EGEC´s response to the EC Public consultation exercise on

"Roadmap for a low carbon economy by 2050"

Brussels, 26.11.2010

Additional comments

VISION 2050

Sector: Geothermal heating and cooling

1. Introduction:

Per definition, geothermal energy is the energy stored in form of heat beneath the earth's surface.

Geothermal heating and cooling is currently produced in two different ways:

- The first one (very low temperature (enthalpy) up to 30°C) is based on the relatively stable groundwater and ground temperatures at typically shallow depths (up to 500 m) – and therefore also near structural elements of buildings. Typically, but not necessarily, heat pumps are used to raise the energy to the temperature level required by the heating, cooling, and ventilation systems for the thermal conditioning of spaces and processes. Heat is extracted from or conducted back into the ground by means of a heat pump, providing a certain energy input into heating, cooling and ventilation systems for the thermal conditioning of spaces and processes. In certain conditions and configurations, this system can be used to change ground temperatures artificially, in order to be used as heat or cold storage. UTES (Underground Thermal Energy Storage) represents a new growing market for combined heating and cooling mainly for commercial and institutional buildings.

- The second one (low and medium temperature-enthalpy) extracts the heat from ground and groundwater at higher depths and temperature varying between 25/30°C and 150°C. Direct applications are found in agriculture (horticulture, drying, fish-breeding...), industrial process, and balneology. It may also be applied to supply energy to a district heating or a combined heat and power

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installation or to drive local absorption heat pumps to provide cooling to the grid. District heating (and cooling) may also be supplied from residual heat left over after the production of electricity from a high enthalpy geothermal heat source..

2. Market evolution :

Trends:

Unlike the other renewable energy sectors, geothermal sector growth appears to be on the right track for reaching the White Paper objectives outlined for 2010. Starting with 1995 up to 2008 the annual new installed heat pumps had been increased by 5 times. The growth is non-linear (Fig. 1). This means that more than 100.000 systems had been installed in the year 2008 (Fig. 2).

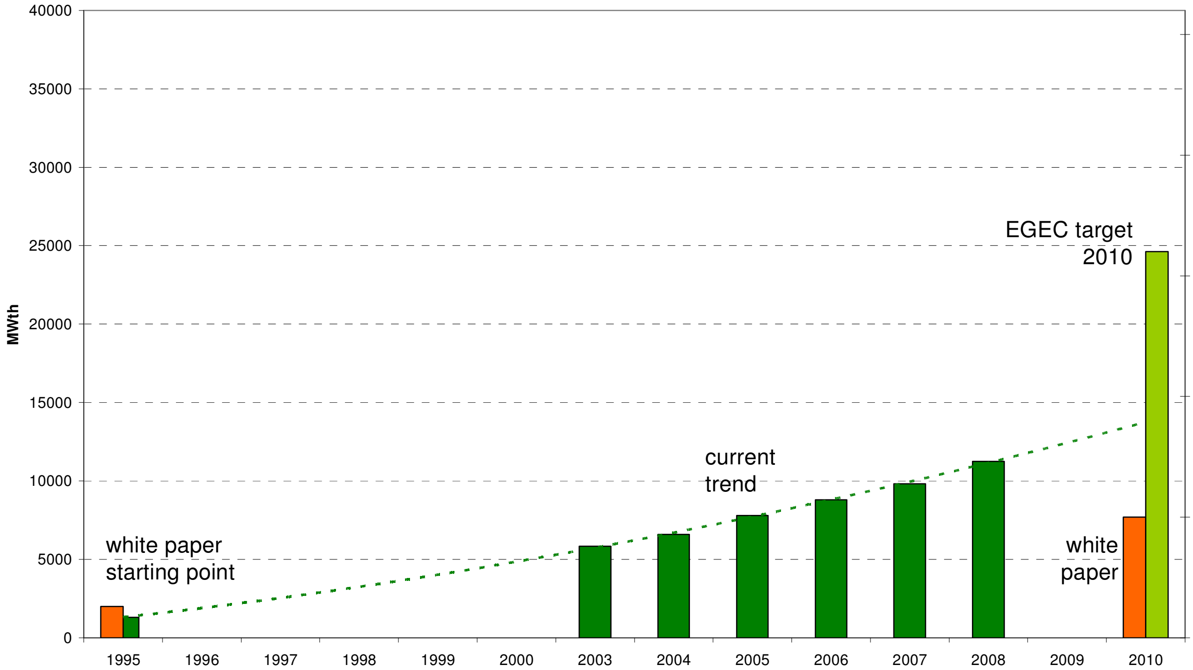

Fig. 1 : Annual installed capacity of geothermal heating & cooling

- **Geothermal heat pumps**

There are different types of geothermal heat exploitment systems.

- Closed loop applications (vertical boreholes)
- Closed loop applications (horizontal, shallow excavated systems)
- Closed loop applications (foundation integrated systems)
- Direct expansion
- Groundwater applications (well based systems)

The most popular one uses vertical collectors, others use horizontal collectors. Most of geothermal heat pumps exchange their heat with ground and groundwater and, in a less widespread way, even through the foundations of buildings (geothermal heat pumps on piles).

Among the different geothermal sectors, the geothermal heat pump industry is currently the most dynamic one. Low enthalpy ground source (the shallow systems) have been experiencing a rapid growth without the requirement of structural subsidies.

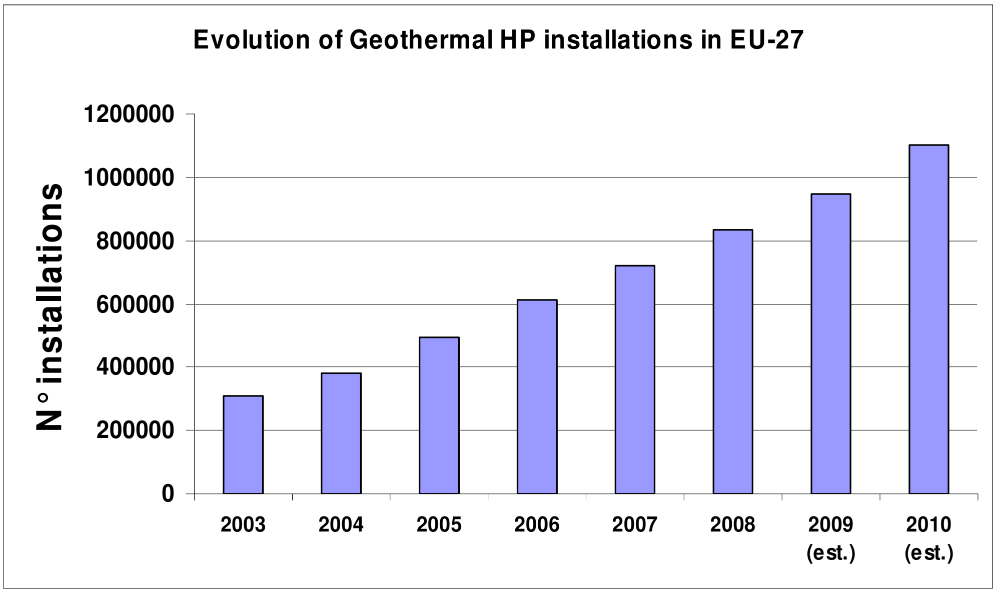

Fig. 2 : Annual amount of geothermal heat pump installations in the European Union

- **Direct uses**

In the European Union, applications linked to direct uses of geothermal heat are widely spread: 18 countries out of 27 use low and medium enthalpy geothermal energy.
Heat from combined Heat & Power installations represents a small percentage. The first low temperature power plants and EGS systems are currently just being installed.

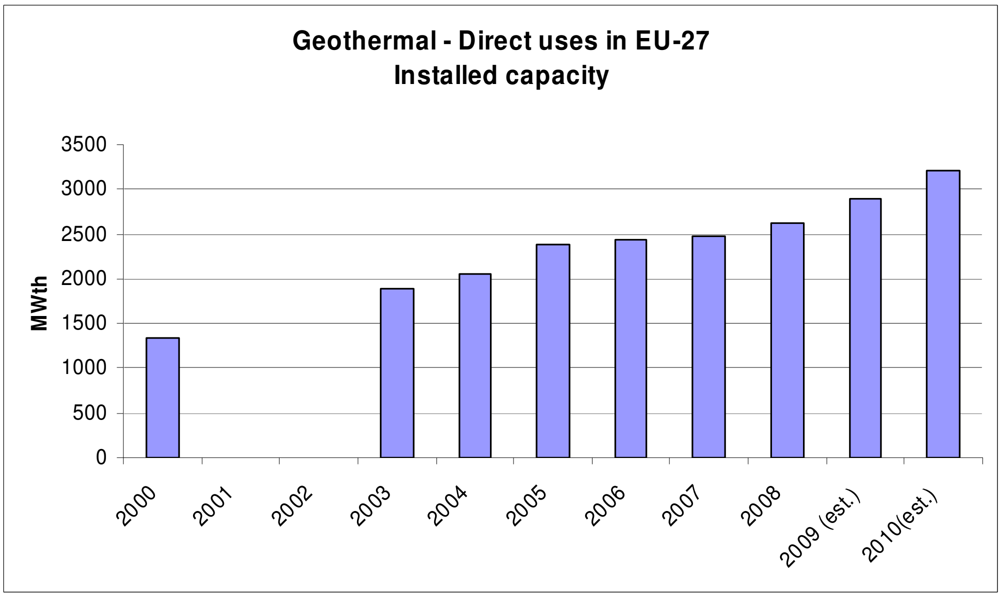

Fig. 3 : Total number of geothermal - direct uses installed capacity in the European Union

3. 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 heat stored at shallow depth without any geographical restriction.

- On the other hand, higher temperatures are available at greater depth everywhere, which constitutes a further resource for direct use. Producing from this resource is restricted by the investment and operating cost required to drill to this depth and the availability of the technology for producing this heat.

Currently, Geothermal energy is converted into electricity and used for district heating, as well as for heating (and cooling) of individual buildings, including both small and large schemes (offices, shops, residential houses, schools, greenhouses, bathing etc.)
A number of new and innovative applications of geothermal energy have been developed, and some of those have already been demonstrated (ice/snow-melting, desalination,…).

Existing houses represent an overwhelming share of the low temperature energy demand that logically can be supplied by 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 – needing the replacement of existing fossil energy based infrastructures - and require therefore longer development times.

But, at present, direct use of geothermal heat is subject to the availability of existing resources, as it is illustrated in the following map:

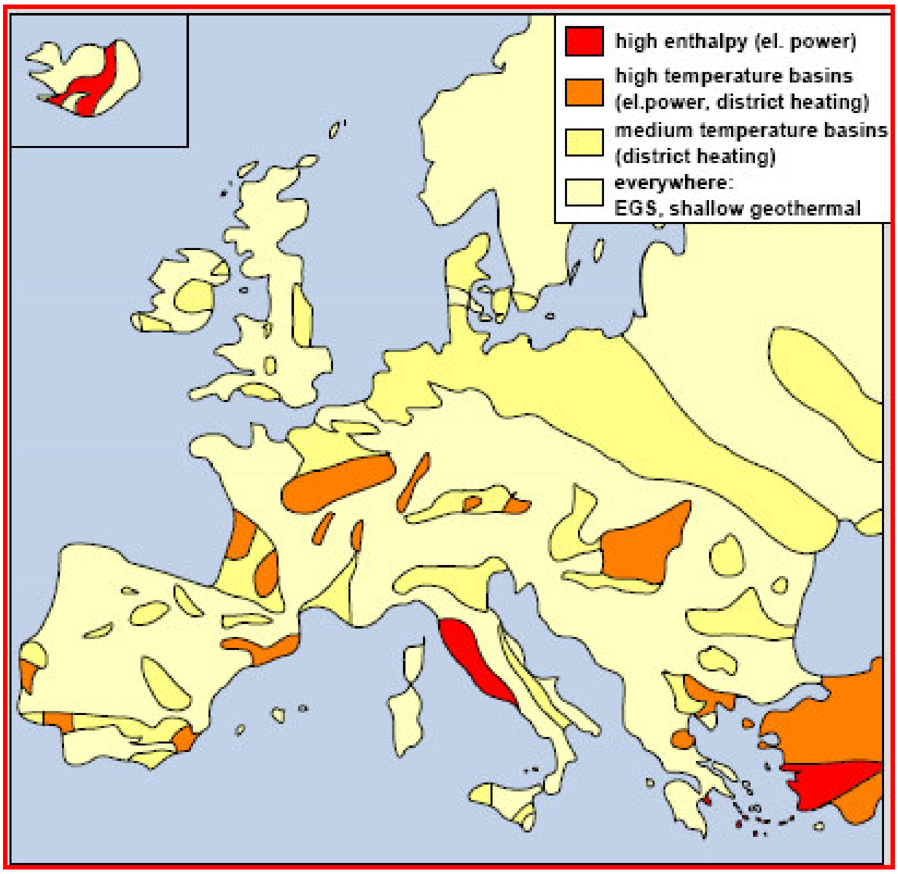

Fig. 4 : geothermal resources in Europe

The key challenge for the widespread direct use of geothermal heat will be the ability to reliably engineer the subsurface heat exchangers (EGS) in a reproducible way to harvest the heat flux at the required temperature.

Thus, to present the vision of the deployment of the geothermal heating and cooling until 2030 is nothing else than to describe the path and costs reduction that permit to go from the nowadays "hunter-gatherer" economy of geothermal energy to a systematic and optimized exploitation of geothermal resources.

The key steps for this deployment are indicated in the following tables:

Shallow geothermal source

Challenge	Impact	Time frame	Critical assumptions
Integrate geothermal energy as a standard in the housing energy system	Increased penetration of the geothermal heat pumps into the market for new residential and commercial buildings	2010-2020 : linear increase of the market share 2020-2030 : constant part of the market at some ten of percent	RES must become the standard in new energy efficient buildings in all countries.

Develop heating and cooling networks integrating geothermal heat pumps and geothermal storage (UTES)	Widespread of H&C networks based on geothermal energy.	Geothermal penetration : 2010-2020 : linear increase of the market share 2020-2030: constant part of the market of tertiary building and small H&C networks at more than 50%.	Rapid diffusion of H&C networks, which have to become the standard in urban planning
Develop geothermal solutions for retrofitting of existing infrastructure	Linear increase use of the penetration of the geothermal heat pumps in retrofitting of old buildings	2010-2020 : linear increase 2020-2030 : constant market share among retrofitted buildings at some ten of percent	Develop products and methodologies for cost effective building energy refurbishment. Higher performance of high temperature heat pumps, or adopting the buildings to low temperature space heating, Importance of improved energy efficiency standards as part of renovation activities to be stressed in buildings regulation

Deep geothermal source

Challenge	Impact	Time frame	Critical assumptions
Exploit favorable sedimentary basins for deep conventional geothermal energy at their full capacity	Systematic exploitation of deep geothermal where there is a resource and a potential use at the surface.	2010-2020 : rapid progression of geothermal projects 2020 -2030: increasing focus on existing urban areas and inner cities.	Environmental and social impacts mastered High exploration cost covered by incentives. Development of cheaper exploration-only drilling technology.
Deployment of EGS technology	Geothermal heat from CHP for industrial process and space heating and cooling	2010-2020 : first operations 2020-2030 : widespread implementation of the technology	Strong involvement of O&G and drilling industry Development of cheaper exploration-only drilling technology Development of large heating networks to absorb the heat

4. Vision for Short term (2020) and Mid term (2030) scenario

1) Costs perspective

Summary of Geothermal Panel targeted costs 2030:

Heating and Cooling	Costs 2009 Range(€-cent/kWh)	Average (€-cent/kWh)	Costs reduction by 2030 (% 2009 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 1-3 K € per kW for closed loop systems. When the capacity is over 100 kW (large residentials, tertiary buildings, schools, museums), open loop systems cost range is 0,5-0,8 K €.
UTES systems for commercial and institutional buildings as well as for district heating and cooling have a capital cost of 100-150 K € per MW_{th} (10% of the investment cost) referring to Swedish and Dutch experiences. The running cost is commonly 20-30 € 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 in Bavaria was estimated at somewhat over 1 million € per MW.

The Geothermal Panel, fixing research priorities for all geothermal technologies until 2030, estimates to decrease costs:

- by 5% for Geothermal District heating: reach 4 €-cent/kWh_h
- by 10% for Geothermal Heat Pumps: reach 5 €-cent/kWh_h for large systems and 9 €-cent/kWh_h for small systems

The general technological objectives of the Geothermal Panel are:

> increasing the information about the useful geothermal potential, amongst the various stake holders: end-users, advisers, authorities, etc

> for direct uses: improving plant efficiency, decreasing installation and operational cost. Transportation of heat for more than a few kilometers is currently uneconomical, the development of geothermal direct heating or cooling is subject to the availability of suitable geothermal sources close to the

user. Therefore the development of EGS is critical for a larger-scale development;

> develop EGS technology:

- exploration strategies and development of affordably priced, exploration-only drilling technology
- improvement of drilling technologies
- improvement of enhancement treatments bringing geothermal reservoirs to an economic use (following the EGS-concept) and sustainable use of EGS (investigate proppant technologies etc., developing)

> for Geothermal Heat Pumps: decreasing installation cost[1], increasing Seasonal Performance Factor (SPF) and optimization of the system (ground heat source/heat pump/distribution, gas driven heat pump systems for single houses), support of activities towards a decreased overall energy demand in buildings

> for UTES applications: diffuse the technology better, education and training of designers and installers and improvement of and standardization of design procedures and components.

Main research priorities for geothermal heating and cooling will be:

1) Combined Heat and Power: cogeneration with Enhanced Geothermal Systems and Low temperature power plants, micro cogeneration
2) Develop commercial deep geothermal projects for industrial use and agriculture applications, desalination and innovative applications
3) 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
4) Heat Pumps performance improvement
5) Underground systems testing devices and methods
6) Measuring consequences on the environment

The roadmap to overcome the technological challenges will be described in the Strategic Research Agenda.

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

2) Potential and market deployment

a) Up to 2020

Today, in 2009 Geothermal energy sources provides more than 10 GW_{th} for heating and cooling in the Europe Union, equivalent to more than 4 Mtoe per year, whereby geothermal Heat Pump systems contribute to the largest part. In EU-27, the contribution in 2020 will amount to around 40 GW_{th} installed corresponding to about 10 Mtoe.

- **Direct Use:** The most promising areas are the building of new district heating & cooling networks (Geothermal District Heating & Cooling, with 5 €-cent/kWh, is one of the most competitive energy technology), optimization of existing networks, and the increase of new and innovative geothermal applications in transport, industry and agriculture. The first development regions will be those blessed by the most accessible resources (for example the Pannonian, Tuscanian or Parisian basins) as well as higher grade resources where combined heat and power projects will be developed (e.g. the Bavarian Malm reservoir).
  A renewed activity for geothermal district heating and direct use can already be identified in France, Germany, Italy and the Pannonian basin countries, as well as from new areas like, the Netherlands Spain and Ireland. In addition the unit size of geothermal projects (linked to the production of an individual well) will direct project development towards existing or to be developed district heating or cooling networks. With absorption heat pumps, local cooling can 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 plants with low temperature installations and Enhanced Geothermal Systems will be developed. The sector forecasts predict to reach 6 GW_e in EU-27. A binary system (Kalina or Organic Rankine Cycle or similar) at low temperature has a simultaneous electrical and thermal capacity of ca. 5 MW_e and 10 MW_{th}, respectively.
  An EGS plant today has a capacity of 3-10 MWe, but future commercial plants will have a capacity of 25-50 MW_e and 50-100 MW_{th} (producing from a cluster of 5 to 10 wells, as in the oil&gas industry). CHP installations could provide heating representing 2 Mtoe by 2020.

- **Geothermal Heat Pumps**: The quantitative development of the European geothermal market in the next ten years is expected to be fuelled mainly through the introduction and consolidation of shallow geothermal systems, with a quite mature market in Sweden and Switzerland and developing markets in Austria, Germany and France.. In other emerging European markets in which a high growth is possible, it is expected over the next years (Italy, France, Spain, UK, Hungary, Romania…). Mature countries (namely Sweden and Germany) will see a steady increase, mainly fuelled 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 regularly neglected, have become very significant, and should be obviously taken into account in any energy development scenario.

Heating & Cooling - EU-27	**2007**	**2010**	**2020**
Shallow Geothermal (MW_{th})	5 700	11 500	30 000
Deep Geothermal (MW_{th})	4 100	4 500	9 000
Total Installed Capacity (MW_{th})	**9800**	**16 000**	**39 000**
Heat and Cold Production (Mtoe)	**2,6**	**4,3**	**10,5**

b) Post-2020

Targets set, by the Geothermal Panel, for the geothermal sector in 2030

Heating & Cooling - EU-27 (Mtoe)	**2007**	**2010**	**2020**	**2030 - Conservative[2]**	**2030 – Enhanced market[3]**
Geothermal Heat Pumps	1,5	2,3	6	*12*	*34*
Geothermal Direct uses	1	1,8	2,3	*6*	*12*
Heating from CH&P	0,1	0,2	2	*12*	*12*
Total Heat and Cold Production	**2,6**	**4,3**	**10,5**	**30**	**60**

[2] Business As Usual (BAU) scenario.
[3] Enhanced market by developing new technologies and new applications.

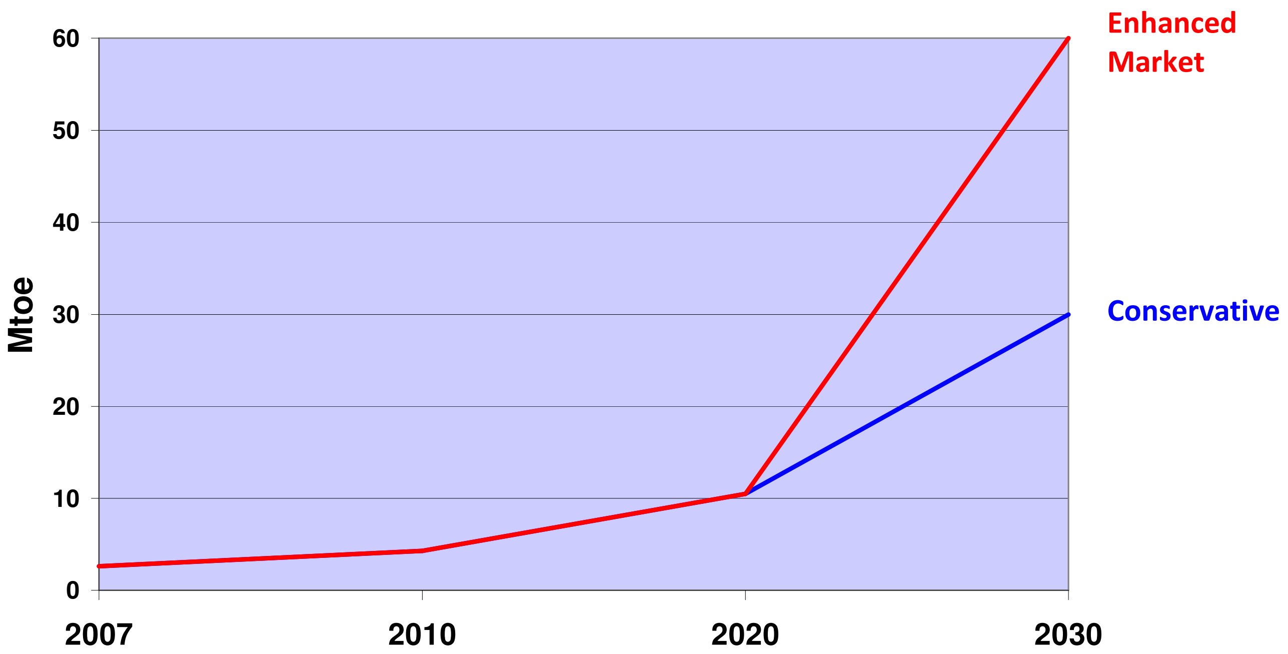

Fig. 5 : Geothermal Heating & Cooling Vision 2020-2030

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 developed for seasonal storage, with specific applications for waste 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. Thus these systems will become an important provider for heating and cooling for individual houses, commerce and services, but also for district heating and cooling.

Direct uses will be further developed notably for agricultural applications heating greenhouses. New applications for pre-heating in industrial processes necessitating high temperature will start to be installed.

The Enhanced Geothermal Systems, 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 dense urban areas.

The long term scenario (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.

Sector: A European vision for geothermal electricity

Introduction

This document is a draft document for the development of a vision of the European geothermal electricity industry.
Starting with the present situation, the Vision sets out in global terms how geothermal stakeholders see the future development of their industry. It reflects on the basic features of geothermal electricity production, on the way the systems are expected to evolve and how the industry and associated stakeholders should evolve to make it happen.

Challenged by climate changes, the need to secure sustainable economic growth and social cohesion, Europe must achieve a genuine energy revolution to reverse today unsustainable trends and live up to the ambitious policy expectations. A rational, consistent and far sighted approach to electricity supply is critical for ensuring such transformation.

Geothermal is the only source of renewable energy capable of driving a consistent and reliable (24h per day, 365 days per year) electricity production. Geothermal energy utilization is based on harvesting the continuous heat flux coming from the earth which represents 25 billion times[4] the world annual energy consumption, therefore representing an almost unlimited and renewable source of energy. The heat flux from the earth to the atmosphere if not harvested is otherwise lost.

It is available everywhere, this local electricity production will reduce the reliance on imports from unsecure suppliers, averting conflict between nations..

The lack of a secure and affordable source of energy is always highlighted as one of the reason for under-development; By removing dependence on fossil fuel imports geothermal energy allievates a big burden on developing countries' budget. In addition the integrated use of heat and power has shown to have an even bigger effect on job

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[4] The total heat content of the Earth stands in the order of 12.6 x 10^{24} MJ, and that of the crust of 5.4 x 10^{21} MJ, indeed a huge figure when compared to the total world energy demand which amounts to ca 5.0 x 10^{14} MJ/yr i.e. the earth contains enough heat to cover the needs of humanity for 25 billion years with present energy consumption rate, not counting its replenishment by radioactive decay of natural isotopes, which has been estimated as 30 x 10^{3} GW or approximately 2 times present worldwide energy consumption.. A very detailed estimation of the heat stored inside the first 3 km under the continents dates back to 1978, applying an average geothermal temperature gradient of 25ºC/km depth for normal geological *conditions* and accounted separately for diffuse geothermal anomalies and high enthalpy regions located nearby plate boundaries or recent volcanism. The high enthalpy regions cover about ten percent of the Earth's surface. The total amount of available heat is huge, about 42 10^{18} MJ. With the present world energy consumption the geothermal heat can be fulfill the world need for about 100,000 years.

creation due to the spinoffs for the application of that heat (green houses, fisheries, food processing, refrigeration, etc).

This document aims to draw a realistic picture of how a European Geothermal Electricity production industry can be built, in the mean time developing a reliable and sustainable sources of energy and providing numerous jobs for all kind of qualifications across the area.

By 2020: Establishing the base of a European geothermal industry

- Develop the hydrothermal resources in Europe from the known High enthalpy resources (Italy and ultra peripheral regions), and from Medium enthalpy resources (e.g. Pannonian basin), and also on non-EU countries (Turkey and the Caspian area, African rift, South America, etc.). This last aim is attractive for Europe's balance of payments where exporting is important
- Expand the EGS concept in the different regions and geological conditions of Europe through the construction of power plants and direct uses of heat, thus maintaining the leadership in this new technology development. This also includes the development of a more efficient binary cycle for low temperature resources.
- Establish the basis of a European model of geothermal power plants in harmony with the environment: medium size plants with fluid re-injection to minimize the impact on landscape, environment and the Grid, and to maximize the benefit to communities through an innovative use of rejected hot fluid from the power plant.
- Launch EU wide exploration programs to allow optimum funding allocation between the different underground potential uses (including geothermal, gas storage, O&G exploration and production, mining nuclear waste repository and carbon storage)
- Europe has pioneered electricity the exploitation of geothermal resources for over 100 years in Larderello and the EU still maintains a leading role due to the development of EGS technology in many parts of the EU with the integration of national projects (in UK and Germany) into a European Project at Soultz-Sous-Forêts (France). In addition, the EU has the first successful commercially funded EGS project in Landau (Germany). All efforts need to be maintained to keep this leadership in developing the geothermal industry of the future, both for research and commercial development

By 2030: toward a competitive source of electricity

- Bring down the cost of EGS plants thanks to technical developments to become competitive with other sources of energy.

- Start implementation of massive construction programs to replace ageing and increasingly costly fossil fuel based power plants, starting with the most promising areas
- Transfer EGS technology outside Europe in areas lacking hydrothermal resources thanks to the technical expertise developed and the capability of the European industry to develop large engineering projects around the world.
- Develop mature technologies for exploitation of supercritical fluids and temperatures, and start exploitation of large off-shore geothermal reservoirs.

By 2050: a substantial part of the base-load electricity supply

- By that time technology will allow EGS to be developed everywhere at a competitive cost, the challenge will then be to implement it widely and quickly enough to capture a large market share from other type of base-load power plants (Coal , nuclear, fuel, etc) in Europe and outside Europe.

Today

What is geothermal electricity production?

The systems for geothermal electricity production can be subdivided in three large categories, which are also linked to the temperature ranges:

1) 80°C<T<180°C (Medium Enthalpy resources): this range of temperature is appropriate for use with binary plants (Organic Rankine or Kalina cycle), with typical power in the range 0.1-10 MWe. These systems are also suitable for heat & power co-generation, typically for single edifice to small towns heating.
2) 180°C-390°C (High Enthalpy resources): temperatures in this range can be exploited with dry steam, flash and hybrid plants, with typical power in the range 10-100 MWe. These systems, characterised by high efficiency up to more than 40%, also allow heat co-generation for large towns district heating. Above 200°C, these resources are generally limited to volcanic areas.
3) 390°C-600°C (Supercritical unconventional resources): temperatures in this range, limited to volcanic areas, generally involve superheated dry steam plants, with power per unit volume of fluid up to one order of magnitude larger than conventional resources.

Besides the temperature range, the methods of exploitation of geothermal energy can be further subdivided in two large categories:

a) conventional hydrological systems, which use the natural aquifers
b) EGS (Enhanced Geothermal Systems), which use the high temperature of rocks with artificial water injection and, generally, with enhancement of permeability

of the hot reservoir. An Enhanced Geothermal System is an underground reservoir that has been created or improved artificially.

A total of ca 530 geothermal units all over the world were reported online in 2010. The maximum addresses 236 binary plants, totalling a 1178 MWe installed capacity (i.e. a unit 5 MWe plant load). The sizes of flash and dry steam plants average 31 MWe and 44 MWe respectively.
In the EU, the total installed capacity is ca. 850 MWe, generating about 7 TWh in 2010. Main production comes from conventional geothermal systems in Italy. Recently, binary power has been produced in Austria and Germany from low temperature geothermal sources and in France and Germany from EGS.
At present, projects representing a total of 400 MWe are ongoing in the EU (EGS and low temperature power plants).

Hydrothermal
As far as conventional geothermal electricity is concerned, the vast majority of eligible resources, in Continental Europe at large, is concentrated in Italy, Iceland and Turkey.
There are two major geothermal areas in Italy, Larderello-Travale/Radicondoli and Monte Amiata respectively, achieving a 843 MWe installed capacity in 2010. Projects, adding a further 100 MWe capacity, have been commissioned and will be completed in the near future.

Iceland is increasing its electricity production, which reached a 575 MWe installed capacity in 2010. Although significant, this capacity ought to be compared to the huge potential of the island, estimated at ca 4000 MWe. This country has recently started pioneering researches about the exploitation of supercritical fluids, able to increase of one order of magnitude the power output of geothermal wells.

Turkey's geothermal resources are mainly located in Western Anatolia on the Aegean sea façade. Some geothermal power plants have been recently installed. The national geothermal electricity potential has been (conservatively) estimated at 200-300 MWe.
In Greece, proven shallow high temperature geothermal resources are located in the Aegean volcanic island arc, in the Milos (Cyclades) and Nisyros (Dodecanese) islands. Recent volcanism and abundance of hot springs indicate the presence of high enthalpy resources at 2-4 km depth in many other places.

A similar situation exists in the small fields of the Guadeloupe and Azores volcanic islands. At Bouillante (Guadeloupe, France), a small, 4.7 MWe rated, plant was built in 1984. Its capacity has recently been increased to 15 MWe.

In the Sao Miguel Island (Azores, Portugal), 43% of the electrical production is supplied, from a high temperature (230°C @ 1200 m) saline brine, by three flashed steam plants (23 MWe total installed capacity) online since 1980. An additional 12 MWe capacity is scheduled in the near future.

In Spain, good perspectives can arise from the exploration on the volcanic systems of the Canaries islands, where a potential of about 50 MW can be assumed.

Binary plants

Recently, binary power has been produced in Austria, Turkey and Germany from low temperature geothermal sources. The conversion process which consists of vaporising a low boiling point working fluid, either a hydrocarbon or refrigerant -Organic Rankine Cycle (ORC)- or an ammonia/water mixture- Kalina cycle- raises considerable interest as it makes it possible to produce electricity from cooler geothermal sources (typically within the 100-120°C temperature range, exceptionally down to 70-75°C depending upon the availability of a cold water source for re-condensation of working fluid). However, no high plant ratings can be expected for obvious thermodynamic reasons. Hence, improvements should concentrate on cycle and plant efficiencies along side cogeneration production. As a result, two development routes are contemplated

(i) plant designs targeted at 5 – 8 MWe CHP or power only capacities presently under development in EU, higher than the medium binary plants installed capacities

(ii) small plant designs targeted at 1MWe/2MWth CHP capacities, close actually to those implemented already in the EU [(0.5 - 3 MWe) / (1-6Mth)], and

(iii) a microgeneration standard for small scale ORC modules (200 kWe – 1 MWe)

EGS

To the question of how could geothermal energy expand its power market penetration share, the EGS issue is the answer. The rationale behind the concept is the following: whereas drilling technology is in the mature stage and efforts dedicated clearly to reducing its costs, stimulation technologies of geothermal rock environments are still in the pilot stage. There exists many geothermal prospects enjoying high temperatures but lacking sufficient rock permeability to allow fluid circulation. Such tight rock, poorly conductive, systems could be turned into technically and commercially exploitable reservoirs, provided their permeability be enhanced by engineering adequate stimulation procedures, such as hydraulic fracturing and acidising. Development of these technologies will make it possible to access a huge geothermal potential.

An EGS plant today has a capacity of 3-10 MWe, but future commercial plants will have a capacity of 25-50 MWe (producing from a cluster of 5 to 10 wells like in oil&gas industry).

Among the ongoing EGS projects worldwide, the Soultz European pilot site is in the most advanced stage, providing already an invaluable data base. A critical aspect of the EGS technology addresses the seismic hazards induced by the hydraulic fracturing process. Commercial exploitation in Europe has already started in Germany and the UK but these are at 3-10MWe scale. Te driving force is the large potential for non hydrothermal countries and the financial tariff proposed by some Member States. EGS has large potential and much wider applications for many of the EU countries.

EGS technology is also being applied to hydrothermal projects to maintain sustainability by reinjection and expansion of dry field on the periphery.

EGS is the technology to move the industry from a resource base industry (targeting the most productive spots) to an engineering based industry (capable of reproducing installations reliably and consistently in all sort of environments).

Cascade use benefits

The possibility, present only for geothermal energy among all the other renewable ones, of an integrated exploitation of electricity and heat, through a cascade approach, is a key element for the success of the technology and for its penetration deeply inside the energy market. The cascade utilization increases the overall utilization of the geothermal energy, with a better total efficiency and important economical benefits. The following are only the most important cascade applications present in the today market (in some cases, electricity may be not present in the scheme, even if the heat content of the fluid is exploited in steps):

- District heating and cooling
- Industrial processing
- Green houses, fisheries
- De-icing, tourism, spa bathes

European Geothermal Industry stakeholders:

<u>Direct players</u>

- Municipalities: e.g. Unterhaching
- Utilities: Major (ENEL, EnBW, RWE), regional (ES, Pfalswerke),
- Private developers: e.g. GeoEnergie Bayern, Exorka, EGS Energy, Petratherm, Geothermal engineering ltd, Martifer...
- Subsurface suppliers: consultants, drillers, services companies, suppliers
- Surface suppliers: consultant, engineers, electricity suppliers, turbine and turn-key binary plants manufacturers, contractors
- Public institutes: Geological surveys, Universities, Research Institutes, policy makers and regulators
- Financial services, lawyers, insurances

Indirect geothermal electricity stakeholders

- Cascade users of heat
- Civil, works and electro-mechanical contractors for whom smaller plants (compared with fossil fuel or nuclear) may mean easier access to the market.

The missing players: oil and gas companies (Total, Shell, BP, Wintershall, Statoil), most utilities (EDF, GDF Suez, Dalkia, etc), large engineering firms (e.g. Technip, Dornier, etc). All of them have a role to play and effort should be made to involve them.

2010/2020: Laying the foundations of a European geothermal industry

Hydrothermal (high enthalpy resources, flash/dry steam plants)

- Development of Italy and ultra peripheral regions (Guadeloupe, Martinique, Azores, Canary Islands, etc) to get the most of the existing exceptional resource (Iceland?) and be used as a show case and base for export in other hydrothermal regions.
- Develop projects in & out of Europe to leverage industry capabilities in term of exploration, project management, financing capability, etc

Hydrothermal (medium enthalpy resources, binary plants)

- On medium and low enthalpy resources (e.g. Pannonian basin)
- Or in combination with steam or flash plants on high enthalpy resources
- Hybrid plants (Geothermal + waste heat or biomass or solar thermal or gas) to optimize efficiency, repeatability and consistency and minimize uncertainty of well heat flux when ordering the surface equipment.

EGS (binary plants)

- Continue development of commercial demonstration plants to validate the concept in all conditions thanks to governmental incentives (feed-in tariffs, green certificates) and risk mitigation schemes (insurances)
- Increase plant size to optimize cost (exploration, drilling, site, etc)
- Establish the base of a financial costing model
- Establish the basis of a European model of EGS plant:
  - All wells starting from a single drilling pad to minimize surface impact during drilling and operations.
  - Minimal surface occupation (possibly water cooled rather that air), building integration
  - Maximize cascade use with innovative proposal for optimal economical and social benefits
  - Possible combined source of heat (waste heat, solar thermal, biomass or gas) to optimize efficiency, repeatability and consistency and minimize uncertainty of well heat flux when ordering the surface equipment.
  - Possible use of CO_2 as a geothermal fluid

    - Master induced seismicity
- Experiments on supercritical EGS

Exploration

There are at some moment some competition between geothermal use and other use of subsurface resources like oil and gas exploration and production, gas storage, carbon sequestration, or mining activities as well as some concerns with environmental impacts and in particular micro-seismicity associated with all subsurface activities. Therefore authorities should launch or optimize regional subsurface exploration programs, going as deep as possible to clearly identify all possible usage of the resources and allocate them in the best interest of the community. Resources allocation may be decided after debates and tendering with schedules and commitments. Such effort would further minimize the main investment risks and act as a strong incentive for private investors.

These geothermal resources surveys (exploration plans) may be managed by national geological surveys (or Universities, Research Institutes etc.) when they have the capabilities, if not they could be outsourced to other GS or private companies. Financing by the authorities (regional, national or European) may be the only way to make sure data are evenly shared to guarantee a fair resource allocation.

Exploration should include the development of a network of dense seismic monitoring networks, to get a better understanding and mastery of possibly induced seismic phenomenon as well as identify and avoid high risk areas.

2020/2030: Making EGS a competitive source of Electricity

Hydrothermal

In 2020, it is very likely that most hydrothermal resources in Europe will be exploited, then potential should be in other countries blessed with such resources but with less technical and financial capabilities to develop projects by themselves. This will be the continuation of the move already started in the previous period, and experience gained in the early days will certainly be very valuable (e.g. ENEL or Icelandic companies). Binary plants, possibly in combination with traditional steam or flash plants shall be the standard for optimal use of heat.

EGS

EGS plants should be present all over Europe and in various places in the world thanks to governmental incentives to compensate for the higher drilling cost and lower heat flux, the challenge is now to bring the cost down to be competitive with other comparable sources of energy.

Technology development in exploration, drilling and well optimization should improve ability to detect from surface the most promising zones (naturally open fractures), predict and optimize fracture propagation, locate the next wells and eventually get the necessary high flow and temperature to make projects viable. Technology should also allow to possibly targeting deeper zones at higher temperature (higher heat flux as well as increased conversion ratio).

Note: Add a few sketches showing cost decrease with flux and temperature.

Progress in the engineering, design and number of well per project also has dramatic effect of drilling costs (in the oil and gas drilling there is commonly a 40% reduction in drilling cost between the first and the 5^{th} or 6^{th} well for a project done by the same team in the same location). This will be an immediate benefit of the size increase of projects, in the mean time novel technologies (spaliation, laser, etc) may also bring additional benefit as well as research made by the oil and gas industry for the drilling in hard rocks.

In the mean time it is expected that fossil fuel electricity production cost to increase both from the effect of fuel price and from the obligation to avoid carbon emissions (CCS is expected to increase electricity price by 25 to 30% compared with present situation, due to a combination of higher fuel demand and higher plant cost).

In terms of cost, the estimated current cost of EGS electricity generation from the first-generation prototype plants is of the order of € cent 20-30/kWh. A continued reduction in cost through innovative developments, learning curve effects and co-generation of heat and power should lead to an electricity cost of around or 5 euro cents /kWh. A dry steam power plant today produces electricity at ca. 5 eurocent / kWh, a flash power plant at 8 euro cents / kWh and a Binary-ORC systems at 10 euro cents / kWh. Industry believes that this cost can be reduced by more than 25% in improving drilling technologies and with better resource identification.

2030/2050: Powering Europe and the world from geothermal

Hydrothermal

In 2030, most hydrothermal resources shall sustainably exploited in Europe and in most countries, the market will be mainly related to the maintenance of existing capacities: work-over and replacement of existing wells, improved surface equipment with higher efficiency. However by 2030 the geothermal market for geothermal production should be EGS.

EGS

By 2030, EGS should be a mature technology capable of providing a reliable, sustainable and competitive source of energy in all area. The challenge will be the implementation all over Europe to replace the ageing existing power production infrastructures.

At present one of the bottleneck for geothermal development is the lack availability of drilling rigs and subsequently the cost of drilling. To reach an objective of 20% of Europe primary energy supply by 2050, an average of 15 drilling rigs dedicated to geothermal should be brought to the European market every year between now and 2050. This is a very large number when compared with the 5 to 10 rigs currently involved in geothermal activity in Europe today, but nothing when you compare with the 3500 rigs operating worldwide for the oil and gas industry.

This means the manufacturing of the rigs but also the development of all associated services representing a big challenge for recruitment and training but also a major opportunity for job creation.

The Geothermal have the resources to supply at least 20% of Europe Global Energy consumption in 2050. The technology is available, should be proven all over Europe in various geological conditions by 2020 and become competitive with other sources by 2030. For large scale development there may be need of some kind guidance / direction with objectives put in place by the authorities to make things happen at this scale.