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The ENGINE Coordination Action (ENhanced Geothermal Innovative Network for Europe)

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ABSTRACT

Late 2005 and during 36 months, the ENGINE European project aimed to coordinate the efforts of those involved in Enhanced Geothermal Systems (EGS) development. The main products of ENGINE are a handbook defining best practices and a strategy proposing a road map for future demonstration projects. The enhancement challenge requires the development of innovative methods for exploring, developing and exploiting geothermal resources that are not economically viable by conventional methods. This definition embraces different methods for enlarging access to heat at depth in order to provide continuous base load-power and to contribute to reach the target of the European Strategic Energy Technology Plan (i.e. 20% renewable market penetration in 2020). It is important on one hand to evaluate the investment and the expected savings on cost operation for each Research and Development initiative and industrial project. On the other hand, it must be demonstrated that geothermal energy can contribute to achieving the goals defined in the European Strategic Energy Technology Plan through EGS demonstration projects. ENGINE built up a task force motivated to develop EGS at the European scale, willing to work within the international community, and also eager share information about geothermal energy.

1. THE ENGINE STORY

The ENGINE Coordination Action (ENhanced Geothermal Innovative Network for Europe) was supported by the European Commission within its 6th R&D Framework Program. ENGINE main objective was to coordinate present R&D initiatives for Enhanced Geothermal Systems (EGS), ranging from resource investigation and assessment stage to exploitation monitoring through socio-economics and environmental impacts. From the 1st of November 2005 (Schuppers, 2006) to the 30th of April 2008 (Piontek, 2008), the ENGINE co-ordination action gathered 35 partners from 16 European and 3 non-European countries including 8 private companies. The backbone of the project was to make partners and related able to meet, present, and exchange their knowledge and to prepare synthesis and prospective documents. ENGINE organised 3 conferences and 7 specialised workshops (Figure 1). All together more than 500 participants attended the meetings where about 420 contributions were presented. The whole material collected and elaborated during the project is available through the ENGINE web site at *http://engine.brgm.fr* (Calcagno, 2008; Link 1). Proceedings, abstracts, slides, posters, reports, newsletters, etc., presenting the completed framework of the project activities, can be downloaded on the web site.

Figure 1 presents the breakdown structure of ENGINE along with its main milestones. Nine workpackages and 2 phases were organised to set up the coordination action. It started with a state of the art phase making an inventory of existing project and techniques for exploring, assessing, exploiting and taking into account socio-economics and environmental aspects for EGS. Then, an expert phase aimed at synthesizing best practises and proposing research areas and a strategy for medium- to long-term (Link 2). After one year of activity, the coordination action was extended to 4 non-European partners in order to share experience with countries among the most significant for geothermal activities outside Europe (Mexico, El Salvador, and Philippines). In the meantime, a stakeholder committee was created to facilitate bottom-up flow and to increase decision makers' awareness. ENGINE was meant to complement other Framework Programme instruments in contributing toward integrating research in Europe through well-planned networking or co-ordination activities. International cooperation has also been developed through the Coordinator participation in the IEA Geothermal Implementing Agreement and links established with other initiatives to promote EGS in the USA and Australia.

2. THE STATE-OF-THE-ART: PROMOTING MOST APPROPRIATE PRACTICES AND FILLING THE GAPS IN KNOWLEDGE

The ENGINE work is synthesized in a Best Practice Handbook presenting an overview of investigation, exploration, exploitation, and economic and socio-environmental impacts of unconventional geothermal reservoirs (UGR) and EGS. The Best Practice Handbook is designed for different groups of interest such as engineers, politicians, and decision makers from industry. The entire EGS life cycle is covered in four chapters (Link 2, Figure 2).

2.1 Chapter 1: Site Investigation

This chapter addresses the best practices for locating of a geothermal site. A scale-dependent workflow is developed for this purpose describing a step-by-step procedure on how to locate a reservoir using different techniques (Kohl et al., 2008). It introduces different tools and approaches to investigate resources from continental to regional, as well as local and reservoir scales (Figure 3). This method is implemented into workflow examples applied to various geo-environments depending on the geological context of the site: sediments, volcanics, granites and metamorphics. Taking into account sites in Iceland, France, Russia, Italy, Germany and Austria, a critical overview of the workflow processes is presented. This first chapter ends with

prospective considerations about mapping parameters, integrating data, and improving imaging between wells.

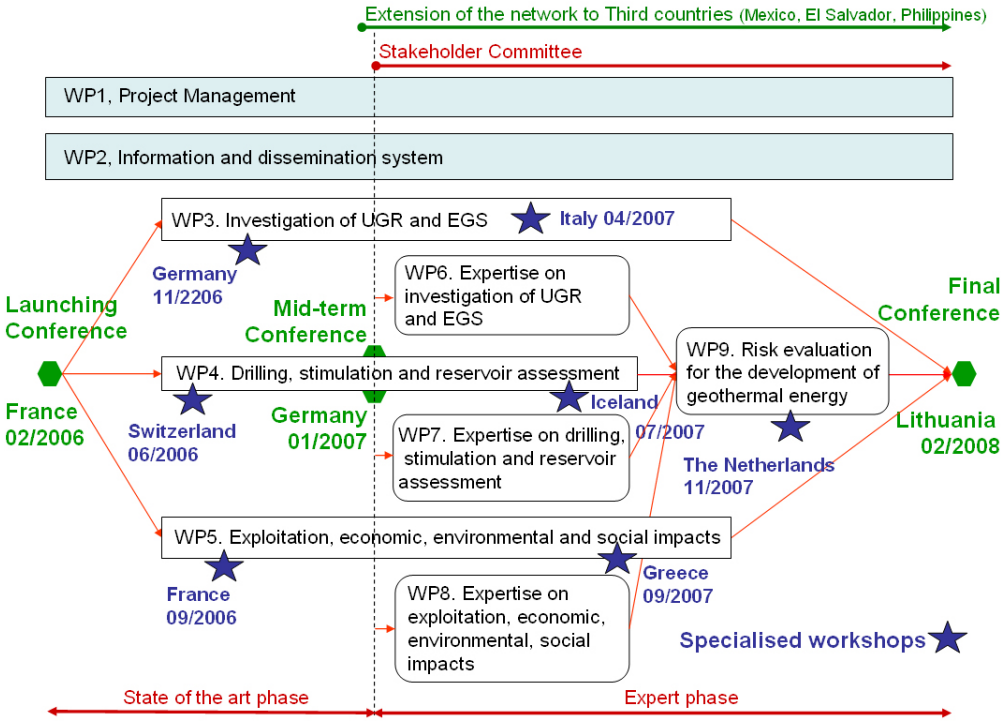

Figure 1: ENGINE breakdown structure and main milestones: 3 conferences (green hexagons) and 7 workshops (blue stars).

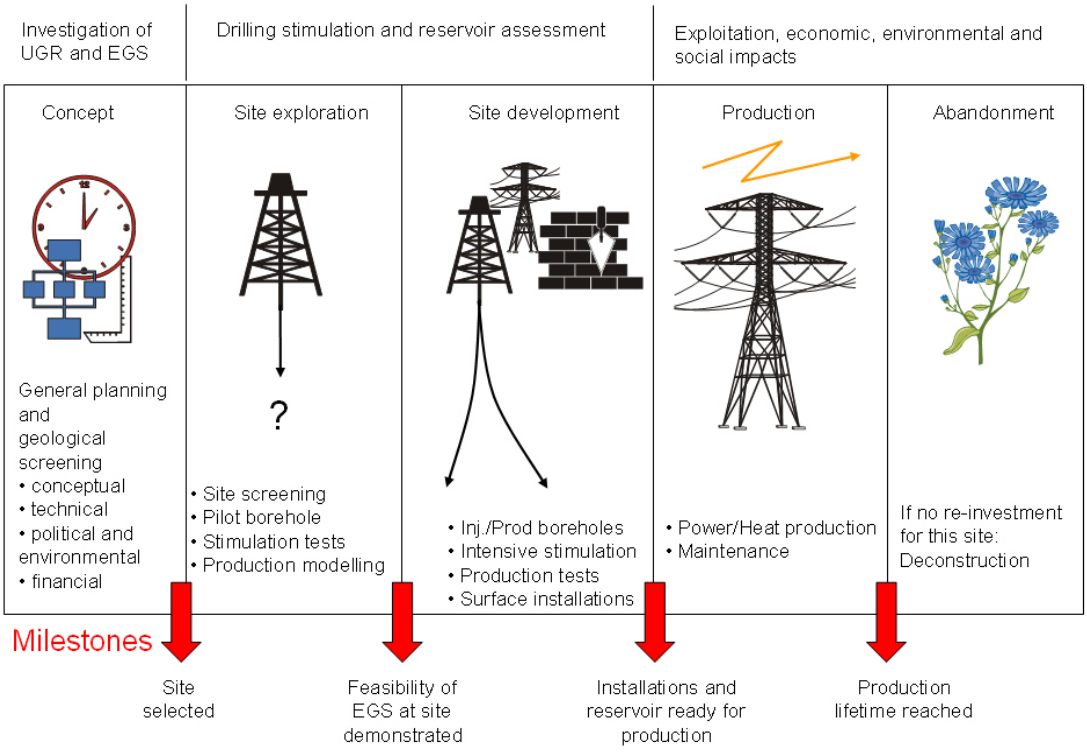

Figure 2: The main milestones of an EGS life cycle are covered in the ENGINE Best Practice Handbook (figure modified from Geowatt).

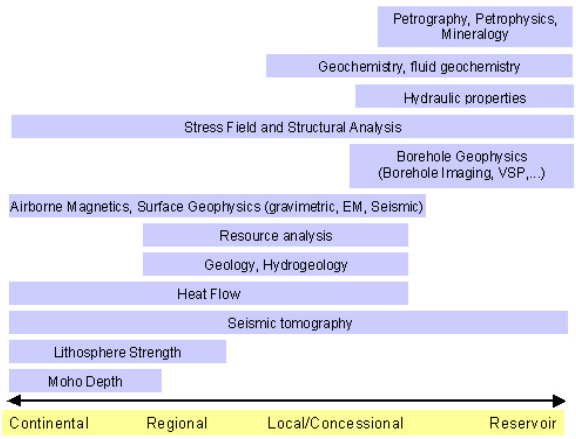

Figure 3: Scale dependent tools for site selection.

2.2 Chapter 2: Drilling, Stimulation and Reservoir Assessment

Drilling operations are performed in order to access geothermal reservoirs for energy exploitation (Schulte et al., 2008). This chapter describes various topics, ranging from drilling of wells to reservoir preparation for exploitation. Drilling techniques are synthesised from the experience acquired on various geothermal sites in Germany, Iceland, France, Italy and the Philippines. They are specifically presented using the geological context classification introduced in the first chapter (sediments, volcanics, granites and metamorphics). Next, the hydraulic, thermal and chemical stimulations are detailed keeping the same geological context classification. Then, testing tools for characterising hydraulic connection between wells are described. The final part of the chapter establishes the state-of-the-art and proposes good practices for reservoir assessment, management and monitoring.

2.3 Chapter 3: Exploitation

Considering the economical context, the exploitation chapter presents plant configurations and technologies for power production and heat supply before making R&D proposals (Karytsas and Mendrinos, 2008). It develops a critical analysis of the geothermal exploitation options from classical condensing power generation to binary units and co-generation plants. The first part of this chapter discusses the key factors for choosing between the possible options and provides important economic considerations. Best practices for technology including fluid supply and power generation (e.g. thermodynamical cycles), are presented in the second part. The chapter concludes with a description on ways to fill the gaps for reducing exploitation costs and improving EGS economics.

2.4 Chapter 4: Environmental and Socioeconomic Impact

The last chapter of the Best Practice Handbook examines how environmental impacts need to be carefully assessed and how geothermal energy project(s) will benefit the environment and local development. This chapter introduces the main benefits offered by geothermal energy, such as emission reduction, local environmental protection and community development. The second part describes the practices needed to minimize environmental impacts linked to geothermal installation of Low Enthalpy Hydrothermal Fields, High Enthalpy Hydrothermal Fields and Enhanced Geothermal Systems. Finally the public acceptance is addressed both at the general scale through education, training and governmental regulations and at the site scale to develop the geothermal project(s) in harmony with the local population.

3. THE STEP FORWARD: DEFINING PRIORITIES IN THE FIELD OF MEDIUM- TO LONG-TERM RESEARCH INVESTMENT

From the state-of-the-art described upper, priorities covering 4 main research areas are defined in the field of medium- to long-term research investment (Ledru, 2008, Link 2, Figure 4)

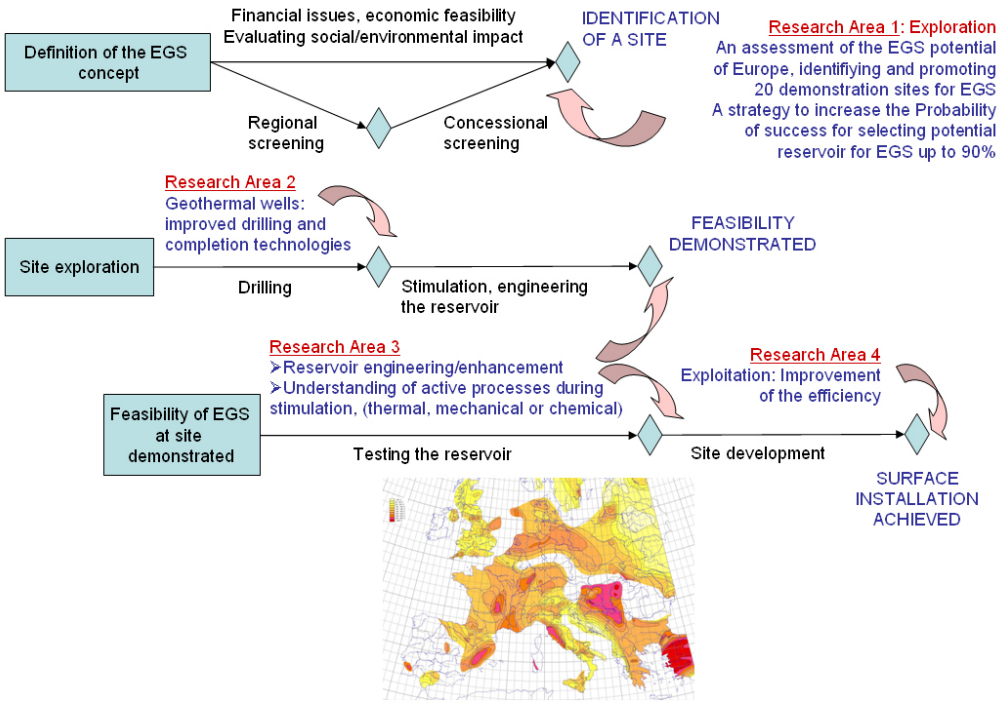

Figure 4: The main research areas defined by ENGINE.

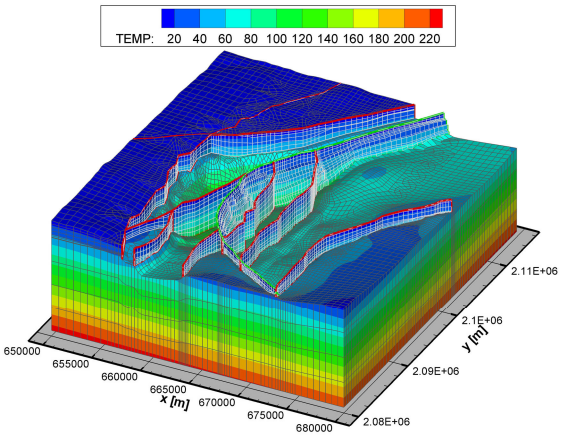

Figure 5: Combination of geological and thermal 3D modelling to infer the geothermal potential in the Limagne d'Allier basin (France) from Baujard et al. (2008).

3.1 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 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 (Figure 5).

The following items still require R&D investment.

3.1.1 Identifying and Assessing Reservoirs

Priority targets for EGS are deep potential reservoirs, where 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 accomplished in the USA in the framework of the MIT panel expert work aimed at evaluating "The future of Geothermal Energy" (Link 3). Such evaluation must be accomplished in Europe to be included in the Strategic Energy Plan. Compatible datasets and 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 actions to be undertaken, with the support of the European geological surveys and in compliance with the INSPIRE Directive (Link 4).

3.1.2 Combining Methods for Prediction

Further exploration of EGS sites 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 local/concessional scale, the geometry of the reservoir and its potential energy needs to be assessed but resolution remains rather low. Main gaps exist in combining various geological, geochemical and geophysical data in 3D. Input from the I-GET Project (Bruhn, 2006; Link 5) 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 when planning to enhance the flow conditions by hydraulic stimulation. This second action is complementing the first requirement concerning database and modelling.

3.1.3 Environmental and Socio-Economics Impacts

Review of case histories shows the importance of social acceptance and of the economic and environmental impacts of 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 the identification of about 20 potential sites for a demonstration program.

The final objective concerning exploration by the year 2020 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. The main R&D challenges to reach this target are (i) the improvement and new development of methodologies able to map and image temperature and permeability in 3D at higher resolution down to a depth of 10 km, particularly at a depths of 2.5-3 km, and (ii) the common use of a 3D modelling platform, as proposed in this Research Area 1. Development of innovative methodologies could also meet challenges for exploring new reservoirs in the oil and gas industry and management of the subsurface, especially for CO_2 sequestration.

3.2 Research Area 2: Geothermal wells, improving drilling and completion technologies

The drilling into geothermal reservoirs is the most costly part of a geothermal project. Drilling into shallow high-temperature reservoirs is almost standardised, while drilling into deep high-temperature reservoirs remains unusual. Standard tools, reliable drilling mud systems, cementing technologies, and a set of casing completions are available for both environments. In hostile environment reliable well completions are only available based on high cost casings.

An extended market penetration of geothermal energy requires that the drilling and completion costs 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 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 must be achieved for the overall drilling activities, including transport management, automatic pipe handling on drilling rigs, and 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 a European demonstration program.

3.3 Research Area 3: Reservoir Engineering, Stimulating the Fluid Flow Underground

Reservoir engineering implies reservoir characterisation, production enhancement through stimulation techniques and assurance of 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 geo-environments, including hydro-mechanical, acidization and thermal techniques. All tasks related to the engineering of the reservoir require sophisticated modelling of reservoir processes that permit prediction of reservoir behaviour with time and minimize the impact from micro-seismicity.

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 testing, 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 reservoir permeability and other characteristics 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 EGS concept and provide decision support tools for seismic hazard mitigation.

3.4 Research Area 4: Exploitation, Improving the Efficiency

The exploitation activities include all technical equipment needed to extract heat and/or electricity from the fluids produced by the wells. For example, this includes the production pump, piping, heat exchanger, power plant, and any auxiliary equipment. Technical equipment is available on the market. However, the efficiency of the different system components can still be improved. This is especially true for low-enthalpy power plant cycles (e.g. Organic Rankine Cycle, 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 (Frick et al., 2008, Figure 6). The net electrical efficiency of the power plant cycle and of combined heat and power systems should be improved by the year 2020 by 20 %. Cost reductions by 10 to 20 % using innovative technologies for district heating and industrial customers should be reached. Other improvements of 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, major efforts must be dedicated to (i) the development of new materials at lower cost (pipes, pump, additives, heat exchangers), (ii) the definition of new industrial processes and treatment of the brine to limit scaling effects, (iii) reaching higher efficiencies and developing cascade uses, (iv) integration of the different system elements within an optimized overall system, and (v) the definition of measures to reduce possible environmental effects during normal or abnormal operation. These targets could be integrated in the European Directorate General Research work program concerning energy efficiency.

4. TOWARDS A DEMONSTRATION PROGRAM INTEGRATING THE DIFFERENT RESEARCH AREAS.

The achievement of the Soultz experiment (Cuenot et al., 2008) and several successful spin off projects (Baumgärtner et al., 2007; Haimberger, 2007) participate to the development of EGS. A total production of 3000 MWe from geothermal sources can be expected in 2020 in Europe. The contribution of EGS sources must significantly increase during the coming years and technologies are already available to plan a demonstration program for the near future. The development of 20 EGS demonstration sites throughout Europe is considered realistic and sufficient to show EGS feasibility (Link 2). Already, some of the ENGINE partners are involved in ongoing or planned projects which include the Icelandic Deep Drilling Program (Fridleifsson and Elders, 2007; Link 6) and the Bruchsal project in Germany (Kölbel, 2009). Projects are also under preparation in Hungary and Turkey.

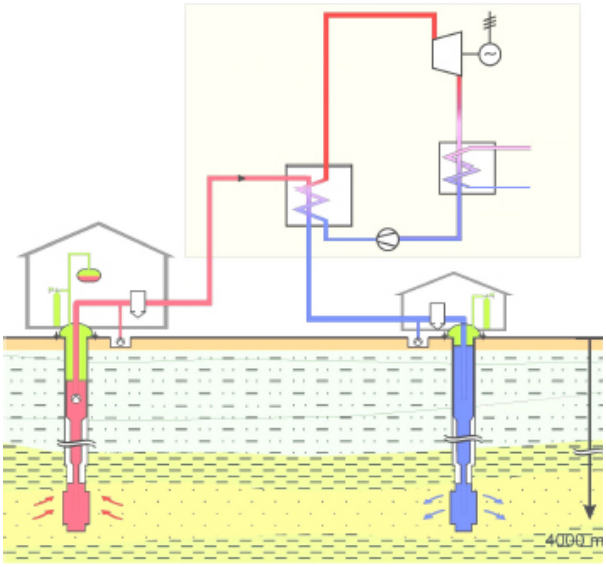

Figure 6: Improving the design of geothermal power plants to improve their efficiency.

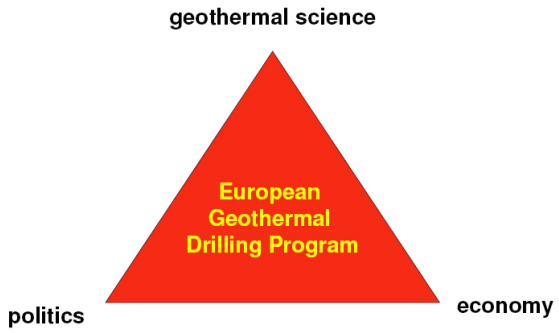

Figure 7: A European drilling program federating existing and forthcoming projects to demonstrate EGS feasibility.

These EGS projects will generate a learning curve for standardization of most operations. Their planning constitutes a roadmap for researchers, industry and funding agencies to develop geothermal energy contributing to the strategic objective of 20% renewable energy sources (RES) and CO_2 reduction in the EU energy mix by 2020. An EGS foundation could be created based on evaluating these projects, which could, in turn, strengthen the links with industrial partners and result in a technological platform (Huenges et al., 2008, Figure 7). This foundation should be aimed at keeping the present European knowledge for the management of non-conventional (Soultz) and conventional geothermal reservoirs (France, Germany, Iceland, Italy) and transferring it to the development of zones of high potential in Europe (Greece, Pannonian basin of Hungary and Romania, Turkey) and in other parts of the world (Southern Australia, Western USA, China, Indonesia, Japan, New-Zealand, Caucasia and Kamchatka in Federation of Russia).

5. CONCLUSIONS

The geothermal sector still needs: (i) generic technologies to expand the use of geothermal heat and power, (ii) public acceptance mainly by reducing induced seismicity, and (iii) a common strategy and a roadmap for future R&D projects and demonstration sites. Moreover, international cooperation must be strengthened to stimulate global development, commercialisation, deployment and access to technologies. A specific Strategic Energy Technology Plan for geothermal energy must mobilise *additional financial resources*, particularly for industrial-scale demonstration projects, early market deployment, and new infrastructure. It must also design *support schemes* for co-generation and heating and cooling, energy efficient vehicles, and energy efficient buildings, combining other renewable energy sources and other low-carbon technologies. By making full use of the FP7 People Programme (Link 7), this plan will also promote education and *training* needed to deliver the requisite quantity and quality of human resources necessary to achieve these goals.

Several projects have been proposed for reaching these objectives. Among them, GEISER – standing for *Geothermal Engineering Integrating Mitigation of Induced Seismicity in Reservoirs* – will operate from 2009 to 2013 in the scope of the 7th R&D Framework Program of the European Commission.

ACKNOWLEDGEMENTS

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WEB LINKS

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http://engine.brgm.fr

2. ENGINE Best Practice Handbook & Proposed Strategy:
http://engine.brgm.fr/BestPractiseHandbook.asp

3. MIT Report "The Future of Geothermal Energy":
http://www1.eere.energy.gov/geothermal/future_geothermal.html

4. INSPIRE Directive:
http://inspire.jrc.ec.europa.eu

5. I-GET Project:
http://www.i-get.it

6. Icelandic Deep drilling Program:
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7. FP7 People Programme:
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