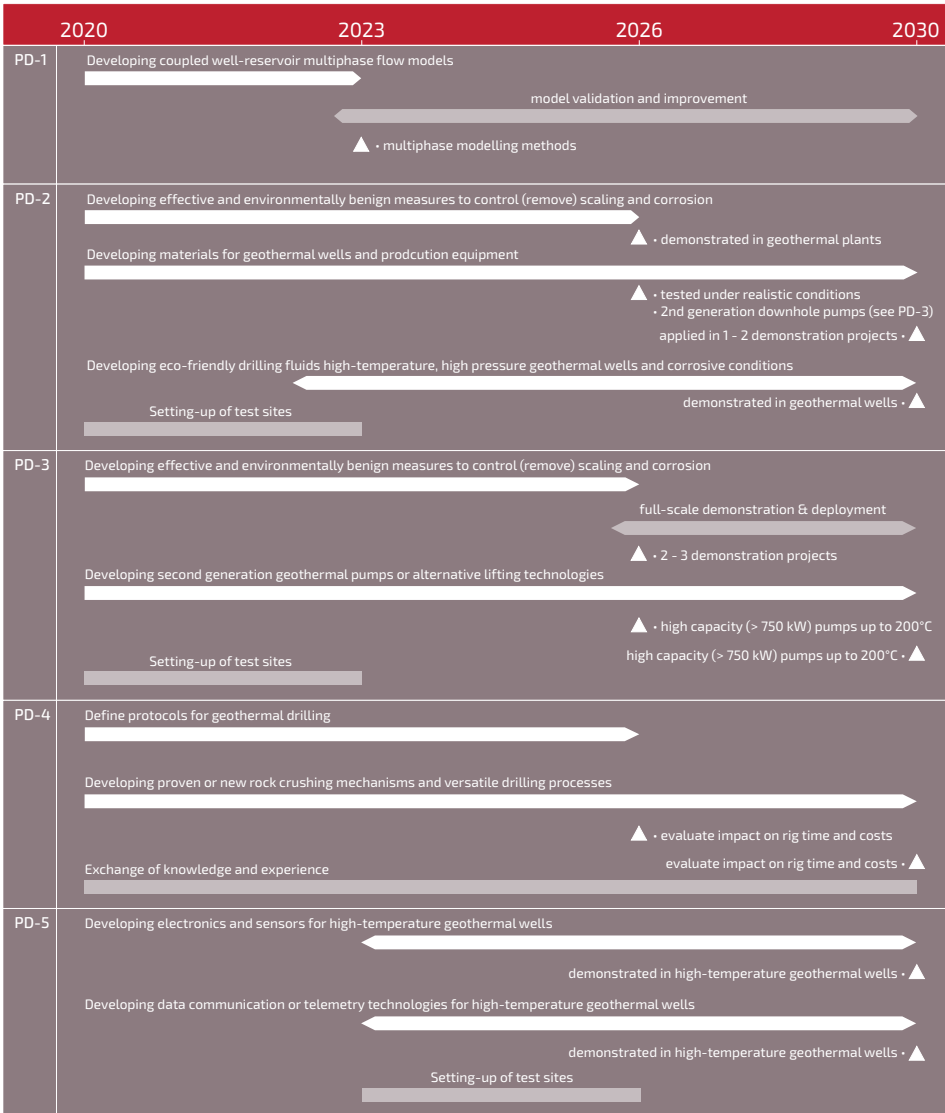


Figure 6: Timeline 2020-2030 Efficient resource access and Development.

**Priority PD-1: Total reinjection and greener power plants**

**Priority: High / Timeline: Short / Budget: € 150 m**

**State of play**

Aeriform emissions and side-effects from geothermal power plants are major concerns that need to be addressed if Europe’s geothermal resources are to be developed to their full potential. Total reinjection of the geothermal fluid could contribute to reaching this goal. As it stands this is not yet common practice and in some cases reinjecting large amounts of NCGs (Non-Condensable Gases) is technically challenging. On the other hand, aeriform emissions from power plants can be reduced or even avoided altogether by applying adequate technologies to the capture, use and/or abatement of non-condensable gasses (NCGs).

Developing technologies to deal with the impact of geothermal plants starts with a good understanding of the behaviour of the geothermal fluid and NCGs in the wellbore and the reservoir. Current modelling tools are limited when it comes to predicting reservoir and fluid behaviour under high-temperature ( $> 350^{\circ}\text{C}$ ) and/or high-salinity conditions ( $> 15\%$  TDS).

### Objectives

The objective of action PD-1 is the development of reliable, safe and cost-efficient technologies to improve the environmental performance of geothermal power systems over their entire lifecycle. This objective can be achieved via reinjection of the geothermal fluid including NCGs or by developing technologies for the capture and sustainable use or abatement of NCGs.

In order to achieve the overall objective, action D1 focuses on:

- The development of coupled well-reservoir multiphase flow models to understand and predict the chemical and physical behaviour of geothermal fluids and geo-mechanical behaviour of reservoir rock. Existing models should be improved and extended to high-salinity/high-temperature conditions in the short term (2020 – 2023) and later subjected to continuous validation and improvement based on laboratory and field data.
- The development and demonstration of technologies for the capture, sustainable use, abatement or reinjection of NCGs. During the period 2020 – 2023, focus will be on the development and testing of technologies under laboratory and relevant conditions (from TRL4 to 7). During the period 2023 – 2026, the objective is to optimise the technologies in two to three demonstration plants (from TRL 7 to 9 by 2026), facilitating market uptake from 2026 onward.

### Targets and KPIs

The aim of priority PD-1 is to reduce geothermal aeriform emissions by 20% by 2026 and 50% by 2030. The effectiveness of the actions related to target D3 will be monitored by the following specific KPIs:

- The number of projects dedicated to demonstrating technology for the capture, sustainable use, abatement or reinjection of NCGs
- LCA-based assessments of geothermal emissions.

### Scope

Development of technologies including laboratory testing and demonstration in relevant environments during the period 2020 – 2023 and demonstration in at least two geothermal areas by 2026.

## **Priority PD-2: Reduce the impact of scaling and corrosion and improve equipment and component lifetime**

**Priority: Moderate to High / Timeline: Short to Medium / Budget: € 75 m**

### **State of play**

Corrosion protection and the inhibition of scaling in geothermal plants are well-established technologies. Films and coatings are applied to protect the equipment against corrosion. These protective layers, however, suffer from erosion. Moreover, their operative window is often limited with respect to temperature and fluid composition; the same is true for the chemicals that are used to control scaling. Another way to deal with corrosion is by using resistant materials. Initial in-situ tests with new alloys, glass-fibre enforced plastics and cement formulations show promising results. These materials can help to prolong the lifetime of geothermal wells and reduce costs and shutdown time due to workovers.

### **Objectives**

Action PD-2 aims to prolong the lifetime of geothermal wells, piping and equipment by making the materials used more resistant to the detrimental effects of temperature, fluid chemistry and flow. This can be done in a number of ways, either through materials research, the use of environmentally benign chemicals, or effective design and operating protocols. In order to reach the overall goal, action D2 will deal with:

- Development of effective and environmentally benign measures to control scaling and corrosion (TRL 6 – 8 by 2023, TRL 9 by 2026)
- Development of safe and environmentally benign measures to remove scaling (TRL 6 – 7 by 2023, TRL 8 – 9 by 2026)
- Development of materials that are resistant to corrosion and/or have anti-scaling properties. Such materials can help to reduce costs and downtime due to workovers and increase the lifetime of components such as submersible pumps and tubing (TRL 5 – 7 by 2023, TRL 8 – 9 by 2026)
- Development of second-generation geothermal pumps with prolonged lifetimes under aggressive fluid conditions or development of alternative lifting technologies (e.g. airlift) (TRL 6 – 7 by 2023, TRL 8 – 9 by 2026)
- Development of materials, including casing couplings and cements, to improve overall heat transfer and guarantee integrity and resistance to fatigue over the well's lifetime under the challenging conditions encountered in geothermal applications. Focus will be on development and laboratory testing during the period 2020 – 2023 (TRL 5 – 6), testing under realistic conditions and in the field during the period 2023 – 2026 (TRL 7 – 8) and application in one or two demonstration projects by 2030 (TRL 8 – 9);
- Development of eco-friendly drilling fluids that are stable under high-temperature and high-pressure conditions and that effectively protect drilling equipment against corrosion (TRL 4 – 5 by 2023, TRL 6 – 7 by 2026, TRL 8 – 9 by 2030).



### Targets

Reduce costs related to workovers and maintaining the transfer piping/steam network and production pumps per MWh produced by 25% by 2026 and 40% by 2030 as a result of:

- Reduced downtime of geothermal plants due to scaling or corrosion, equipment replacement or cleaning
- Increased lifetime of components and equipment
- Improved environmental performance and mitigated unsolicited side effects.
- The effectiveness of innovations developed under priority PD-2 is evaluated using the following KPIs:
- The capacity factor of geothermal plants: the minimum capacity factor for geothermal power plants in 2017 was 58%, while the minimum capacity factor for district heating was 15%
- The cost of workovers on wells (excluding costs for the repair/maintenance of production pumps or other lifting equipment) and maintenance of the steam network
- The operational lifetime of pumps or other lifting equipment: the current lifetime of production pumps is between 3 and 5 years, but it can be significantly shorter under demanding conditions (brine with strong likelihood of scaling and/or corrosion, high temperatures, numerous start-stop cycles).

### Scope

Priority PD-2 includes the development of sites that are equipped for testing materials, chemicals and equipment under realistic conditions.

## Priority PD-3: Efficient resource development

**Priority: Moderate / Timeline: Short to Medium / Budget: € 200 m**

### State of play

Over the last 50 years, several techniques to stimulate fluid circulation through low-permeability rock have been developed, mainly by the oil and gas industry. These techniques include chemical, hydraulic or mechanical stimulation. In some cases, complex well geometries such as multi-lateral wells or radials are used to extract fluids from low-permeability reservoirs. Many of these techniques have been tested in geothermal projects. These tests show the need for adaptation to meet the specific requirements of geothermal projects. As an alternative to reservoir stimulation, options to extract heat from deep, hot rock through conductive heat flow and/or natural convection are being investigated.

Reservoir output can be raised by active lifting of the hot geothermal fluid. This is especially true for deep geothermal reservoirs with a low permeability. Currently, electro-submersible (ESP) and (enclosed) line shaft (LSP) dominate the market for geothermal production pumps. They are



currently applied at temperature, depth and power ratings within 80°C-180°C, up to 900 m (ESP) and 500 m (LSP) installation depths, and between 500-1600 HP. High-temperature serviced ESPs operate at approx. 250°C. However, it should be borne in mind that (i) power ratings are limited to approx. 250 HP, and (ii) the induced motor winding temperature is 300°C. Elsewhere such operating conditions would require considerable efforts to design high-temperature resistant enclosed line shaft/bearing assemblies and stable shaft lubricating mixtures.

Beyond the search for higher temperatures (> 200°C), the booming development of medium temperature (80°C-180°C) resources in combination with large scale district heating and combined heat and power (CHP) production urges the pump industry to solve current technical problems in order to build pumps with a high power rating (1600 HP or more) to cope with high lift (up to 1000 m) and high flow rates (80 l/s or more).

### Objectives

Priority PD-3 aims to:

- Develop effective and safe technologies for enhancing energy extraction from low permeability rock (TRL 5 – 6 by 2023, TRL 7 – 8 by 2026, TRL 9 by 2030)
- Develop second-generation geothermal pumps with prolonged lifetime under aggressive fluid conditions, or alternative lifting technologies (e.g. airlift) (TRL 6 – 7 by 2023, TRL 8 – 9 by 2026)
- Increase the ability to predict the thermal flow and operational behaviour of geothermal reservoir, well field and steam network in order to improve the ability to control and predict the management efficiency of a geothermal power plant. This requires the development and testing of thermodynamic models coupled to the flow of steam as well as models to evaluate mass and heat transport in geothermal wells and reservoirs.

Priority PD-3 focuses on researching mass and thermal flow modelling (2020 – 2026), technology development, testing and validation (2020 – 2026), and the realisation of least three demonstration projects for enhanced heat extraction from low permeability resources by 2030.

### Targets

Priority PD-3 seeks to:

- Improve the energy yield of geothermal wells through enhanced hydraulic connection to the reservoir and increase reservoir performance by 20% by 2026 and 30% by 2030
- Lift the operational window of high capacity (> 750 kW) pumps / lifting technologies to 200°C by 2026 and 250°C by 2030.



The effectiveness of the actions related to the exploitation of the resource is evaluated using the following KPIs:

- The costs related to reservoir stimulation (€/MW)
- The effectiveness of stimulation technologies (energy yield after stimulation over energy yield before stimulation)
- The gross energy yield of the field (GWh/y)
- The power demand of production pumps (MWth/MWe): for pumped wells, the unit of thermal energy output per unit of electricity needed to drive the pumps ranges from 17 to 25 MWth/MWe
- The operational window of pumps and other lifting technologies: the current operational temperature window for pumps with a high power capacity ranges up to 130 - 140°C for ESP and 175 - 200°C for line-shaft pumps.

### Scope

Priority PD-3 includes the development of laboratories and test sites that are equipped for testing stimulation technologies, pumps and equipment under realistic (in-situ simulated) conditions.

## **Priority PD-4: Improved rate of penetration technology for accessing the resource**

**Budget: € 165 m**

### State of play

Rotary drilling is the dominant drilling method used in the geothermal sector. Recent decades have seen the development of several alternative techniques for breaking rock. Laboratory and field data indicate that under certain geological conditions, these techniques can result in higher rates of penetration, less wear and lower energy use than conventional rotary drilling. In addition, the oil and gas and mining industries have developed new downhole sensors, communication tools and algorithms to analyse and interpret drilling data in order to optimise the drilling process. When adapted to the specific conditions of geothermal wells, these tools can help to reduce drilling risks and avoid lost-in-hole accidents.

### Objectives

Priority PD-4 deals with developing proven or new rock crushing mechanisms into highly efficient and versatile drilling processes for geothermal applications.

The activities are also aimed at defining protocols and tools to ensure wellbore stability and avoid lost-in-hole incidents. Exchanging knowledge and experience with the oil and gas as well as the mining industry could accelerate developments, but protocols and tools should be attuned to satisfy the stringent constraints faced in geothermal projects.

**Targets and KPIs:**

Priority PD-4 aims to achieve cost reductions in resource access by:

- Reducing the time needed to drill and complete a well by 25% by 2026 and 50% by 2030
- Reducing delays due to wellbore stability issues by 40% by 2026 and 75% by 2030
- Reducing costs due to lost-in-hole accidents by 40% by 2026 and 75% by 2030.

**Scope**

Implementation of action D4 includes the establishment of a framework for knowledge exchange among geothermal operators/drilling companies as well as between the geothermal industry, the oil and gas industry and the mining industry.

### **Priority PD-5: New electronics to monitor and operate geothermal wells**

**Budget: € 60 m**

**State of play**

Many of the tools that are used to monitor well conditions during and after drilling are limited to 175°C. Logging tools that are resistant to high and ultra-high temperatures, meanwhile, are scarce and limited in use. Reliable measurement-while-drilling (MWD) tools can help to perform continuous integrity checks for the wellbore and wellbore equipment. In addition, logging-while-drilling (LWD) tools, in combination with broadband communication and artificial intelligence, can help to predict drilling conditions and avoid wellbore instability. Current communication along wire-line has improved and it is now chiefly restricted to temperatures below 300°C.

**Objectives**

Action D5 deals with:

- Development of electronics and sensors to be used in high-temperature geothermal wells during drilling operations. This will lead to better control of the drilling process, reducing the risk of wellbore instability and lost-in-hole incidents.
- Development of data communication or telemetry technologies allowing fast and reliable data transfer under high-temperature conditions.

**Targets and KPIs**

Priority PD-5 aims to:

- Develop electronics and sensors that can withstand temperatures up to 350°C by 2030.
- Develop data communication technologies that can withstand temperatures up to 350°C by 2030.

**Scope**

Action PD-5 includes setting up infrastructure that allows for testing ICT that is resistant to the conditions met in hot and ultra-hot geothermal wells under realistic conditions. This action is related to action PD-4 and calls for collaboration with the ICT industry (see Deliverable 5.3: External stakeholders, common RD&I needs and complementary actions).



## DEPLOY HEAT AND ELECTRICITY GENERATION AND SYSTEM INTEGRATION

The nine RD&I topics as defined the SRIA are:

- Topic 1: Advanced binary plants
- Topic 2: Innovative design and integration of binary cycle technology into new and existing flash plants
- Topic 3: High-temperature binary power plants
- Topic 4: Power cycles and mitigation for super high-temperature resources, high-enthalpy steam direct expansion
- Topic 5: Flexible production of heat and power
- Topic 6: High-Temperature Thermal Energy Storage (HT-TES)
- Topic 7: Developing hybrid plants
- Topic 8: Exploiting mineral production from geothermal sources
- Topic 9: Generating at different voltages for smart grids

In the process of defining the Roadmap, these topics were ranked and then merged into four priorities for this chapter on "Deploy heat and electricity generation and system integration" in the Roadmap.

Total Budget= € 550 million

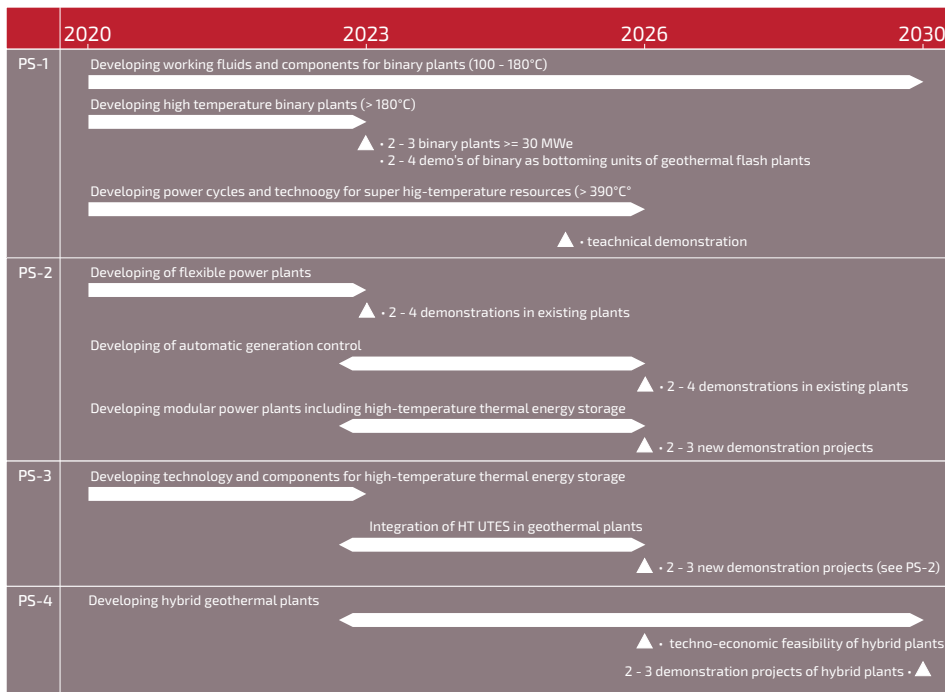


Figure 7: Timeline 2020–2030 Heat and electricity generation and System integration.

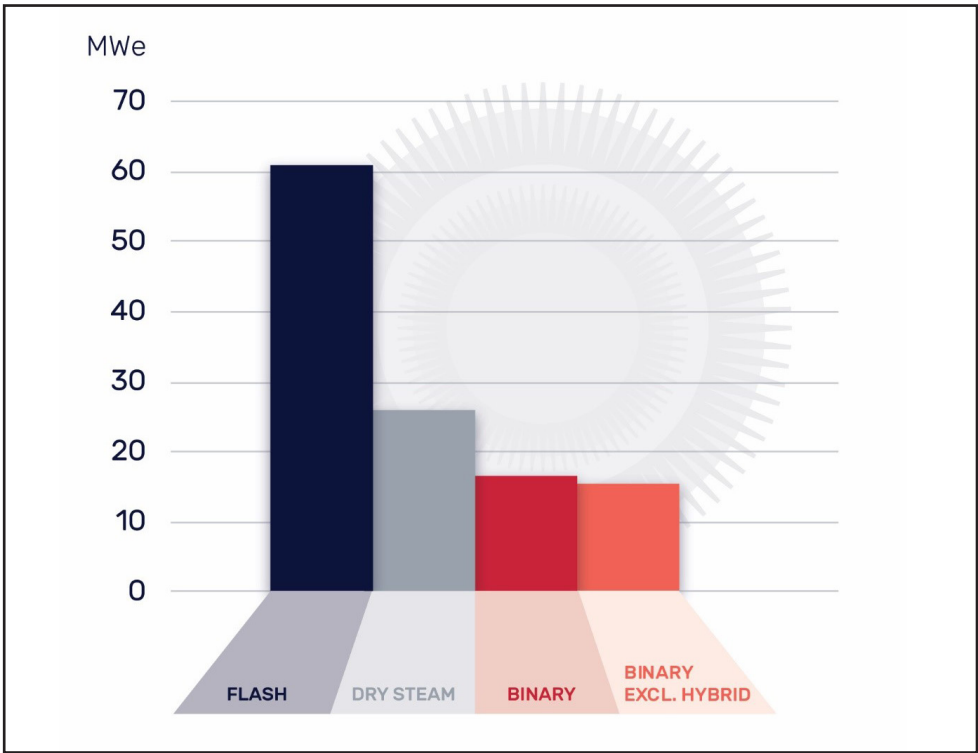
**Priority PS-1: Developments in turbines**

**Budget: € 100 m**

**State of play**

In Europe, the installed capacity of geothermal power reached 3,091 MWe in 2018, corresponding to 127 geothermal power plants in operation and 17.1 TWh of geothermal electricity production: 52 plants are equipped with a flash turbine (with a total capacity of 2017 MWe) and 75 plants with a binary turbine (representing a capacity of 1194 MWe). Meanwhile, despite the benefits, there are currently only a few binary plants (6 hybrid plants for 175 MWe) which have been integrated into flash plants as bottoming units.

At the present time, most installed geothermal binary power plants utilise hydrocarbons as working fluid, but new organic materials are being developed. Binary technology has traditionally proven to be applicable for electricity generation with low-temperature resources (close to 90-100°C), but the development of very high temperature geothermal plants will require new turbines. These new turbines are also required for upscaling EGS plants.



*Average size of installed geothermal plants in Europe, per turbine technology*

### Objective

The first objective is to develop advanced low-to-medium temperature (usually 100–180°C) binary plants by 2030 (from TRL 5–6 to 8). This must notably address the need for flexible heat/cold and electricity supply from binary cycles, including upscaling capacity from the binary plants.

The improvement of plant performance should focus on the working fluid and on specific components (improved heat exchangers with higher effectiveness and lower pressure drop, material selection, surface structure and coating, hybrid cooling) of the binary cycle (from TRL 4–5 to 6–7 and then 8).

- Working fluids: Develop high-potential working fluids in laboratories, first testing these fluids in an initial turbine/plant demonstration, then in more demonstration sites in order to achieve higher TRL (8) by 2030.
- Components: Improve performance (from TRL 5–6 to 7–8) of the major components of a turbo-generator: impellers/blades, shaft/rotor, nozzles, inlet guide lanes, disks, casings and the associated components for power and heat generation, such as the heat exchanger and an air-cooled condenser with higher effectiveness and lower pressure drop, in addition to pumps and piping.

Secondly, RD&I must develop advanced high-temperature binary plants by 2020–2023 (from TRL 5–6 to 8), upscale the capacity of binary plants (from TRL 5 to 7) and improve geothermal **heat** to power conversion efficiency via the integration of binary plants as bottoming units in geothermal flash plants. (from TRL 5–6 to 8, 2020–2023 period).

- Binary turbines: upscaling the capacity of binary plants (from TRL 5 to 7), developing advanced high-temperature binary plants with demonstrations in two to three plants at 30 MWe, and then optimisation in two to four more plants at 30 MWe or more.
- Binary plants as bottoming units of geothermal flash plants: optimisation in two to four existing plants.

Thirdly, a longer-term objective is to develop power cycles and technologies for the mitigation of super high-temperature resources, as well as high-enthalpy steam direct expansion (from TRL 3–4 to 6–7 and then 8, 2020–2023–2026 period).

- Power and heat generation with very high-temperature resources: > 390°C (€ 30 million): develop turbine components in laboratories before testing them in an initial turbine/plant demonstration, then across more demonstration sites to achieve higher TRL (8) by 2030.

### Targets and KPIs:

Among the major targets and KPIs related to generation technologies, this action refers to:

- Maximising electrical and thermal generation and subsurface storage efficiency by 10% by 2030 (from an average conversion efficiency of geothermal binary plants of 12% in 2019)
- Reducing the production costs of various applications by 15% (with respect to specific technologies) by 2030
- Demonstrating the technical and economic feasibility of responding at any time to commands from a grid operator to increase or decrease output, ramping up and down from 20% to 110% of nominal power.

Other specific KPIs for this action are to:

- Reduce the surface part of power plant costs by 15 % by 2030:
  - KPI: Manufacturing cost of a custom design 5 MWe ORC turboexpander, which stands at one million euros in 2019.
- Upscale binary plants:
  - KPI: Plants with a capacity higher than 30 MWe, including for EGS (currently the largest is 25 MWe).

#### Scope

KPI: A main scope of this action is to minimise the second-law efficiency losses

This action calls for collaboration with other RES sectors: biomass, CSP

### **Priority PS-2: Flexible production of heat and power and integration with smart grids**

**Budget: € 150 m**

#### State of play

Flexible generation from geothermal plants should provide additional services to the grid such as peak power while also playing a role in electricity balancing and the reserve market. Geothermal plants can play an important role in providing back-up power by adjusting power production within various response timeframes in order to assist in stabilising the grid.

#### Objective

Demonstrating the technical and economic feasibility of responding to the grid operator's requests at any time is the primary objective. In the case of geothermal plants this includes the ability to increase or decrease output and ramp up and down.

- Flexible power plants responding in less than 20 seconds: optimisation in two to four existing plants. (from TRL 5-6 to 8, 2020-2023 period)

Another aim is to demonstrate automatic generation control (load following/ride-through capabilities for grid specifications) and develop the ancillary services of geothermal power plants. The potential flexibility of geothermal power production should be linked to the concurrent supply of geothermal heat to district heating, agricultural or industrial applications and the ability of high temperature thermal energy storage to increase the flexibility of the plant (as detailed in topics 3 and 4 below).

- Power plants with automatic generation control: optimisation in two to four existing plants. (from TRL 5 to 7-8, 2023-2026 period).

In order to increase the flexible operation of binary plants, novel or adapted turbines and expanders will need to be developed (in combination with topic 1) together with high-temperature thermal



energy storage with higher storage efficiency and higher specific storage capacity. The adaptation of expanders/turbines and other components aims to increase flexibility, moving towards electricity production which can cope with the needs of the electrical and thermal network in a cost-effective way. This will be done together with a more modular approach (smaller, cascaded, and controlled units).

- Power plants with a modular approach including high-temperature thermal energy storage: optimisation in two to three new demonstration plants. (from TRL 5 to 7-8, 2023-2026 period).

#### Targets and KPIs:

Among the major targets and KPIs related to generation technologies, this action refers to:

- Demonstrating the technical and economic feasibility of responding at any time to commands from a grid operator to increase or decrease output and ramp up and down from 60% to 110% of nominal power:
  - KPI: In 2017, one geothermal power plant demonstrated ramping up and down in 15 seconds from 100% to 20% and back to 100%.

Other specific KPIs for this action are to:

- Improve the modular design of power plants to better adapt to electricity requirements and heat demand without reducing overall electrical efficiency and annual production:
  - KPI: Average conversion efficiency of 12% and capacity factor of 80%
- Generating different voltages for smart grids with specific applications, such as for an island or island mode
  - KPI: Currently geothermal power plant generation is for medium voltage distribution.

#### Scope

Liaison with the transmission and distribution grid infrastructure operators.

### **Priority PS-3: High-Temperature Underground Thermal Energy Storage (HT-UTES)**

**Budget: € 100 m**

#### State of play

UTES applications cover a wide variety of opportunities: ATES (Aquifer Thermal Energy Storage), BTES (Borehole Thermal Energy Storage), PTES (Pit Thermal Energy Storage), TTES (Tank Thermal Energy Storage), and MTES (Mine Thermal Energy Storage) systems.

These systems rely mainly on rather low temperatures and shallow depths for local uses. High-Temperature UTES (HT-UTES) covers temperatures above 25°C, and targets of interest can reach depths of over 2000 metres below ground level. Experience with HT-UTES is limited to a few



projects worldwide. 99% are low-temperature systems (LT-ATES) with storage temperatures of < 25 °C. When looking at systems with injection temperatures above 30-40°C, the number of implemented systems is limited, and only five high temperature systems (> 60°C) are currently in operation worldwide. The most frequent problems related to UTES systems in general, and more specifically to HT-ATES, are:

- Scaling and clogging of wells and heat exchangers
- Corrosion of wells
- Buoyancy flow or thermal breakthrough
- Imbalance of stored heat and cold
- Swelling of clay minerals

Research has shown that most problems can be avoided by careful pre-investigation and an appropriate operational strategy.

### **Objective**

The main goal is developing technologies and workflows to boost HT-UTES system implementation by improving heat-storage and production performance. The objective is the integration of underground thermal energy storage to cope with daily, weekly and seasonal variations in heat demand and handle available heat from the large number of industrial processes with excessive heat. The integration of a medium/long-term storage system will be subject to the technological and economic constraints of the waste heat source and will combine network flexibility and the integration of other energy sources into complex energy systems.

This includes combining surface structures (i.e. waste heat sources, heat exchangers, distribution network systems including different energy storage technologies and advanced demand-side management) and subsurface characterisation, target identification, monitoring and management (i.e. reservoir modelling, tracer tests, drilling and well integrity preservation) into a unique source-to-sink system. Reservoir characterisation will include, but will not be limited to, 3D geological modelling, petrophysical static reservoir modelling, predictive dynamic thermal-hydraulic-mechanical-chemical modelling prior to drilling, as well as calibration and validation of models after drilling in order to produce a number of models enabling developers to reduce subsurface uncertainty and define the optimal storage strategy. In terms of surface infrastructure, the focus will be upon the implementation of gathering systems to limit thermal losses, and materials for piping and heat exchangers that can withstand potentially corrosive fluids while mitigating scaling phenomena.

- Advanced technologies and components (from TRL 5 to 7-8, 2020-2023 period)
- Optimisation of two to three new demonstration plants (from TRL 6 to 7-8, 2023-2026 period).

### **Targets and KPIs:**

Among the major targets and KPIs related to generation technologies, this action aims to:

- Increase electrical and thermal generation and subsurface storage efficiency by 10% by 2030
- Reduce the production costs of various applications by 15% (with respect to specific technologies) by 2030.



And more specifically:

- Reduce the costs of HT-UTES

KPI: Current data is unavailable.

- Increase the efficiency of HT-UTES by:
  - Preventing heat losses in the surface gathering system and the subsurface to ensure that heat demand is supplied using stored heat
  - Preventing corrosion and scaling in the gathering system and heat exchangers
  - Developing heat exchangers with high effectiveness and low pressure drop to increase the overall storage efficiency

KPI: At present, subsurface storage efficiencies range between 40 and 85%. The goal will be to reduce that range by shifting it towards 50-90% efficiency. Additionally, the overall efficiency of an HT-UTES system will be improved by limiting heat losses in the distribution systems to 1°C/km.

- Ensure that the lifetime of the storage reservoir is more than 25 years

### Scope

Connect to the district heating controller, process controller, grid controller and market interface. Liaison with the other storage initiatives.

### **Priority PS-4: Developing hybrid plants and exploiting mineral production from geothermal sources**

**Budget: € 200 m**

### State of play

Geothermal and solar (thermal and photovoltaic) are complementary, meaning that production from solar is higher during the sunniest and hottest days of the year, when the thermal efficiency of the geothermal plant is lower. The increased delivery of power during peak hours also enables a more load-following production profile. It can optimise efficiency, repeatability and consistency, while minimising the uncertainty of well heat flux when ordering the surface equipment.

Several pilot plants worldwide have been built to extract salts, silica, lithium and specific metals from brines, but industrial production has only taken place at a few locations and has been limited to the production of silica, Li, Br, J and Sn. Geothermal plants can optimise the production of both energy and metals/materials according to market demands by exploiting deep geological formations. The exploitation of mineral production can also help geothermal plants become more economically competitive.

### Objective

One objective is to couple geothermal not just with other renewable energy sources to generate power and heat, but also with storage facilities, notably by integrating thermoelectric energy storage with district heating networks and dedicated equipment (e.g. heat pumps, ORC turbo-

expanders, and heat exchanger networks with hot and cold reservoirs able to cover variable demand for heat, cold and electricity).

This also involves demonstrating the applicability of geothermal when combined with other sources for district heating and cooling at industrial and/or residential sites, including the use of high-temperature heat pumps and Underground Thermal Energy Storage (UTES) at elevated temperatures, as well as demonstrating integration into smart thermal grids.

- Development of hybrid plant equipment (e.g. combining geothermal with waste heat, biomass, concentrated solar thermal or green gas): (from TRL 5 to 7-8, 2023-2026 period)
- Optimisation of two to three new demonstration plants: (from TRL 5 to 7-8, 2023-2026 period).

The goal is also to demonstrate the technical and economic feasibility of hybrid plants with regard to responding to commands from a grid operator at any time (see topic 2).

The third objective is to develop novel and potentially disruptive technological solutions that can help satisfy European needs for energy and strategic metals as well as other economical non-metallic materials in a single interlinked process. This means increasing the selectivity and efficiency of the separation techniques used for minerals and geothermal brines, as well as developing new, potentially disruptive technologies to separate and transform the chemical components of geothermal brines into more valuable products.

- Technologies for metal extraction: (from TRL 4-5 to 7-8, 2020-2023 and 2023-2026 periods)
- Optimisation in two to three new demonstration plants: (from TRL 4-5 to 7-8, 2023-2026 period).

#### **Targets and KPIs:**

Among the major KPIs related to generation technologies, the main one related to this action is:

- Reducing production costs for various applications by 15% (with respect to specific technologies) by 2030.

Other specific KPIs for this action concern:

- Developing novel hybrid plants which use other energy sources to increase the temperature of the geothermal brine or use geothermal to stabilise the supply of variable sources:

KPI: No hybrid plants exist in Europe. The goal is to improve the performance of low to medium temperature geothermal resources.

- Reduce the cost of metal extraction

KPI: Current costs are hard to assess as the aim is to develop new technologies.

- Developing a new type of future facility that is designed and operated as a combined heat, power and mineral extraction system from the outset.

KPI: No such a plant is in operation.

#### **Scope**

Related to other RES: : combining geothermal with waste heat, biomass, concentrated solar thermal or green gas



## MISSION 2: IMPROVING SOCIAL WELFARE

### MOVE FROM R&I TO DEPLOYMENT

The nine topics in the SRIA are:

- Topic 1: Setting the right Policies
- Topic 2: Engaging with the public and other stakeholders
- Topic 3: Reinforcing competitiveness
- Topic 4: Establishing Financial Risk Management schemes
- Topic 5: Geothermal deployment support schemes
- Topic 6: Establishing a legal and regulatory framework
- Topic 7: Embedding geothermal energy into the circular economy
- Topic 8: Harmonised protocols for defining the environmental and health impacts of geothermal energy and mitigation planning
- Topic 9: Human deployment

In the process of defining the Roadmap, these topics were ranked and then merged into three priorities for this chapter in the Roadmap.

Total budget= € 40 million

### ***PM-1: Improving the policy and regulatory framework***

#### **State of play**

In terms of policies and regulations contributing to the development of geothermal energy, there are European (and some national) climate and energy frameworks established for 2020, 2030 and 2050. In addition, at the European level, there is a long-term objective to reduce emissions by 80% to 95% by 2050, to which the Paris agreement adds the objective of achieving carbon neutrality by the middle of the century. This long-term objective is being pursued through intermediary targets, notably for 2020 and 2030. In addition to the European framework, each European country has set its own national legal and regulatory frameworks regulating the geothermal sector.

Deep geothermal energy is a heavily regulated sector and typically requires a specific support framework. When considering the European regulatory and policy framework, various interlinked regulations and policies create a complex regulatory background. Although this complex regulatory framework may not necessarily result in the over-regulation of geothermal projects, and may indeed provide a consistent and robust framework allowing for confidence in deep geothermal energy projects, its lack of readability may be a deterrent to the emergence of new geothermal markets.

### Objective

The goal is to establish a legislative framework allowing for geothermal deployment, its penetration and profitability, while guaranteeing that resources are properly managed.

In order to develop deep geothermal in Europe, whether for juvenile or mature national markets, geothermal stakeholders need a European and national political framework for the short, medium and long term, which:

- Sets up a level playing field at the European and national levels
- Establishes dedicated policies and a long-term vision and strategy for the development of deep geothermal in Europe
- Provides appropriate European and national legislation and regulations.

For the 2020-2030 framework, reference should be made to geothermal in the National Climate and Energy Plans (NECPs). This includes the establishment of appropriate European and national legislation and regulations by:

- Assessing and optimising the environmental, social and economic footprints of deep geothermal
- Introducing a unifying process for geothermal projects (one address for all ministries)
- Establishing licensing processes (first-come, first-served, licensing rounds, competition window, etc.)
- Establishing works authorisation processes

### Target and KPIs

Geothermal deployment would be accelerated by:

- Developing a welfare analysis of the results of an increase of deep geothermal energy in the energy mix
- Replicating best practices on policies relevant for RD&I in deep geothermal energy
- Laying out a long-term vision and strategy for deep geothermal
- Providing recommendations for European harmonisation, including mutual recognition of adequate national regulations: codes, licensing, permitting, etc.

The two major KPIs on market uptake are to:

- Reach more than 5 GWe installed capacity in 2030 (from 3 GWe in 2019)
- Reach more than 15 GWth installed capacity in 2030 (from 5 GWth in 2019)

A specific KPI for this action is to:

- Achieve substantial and measurable time reductions (by six months on average) for project developments, whilst still fully addressing the needs for environmental impact assessments and public engagement. Currently in some European countries the administrative procedures can last for more than two years.

### Scope

It is expected that the solution proposed will contribute to developing more informed policies at European, national, regional and local level.



## ***PM-2: Ensuring public engagement and mitigating environmental and health impacts***

### **State of play**

Although social and non-technical aspects are increasingly considered key determinants in the transition towards a low-carbon society, social sciences and human factors on geothermal energy in Europe are still scattered and often lack a uniform approach. At the same time, the geothermal community seems to have shown a growing interest in this issue in recent years, probably as a result of new forms of opposition emerging from different countries.

It often appears that the general public is not well-informed about geothermal technologies and is not able to distinguish between different geothermal energy systems and related environmental and technological issues.

One objective for public engagement is to develop organisational models and best practices for geothermal energy projects sharing the economic benefits or other advantages they create with local communities. Examples of this include local co-ownership and local crowd funding, (financial) compensation mechanisms or the creation of local green jobs.

### **Objective**

In order to make sure that deep geothermal energy can play its role in Europe's future energy supply in a sustainable fashion, it is essential to engage in strong interactions with strategic groups and:

- Better understand a range of social and cultural aspects and factors which shape individual and community acceptance of geothermal
- Foster mutual learning among stakeholders, enhancing contributions from all societal actors and unlocking the potential of geothermal
- Include perspectives from the public and other stakeholders as part of the innovation process for geothermal, and develop tools to include perspectives from the public and other stakeholders as part of the innovation process for geothermal energy technologies, ensuring public engagement
- Respond to environmental concerns while highlighting the benefits of deep geothermal market uptake, focusing on the environmental and health impacts

The aim is to create a robust strategy which responds to environmental concerns (e.g. regarding environmental impacts, incidents and risks) and highlights the benefits of the deep geothermal market uptake, focusing on the environmental and health impacts. This would include a harmonised and modelled LCA (Life Cycle Assessment) on environmental impacts, strengthening knowledge of the environmental and health impact of geothermal activities in the scientific community and developing knowledge about preventive measures in connection with risk communication and enhancing the environmental health literacy of communities living in geothermal areas.

### Target and KPIs

Overcoming non-technical issues such as social acceptance is required in order to successfully develop energy technologies, and these issues require a highly interdisciplinary approach. This should be borne in mind by researchers, policy makers and funding providers when considering the allocation of resources, research and development strategies, and project evaluations.

The following main targets for successful societal engagement have been identified:

- Definition of guidelines for systematic information provision
- Education and information campaigns about geothermal energy technologies and developments
- Definition and testing of public engagement strategies and practices in the geothermal field
- Promotion of a life cycle assessment (LCA) model for geothermal installations
- Effective communication with the general public regarding environmental and health concerns
- Adoption of geothermal standardisation procedures and quality branding focused around the circular economy and improving the applicability and use of recycled/secondary materials/waste in geothermal plants
- Development of new business models with eco-friendly geothermal actors and innovative, greener and eco-friendly geothermal products, components and systems, transitioning to the use of sustainable materials

The two major KPIs on market uptake are to:

- Reach more than 5 GWe installed capacity in 2030 (from 3 GWe in 2019)
- Reach more than 15 GWth installed capacity in 2030 (from 5 GWth in 2019)

A specific KPI for this action is:

- The number of Member States developing and adopting guidelines for systematic information provision and public engagement in the field of geothermal energy development (there are none currently)

### Scope

It is expected that the solution proposed will facilitate the introduction of geothermal technologies and increase the share of renewable energy in the final energy consumption mix.



### **PM-3: Develop innovative financing and reinforce competitiveness**

**Priority: Medium / Timeline: 2020-2030**

#### **State of play**

Public support for geothermal energy is such that it is necessary to mobilise private financing in a difficult investment climate. The economic and financial crisis has certainly affected investment in clean energy. The picture is already a complicated one, and it should be noted that geothermal is a capital-intensive technology that takes some years to develop. Such a barrier can be tricky to overcome, especially when European stock markets are still uncertain and banks are looking exclusively for zero-risk investments.

It is also valuable to assess national schemes dedicated to financing deep geothermal projects. A Geothermal Risk Insurance Fund is seen as an appealing public support measure for overcoming geological risk. As costs decrease and markets develop, the private sector will be able to manage project risks with, for example, private insurance schemes, and attract private funding.

With the notable exception of a few European market participants operating in well-developed geothermal regions, project developers have very little ability to manage the financial risk associated with poor knowledge of the deep subsurface, a lack of technological progress and high costs.

LCoE is one of the criteria most used to compare the competitiveness of different energy sources, notably in policy making. It is a very partial indicator, however, as there is no consideration of system costs such as the cost of transmission, or other network costs such as impact on system balancing, impact on state/system energy security, and the costs of external factors such as government-funded research, residual insurance responsibilities borne by the government, external costs of pollution damage or external benefits (e.g. the value of knowledge for future generations). Current market models are unable to remunerate energy sources with low operational costs, hence there is a need for 'out-of-market' remuneration (feed-in tariffs, contracts for difference, premiums, capacity remunerations).

#### **Objective**

Support schemes are crucial public policy tools for geothermal in order to compensate for market failures and to allow the technology to progress along its learning curve. The objective is to:

- Facilitate the financing of RD&I in deep geothermal energy, most notably for deep geothermal demonstration projects. Specifically, this would involve:
- Facilitating access to financing for projects (i.e. information on funding facilities etc.)
- Reducing the cost of financing for innovation in deep geothermal energy: identifying and reducing the capital costs incurred by non-technological risks
- Develop innovative financial support schemes to deploy geothermal
- Establish financial schemes to mitigate resource risk
- Develop fair competition between energy sources beyond a limited LCoE approach, with energy market models able to properly remunerate the various benefits of geothermal energy
- Establish fair competition globally with geothermal stakeholders from around the world



Improving the accessibility of financing for deep geothermal RD&I helps to remove major barriers to technological development across the whole value chain. It also reduces the delay in scaling technology innovation up to market readiness.

Financial instruments fit for the specific constraints of deep geothermal allow more projects to be undertaken and innovation to be achieved.

### Targets and KPIs

Research areas on this topic include:

- Establishing financing mechanisms adapted to the specificities of geothermal technologies and the maturity level of markets and technologies, notably to allow market deployment of innovation
- Creation of a risk-sharing facility at national level and across borders (pan-European)
- Development of a comparison model looking at the full costs of competing heat and power energy forms
- Establishing carbon pricing in order to integrate the costs of external factors into the full costs of an energy source.
- Development of new business models for geothermal developers and operators, allowing them to sell their heat and power on different markets

### KPIs:

The two major KPIs on market uptake are to:

- Reach more than 5 GWe installed capacity in 2030 (from 3 GWe in 2019)
- Reach more than 15 GWth installed capacity in 2030 (from 5 GWth in 2019)

### Scope

It is expected that the solution proposed will develop more informed policy, market support and financial frameworks, notably at national, regional and local level, leading to more cost-effective support schemes and lower financing costs for geothermal facilities.



## KNOWLEDGE SHARING

The three topics related to knowledge sharing examined during the consultation were ranked by priority and urgency.

The topics in the SRIA are:

- Topic 1: Sharing underground data - unlocking existing subsurface information
- Topic 2: Organising and sharing geothermal information
- Topic 3: Shared research infrastructures

Total budget= € 50 million

### **Priority PK-1: Shared and harmonised geothermal information**

**Priority: High / Timeline: Short for initial implementation with continuous updates later**

#### **State of play**

A wealth of information from past subsurface exploration for geothermal, oil, gas and mining prospecting and development is available, but in most European countries data is not easily accessible and only a very limited quantity has been organised at national level in geothermal databases with varying formats and structures. Other technical and non-technical topics (e.g. geothermal operational issues, national energy policies, economic and regulatory information, geothermal energy production, market and social requests, and training offers) of relevance for geothermal deployment are organised separately by each Member State, and only a few types of information are organised and coordinated at European level (e.g. energy production and installed capacity for Eurostat). The concept of a shared and harmonised geothermal information database has been launched as part of the Geothermal ERA-NET project, but only a few parts have been achieved based on trans-national activities.

#### **Objectives**

Achieve open access and acquire subsurface data from geothermal, hydrocarbon and mining exploration and production, and harmonise this at European level. Establish a joint strategy for organising and accessing geothermal information. This requires:

- Harmonisation of underground data at national level and development of a protocol for harmonisation by 2023 (TRL 2 to 3)
- Digitisation of data and information, publication of existing national databases and information using the harmonised protocol. Harmonisation of current national databases and public information by 2025 and continuous updates thereafter (TRL from 3 to 5)
- Implementation of an EU-based platform, with development of the main concept by 2023, proof of concept by 2025, and continuous updates thereafter (TRL from 3 to 6)
- Drilling of exploration and development wells and contribution to geothermal data (stratigraphy data, logs, cores, thermodynamic and hydrogeological parameters)

### Targets and KPIs

The main target is to improve access to relevant data in order to reduce exploration costs, manage technical and financial risks, and share technical and non-technical information of interest at EU level.

The two major KPIs are to:

- Achieve 100% harmonisation of geothermal data in national databases at European level
- Create a pan-European geothermal information platform

### Scope

It is expected that the solutions proposed will lead to more effective coordination between academia and research entities and industry.

## Priority PK-2: Shared research infrastructures (RI)

### Priority: Medium / Timeline: Long

#### State of play

While research centres working in the geothermal sector may already be involved in large RI in various fields (e.g. EPOS), there is no shared RI specifically dedicated to geothermal topics. Access to geothermal wells and plants for testing and demonstrating RD&I tools is usually restricted to specific projects and remains otherwise inaccessible.

#### Objectives

Build a shared RI specifically dedicated to geothermal topics and technologies, by:

- Establishing a network of research laboratories carrying out RD&I in the Deep Geothermal sector by 2023
- Organising a campaign for collecting geothermal samples and data. A drilling campaign of slim-holes should be launched in Europe in order to gather more geological data, and greater access to well and production data should be established at European level, starting in 2022 and providing organised data by 2030 in conjunction with PK-1 (data sharing)
- Organise and coordinate access to in situ laboratories (wells and plants) for developing and testing prototypes by 2025

#### Targets and KPIs

The main targets are:

- Improved facilities for testing and developing innovative concepts in deep geothermal
- Increased quantity of shared geothermal information

The major KPI is to:

- Create five Research Infrastructures dedicated to geothermal energy (e.g. shared laboratories, wells, plants, cores)

#### Scope

It is expected that the actions dedicated to this priority will develop a partnership between geothermal stakeholders, as well as a resulting demonstration



## NEXT-GENERATION DEEP GEOTHERMAL TECHNOLOGIES

**Total budget: € 120 m**

A strong scientific foundation involving fundamental and pioneering research is needed in order to push development beyond the activities of today and tomorrow. This groundwork shall address long-term applications and stimulate breakthrough possibilities with concepts currently at TRL 1-2 to progress to TRL 3-4.

When it comes to developing the next generation of geothermal technologies, one challenge is bringing these new energy conversion solutions, new energy concepts and innovative energy uses to commercialisation more quickly, taking into account social acceptance and the provision of a secure and affordable energy supply. These new technologies must not only have commercial potential, they should also have a lower environmental impact and produce fewer greenhouse gas emissions than current renewable energy technologies.

## FINANCING THE ROADMAP

The Geothermal Roadmap will be implemented using various resources depending on the nature of the research, innovation priorities and the specific needs of the technologies. Several mechanisms for supporting investments in deep geothermal energy exist at European and national level. These mechanisms can address different project stages and can come from different sources.

All technologies pass through the same stages of the innovation cycle: from basic research through to development, demonstration, deployment, and commercial market uptake. During these phases public funding for continuing industry-led research, development, and deployment is needed. It is crucial to invest in new renewable technologies and to improve existing ones through RD&I.

Unlocking geothermal energy		Funding needs 2020-2030
	Better Prediction and assessment of geothermal resources	€ 450 million
	Efficient resource access and development	€ 650 million
	Deploying heat and electricity generation and system integration	€ 550 million
Improving social welfare		
	Move from R&I to deployment	€ 40 million
	Knowledge sharing	€ 40 million
Next generation of technologies		€ 120 million
<b>Total</b>		<b>€ 1.85 billion</b>

*Funding needs 2020 - 2030*

### INVESTMENT CLIMATE FOR GEOTHERMAL TECHNOLOGIES

The deep geothermal sector has been growing steadily over the past decade. Many new areas of Europe are now geothermal regions for power and heat, and some countries that used to be marginal in terms of geothermal energy are now key markets. This evolution was enabled by the provision of RD&I funding and public support in the form of capital investment or operating aids in pursuit of renewable energy objectives, as well as the development of new financing schemes to channel this funding to geothermal projects. However, while progress in renewable energy



deployment has been significant, public policies are increasingly geared towards providing greater exposure to market financing for such projects, including for geothermal energy. This means that public support will increasingly be a complement to private finance instead of a primary driver of investment. Such an evolution poses the question of how geothermal projects can attract private financing, which business models and which financing schemes are currently being developed, and what trends are emerging in light of this challenge.

Geothermal energy projects are indeed challenging to finance and require specific schemes. Among the specific constraints embedded in the development of new geothermal projects, the geological risk and the very capital-intensive structure of project financing constitute a challenge, which can slow down the deployment of new geothermal capacity. Moreover, considerable diversity in the quality of geothermal resources and the level of market maturity creates widely varying conditions for geothermal project developers. In order to fund geothermal projects it is therefore necessary to lay out the right financing scheme for the right project.

Accelerated deployment of geothermal energy will require investments that cannot solely rely on public funds. Hence, the engagement of the private sector is crucial. However, financial barriers to developing geothermal power projects in Europe persist and need to be overcome through public support from the outset of geothermal development. The establishment of a favourable framework is also required in order to ensure security for investment in deep geothermal.

The Implementation Working Group on Deep Geothermal of the SET-Plan has forecast an investment budget of around € 936 million to execute its Implementation Plan, largely by 2023:

- € 456 million from industry (49% of the total)
- € 342 million from national R&I programmes (36.5 % of the total)
- € 138 million from European programmes (14.5 % of the total)

The ETIP-DG Roadmap base its funding needs for Research and Innovation on these forecasts, but for a longer time period. The Roadmap will cover a 10-years period from 2020 to 2030.

## FUNDING GEOTHERMAL R&I

Grant-based financing is a staple of public support for deep geothermal energy projects, notably when it comes to supporting innovative technologies, demonstration projects or high-risk projects. In Europe, grants generally do not cover the entirety of a project's funding needs and other sources of capital would often be needed for 50% of the total investment costs. However, grants are usually designed to decrease the cost of capital – which increases with the risk. This is intrinsically the case when part of the project is funded for "free". The fact that grants can come in at the early stages of the project to provide funding for project development or high-risk stages of the project (such as

drilling an exploratory well for a geothermal project) can provide benefits in terms of cost of capital that far outweigh the actual size of the grant.

Nevertheless, while R&I grant-based funding is vital to early-stage technological development, it still lacks the scale needed to help demonstrations and pilot projects in energy progress beyond the financial "valley of death" and towards commercialisation and industrial roll-out.

By way of response to such a crucial issue, instruments such as the NER300 – soon to be substituted by the new Innovation Fund – do provide a much-needed boost to the demonstration of innovative geothermal energy technologies in Europe, plugging the gap between R&I funding and revenue support instruments such as Member States' renewable energy support schemes.

Industry experience still suggests that there is room for improvement however; the NER300, for example, did not fully tackle some of the essential challenges faced by innovative and capital-intensive technologies, such as a lack of upfront funding. Revenue support provides long-term market visibility, yet it does not address the risks of early-stage technologies. There is a lack of clarity over who bears the risk should a project fail.

### Recommendations

Based on the analysis of the case studies examined as well as the existing framework for financing geothermal demonstration projects, ETIP-DG proposes the following recommendations, also illustrated in figure 8:

1. The European Commission should maintain a focus on grants as an essential delivery mechanism for the demonstration of innovative renewable technologies at scale. Grants are unparalleled in allowing the development of innovation along the whole value chain of the project. In the case of geothermal it is important not only to demonstrate the feasibility of a given technology, but also for the workforce to acquire valuable skills and experience that can then prove beneficial in projects with greater share of private financing or different types of instruments.
2. Upfront, de-risked, non-conditional finance. For grants, a milestone system could be used to maintain incentives for efficient device/project development, though 80% of the payouts should remain upfront in order to de-risk the finance provided, while a maximum 20% of the funding should be dependent upon performance (energy production or GHG emissions reduction).
3. Blending finance is another potentially valuable instrument to scale innovation more widely than with grants. Combining traditional grants with hybrid financing, like non-interest bearing instrument, and, possibly, grants and loans will bring more funding opportunities for innovative technologies. The resource risk<sup>8</sup>, the long lead times for project development and the high capital intensity of geothermal project development are significant barriers to financing geothermal energy projects. Grants can incentivise geothermal energy development in potentially high risk activities and for R&D activities. Hybrid financing provides new opportunities with the ability to shift funding from grant to

<sup>8</sup> <https://www.georisk-project.eu/>



loan. This instrument offers public financial authorities a new way to support innovation and to de-risk geothermal energy technologies, with the potential to benefit from loan interest. Hybrid financing can be used to lower geothermal resource risk, and for market uptake in juvenile markets. Blending, provided it is properly tailored to the specificities of the financing needs of different technologies, can be one of the missing links required to bring these technologies to market.

4. Targeted risk mitigation schemes covering the drilling part of geothermal demonstration projects are essential. Such instruments, though already in existence, need to go hand in hand with the different financial instruments available in order for funding to be effective.
5. Financing for demonstration projects should not be always conditional to specific achievements such as the levelized costs of energy. Making awards or pay-outs conditional to LCoE reductions is a non-starter, regardless of the level of reduction required: valley of death projects inherently possess objectives for the assessment of production rates and identification of failure potentials and cost reduction pathways. . Costs reduction is an overall target and the later deployment phase, with its economies of scale, can and should aim at reducing costs significantly. Additionally, valley of death technologies naturally lack a baseline against which costs can be compared, as previous projects have been RD&D developments.

The implementation of the Deep Geothermal Roadmap will also require an international cooperation for some specific activities being capital intensive, opportunities for exporting European technologies and on some next generation of technologies.

For example, International cooperation, under EU programme such as Horizon 2020, can take place in different forms: joint or coordinated calls, specific joint initiatives, or networking between projects. This provides several opportunities for geothermal to give Europe access to the best knowledge and resources where they are located around the world and to help establish new opportunities for European geothermal industries through participation in global value chains and access to new and emerging markets.

The US DoE funding of €2M in Geothermica (ERANET) and the GEMEX project co-funded by the EC and Mexico are two examples of this cross-continent collaboration. Mexico, USA and Europe have high potential for geothermal energy generation; in particular the American and Mexican geothermal resource settings provide a unique opportunity to apply and further develop methodologies and technologies in the field of EGS (Enhanced Geothermal Systems) and of superhot systems.

The objective is to progress in the technology development applying and consolidating concepts and technologies in different geological contexts therefore reducing technological and social risks of geothermal developments. In this context a strengthening of the European geothermal technology base is also expected, expanding European market for geothermal technologies, further establishing scientific exchange of researches and developing capacity building.

Finally, it is crucial that financial support for market development is also mobilised across Europe. For this Deep Geothermal Implementation Roadmap, Countries in Europe must progressively increase national funding for market development, with the aim of reaching the two major targets on market uptake in Europe:

- Reach more than 5 GWe installed capacity in 2030 (from 3 GWe in 2019);
- Reach more than 15 GWth installed capacity in 2030 (from 5 GWth in 2019).



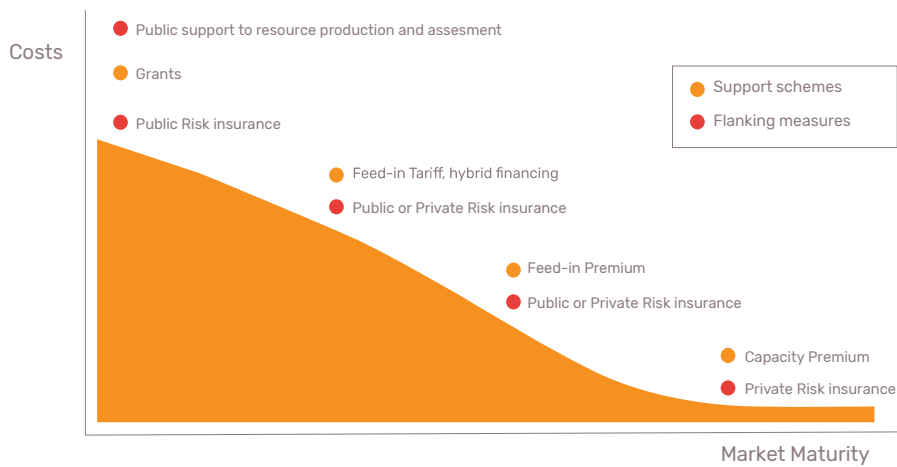


Figure 8: Support schemes for Geothermal adapted to technology maturity

## FUNDING INSTRUMENTS

The level of support received by geothermal is strengthened by the advantages it provides to the energy system (renewable baseload, no need for back-up, alleviating the need for transmission and distribution infrastructure etc.).

While conventional geothermal power is already a competitive energy source, low-temperature systems and EGS will become competitive within a few years if substantial research, development and demonstration (RD&D) resources are allocated to these technologies. Likewise, geothermal heating and cooling also need RD&D funding to further improve the efficiency of their systems and to decrease installation and operational costs.

Consequently, there are three complementary avenues to consider for the leveraging of resources required for implementation.

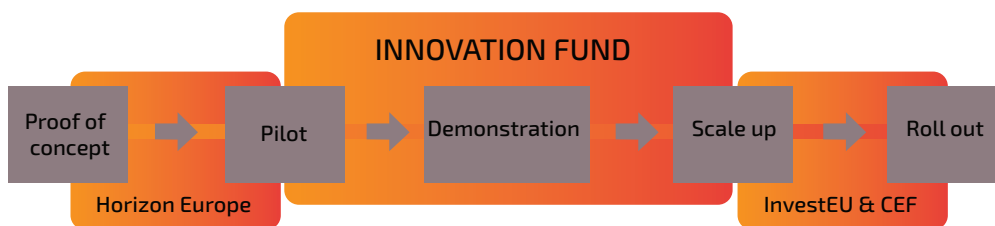
## PUBLIC FUNDING FOR R&D AT EUROPEAN LEVEL

Horizon 2020 is the main EU Research and Innovation programme, with nearly €80 billion of funding made available over 7 years (2014 to 2020). It serves the "Innovation Union", an EU initiative that aims at promoting Europe's competitiveness. Projects at different stages of the research and innovation process can receive funding under Horizon 2020.

As a matter of fact, EU R&I funding allocated to geothermal energy during the Horizon 2020 European program amounted to around € 250 million by the end of 2018. This sum was divided between an EU contribution of € 160 million and a private sector contribution of € 85 million. In total, 36 projects have been co-funded by public money from H2020 calls on RES&EE and Industrial leadership, as well as from SME-instruments, INTERREG and ERASMUS+.

The new framework programme currently under negotiation, Horizon Europe, will also serve as the main EU Research and Innovation programme with a budget of around € 100 billion. Given continued debate as to the potential shape of Horizon Europe, the facility replacing Horizon 2020, it appears imperative that it continues to prioritise emerging renewable sources such as geothermal. Public support for geothermal, at European level in particular, has proven effective in unlocking innovation and opening new markets for geothermal energy.

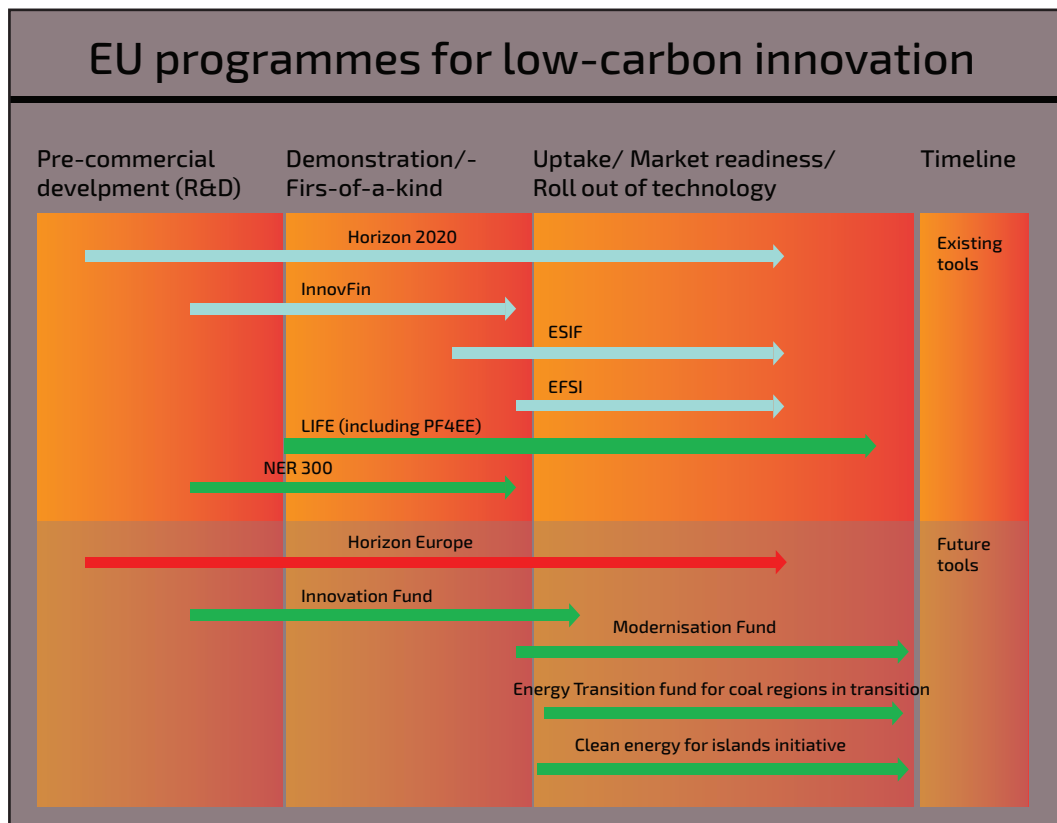
Another financing instrument at EU level is the NER300 programme, so named because Article 10(a) 8 of the revised Emissions Trading Directive 2009/29/EC contains the provision to set aside 300 million allowances (rights to emit one tonne of carbon dioxide) in the New Entrants' Reserve of the European Emissions Trading Scheme in order to subsidise installations for innovative renewable energy technology and carbon capture and storage (CCS). The NER300 currently supports 3 geothermal projects. In 2020 it will be replaced by a so-called Innovation fund, which has the same purpose. This change to the "Innovation Fund" should result in a different allocation of funding financial instruments.



*Timeline of Innovation Fund*

A new financing tool created recently is GEOTHERMICA – ERANET Cofund. This is currently supporting eight transnational projects on geothermal energy. The total investment in the projects is close to € 50 million. About half is funded by GEOTHERMICA and the other half comes from project partners. This is the first series of GEOTHERMICA-funded projects, bringing innovative geothermal (primarily deep geothermal, though some projects also deal with shallow geothermal) energy solutions closer to commercial deployment. A second call was launched in May 2019. The available budget for the Second Call is close to €20 million in total. Moreover, the GEOTHERMICA Consortium will be broadening for the Second Call, with Norway and USA joining, giving GEOTHERMICA now the weight to influence and accelerate the development of geothermal energy globally, enlarging export opportunities for European entities.

A total of around € 300 million was spent from European-level co-funding between 2014 and 2018. Extrapolating this figure, the sector is not far from reaching the full amount of R&D money expected from public support at European level within the period of Horizon 2020 (2014-2020): around € 400 million.



*New EC instruments for the period 2020-2030*

The implementation of the Deep Geothermal Roadmap will require a yearly investment of approximately € 600 million of EU resources, totalling € 1860 million by 2030.



## Public funding for R&D at national level

It is crucial that research resources are also mobilised across Europe. R&D support from Member States and regions must be coordinated at European and national level. Geothermal R&I spending shows major variation among Member States, but there are research priorities that are shared between some technologies within certain groups of countries. Synergies should be exploited in these areas, which is of particular importance for capital-intensive R&I activities.

Funding awarded under national or local programmes is granted in pursuit of numerous policy priorities. These range from environmental protection to civil society development, including research and the protection of cultural heritage. These facilities put a strong emphasis on climate and energy however, focusing on renewable energy, green industry innovation or energy efficiency. The Smart Specialization Platform on geothermal energy "S3 Partnership Geothermal Energy 2.0" launched in 2019 will increase the interregional cooperation along shared priorities related to geothermal energy.

This Regional Partnership aims at helping local policy makers to better use the related European Structural Investment Funds (ESIF) and other public/private investments smartly, in order to harness their place-based competitive advantages on the most appropriate way.

EU structural and investment Funds dedicated to regional policies of interest for the geothermal sector are the following: the Cohesion Fund, the European Regional Development Fund (ERDF), the European Social Fund (ESF) and the European Agricultural Fund for Rural Development (EAFRD).

Funding can be obtained by responding to competitive calls for tender or proposals.

In order to put the Implementation Roadmap into action, Member States and Regions must progressively increase national R&D funding for geothermal, with the aim of reaching an overall effort of € 550 million for the 2020-2030 period.

## INVESTMENTS BY THE PRIVATE SECTOR

Significant levels of funding for R&I are coming from industry. A large part of the RD&I from industry is dedicated to innovation and high TRL. The total number of private projects is hard to estimate, but it can be assumed that it represents a third of all RD&I investment for geothermal in Europe.

The variation in R&D efforts among EU Member States also holds true for the R&D expenditure of industries in the geothermal sector. The scale of technologies involved is so vast and the related value chain so complex that it is impossible to identify all private investments at the different stages of geothermal innovation processes.

Crowdfunding (CF) is an emerging alternative source of financing. It refers to open calls to the public, generally via internet platforms, to finance any kind of project. There are four types of CF transactions/relationships:

- Donation: A donor contract without an existing reward = supporter/fan
- Reward: A purchase contract for some type of product or service = client, buyer
- Lending: A credit contract, credit is to be repaid plus interest = creditor
- Equity: A shareholding contract providing shares, equity-like instruments or revenue sharing in the project/business = investor

The approach adopted was therefore to estimate the R&D commitments from industry between 2020 and 2030, basing this calculation upon the resources dedicated to R&D on an annual basis. According to our estimation, the total turnover of geothermal industries in the EU was € 2.7 billion in 2018. Nearly all private R&D investments are currently carried out by material and equipment manufacturers: the turnover generated by the sale of services (e.g. installation, planning, maintenance) has therefore been excluded from the following calculations. The ratio of R&D expenditure to net sales varies significantly, however for most companies this is in the range of 1% to 3%.

The table below illustrates the total level of investment expected from the private sector between 2020 and 2030, calculated as a proportion of the net sales of the component industries:

Deep Geothermal	
Total installed capacity: Electricity (GWe, year 2030) Deep GT H&C (GWth, year 2030)	5 GWe and 15 GWth
Investment costs (average) H&C (€/MWth, year 2018) Electricity (€/MWe, year 2018)	€1,5m/MWth and €4m/MWe
Annual capital costs reduction	2-10%
Turnover of the entire sector, including services (mil. euros, 2020-2030 period)	€50 000 m
Manufacturing industry as percentage of sector turnover	40%
Manufacturing industry turnover (mil. euros, 2020-2030 period)	€20 000 m
R&D as percentage of manufacturing industry turnover only (average)	3.5-4%
R&D investments of manufacturing industry (mil. euros, 2020-2030 period)	€700m

*Total level of investment expected from the private sector between 2020 and 2030*

In order to implement the Geothermal Roadmap, industry must spend around € 700 million across the 2020-2030 period on R&D funding for geothermal.

The R&D work should be accompanied by strong educational/training activities and the resolution of non-technical issues such as quality certification, guidelines, regulation, infrastructure and so on, which will in turn require extra financing.



## BUDGET OVERVIEW

From this analysis it is clear that among those technologies experiencing technological progress, geothermal is the one receiving a low amount of financial support despite all the advantages it provides to the energy system (renewable baseload, no need for back-up, alleviating the need for transmission and distribution infrastructure etc.).

While some geothermal technologies are already competitive (conventional power, geothermal DH), others such as CHP, low-temperature systems and EGS will become competitive within a few years if substantial research, development and demonstration (RD&D) resources are allocated to those technologies. Likewise, geothermal DH also requires RD&D funding in order to further improve the efficiency of its systems and to decrease installation and operational costs.

In order to pursue the EU objective of decarbonising the power and heating and cooling sectors, there is a clear need for more resources to be invested by the European Union and the Member States. The ETIP-DG estimates that € 1.85 billion is required for the successful implementation of this Deep Geothermal Roadmap.

The figure below illustrates the proposal that the expected resources be committed by European industry (38%), the European Commission (32%) and Member States (30%) & Regions, respectively. Across the 2020 – 2030 period, an average of €185 million should be allocated annually to deep geothermal research and innovation activities.

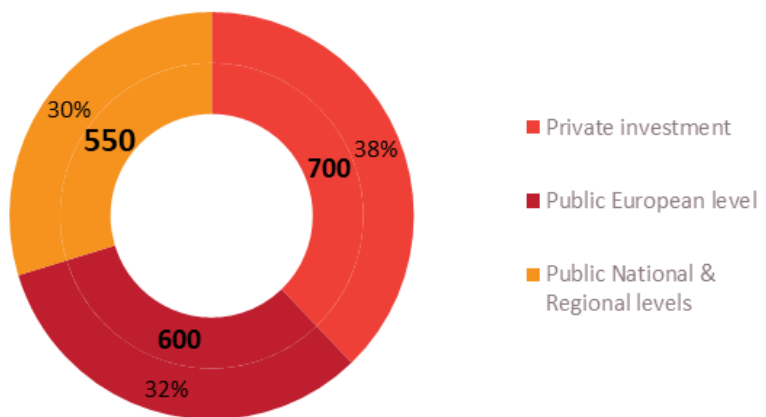


Figure 9: Estimation of the total resources required to implement the Geothermal SRiA between

The total amount of R&D money spent by industry (2020-2030)	Around € 700 million
The same value is expected from public support ( European level, Member States and Regions)	Around € 1150 million
<b>Total R&amp;D investment required between 2020 and 2030:</b>	<b>€ 1850 million</b>









# ETIP-DG

European Technology & Innovation  
Platform on **Deep Geothermal**

The European Technology & Innovation Platform on Deep Geothermal (ETIP-DG) 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.

For more information on its activities visit [www.etip-dg.eu](http://www.etip-dg.eu)

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