RESEARCH AGENDA FOR GEOTHERMAL ENERGY

Strategy 2008 to 2030

Preliminary Notes

The European Geothermal Energy Council (EGEC) prepared a list of priorities for Research and Development (R&D) in the geothermal sector. The paper was discussed during the workshop organized by EGEC the 05/09/2008 in Brussels.
A list of main priorities has been selected and proposed in a first consultation document issued in October 2008.

The conclusions are now presented in the final version of the Research Agenda, integrating the inputs received.

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Introduction

The R&D topics proposed here aim at reducing the costs to (attract more financing and so) reach for 2020 and beyond the targets forecasted for geothermal energy:

- Heat production for all Europe = 11 Mtoe
- Electricity production for all Europe = between 40 000 and 80 000 GWh/y

Objectives:

- R&D for heating & cooling
  > increasing the knowledge about the usable geothermal potential,
  > improving plant efficiency,
  > decreasing installation and operational cost
  > Geothermal Heat Pumps: decreasing installation cost, and increasing Seasonal Performance Factor (SPF), optimization of the entire system (ground heat source/heat pump/distribution)

- R&D for electricity:
  > Develop enabling technologies for the exploitation of geothermal resources
  > Prove the sustainability of Enhanced Geothermal System(EGS) technology
  > Develop enabling technologies and demonstrators for the microgeneration and co-generation with low temperature water (<120°C), also in hybrid plants (e.g. biomass and geothermal).

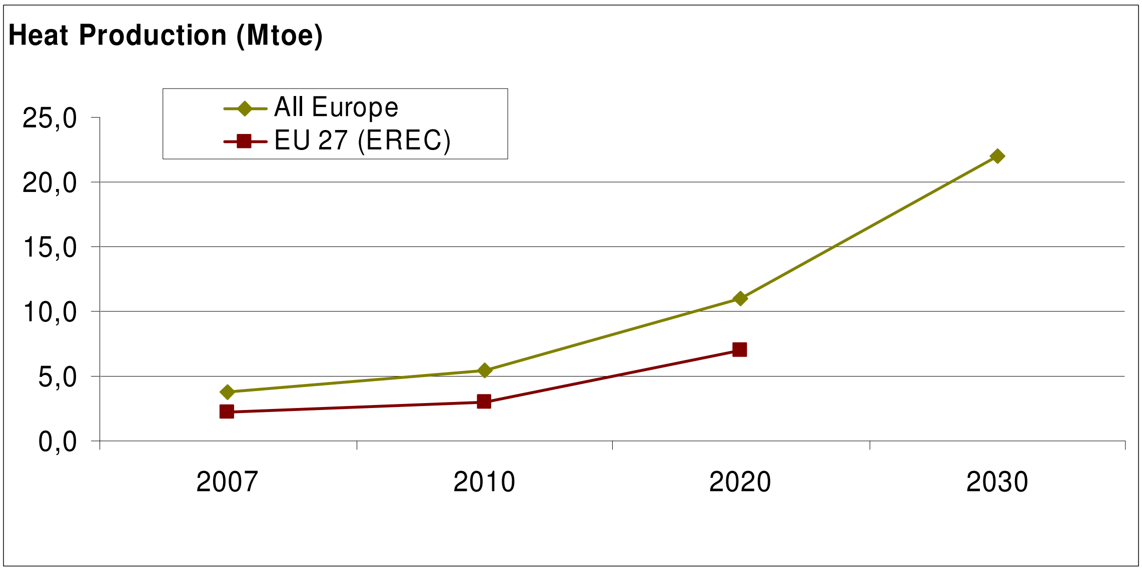
Methodology:

The goal is to fix here the r&d priorities for the sector, agreed by the Geothermal Community.

A first stage was the consultation process in order to have a large consensus on the topics selected.
A second stage is the definition of the Research Agenda. It sets out research and technologies development priorities. They will be disseminated and presented to the relevant authorities at national, European and world level.
A participation to the EU Technology Platforms (Advanced Engineering Materials and Technologies, European Construction Technology Platform, European Technology Platform for the Electricity Networks of the Future, European Technology Platform on Sustainable Mineral Resources, Renewable Heating & Cooling TP) will help in detailing some research topics.
A third step will be to implement this research agenda notably in adopting management structure and procedures.
The implementation involves support from a range of sources: International programmes, EC programmes, other sources of European funding, national research programmes, industry funding and third-party private finance.

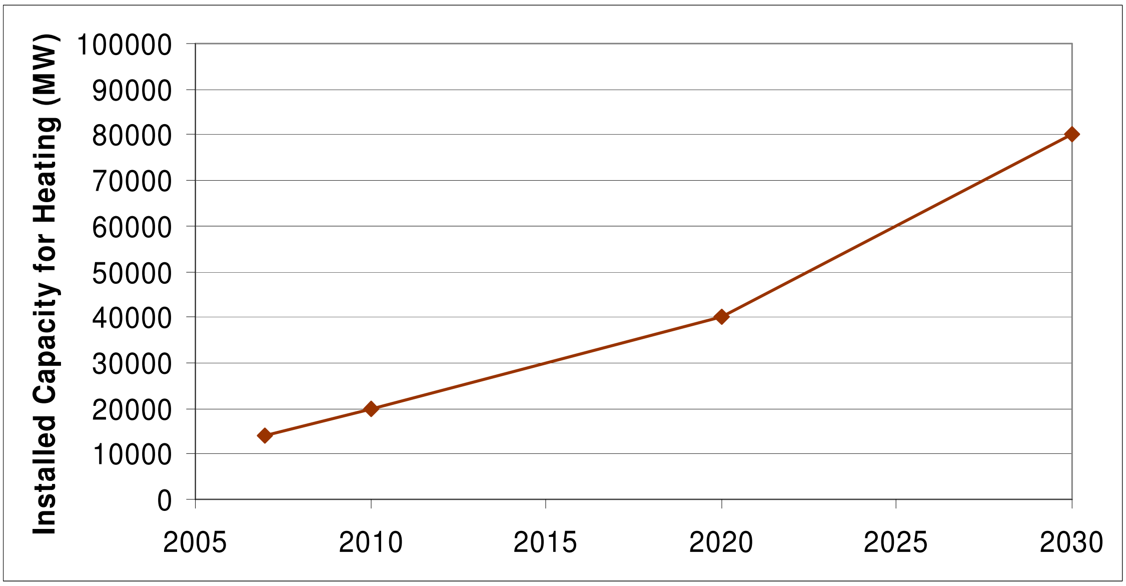
For heating & cooling:

In 2007 a total of approximately 2,5 Mtoe (Million Tons of Oil Equivalent) has been supplied by geothermal heating within European Union - 27, and more than 1 Mtoe in other European countries.



The installed thermal capacity (including geothermal heat pumps) in 2007 amounts to ca. 10.000 MWth (MegaWatt thermal) in EU-27 and 15.000 MWth for all Europe.

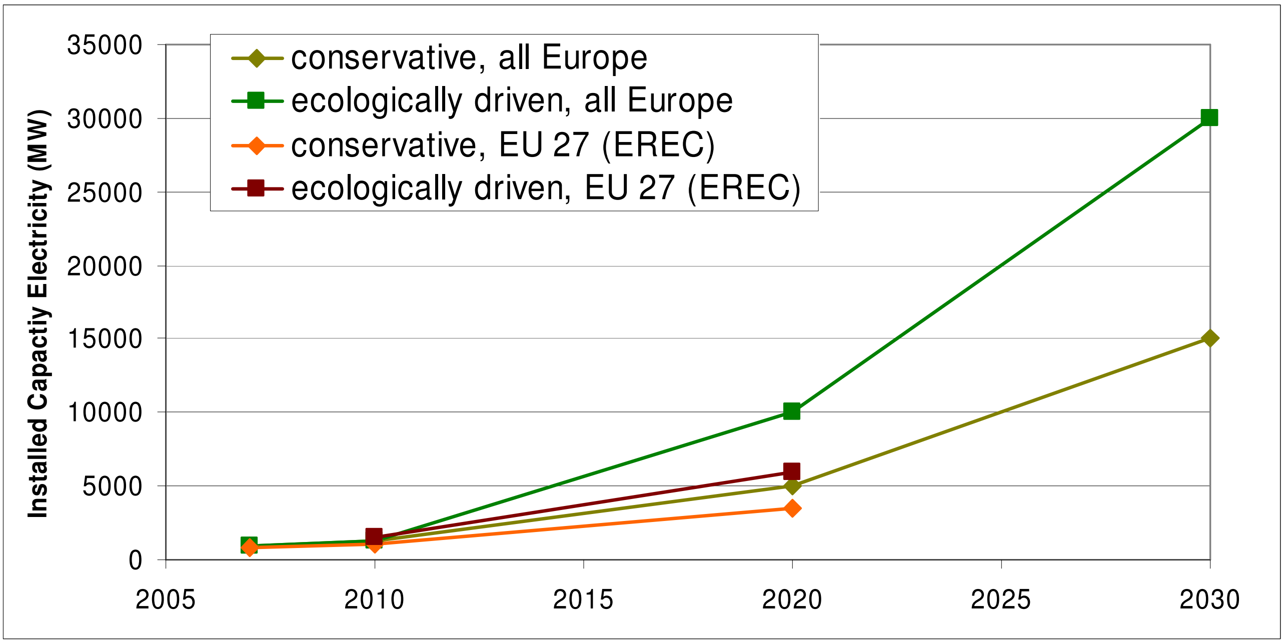
The target of the sector[1] for All Europe is to reach 20.000 MWth in 2010, 40.000 MWth in 2020 and 80.000 MWth in 2030.



[1] EGEC Brussels' declaration : 05/09/2008

For electricity :

Installed geothermal electricity capacity in the EU-27 is approaching the 1 GWe (Gigawatt-electric) threshold, 10% of the world geothermal installation. Other European countries count for ca. 0.5 Gwe. The gradual introduction of new developments will boost the growth rate, thus reaching the targets[2] for all Europe of 1,4 GWe for 2010, and 6 to 10 Gwe installed in 2020 and 15 to 30 GWe in 2030.



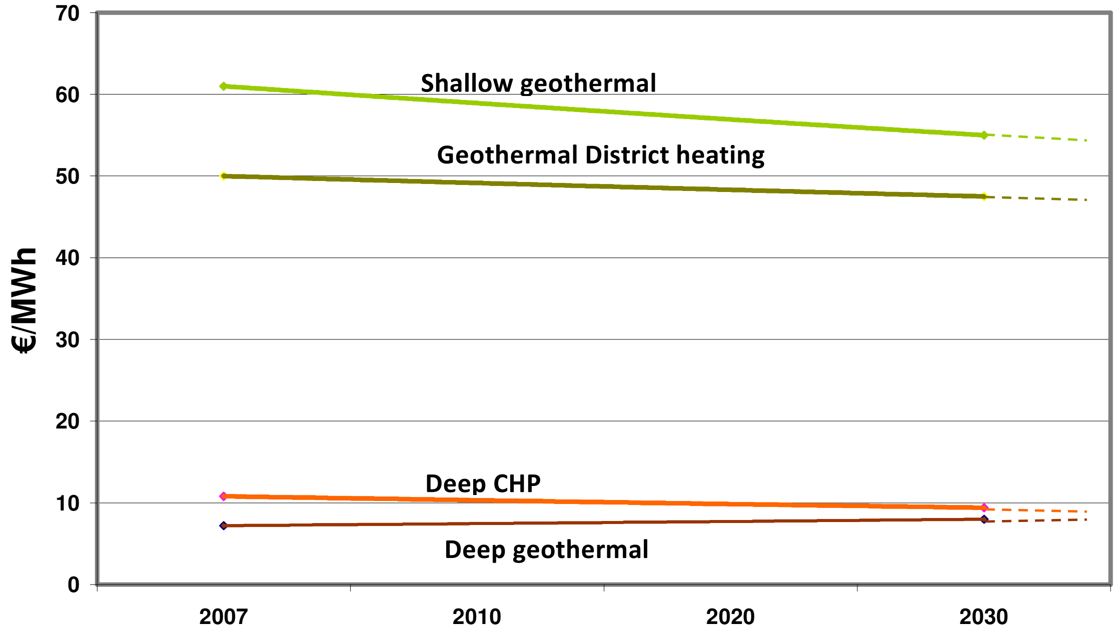
These targets can only be reached by reducing the costs. The research agenda presents the strategic priorities in r&d to decrease significantly the costs of the geothermal energy technologies.

Table: Summary of targeted costs

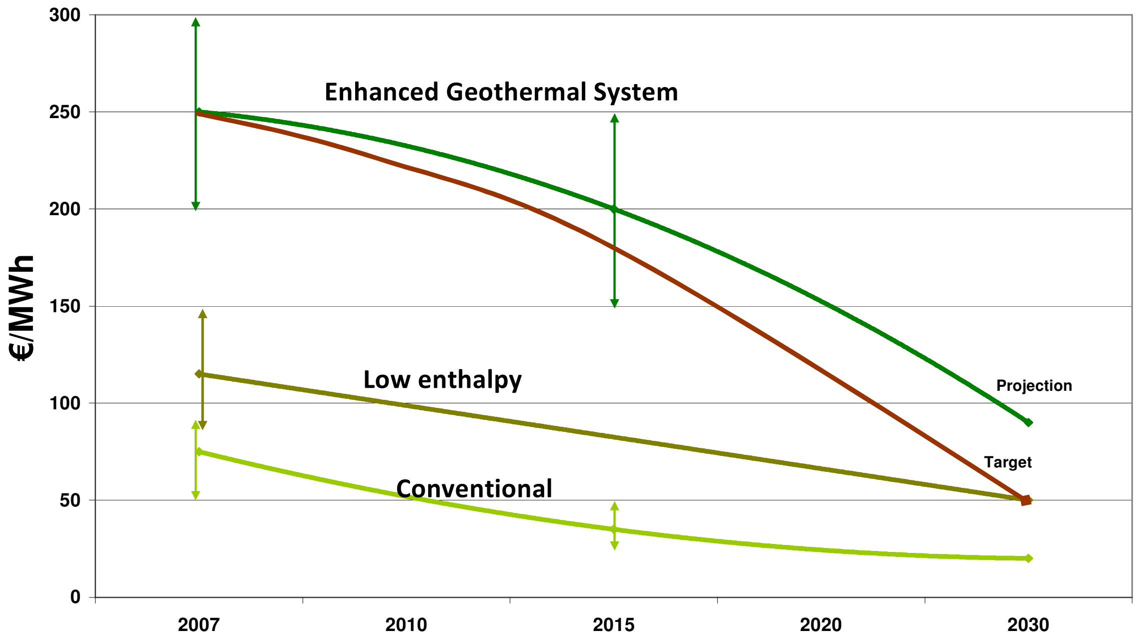
HEATING & COOLING		Costs 2005 Range(€/MWh)	Average (€/MWh)	Costs reduction by 2030 (% 2005 costs)
Deep geothermal		2 to 40	7,2	+11
District Heating		40 to 80	50	-5
Shallow	Heat only	10,8 to 320	19	-9
	H&C: heating	7,2 to 270	61	-8
	H&C: cooling	7,2 to 350	16	-8

NB : The figures for deep and shallow geothermal are from the IEA report 2007: *Renewables for heating & cooling*. The data on District Heating are EGEC projections for geothermal DH in Europe.

[2] EGEC Brussels' declaration : 05/09/2008



ELECTRICITY	Costs 2007 Range(€/MWh) (€/MWh)	Average	Costs 2030 Average (€/MWh)
Conventional Geothermal Power	50 to 90	70	20
Low Enthalpy Production	80 to 150	115	Target: 50
EGS	200 to 300	250	Target: 50 Projection: 90



1) STRATEGIC RESEARCH PRIORITIES

The main priorities are divided in two groups: those requiring a small R&D financing and the others necessitating a stronger financial support.

A) SOFT R&D MEASURES

➢ Geothermal Heat Pumps

- Improved underground systems
  Development of components which are easy to connect and disconnect from the surface*:* Robust, reliable and low-maintenance geothermal heat pump systems.

- Further increase of efficiency of ground source heat pumps and of performance of borehole, optimised system concepts, application of advanced control systems, improved components and materials (pumps, drilling, compressors, refrigerants, pipes, etc.). Completion techniques: integration of fibre-optic cables, etc.

- Improve performance of geothermal HPs on cooling

- Improve Heat Pumps performance (higher Coefficient of Performance): Optimize the component level design including heat transfer fluids. Adaptation for refurbished buildings (high temperature pump: fluids, compressors). Reduce environmental impact. New fluids…

- Non-technical issues like quality certification, guidelines, regulation, infrastructure, etc.

Costs reduction: The objective is to reduce total cost (investment, operation and maintenance costs) of geothermal heat supply **by 10%** in 2030: from ca. 60€/MWh to 54 €/MWh.
A priority is to reduce drilling costs.

➢ Geothermal Energy Storage

- Storage of heat or cold and combined

- High temperature heat storage. Integration of waste heat.

- Demonstration with building integrating several Renewable Energy Sources technologies, geothermal energy and heat storage.

➢ Hybrid heating & cooling systems

- solar, biomass… for heating and cooling

- use geothermal borehole as a heat sink in cooling applications (example: solar cooling in combination with thermal solar energy and geothermal well as a heat sink)

- **Research on Design of geothermal systems**

- Enhanced Thermal response test

B) NEED OF LARGE FINANCING

This part 'Need of Large Financing' is divided into three sub-sections; drilling improvements, resource identification and Enhanced Geothermal Systems (EGS). The first two topics are both research areas for EGS and conventional geothermal resources. Specific research areas for enhanced systems are listed separately under the EGS section.

- **drilling improvements**

  - **objectives**

. Methodological and technological developments in drilling
. Cooperation with other sector: oil-gas-hydrocarbon industry
. Two thirds of the costs associated geothermal plants are associated with drilling the wells. Great advances are possible in drilling technology.

  - **research priorities**

Concentrate on geothermal drilling activities:

- Development of innovative drilling technology for exploration and preliminary reservoir assessment.
- Drilling for reservoir development and exploitation
- Use of supercritical CO2 as fluid
- Optimisation and development of in-situ measurement technologies and borehole monitoring with fiber optics
- Development of data interpretation methodologies: e.g. electrical borehole tomography
- R&D in drilling for heat exchangers in Low-Enthalpy reservoirs to improve techniques and reduce costs.

Micro drilling for exploration and preliminary resource assessment is not considered as a priority for the geothermal sector (more for oil & gas sector) in the next years. Other technologies as laser drilling and fusion drilling for drilling the main borehole, should first be analysed by reliable prefeasibility studies to prove their viability.

  - **impacts**

Decrease the costs by 25%

➢ Resource Identification

- **Objectives**

The two main ideas are to promote the basic research areas to create quality public databases to promote private initiative participation and to foster support lines for basic research on geothermal resources, geochemistry and geophysics campaigns (prior to drilling (pre-drilling)).

- **Research priorities**

* Reinterpretation of existing geophysical, geological, geochemical data, and new data acquisition

. Methodological and technological developments

- exploration data (surface, borehole) as well as additional laboratory experiments to identify statistical representative ranges values (mean squares, standard deviations) of physical rock properties
- Evaluation of technical and financial conditions for a further use of existing boreholes, tunnels and mines for geothermal exploration

* Reservoir identification for deep and very deep geothermal: < 4 Km and > 4 Km depth, in order to decrease the risk and the costs

* New Geological & geophysical methods (3D modelling, 3D seismics, magnetotellurics …). Use of 'Global Monitoring for Environment and Security' (GMES)

* Resource assessment (productivity when related to the injectivity) at different scales : European, National, Regional, Local

. In-situ analysis of reservoir properties, modelling of geothermal reservoir behaviour and management

- 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 to enable modelling of the long-term geothermal reservoir's behaviour (including economically viable options for reservoir management). Using recursion formula optimised tools would deliver improved (in-time) predictions by comparing in-situ data (drilling, pumping,.. results) with geophysical, geological, geochemical information
- Scale relevant experimental investigations of the principal processes dominating the geothermal reservoir behaviour under energy extraction in terms of optimisation of available resources.

* Improve the permeability and injectivity prediction of boreholes

➢ Enhanced Geothermal Systems

- **Objectives**

Demonstration of increased, more efficient and environmentally sound electricity production from Enhanced Geothermal Systems (EGS); reduced costs; higher efficiency of energy extraction, conversion and end-use (electricity and heat); better understanding of plant operation…
At each stage of EGS development proven methodologies can be applied and bottlenecks identified. From this state-of-the-art, priorities covering 5 main research areas have been defined in the field of medium to long term research investment.

The key intended outcome will be widely deployed, competitively priced geothermal energy underpinned with reduced capital, operations and maintenance costs. Fast progress (and continuous improvement) will be underpinned with coordinated international efforts to successfully implement high priority, complementary R&D and interoperable databases.

Aligned International & National Research Priorities (to reduce capital, operations and maintenance costs and yield efficiencies in general):

1. Share knowledge & drive complementary research 2. Standard geothermal resource & reserve definitions 3. Predictive production modelling 4. Predictive reservoir and stress field characterisation 5. Mitigate induced seismicity / other Hazard and Operability Studies (HAZOPS) 6. Condensers for high ambient-surface temperatures (incl. air cooling) 7. Use of CO2 as a working fluid for heat exchange 8. Improve power systems 9. Education / training 10. Economic modeling tools 11. Technologies & methods to minimize water use	Priotirities shared with the upstream petroleum industry 12. improved / revolutionary HTHP hard rock drill equipments 13. Improved HTHP zonal isolation / completion (packers, etc.) 14. Reliable HTHPHV pumps for surface and modest hole diameter 15. Enable well longevity (20-30 years) 16. Optimum HTHP fracture stimulation methods/technologies 17. HTHP logging tools and sensors (temperatures, imaging, etc.) 18. HTHP flow survey tools 19. HTHP fluid flow tracers 20. Mitigation of formation damage, scale & corrosion (rock-fluid interaction) HV: High Volume, HT: High Temp, HP: High Pressure

Finally the suggested approach should be closely linked to the corresponding R&D activities on the international scene. Already existing ties like the IEA Geothermal Implementing Agreement could be instrumental in this.

- **Research priorities**

A specific research agenda for EGS has been developed within the ENGINE project, and is given here as an appendix at the end.
The proposed program endorses the Engine propositions for the definition of Research areas on Enhanced Geothermal Systems.
The ENGINE outcome clearly emphasizes that one of the prerequisites of a dissemination of EGS technology is the proof that the underground heat exchanger can be engineered independent of site conditions. The entire EGS R&D suggested should concentrate on this issue.

The main areas defined therein are:

- Research area 1: Exploration, finding access to potential reservoir at depth
- Research area 2: Geothermal wells, improving drilling and completion technologies
- Research area 3: Reservoir engineering, stimulating the fluid flow underground
- Research area 4: Exploitation, Improving the efficiency
- Research area 5: Monitoring, reservoir management

The two first research areas have been covered above (drilling and resources identification). The fourth area is covered in the others topics.
The third and fifth areas constitute the hearth of the EGS concept, and should there be addressed in priority:

.The aim of the stimulation by fracturing is to increase the geothermal energy production by increasing the surface of the natural heat exchanger. Fracturing and production processes are hereby monitored by innovative monitoring techniques. This means control and management of the fractures' creation, maintenance and restoration of fractures as well as supervision of energy production.

- Optimisation of stimulation technologies: costs reduction for hydro fracturing; improvement of innovative stimulation methods (physical, chemical.)
- micro seismic / passive seismic, localisation and seismological assessment of cracks, determining of crack parameters
- resistivity monitoring, resistivity tomography, monitoring electrical potentials by kinetic and chemical processes
- developing a slim-line high temperature directive borehole radar to investigate structure and extend of geothermal usable strata
- development of sensors (physical parameters, chemical tracers' analysis) and data transmission techniques to be used in deep geothermal boreholes

- development of soft- and hardware (e.g. high temperature packers…..)
- Advanced stimulation technologies
- Development of methodologies and software for integration of tracer and geophysical data. (In the petroleum industry, such integration has been found most valuable).[3]

.The objective is to develop and test advanced methodologies and technologies to enhance fluid-transport properties of existing and induced fracture systems. Controlled stimulation schemes should maximise the interwell connectivity while mitigating the risk of induced seismicity.
The results should lead to a significant improvement in the engineering of underground heat exchangers, not only with respect to flow impedance, but also in terms of time- and cost-efficiency and control of induced seismicity. This will significantly increase the possibilities to use this energy technology in densely populated areas.

.The main difficulty in EGS reservoir creation and operation is the remoteness of the underground heat exchanger. Characterization and tailoring the properties and processes at depth needs special instrumentation and methodology.

. Another issue concerns the control of water losses (both water itself and the power consumed by the lost amount) and the control of water chemistry.

.Understanding and Mitigation of Induced Seismicity Associated with Geothermal Field Development:
The objective is to study the mechanisms of induced seismicity related to geothermal field development and operation, in particular enhanced geothermal systems (EGS). The research should (a) analyze the distribution in time and space of the magnitude of seismic events, (b) set requirements for seismic monitoring, (c) recommend management strategies for prolonged field operation, and (d) provide a methodology for the estimation of site-specific seismic hazard prior to development of potential sites for EGS.
The results should lead to a better understanding of the mechanisms of seismic events in geothermal reservoirs. This will enable to define strategies for fluid injection, for the extraction of heat over a prolonged period, and/or for the creation of EGS.

- **impacts**

The estimated current cost of EGS electricity generation from the first-generation prototype plants is of the order of € 0.20-0.30/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 0.09 €/kWh, or 0.05 €/kWh** if a strong support is brought (Strategic Energy Technology SET- plan).

[3] Tracer Technology: **Application of tracer technology in well-to-well tracer tests to obtain information about fluid flow in the reservoir. The improved reservoir knowledge gained from the tracer tests is important in order to optimise production strategy and thereby obtain enhanced oil recovery and reduced production costs.**

2) OTHER TOPICS: List of secondary research areas

➢ **Low Enthalpy electricity production**

- **Objectives**

R&D interest in binary plant schemes/installations based on Low Enthalpy resources (i.e. waters above ca. 80-90 degrees C) is raising more and more interest in Europe.
Utilization of lower temperature resources (80°C ?) can be achieved with binary plant, increasing the overall exploitable potential.
The main objective for low/medium enthalpy geothermal power is to improve the technologies and efficiencies and to demonstrate the viability and efficiency of power generation from geothermal fluids of the lowest possible temperature, including hybrid solutions coupling geothermal with additional energy resources (solar, biomass, etc.) for improved efficiency.
First small (0.5 – 3 MWe) pilot/small scale installations have been working in Austria and Germany but there is a beginning of development and many issues are to be dealt with (efficiency increase, selection of working fluids, large amount of waste heat disposal – also for heating systems, etc).

- **Research priorities**

Issues to be addressed include production levels and methods in plant operation, e.g.:

- balancing extraction and production rates;
- improving energy conversion efficiency and reducing parasitic loads;
- increasing the operational life of equipment etc.
- Development of simulation tools to predict heat exchangers long term behaviour
- Application of drilling and simulation experiences obtained for High-Enthalpy reservoirs in Low-Enthalpy resources to take advantage of these results.

New or existing facilities should become operational within substantially shorter lead times and should make use of well-known and promising sites.
Technologies and systems to be demonstrated should be environmentally sound and well suited to their site.

- **impacts**

Development and demonstration of an increased range of potentially interesting geothermal sites for exploitation, leading to a **cost reduction.** The objective is to reduce costs from ca. 115€/MWh now to 50 €/MWh in 2030.

The optimization of the choice of the pilot plants can also participate to the costs reduction.
The objective is to develop and test economically feasible prototype plants (both purely geothermal and hybrid) in the most suitable sites of Europe, i.e. with the highest temperatures at the lowest depth, to assess the optimum economic effectiveness.: test sites for low/medium temperature plants fed by low depth wells with high economic appeal, in which to experiment, for instance, technologies to use heat exchangers installed in wells.

➢ Combined Heat & Power (CHP)

- **objectives**

Use of low-temperature resources (down to 80 °C ?) in combination with binary power units shall enhance the energetical use of the resource and the profitability of the investments.

- **Research priorities**

- conversion of heat into electricity (see above),
- CHP with low/medium temperature resources
- CHP, adapted power and District Heating (DH)-systems
- Cascade utilization
- R&D on improvement of components

- **Impacts**

Increased overall economy and energy efficiency of geothermal systems.
Cost reduction: 20 %.

➢ Supercritical fluid, Supercritical Zones in Geothermal Fields

The long-term evolution for geothermal resource exploitation concerns the supercritical zones of geothermal fields with very high temperatures (up to 500°C) at relatively shallow (< 4 km) depths.. Such reservoirs could deliver very high enthalpy fluids with high flow rates due to the low viscosity of supercritical water. These supercritical geothermal fields hold very high risks concerning the physical controllability of these very high temperatures and pressures. Indeed the exploitation of these zones will open new fields in materials' research.
The objective is to develop and test innovative, reliable tools and instruments for the characterisation and exploitation of high-temperature unconventional geothermal energy resources. The research and development should aim at cost-effective, reliable operation at temperatures above 200°C, with increased time downhole.
The results should expand the temperature window for geothermal data gathering, and improve the competitiveness of the downhole measurements service industry.
Supercritical geothermal systems can be found in Iceland. A connection to the Iceland Deep Drilling Project (IDDP) should be made.

➢ Exploitation, Economic, Environmental and Social Impacts

Handling of heat-carrying fluids and direct vaporisation
Development of holistic concepts for the management of geothermal resources: combination of funding and feed-in, combination of house heating and cooling
Systems analysis: impacts on society when using geothermal energy (acceptance, availability, cost calculation, CO_2 reduction aspects, ..).
Understanding and preventing scale deposition (calcite silica, etc). This will be important in maximising efficient extraction of energy to low temperatures.

Risk evaluation for the development of geothermal energy: Quantitative estimation of the risks (e.g. costs and capacity) by use of geothermal energy (EGS, hydrothermal, geothermal heat pumps) especially by involving technical quantities (e.g. rock specific drilling progress) analogue to methods in the oil industry.

➢ District Heating

- Construction of new district heating networks, and optimisation of existing networks and plants, in particular in East/South Eastern Europe and Turkey
- Improve site assessment
- R&D on improvement of components (pumps, drilling…)
- Optimisation of networks, optimised exploitation framework
- Re-injection into difficult aquifers (e.g. sandstones in the Pannonian basin, European Lowlands' basin).

Cost reduction: 5 %. A challenge for costs reduction is the scarcity of sites and many of the good sites are already developed.

➢ Direct uses

- Improved site assessment (incl. Geographical Information Systems GIS), exploration and installation, and dissemination of successful approaches from some countries to the whole European Union
- Cascade uses (district heating, industry, agriculture, and other)
- Increased application and innovative concepts for geothermal energy in agriculture, aquaculture, industrial drying processes, desalination, absorption cooling, industrial applications, snow melting and road de-icing…
- Heat extraction from mine waters and air. Use the abandoned, exploration/post-oil/gas extraction, etc. wells for geothermal purposes.

➢ Components:

- Corrosion, longevity, low energetic losses, high efficiency, cost reduction…
  Inhibitors against scaling/corrosion
- R&D on improvement of components[4]: turbines, heat exchangers, generators, cooling devices…

[4] Because currently available "green" Freons or hydrocarbons have been well analyzed, there is very little left for improvement of thermodynamic cycle efficiency.
The temperature drop over heat transfer surfaces is already at the diminishing returns limit leading to large heat transfer areas and pressure drops (parasitic pumping losses), and can hardly be reduced further.
Turbine aerodynamic efficiency is very close to that attained (at very high R&D cost) in large steam and gas turbines, so there is not much to gain here. Screw expanders have lower costs but their efficiency is lower.

- R&D on improvement of power cycle (Organic Rankine Cycle: ORC, Kalina) to decrease the costs and increase the efficiency (in collaboration with the power sector)
- Adaptation of tools and methods of the hydrocarbon industry to geothermal energy, in innovative components (pumps, heat exchangers, etc.), in the optimisation of District Heating networks.
- Casing drilling with composite plastics (depth: < 3 Km)

Geothermal research is generating results that can be applied in other domains, for instance, in material durability, where experimental from geothermal projects can assess the corrosion resistance of the components exposed for long periods to the hot water from the bottom of the bore.

3) CONCLUSIONS

Prioritizing of the R&D tasks

Geothermal energy is very diversified, and EGEC wants to promote all kinds of geothermal energy.
The proposal is to concentrate big amounts on drilling & demonstration plants and to keep an effort on other technologies .

Two thirds of the costs associated geothermal plants are associated with drilling the wells. Great advances are possible in drilling technology (**5 M EUR/year**).

Exploration and the identification of sites suitable for geothermal bores requires improved tools for resource mapping, a better understanding of techniques to prolong the lifetime of existing boreholes and the re-interpretation of existing geophysical, geological and geochemical data to identify patterns that suggest the presence of a good resource below ground. Numerical models of geothermal bores must be improved to better predict the bores' long-term behaviour (**4 M EUR/year**).

Enhanced Geothermal Systems:
The stimulation of the bores, which means the fracturing of rock or other methods to increase the amount of rock surface in contact with the water pumped down from the surface, must be improved and the fractures' creation, maintenance and possible restoration must be checked automatically and constantly. In-situ measurement technologies should be developed, perhaps using fibre optic cables and tomography (**1 M EUR/year**) It is suggested that a slim-line high temperature directional borehole radar be developed to investigate the structure and extent of usable geothermal strata. Monitoring of cracks through micro-seismic and passive seismic techniques, through electrical potentials and through kinetic and chemical processes also needs to be increased (**1 M EUR/year**).
One objective is to promote the implementation of geothermal drilling in deep EGS demonstration projects located in new areas (Spain, Portugal…) with geothermal potential in Europe. Such aid would be needed on the horizon for the next 3 years, and once defined the greatest potential areas it will be possible to begin developing these deep geothermal projects.
The experience gathered in Soultz should now be applied to other locations.

Demonstration projects should aim at improving geothermal reservoir detection technology, increasing the performance of fluid production systems (corrosion and scaling), increasing the efficiency of electricity generating systems.
There is a special need for demonstration plants:

- Pilot commercial plants: These plants will demonstrate the "normal" use of geothermal energy as reliable heat and/or power producer and should be implemented in the public heat and/or electricity net. They serve as test platform (e.g. for an energy supplier) and will deliver first of all operating data. Besides optimisations can be done under normal operating conditions. They will be operated in a way that maximises return on investment.
- Researchers test facility (or plant): There is a further need of these platforms for knowledge transfer to young scientists and for testing several new techniques e.g. new stimulation, operation and monitoring techniques etc. test plants for researchers trying out

new stimulation techniques or operating and monitoring procedures, with the aim of understanding better the science of geothermal energy production. One of these could be located at in a supercritical geothermal zone, where very high temperatures (>500 °C) are to be found at relatively shallow depths (<4 km). Supercritical water has low viscosity allowing for high flow rates. In Europe, these exist in Italy, Iceland and maybe also in Greece and the Azores. Much remains to be learnt about the degree to which such high temperature systems can be controlled and the appropriate materials to use in them.

Currently the European Union funds one geothermal electric power project, in Alsace at Soultz sous Forêts. More demonstration plants are needed.

15M EUR / year would finance three projects: a commercial demonstration plant, a test plant in a <500°C zone and a test plant in a >500 °C zone.

Beside geothermal electric power generation, a very high potential already harassed initially is on the sector of heating and cooling. Here R&D support is required both for geothermal district heating and for shallow geothermal systems / geothermal heat pumps:

For geothermal district heating, beside improved site assessment (tools already covered above), further work is needed on re-injection into difficult aquifers (e.g. sandstones like in the Pannonian basin or European Lowlands Basin embracing Germany and Poland) (**1M EUR / year**). This is crucial for sustainable use of geothermal heat in countries e.g. Hungary, Slovakia, Poland, Germany. Another **0.5M EUR / year** should be spent on supporting work to get new plants closer to economic viability, in particular in adaptation of tools and methods of the hydrocarbon industry to geothermal energy, in innovative components (pumps, heat exchangers, etc.), in the optimisation of networks.

On the shallow geothermal sector, **2M EUR / year** are required to increase of efficiency of ground source heat pumps.

1 M EUR/year would finance inter-seasonal energy management (energy storage) issues.

Finally, some new and evolving technologies not covered in one of the classic fields of geothermal energy use need support in R&D to become feasible eventually, and later to demonstrate their potential. These ideas, for which **1M EUR / year** should be dedicated, comprise the following:

- innovative concepts for geothermal energy in agriculture, aquaculture, drying processes
- Agricultural uses in combination with geothermal waters and chemicals
- De-icing, snow melting on roads, bridges, airport runways, etc.
- Sea-water desalination
- Geothermal absorption cooling

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

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

Appendix, from ENGINE project:

Propositions for the definition of Research areas on Enhanced Geothermal Systems

Extending the resources far beyond a conventional use of geothermal fields requires the use of non-conventional methods for exploring, developing and exploiting resources that are not economically viable by conventional methods. The **Enhanced Geothermal Systems** (EGS) concept covers specifically reservoirs at depth that must be engineered to improve hydraulic performance.

Promoting most appropriate practices and filling the gaps in knowledge

During more than 2 years, Enhanced Geothermal Innovative Network for Europe (ENGINE), a Coordination Action of the 6th Framework Program, has co-ordinated ongoing research and promoted the development and uptake of new technologies. Conferences and dedicated workshops have strengthened the collaboration between research teams and developed links with stakeholders, industry, international organisations… The results, available on the website at http://engine.brgm.fr presented during the final conference hold in Vilnius, Lithuania (12-15 February 2008), marks a milestone in EGS development towards its ultimate goal, i.e. the development of a technology to produce electricity and/or heat from the internal heat of the Earth in an economically viable manner, independent of site conditions.

Following up this coordination action, a program is now needed to demonstrate that EGS reservoirs with the required characteristics (well distributed, sufficiently large heat exchange surfaces, sufficiently high flowrate and temperature, low flow impedance, low water loss) constitute a sustainable source of energy at a price competitive with other renewable energy technologies. This demonstration should also define a strategy for upscaling EGS output to several 100 MWt and/or several 10 MWe. Priorities are defined towards the perspective of such a demonstration programme.

Defining priorities in the field of medium to long term research investment

Lessons learned from the Soultz EGS experiment, the sustainable development of the Larderello field in Italy, and the Icelandic geothermal power network, among other case histories, highlight the importance for coordinated research for technology improvement and for a continued reduction in cost through R&D developments. EGS are geothermal reservoirs with minimum temperatures of 85-100°C but that require artificial improvement of the hydraulic conductivity for economically viable produced flow rates.At each stage of EGS development proven methodologies can be applied and bottlenecks identified. From this state-of-the-art, priorities covering 4 main research areas have been defined in the field of medium to long term research investment:

Research area 1: Exploration, finding access to potential reservoir at depth

Exploration and investigation must identify closely the nature of geothermal heat concentrations and prospective reservoirs and to improve methods predicting reservoir performance/lifetime. Based on the past 50 years of exploration, *a priori* knowledge enables the definition of several prospective areas for EGS exploration in Europe. This definition of investigation targets does not raise major R&D barriers at a regional scale. The knowledge of the European lithosphere, collected information during ENGINE, recent surveys and reassessment of potential resources available in atlas and 3D models enable the identification of zones of interest for exploration. The following items still require R&D investment:

- Priority targets for EGS are deep potential reservoirs for which permeability could be enhanced through stimulation. A uniformed approach to identify such reservoirs and assess their geothermal potential at different depth underground is still needed. A significant step forward has been recently done for US in the framework of the MIT panel expert work: aimed at evaluating "The future of Geothermal Energy". Such evaluation must be accomplished in Europe to be included in the Strategic Energy Plan. Compatible datasets, compilation and exchange of data are a prerequisite to build models predicting the distribution of heat at depth and should be one of the first action to be undertaken, with the support of the European geological Surveys and in compliance with the INSPIRE directive.
- Further exploration of EGS site must prove the presence of temperature higher than 85°C and the existence of rock permeability above a certain threshold either due to porosity in sediments or to fractures in crystalline and volcanic rocks. At the concessional scale, the geometry of the reservoir and its potential energy needs to be assessed and resolution remains rather low. Main gaps exist in combining in 3D geological, geochemical and geophysical data coming from different methods. Input from the IGET project is expected and should provide some advances in exploring the deep geothermal resources. Additionally, the stress conditions in the study area should be better known to enhance the flow conditions by hydraulic stimulation. This second action is complementing the first requirement concerning database and modelling.
- Review of case histories shows the importance of social acceptance and of the economic and environmental impacts of the EGS projects. The definition of new investigation sites must be accompanied by feasibility studies that must be formalised.

The main deliverables from this research area will be an assessment of the EGS potential of Europe and identification of about 20 potential sites of a demonstration program.

The final objective concerning exploration at the 2020 horizon is to improve the probability of successful EGS operation. Continuous efforts should lead to 90% successes with a 20% reduction of exploration costs for defining targets for exploration of EGS at the concessional scale. Improved and newly developed methodologies able to map and image in 3D temperature and permeability at higher resolution down to a depth of 10 km, and in particular at a depth of 2.5-3 km and the common use of a 3D modelling platform, as proposed in this Research area 1, are considered to be the main R&D challenges to reach this target. Development of innovative methodologies could also meet challenges for exploring new reservoirs in oil and gas industry and management of the underground especially for CO2 sequestration.

Research area 2: Geothermal wells, improving drilling and completion technologies

The drilling into geothermal reservoirs requires most of the specific costs of geothermal energy provision. Drilling in shallow high temperature reservoirs is almost standardised and in deep high temperature reservoirs single experiences are made. Standard HC tools, reliable drilling mud systems, cementing technologies, and a set of casing completions are available for both environments. In hostile environment reliable completion is only available based on high cost casings.

An extended market penetration of geothermal energy requires that the drilling and completion costs must be cut by 20 to 30% by 2020. Further expansion of geothermal energy requires reliable technologies for deep reservoirs and equipment reliable under high temperature conditions during the overall drilling and completion technologies, with mitigated formation damage. In order to cut the drilling costs, drilling operations must become faster without loosing reliability. Improved performance requires facing new challenges. Shared know how and experiences must be supported by a new R&D project covering this research area. Stronger management of the overall drilling activities must be achieved including transport management, automatic pipe handling on drilling rigs, cementing at high temperature. Minimised infiltration of drilling mud into the reservoir constitutes another challenge. Low cost completion materials and new monitoring techniques down hole must also be available addressing strong hostile corrosive conditions during drilling and stimulation of the reservoir. The use of wire drill pipes while drilling can bring in real-time down hole information saving time for directional drilling or other related operations. These innovative approaches should be tested and implemented in the framework of an European demonstration program.

Research area 3: Reservoir engineering, stimulating the fluid flow underground

Reservoir engineering implies reservoir characterisation, production enhancement through stimulation techniques and assurance of the resource-sustainability. The characterization of the reservoir is achieved through assessment of reservoir parameters such as fracture and matrix properties, definition of reservoir boundaries and geometry. The enhancement methods require the application of specific technologies in different geoenvironments, including hydro-mechanical, acidization and thermal techniques. All tasks related to the engineering of the reservoir require a sophisticated modelling of the reservoir processes and interactions being able to predict reservoir behaviour with time and to minimize sensible micro-seismic impact.

An increase by a factor of 10 compared to the present achievements should be targeted in a 2020 perspective. Several tracks could be followed to achieve this goal. New visualization and measurement methodologies (imaging of borehole, permeability tomography, tracer technology, coiled tubing technology) should become available for the characterization of the reservoir. Standardized chemical and hydraulic stimulation technologies for all geo-environments need to be developed yielding reliable and reproducible results. In parallel new decision tools for modelling should be developed, namely for on-site support during test, integration of surface data for reservoir evaluation, design of optimum reservoir creation strategies, optimization of test duration and performance and multi-well layout planning.

In addition, in order to mitigate risks related to induced seismicity, conceptual models for irreversible enhancement of permeability of the reservoirs are needed in order to set requirements for seismic monitoring and recommend management strategies for prolonged field operation. Imaging fluid pathways induced by hydraulic stimulation treatments through innovative technology would constitute a major improvement of the Enhanced Geothermal Systems concept and provide decision support tools for seismic hazard mitigation.

Research area 4: Exploitation, Improving the efficiency

The exploitation activities include all technical equipment needed to provide heat and/or electricity from wells. This includes e.g. the production pump, the piping, the heat exchanger, the power plant and any auxiliary equipment. Technical equipment is available on the market. However, efficiency of the different system components can still be improved. This is especially true for low-enthalpy power plant cycles (e.g. ORC, Kalina Cycle), cooling systems, heat exchanger and production pumps for the brine. Integration of the different components within the overall system also needs to be optimized.

Several targets can be proposed taking into account recent improvement in technologies and the growing geothermal activity. The net electrical efficiency of the power plant cycle and of Combined Heat and Power systems should be improved till 2020 by 20 %. Cost reductions by 10 to 20 % by using innovative technologies for district heating and industrial customers should be reached. Other improvements up to 20 to 25% could also be targeted for energy demand of the pump, piping, and avoiding scaling and other undesired effects within the brine cycle. To achieve these goals, the main effort must be put on the development of new materials at lower cost (pipes, pump, additives, heat exchangers), the definition of new industrial process and treatment of the brine to limit scaling effects, reach higher efficiencies and develop cascade uses, the integration of the different system elements within an optimized overall system, the definition of measures to reduce possible environmental effects during normal or abnormal operation. These targets could be integrated in the DG Research work program concerning energy efficiency.

Towards a demonstration program integrating the different research areas

The achievement of the Soultz experiment and several successful spin off projects open the adult age for the development of EGS. The contribution of EGS sources must significantly increase during the coming years and technologies are already available to plan a demonstration program for the next coming years. The development of 20 EGS demonstration sites throughout Europe is considered as realistic and sufficient to show EGS feasibility. Already, some of the ENGINE partners are involved in ongoing or planned projects among which:

- Icelandic Deep Drilling Program (2008-2009) financed by a consortium of three leading Icelandic power companies, Hitaveita Sudurnesja Ltd., Landsvirkjun, Orkuveita Reykjavikur, together with Orkustofnun (National Energy Authority) and Alcoa Inc. (an international aluminium company).
- Zala County and Fabiansebestyen drill site (Hungary 2008-2009). Contacts have been established between MOL, the industrial supervisor, and the ENGINE steering committee to include these 2 projects within a demonstration program.
- Roquette project in the Rhine Graben. Contacts between the Soultz consortium and some other partners of ENGINE have concurred to design this project aimed at using steam from deep geothermal origin to dry the industrial production of starch.
- Kosice (Slovakia) in preparation by ENEL and others
- Groß Schönebeck power plant (Germany), financed by German Government and an industry partner
- Bruchsal power plant (Germany), financed by EnBW among others
- Unterhaching co-generation plant (Germany), financed by local authority Unterhaching
- Landau power plant (Germany), financed by a local power company
- Podhale power plant (Poland) in preparation

- Green Campus Izmir project (Turkey), in preparation with local institutions

These projects will generate a learning curve for standardization of most operations. Their planning constitutes a roadmap for researchers, industry and funding agencies as a response to new perspectives of development of geothermal energy in order to contribute to the strategic objective of 20% renewable energy sources (RES) and CO2 reduction in the EU energy mix by 2020. An EGS foundation could be created based on the following up of these projects and could strengthen the links with industrial partners and result in a technological platform. This foundation should be aimed at keeping the present European knowledge for the management of non conventional (Soultz) and conventional reservoirs (France, Germany, Iceland, Italy) and transfer it for the development of zones of high potential (Greece, Pannonian basin of Hungary and Romania, Turkey) or out of Europe (Southern Australia, Western US, China, Indonesia, Japan, New-Zealand, Caucasia and Kamchatka in Federation of Russia).

Conclusion

The geothermal sector still needs generic technologies to expand the use of heat and power. This expansion must be performed in a strengthened international cooperation in order to stimulate global development, commercialisation, deployment and access to technologies. It must also design support schemes for co-generation and heating and cooling, combining other renewable energy sources and other low-carbon technologies. It will also promote education and training to deliver the quantity and quality of human resources that will be required, by making full use of the FP7 People Programme.

Appendix, proposal for SET-plan:

Suggestion for initiative on geothermal energy SET plan – EGS Geothermal Power Production everywhere through EGS

After more than 30 years of R&D efforts, electric power generation using EGS technology now for the first time can be demonstrated in a pilot plant (Soultz-sous-Forêts, France). However, to unleash the full potential of EGS, a concerted action is required to transfer the technology from the one site to other sites in similar geological situation and later to sites in all possible geological framework.

The major problem with proliferation of EGS is the high cost of drilling. On the other hand, without a first drilling for a new site, the technical viability of a plant on a new site cannot be judged. Without a massive support of exploration, drilling and completion of deep wells on new sites, the replication of the EGS principle as demonstrated in Soultz cannot be done.

Business as usual here would mean to limit geothermal power production to the few high-enthalpy areas in Europe, or to the low-temperature binary systems. A major effort to introduce EGS, on the other hand, could create a substantial base-load electric power production, as geothermal energy is available independent from the time of day or year, of climate, weather, etc.

R&D still will be required to improve the system, even after being a proven technology. The initial cost is a barrier, European consortia might be established to overcome this barrier and exchange experiences.

A steady increase in geothermal power production could be expected in all EU countries.

Objective

The sole objective of the initiative would be to proliferate the technology of Enhanced Geothermal Systems (EGS), from the one European R&D- and pilot-site in Soultz-sous-Forêts (Alsace, France) to other Member States and to different geological situations.

A target of the initiative will be to create about 20 (a minimum of 15) operating EGS power plants; the first group within geologically similar regions (Graben areas with lateral stress fields, e.g. Upper Rhine, Rhone, Limagne), the second group in other regions with favourable conditions (geothermal anomalies, crystalline rocks in suitable depth, tectonic stresses), and the third and last group in regions without any special advantage for EGS use. Milestones could be set in such a way that at least 3 plants have to be finished successfully in each category, before the practical work for the respectively more difficult regions starts; theoretical and geoscientificial work could be done for all of Europe simultaneously.

Each power plant should have an installed capacity of at least 5 MW_{el}, with increasing size for replication of plants in similar category (see above). The goal should be to have at the end of the program about 200 MW_{el} of installed power operational, producing base-load energy with a load factor of >90%, and thus generating about 1580 GWh of electricity each year.

The amount of power installed through these plants will be ca. 15%-25% of the goal of 6-10 GWe for 2020 as set forth in the EGEC targets, and would amount to about 20 % of the geothermal power produced currently in the classical high-enthalpy geothermal power plants.

Main elements

The main element would be the construction of demonstration plants for the EGS-technology, based on the European EGS project in Soultz-sous-Forêts as a pilot plant. Due to the differences of the underground situation, each of the demonstration plants will also be a kind of pilot plant in new geological surroundings. Thus the boundary between pilot and demonstration character is not sharp, and a lot of R&D will be required to make the new plants possible. Also R&D is required for the understanding of the behaviour of the rocks at great depth and under stress, while artificial fracturing is run in order to create the necessary underground heat exchanger (e.g. for avoiding seismic events).
In the course of the identification and investigation of suitable sites, a linking of existing geoscience information at national or regional level, at research centres, universities, geological surveys, etc. should be attempted. A common European geoscience data platform could substantially support the application of EGS technology throughout the Member States, and will also be of great help for other geothermal technologies yet on the market.

Instruments and resources

Instruments :

- Financial instruments : Public-Private Partnership, Grants
- Technical instruments : EEIG/GEIE, FP7 (technology platform), Platform of Geological Surveys. etc.

Co-financing :

- Public : EU, IFI's, national-regional authorities, Public Funds
- Private : Investors, Banks, Industries
- Scientific

The resources needed :

- **1 plant = 50 M €**
- **20 plants = 1'000 M€**