Strategic Research Priorities for Geothermal Technology

European Technology Platform on Renewable Heating and Cooling

RHC Renewable Heating & Cooling
European Technology Platform

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1. Introduction
Geothermal Energy

1. Introduction to Geothermal Energy

Per definition, Geothermal Energy is the energy stored in the form of heat beneath the earth's surface. This energy can be found at different temperatures in the ground and the ground water, depending on local geology and depth.

With geothermal energy for heating and cooling, two main resource types are distinguished:

- The first one (very low temperature in the range of the annual mean air temperature on site, up to about 30 °C) is based on the relatively stable groundwater and ground temperatures at shallow depth (the limit is typically set at 400 m). Typically, heat pumps are used to extract energy from the ground and raise the temperature to the level required by the heating systems.

- The second one (low and medium temperature, ranging from 30 °C to over 100 °C) extracts the heat from ground and groundwater at higher temperature, and typically at greater depth.

A third category, high temperature (high enthalpy) resources of well over 100 °C to some >300 °C, is primarily used for electric power generation. However, residual heat from such applications can still provide energy for heating, and some high-temperature industrial processes could be supplied directly with heat from this type of resource.

Concerning the application side, a distinction can be made between systems using additional energy and devices to match the temperature requirements, and those using the geothermal heat directly:

- If the geothermal heat is at a level of temperature lower than the temperature required by the heating system, further system components are installed:

    - Heat pumps can be used to raise the temperature to the required level (ground source heat pumps, GSHP). In this case ground and ground water might also be used for cooling; directly in cases with the right boundary conditions, or by using a heat pump as cooling machine if lower temperatures are required

    - The ground could also be used for heat or cold storage, UTES (Underground Thermal Energy Storage), e.g. for combined heating and cooling in commercial and institutional buildings

- If the geothermal heat is at a level of temperature compatible with the temperature required by the heating system, the energy from the ground or the ground water can be used directly (without any thermodynamic device). Direct applications are found in:

    - district heating or combined heat and power installations
    - agriculture (horticulture, aquaculture, drying)
    - industrial processes
    - balneology
    - absorption heat pumps for cooling purposes

Also in the low to medium temperature range UTES is an option, making use of available surplus heat from building cooling or from heat and power cogeneration, or of renewable heat as from geothermal or solar thermal sources.

On a world-wide scale, the earth continuously emits about 12 TW of heat from the land surface alone. For all Europe, the geothermal heat flux, transporting heat from beneath into underground layers in accessible depth, can be assessed to a total of 814 GW. This amounts to 7100 TWh or 610 Mtoe annually for Europe, of which 260 Mtoe per year are produced under the surface of the EU 27. And in the shallow underground, this amount of heat is complemented by solar irradiation and infiltrating surface water.

Hence the potential of geothermal energy in Europe is huge. Shallow geothermal energy can be used virtually everywhere, mainly in the form of ground source heat pumps (GSHP). At present, deep geothermal technology is deployable in a number of areas already, and EGS technology, successfully demonstrated meanwhile, can open other regions for deep geothermal use. The extent of the deployment is therefore limited only by the demand for heat. By 2050, a value in excess of 150 Mtoe of heat production is deemed possible (45% of heat demand under the RDP scenario).

2. Geothermal heating and cooling – Vision 2020-2030

2. Geothermal heating and cooling – Vision 2020-2030

2.1 Market evolution

2.1.1 Trends

Regarding the 1997 White Paper objectives (COM, 1997) outlined for 2010, unlike the other renewable energy sectors, geothermal heat exceeded three times the projected installed capacity of 5 GWth, achieving more than 15 GWth in the EU. From this number, almost 13 GWth are from shallow geothermal systems, and close to 3 GWth from deep geothermal plants. The distribution in the member states is quite different, with Sweden, Germany and France leading in shallow geothermal (GSHP), and Italy leading in geothermal district heating (Fig. 2). In Hungary, the widest variety of applications can be found, with a good share of agricultural and balneological applications. Outside EU 27, the largest users of geothermal district heating are Iceland and Turkey, while Switzerland and Norway take the lead in GSHP (Fig. 3). Since 2006, a number of about 100'000 new GSHP has been installed each year in the EU (Fig. 4).

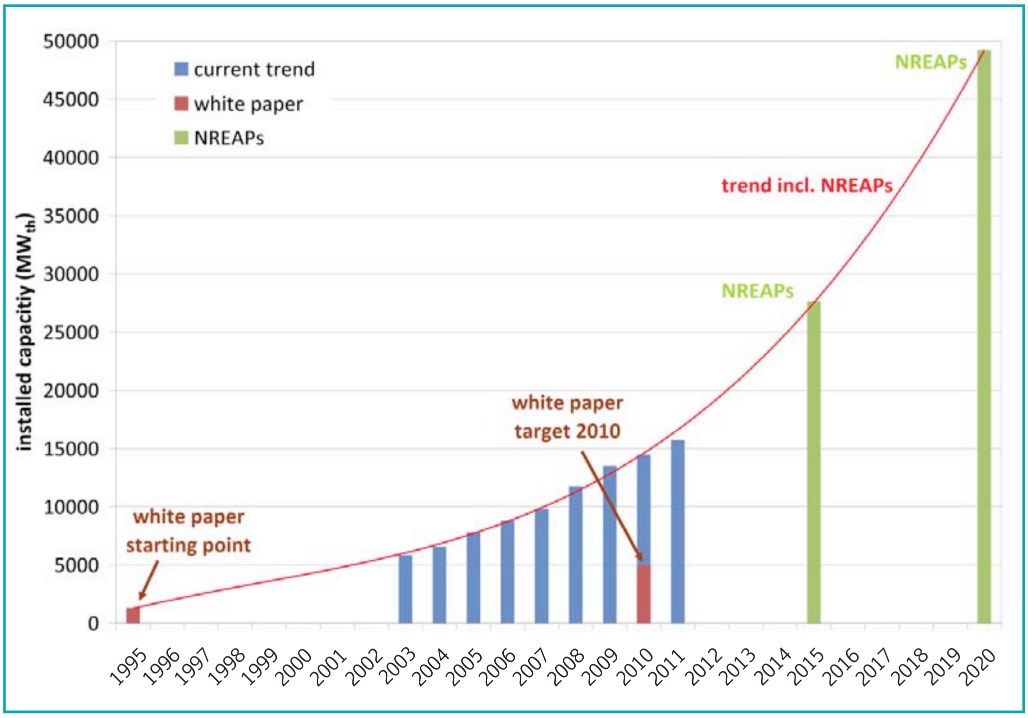

Figure 1 – Development of installed capacity in geothermal heating & cooling in the EU (MWth)

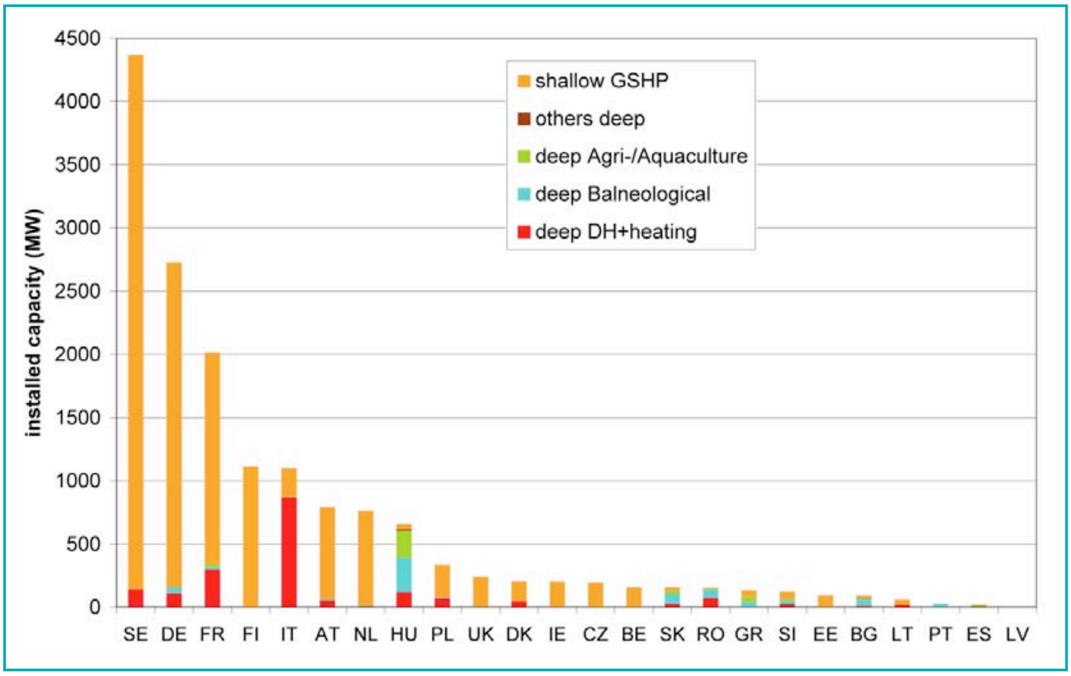

Figure 2 – Distribution of installed capacity (MWth) in EU 27 member states (after data from WGC, 2010; EurObservER, 2011; EGEC, 2011)

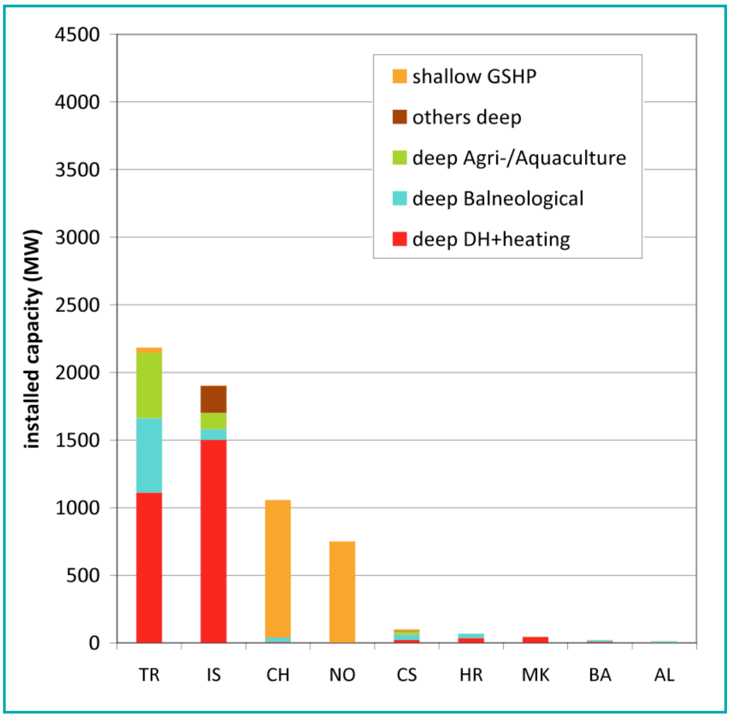

Figure 3 – Distribution of installed capacity (MWth) in some non-EU countries (after data from WGC, 2010)

• Geothermal heat pumps

There are different types of geothermal heat pumps for heating and cooling applications, distinguished by their method of coupling to the ground:

- Closed systems
  - Borehole heat exchangers (BHE), also known as vertical loops
  - Horizontal ground collectors, also known as horizontal loops
  - Foundation integrated systems (e.g. energy piles)
  - Direct expansion in horizontal or vertical loops

- Open systems
  - Groundwater wells (typically as doublet)
  - Water from tunnels or mines

The current industry standard is the geothermal heat pump installations with vertical borehole heat exchanger (vertical loop). A number of mostly small residential applications use horizontal collectors, while open systems typically are applied for larger installations.

Among the different geothermal sectors, the geothermal heat pump industry is currently the most mature. Ground source heat pumps have been experiencing a rapid growth and are established on the market without the requirement of subsidies in several countries. In the past years, the formerly very dynamic market showed some saturation on a level just above 100'000 units a year in EU 27 (Fig. 4). One reason is the mature market situation in the country with the largest number of GSHP, in Sweden; other reasons are the economic crisis after 2008 (cf. Fig. 4), and regulatory barriers in some countries. Some increasing momentum for the market can be seen recently in the Mediterranean countries, with an emphasis more on cooling than on heating. The development of installed heating capacity can be seen in Fig. 5.

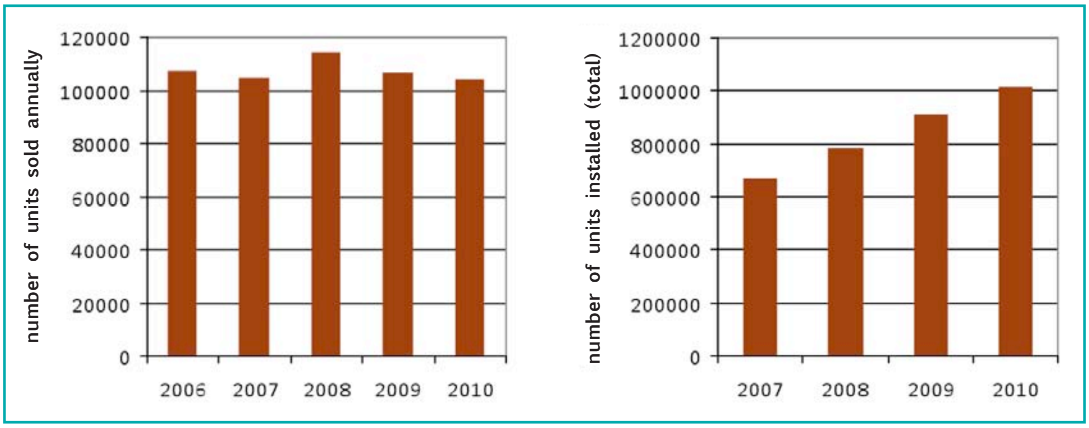

Figure 4 – Annual amount of geothermal heat pump installations (left) and total number of geothermal heat pumps installed in the EU 27 (right), after data from EurObservER, 2011[1]

[1] only heat pumps <50 kW heating output are counted in EurObservER

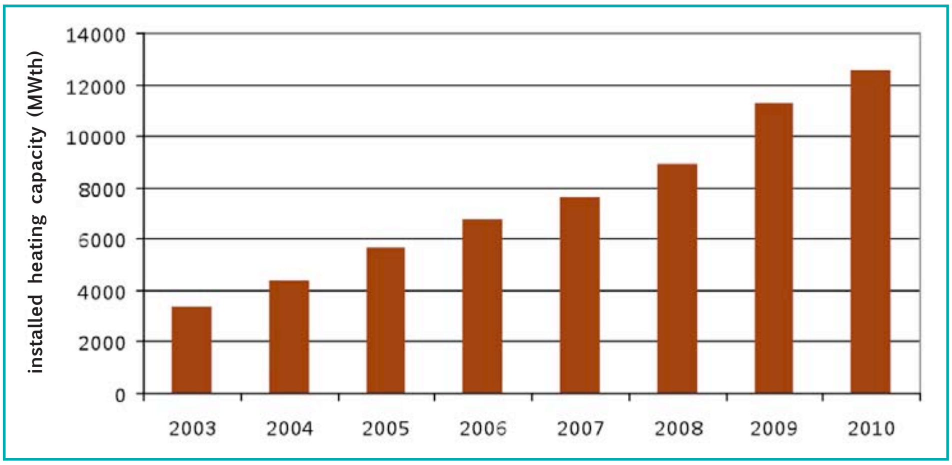

Figure 5 – Development of installed heating capacity of geothermal heat pumps installed in the EU 27 (after data from EurObservER, 2011[1] and older, where only heat pumps <50 kW heating output are counted)

- **Direct use**

Installations for direct use of geothermal heat are widely spread in Europe, including district heating, agricultural uses, balneology (spa), etc. A number of 212 geothermal district heating systems was operational in Europe in 2011, with an installed capacity of almost 1,7 GWth (Fig. 6). They represent the main part of the geothermal direct uses.

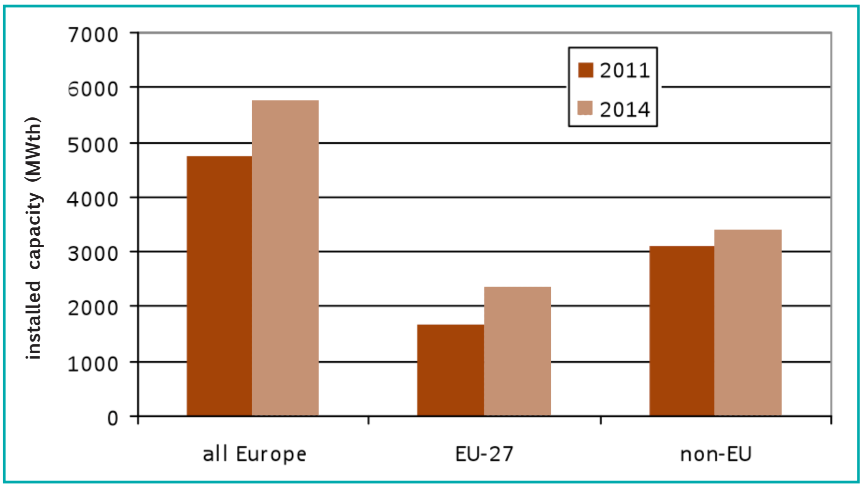

Figure 6 – Installed capacity for geothermal district heating (direct use) in Europe; the numbers for 2014 are the minimum extrapolation, based on already known capacities, as more plants are under construction without such data (after data from EGEC, 2011)
NB: This is not the total for deep geothermal, as there are other applications (e.g. spas) not covered in the figure.

[2] only heat pumps <50 kW heating output are counted in EurObservER

In the European Union, low and medium enthalpy geothermal energy is used directly in 18 countries out of 27 (cf. Fig. 2). In recent year, many new operations have been launched in traditional regions like the Paris Basin and the Munich area, and in new areas like Madrid or Newcastle. Heat from combined heat & power installations today represents only a small percentage, as the first few low temperature power plants are successfully implemented, and EGS systems are currently just being demonstrated.

2.1.2 Deployment towards 2030: a technological perspective

There is no principle geographical restriction for the production of geothermal energy, geothermal heating and cooling supply can match the H&C demand anywhere because the resource is available everywhere:

• On the one hand, geothermal heat pumps can use the temperature at shallow depth without any geographical restriction.

• On the other hand, higher temperatures are available at greater depth everywhere, which constitutes a resource for direct use. Production from this resource is restricted by the investment and operating cost required to drill to this depth, and the availability of the technology for retrieving this heat. Deep geothermal energy is economically favourable today in regions with good geological conditions (permeable layers with hot water at easily accessible depth, cf. Fig. 7), while for other regions (low permeability, low geothermal gradient) just the technical feasibility is given yet.

At present, geothermal energy is used for heating (and cooling) of individual buildings, including both small (5-30 kW, mainly residential), medium (30-500 kW, mainly commercial) and large schemes (> 500 kW), as well as for district heating. The range of users comprises residential houses, offices, shops, health care, schools, universities, museums, as well as commercial, institutional, religious buildings, and even some parliaments! Direct use of geothermal energy also supplies heat to greenhouses, aquaculture, agricultural and industrial processes, etc., and of course to numerous spas and swimming pools. A number of new and innovative applications of geothermal energy have been developed, and some of those have already been demonstrated, such as absorption cooling, melting snow or ice, and sea water desalination.

Existing housing infrastructure represents an overwhelming share of the low temperature energy demand that can be logically supplied by geothermal heat pumps and geothermal district heating systems. Geothermal district heating will be increasingly targeted at existing buildings and old inner cities rather than new housing developments. Current benchmark studies indicate that direct use geothermal energy and district heating grids are probably the most effective option for this market, both in terms of carbon footprint and economics. However, these developments are intrinsically fairly complex, replacing existing fossil energy based infrastructure, and therefore require longer development times.

The key challenge for the widespread use of geothermal heat will be the ability to reliably design, engineer and control both geothermal district heating and ground source heat pump installations, in order to be able to use the year-round potential of geothermal energy for sustainable heat and cold supply.

The presentation of a vision regarding the deployment of geothermal heating and cooling by 2030 is focused on describing the actions and cost reductions that will allow the evolution of the current 'hunter-gatherer' economy of geothermal energy to a systematic and organized exploitation of geothermal resources. The key steps for this evolution are indicated below and discussed for both shallow and deep geothermal sources, in relation to 4 key aspects:

- Challenge
- Impact
- Time frame
- Critical assumptions

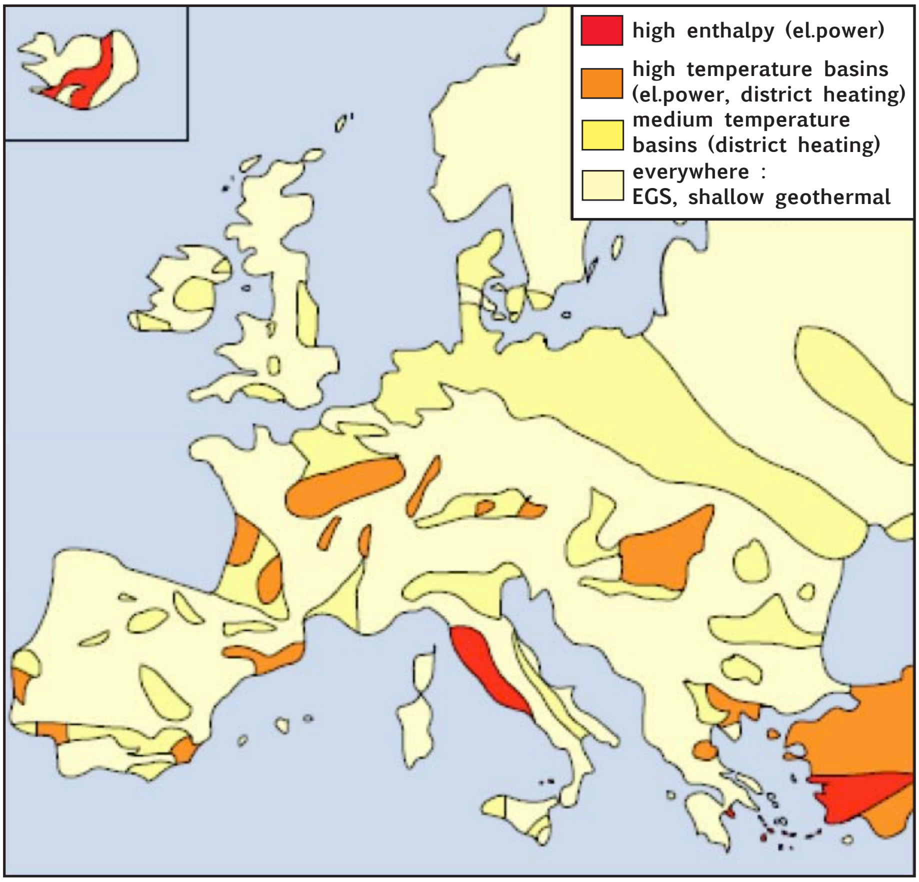

Figure 7 – Favourable areas for deep geothermal resources in Europe

2.1.3 Shallow geothermal resources

- **Integration of geothermal energy in standard housing energy systems**

Such a step necessitates the increased penetration of geothermal heat pumps into the market for new residential and commercial buildings. The time span which this implies is a linear increase in the market share from 2012-2020, and during the period 2020-2030 it is foreseen that a constant 10% of the market will have been gained. This advancement is dependent on renewable energies (RES) becoming standard in new energy efficient buildings in all countries.

- **Develop Heating & Cooling networks integrating GSHP and UTES**

Such a development would mean widespread Heating & Cooling networks based on geothermal energy in a time frame seeing a linear increase in the market share from 2012-2020, followed by a constant part of the market of tertiary building and small Heating & Cooling networks at more than 50%. This would be based upon the rapid diffusion of Heating & Cooling networks, which have to become standard in urban planning. Ground source heat pumps (GSHP) can complement the networks in areas with less building density, and Underground Thermal Energy Storage (UTES) can offer levelling of seasonal unbalances in supply and demand.

- **Develop geothermal solutions for retrofitting of existing infrastructure**

In order for this development to evolve, it is foreseen that there ought to be a steady increase in the use of geothermal heat pumps in retrofitting of old buildings. This would be a linear increase from 2012 to 2020, followed by a predicted market share of 10% amongst retrofitted buildings. This advancement is based upon a number of critical factors. Firstly, products and methodologies for cost effective building energy refurbishment must be developed. Secondly, there must be a higher performance of high temperature heat pumps, or adoption of the buildings to low temperature space heating. Finally, the importance of improved energy efficiency standards, as part of renovation activities, is to be stressed in buildings regulation.

2.1.4 Deep geothermal resources

- **Exploit favourable sedimentary basins for deep conventional geothermal energy at their full capacity**

This step implies the systematic exploitation of deep geothermal energy wherever there is a resource in the underground and a potential use at the surface. A rapid progression of geothermal projects is seen from 2012-2020, while increasing focus on existing urban areas and inner cities is predicted for 2020-2030. Factors underlying this progression include the control of environmental and social impacts. High exploration costs are foreseen to be met by incentives and the development of cheaper exploration-only drilling technology.

- **Deployment of EGS technology**

Such a development is seen with geothermal heat from combined heat and power (CHP) for industrial process and district heating & cooling. The first operations are expected for the period 2012-2020, with widespread implementation of the technology during 2020-2030. Successful advancement is based on a number of critical factors such as strong involvement of the oil & gas and drilling industry, development of cheaper exploration-only drilling technology, and also more large heating networks to absorb heat.

2.2 Short term (2020) and mid-term (2030) scenarios

2.2.1 Cost perspective

The following table 1 gives a summary of targeted heat/cold cost 2030.

Table 1 - Cost for heat/cold from geothermal sources

Heating and Cooling	Costs 2010		Costs 2030
	Range (€-cent/ kWh)	Average (€-cent/ kWh)	reduction by 2030 (% 2010 costs)
Deep Geothermal - District Heating	4 to 8	5	5%
Geothermal Heat Pumps – large systems and UTES	5 to 10	6	10%
Geothermal Heat Pumps – small systems	9 to 15	10	10%

Residential geothermal heat pumps with a capacity of 10 kW are routinely installed for around 1500-2500 € per kW for closed loop systems. When the capacity is over 100 kW (large residential and tertiary buildings, schools, museums), the cost range for open loop systems is 500 – 800 € per kW installed.

UTES systems for commercial and institutional buildings as well as for district heating and cooling have a capital cost of 100-150 K€ per MWth referring to Swedish and Dutch experiences. The operating cost is commonly 25-30 € per MWh (SPF varies normally in the range of 5-7).

District heating systems may benefit from economies of scale if demand is geographically dense, as in cities, but otherwise piping installation will dominate the capital costs. The capital cost of one such district heating system is estimated at somewhat over 1 million € per MWth.

Assuming successful accomplishment until 2030 of the research priorities set out in this document for all geothermal technologies, a decrease of costs in the range given below can be expected:

- by 5% for Geothermal District heating: target 4 €-cent/kWhh

- by 10% for Geothermal Heat Pumps: target 5 €-cent/kWhh for large systems and 9 €-cent/kWhh for small systems

2.2.2 R&D Priotities

The general technological objectives can be summarised as:

- General: Increasing the information (via Internet, social tools, communication materials) about the useful geothermal potential, among the various stake holders (end-users, advisers, authorities, etc.)

- Geothermal Heat Pumps: Decreasing installation cost[3], increasing of Seasonal Performance Factor (SPF), optimisation of the system integration (ground heat source / heat pump/ distribution), and support of activities towards a decrease of overall energy demand in buildings.

- UTES applications: Better diffusion of the technology, education and training of designers and installers. In addition, there ought to be improvement and standardization of design procedures and components.

- Direct uses: Improving plant efficiency, decreasing installation and operational cost, development of user-friendly, efficient and economic software tools for the design and management of heating and cooling systems. Transportation of heat for more than a few kilometres is currently not economical, and so the development of geothermal district heating or cooling is subject to the availability of suitable geothermal resources close to potential users. Hence the development of EGS is critical for ubiquitous larger-scale development.

- EGS technology: Exploration strategies and development of affordably priced, exploration-only drilling technology, generally improved drilling technologies. Improvement of enhancement activities for bringing geothermal reservoirs to an economic use (following the EGS-concept), sustainable use of EGS (investigation into proppant technologies etc.).

The main research priorities for geothermal Heating and Cooling will be:

- Combined Heat and Power: Cogeneration based on EGS and low temperature power plants, micro cogeneration

[3] Today, capital cost reduction of more than 25% compared to 2005 could be achieved, the operating cost (system efficiency and maintenance) could also be reduced significantly.

• New direct use applications: Develop commercial deep geothermal projects for industrial use and agriculture applications, desalination and other innovative applications

• Geothermal district heating: Development of large integrated District Heating and Cooling systems in which geothermal energy is flexibly used in different forms, individually or in combination with other Renewable Energy Sources

• Geothermal Heat Pumps: Heat pump performance improvement (cf. the relevant items in the Cross-Cutting Research Priorities), improvement of ground-coupling technologies for better efficiency and easier installation.

• Deep and shallow: Underground systems testing devices and methods

• Environment: Measuring consequences on the environment , and improve technology for sustainable deployment of shallow and deep geothermal energy

• Design: Development of more advanced and efficient, user-friendly and economic modelling software for optimising the design, monitoring and management of heating and cooling systems.

• Operation: Monitoring of the installations (ground and surface part)

2.3 Potential and market deployment

2.3.1 Up to 2020

Currently, geothermal energy sources provide about 24 GWhth for heating and cooling in the European Union, equivalent to 2.1 Mtoe per year, whereby geothermal Heat Pump systems contribute to the largest part. In EU 27, the installed capacity in 2020 will amount to around 50 GWth installed corresponding to a contribution of more than 10 Mtoe.

• **Geothermal Heat Pumps:** The quantitative development of the European geothermal market in the next ten years is expected to be fuelled substantially through the introduction and consolidation of shallow geothermal systems, with a quite mature market in Sweden Switzerland and Germany and developing markets in Austria and France. In other emerging European markets, a high growth is possible and it is expected over the next years (Italy, Spain, UK, Hungary, Romania and others). Mature market countries (namely Sweden and Germany) will see a steady increase, mainly stimulated by sales in the renovation segment, but all other countries will see a significant growth. 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.

• **Direct Use:** The most promising areas are the construction of new district heating & cooling networks (Geothermal District Heating & Cooling, with 5 €-cent/kWh, is one of the most competitive energy technologies), optimization of existing networks, and the increase of new and innovative geothermal applications in transport infrastructure, industry and agriculture. The first development regions will be those possessing the most easily accessible resources (for example the Pannonian, Tuscan or Paris basins) as well as higher grade resources where combined heat and power projects can be developed (e.g. the Bavarian "Malmkarst" reservoir).

[4] comprising Hungary and parts of Austria, Slovakia, Romania, Serbia, Croatia and Slovenia

A renewed activity for geothermal district heating and direct use can already be identified in France, Germany, Italy and the Pannonian basin countries[4], as well as from new areas like the Netherlands, Spain and Ireland. In addition, the unit size of geothermal projects (linked to the possible production from an individual well) will direct project development towards existing or newly developed district heating or cooling networks. With absorption heat pumps, cold can be produced centrally and distributed through a dedicated grid, but local cooling can also be provided using the district heating grid as energy provider (heating and cooling using the same distribution network).

- **Heat from cogeneration geothermal systems:** During the next 10 years, geothermal combined heat and power (CHP) plants with low temperature installations and enhanced geothermal systems (EGS) will be developed. The sector forecasts predict to reach 4-6 GWe in EU 27 by 2020. A binary system (Kalina Cycle, Organic Rankine Cycle, or similar) at low temperature can have a simultaneous electrical and thermal capacity of up to about 5 MWe and 10 MWth, respectively.

An EGS plant today has a capacity of 3 MWe or more, but future commercial plants will have a capacity of 25-50 MWe and 50-100 MWth (producing from a cluster of 5 to 10 wells, as in the oil & gas industry). CHP installations could provide heating representing 2 Mtoe by 2020.

Table 2 - Heating & cooling capacity installed in EU 27, current and forecast

Heating and Cooling in EU 27		2010	2020
Shallow Geothermal	GWth	12.8	35
Deep Geothermal	GWth	2.9	15
Total Installed Capacity	GWth	15.7	50
Heat and Cold Production	TWhth	24	120
Heat and Cold Production	Mtoe	2.1	10.5

2.3.2 Post-2020

The targets deemed feasible to be achieved by 2030 are listed in Table 3 and shown in Fig. 8. Two scenarios are considered: a conservative approach (continuing primarily with business as usual), and an enhanced market approach (assuming the full set of support measures both for R&D and deployment, and new technologies and applications).

Table 3 - Scenarios for heating & cooling capacity installed in EU 27 up to 2030

Heating and Cooling in EU 27		2010	2020	[5]2030 conserv	[6]2030 enhanced
Geothermal Heat Pumps	Mtoe	1.1	6.0	10	12
Geothermal Direct uses	Mtoe	0.9	2.5	5	6
Heating from CH&P	Mtoe	0.1	2.0	7	12
Total Heat and Cold Production	Mtoe	2.1	10.5	22	30

[5] conservative approach (continuing primarily with business as usual)

[6] enhanced market approach (assuming the full set of support measures both for R&D and deployment, and new technologies and applications)

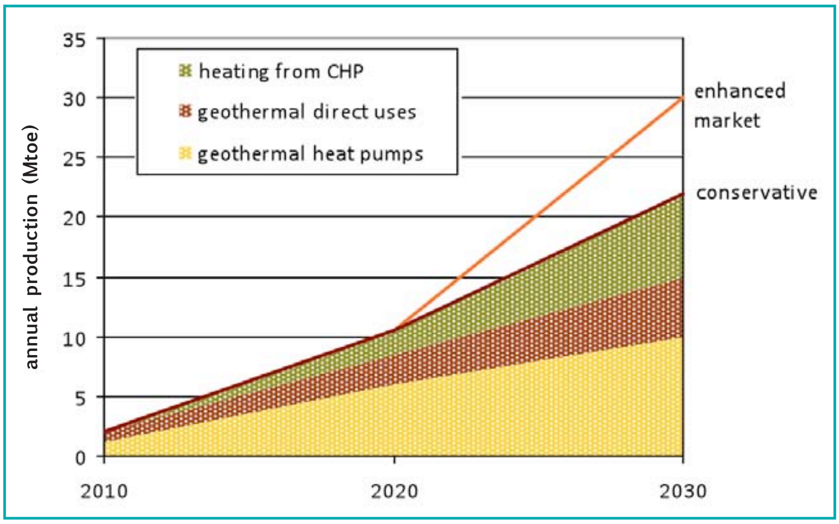

Figure 8 – Geothermal heating & cooling scenarios 2020-2030

Geothermal heat pumps will be firmly established in the markets of all EU countries, and a continuous growth is expected everywhere. They will be classically integrated in energy systems for buildings, combined with other renewable systems, in particular in heating & cooling networks. Multi-functional networks (buildings and industrial processes) will be developed too. Geothermal energy storage (UTES) will be built-up for seasonal storage, with specific applications for residual heat from industry and storage of solar energy (high temperature storage). For low temperature heat pump supported applications, natural heat and cold from the air, or surface water will be stored underground and used for combined heating and cooling. These systems will become an important provider for heating and cooling for individual houses, industry and services, but also for district heating and cooling.

Direct uses will be further developed notably for agricultural applications (heating greenhouses, etc.). New applications for pre-heating in high-temperature industrial processes will begin to be installed.

The enhanced geothermal systems (EGS), a real breakthrough technology will experience a strong development in Europe, producing a large amount of electricity and combined heating/cooling with cogeneration installations. These installations will allow development of new district heating systems for urban areas.

The long term scenario, with the expectation of 150 Mtoe being supplied from geothermal soruces in 2050, requires Geothermal Heating and Cooling systems to be available and economic everywhere in Europe, for both individual buildings and Geothermal Heating/Cooling from enhanced and combined systems for urban areas.

▶ 2.4 References

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3. Shallow Geothermal

3 Shallow Geothermal

3.1 Introduction

3.1.1 EU and national scope

As stated in the RES directive (2009/28/EC), each EU member state has a mandatory 2020 target of a specified share of renewable energy in the gross national energy consumption, in order to achieve the overall 20 %-target for EU 27.

Shallow geothermal systems, without or with the use of heat pumps, are generally considered a renewable technology in the directive 2009/28/EC; the definition in Art. 2 c) states: "'geothermal energy' means energy stored in the form of heat beneath the surface of solid earth". If a heat pump is used in the process, the system has to achieve the energy efficiency criteria as stated in annex VII of the directive (i.e. to provide at least 1.15 times the thermal output as compared to the primary energy input). The limits of shallow geothermal technologies towards depth are not fixed; by common understanding, and in accordance with support schemes in some countries, the deep geothermal realm starts at about 400 m depth.

3.1.2 Technology and potential

Shallow geothermal systems are in use throughout Europe to meet ambitious energy savings targets, whilst at the same time achieving high comfort levels through the inherent heating and cooling capability.

Although some systems, mainly cooling applications and underground thermal energy storage (UTES), can make direct use of the available ground or groundwater temperatures, most shallow geothermal systems incorporate heat pumps to meet end user temperatures for heating and cooling.

In the Northern latitudes, heating is usually the dominant mode, in the middle latitudes both heating and cooling are used, and in Southern Europe cooling is dominant in tertiary buildings, although heating is also required in the cooler periods as well as for the production of domestic hot water (DHW).

The number of shallow geothermal heat pump systems is growing as they are regarded as a sustainable, renewable and reliable renewable energy technology at all scales of implementation. Everyday applications range from individual homes and apartments with individual systems of 3-10 kWth in capacity to commercial and public buildings, with geothermal heat pump installations up to more than 1 MWth.

Further improvement of energy efficiency and reduction of installation cost will contribute significantly to increased deployment of geothermal systems in the heating and cooling market and will allow local, regional and overall EU targets for renewable energies and energy savings to be met.

Shallow geothermal heat pump technology is attractive for the following reasons:

- Suited for European-wide geology, hydrogeology, and climate
- Suitable for a variety of small as well as large applications
- High energy savings potential for both heating and cooling
- Energy capture and storage capability, around the clock operability
- Integration through (thermal) storage potential as controllable load into smart electrical grids on small

and large scale

- Integration and amplification options with other sustainable technologies (hybrid systems)

- Current state of the technology already allows practical implementation on large scale (proven technology with good track record)

- Potential of integrating shallow geothermal technology in local existing businesses, especially SME

- Zero pollution systems

3.1.3 Energy efficiency and sustainability

Most shallow geothermal systems use heat pump technology. All heat pumps improve their thermal efficiency at low temperature difference between the evaporator (cold) and condenser (warm) side of the machine. This result in a larger thermal output (kW) and an improved energy efficiency through a better ratio between the thermal output (heating or cooling) and the energy input (electric power or gas) for operating the heat pump.

On the building side of systems this calls for energy efficient design using low temperature heating and high temperature cooling systems. This requires consideration of the use of geothermal heat pump systems already in early stages of design, and the development of optimised installation concepts and operating strategies and controls that fully exploit the geothermal heat pump qualities.

On the ground side of geothermal heat pump systems further improvement of Borehole Heat Exchangers (BHE) will optimise operating temperatures (better energy performance) and reduce installation cost, which currently are a major factor in every project.

Last but not least, the use of shallow geothermal heat pump systems should not only be attractive from the energy point of view, but their installation and operation should also be environmentally beneficial and thereby sustainable in the long term.

3.1.4 Focal areas for improvement and research

Currently the main focal areas for improving efficiency, cost effectiveness and extending the technology are:

- Integration of design of the shallow geothermal system and building energy system with regard to optimum thermal use and operational strategy

- Optimisation of components such as borehole heat exchangers, well completion materials, compressors, pumps etc.

- Improved drilling methods for cost reduction, but also to reduce impact on the surroundings (e.g. sensitive clays, groundwater), techniques to control borehole deviation, etc.

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

- Improving the understanding of the shallow geothermal reservoir in the way it reacts to the thermal loading/unloading (boundary losses, storage capacity, geochemistry)

- Standards for design, materials and implementation
- Training and educational programmes and infrastructure to ensure the installed systems quality conforms (or approaches) to the theoretical optimum
- Benchmarks to allow end users and designers to judge and performance value a system
- Investigate the scientific facts related to environmental impact of shallow geothermal systems to allow regulatory authorities to better develop and amend regulations.

This listing comprises both technical and non-technical issues (standards, training), as well as scientific work not directly leading to improved components, but necessary to better understand processes and environmental aspects.

3.1.5 Scope and goal of the shallow geothermal research priorities

The Shallow Geothermal Research Priorities are intended to identify technical, environmental and economic topics that will enhance the deployment of shallow geothermal systems (ground source heat pump, GSHP, and underground thermal energy storage, UTES) in the European context. The topics have been selected with an emphasis on the potential for further development and contribution to the improvement of the overall market potential of shallow geothermal systems.

Shallow geothermal systems not only use heat pumps, which are covered in the Cross Cutting research priorities, but also have many other components in common with conventional HVAC (Heating, Ventilation & Air-Conditioning) systems. These components such as circulation pumps, heat exchangers, pipework etc. are not investigated separately in this document, but are part of the integrated design approach. Also for hybrid or storage systems other classes of components (e.g. solar thermal panels, available residual heat, etc.) have to be integrated.

The SRA focuses on the components, issues and processes that are unique and relevant to the geothermal application and that, following consultation of the geothermal community, indicate the largest potential for improvement.

3.2 Underground system components and materials

3.2.1 Overview

Shallow geothermal systems either use wells to access the groundwater directly (“open systems”) or use a heat exchanger installed in the underground (“closed systems”). Research topics concerning the underground are identified and presented here for the closed systems mainly; for open systems, standard well construction components are mostly adequate.

The ground heat exchanger system normally consists of one or multiple vertical boreholes, in which pipes (typically Polyethylene, PE) are installed as loops, forming a Borehole Heat Exchanger (BHE) or “vertical loop”. The individual BHE are connected together in an array that forms a closed hydraulic circuit. A BHE can be used to extract thermal energy from the underground and/or to inject thermal energy into the underground. Mostly a heat pump will be used to reach the final temperatures required for the heating and/or cooling application. Although heat pumps can also be used in combination with air, solar or waste heat, the geothermal application of a heat pump has several distinct advantages of which the most notable are:

• The undisturbed ground temperature in 10-20 m depth reflects the average annual air temperature for a location. Therefore in wintertime, when using the heat pump system for heating, the temperature conditions for the BHE are favourable compared to the air temperature, especially under peak conditions. In summertime, during cooling with the heat pump system, again ground conditions are much more attractive than air.

• Unlike air, the ground has thermal storage capability. Warm water from summer cooling operation is injected into the BHE, creating improved conditions for wintertime heating. Wintertime heating cools the surroundings of the BHE, preparing it for summertime cooling.

• Because of the ground's continuous thermal storage capability, geothermal heat pump systems offer integration opportunities with (sustainable) technologies that have cyclic behaviour (solar thermal). In UTES, this storage capability is actively addressed to provide cooling or heating from sources delivering heat or cold at different times than the demand is given, e.g. seasonal storage of winter cold, solar heat in summer, or residual heat from batch processes.

• BHE at operating temperatures below 40 °C using materials such as PE or PEX have an anticipated life span of more than 50 years and are virtually maintenance free. This allows for very high reliability and low exploitation cost.

• Geothermal heat pump installations reduce noise emissions and visual impact, as they extract or reject energy into the ground and not into the ambient and therefore have no equipment on the roof. This is a valuable amenity for planning purposes.

Currently the underground heat exchangers are a significant cost factor (40-60%) in shallow geothermal heat pump system projects. Improving the thermal and hydraulic characteristics of the BHE systems will improve energy efficiency of the geothermal installations, not only reducing payback time when the system is operational, but also allowing the reduction of capital cost for installing the system.

3.2.2 Borehole heat exchangers (vertical loops)

A closed loop heat exchanger can be constructed of different materials; currently the most common one is PE 100 SDR 11 pipe in the diameters 25 mm, 32 mm or 40 mm. The common feature of all heat exchangers is that they are part of a closed hydraulic circuit, they contain a pumped circulation medium and they exchange thermal energy with the surrounding ground through a temperature difference between the circulation medium and the ground. Usually, and with the best efficiency and stability, the heat exchanger is installed in vertical drilled boreholes, but the heat exchanger can also be installed horizontally, at an angle or integrated in a foundation structure of a building.

The most common form of BHE is either the single-U-loop (mainly in Scandinavia) or the double-U-loop (preferred in Central Europe); triple-U-loops or concentric (coaxial, pipe-in pipe) BHE are also in use in minor numbers (Fig. 9).

Although pipe of different materials (copper, stainless steel, PVC etc.) can be used, the most common material is PE 100, with the version PE 100-RC (Resistance to Crack) become more popular in recent times. The material is extruded into pipes that are joined with a stub-welded U-bend in the factory. PE 100 is a mass produced standard product and is used in the gas and water industry throughout the world. Fittings to produce pipe connections are available from many sources.

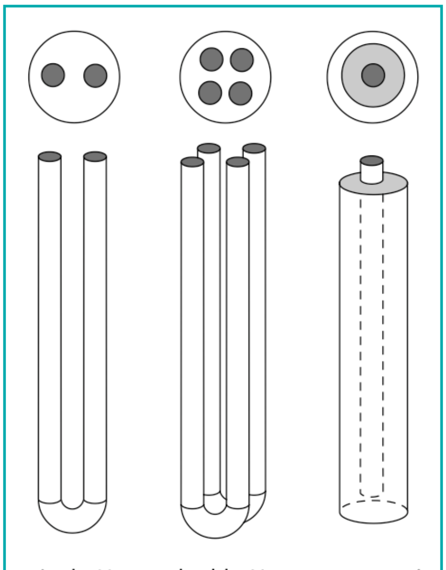


Figure 9 – Schematics of BHE (vertical loops, left) and coiled double-U-loop BHE ready for installation (right)

The PE 100 material has a thermal conductivity of 0.42 W/m·K, is chemically inert and has an anticipated life span of 100 years in low temperature applications. The PE 100 is flexible and is able to handle strain and some deformation, and in the form of PE 100-RC it has specific resistance to punctual pressure, grooves etc. Joining techniques such as welding are available and the material is not excessively costly.

Normal operating temperature range for PE 100 material is from –10 to 40 °C. For higher temperatures PEX or Polybutene (up to 95 °C) are available as plastic materials.

• Potential for technological development

Essential optimisation characteristics for all earth-coupling heat exchangers are:

- Low resistance to thermal energy transfer
- Long term durability at various operating temperatures and pressure ranges
- Low hydraulic losses
- Optimum ratio between cost, performance and reliability

Loops could be made of alternative materials with similar lifespan and lower resistance to energy transfer. Vertical heat exchangers could also be constructed in different geometries that improve heat transfer, are beneficial to pumping losses, or are easier to install in field conditions.

Increasing the conductivity of the pipe material is of considerable interest, as it would improve thermal energy transfer (with the limitation that there is no much further improvement for thermal conductivities much in excess of those of the natural ground). Also if from an installation and lifespan point of view it would be preferable to use higher wall thicknesses than with current PE 100 SDR 11, a higher-thermal conductivity would be required, as thicker walls would give rise to a higher thermal resistance which introduces a temperature penalty[7]. A higher thermal conductivity of the plastic material could

[7] A temperature penalty means a performance penalty - the Coefficient of Performance (COP) of a typical heat pump changes by about 3 % for every degree of lower source temperature.

counter this increased thermal resistance.

The overall borehole resistance, which includes the characteristics of the loop material, the fluid characteristics and pipe geometry, but also the diameter of the borehole and the type of backfilling, plays an important role in the energy transfer between the circulation fluid and the ground. A lower borehole resistance improves temperatures and heat pump efficiency and output; development of BHE with reduced borehole resistance will contribute to better efficiency and/or lower drilling cost

Concentric heat exchangers with different pipe dimensions, grooved or turbulence-enhanced pipe designs, pipes with fins are examples of further possible development of the vertical pipe heat exchanger.

3.2.3 Foundation type heat exchanger & installation

Heat exchangers integrated into foundation structures of buildings in the construction process are currently only a small proportion of the total of installed "ground coupled" heat exchangers. There is a growing interest in the construction industry for this application, because of the obvious and potentially efficient integration with the foundation works and the consequential cost savings.

Not only can heat exchangers be installed in foundations, but also in infrastructure such as roads, parking lots, airport runways or bridge decks. These heat exchangers act effectively as solar collectors and can be used to collect (seasonal) heat that is then stored in open wells (ATES) or closed loop (BTES) applications. Also "slab collectors" can be used to regenerate closed loop or open well applications that are thermally unbalanced. Collector pipes in the walls of tunnels, road or railway cuttings, underground parking facilities can exploit yet another source of shallow geothermal energy for the use with heat pumps.

Similar to the vertical or horizontal type heat exchangers, PE 100 pipe materials are used to circulate a heat transfer medium. The pipe is integrated into concrete structural elements such as piles, slabs and foundations. Installation of the heat exchanger can be done with off site pre-cast concrete piles driven into the ground or slab segments lowered into trenches, or they can be installed on site into diaphragm walls, drilled piles or slabs cast in situ.

• Potential for technological development

As foundations are always designed on the basis of structural requirements, there are a number of limitations concerning the use of foundations as heat exchangers. These require further investigation and development in order to lead to success:

- Design tools for combined thermal and mechanical-structural calculations.

- Foundation type heat exchangers need to be integrated into foundation work routines that have their own methodology and planning, potentially conflicting with the pipe fitting. Current installation techniques are cumbersome and require a lot of manual work, are slow in production and prone to failure.

- Design an installation method that allows the complete structure to be used for the heat exchanger. Steel structural re-enforcement (rebar) for piles is now often limited to a section of the total pile length, limiting heat exchanger length.

- To ensure the longevity of the system, structural engineers need insight into the thermo-mechanical behaviour. Thermal cycling can cause mechanical stresses in structural elements such as piles. In non-saturated soil conditions, heating of the piles could also give rise to irreversible drying out of certain clays and thereby increasing resistance to thermal transfer from the element to the soil.

- Materials research on heat exchanger materials (PE, PEX, etc.)

- Material development of the pile material itself, to improve the thermal characteristics, and to enhance and guarantee thermal contact between the heat exchanger and the pile material (which may be corrupted by cyclic thermal expansion-contraction of the material).

- Design tools for integration of foundation energy use in total building energy demand.

3.2.4 Heat pipes

Heat pipes currently are used in practice mainly for cooling in electronic applications. The working medium (refrigerant) is circulated between the evaporator and condenser using expansion and differences in density (upward movement of steam and downward movement of fluid). Heat pipes of larger scale are also in use for extracting heat out of the ground in order to keep permafrost intact beneath structures (e.g. pipeline foundations in Alaska). The system contains no moving parts and is therefore reliable and energy efficient in operation. Due to the physical concept of operation, heat pipes can only be used for transporting heat upwards (i.e. out of the ground, for heating purposes); they cannot be used for injecting heat into the ground and thus are not suitable for cooling applications.

• Potential for technological development

Ground source applications of heat pipes have started several years ago, but have not yet a secure standing on the market. Further work is needed towards long-term reliability, adaptation to ground parameters, optimisation of working media, etc.

3.2.5 Open systems

Open systems (well-based systems) are applicable in areas where groundwater quantity, groundwater quality and groundwater legislation allows the use of this type of shallow geothermal resource. In general this is the cases where the hydrogeology consists of relatively young, medium- to coarse-grained aquifers of fluvial, glacial or marine origin. Depending on local conditions and hydraulics, other formations such as Sandstone, limestone, chalk, dolomite and even fractured crystalline rocks are useful minor aquifers.

Well based systems are originally based on groundwater well technology (drilling, well completion, pumping/testing) and extract water to be used in the building installation. The source water can be used for heating and cooling through the use of heat pump technology. If the extracted water temperatures allow, the water can also be used for direct cooling, usually via a heat exchanger, hydraulically separating the well water from the water in the building installation.

Based on common sense and led down in legislation it has become standard practice to return the ground water to the formation from where it was extracted. Therefore, most well-based systems consist of an extraction and an injection well (doublet). Depending on the type of operation (heating or cooling) of the building, the water in the injection well is returned at a lower or a higher temperature than the water extracted. In some countries with favourable groundwater conditions, such as the Netherlands, open well systems are the most prominent type of shallow geothermal application.

Underground Thermal Energy Storage (UTES) using groundwater wells is called aquifer storage (ATES). Systems with the same pumping direction over the whole year exist as well as others with seasonal reversal of the extraction and injection well(s). With the latter, the thermal storage function of the aquifer is optimised. Cold water generated by winter heating is used in summer time for cooling, whilst the water that is warmed up by this process is extracted for heating in winter time. Numerous plants of the type exist in the Netherlands and Sweden, with some more in Northern Belgium and in Germany.

• Potential for technological development

The essential issues with well type applications are:

- The availability and quantity of water to be extracted and re-injected
- The quality, geochemistry and microbiology of the groundwater to be utilized
- Hydraulic and thermal effects of individual and/or multiple well systems
- Legislation, licensing and sustainability

Technological development is directly relevant to the first three points. Well testing technology and methodology has been developed mainly for extraction of water and not for injection. Quality issues and groundwater geochemistry and microbiology have been extensively researched in areas where this is relevant to drinking water, industrial usage, agricultural use, and concerning issues of contamination and the environment. Information is lacking on the use of groundwater at greater depth and at elevated temperatures (cf. the items on UTES in the storage part of the Cross Cutting Research Priorities).

Hydraulic and thermal effects within well based systems (thermal short circuiting between wells) and hydraulic and thermal interaction between different well based systems as well as the potential optimisation of multiple well based systems needs further research.

Obviously technological development of drilling techniques, well materials, pumps and system hydraulics will improve the applicability of the technology, reduce maintenance issues and cost and improve well life. Development of methodology and strategies with regard to system interaction is a requirement for acceptance and sustainability.

3.3 Installation of underground heat exchangers

3.3.1 Overview

Most heat exchangers used for geothermal heat pump applications are installed in boreholes which are drilled using standard drilling technologies derived from water well drilling, foundation drilling, and exploration drilling.

Drilling for closed systems (BHE) is usually done by rotary direct circulation technology in sediments and soft formations (sands, clay, chalk, mudstones etc.). This is done by using water or mud as circulation media to stabilize the borehole and carry cuttings to the surface. Depending on water losses to the ground whilst drilling, casing may be used for parts of the borehole.

In more consolidated and hard formations (sandstone, shale, dolomite, limestone, granite), the down-hole-hammer (DTH) is applied, using air (in some cases foaming agent added) as a circulation medium. Depending on the stability of the drilled borehole, sections may have to be cased.

Other drilling methods such as the classical cable-tool drilling and augering (for shallow holes in soft ground), as well as newer techniques such as water-jetting or sonic drilling, are also used, although these methods are by far not as common as the direct circulation rotary method. The new methods still require further development before they can be considered for routine use.

Over the last years, under European and National Health & Safety directives and working condition regulations, drilling rigs have become safer, more automated and mechanised therefore the manual handling of drillrods, weights etc. has been reduced and working conditions have improved.

Table 4 - Overview of applicability of drilling techniques for different ground types

Main techniques	Consolidated rocks, hard / medium / soft	Unconsolidated soil, young sediments	Depth interval
Direct flush rotary	medium - soft	standard method	0 - 400 m
Reverse circulation rotary	soft formation	non-standard	0 - 150 m
Down Hole Hammer (DHT)	hard - medium	not applicable	0 - 200 m
Sonic rotary	medium - soft	non-standard	0 - 150 m
Auger	soft formation	standard in loam etc.	0 - 30 m
Water-jetting	medium	partly usable	0 - 100 m (?)

Figure 10 – Direct rotary drilling (left), with mud containers in the foreground, and DTH drilling (right), with yellow air compressor coupled to the drill rig

Obviously the drilling of the boreholes is only one aspect of the installation, other relevant technological aspects are:

- Drilling fluids and additives
- Insertion of the heat exchanger
- Backfilling (grouting) of the borehole, backfill and grout materials
- Process management of circulation water (mud) and disposal of material from the borehole (drill cuttings)

The cost of the installation of a BHE is largely dictated by the drilling cost. A reduction of drilling time and cost and an improvement of the working conditions and the management of mud and water on site would be very beneficial to shallow geothermal heat pump projects. Moreover, mitigation of the risk of lost or abandoned boreholes is important.

As most drilling companies and companies supplying material and services to the shallow geothermal industry are relatively small and based regionally, development of specialized equipment is not advanced, but would fill a technological gap and find widespread implementation.

▶ 3.3.2 Drilling

Drilling for shallow geothermal systems is mostly done using very traditional drilling methods, operational skills and machinery. At the very best, only specific parts of the drilling process, such as the handling of drilling rods, have been automated and mechanized.

Drilling progress (meters per day) is often highly uncertain, as underground drilling conditions have not been extensively investigated and the adequate matching of methodology, machines and tools is lacking. Time loss and the cost involved are significant factors in overall drilling cost. But also borehole quality (calliper, section) is a relevant factor for improvement.

Drilling is very physical work with significant health and safety risk's, usually noisy and subject to weather and season. Consequently production is limited by these factors as well as by technical breakdowns because of the wear and tear on machinery that is operating in a non-controlled environment and often lacking professional maintenance.

Benefits of developments in this area are:

- Better working conditions for drillers and increased productivity
- Improved quality of installation, backfilling/grouting, connections
- Acceptance and integration in building industry due to increased productivity and constant quality
- Reduction of environmental risk and improved product reputation due to better and constant quality

• Potential for technological development

There is a significant potential for the development of dedicated drilling rigs capable of reliable, predictable, fast production with low maintenance requirements, constant process quality and acceptable working conditions. Although it is not expected to develop completely new drilling techniques, significant improvements can be achieved with:

- Handling process of drill cuttings and drilling fluid
- Management of process water
- Working conditions, quality, production and safety
- Optimization of the drilling rigs with regard to production speed
- Better control of borehole deviation, in regard to other underground installations and neighbouring BHEs

▶ 3.3.3 Grouting and backfilling of boreholes

Grouting and backfilling of boreholes with installed heat exchangers is required to warrant the following:

- Long-term thermal performance, good connection of pipes to natural ground
- Long-term mechanical integrity of the borehole and BHE configuration

• Long-term environmental integrity of the BHE and the geological formation (sealing of the perforation / borehole annulus)

Grouting/backfilling is currently addressed in some national guidelines, however, the importance to the overall quality of the drilling/installation process is often overlooked.

• Potential for technological development

Development of the following is of importance:

• High performance, quickly installed, low cost grout, including specialized machinery/plant.

• Development of grouting machinery with control over the grout properties, including automatic documentation of the grouting procedure

• Non-destructive inspection technology to verify correct application of grouts/backfill and to warrant the quality of the work carried out.

▶ 3.3.4 Specific improvements for open loop well installation

A significant number of well based systems cope with a decreasing yield of water, an increase in injection pressure and costly periodic maintenance. A number of these problems can be traced to poor design and installation of the wells, others may find their origin in the geochemistry of the water, mixing of different water types or even bacterial growth in the wells or connecting pipes.

Guidelines have been developed to improve well quality and in most countries minimum quality requirements for wells, well heads and associated pipework have been re incorporated into the applicable legislation.

• Potential for technological development

Specific development is needed in the following areas:

• Design of wells and well systems, optimised for local conditions

• Test procedures for extraction and injection

• Well materials, components and instrumentation

• Sampling and testing of groundwater chemistry and microbiology

• Better understanding of hydrochemical and microbiological processes, development of strategies to avoid related problems

• Well maintenance, sanitation and rehabilitation

▶ 3.3.5 Issues surrounding urban installations

To make drilling for geothermal applications more acceptable on building sites, in particular for urban settings and retrofitting projects, the process needs to be better managed and controlled. Especially the release of large quantities of water and drilling mud in combination with the use of tracked machinery create unacceptable conditions and consequently high cost for remediate action.

In an increasing number of projects drilling is taking place in areas where future foundation works are planned (Fig. 11). Disturbance in these areas is costly because of the delay to subsequent construction work.

Figure 11 – Drilling and BHE installation with 3 rigs simultaneously on building site

• Potential for technological development

Often geothermal sites are in urban areas where traffic management is already an issue. Therefore additional movement by trucks moving material off site is unwanted. On site processing and storage of excavated materials would benefit the installation process. Also noise reduction, low emissions and relatively clean construction sites are desired (cf. Fig. 11).

- Developing drill rigs with small footprints
- Minimizing disturbance on building sites, existing landscaping / gardens
- Procedures for clean handling and disposal of materials
- Development of "careful" drilling methods (e.g. further development of DTH with water instead of air) and methods for very sensitive areas (e.g. quick clay)

3.4 Integrated Design

3.4.1 Overview

Due to the dynamic coupling of the geothermal system with the mechanical system and building, an integrated design approach is needed for an efficient implementation and operation.

Using the ground to extract, inject or store thermal energy affects the temperatures, groundwater flow, geochemistry, and, in general, the hydrogeological and geophysical conditions of the soil. Whether or not these effects may cause significant perturbations to the geothermal resource is a question covered under the concept of sustainability, understood on one side as energy sustainability and on the other hand as environmental sustainability. The latter covers the sustainable pressure conditions in the resources, thus avoiding reduction of available fluid volumes and water quality as well as possible interference with aquifers and any other subsurface resources (such as thermal or mineral waters), maintenance of groundwater conditions and provisions for abandonment and proper restoration.

Energy sustainability can be understood in particular as the ability to efficiently meet the thermal demands planned along the lifetime of the building. This requires an integrated and rational design system, the knowledge of building load and thermal demands and the acquaintance of the relevant hydrogeological, geological and thermal parameters. The goal is to balance the extractions and injections of thermal energy in the field with the natural regeneration ability of the soil and with other thermal energy sources that may enter into the system. Depending on the complexity of geothermal applications, the maintenance of efficient operation may also have to react to large variations in respect to the original design conditions, and thus a flexible operational and control strategy is also part of any sustainability approach.

The environmental sustainability is perfectly expressed and guaranteed in the implementation and enforcement of environmental standards. In geothermal exploitation of shallow groundwater it must be ensured that the conditions are qualitatively and quantitatively foreseeable, well documented and environmentally acceptable.

Moreover, closed loop systems will generate in the coming years a significant number of drilling in areas, usually urban, were little experience is available on possible environmental issues and interaction effects. Smart integrated design and planning tools will have to be developed to ensure minimisation of possible problems without strangling the implementation of this form of energy.

▶ 3.4.2 Site investigation and Thermal Response Tests

To start a desk study to any feasibility approach or detailed well field design, input information, site and field data are essential. Information requirements, amongst others are detailed geology, hydrogeology and the thermal characterization of the underground (e.g. geological stratigraphy, hydraulic conductivity, porosity or fracture patterns, ground water presence and gradient, soil quality, pollution, thermal conductivity, heat capacity, vertical temperature gradient).

Other relevant information may consider legal limitations, environmental conditions, contaminant issues or use of the underground by others that may interfere with geothermal heat extraction/injection. Such information today is often insufficient in traditional terms (lack of data) and is quite ignored or undervalued when dealing with spatial variability and with time variability of underground properties. Basic information for a desk study would be available from sources such as a geological surveys, municipal records, utility companies, water board, etc. Investigations on the mechanical properties of the soil in preparation of the building foundation design may also be available at an early stage.

There are different ways of gathering field information. Throughout the EC geological information is available in some of the national or regional surveys, although the level and extent of available data is very inhomogeneous. More or less sophisticated geophysical methods (such as geoelectric and seismic surveys) are also available as well as test drilling techniques.

More specific methods include thermal response test (TRT, Fig. 12), temperature/depth profiles, pumping test, etc. By these investigations it is possible to determine the basic parameters useful for a good design: stratigraphy, underground thermal properties (thermal conductivity, heat capacity, and vertical temperature gradient), hydrogeological properties (permeability, storage, groundwater levels and gradient), and the thermo-hydraulic properties of the drilled holes. But very few or no data are collected concerning the vertical and horizontal variability of interesting parameters as well as concerning the hydrogeological dynamics. Enhanced testing with stepped heating pulses or heating and cooling pulses can quantify groundwater effects. Some geophysical testing (on site surface or as borehole logs) is also undertaken, but this is rather rare.

Nowadays, site characterization methods are quite limited for a variety of reasons. Public available information is scarce, often not existing. General purpose techniques do not reach the depths relevant for geothermal uses and TRT testing technologies are often not used in a feasibility stage, because of its cost and complexity, or are executed at unacceptable quality levels (due to cost or knowledge restrictions) which hampers rather than helps the design process.

Figure 12 – Examples of Thermal Response Tests (TRT) from various European countries

• Potential for technological development

The online availability of relevant information through databases and GIS systems would be beneficial, especially if information on underground infrastructure and the position of other geothermal systems is included. Borehole characterization by geophysical logging will be relevant for design but allows for establishing compliancy of borehole design and construction with environmental legislation.

TRT is well developed for standard heat injection/heat extraction tests (Fig. 12); results are useful only if tests are carried out properly. In more complex situations with varied geology or hydrogeological influence more advanced TRT testing should be developed to characterize the thermal behaviour of the ground and groundwater effects.

Development of small and easy to use TRT and borehole logging equipment, together with a clearly described standardized methodology, will allow better site characterization at acceptable costs. In a longer term vision, non-invasive geophysical technologies should be developed that include the characterization of thermal soil parameters.

Technological challenges are:

• Developing test procedures to include other heat transport processes than conduction (e.g. ground water movement)

• Developing test methods that allow for measuring additional parameters (such as specific heat capacity) and formation-specific parameters

• Developing test methods for non-standard geometries (energy baskets, spirals, foundation piles)

• Development of a standard evaluation of quality of test data and results and of a decision system for selecting the level of testing needed for a specific project, depending on local circumstances and system parameters

There are some initiatives towards reaching these goals already, but currently without sufficient focus or co-operation.

▶ 3.4.3 Gound Heat Exchanger design

The purpose of a ground heat exchanger is to exchange heat (either during heating or cooling operation of the plant) with the ground volume. The ground heat exchanger can be defined as an arrangement of individual heat exchangers, that can be of different types such as U-loop heat exchangers or coaxial heat exchangers installed in boreholes (borehole heat exchangers, BHE), foundation piles, energy baskets, horizontal loops, etc. Generally a ground heat exchanger field is part of a more or less complex heating and cooling system, but another important aim may be the storage of energy in form of heat or cool.

Open systems are based on direct use of ground water, and although these systems exchange heat with the ground water and also the matrix, they are not considered ground heat exchangers as such.

In shallow geothermal heat pump installations the four key design factors are:

• The building energy profile (heating and cooling demand to be covered for achieving comfort levels)

• The heat pump installation (mechanical heating/cooling installation, including pumps)

• The ground heat exchanger field (number and depth of BHE or other ground heat exchange devices)

• The operational strategy that will ensure the integration of the first three factors and will secure energy efficiency and long term sustainability of the system.

Dealing with design of a ground heat exchanger field, the main tool consists in space-time models quantifying the exchange of heat into and out of the reservoir, and the natural thermal transport processes in the underground. Often, monitoring has to be put in place to control the correct performance of the reservoir exploitation and to check the modelling adopted.

The core of this design is the modelling of underground thermal energy flow. While a full modelling is quite complex because it involves heat and mass flow (conduction, convection, advection) and may include phase-changes or sometimes significant geochemical aspects. Sometimes very simplified schemes can be adopted, where semi-numerical or even analytical solutions become usable. This is the case in most state of the art BHE design models, which only consider conduction between the thermal mass of the soil and the BHE.

The aim of modelling is to size the ground system in such a way that the temperatures remain within certain limits, given a specific thermal loading and to obtain estimates of how the temperature profiles of the heat exchanger will interact at short, medium and long term with the system operation. This knowledge is essential and has major implication in system day-to-day operation, where high transient loads (peak loads) may have to be considered, as well as in the long term energy sustainability of the geothermal exploitation.

In the case of BHE fields, there are – in the case of multiple heat exchangers in medium to large projects - software tools (such as EED, EWS, GLD, DST, SBM etc.; Fig. 13) which are considered adequate to design BHE fields in some standard configurations, just considering the thermal mass and heat flow due to conduction of the soil itself, i.e. without considering a physically realistic representation of the actual spatially varying reservoir properties. Groundwater flow, details on the thermal effects of the horizontal connecting pipework or other major alteration of the energy flow caused by other interferences cannot be taken into account within these schemes. On the other hand, these tools are rather comfortable; their use is quite widespread and does not imply severe costs.

In the specific case of foundation piles, some limited design tools exists such as the Swiss software PILESIM.

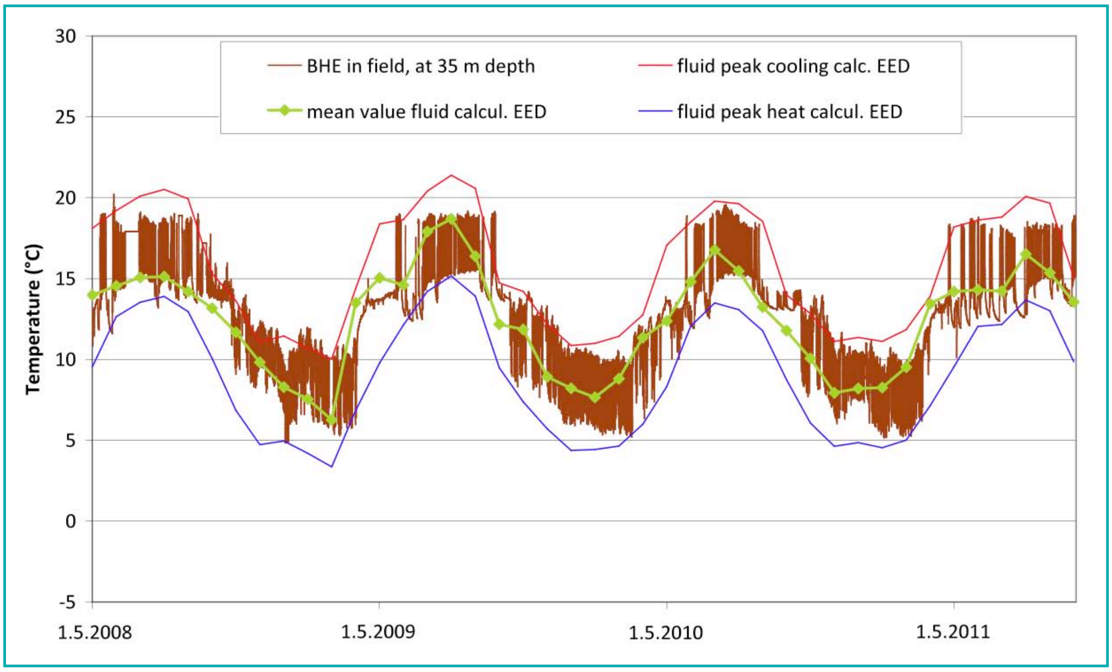


Figure 13 – Example of BHE design software: Validation of EED-calculation with measured data of ground temperatures in a large BHE field of >150 boreholes

• Potential for technological development

The most relevant challenge for design of ground heat exchanger fields is meaningful integration of the ground side model into the simulation environment for the whole system. Moreover it is necessary to develop software tools that enable designers to adjust the design effort gradually depending on the economic size of the heat exchanger system.

Concerning high-level predictive models, several technological developments are needed, as well as new developments improving existing features. For instance:

• Interaction between the movement of groundwater and the direction of heat flow; more accurate prediction of the long-term behaviour of the geothermal system, both in terms of change of underground temperature, and in terms of energy consumption

• Taking into account the inhomogeneity of thermal properties of different soil types, and Inclusion of representation of layered geology and modules for hydrogeology

• Include thermal interference caused by other underground systems, such as other geothermal projects or geotechnical works

• Provide an easy interface with present or future geothermal information databases

• Simple and reliable design methods and procedures for everyday use (small systems) aimed at guaranteeing efficient small systems

• Geo-engineering tool for GHE risk assessment (site characterisation...), development of probabilistic analysis in which a certain degree of uncertainty of each variable is admitted and translated into a risk assessment scheme

• More integrated design approach and automatic optimisation of hybrid shallow geothermal systems

• Improved interface to building load calculation software

• 3D representations of underground temperature evolution and temperature maps following the specific probability considered

Concerning low-level models, minor developments are necessary. In principle the multi-layered approach with a single water table must be taken into account including a simplified spatial and temporal variability of parameters. A simple technical risk analysis must be adapted, by considering the level of uncertainty of the specific reservoir at hand. Smart procedures of pre-evaluation of case study complexity with proposed designing paths would give, in any case, an interesting link between the different levels of difficulty within a given situation.

▶ 3.4.4 Design for open loop systems

In the past, design of groundwater-based system has made use of traditional water well technology. In systems where groundwater is extracted for cooling purposes and not returned to the aquifer this may work, but the current state of the art in application is to extract and re-inject water into the aquifer. This fact, in combination with temperature and pressure changes to the groundwater used, results in challenging geochemical conditions such as changes in chemical stability caused by changing redox conditions, iron flocculation, degassing, etc. Another focal point for design is the issue of bacterial growth in wells and well systems. For ATES, these problems are addressed in the Cross Cutting Research Priorities.

The potential for hydraulic and thermal interaction between adjacent well based systems or thermal interaction with nearby systems using BHE needs special attention.

• Potential for technological development

• Testing and design for geothermal wells

• Pumping and injection strategies, well maintenance

• Modelling of hydrogeolical and thermal interaction

• Hydrological and geochemical, as well as bacteriological toolkits

(see also the paragraph on UTES in the Cross Cutting Research Priorities)

▶ 3.4.5 Integrated Design and Design of Controls

Integration of design guarantees the optimum interaction between the building energy demand, the ground side installation (BHE, wells, etc.), and the heat pump equipment. This optimised interaction is described in the operating strategy, which is the “roadmap” of the design of the geothermal heat pump installation.

The controls of an installation should have the control functions available that will allow for implementation of the control strategy and monitoring of performance, ensuring robustness of the system and the long term efficiency.

In the current situation shallow geothermal heat pump systems are designed on standard performance criteria provided by the manufacturers of equipment such as heat pumps, pumps, heat exchangers etc. Usually these performance criteria are given for one operational condition (temperatures, load) only, not taking into account the effects of variations in conditions during actual use. Moreover, current design methods are primarily based on capacity design with relatively large over-design factors, which are detrimental to system performance.

For some smaller installations, installation concepts including the control strategies have been developed. Development of standard design concepts (and operating strategies) for larger and more complex systems will provide guidelines for installers to improve both quality of installation and lifetime operating cost.

• Potential for technological development

To date little research has been carried out on integrated ground-source systems, and virtually none on integrated control strategies. A number of potential research issues can be identified to address this deficiency:

- optimisation of thermal use of the ground heat exchanger, design methodology

- fluid pumping strategies, especially with regard to pumping power, thermal load, thermal resistance (turbulent / laminar flow regimes)

- design optimisation of hybrid systems

- integration of a geothermal system with other technologies including (but not limited to) free cooling, free heating, solar heat, storage

- Integrated control of ground source heat pump systems to include ground side, heat pump, building circuits and building characteristics; multiple input - multiple output control approaches

▶ 3.5 Sustainability and environmental impact

▶ 3.5.1 Overview

As far as the thermal effects on the earth are concerned, the use of shallow geothermal energy is sustainable as local ground temperatures will recover after the use of the geothermal heat pump system is stopped (reversibility of the process).

The environmental sustainability is less straightforward, as the drilling and installation of the BHE cannot be undone. As with all human activity, the process will have to be reviewed regarding the benefits and the drawbacks. Some of the issues to be considered for closed systems are:

- BHE has a very long life expectancy (>50 years)

- PE pipe is non-toxic, chemically inert, consisting of Carbon and Hydrogen atoms only

- Energy exchange (heating or cooling) only with the ground, no pumping of water or geochemical alterations of groundwater quality.

• High energy savings on primary energy via geothermal heat pump system

• Recovery of process/waste energy from building heating/cooling cycles

• BHE pipes remain in the ground, their degradation after abandonment of the geothermal system is very slow

For open systems using groundwater, the effects on groundwater resources, chemistry, microbiology, etc. must be taken into account.

▶ 3.5.2 General issues

The sustainability of a shallow geothermal system is one of the great attractions of the technology, as it uses environmental energy and functions as a heat/cold store. Another aspect of sustainability is the ease of integration with other (sustainable) technologies. The sustainability is reflected in the potential long life span of the system and its continuous energy savings. Table 5 lists the main aspects.

Table 5 - Main aspects for sustainability and environmental impact

Sustainability and environmental impact	positive	negative
Using renewable energy from the underground	+	
Using system buffer capacity to store residual process energy	+	
Reducing primary energy usage and reducing emissions	+	
Using easily available volume in shallow underground	+	
Geothermal system has a very long service life	+	
Installing wells or BHE disturbs the ground		-
Drill cuttings can be problematic[8]		-
Spreading of pollution already existing in the subsurface		-
BHE (and also some wells) remain in ground after use		-

• Potential for technological development

The development of a model (tool) in which the sustainable aspects of shallow geothermal systems on a local or more regional scale become visible, and which can be used as a planning tool for local or regional development.

As heat pumps use electricity, this tool can also be used to optimise the development of the electrical infrastructure utilising the grid network, but also local power production, and can include the demand-side management opportunities given by heat pumps with some storage capacity. Furthermore, the storage potential of (temporary) excess heat or cold for future use can be considered.

National databases of installations could help in optimal deployment and environmental monitoring of shallow geothermal systems.

For closed systems that are designed for ground-side temperatures below 0 °C or require frost protection of the evaporator of the heat pump, antifreeze is added to the water of the heat transfer fluid circulating in the ground heat exchanger. In Northern Europe (Scandinavia) often Ethanol is used, while

[8] Depending on the rocks drilled, the cuttings can contain naturally toxic materials (e.g. heavy metals, arsenic) or might show elevated natural radioactivity (mainly in some crystalline rocks)

in the rest of Europe generally Monoethylene glycol (Ethanediol) or, to a lesser extend because of its viscocity, Monopropylene glycol (Propanediol) is used. Other materials like Potassium Carbonate, some acetates or tartrates have been tried, but they all showed specific drawbacks (e.g. corrosion, increased leakage, degradation).

Frost protection using Monoproylene glycol is detrimental to pumping energy especially at low operating temperatures because of the considerable viscosity of the circulation medium. Development of frost protection with low pumping losses and high specific heat capacity would improve energy transfer and efficiency of closed ground source heat pump systems.

The eco-toxicological effects (on humans and aquatic) of both types of glycol are relatively well known. Specific effects on soil organisms (effects on terrestrial organisms and ecosystems) have not been investigated in detail. Degradation of glycols to alcohols, fatty acids and eventually carbon dioxide is usually very rapid under oxidative soil conditions. Additives to glycol (for stabilisation and to prevent corrosion) are considered the main problem. The main items for R&D concerning the heat transport fluids are:

- Non-toxic antifreeze, easily degradable under soil and groundwater conditions, but stable inside the closed circuit

- Antifreeze with low viscosity (low pumping losses) and improved specific heat capacity will benefit the efficiency of the overall heat pump systems

- Standard methods for checking quality (biofouling, bacterial degradation etc.) and concentration of antifreeze in systems

- Development of antifreeze without the additives that are used in conventional systems (e.g. automotive radiators, metal components etc.)

- Cost reduction of heat transfer fluid

3.5.3 Specific environmental issues for groundwater systems

Good quality groundwater is regarded as a key resource that should be handled with care. Groundwater that is used for drinking water is usually protected by legislation and permits are usually required for drilling and exploitation. Groundwater abstraction and injection can give rise to local changes in groundwater levels, which may have structural or ecological impact.

Outside protected zones groundwater of varying quality can be used, however, it is standard practice not to mix water of different quality. Well based systems require maintenance, sometimes requiring flushing or even chemical cleansing of systems and disposal of large quantities of (contaminated) water. In areas with mobile contaminants in the groundwater, open wells can actively circulate and spread contaminated water.

- Potential for technological development

- Design tools for environmental impact

- Active use of geothermal well based systems in contamination remediation

- Integrated use of drainage water (tunnels, soil drainage, water management) through geothermal well based systems

Groundwater issues for ATES systems are mentioned in the relevant paragraph of the Cross Cutting Research Priorities.

3.6 Shallow geothermal heat pump systems in 2020

3.6.1 The current benchmark

The current (2011) shallow geothermal heat pump market in Europe has shown a steady growth over the decade from 2000, with some levelling out after 2008 (cf. chapter 2.1). Not only have the number of installed systems increased significantly in the founding countries such as Germany, Sweden and Switzerland but the technology has also taken flight to a large number of other countries such as Austria, France, Finland, the Netherlands, Norway, the UK, etc.

As indicated in Table 6, current technology is already able to achieve significant savings on primary energy (>40 %) and CO2-emissions (about 50 %). With a current (January 2011) NL gas price of 0.55/m3 (including taxes) the cost savings per year are about 380 €. This leads to a pay back of extra cost when compared to a gas boiler of about 10 years.

In 2010, about 5.7 TWh/year were produced by GSHP in Germany (using some 4 TWh/year of heat from the ground, Fig. 14). This amounts to savings of 2.2 TWh/year in primary energy, and avoidance of emissions of about 680·103 tonnes of CO2.

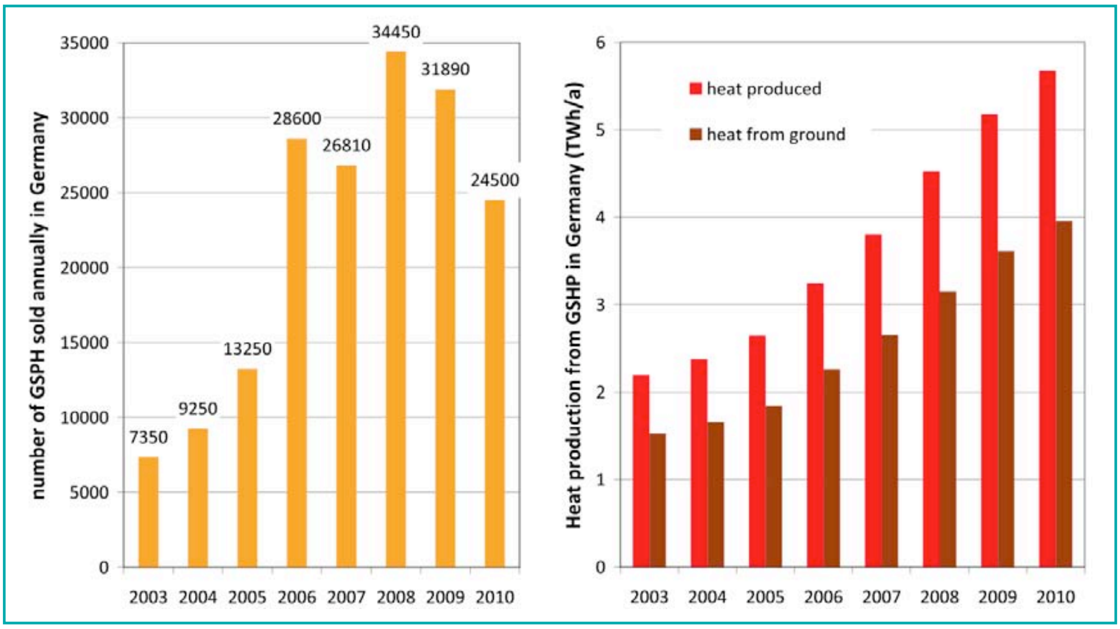


Figure 14 – Annual GSHP sales in Germany (left) and heat produced by GSHP in Germany (right)

Table 6 - Example of standard home with four inhabitants, energy demand for heating and domestic hot water (DHW); primary energy factor for electricity 2.7

Installation	Energy demand	Efficiency	Energy input	Primary energy	CO2 factor	CO2 amount
Gas boiler	10 MWh	0.9	11.1 MWh gas	11.1 MWh	0.185	2.05 tons
GSHP	10 MWh	4.0 (SPF)	2.5 MWh el.	6.7 MWh	0.430	1.08 tons

3.6.2 Technological and strategic benefits from R&D

Technological improvements show most promise when they are aimed at both reducing capital cost (cost for installing the ground-side system and heat pump) and reducing long-term operating cost. In current systems roughly half the cost (50 %) is spent on the ground-side system, and the other 50 % on the heat pump installation and controls.

Cost reduction in installation of systems can be realized through the following actions:

- Optimisation of selected building energy profile, heat pump and ground-side system
- Improved efficiency in ground heat exchanger installation
- Optimising hybrid design

Cost reduction in the exploitation phase of the installations can be realised through

- Higher heat pump efficiency, through improved source and load temperatures
- Lower pumping cost
- Higher system quality and lower replacement and maintenance cost
- Improving energy storage in the underground

Strategic benefits from shallow geothermal heat pump systems

- Powerful renewable energy savings technology, to be combined with other renewable energy production (two sided approach).
- Decreasing energy dependence, less imports, less risk
- Flexibility in energy infrastructure on local and regional scale
- Stimulating the European industry and increasing market opportunities especially for SMEs

3.6.3 The 2020 goals from R&D effort

Table 7 summarises the R&D efforts suggested in the previous chapters and gives an estimation of their potential impact. Hence the R&D effort should result in:

- **Improved efficiency**: Reduction of primary energy input, operating cost savings & emission reductions
- **Standard technology**: System concepts, products, tools and implementation accepted by heating and cooling industry and the construction industry in general
- **Wider acceptance**: Accepted as standard feature by general public and governing bodies

Higher efficiency and wider acceptance will lead to more installed systems and more energy savings.

Table 7 - Summary of R&D efforts and benefits

Topic	Improved efficiency	Standard technology	Wilder acceptance	2020
GSHP in general	+++	0++	00+	Increase of 2010 benchmark SPF of 4 by 25% to 5
Foundation type heat exchanger	00+	+++	+++	Main benefits will be a building in-dustry acceptance and a standard (energy) concept.
Heat pipes	0+	00+	+++	Develop into a marketable tech-nology
Underground Installation	00+	+++	+++	Slight energy efficiency benefit, but large first cost reduction and industry acceptance
Integrated design	+++	+++	+++	Increase in energy efficiency through highly efficient con¬cepts. 2020 shallow geother¬mal heat pump concepts should range from SPF 5 (basic) to SPF 8 (top range hybrid)
Sustainability & environ¬mental issues	000	0++	+++	Guidelines, standards, training will lead to acceptance as standard technology

+++ High R&D benefits
0++ Good R&D benefits
00+ Limited R&D benefits
000 No benefit

3.7 Summary: shallow geothermal

Over the last 10 years shallow geothermal heat pump systems have experienced a rapid acceptance by the European market, notably in countries such as Sweden, Switzerland, and Germany. The autonomous growth, without a substantial subsidy base, is mainly based on the energy saving capabilities of the systems, acceptable payback and their wide acceptance and reputation as “green technology”.

Shallow geothermal heat pump systems can be used both for heating and cooling for virtually every building type. In the northern latitudes heating will be the dominant application, whilst in Southern Eu-rope cooling will lead the way, although in these conditions the systems are also capable of providing domestic hot water at high energy efficiency whether or not integrated with solar thermal systems.

Underground Thermal Energy Storage (UTES) has reached a stable market for low temperatures (cooling, heating using heat pumps) in some countries like Sweden and the Netherlands, and individual project examples can be reported from many more countries. UTES application necessarily requires a certain minimum project size, so typical applications are for large office buildings, shopping malls, schools/ universities, etc. For UTES at higher temperatures (>30 °C), only a few demonstration plants exist yet. In the light of the interesting potential for storage of renewable heat (solar, geothermal), heat from CHP at times of low heat demand, or residual heat from industry, R&D in this field should be continued.

The main effects of R&D effort should result in higher system efficiency and lower capital cost when installing a system. Most of the development would be required – and achievable – in a short-term timescale, however, some research in particular on materials might lead to new solutions only in a medium term. The items deemed of highest priority for the next years (up to 2013) and for the start of the upcoming framework program Horizon 2020 (2014) are listed in table 8.

In this document on research priorities we have identified the following areas where focused R&D will make a significant contribution (Table 9 with more details):

Underground heat exchanger construction and installation

Current technology is some 30 to 40 years old (almost 70 years in the cases of horizontal loops and groundwater wells!) and is no longer the optimum for high efficiency systems, current health and safety requirements and environmental regulations. Further improvements in material and design of geothermal components, in mechanisation and automation of (shallow) drilling technology, in material handling and in process management will lead to more energy savings (20 - 40 % foreseen compared to current systems) and lowered capital cost (10 - 20 % foreseen compared to current installation cost).

Integrated system design

Currently there is no coherent and holistic design of shallow geothermal systems, as there is no specific knowledge infrastructure, and skills are required from a variety of backgrounds (geology, hydrogeology drilling technology, mechanical engineering, electrical engineering, process control, construction engineering, manufacturing etc.).

Environment and sustainability

Technical issues with regard to environmental aspects and sustainability need to be clarified and become available to the public domain. This will allow specific legislation to be developed and geothermal applications to become a standard tool for planning.

Table 8 - List of some short-term R&D-priorities to be addressed immediately

Timeframe	Priorities
up to 2013	• Better installation efficiency, reduced environmental impact and further increase of thermal efficiency of BHE systems (e.g. small borehole diameters, alternative installation techniques, applica¬tion of new materials, ...) • Understanding foundation heat exchangers ("energy piles", slabs etc., tunnels...) • Improving the use of the storage function of the ground in the framework of smart electricity grids and smart thermal grids (e.g. intermediate depth, integrated design, ...) • Shallow geothermal energy use in historic buildings
2014 - 2015	• Reduction of Borehole Thermal Resistance by means not yet tried • Provide ground design data for closed and open systems (e.g. use results of project Thermomap for representing such data, ...)

Table 9 - Summary list of shallow geothermal research priorities and targets

	Short term (2020)	Medium term (post 2020)
Basic research	Improvement to BHE materials	New (plastic) materials for BHE with enhanced thermal conductivity
	Improvement to antifreeze agents	New environmentally benign heat transfer fluids with low freezing point, low viscosity and high specific heat capacity
	Better understanding of thermal impact in building elements used as ground heat exchanger	
	Environmental impact of shallow geothermal applications	
	Short term (2020)	
Applied research & development	Improvement of BHE design and construction	
	Improved grouting materials (sealing, thermal conductivity)	
	Mechanised and optimised drilling and installation technologies (incl. mechanised grouting, quality monitoring, etc.)	
	Standardised installation technology for building elements as ground heat exchangers	
	Further development of heat pipes as BHE	
	For open systems, improved well construction and completion, injection well control, water treatment	
	Improved methods for determining underground parameters (TRT, geophysics)	
	Integrated design and modelling tools	
	Effect of open systems (groundwater) on hydrochemistry and microbiological composition of the subsurface	
Demonstration	GSHP and UTES plants with improved efficiency in different climate and geology, including improved control strategies	
	Hybrid applications with integrated planning and operation control	
	Use the storage function of the ground in the framework of smart electricity grids and smart thermal grids	
	Collect and provide ground design data for closed and open systems in easily accessible geographical databases	




4. Deep Geothermal

4. Deep Geothermal

4.1 Introduction

The contents of this part of the document are based on the research priorities decided by the working groups of Focus Group 2 (FG2) "Deep Geothermal Heating and Cooling Systems" of the Geothermal Panel, and the inputs taken from our meetings in Brussels, Munich and Pisa. It is based partly on the EGEC Research Agenda for Geothermal Energy: Strategy 2008 to 2030.

For each topic the current status is indicated and the potential for R&D is given. Each section highlights the topics deemed relevant with respect to future implementation and utilisation of deep geothermal heating and cooling systems[9], reviews the current state of the art, assesses the development potential, and defines research priorities accordingly.

It is also worthy to mention that geothermal research can be a benefit to other sectors, in particular in regard to material development concerning resistance in adverse high temperature, high pressure, thermo-chemically hostile environments.

4.1.1 Development objectives

It is clear that, in order to meet the development targets for geothermal power and geothermal heat, new resource and utilisation environments need to be explored and assessed, efficient production/conversion technologies designed and demonstrated, in addition to the extension of the life cycle of existing and future systems to secure sustainability requirements. The aforementioned aspects will be highlighted through selected case studies and development obstacles, constraints and incentives discussed accordingly.

Meeting those ambitious development objectives for geothermal heat (and geothermal power) requires that efforts do focus on the following priorities, based upon reliable assessments of recoverable reserve and upon sustainable heat production technologies:

- **Deep geothermal** (< 4000 m) - harnessing the huge medium enthalpy reserve and CHP (Combined Heat and Power) opportunities; implementation of district heating/cooling grids and other direct uses.
- **Ultra deep geothermal** (≥ 4000 m) - mobilise an ad-hoc task force for putting EGS on track, by first concentrating on the mid-grade, poorly convective EGS sites before tackling the low grade, conduction-dominated, EGS frontier[10].

For high enthalpy resources in volcanic environment, this depth classification does not apply. The key issues are illustrated in Figures 15, 16 and 20.

Last but not least, deep geothermal development requires that a large geothermal market be created and a geothermal industry structured. Although geothermal accomplishments scored well, thanks to extraction and conversion technologies mastered to mature stages, geothermal energy development in Europe is at a crossroads.

[9] Items pertaining to geothermal power production, in particular for the energy conversion in the surface installations, are covered in a separate document elaborated by a special experts group.

[10] EGS defined as Enhanced or Engineered Geothermal System, is an underground reservoir that has been created or improved artificially.

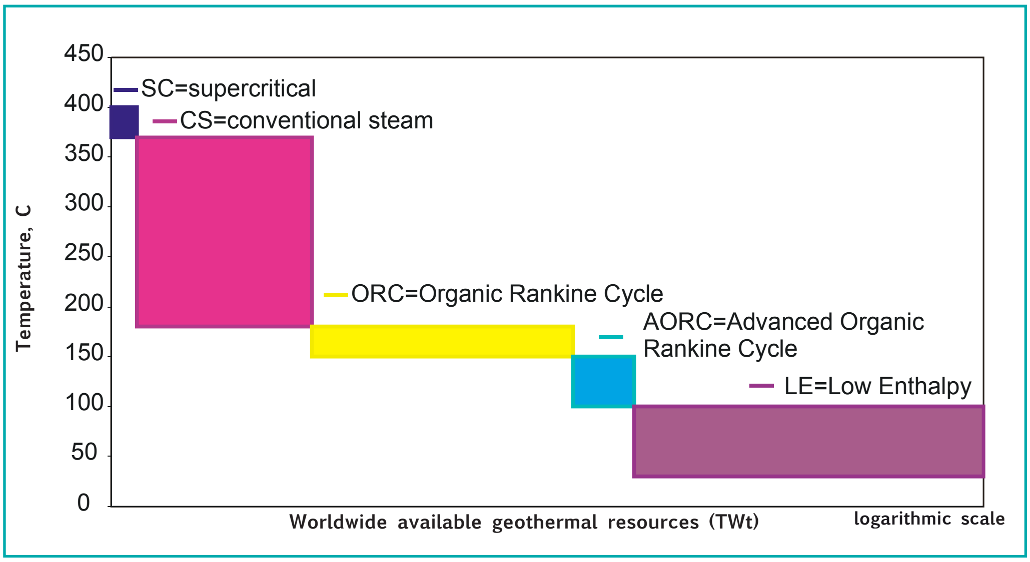


Figure 15 – Geothermal resource utilisation potential, a tentative assessment from P Ungemach (GPC-IP)

4.1.2 Resource environments

Europe exhibits a variety of geothermal resource settings, displayed in sketch map in Fig. 16, which relate to distinct geodynamic environments, namely:

- ***Large sedimentary units*** subdivided into:

• intracratonic (Paris–Hampshire, Aquitaine, Tajo, Castillan, Rhone–Languedoc, West Yorkshire–Netherland, North German, Danish, Warsaw, Thracean)
• orogenic belt foredeep (Pyrenean, Ebro, Caltanisetta, North Alpine, Po Valley, Apenninic, Carpathian)
• marginal/back arc basins (Pannonian, Transylvanian, Aegean)
These host, generally multiple, aquifer systems with normal, low and high geothermal gradients respectively, favouring direct uses, among which geothermal district heating holds a prevailing share.

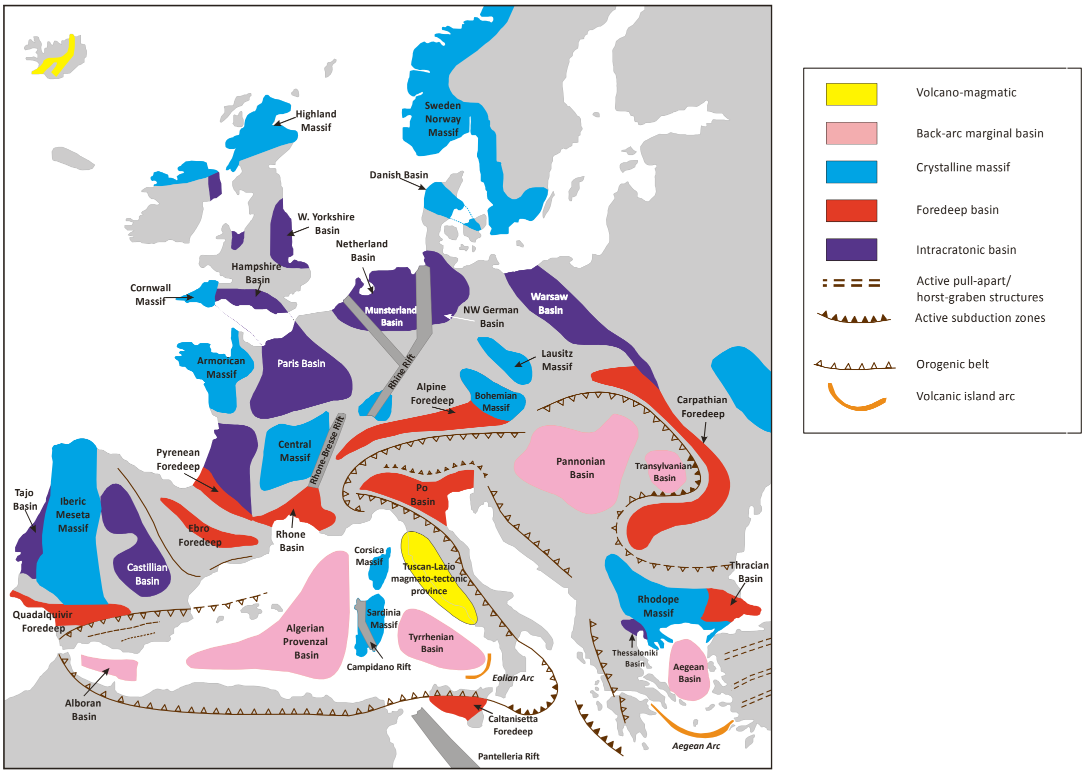
• ***Tertiary-quaternary continental rifts*** (Rhine Graben, Limagne, Rhone – Bresse, Campidano, Pantelleria) eligible to medium enthalpy/CHP prospects and, ultimately, to EGS developments. Two EGS plants in this setting are operating (Soultz FR, Landau DE), while one was abandoned during construction (Basel CH).

• ***Orogenic fold-belts and foreland platforms***, often associated with deep faults and upwards hydrothermal movements, thus creating medium enthalpy reservoirs. Provide ground design data for closed and open systems.

• ***Crystalline massifs*** (Iberic Meseta, Armorican, Central France, Bohemian, Rhodope) with hot springs and hydrothermal fault systems.

• ***Recent "in plate" Pliocene/Quaternary volcanism*** (Catalunya, Chaine de Puys, Eifel, Campidano, Susaki), regarded as candidates for medium enthalpy, if not EGS, projects.

• ***Active subduction zones, volcanic island arcs, active magmatic and recent or active extensional horst and graben structures***, excellent in high-enthalpy geothermal resources currently in production for power, and to be developed in the future.



EUROPEAN GEODYNAMIC SETTINGS
(after C. Sommaruga)

Figure 16 – European geothermal resource environments from P Ungemach (GPC-IP) & C Sommaruga

4.1.3 Scope of deep geothermal application

Deep geothermal heating and cooling (low and medium temperature/enthalpy) is currently produced by extracting the heat from ground and groundwater at depths and temperatures standing within 500 m -5000 m and 25 °C - 150°C, respectively. Direct applications are used in agriculture (horticulture, drying, crop processing), aquaculture, industrial processes and balneology. They are also widely applied in the district heating sector and can supply energy to combined heat and power (CHP) plants and drive absorption cooling heat pumps thus providing cold to a heating/cooling grid. The residual heat released by a geothermal power (flash or binary) plant can be used as a (downstream, cascading) source for driving a geothermal district heating/cooling system.

4.2 Resource Assessment

4.2.1 Introduction

The two principal goals are to promote basic research for creating high-quality public data bases to be used by follow-up commercial initiatives, and to propose a framework for pre-drilling basic research on geothermal resources, geochemistry and geophysics campaigns.

4.2.2 Creation of a European geothermal data base

The action here will be primarily to set up a user-oriented updated data base aimed at identifying and ranking exploration/development targets according to hydrothermal settings, well control and production risk. Issuing of a Reporting Code could complete this action.

- Potential for technological development
- Creation of a European geothermal resource data base
- Update of European Geothermal Atlas
- Evaluation of the EU EGS potential
- Reinterpretation of existing geophysical, geological, geochemical data, and acquisition of new data
- Methodological and technological developments

4.2.3 Exploration technologies for subsurface imaging

One goal is the identification, in a statistically meaningful way, of mean values and standard deviations of physical rock properties from exploration data (surface, borehole) as well as additional laboratory experiments.

The three dimensional delineation of geologic structure and characterization of bulk properties of geothermal systems are major goals for accurately evaluating the resource development potential, as well as for locating drilling targets. The determination of accurate borders of the reservoir is a significant legal issue as well, because of the exact authority permits.

An evaluation of technical and financial conditions for a further use of existing boreholes, tunnels and mines for geothermal exploration might provide further data acquisition opportunities.

- **Potential for technological development**

Development of innovative, cost-effective, subsurface imaging tools capable of investigating up to a depth of about 6000 m, including combined surface and airborne geophysical surveys and measurements while drilling, including rock and fluid sampling, with the following details:

- Reservoir identification for deep and very deep geothermal (< 4 Km and > 4 Km depth), in order to decrease the risk and the costs
- Resource assessment (productivity when related to the injectivity) at different scales: European, National, Regional, and Local
- In-situ analysis of reservoir properties, modelling of geothermal reservoir behaviour and management
- Application of new geological and geophysical methods (3D modelling, 3D seismic, magnetotellurics, etc.)
- Use of 'Global Monitoring for Environment and Security' (GMES)

4.2.4 Modelling tools for resource assessment and reservoir performance evaluation

Heat transfer processes and temperature distribution in the subsurface need to be better understood, as well as the stress field and fracture patterns related to fluid flow in the reservoir. 3D geo-modelling is an important tool for defining the boundary conditions for 3D reservoir simulations in view of assessing the performance of a future operated reservoir and its uncertainty.

• Potential for technological development

Development of innovative tools for realistic structural as well as flow and transport models of for predicting long-term fluid and heat extraction rates and their uncertainty, with the following details:

• Optimisation and further development of numerical tools for systematic measurements of the thermal, chemical, hydraulic and mechanical long term behaviour of geothermal facilities (especially hydrothermal and EGS facilities).

• Development of numerical modelling tools for modelling long-term geothermal reservoir behaviour (including economically viable options for reservoir management).

• Scale relevant experimental investigations of the principal processes dominating the geothermal reservoir behaviour under energy extraction in terms of optimisation of available resources.

• Improve prediction of borehole permeability and injectivity.

4.2.5 Exploration risk assessment and mitigation

Several risk factors (e.g. technical, financial, and environmental) need to be carefully evaluated during the exploration phase while the subsurface model is not well understood, the resource not completely proven and the development scenarios not yet clearly defined. In particular, seismic risks associated with EGS projects and ground deformation associated with exploitation of shallow reservoirs should be addressed and mitigation actions identified accordingly in stimulation planning.

It is assumed that in early exploratory stages a framework insurance policy would be promoted to mitigate the exploration risk. It should act as a stimulus until, after the initial high level risk be mastered, developers carry out exploration/development issues under their own responsibility and resources.

• Potential for technological development

Development of advanced approaches, guidelines and tools addressing exploration risk assessment and mitigation easing the decision making process

4.3 Deep Drilling

More than 50 % of the cost of geothermal plants is associated with drilling of wells (Fig. 17). Progress in drilling technology can help reducing the cost by 25 %. 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

4.3.1 Novel drilling concepts

Novel drilling concepts at the technological frontier are expected to allow for dramatic drilling time / cost breakthroughs in an unforeseeable future. The concepts should be investigated today, and basic (and later applied) research supported in order to have these techniques available for geothermal drilling in the medium/long term timeframe. A non-exhaustive list of concepts comprises:

- millimetre wave deep drilling

- hydrothermal and instant steam spallation drilling

- robotic, ultra-deep, high temperature/pressure drilling technologies

Other technologies as laser drilling and fusion drilling should first be analysed by reliable assessment studies to prove their basic viability.

• Potential for technological development

- Set up an (ad-hoc) evaluation panel

- Basic research and subsequent R&D for selected prospective technologies

- low-cost, proof-of-concept projects for new and innovative technological approaches

4.3.2 Current drilling technology

In order to make best use of current drilling techno logy, an assessment of the state of the art of hydrocarbon and mining drilling should be carried out, and fields which require specific solutions for geothermal settings being indentified.

• Potential for technological development

- Technology transfer from other deep drilling sectors to geothermal drilling engineering and practice

- Definition of specific geothermal requirements regarding drilling

Figure 17 – Drilling for geothermal energy in the Larderello area, IT

4.3.3 Improved drilling technology

Investigation of those topics likely to improve rates of penetration, cutting recovery, equipment/borehole integrities, prevent formation damage and reduce/mitigate technological risks, safety requirements and therefore ultimately save rig time, reduce costs and environmental impacts.

• Potential for technological development

- Low-cost, exploration only drilling technology
- High temperature (>150°C) directional drilling (DD) and measurement while drilling (MWD)
- Directional and horizontal drilling in general, casing while drilling, seismics and logging while drilling
- Continuous, flexible hose, drill lines, coiled tubing developments, application of composite thermoplastics below 3 km depths
- Improved drilling and installation technology for deep borehole heat exchangers (BHE)
- Mud jets with PDC (polycrystalline diamond compact) drill bits
- Deep air/foam balanced drilling
- High temperature, high pressure cement slurries
- High temperature, high pressure inflatable/metal packers for open hole and casing
- Mud logging/processing

• Improvement of drilling engineering design, crew/staff training

4.3.4. Optimisation of economics

Assessment and strategic planning of future EU geothermal heating/cooling markets and subsequent drilling requirements (rig force, crews, staff, engineering support) and budgets will allow for optimum allocation of technical and human resources.

Other topics for economic optimisation are slimhole vs. standard well exploration campaigns, approaches to early reservoir assessment/performance, guidelines for risk assessment/mitigation, methodology for economic projections and anticipated cost benefits.

• Potential for technological development

Elaboration of a coherent exploration/development strategy (objectives, timing) and of relevant tasks, rig forces and human resources with reference to district heating/cooling and CHP/EGS targets

4.4 Production technologies

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. These challenges are dealt with in the following paragraphs.

4.4.1 Material definition, well design and completion

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.

Well design has to target longer well life, optimisation of well delivery and productive/injective capacities, prevention of particle invasion and well/formation impairment, reduction of well maintenance and work-over cost. The well completion technology needs to be improved in order to fulfil these design goals.

• Potential for technological development

• Design and testing of high temperature, high pressure mechanically resistant metal, alloyed, composite materials

• Improved materials for tubing, cements, completions, well head

• Design of optimised production well completion in soft (clastic) deposits and hard (crystalline, metamorphic) rocks

• Optimisation of well geometry, side-tracks, multilaterals, horizontal legs

• Develop suitable injection wells for sensitive (sand, sandstone) reservoir settings (e.g. in the Pannonian basin and the North German - Polish basin)

4.4.2 Well stimulation, formation damage

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. Formation damage can be limited by avoidance (or mitigation) of plugging mechanisms and kinetics via adequate fluid processing and well completion design and critical sand face velocities. Remedial procedures need to be designed and secure, sustainable water injection achieved.

• Potential for technological development

• Design and field implementation of hydraulic, chemical, thermal stimulation techniques in selected rock and structural settings (sedimentary/stratified, volcano/tectonic, crystalline/metamorphic)

• Improved prediction and monitoring of chemical and hydraulic developments

• Field testing of candidate fluid handling processes/facilities, well completion, water sand control protocols and removal/remedial procedures

• Development of thermally activated/deactivated reagents

4.4.3 Corrosion and scaling

Corrosion and scaling are among the main problems during operation of deep geothermal plants, jeopardising plant efficiency and longevity. So it is of highest importance to combat corrosion and scaling, by preventing design shortcomings and securing well/equipment integrities.

• Potential for technological development

• Investigate further on scaling and corrosion processes, experiments to establish effect of lowering pH at high temperature

• Develop well and plant design with lower scaling and corrosion risk,

• Design and testing of candidate chemical inhibitor formulations (incl. stability tests), injection systems and monitoring protocols

• Selection of new environmentally friendly (“green”) inhibitors

• Selection of improved corrosion monitoring systems (e.g. Gamma transmission measurements), “early warning” methods, corrosion measurements in pilot projects

• Application of improved (e.g. composite) materials for pipes, screens, heat exchanger, etc. (cf. 4.4.1)

4.4.4 Downhole instrumentation, monitoring and logging

Downhole instrumentation is required for collection of reliable information on reservoir and fluid properties in actual, often adverse, geothermal environments. Also a wider utilization of geophysical measurement tools during operation is suggested. For sustainable operation, continuous in-situ measuring and recording of reservoir, rock and fluid parameters and properties is crucial.

• Potential for technological development

• Improvements to high temperature, high pressure downhole gauges for temperature, pressure and yield, fluid samplers and cables, and resident bottom-hole recording devices

• In situ / continuous well monitoring (e.g. using fibre optics): temperature, conductivity, flow, pressure, seismicity, fractures propagation, etc.

• Implementation of in situ hydraulic, thermal, mechanical and seismic monitoring systems on selected demonstration sites

4.4.5 Pump technology

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.

• Potential for technological development

• Development of high temperature resistant, high efficiency electrical submersible pumps (ESP)

• Improvements in line-shaft and submersible pump technology to increase flow and efficiency, and to enhance resistance against high temperature and pressure

4.4.6 Production management and retrofitting

Based on regional hydrogeological modelling, well and field exploitation can be optimised in compliance with sustainable management requirements. Sustainable and balanced operation of production and re-injection need to be ensured in the long term.

• Potential for technological development

• Field simulation scenarios, interference and tracer measurements

• Methods for investigating transit time from production to injection well, identification of different transport paths between production and injection wells

• Develop methodologies and materials for retrofitting (cement, casing, general reactivation, etc.)

4.5 Surface systems for direct heat uses and CHP

A growing interest towards utilisation of low to medium temperature geothermal resources for energy production in binary cycles and in cascading systems can be seen; there is a general consensus among the geothermal community that this market will develop extensively worldwide. Markets and energy "products" of this technology include:

• electricity production (in CHP)

• space heating and/or cooling, mainly in district heating/cooling grids (Fig. 18)

- greenhouse heating, aquaculture, drying of produce/crop/wood etc. (Fig. 19)
- industrial process heat
- spas and balneology,
- snow melting, seawater desalination, and other new applications

Cooling is a fast growing segment particularly in Southern Europe. Certain applications on different temperature levels can be combined into cascading uses, with the residual heat from one process being the input to a process at lower temperature.

Figure 18 – Plate-heat exchangers in a geothermal district heating station

This chapter focuses on energy conversion processes and surface energy chains. It is worthy to note, 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 demands costs, which requires the following priorities to be addressed:

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

Cutting down costs can be achieved by decreasing the unit power investment ratio (i.e. €/kW installed) and/or the operation and maintenance costs. Optimisation aims at upgrading both the efficiencies of components in the chain, and the cascading from high to low temperature users. The risk issue, being less critical than its counterparts in the fields of exploration and drilling, should address mitigation of the impacts in sensitive, natural and urban, environments.

Hence this chapter is targeted at optimising the sustainability and economic viability of geothermal electricity (CHP) and direct use heating/cooling undertakings, and increasing the market share. These objectives can be subdivided in five thematic areas:

• Energy conversion efficiency

Efficiency here is constrained, when compared to conventional fossil fuel fired power conversion cycles, by the low temperature level of the resource. The objective is to reduce this gap by bringing component efficiencies closer to their maximum physical figures (for the reference thermal level) at reasonable unit investment cost ratios.

• Residential, tertiary building market penetration

Here the priority is given to existing houses/buildings and cities intra muros. This requires the creation/implementation of adequately designed district heating/cooling grids and of low temperature heating systems within existing dwellings and buildings. On way to achieve this is by installing heating/cooling systems based on efficient floor heating and/or ceiling cooling. Cooling hardware generally is reaching a higher standard in modern thermal engineering designs. When dealing with existing, conventionally designed, homes and buildings, an economic solution would consist of substituting modern low energy demand heating (cooling) devices/processes, such as low temperature (natural or forced convection driven) convectors, for the obsolete high temperature cast iron radiators. Modern technology reversible heat pumps can add a significant input by adding cooling to a load previously devoted to heating alone.

• Cascading

It has been previously stressed that cascading provides a unique opportunity to optimise the overall chain/system efficiency in a sustainable and cost effective manner. It stimulates the design and implementation of new geothermal direct use concepts, with either centralised or decentralised back up/relief supply solutions. These can be based on three-pipe grids and heat pump applications, the latter particularly rewarding in retrofitting conventional heating systems often demanding high temperature. All these improvements aim at lower return temperatures and increased geothermal load factors. When contemplating higher enthalpy sources, CHP designs are preferable, as the allow for recovering the turbine outlet heat which would otherwise be wasted to atmosphere.

• Cooling issues

The cooling demand is considered to rise significantly as a result of improved housing/building insulation and increased standards for comfort in office/tertiary facilities. Absorption cooling driven by heat from conventional sources is energy consuming, costly and, above all, poorly efficient. Cooling from low-carbon geothermal energy can prove a rewarding substitute whenever source temperatures exceed 75 °C, in which case absorption chillers can be contemplated, or when associated with compressor heat pumps suitable for district heating and cooling applications. For individual buildings, such systems have already proven competitive in retrofitting of existing office buildings.

• High temperature heat storage

Inter-seasonal heat storage means sustaining deep geothermal reservoir life either as a result of injecting residual heat (hot water) from cooling in summer, thus recharging the resource prior to the next winter heating cycle, or in combination (hybrid mode) with other renewable sources (chiefly solar thermal) or industrial residual heat. Such systems, similar in principle to shallow aquifer thermal energy storage (ATES), require a careful assessment and monitoring of their thermo-chemical (e.g. scaling) and environmental (biochemical, water quality) impacts, as are mentioned also in the relevant paragraph of the Cross Cutting Research Priorities.

Implementation of the aforementioned aspects is presently clouded by non-technical legal, regulatory and institutional barriers, amongst others; all these matters need to be tackled in a dedicated working group.

Figure 19 – Agricultural uses of geothermal energy: Greenhouse heating (left, Romania) and animal food processing (right, Hungary)

4.5.1 Power cycles, CHP

Use of low-temperature resources in combination with flash and binary power units should enhance the energy output and use of the resource alongside return on investment. Research is required for increased energy efficiency, applicability at lower temperatures, and cost reduction. Energy conversion technology for geothermal power production is also covered, in more detail, in a separate document elaborated by a special experts group.

• Potential for technological development

• Improvements to conversion cycles (e.g. ORC, Kalina), efficiency of components, cost abatement efficiency increase (collaboration with the power sector)

• R&D on improvement of components (turbines, heat exchangers, generators, cooling devices, auxiliaries like gas separators, filters, insulations)

• In the medium/long term, overcoming some current barriers to improvement[11]

• Low to medium temperature CHP (combined power generation/district heating schemes)

• Cascade utilisation, integration with heat (or cold) supply via novel cascading concepts

[11] Available working media well analysed, little left for improvement of thermodynamic cycle efficiency; temperature drop over heat transfer surfaces already low, further improvement large heat transfer areas and pressure drops leading to parasitic pumping losses; turbine aerodynamic efficiency is very close to that attained in large steam and gas turbines, screw expanders have lower costs but their efficiency is lower

4.5.2 District heating, direct uses, cascading and storage

Market penetration calls for construction of new district heating networks, and optimisation of existing networks and plants, in particular in East/South-Eastern Europe and Turkey. A combination with geothermal CHP plants should be attempted, notably in EGS environments. High-temperature heat storage in the geothermal reservoir allows for integration with other renewable heat sources and residual heat, and can increase the capacity of source and grid. Development generally aims at increased energy efficiency, increased capacities, lower temperatures, and cost reduction.

Improved site assessment (e.g. using Geographical Information Systems, GIS) and exploration methods, and technological improvements for processes (drilling/completion) and components (e.g. downhole pumps) as described in the relevant chapters above will help to improve the economic feasibility of geothermal district heating.

• Potential for technological development

• Optimisation of district heating/cooling grids and their exploitation, novel geothermal district heating/cooling grid concepts

• Upgrade of heat/cold recovery via lowering the building/grid supply and return temperatures, implementation of low temperature heating systems in existing buildings/dwellings

• Development of suitable systems and components for optimisation of cascading structures using heat pumps

• Application of innovative concepts for geothermal energy use in agriculture, aquaculture, drying processes, desalination, industrial uses, snow melting and road de-icing, etc.

• Heat recovery from miscellaneous sources (mining waters, tunnels, air, abandoned oil and gas exploration/development wells)

• Investigation of behaviour and energy losses of high temperature heat storage in the reservoir

• As a non-technical issue, the dissemination of proven successful approaches need to be increased

4.5.3 Absorption cooling

Geothermal absorption cooling allows for cooling with low carbon footprint. Climatic conditions typically lead to increased cooling loads in low heat demand periods, thus for the geothermal system, adding cooling upgrades well delivery and balances the demand curve.

• Potential for technological development

• Increase the efficiency of the components (hot water driven absorption chillers) and reduce equipment cost

• Improve integration of the absorption heat pump / chiller into the system concepts

4.6 Enhanced Geothermal Systems (EGS)

4.6.1 Overview

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). The realm of EGS technology within the geothermal continuum is shown in Fig. 17.

At each stage of EGS development, proven methodologies can be applied and bottlenecks identified. From this state-of-the-art 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.

The proposed programme endorses the ENGINE Project[12] recommendations. The ENGINE outcome clearly emphasises that the prerequisite for disseminating EGS technology is the demonstration that the underground heat exchanger can be engineered independently from site specific constraints. The entire EGS R&D stream should therefore focus on this key issue.

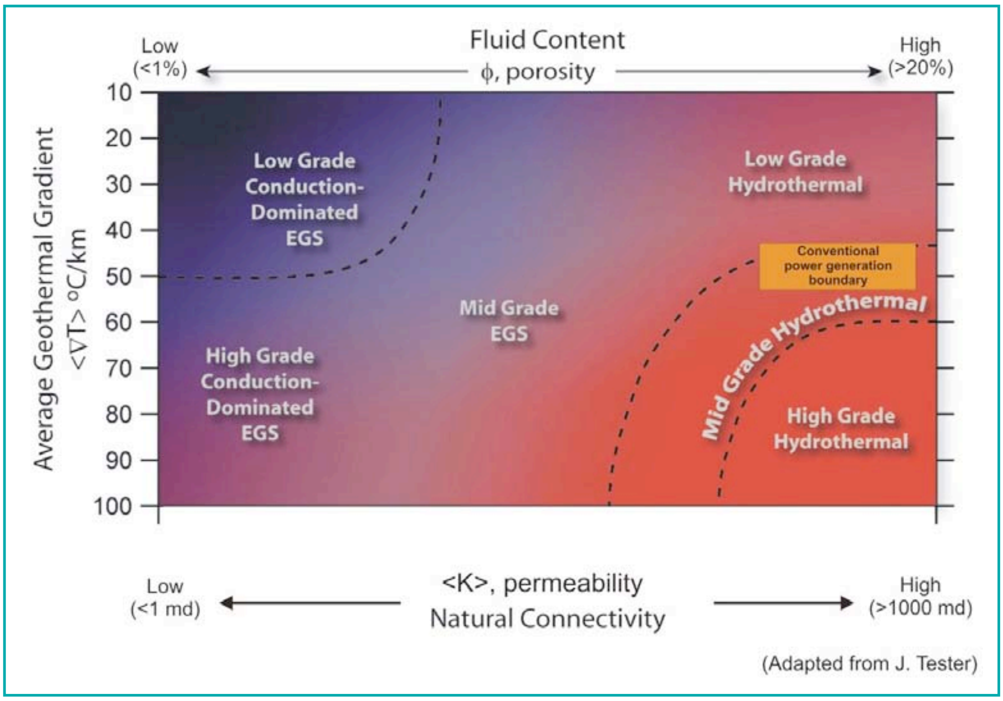


Figure 20 – Geothermal continuum - the EGS source adapted by P Ungemach (GPC-IP) from J Tester (MIT Report: 'The Future of Geothermal Energy')

The main areas defined for R&D on EGS comprise:

1. Exploration, easing access to potential reservoirs at depth
2. Geothermal wells, upgrading drilling and completion technologies
3. Reservoir engineering, stimulating reservoir connectivity and fluid convection
4. Exploitation, Improving efficient energy recovery processes
5. Monitoring, sustainable reservoir management

12 The ENGINE project (ENhanced Geothermal Innovative Network for Europe) was a co-ordination action supported by the 6th R&D Framework Programme of the EU, see: http://engine.brgm.fr

Research areas 1 and 2 have been already discussed in the chapters dealing with drilling and resources identification (4.2, 4.3 and 4.4), and research area 4 has been addressed in the previous chapter 4.5 on surface systems, as well as being covered in the dedicated document on geothermal electricity conversion. Research areas 3 and 5, regarded as the nucleus of EGS concept of heat production, are therefore addressed as a priority.

The R&D topics discussed in this chapter should enable the building up of a corpus of EGS state-of-the-art documents and standards, applicable to any deep and hard rock setting, whatever the singularities inherent to deep seated geologic structures. Such issues could in a sense help with bypassing the "mining" rationale (as inherent in exploration for conventional hydrothermal sources) of searching lithological and structural anomalies, by developing the deep underground almost anywhere (i.e. on accessible localities on land and shallow offshore). The EGS approach therefore can be regarded as a geothermal continuum, eligible to artificially enhanced convective systems.

Pilot test sites (Fig. 21) selected according to their geodynamic, geomechanic, tectonic and petrographic environments are required in a view to better appraise the behaviour of EGS reservoirs and define accordingly a set of guidelines of how to engineer and operate such artificially enhanced systems. The mechanism of microseismic events triggered during the build-up and early operation stage of EGS systems need to be understood and methods for prediction of these events developed, in order to mitigate their social and economic impact, and to accurately design and optimise the stages of both rock stimulation and reservoir exploitation.

Figure 21 - View from the current EGS installation in Soultz-sous-Forêts, FR, to the first drillsite from the 1990s (GPK1); the first sustained circulation over this distance was achieved in 1997

Heat production from a network of mining tunnels at great depth (several kilometres, in the extreme about 20 km) has been proposed as an alternative to reservoir stimulation used in EGS. Evaluation studies for these proposals have raised numerous questions and problems that can not be solved yet. The technical feasibility of this concept is not given with technology available today, and a realisation in the foreseeable future is doubted.

The challenge is straightforward: increase by one order of magnitude the world recoverable geothermal reserve. A considerable effort is required to assess the reliability and applicability of the concept. It should be the ambition to develop several co-generation (CHP) pilot EGS plants in the range of 5 to 10 MWe and 10-15 MWth, before encompassing the further industrial stage with ratings of 50-100 MWe and 100 MWth. Such accomplishments would be accompanied by relevant seismic impact assessment and mitigation to reconcile the public with a sustainable, innovative and environmentally friendly energy technology.

4.6.2 EGS environments

Elaboration of and agreement on a relevant nomenclature of EGS environments concerning geodynamic/structural settings, rock type (crystalline, metamorphic, tight sedimentary), and in-situ stress fields (compressive, extensional/distensive) is a prerequisite. Grouping of potential test sites sharing similar characteristics, which may lend themselves to a technological replication.

• Potential for technological development

- Assessment of potential EGS targets
- Selection of test and demonstration sites

4.6.3 Hard rock drilling technology and well completion

In addition to chapter 4.3, some specific development is required for drilling in very hard rock formations. Oil, gas and mining technologies might be adapted to EGS hard rock settings with focus on rock bits, bottom-hole assemblies (BHA) and deviation control. Expected benefits are faster drilling (rig time gains) and mitigation of technological risks with drilling.

Also in well designs (diameter, profile, casing) some specific development is needed for minimising of completion risk, well pressure and heat losses, and maximizing flow performance and well life.

• Potential for technological development

- Design and testing of hard rock drill bits
- Development of large diameter, high thermal insulation wells

4.6.4 Fracture identification, reservoir stimulation, seismicity

Rock stimulation aims at improving well and reservoir hydraulic connectivity, and at creating a large heat exchange area/volume. Simultaneously with suitably designed well architectures, it should ultimately achieve commercial flow performance (well delivery) and reservoir thermal life, therefore securing sustainable EGS exploitation. In so doing the in-situ stress field and the natural pre-existing state of fracturing play a decisive role with respect to fracture initiation, propagation and (self) propping. Strategies should be implemented which address the development of multiple parallel fracture paths, boosting fracturing pressure gradients (via for instance simultaneous well pressurisation, straddle packer isolated interval hydrofrac, chemical leading / self propping, etc.).

The risk of induced seismicity during EGS reservoir creation/development and exploitation need to be analysed and mitigation strategies developed.

• Potential for technological development

The following actions are recommended to address the issues associated with the reservoir creation:

- Development of methods for low-cost in-situ stress determination
- Development of high resolution imaging of natural and stimulated fractures
- Optimisation of stimulation technologies; hydro fracturing at reduced cost, implementation of innovative advanced stimulation methods and protocols (physical, chemical), reservoir stimulation at very high temperatures
- Improved creation and sustaining of large (self) propped, rock fractured volumes
- Microseismic / passive seismic monitoring, localisation and seismological assessment of crack morphology and parameters
- Resistivity monitoring/tomography, monitoring electrical potentials via kinetic and chemical processes
- Developing a slim-line high temperature directional borehole radar to investigate the structure and extent of the engineered reservoir
- Development of sensors (physical parameters, chemical tracers' analysis) and data telemetry to be run in deep geothermal boreholes
- Development of software suites (geo-modelling, hydrothermo-mechanical simulators) and hardware equipment (isolation, straddle packers, etc.)
- Development of global methodologies and software integrating tracer, thermal and geophysical data collection, processing and interpretation (as elsewhere successfully practiced by the oil and gas industry)
- Assessment of induced seismicity, development of mitigation strategies

▶ 4.6.5 Logging/testing/monitoring, reservoir modelling

EGS oriented measuring methodology has to be built up, addressing the phases of drilling/completion (high temperature logging, measuring while drilling), hydrothermal and hydrochemical well testing, well stimulation/exploitation (microseismicity, flow performance), and operation monitoring.

Reliable methods are required for assessment of heat exchange areas and volumes. Tracer technology can be used in testing the circulation in EGS reservoirs. This includes various forms of tracer tests to delineate the heat transfer area, the heat exchange volume, change in the reservoir impedance (should improve as the rock cools), and predict a possible development of preferential path (short circuit), so that measures can be developed to remedy this. Tracers also allow for studies of reservoir growth due to uncontrolled fluid losses and its effect on the generation of seismicity.

Concerning reservoir modelling, interactive calibrated simulations can be implemented enabling to match actual/monitored EGS reservoir behaviours and reliably forecast future pressure/ temperature/ flow trends and reservoir life

• Potential for technological development

- Development of hard rock logging tools and imagers
- Downhole pressure, temperature and seismic monitoring, fibre optics sensors
- Detection of fluid filled or realed in fractures
- Develop specific EGS well testing/tracing, improve the use of tracers for delineating the heat transfer area and exchange volume
- Development of new "green" tracers (selection, characterisation and stability tests of the new environmentally friendly high temperature geothermal tracers, development of analytical techniques in order to enhance the detection limits, development of techniques for on-line monitoring of selected tracer candidates)
- Develop interactive, 3-D, hydrothermo-mechanical simulation of EGS reservoirs

4.6.6 Sustainability, rock/water interactions

Lifetime predictions are required for EGS plants and reservoirs in hard rock and fractured environments. Heat transfer area and heat exchange volume will give some idea of the lifespan of the EGS reservoir, but reliable simulation techniques are crucial for better determination. Rock/water interactions can be critical for the long-term behaviour of EGS reservoirs (sustainability issue), the impact of chemical leaching need to be understood better.

• Potential for technological development

- Creation of a knowledge and experience base from monitoring of operating EGS systems
- Development of predictive simulations via calibrated/reproducible EGS reservoir models
- Studies on the effect of scaling and corrosion on the casing for EGS conditions
- Development of geochemical modelling of chemical leaching processes and fluid-exposed heat exchange areas, improvement of related tracer testing (absorbed, non-absorbed)
- Investigation of rock properties (heat, stress, geo-mechanics, etc.) and geochemical processes

4.6.7 EGS, further issues and summary

Most of the EGS resource base addresses the heat stored in deep seated, conductive/radiogenic dominated, tight sediments and hard crystalline basement rocks. The essence of EGS technology is the engineering of artificially enhanced geothermal reservoirs by stimulating these low permeability/low connectivity rock environments to recover a fraction of this vast dormant energy.

Recent EGS designs have replaced the former HDR (hot dry rock) concept of heat production, which aimed initially at connecting two wells, via a set of parallel (sub)vertical artificial fractures, by stimulating instead (pre)existing natural fractures and have them connected to production and injection wells. The primary objective of a commercial EGS plant is to sustain power and heat production over a minimum 20 years lifetime, according to the specifications outlined in Table 10.

Table 10 - EGS reservoir issues (for a target of 5 MWe /module)

LIFE OF THE SYSTEM	~ 20 Years
TEMP OF THE WELLS	~ 200 °C
SEPARATION BETWEEN WELLS	~ 600 m
PRODUCTION FLOW RATE	~ 75 Kg s-1
FLOW IMPEDANCE	~ 0.1 MPa L-1 s-1
WATER LOSS	~ 10 % MAX
THERMAL DRAWDOWN	~ 10 %
CONTACT SURFACE AREA	~ 10 million m2
RESERVOIR ROCK VOLUME	~ 300 million m3
INTEREST RATE FOR THE CAPITAL	~ 5 %
SUPPORT	No CO2 levy support

A distinction ought to be made at this stage between high grade and low grade EGS source settings. High grade EGS would normally address tight sedimentary formations exhibiting some matrix properties (low permeability, in the milidarcy range), generally overlying radiogenic granite basement rocks displaying no flow performance whatsoever, unless conductive fractures can be accessed via stimulated flow paths. These two settings coexist in the earlier assessed, as yet not developed, North Madrid Tajo Basin location and the upper Rhine Graben continental rift where two such EGS undertakings have been completed at the Landau and Soultz sites. The present outlook still rests below expectations as seen by Table 11 which looks at targets versus best so far accomplished records.

Table 11 - EGS targets vs. achievements. 2008 status

Topic	Economic targets	Best so far
System life	20 years	5 years (Rosemanowes)
Drilling cost	12 m€ for 6km well	5 m€ for 5 km (Soultz)
Temperature	200 °C+	270°C @ 2.2 km (Hijiori)
Separation between wells	600 m	600 m (Soultz)
Flow-rate	~ 75 l/s	26 l/s (Soultz)
Flow Impedance	0.1 MPa/l/s	0.29MPa/l/s (Soultz)
Water loss	10 %	0 % (Soultz)
Thermal drawdown	10 % after 20 years	
Contact surface area	10 million m2	
Reservoir rock volume	300 million m3	
Interest rate	~ 5 %	

EGS performance may be upgraded by circulating working fluids other than water, such as CO2, a topic already investigated. Owing to a higher mobility ratio, supercritical CO2 could secure much higher flow rates and subsequent heat extraction, in spite of a lower heat capacity; contrasted production vs. injection well head pressures would elsewhere boost thermo siphon circulation (buoyant drive), possibly saving the use of a submersible pump. Among the negative impacts are the faster cooling kinetics and more severe density segregation effects causing, if not carefully controlled at the production well, premature thermal breakthrough. Thermo chemical interactions with respect to sensitive mineral species and related super saturation/precipitation shortcomings require in depth appraisals for candidate EGS rock petrographic settings.

Present EGS know-how and findings may be summarised as follows:

- Fracture initiation and growth are governed by the natural fracture network and in situ stress field

- Low pressure shearing is the driving rock stimulation mechanism

- Low hydraulic impedances and large heat exchange areas, the so-called HDR paradox, are the key factors governing system efficiency

- Limited reservoir performance (≤2 MWe capacity) recorded so far

- System reliability merely site specific

- Social acceptance occasionally clouded by microseismicity induced during hydraulic fracturing and reservoir growth

In this respect, the striking differences noticed between the Soultz (distensive graben stress field, sub-vertical fracture pattern, low pressure system) and the Australian Cooper Basin (compressive stress field, horizontal fracture propagation, over-pressured reservoir) EGS sites ought to be mentioned, thus emphasising the need for a widened scope of EGS field assessments.

On-going and future research priorities should concentrate on:

- Upgrading hydraulic conductivity/connectivity and relevant EGS reservoir performance

- Identifying active heat exchange areas and stimulated rock volumes respective to the in situ stress field

- Securing reservoir life and sustainability issues

- Mastering induced seismicity according to stimulated reservoir growth, recorded natural background (micro) seismicity and (long) accumulated stress release

4.7 SUMMARY: DEEP GEOTHERMAL

A summary of the R&D priorities for heating and cooling from deep geothermal resources is given in tables 12 and 13.

Table 12 - Research priorities for deep geothermal

Short term (2020)	Medium term (post 2020)
Ressource assessment	
Well records & compilation, resource inventory and nomenclature update, resource/reserve reporting code, geothermal data bases	
Basin studies/reservoir evaluation, integrated geophysical/geochemical investigations	
Adaptation of hydrocarbon drilling advances	
Improvement of geothermal drilling, completion and testing practice	
Development of logging and instrumentation, measurement while drilling, etc.	
Development of high-temperature, high-pressure instrumentation, test lab	Test site for high-temperature, high-pressure instrumentation
Evaluation of candidate novel drilling technologies	Development of identified novel drilling technologies
Drilling	
Pumping (production/injection) technology, high temperature submersible pump technology	Pump technology resistant to very high temperature and pressure
Well head/pipe design, new well completion concepts	
Solutions to injection problems in selected clastic environments	
Material definition, development and testing	Material improvement
Corrosion and scaling inhibition	
Sustainability	
Surface installations / components	
Improvements in heating/cooling technology, new building heating/cooling designs	
Combined heat & cold production/distribution	
Retrofitting	
Heating and cooling grid designs (cf. Cross Cutting Research Priorities)	
Power conversion, efficient conversion cycles (binary)	Overcoming development barriers for efficiency improvement for binary cycles
Improved performance of high-temperature heat pumps and absorption chillers (cf. Cross Cutting Research Priorities)	

Table 13 - Specific research priorities for EGS

Short term (2020) to medium term (post 2020)
EGS nomenclature
Determination of in-situ stress
Hard rock deep drilling stimulation, enhanced stimulation techniques and adequate stimulation strategies to the configuration of every well
Deep drilling, high temperature-pressure instrumentation, well completion
Fracture mapping, assessment of heat exchange areas
Methods for investigating transit time from injection to production well, identification of different transport paths between injection and production wells
Microseismicity, induced seismicity
Rock water interactions
Interactive hydro-thermo-mechanical modelling
Sustainability

APPENDIX A – SECRETARIAT OF THE RHC-PLATFORM

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

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