

Geothermal Technology Roadmap

European Technology Platform
on Renewable Heating and Cooling







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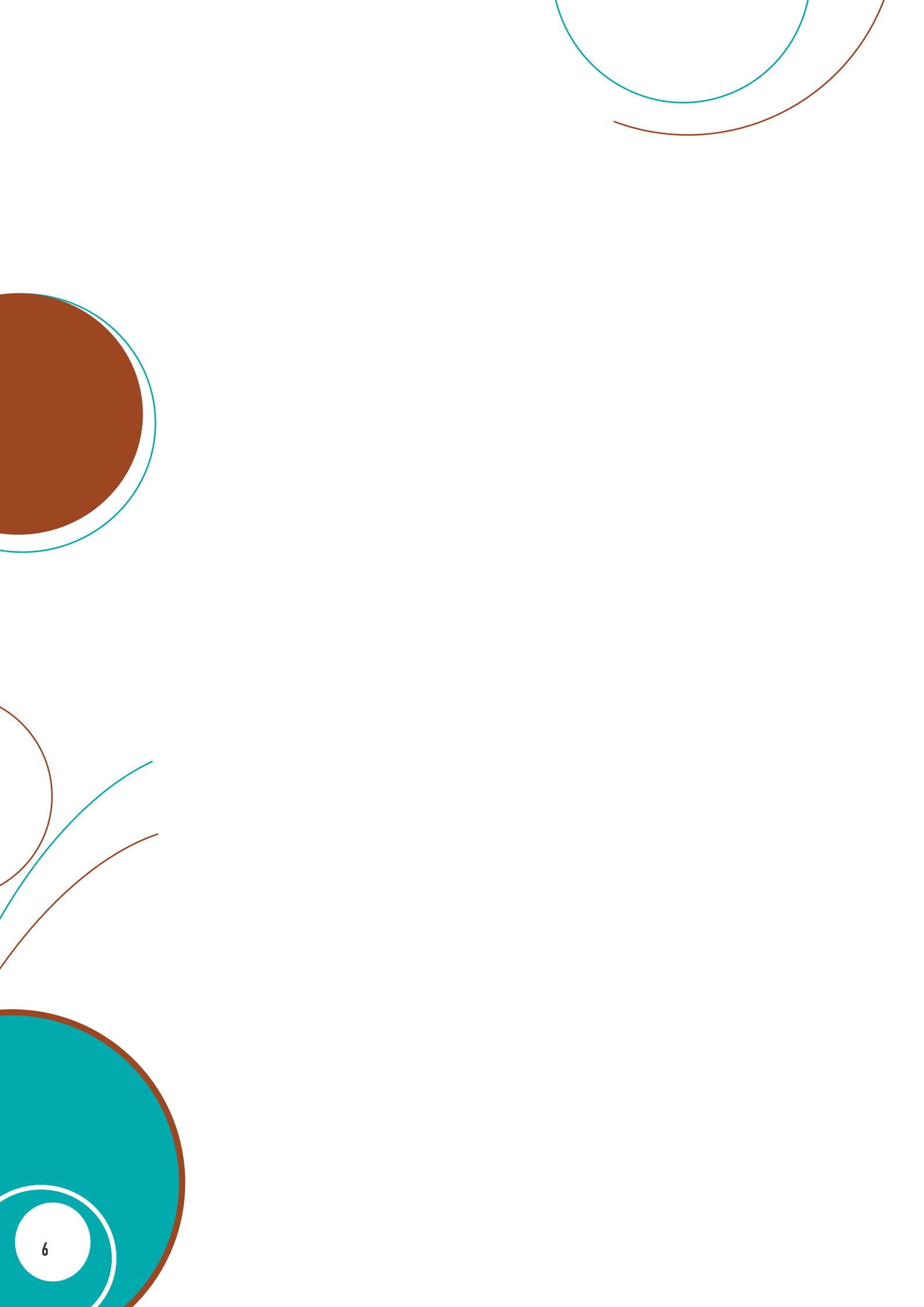
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TABLE OF CONTENTS

1. STATE OF PLAY AND 2020 OBJECTIVES.....	7
2. KEY PERFORMANCE INDICATORS AND MAJOR MILESTONES.....	11
3. IMPLEMENTATION PLAN 2013 - 2020.....	17
4. FINANCING.....	27
APPENDIX I: SCALE OF TECHNOLOGY READINESS LEVELS (TRL) ADOPTED BY THE RHC-PLATFORM.....	34
APPENDIX II: GLOSSARY	35
APPENDIX III: SECRETARIAT OF THE RHC-PLATFORM	35

Figures	Page
LC of Geothermal Heat	15
LC reduction	16
Levelised Cost of Heat Reduction	16
Implementation Plan structure	18
Time line of planed research activities for shallow geothermal 2013-2020	21
Time line of planed research activities for deep geothermal 2013-2020	26
Timeline for the implementation of relevant EU legislation for geothermal energy	29
FP6 - FP7 - non-nuclear energy spending by sector	30
EU R&D funding allocated to energy technologies during the FP6 and FP7	31
estimation of total resources required to implement the geothermal SRA between 2014 and 2020,	33



1

State of Play and 2020 objectives



1 STATE OF PLAY AND 2020 OBJECTIVES

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

Geothermal heating & cooling can supply energy at different temperatures (low or high temperature), at different loads (it can be base load and flexible) and for different demands (heat and cold: less than $10 \text{ kW}_{\text{th}}$ to a tenth of a MW_{th}). Geothermal is a renewable energy source which is local, manageable and flexible. It should be integrated in a regional approach which reduces costs for society (system costs: infrastructures and storage facilities, and externalities; Greenhouse Gas emissions etc.) and improves local security of supply.

Geothermal will be a key energy source both in smart cities and in smart rural communities, being able to supply both Heating and Cooling (H&C) and electricity as well as solutions for smart thermal and electricity grids via underground thermal storage.

Currently, geothermal energy sources provide more than the equivalent of 4 million tonnes oil (Mtoe) per year for heating and cooling in the European Union, equivalent to more than 15 GWth installed capacity, where geothermal Heat Pump systems contribute the largest part. But still the potential is huge. Geothermal can be used virtually anywhere in residential and tertiary sectors, but also in industry up to temperatures in the range of 200-250°C.

Following current trends, in the European Union (EU-28), the contribution in 2020 will amount to around 40 GWth installed, corresponding to about 10 Mtoe.

The total installed capacity for geothermal power in the EU now amounts to around 946 MWe, producing some 5,56 TWh of electric power yearly. Combined Heat and Power (CHP) plants are marginal, with less than 1 GWth capacity for heating, but the development of Enhanced Geothermal Systems (EGS) will provide further opportunities for CHP systems.

The technological challenges for an accelerated deployment of geothermal heating & cooling across Europe are to develop innovative solutions especially for refurbishing existing buildings, but also for zero and plus energy buildings, as the systems are easier to install and more efficient at low temperature for both heating & cooling. Secondly, to develop geothermal District Heating (DH) systems in dense urban areas at low temperature with emphasis on the deployment of Enhanced Geothermal Systems. Finally, the third goal is to contribute to the decarbonisation of industry by providing competitive solutions for heating & cooling.

Geothermal in an Energy System Approach

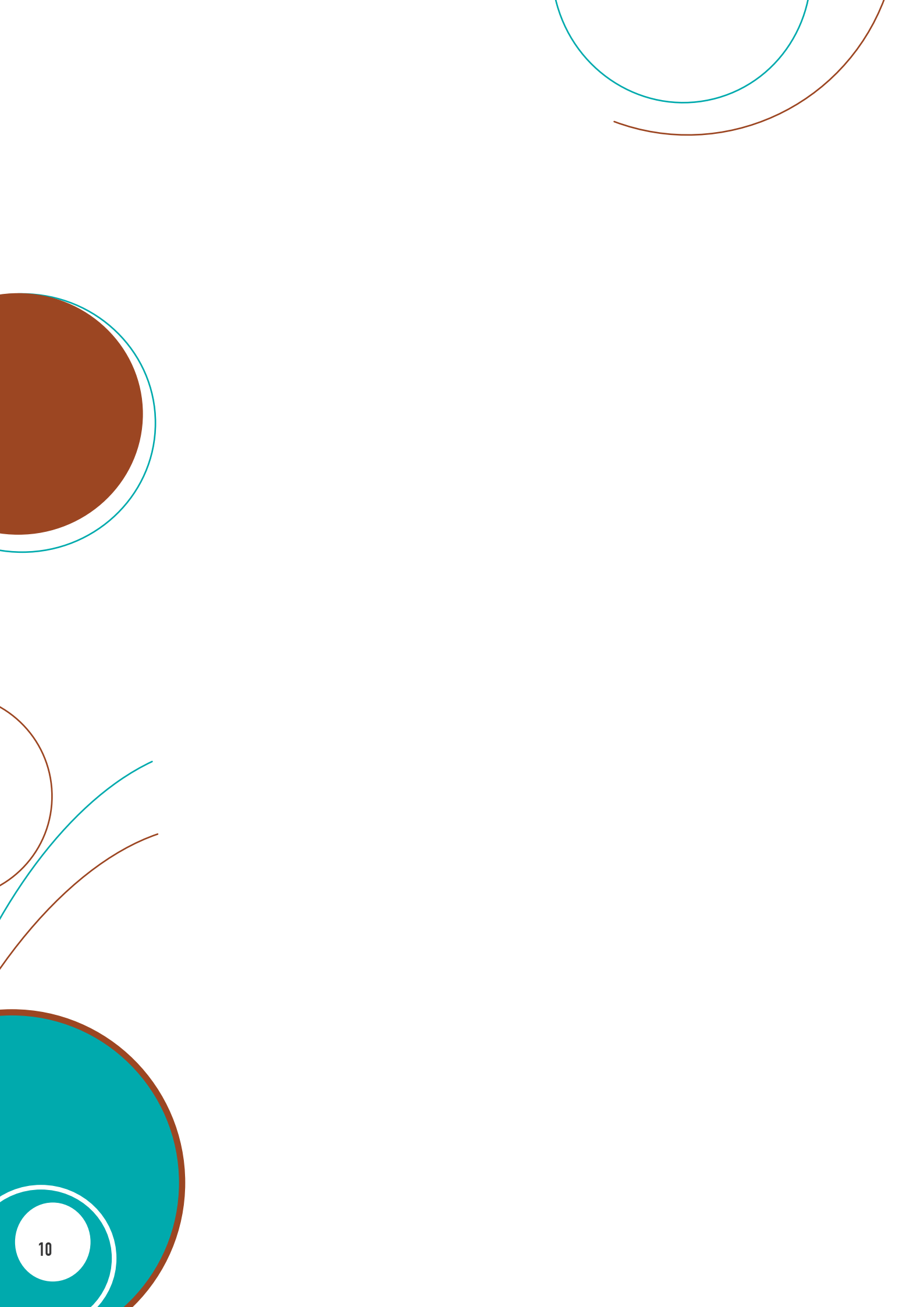
refurbishing existing buildings
Energy for smart cities and communities
decarbonisation of the industry

The quantitative development of the European geothermal heating & cooling market in the next ten years is expected to be fuelled mainly through the introduction and consolidation of shallow geothermal systems, with a quite mature market in Sweden and Switzerland and well developed markets in Austria, Norway, Germany and France. In other emerging European markets, high growth is possible and is expected over the next years (Italy, Spain, the United Kingdom, Hungary, Romania, Poland, and the Baltic states). The aforementioned mature markets will see a steady increase, mainly stimulated by sales in the renovation sector, while in all other

countries, a significant growth is to be expected. Fast development for geothermal heat pumps illustrates how shallow geothermal energy resources, previously often neglected, have become very significant, and should be taken into account in any energy development scenario.

Promising areas are the development of smart thermal grids (1st generation) with the building of new district heating & cooling networks (Geothermal District Heating & Cooling, with ca. 5 €-cent/kWh, is one of the most competitive energy technologies), optimisation of existing networks, and the increase of new and innovative geothermal applications in transport, industry and agriculture. The first regions to develop will be those possessing the most accessible resources (for example the Pannonian, Tuscan or Parisian basins) as well as higher grade resources where combined heat and power projects will be developed (e.g. the Bavarian Malm reservoir and the Upper Rhine Graben).

During the next 10 years, new geothermal combined heat and power plants with low temperature installations and Enhanced Geothermal Systems will be developed. The sector is forecasted to reach an installed capacity for geothermal electricity of 3-4 GW_e in the EU-28. A binary system (Kalina or Organic Rankine Cycle or similar) at low temperature has a simultaneous electrical and thermal capacity of ca. 5 MW_e and 10 MW_{th}, respectively. A typical EGS plant today has a capacity of 3-10 MW_e, but future commercial plants will have a capacity of 25-50 MW_e and 50-100 MW_{th} (producing from a cluster of 5 to 10 wells, as currently found in the oil & gas industry). CHP installations could provide heating representing 2 Mtoe by 2020 at high temperature, suitable for energy intensive industry.



2

Key performance indicators and major milestones



2 KEY PERFORMANCE INDICATORS AND MAJOR MILESTONES

DESCRIPTION OF GROUND SOURCE HEAT PUMP (GSHP) SYSTEMS

GSHP technology is suitable for small, individual houses as well as larger multi-family houses or groups of houses, with capacities ranging from under 10 kW_{th} to over 500 kW_{th}. The depths of geothermal heat exchange range from a few meters to more than 200 m, depending upon technology used, geological situation, demand profile, and other design considerations. For space cooling, in certain regions with moderate climate, direct cooling from the ground via cooling ceilings etc. is possible, allowing for space cooling with minimum energy input. In warmer regions with higher cooling demand, the heat pump can be used in cooling mode.

One major non-technical issue concerns the lack of awareness about shallow geothermal. Knowledge about this technology is still very limited. In particular, many project developers in the residential, tertiary and industry sector are not sufficiently aware of solutions provided by shallow geothermal. A large communication campaign should be launched to complement research activities presented in this roadmap.

For well-insulated houses with a forced ventilation system, geothermal energy can contribute to pre-heating or pre-cooling ventilation air while it passes through intake pipes buried in the ground.

Another geothermal technology useful for industrial applications and for the heating and cooling of larger buildings is underground thermal energy storage (UTES). In particular UTES at 40-90 °C can directly supply heat for low temperature industrial needs such as batch processes or seasonal industries (e.g. sugar refineries), where periods of heat (and/or cold) demand are followed by phases of inactivity.

Whilst the number of geothermal heat pumps with a capacity below 50 kW crossed the threshold of 1 million units in 2010, further R&D and practical experience is crucial to fully exploit the advantages of geothermal heat pumps in supplying heat and cold from one single installation.

Main Key Performance Indicators (KPI) for GSHP

- The performance of geothermal heat pump systems improved substantially since their introduction in Europe in the 1970s. The first plants were installed in Sweden, Germany, and Switzerland, and used for heating only. In these regions the typical efficiency, expressed as Seasonal Performance Factor, increased from below 3 in the 1980s to well above 4 today, and with continued R&D, average values in the order of 5 seem feasible for 2020.
- Component efficiency improvement: The most popular ground-coupling technology is the borehole heat exchanger (BHE); a good efficiency of a BHE results in a small temperature loss between the ground and the fluid inside the BHE. This temperature loss is controlled by the borehole thermal resistance, R_b . This Performance Indicator has been reduced by more than 40% over the last ten years. The overall impact of this value to a defined shallow geothermal system is given by the Hellström-efficiency, which has increased from below 60% to about 75% in state-of-the-art installations over the past 10 years. There is still room for improvement, so provided the technology progress is continued, efficiencies of about 80% in 2020 seem achievable.
- The cost shows a steady reduction in the last decades. A study of the Swiss Heat Pump Association (Fördergemeinschaft Wärmepumpen Schweiz, FWS) calculated the cost for a BHE-system (drilling, heat exchanger, and heat pump) for a small house, and found a reduction of 27.5% over 12 years, from 1992 to 2004. Whilst the initial cost of a BHE system has decreased slightly, improvements in efficiency, which result in less energy being used to operate the system, have led to a substantial cost reduction overall.

Need for R&D for GSHP technologies

Shallow geothermal systems consist of the integration of the devices for exchanging heat with the underground, with the components to make this heat available for use in the building, such as heat pumps, conventional heating, and HVAC (Heating, Ventilation & Air-Conditioning) equipment. The heat pump as such is covered in the Cross Cutting research priorities. Any progress in HVAC components (better efficiency, lower cost, adaptation to temperatures delivered by geothermal systems) will also benefit geothermal systems overall. Specific R&D for geothermal heating and cooling in the residential sector thus **mainly concerns ground-coupling technologies**. On the other hand, as most of the buildings which will exist in 2020 are already built, the development and testing of underground coupling systems suitable for retrofitting or adapting into old/historical buildings is crucial to substantially increase the penetration of GSHP technologies.

DESCRIPTION OF GEOTHERMAL DIRECT USES AND HIGH TEMPERATURE COGENERATION

Deep geothermal energy production is the relevant technology in sectors which demand electricity and heat in the **medium temperature range (80-250°C)**, which includes many industrial processes, DH systems, and large individual buildings in the service sector as well as other applications such as agriculture and balneology.

The heat supply is achieved mainly with direct heat supply by thermal water production and reinjection, but also using other technologies like deep borehole heat exchangers (BHE) or heat from geothermal CHP plants. The capacity of such installations can start from about 0,5 MW_{th} (in particular deep BHE) and may achieve values in excess of 10 MW_{th}. The heat may be fed directly into a district heating system if production temperature matches the required supply temperature, or be used as a heat source for large heat pumps (including absorption heat pumps, engine-driven compression heat pumps, etc.). Also cold production is possible with absorption chillers driven by geothermal heat. Taking advantage of further development in DHC technologies (including cascading and storage) will make it possible to use geothermal heat even more efficiently.

Geothermal energy can provide heat above 80°C from deep geothermal resources and from high-enthalpy geothermal resources. High enthalpy resources, some of which have temperatures over 250 °C, are used almost exclusively for electric power production, though its utilisation for industrial purposes (energy intensive industry) is also feasible. R&D will be required to provide the right matching and adaptation of the geothermal heat source to the specific characteristics of the industrial process concerned.

For the heat source as such, most R&D needs are the same as for deep geothermal in DHC, as long as temperatures below about 120 °C are considered. As the temperature of the geothermal fluid increases, other problems need to be solved, like degassing of the fluid (pressure control), corrosion, and insufficient pump technology.

Finally, geothermal electricity from CHP can bring many advantages for our future electricity mix: 1) as a proven base load renewable resource (can run >8000 h/ year); 2) because of its flexibility and scalability (right response for grid stability); 3) due to its easy integration into existing power systems; and 4) because of its local character, limiting new infrastructure and reducing system costs.

The aim should be to have a step between centralised and completely decentralised systems with regional security of supply. In this aspect, geothermal CHP production is key.

Moreover, the largest source of flexibility in power systems is the ability of dispatchable power plants such as geothermal plants to ramp output up and down on demand. Geothermal plants can be dispatchable as they are able to respond to commands from a system operator, at any time, within certain availability parameters, and to increase or decrease output over a defined period. Geothermal plants are 'base load', designed for operating 24h per day throughout the year. They could be also flexible because plants should be ready to respond with at least six-hours notice. The decarbonisation of the electricity sector will only be possible with a large additional contribution from the flexible renewable energy sources in order to replace base load production from coal, gas, and nuclear. A high penetration of geothermal CHP-plants could play a positive role on the operation of distribution networks and the ancillary services these units could provide to the electricity system, under consideration of the different operating modes e.g. heat/ power driven, with/without storage, afforded by their operational flexibility.

Main Key Performance Indicators (KPI) for Deep Geothermal Technologies

- Improved exploration of geothermal resources and creation of a European geothermal resource database. Presently, technology is mainly based on extrapolation of products tailored for hydrocarbon industry (e.g., geophysical software, logging tools, etc.) into the geothermal sector. A drilling campaign of slimholes should be launched in Europe for getting more geological data. In the future, not a single project should need to be abandoned after the decision to go ahead with drilling.
- Deep drilling cost reduction. The drilling of boreholes is a major share of the necessary investment. Hence, reductions in drilling cost can substantially influence the overall economics of a deep geothermal plant. R&D should focus both on novel drilling concepts and on improvements to current drilling technology, as well as for other ways to optimise the economics of drilling operations (horizontal, multi-wells etc.). Nowadays, drilling for deep geothermal energy is done using equipment originally intended for the hydrocarbon industry. The target is to reduce cost for drilling and underground installations by at least 25% compared to the situation today.
- Novel production technologies to improve efficiency, reliability and cost of heat production (including well design and completion, definition of suitable materials, reservoir stimulation, prevention of formation-damage, high temperature-high pressure tools etc.). Geothermal well design has reached a good standard, and specifically-designed components like pipes and pumps are available. Production pumps cause high power consumption. However, there is room to reduce operation and maintenance cost by at least 25%, improve system reliability and energy efficiency of operation, in particular by decreasing energy consumption of production pumps by at least 50%.
- Surface systems for heat uses in DHC (including CHP) and industrial processes. The use of geothermal heat for DHC, process heat or large buildings requires specific technologies to transfer the geothermal energy into useful heat inside a network, a building or an industrial plant. The basic technologies to exchange heat between the geothermal source and the heat transfer fluid in the system in the network still offer a wide range of possible improvements, both in energy efficiency and resistance to corrosion, e.g. new materials or innovative geometries. Any further development in DHC technologies (including cascading and storage), also has the potential for improving the efficiency and performance of geothermal district heating. Standard heat exchange and heat/cold distribution systems for conventional heat and cold sources are applied; the characteristics of geothermal heat (steady supply, mostly limited temperature, mineralised waters) are addressed by design, but not with innovative solutions and components. The target is to provide optimum heat transfer from the ground system to the distribution system, increase heat exchange efficiency by 25% and component longevity in the thermal water circuit by 40%.
- Enhanced Geothermal Systems (EGS). EGS is a technology for accessing the heat in hot but impermeable basement rock. Once fully developed it will provide a major increase in the geothermal resource base, both for heat and electric power. In spite of its potential and although the basic concepts were already developed in the 1980s EGS has not yet matured into a ready-to-implement technology. Experience in the few existing research facilities and operational power plants revealed a significant discrepancy between initial layout figures and final result, both with respect to the stimulated underground heat exchanger and the realised thermal and electrical output. Therefore, apart from necessary flanking measures with regard to training, education and public acceptance, major efforts are required for developing tools and layout procedures for a design of EGS with reliable performance parameters, such as flow rate, temperature and thermal and electrical power. Ultimately, this will establish EGS as a technology applicable almost everywhere for both heat and power production.

Cost Reduction

Geothermal heat may be competitive for district heating where a resource with sufficiently high temperatures is available and an adaptable district heating system is in place. Geothermal heat may also be competitive for industrial and agriculture applications (e.g. greenhouses).

As Geothermal Heat Pumps can be considered a mature and competitive technology, future market competition with the fossil fuel heating systems will allow the phasing out any subsidies for shallow geothermal in the heating sector.

Where high-temperature hydrothermal resources are available, geothermal electricity from CHP is in many cases competitive with newly built conventional power plants.

Binary systems can also achieve reasonable and competitive costs in several cases, but costs vary considerably depending on the size of the plant, the temperature level of the resource and the geographic location.

EGS cost cannot yet be assessed accurately because of the limited experience derived from pilot plants.

Although geothermal electricity and heat can be competitive under certain conditions, it will be necessary with R&D to reduce the Levelised Cost of Energy of less conventional geothermal technology.

LC of Geothermal Heat	Costs 2012 Range(€/ct/kWh) Average (€/ct/kWh)		Costs 2030 Average (€/ct/kWh)
Geothermal HP – large systems and UTES	5 to 10	6	5
Geothermal HP – small systems	10 to 30	10	7
Geothermal DH	4 to 8	5	4
Geothermal direct uses ¹	4 to 10	7	4

LC of Geothermal Electricity (CHP)	Costs 2012 Range(€-cent/kWh) Average (€-cent/kWh)		Costs 2030 Average (€/ct/kWh)
Electricity Conventional – high T°	5 to 9	7	4
Low temperature and small high T° plants	10 to 20	15	7
Enhanced Geothermal Systems	20 to 30	25	7

Figure 1: Levelised costs of energy production from geothermal technologies

¹ Direct uses are geothermal applications in balneology, greenhouses, agro-industrial processes etc.

Potential cost reduction

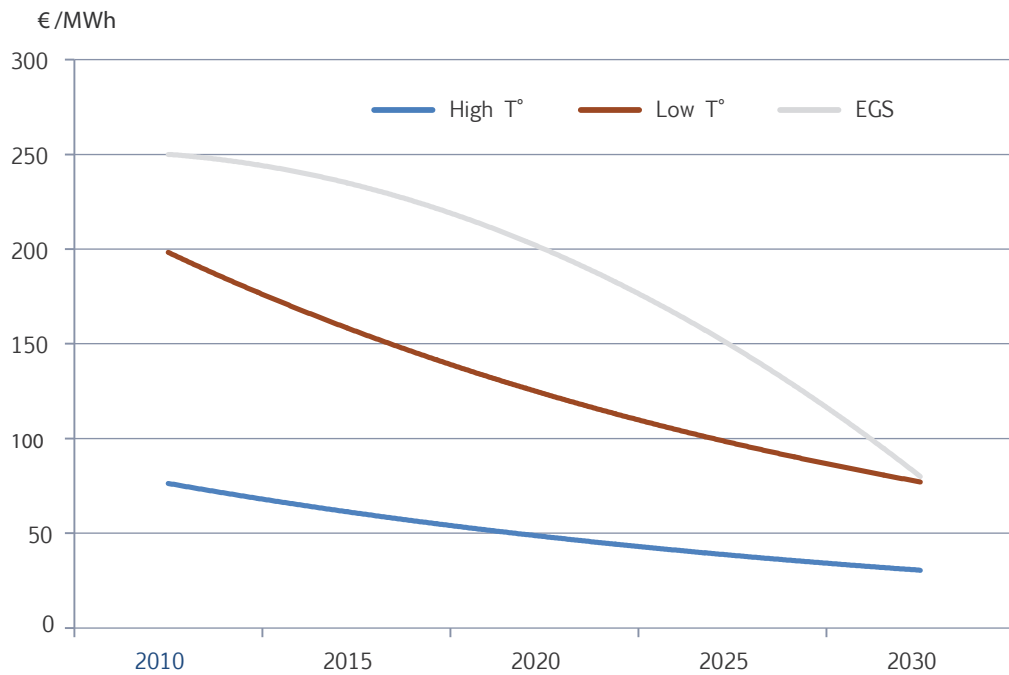


Figure 2: LC reduction for geothermal electricity technologies costs (€/MWh) 2012-2030

Ref: 2013 Update of Strategic Research Priorities for Geothermal Technology (2012, European Tec Platform on Renewable Heating and Cooling)

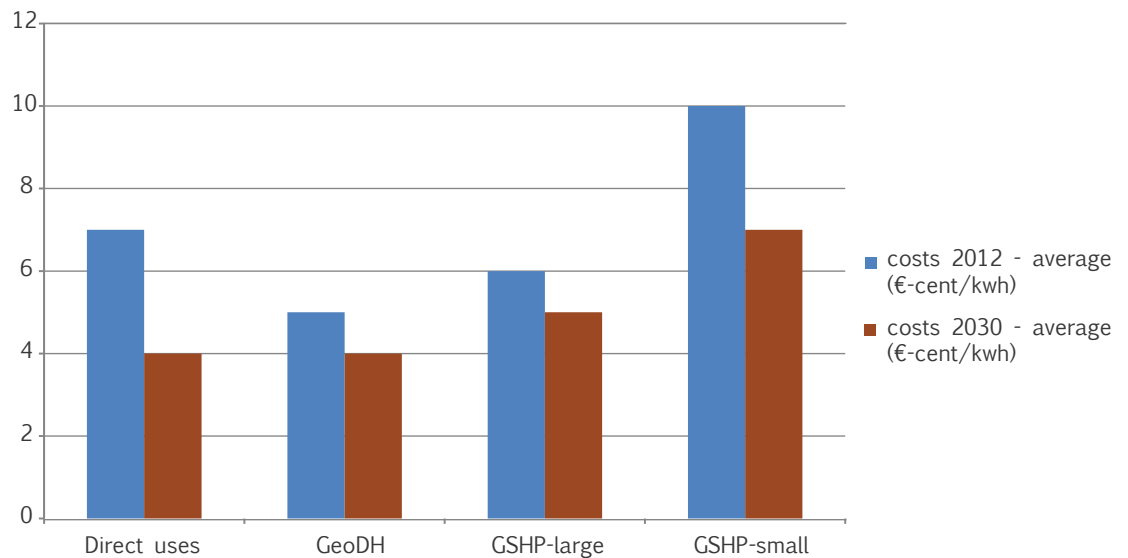


Figure 3: Levelised Costs reduction for geothermal H&C technologies 2012-2030

Ref: 2013 Update of Strategic Research Priorities for Geothermal Technology (2012, European Tec Platform on Renewable Heating and Cooling)

3

Implementation Plan 2013 - 2020



3 IMPLEMENTATION PLAN 2013 - 2020

The Geothermal H&C implementation plan 2013-2020 follows the timing of the next Horizon2020 EU programme for RD&D, and presents a plan for developing research projects. The implementation plan for R&D departs from the need to establish a European Industrial Action. The Geothermal Section would be structured in the following way:

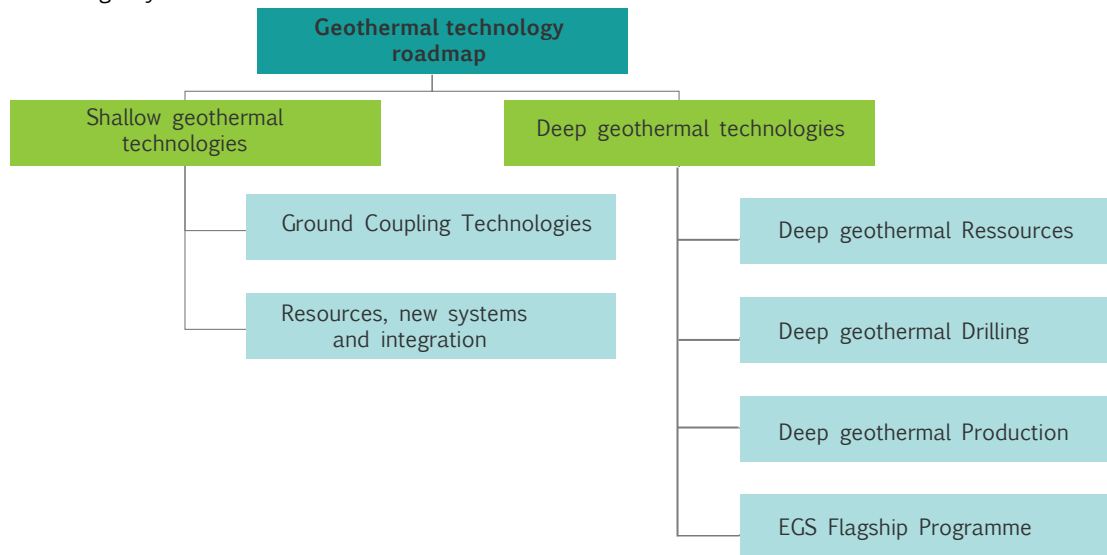


Figure 4: Implementation Plan structure

SHALLOW GEOTHERMAL

A) Shallow Optimisation Geothermal Subsection - Ground Coupling Technologies Area

Definition The ground coupling technology area comprises the initiatives and actions discussed within the Geothermal SRP under subchapters 3.2 and 3.3, with specific references to new areas, such as the development of new piping materials.

Keywords Innovative drilling methods, enhanced grouting materials, new piping materials, horizontal collectors, new collector types and geometries, geothermal piles, new geothermal-activated civil engineering structures, etc.

Discussion and scope For geothermal systems with borehole heat exchangers or groundwater wells, the drilling of the necessary boreholes is a major cost factor. Hence systems can be made much more economic by improved and innovative drilling methods, allowing for cost reduction. A lot can also be expected from further reducing manual work in drilling and installation, with automation and robotics. **R&D in specific shallow geothermal drilling technology** is also required to further reduce the impact on the surroundings (e.g. sensitive clays, groundwater), to provide techniques to control borehole deviation, etc.

In particular in the residential sector, **other types of geothermal heat exchangers like horizontal loops** are in use in addition to drilling of boreholes. **The use of geothermal activated structures** (geothermal piles, diaphragm walls provided with embedded heat exchanges, etc.) may also lead to substantial cost reductions. However, the detailed thermo-hydro-mechanical interaction between these structures and the soil and its long term stability and performance is an area that needs substantial experimental backup, standardised approaches and new algorithms and software developments. Also here the reduction of cost, through optimised and mechanised installation methods, is an issue and needs further R&D-work.

The efficiency of heat exchange with the geological strata can be increased by R&D for optimisation of components such as borehole heat exchangers (design, pipe material, grouting material), well completion materials, compressors, and pumps.

One more concern is about the identification/development of an environmentally benign, low viscosity antifreeze ('thermal transfer fluid') fluid for closed loop GSHP systems in order to have thermal characteristics that are equal to, or better than, mono-ethylene glycol. The objective is to produce a fluid with long term stability - at least as good as mono-ethylene glycol; and preferably derived from a sustainable source. Such antifreeze could contribute to system efficiency by reducing power demand of circulation pumps, and to acceptance with authorities by imposing no threat to the groundwater.

State of play For ground coupling, the cost varies between different technologies and different geological settings. A borehole heat exchanger today costs 30-60 €/m, with the lower prices prevalent in Scandinavia and the higher in Austria and Germany. Assuming a typical single family house, this results in some 350-700 € per kW installed capacity of the ground heat exchanger only (i.e. excluding the heat pump). The efficiency of ground coupling can be measured by a parameter called borehole thermal resistance; values for current up-to-date technology can be as low as about 0.07-0.08 K/(W·m). To compare these values in their impact on the whole system, the Hellström-efficiency has been defined; currently values in the order of 75 % can be achieved.

Targets Reduction of average installation cost by at least 25% in 2020, and 50% in a longer term. Increase of heat exchange efficiency to 2020 by 25% (expressed by reduced borehole thermal resistance or similar), allowing for either higher efficiency (for boreholes, expressed as increase in Hellström-efficiency) or reduced cost.

Type of activity Basic R&D (25%), Applied R&D (75%)

Required partnerships Public / private initiative, (drilling companies, piping companies, specialised engineering and component manufacturing companies, cement manufacturing companies for special grouting materials, antifreeze materials, a.s.o), synergies with Civil Engineering Institutes (possible launch of an Geothermal Civil Structures Initiative), building companies (to support large infrastructure geothermal activation projects, e.g. bridges, roads, etc.).

B) Shallow Geothermal Subsection - Resources, new systems & integration Area

Definition The systems, the integration, and the environment area comprise the initiatives and actions discussed within the Geothermal SRP under subchapters 3.4 and 3.5, with specific references to new transversal interest areas, such as the development of high capacity systems or the development of new geo based concepts for cooling in warmer climates.

Keywords Improved reservoir investigation and mapping, improved system modelling and integration, environmental assessment, new systems for cooling applications in hot climates, high capacity applications

Objectives Improving the understanding of the shallow geothermal reservoir as an entity and as a process involves the characterisation of the important parameters (thermal, hydrogeological, environmental) as well as engineering.

State of Play Heat transport in the underground, both conductive and advective, has been studied in shallow geothermal R&D-projects since the 1980s. Suitable design methods and operation strategies are available today, but still not all of the processes are fully understood, and optimisation potential is given. In particular in the field of groundwater quality for open-loop systems the progress is not yet as desired. In respect to environmental impact the long-term consequences in particular need more investigation. The Transient Response Testing Method can be applied to characterise soil thermal properties, but databases and information useful for widespread GSHP design is scarce and very heterogeneous. Furthermore, these methods are not usable for special ground source heat exchanger designs.

Targets Increase of efficiency by at least 25% through better overall system design and operation. Avoid negative effects of shallow geothermal systems to ground and groundwater. General coverage of GIS soil thermal properties databases. Improve awareness of technology.

Type of activity Basic R&D (25 %), applied R&D (75 %)

List of R&D projects under section Geothermal - Subsection Shallow Geothermal

Subsection	R&D programme area acronym	R&D programme area title	Indicative budget*	Classification & TRL's
Ground coupling technologies subsection	GEO S 1	Improved vertical borehole drilling technologies to enhance safety and reduce cost of BHE installations - Improved installation technologies and geometries for ground Heat Exchange technology.	15 mln Euro	Development TRL 6
	GEO S 2	European-wide Geoactive Structures Alliance. Development of a network of laboratories to create 4 testing sites.	30 mln Euro	Research & Development TRL 5
	GEO S 3	Improved pipe materials for borehole heat exchangers (BHE) and horizontal ground loops. New pipes for higher temperatures. Better thermal transfer fluid.	15 mln Euro	Research TRL 3-4
	Total		60 mln Euro	
Systems, integration and environment	GEO S 4	Creation of a new European wide database to map conductivities and potential (to 100 m depth) and feasibility of vertical BHE systems	6 mln Euro	Development TRL 7-8
	GEO S 5	Development of geophysical tools for Shallow reservoir potential estimation – enhanced TRT methods for non-conventional systems.	3 mln Euro	Research & Development TRL 4-5
	GEO S 6	Integration of design of the shallow geothermal system and building energy system with regard to optimum thermal use and operational strategy.	10 mln Euro	Development TRL 7-8
	GEO S 7	System concepts and applications for geothermal large scale and medium scale cooling in warm climates – hybrid systems, new high temp pipe materials and new short term storage materials and concepts. Campaign to support 50 demonstration plants	20 mln Euro	Research & Development TRL 6-7
	GEO S 8	Development of ground coupling technologies and installation techniques for high capacities through hybrid systems and integration with other RES sources. Campaign to support 50 demonstration plants	30 mln Euro	Development TRL 7-8
	GEO S 9	Non-technical provisions: measures to increase awareness, harmonisation of shallow geo-standards, shallow geothermal installer EU wide training certificate, shallow geothermal Smart City deployment policy along the line of previous projects	4 mln Euro	Development TRL 9
	Total		73 mln Euro	
Total Budget			133 mln Euro	

* Indicative budget: this figure represents the amount expected from public funding: horizon2020 and Member States. see details below in the chapter: Financial Instruments (available & required) with Budget overview

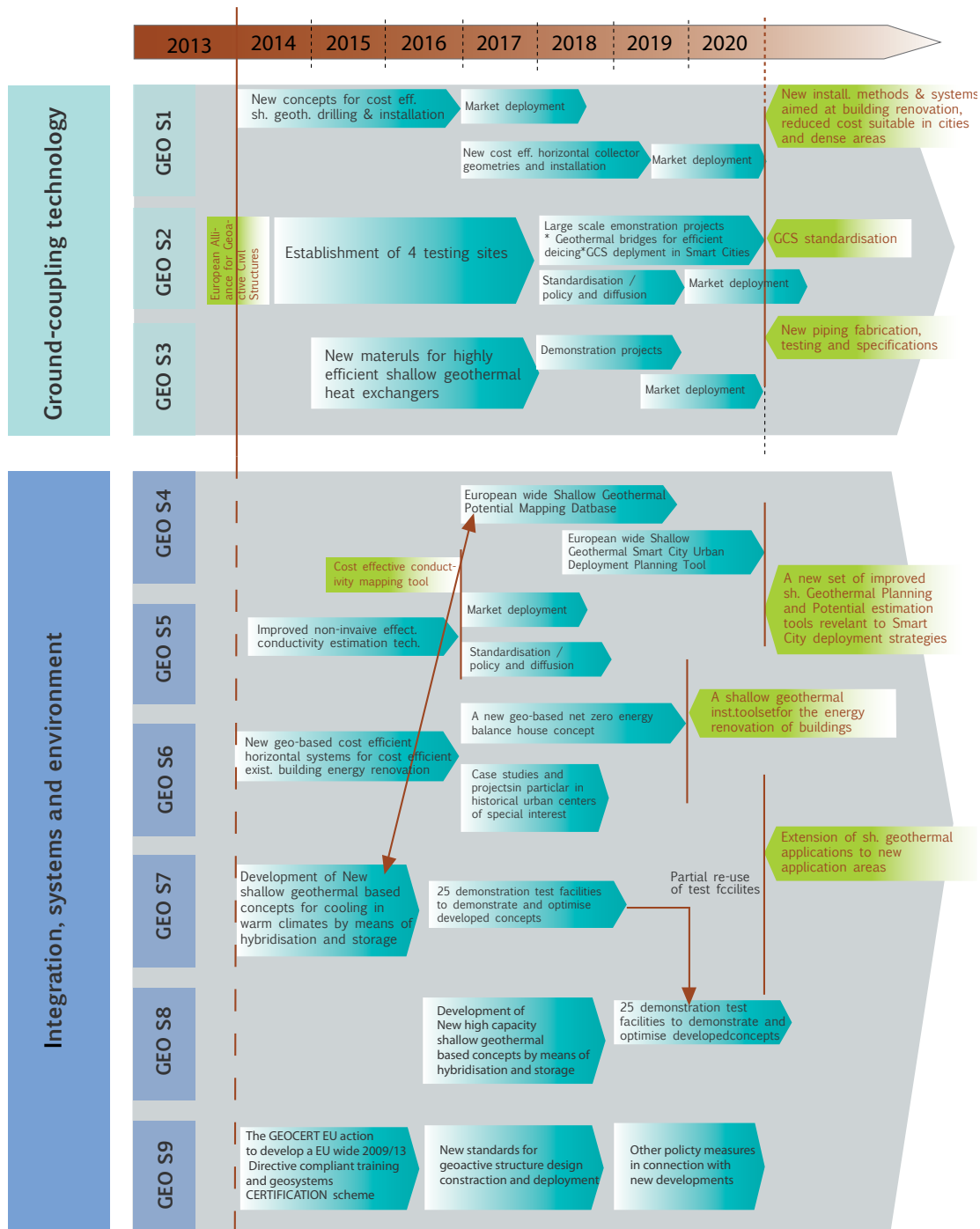


Figure 5: Time line of planned research activities for shallow geothermal 2013-2020

DEEP GEOTHERMAL

A) Deep Geothermal - Resources

Definition The deep geothermal resources area comprises the initiatives and actions discussed within the Geothermal SRP under subchapter 4.2.

Keywords geothermal database, exploration, modelling, reservoir performance

Discussion and scope The two principal goals are to promote basic research and a European drilling campaign. To decrease the cost of exploration, a framework for pre-drilling basic research on geothermal resources and geochemistry, in addition to geophysical campaigns, will be proposed. The aim of the drilling campaign is to further reduce risk, and thereby promote commercial initiatives, by supporting secondary exploration through drilling of characterisation wells in prospective regions based on commercial initiatives. Data will be collected in high-quality public databases.

State of play Geological data is not available everywhere and national databases don't have the same structure. Exploration, modelling and slimhole technologies exist but they are currently too costly.

Targets Reduction of exploration cost by at least 25% in 2020, and 50% in the longer term. Decrease geological risk to 2020 by 25% (expressed by reduced number of abandoned projects due to low temperature or flow).

Type of activity Basic R&D (33%), Applied R&D (67%)

Required partnerships Public (geological surveys, research institutes) / private initiative (drilling companies, specialised engineering and component manufacturing companies), synergies with oil and gas sector.

B) Deep Geothermal Subsection - Drilling

Definition The deep geothermal drilling area comprises the initiatives and actions discussed within the Geothermal SRP under subchapters 4.3.

Keywords novel drilling technologies, improve current drilling, new drilling concepts

Discussion and scope Concerning geothermal drilling activities, the main areas involved are:

- Development of innovative drilling technology for exploration and preliminary reservoir assessment
- Optimisation and development of measurement-while-drilling (MWD) technologies, development of data interpretation methodologies
- Improved drilling for reservoir development and exploitation
- Drilling and installation for deep borehole heat exchangers (BHE) in low-/medium enthalpy, low permeability reservoirs to improve techniques and reduce costs
- New drilling concept: horizontal, multi-well.

State of play More than 50 % of the cost of geothermal plants is associated with drilling of wells

Targets Progress in drilling technology can help reducing the cost by 25 %.

Type of activity Basic R&D (67%), Applied R&D (33%)

Required partnerships Public (geological surveys, research institutes) / private initiative (drilling companies, specialised engineering and component manufacturing companies), synergies with oil and gas actors.

C) Deep Geothermal Subsection - Production

Definition The deep geothermal production area comprises the initiatives and actions discussed within the Geothermal SRP under subchapters 4.4 and 4.5.

Keywords well design-completion-stimulation, reservoir creation and management, stimulation, corrosion & scaling, downhole instrumentation, monitoring and logging, pump technology, surface systems for direct heat uses and CHP

Discussion and scope Sustainable and reliable production of geothermal heat from deep geothermal resources is associated with various challenges, mainly related to the high temperature, high pressure environment, and geothermal fluid composition.

State of play Creating/stimulating and managing the geothermal reservoir is a crucial step, which includes methods for identification of flow paths and maintaining flow rates in different types of geological reservoirs. In both these aspects (creation and operation of the reservoir) advancement of reservoir modelling is crucial, in addition to monitoring tools and sensors. The materials required need to cope with hostile and abrasive reservoir environments and thermo-chemical fluid properties; the goal is to improve equipment reliability and to increase the plant utilisation factor. The target of well stimulation is to boost well, near well and reservoir performance, to remove well and formation damage, and to develop and prop fracture networks. Corrosion and scaling are among the main problems during the operation of deep geothermal plants, jeopardising plant efficiency and longevity. Downhole instrumentation is required for the collection of reliable information on reservoir and fluid properties in actual, often adverse, geothermal environments. Also a wider utilisation of geophysical measurement tools during operation is suggested. During operation, energy demand for pumping can be a burden on overall plant efficiency. Hence there is a need to improve pump efficiency and longevity, to secure production reliability, to develop tools for avoiding two-phase flow in wells, etc., in order to upgrade exploitation economics.

This area covers also energy conversion processes and surface energy chains. It is worth noting that, that in many respects it deals with well-established technologies, several of them being practiced for decades. Nevertheless, there exists a substantial space for improvements in order to meet these vast market demands at competitive costs.

Targets The following priorities must be addressed.

- **cost reductions**
- **optimising the efficiency of the whole chain**
- **risk limitation**

Type of activity Basic R&D (50%), Applied R&D (50%)

Required partnerships Public (geological surveys, research institutes and EERA-JPGE) / private initiative (specialised engineering and component manufacturing companies), synergies with materials & chemical sectors.

D) Deep Geothermal Subsection - EGS Flagship Programme

R&D activities described above could be used for developing EGS combined heat & power plants. An EU flagship programme for EGS should be launched under the Horizon 2020 programme, making it competitive. One objective is to consider also EGS development in an electricity system approach.

Definition The EGS flagship programme comprises the initiatives and actions discussed within the Geothermal SRP under subchapters 4.6.

Keywords EGS, Test laboratories, demonstration plants, upscaling, different geological settings, training & education, public acceptance, flexible generation

Discussion and scope This chapter covers the development and demonstration of energy efficient, environmentally sound and economically viable electricity and heat and cold production from Enhanced Geothermal Systems (EGS) and its integration in a flexible electricity system. Moreover, it covers flanking measures such as training and education of professionals on EGS and ensuring public acceptance.

State of play At each stage of EGS development, proven methodologies can be applied and bottlenecks identified. From this state of play assessment, priorities encompassing five main areas have been defined for medium to long term research. The expected outcome will be geothermal energy in a form that can be widely deployed and competitively priced, underpinned with reduced capital, operational and maintenance costs. Swift progress (and continuous improvement) will be pooled with coordinated international R&D efforts, with a view to successful demonstration and implementation.

Targets Reduction of capital cost by at least 25% in 2020, and 50% in the longer term. Reduction of production costs below 120 €/kWh by 2020, in increasing of conversion efficiency to 2020 by 25%, allowing for either higher efficiency (for production, turbine etc.).

Type of activity Basic R&D (25%), Applied R&D (75%)

Required partnerships Public / private initiative, synergies with the oil and gas sector. Test laboratories and demo sites in cooperation with EERA-JPGE and GEIE Soultz

List of R&D projects under section Geothermal - Subsection Deep Geothermal

Subsection	R&D programme area acronym	R&D programme area title	Indicative budget*	Classification & TRL's
DEEP GEOTHERMAL RESOURCES	GEO D 1	Create a European Geothermal resource database.	25 mln Euro	Development TRL 5-6
	GEO D 2	Exploration technologies (geochemical and geophysical exploration campaigns), characterisation and assessment of geothermal reservoirs	40 mln Euro	Research TRL 3-4
	GEO D 3	European campaign of slimholes: new technologies & drilling campaign	10 mln Euro	Development TRL 6
	Total		75 mln Euro	

DEEP GEOTHERMAL DRILLING	GEO D 4	Improve current drilling technologies	20 mln Euro	Development TRL 5
	GEO D 5	Develop novel drilling technologies by 2020: in laboratories (by 2015), on site (by 2017), on a demonstration plant (by 2020)	15+25+40 = 80 mln Euro	Research TRL 3
	GEO D 6	New drilling concept: horizontal, multi-wells, closed loop systems	15 mln Euro	Research TRL 3-4
	Total		115 mln Euro	

DEEP GEOTHERMAL PRODUCTION	GEO D 7	Reservoir engineering: Well design & completion, reservoir stimulation and management.	20 mln Euro	Research TRL 3-7
	GEO D 8	New Materials: corrosion, scaling	15 mln Euro	Research TRL 2-3
	GEO D 9	HT/HP tools, high temperature production pump	25 mln Euro	Development TRL 5-6
	GEO D 10	Surface systems equipment: low temperature systems, heat pumps, turbines, cooling generation (via heat absorption)	20 mln Euro	Development TRL 6-7
Total			80 mln Euro	

EGS FLAGSHIP PROGRAMME	GEO D 11	Establish network of complementary 5-10 European EGS test laboratories.	15 mln Euro	Development TRL 6
	GEO D 12	Demonstration sites in different geological settings (3 plants of 5 MWe-10MWth), and upscale (1 plant=10 MWe-20MWth & 1 plant=20 MWe-40MWth).	105 + 70 + 130 = 305 mln Euro	Research & Development TRL 3-4
	GEO D 13	Training and education of new geothermal professionals specialized in EGS.	2 mln Euro	Development TRL 6
	GEO D 14	Public acceptance: microseismicity, stimulation, environmental impact, emissions	5 mln Euro	Development TRL 6
	GEO D 15	Grid flexibility: Flexible and base load electricity production from EGS plants, test on dispatchability, design regional flexible electricity system.	10 mln Euro	Development TRL 3-6
Total			337 mln Euro	
Total budget deep geothermal			607 mln Euro	

* Indicative budget: this figure represents the amount expected from public funding: Horizon2020 and Member States. See details below in chapter Financial Instruments (available & required) with Budget overview

TOTAL GEOTHERMAL INDICATIVE BUDGET = 740 Mln Euro

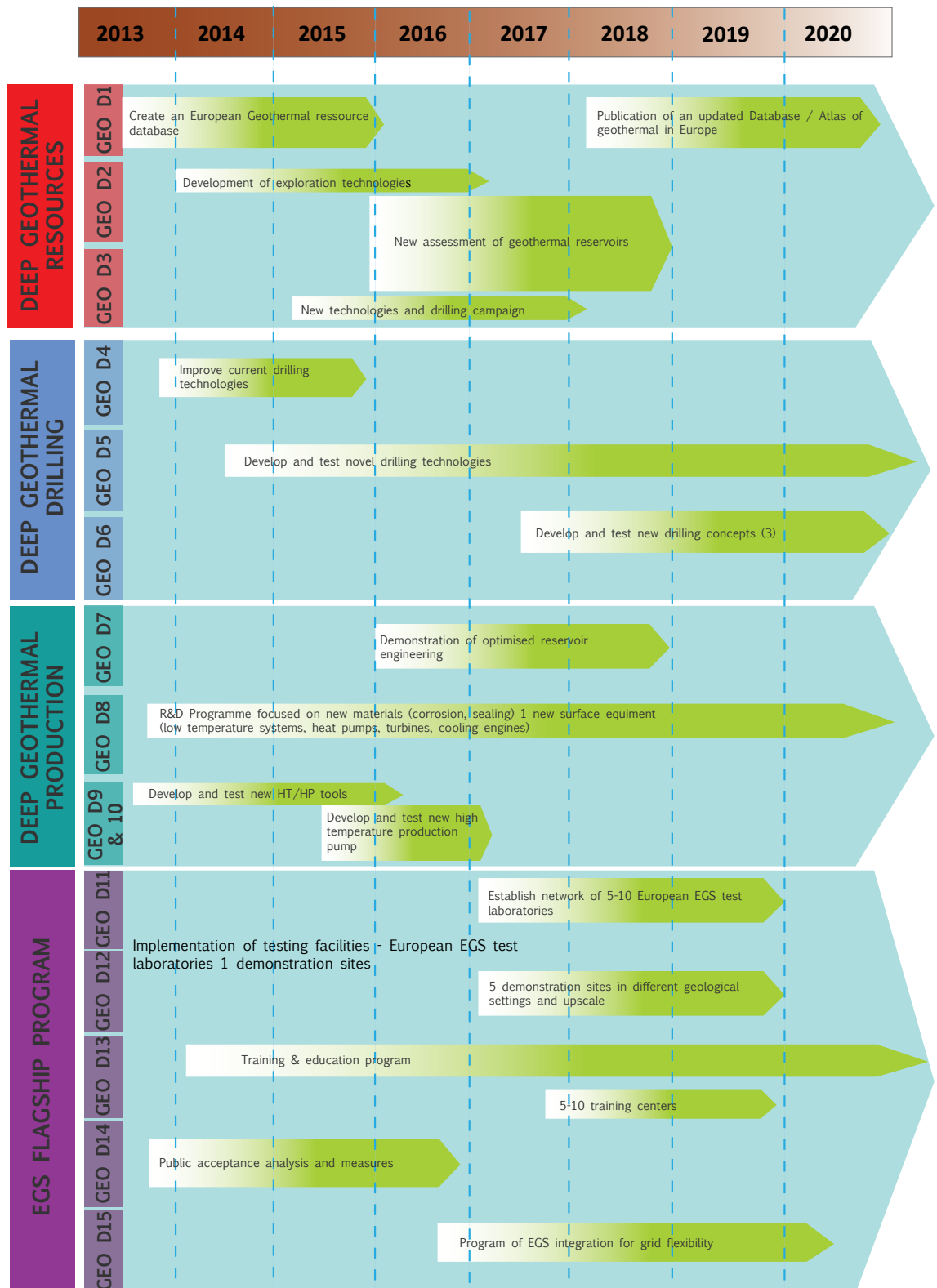


Figure 6: Time line of planned research activities for deep geothermal 2013-2020

4

Financing



4 FINANCING

REQUIRED PARTNERSHIPS

For implementing this Geothermal Roadmap, several partnerships are necessary.

On deep geothermal, a cooperation between the Geothermal Panel and:

- EERA-JPGE representing the geothermal department of the public research centres. All the topics of interest for a cooperation between the industry and the scientists are:
 - Exploration technologies (geochemical and geophysical exploration campaigns), characterisation and assessment of geothermal reservoirs,
 - Reservoir engineering: Well design & completion, reservoir stimulation and management,
 - The launch of an EGS flagship programme: the establishment of a network of 5-10 complementary European EGS test laboratories. Demonstration sites in different geological settings (3 plants of 5 MWe-10MWth + GEIE Soultz), and upscale (1 plant=10 MWe-20MWth & 1 plant=20 MWe-40MWth). Training and education of new geothermal professionals specialised in EGS.
- ERANET-geothermal: the consortium of funding agencies working together on coordinate geothermal R&D support programmes, supported by FP7. Cooperation between the geothermal Panel and ERANET-geothermal could concern the creation of a European Geothermal resource database (Activity coordinated by ERANET).
- The National and international Deep Drilling Programmes: Common areas of interest are to Improve current drilling technologies and to develop a new drilling concept: horizontal, multi-wells, closed loop systems

On Shallow geothermal, the main cooperation will be with:

- The Heat Pump sector
 - Development of alternative (low cost) controls for currently available high efficiency (A, A++ etc.) circulation pumps, which will control on either delta-T, or flow rate. These are for use on domestic sized GSHP ground loops to minimise parasitic energy consumption. Most pumps currently on offer control pressure, which is the opposite of what is required for ground loop pumps
 - Development of low impact, low cost, reliable COP and SPF monitoring devices for domestic GSHP systems. This Relies on the availability of low pressure drop flow meters sized for heat pump flow rates and heat pump delta-T's. It is ultimately for connection to SMART meters etc. Most heat meters that are currently available in the market place have been designed on the basis of low (specific) flow rate, high temperature, high delta-T boiler systems
 - Investigation of the impact on the electricity supply network of the adoption of large numbers of domestic GSHPs, particularly in those countries with single phase domestic electricity supplies. Loading impact, harmonics impact, interference issues etc.
- Other actors active on cross-cutting topics for shallow geothermal plants
 - Investigation of the role/benefit of variable speed compressors for domestic GSHP systems. Particularly for countries with single phase domestic electricity supplies.
 - Investigation of methods for reducing peak electricity demands during periods of lowest external temperatures, e.g. thermal storage / PCM / multi or variable speed compressor etc. To reduce impact on electricity grid at periods of high heat pump demand when heat pumps are installed in significant numbers in a locality/region/country.

Political framework

Key EU Legislation for Geothermal Energy

- Directive 2009/28/EC on the promotion of the use of energy from renewable sources
- Recast Directive 2010/31/EU on energy performance of buildings
- Directive 2012/27/EU on energy efficiency
- Recast Directive 2009/125/EC establishing a framework for the setting of Ecodesign requirements for energy-related products
- Recast Directive 2010/30/EC on the indication by labelling and standard product information of the consumption of energy and other resources by energy-related products
- Directive 2000/60/EC establishing a framework for Community action in the field of water policy
- Directive 2006/118/EC on the protection of groundwater against pollution and deterioration

Date	Provision
By 9 th July 2012	Member states to transpose the 2010 version of the Energy Performance of Buildings Directive repealing an older version of 2002
As of March 2013	Commission issues guidelines on how to calculate renewable energy from heat pumps
As of 2014	Member States to renovate each year an average 3% of the public building stock owned by central governments (EED)
As of 2015	Member states to introduce, where appropriate, measures to set the minimum levels of RES which should be used in buildings (RES Directive)
2015	Energy label for brine-to-water heat pumps A++ to G introduced (to be substituted with a new label ranging from A+++ to D in 2019)
31 st December 2018	All new buildings owned or occupied by public authorities shall be nearly zero-energy buildings (EPBD)
31 st December 2020	All new private buildings shall be nearly zero-energy buildings (EPBD)

Figure 7: Timeline for the implementation of relevant EU legislation for geothermal energy

Financial Instruments (available & required) with Budget overview

Main budgetary items, Procedure and assumptions

The Geothermal Roadmap will be implemented with various resources, depending on the nature of the research and innovation priorities and the specific needs of the technologies. Several mechanisms for supporting investments in 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 development, demonstration, deployment, and commercial market uptake. During these phases public funding for the continuing industry-led research, development and deployment, is needed. Recent European Commission documents point out how crucial it is to invest in new renewable technologies and to improve existing ones

through RD&D. Member States have spent 4.5bn Euro on renewable energy R&D over the last 10 years with the EU spending 1.7bn Euro from the Sixth (FP6) and Seventh Framework Programme (FP7), and the European Energy Programme for Recovery (EERP). However, as Figure 8 overleaf clearly shows, the allocation of these funds between different technologies across the energy sector was all but fair.

FP6 - FP7 - non-nuclear energy spending by sector (%)

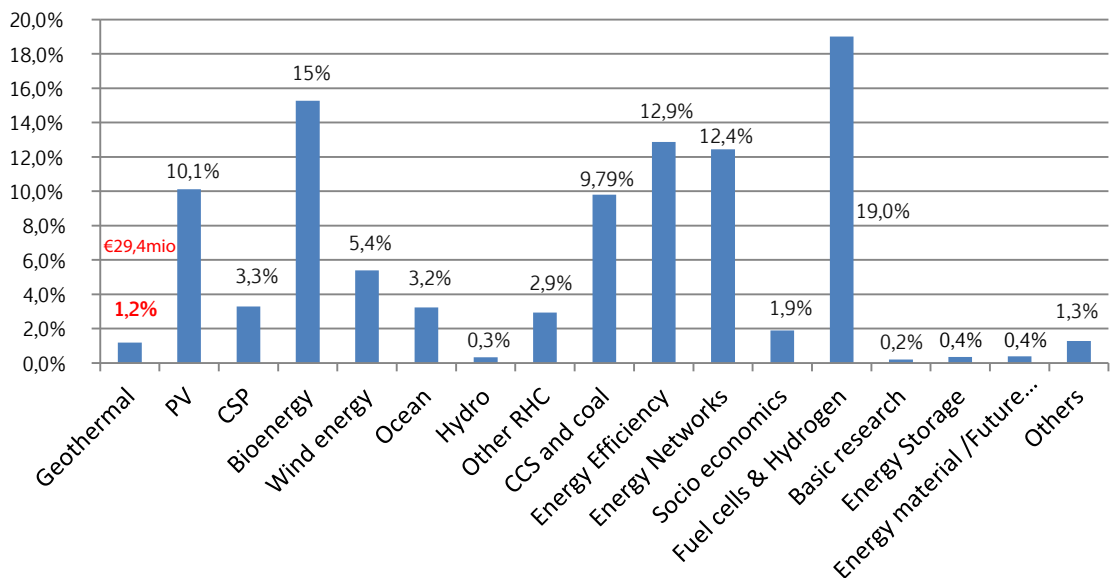


Figure 8: EU R&D funding allocated to energy technologies during the FP6 and FP7

There are three complementary routes considered to leverage resources required for the implementation:

Public funding for R&D at EU level

As a matter of fact, EU R&D funding allocated to geothermal energy during the FP6 and FP7 until March 2012 amounts to 29.4m Euro. This is indeed negligible if compared to what was allocated to other technologies. The EERP is a 4bn Euro programme set up in 2009 to co-finance 59 projects designed to make energy supplies more reliable and help reduce greenhouse emissions, while simultaneously boosting Europe's economic recovery. However, no geothermal projects have been financed as this programme exclusively funded 44 gas and electricity infrastructure projects, 9 offshore wind projects and 6 carbon capture and storage projects.

Another financing instrument in existence at EU level is the NER300 programme, so-called 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 for subsidising installations of innovative renewable energy technology and carbon capture and storage (CCS). In December 2012, the European Commission awarded NER300 funds to the Geothermal South Hungarian Enhanced Geothermal System (EGS) Demonstration Project. The Hungarian project is one of the 23 innovative renewable energy technology projects funded according to the outcome of the first call for proposals under the NER300 programme. A second was been launched in 2013.

'Horizon 2020' – the new EU funding programme for research and innovation – enters into force from the 1st January 2014. Geothermal should receive more attention from the very start of the H2020 programme as substantially higher RD&D funds are needed in order to become more competitive. If the EU does not devote significant and sufficient funding to geothermal research and innovation, it risks losing its technology lead in the sector, notably on Geothermal DH, EGS and GSHP.

The implementation of the geothermal-SRA will require a yearly investment of approximately 100 mln Euro of EU resources, totalling 740 mln Euro by 2020.

Public funding for R&D at MS level

It is crucial that research resources are also mobilised across Europe. R&D support from member States must be coordinated at European and national level. Initiatives like ERANET-geothermal should allow the establishment of this coordination. As mentioned above, geothermal R&D spending shows major variations among Member States, but some research priorities are common in some technologies among groups of countries. Synergies should be exploited in these areas, which is of particular importance for capital-intensive R&D activities.

EU R&D funding from Member States allocated to geothermal energy during the period 2000-2010 amounts to around 210mln Euro, so a yearly amount of 21mln Euro.

For the implementation of the geothermal-SRA, Member States must progressively increase national R&D funding for geothermal, with the aim of quadrupling the overall effort by 2020: 588 mln Euro for the period 2014-2020.

Country specific budgets for geothermal RD&D as reported to the IEA

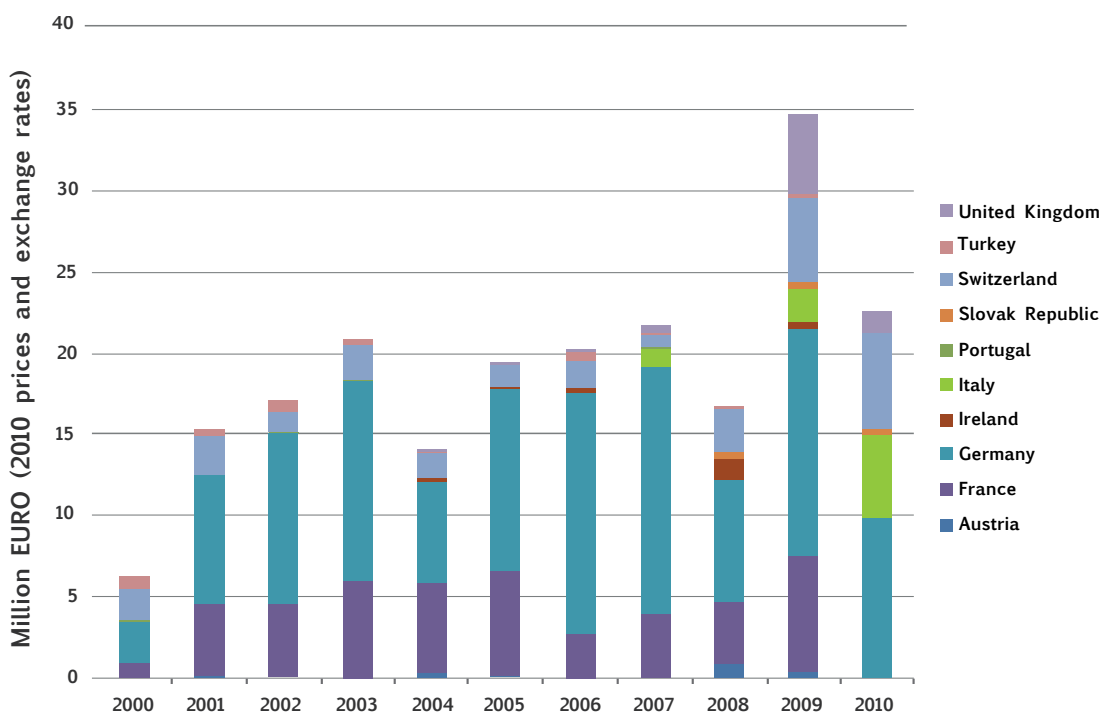


Figure 9: EU R&D funding allocated to energy technologies during the FP6 and FP7

Investments by the private sector

The heterogeneity in R&D efforts among EU Member States also holds true for the R&D expenditures of the industries in the geothermal sector. The scale of technologies involved is so extended and the related value chain so complex that it is not possible to identify all private investments at the different stages of geothermal innovation processes.

The approach adopted was therefore to estimate the R&D commitments by industry to 2020, using as basis for this calculation those resources dedicated on annual basis to R&D. According to our estimation, the total turnover of the geothermal industries in the EU was 41.2 billion Euro for 2011. Nearly all private R&D investments are actually conducted by the material and equipment manufacturers, therefore the turnover generated by sales of services (e.g. installation, planning, maintenance) is excluded in the following calculations. The ratio of R&D expenditure to net sales varies significantly, however for most companies this is in the range from 1% to 3%. The table below illustrates the total investments expected of the private sector between 2014 and 2020, calculated as a proportion of the net sales of the component industries:

	Geothermal
Total installed capacity:	
H&C (MWth, year 2020)	50000
Electricity (MWe, year 2020)	1600
Investment costs	
H&C (€/MWth, year 2012)	0.5 - 1.8
Electricity (€/MWe, year 2012)	3 - 12
Annual capital costs reduction	2-10%
Turnover of the entire sector, including services (Mln Euro period 2014-2020)	41808
Share of manufacturing industry on sector turnover	40%
Turnover manufacturing industry (Mln Euro period 2014-2020)	16651
Share of R&D on turnover of manufacturing industry only	2 % (5% for EGS)
R&D investments of manufacturing industry (Mln Euro period 2014-2020)	Ca. 400

For the implementation of the geothermal-SRA, The industry must spend around 400 mln Euro for the period 2014-2020 in R&D funding for geothermal.

The R&D work should be accompanied by strong educational/training activities and solve non-technical issues, like quality certification, guidelines, regulation, infrastructure, etc. This will need extra financing.

The geothermal industry is currently suffering a shortage of geothermal scientists and engineers, so it is very important that emphasis be placed on providing specific geothermal education at the higher under-graduate and graduate levels as well as training for technical staff, if the Strategy being proposed here is to be successful.

Budget overview

From this analysis it is clear that geothermal is, amongst those technologies experiencing technological progress, the one receiving the smallest amount of financial support despite all the advantages it provides to the energy system (renewable base-load, 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 with low-temperature systems, and EGS will become competitive within a few more years if substantial research, development and demonstration (RD&D) resources are allocated to those technologies. Likewise, geothermal HP also need RD&D funding to further improve the efficiency of the systems and to decrease installation and operational costs.

In order to pursue the EU objective of decarbonising the heating and cooling sector, there is a clear need for more resources being invested by the European Union and by the Member States. The geothermal panel estimates that 1,140 mln Euro are required for the successful implementation of this Geothermal Strategic Research Agenda.

The figure below illustrates the proposal for the resources expected to be committed respectively by the European industry (33%), European Commission (33%) and Member States (33%). Over the period 2014 - 2020, on average 163 mln Euro should be allocated annually to geothermal research and innovation activities.

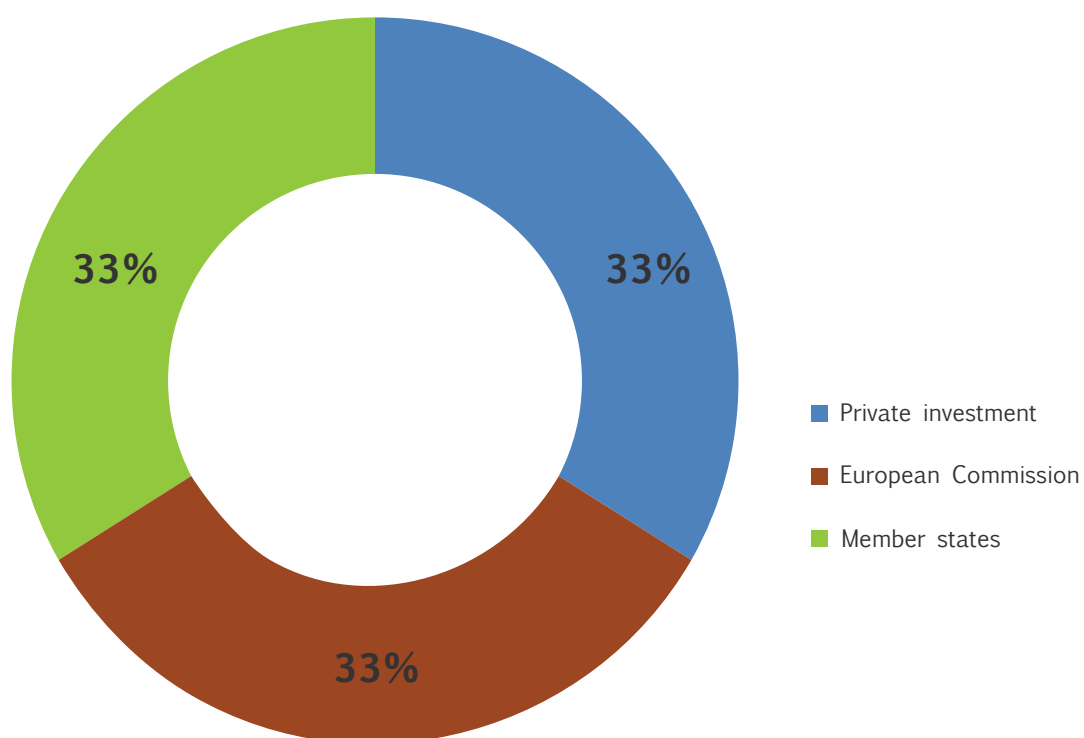


Figure 10: Estimation of total resources required to implement the geothermal SRA between 2014 and 2020, in million Euro and in %.

The total amount of R&D money spent by industry within Horizon 2020 (2014-2020):	Around 400 Mln EUR
The same value is expected from public support (national and EU)	Around 740 Mln Euro from Horizon2020 and from Member States
Total R&D investment needed between 2014 and 2020:	1140 Mln EUR

APPENDIX I

SCALE OF TECHNOLOGY READINESS LEVELS (TRL) ADOPTED BY THE RHC-PLATFORM²

TRL 1: Basic principles observed

The initial scientific research has been completed. The basic principles of the idea have been qualitatively postulated and observed. The process outlines have been identified. No experimental proof and detailed analysis are yet available.

TRL 2: Technology concept formulated

The technology concept, its application and its implementation have been formulated. The development roadmap is outlined. Studies and small experiments provide a "proof of concept" for the technology concepts.

TRL 3: Experimental proof of concept

The first laboratory experiments have been completed. The concept and the processes have been proven at laboratory scale, table-top experiments.

TRL 4: Technology validated in lab

A small scale prototype development unit has been built in a laboratory and controlled environment. Operations have provided data to identify potential up scaling and operational issues. Measurements validate analytical predictions of the separate elements of the technology. Simulation of the processes has been validated.

TRL 5: Technology validated in relevant environment (industrially relevant environment in the case of key enabling technologies)

The technology, a large scale prototype development unit, has been qualified through testing in intended environment, simulated or actual. The new hardware is ready for first use. Process modelling (technical and economic) is refined. LCA and economy assessment models have been validated. Where it is relevant for further up scaling the following issues have been identified: health & safety, environmental constraints, regulation, and resources availability.

TRL 6: Technology demonstrated in relevant environment (industrially relevant environment in the case of key enabling technologies)

The components and the process, the prototype system, have been up scaled to prove the industrial potential and its integration within the energy system. Hardware has been modified and up scaled. Most of the issues identified earlier have been resolved. Full commercial scale system has been identified and modelled. LCA and economic assessments have been refined.

TRL 7: System prototype demonstration in operational environment

The technology has been proven to work and operate a pre-commercial scale – a demonstration system. Final operational and manufacturing issues have been identified. Minor technology issues have been solved. LCA and economic assessments have been refined.

TRL 8: System complete and qualified

The technology has been proven to work at a commercial level through a full scale application. All operational and manufacturing issues have been solved.

TRL 9: Actual system proven in operational environment (competitive manufacturing in the case of key enabling technologies; or in space)

The technology has been fully developed and is commercially available for any consumers.

² The present scale of Technology readiness levels (TRL) is based on HORIZON 2020 – WORK PROGRAMME 2014-2015, General Annexes, G. Technology readiness levels (TRL), available at http://ec.europa.eu/research/participants/data/ref/h2020/wp/2014_2015/annexes/h2020-wp1415-annex-g-tr_en.pdf. The description of the TRLs is based on the related FAQs, available at http://ec.europa.eu/research/participants/portal/doc/call/h2020/h2020-lce-2014-1/1595100-faq_1_lce_call_en.pdf. Both webpages were accessed early March 2014.

APPENDIX II

GLOSSARY

BHE: Borehole Heat Exchangers

CHP: Combined Heat and Power

DH: District Heating

EGS: Enhanced Geothermal Systems

Giga-Watts thermal: GW_{th}

H&C: Heating and Cooling

KPI: Key Performance Indicators

MWD: Measurement-While-Drilling

Mega tonnes oil equivalent : (Mtoe)

Mega-Watts thermal: MW_{th}

Storage Terawatts hour: TWh

UTES: Underground Thermal Energy

APPENDIX III

SECRETARIAT OF THE RHC-PLATFORM

This document was prepared by the **Geothermal Panel of the European Technology Platform on Renewable Heating and Cooling (RHC-Platform)**, managed by the European Geothermal Energy Council



The Secretariat of the European Technology Platform on Renewable Heating and Cooling is coordinated by the Association of European Renewable Energy Research Centres (EUREC) and jointly managed with:

European Geothermal Energy Council (EGEC)

European Solar Thermal Industry Federation (ESTIF)

European Biomass Association (AEBIOM)

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