Enhanced Geothermal Innovative Network for Europe: The State-of-the-Art

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ABSTRACT

The European Commission support for geothermal energy research has been constant since the end of the 1980s and has significantly increased within its 6th R&D Framework Program. One of the most prominent activities co-financed by EC-funds is the ENGINE Coordination Action (ENhanced Geothermal Innovative Network for Europe), which is aimed at co-ordinating present R&D initiatives for Enhanced Geothermal Systems (EGS), ranging from the resource investigation and assessment stage to exploitation monitoring. Thirty five partners are involved in ENGINE, representing 15 European Countries plus Mexico, El Salvador and Philippines. By mid-term, the project has organised 2 conferences and 4 specialised workshops. After one year, materials available on the web site http://engine.brgm.fr already show the work that has been completed revealing a strong motivation of the scientific community for updating the framework of activities, preparing a Best Practice Handbook and defining new ambitious research projects.

In relation with the increasing price of energy and the goal of limiting greenhouse gas emissions, there is a noticeable increase in interest from industry in Europe in geothermal energy. ENGINE is now well known as a scientific exchange platform for promoting past and on-going experiences by making them visible and reproducible. Through a recently established stakeholder committee, ENGINE could also become a "political" platform. It could, for example, establish a permanent working group that would have the technical and economic background to set up an industrial and public European consortium and define an ambitious strategy for 2030 proposing shared-risk projects at the scale of Europe. The proposal to evaluate the geothermal potential of former oil and gas field could also be one way to limit the risk and start new demonstration projects.

Introduction

The *ENGINE Coordination Action (ENhanced Geothermal Innovative Network for Europe)*, supported by the European Commission within its 6th R&D Framework Program has started in November 2005 (Schuppers, 2006). Its main objective is to co-ordinate present R&D initiatives for Enhanced Geothermal Systems (EGS), ranging from the resource investigation and assessment stage to exploitation monitoring. Thirty five partners are involved in ENGINE, representing 15 European Countries plus Mexico, El Salvador and Philippines. It is meant to complement other Framework Programme

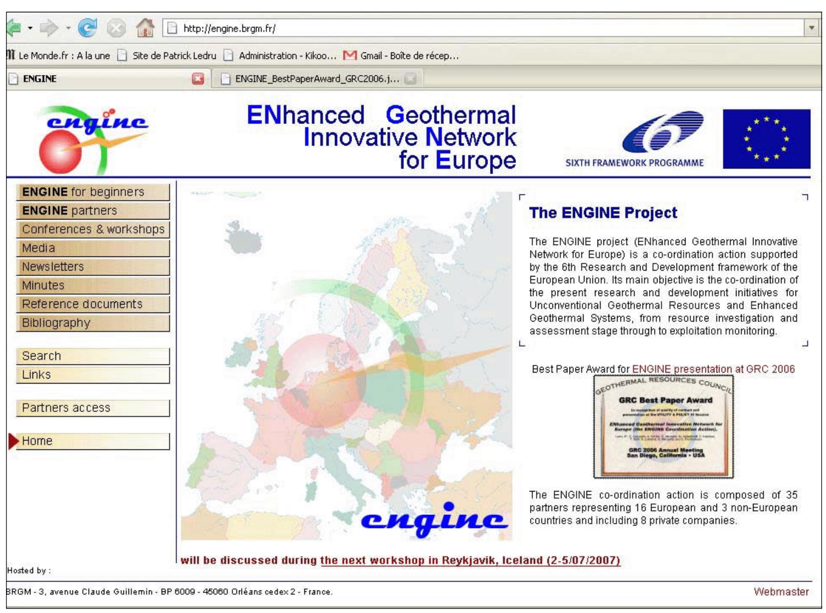

Figure 1. ENGINE website.

instruments in contributing toward integrating research in Europe through well-planned networking or co-ordination activities. Two Specific Target Research Projects are dedicated to the Hot Dry Rock Project at Soultz-sous-Forêts (Fritsch and Gerard, 2006) and to the development of an innovative geothermal exploration approach based on advanced geophysical methods (the I-GET Project, Bruhn et al., 2006). Other on-going EGS projects like Gross Schönebeck (Germany, Huenges et al., 2006), Basel (Switzerland, Hopkirk and Haring, 2006) and Cooper Basin (Australia) provide valuable experience input to the ENGINE Co-ordination Action. ENGINE is also deeply connected to the HITI STREP dedicated to high temperature tools for investigating supercritical fluids as well as high temperature reservoir conditions (Asmundsson, 2007). To complete this screening of the 6th Framework Program, the LOW-BIN project aims in improving cost-effectiveness, competitiveness and market penetration of geothermal electricity generation schemes (Karytsas and Mendrinos, 2006). In addition, international co-operation takes place through the Commission participation in the IEA Geothermal Implementing Agreement.

By mid-term, the ENGINE project has organised 2 conferences and 4 specialised workshops. Materials available on the web site http://engine.brgm.fr already show the work that has been completed (Calcagno 2007, Figure 1). Dissemination of results is also done through newsletters collecting a review of all the activities, updated bibliographies and draft papers shared by the partners through the website, presentation of lighthouse projects showing the domain of excellence of each partners, etc. These different items are under construction but already provide a unique snapshot of on-going activities.

Preliminary syntheses concerning:

- Defining, exploring, imaging and assessing reservoirs for potential heat exchange (Bruhn and Manzella, 2007),
- Stimulation of reservoir and microseismicity (Huenges and Kohl, 2007),
- Environmental impacts by the use of geothermal energy (Frick and Kaltschmitt, 2007),
- Electricity generation from EGS (Le Bel and Kaltschmitt, 2007),

EGS technology	Priority A	Impact of innovation	Priority B	Impact of innovation	Priority n	Impact of innovation
Resource investigation	Topic 1	x%	Topic 2	y%	Topic n	z%
Drilling, stimulation and reservoir assessment	…		…		…	
Exploitation, reservoir management and monitoring	…		…		…	
Economic, environmental and social impacts	…	high	…	medium	…	low
…						

Figure 2. How to prioritise R&D needs?

reveal a strong motivation of the scientific community for updating the framework of activities and establishing a long term partnership with stakeholders and industry. This phase of synthesis and of identification of bottlenecks will be concluded by an evaluation of the priorities for defining new research projects (Schuppers, 2007, Figure 2).

An Updated Framework of Activities and New Projects for the Development of EGS

Investigation of Unconventional Geothermal Resources and Enhanced Geothermal Systems.

The synergy with the FP6 IGET project dedicated to Integrated Geophysical Exploration Technologies proved to be fruitful since the kick off meetings. This project is aimed at developing an innovative geothermal exploration approach based on advanced geophysical methods and consists of improving the detection, prior to drilling, of fluid bearing zones in naturally and/or artificially fractured geothermal reservoirs. The ENGINE coordination dedicated a workshop in Potsdam in November 2006 to the identification of the parameters that are needed before exploration drilling within potential geothermal reservoirs. It was agreed that structural geology, temperature distribution, stress and fluid pathways, as well as the chemical and mineralogical composition of the rocks hosting the geothermal system, constitute key elements that can be considered as priorities in terms of research needs.

Structural Geology is fundamental for imaging potential geothermal reservoirs. Geophysical methods are suitable for determining the architecture, geometry, and quality of the target intervals. However, existing methods must be improved and used in combination with different, highly sensitive techniques (passive and active seismics, MT, etc.) in order to meet the specific requirements of modern geophysical exploration for geothermal purposes. A significant effort has to be made in the interpretation of geophysical features that must be supported and validated by both petrophysical laboratory and borehole measurements, as well as by modelling. *Finding heat at depth* is a second challenge of the investigation phase. The extension of large-wavelength heat-flow anomalies at depth is often inaccurate due to insufficient knowledge of the causes of the heat-flow anomaly and of the thermal properties of the main lithologies. Several physical parameters are coupled with temperature and can be imaged by different geological, geophysical and geochemical methods. Thus, the definition of possible targets for EGS could be improved by the use of a 3D modelling platform, in which all solutions from geological, geochemical and geophysical modelling, direct and inverse, could be combined and analysed (Figure 3). The links with other investigation programmes, such as nuclear waste storage, capture and geological storage of CO_2 and oil and gas field development, could be also developed as a way to benefit from existing installations and experiences.

The knowledge of *the stress field* is another parameter crucial for understanding and stimulating fluid circulation. The influence of the stress field on

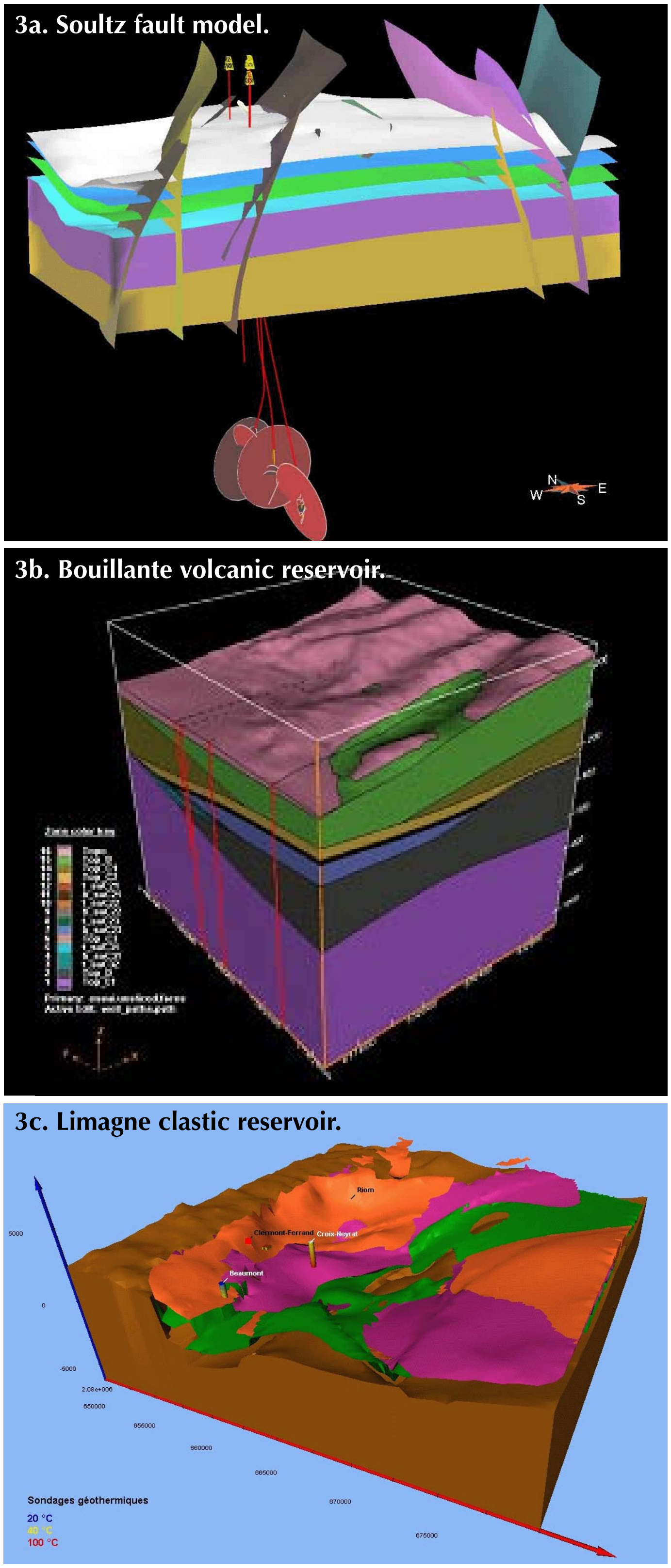

Figure 3. Definition of possible targets for EGS by the use of 3D modelling platform. The presented 3D geometrical models have been realised using different modelling tools available on the market (a: GoCad, b: Earth Vision, c: 3D Geomodeller) by different research teams. The generalised use of such tools is crucial for a more accurate definition of reservoir and a better modelling of heat and fluid flow.

hydro-fracturing is observed while the mechanisms of rupture and propagation of an existing fault system and related displacement remain debated as well as the actual permeability associated with. The ability of the fault and fracture systems to channel fluids is directly dependant on the stress field (orientation and intensity). Favourable and unfavourable conditions exist depending on the tectonic setting and the geological environment. In conclusion, *defining integrated conceptual models* is a next step for defining the necessary starting conditions for the development/stimulation of an EGS. There is a need to refer to conceptual models of the main geothermal sites, ranging from extended active geothermal sites to EGS for which heat distribution and permeability networks are available for modelling pathways for fluid circulation, gas-water-rock interaction processes and heat exchange. A significant improvement of knowledge is expected from natural analogues on which hypotheses could be tested, for example circulation of fluids in relation to seismicity and lithology heterogeneity, or the thermal imprint of fluid circulation. The complex interactions between lithology, fracture and stress field are illustrated on Figure 4, overleaf.

The mineralogical composition of the host rock and the hydrothermally altered products are derived from cores, cuttings, and geophysical well logging analyses (Figure 4a). These mineralogical data are fundamental to characterize the EGS reservoir because chemical interactions between injected fluid and the fracture fillings govern a dissolution and/or precipitation process that means permeability variations. From oriented borehole image logs and their comparison with other flow logs (Figure 4 b,d), the location and the geometry of open fracture network are acquired. This stage is very important because pre-existing fractures represent the fluid pathways. Then, stress field orientation could be determined from wellbore failure (Figure 4c) combined with hydraulic observations (Valley and Evans, 2007) in order to understand if the present-day tectonic conditions are favourable or not to fluid circulation. Then, analysis of these interactions requires the visualisation of fractured zones, in situ measurement of their properties by geophysical logging, measurement of the stress field, fluid-rock interaction as well as a good understanding of the geological evolution.

Drilling, Stimulation and Reservoir Assessment

During the first year of the ENGINE project, the main focus has been on the enhancement methods. Enhancing or engineering the reservoir is a key issue for EGS and mechanical and chemical stimulations are commonly used to enhance their hydraulic properties. Moreover, the associated induced microseismicity, geochemical tracing and thermal evolution of the system provide an exceptional opportunity to characterize the reservoir and its dynamics (Mégel et al., 2006; Sanjuan et al., 2006). Because of the limited experience in EGS development, the success of such ventures is still a matter of trial and error, depending on the variety of geological contexts and site conditions. More detailed reviews of some stimulation methods have been planned, and exchanges with hydrocarbon industry and underground nuclear waste and CO2 storage platforms are encouraged. As it is already partly expressed in the R&D

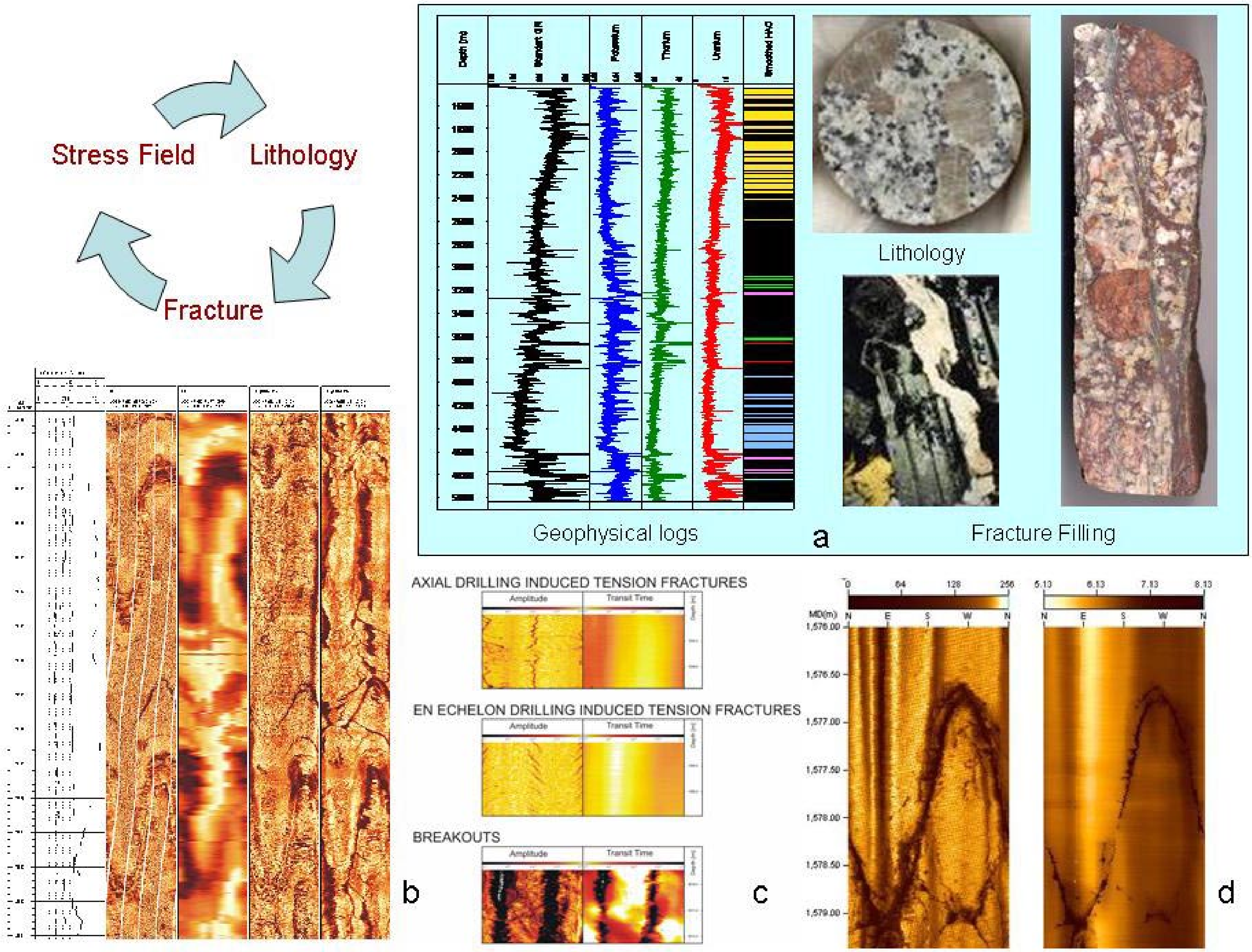

Figure 4. Interactions between lithology, fracture and stress field (Soultz well data). a) geophysical well logging (U, Th, K) in a Soultz well, sample and fractured granite core; b) borehole image log comparison in a Soultz well; c) Typology of wellbore failure for stress field determination; d) Open fracture visible on acoustic borehole image.

7th Framework Program (FP7) of the European Commission, research should (a) define conceptual models for irreversible enhancement of permeability of the reservoirs (relationships between stress field and strain mechanisms, fluid-rock interaction, fluid pressure development…), (b) analyse the distribution in time and space of the magnitude of seismic events in order to improve the 3D imaging of the fracture system and stress field (interaction between tectonic, lithostatic and fluid pressure), (c) set requirements for seismic monitoring (modelling and observation networks) and 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. Finally, the induced earthquake in Basel on the 8th of December 2006 reveals the urgent necessity to fill the gap in knowledge about this matter. An innovative project dedicated to the role of induced seismicity in EGS has been prepared following the 1st call for proposal of the 7th FP and is considered as a spin-off project from ENGINE.

Economic, Environmental and Social Impacts

The definition of an area thermally suitable for the development of an EGS is also highly dependent on the *exploitation* and business plan including an evaluation of the economic, environmental and social impacts. One of the R&D perspectives related to this aspect is to analyse and assess possibilities and limitations of the currently available power plant technology using the energy retrieved from low enthalpy geothermal sources. To get an overall view, representatives of research and industry as well as project operators and planners have been brought together during a workshop and further discussed during a meeting of the Stakeholders committee. The available know-how from existing geothermal power plants shows that electricity production from low enthalpy resources in Europe is still a fairly young technology which lacks wide experience. Nevertheless there are quite a lot of projects planned and considerably more experience will be available in the years to come.

The contradictory discussion about ORC vs. Kalina cycle, air vs. water cooling, innovative vs. proven technology and Power vs. Combined Heat Power is of no interest in terms of a further development of geothermal energy use. The main task of project developers is considered to be the identification of the optimisation potential in terms of the design of the working fluid, the cycle and turbine designs as well as the cooling systems. New and innovative technology is typically accompanied by technical and financial risks. With an increasing technical effort and innovative ideas, the efficiency of a power plant cycle can be improved. Before being able to break into the market these technologies need to be tested, which is generally not possible on a purely commercial basis. Here the governments, national agencies and Europe are asked to support the market access of such new and innovative technologies which are definitely needed for further establishing geothermal electricity production in Europe. Both these concepts developed within the ENGINE action have been directly applied by choosing a Turboden-Cryostar binary power plant for the Soultz-sous-Forêts experiment (Gérard et al., 2006).

Another approach to promote geothermal electricity production from low enthalpy resources was stated as a combination with other sources of energy. New concepts of combining different energy options supplying heat on different temperature levels can result in a higher overall efficiency and thus profitability, and hence can be decisive for realising geothermal-based electricity production.

A Long Term Partnership with Stakeholders and Industry

In relation with the increasing price of energy and limitation of greenhouse gas emission, there is a noticeable increase in interest from industry in Europe in geothermal energy. The aim of the stakeholder committee is to provide information about on going R&D efforts in Europe about Enhanced Geothermal Systems and insight into the newest achievements made by industrial projects. Strategic guidance to the Executive Group and to Contractors in general is expected through suggestions and recommendations of the Committee. Several points of convergence are already underlined.

The general question of demonstrating the efficiency of a large range of geothermal applications has first been raised. If all R&D teams and stakeholders are convinced, an effort of communication in Europe still has to be done to promote the geothermal energy as a cost-efficient alternative source of energy, whether from high-enthalpy fields like in Tuscany (Italy), Iceland or Guadalupe (France) or from very low enthalpy in Sweden, Norway or Switzerland where geothermal heat pumps are widely spread. This is a *first point of convergence and a communication plan* need to be proposed.

Several stakeholders express their interest for such an organisation as ENGINE that aims at co-ordinating present research and development initiatives for Enhanced Geothermal Systems. Thus, the need of good synthesis of the knowledge and collection of existing datasets for modelling and assessment of the resources, prior to drilling is emphasized. R&D teams have, on their own, underlined the need of a sustainable support of industrial partners and public bodies to ambitious research projects. This is *a second point of convergence* that fully justifies the existence of such Stakeholder Committee. From this convergence of interest, and in agreement with its main objectives, ENGINE should play the role of *a scientific exchange platform* for promoting past and on-going experiences by making them visible and reproducible.

The needs for research expressed by stakeholders are in general very specific of bottlenecks encountered for improving cost-efficiency of existing technologies, like improvement of submersible pumps, better combination of heat and power generation, control of scaling in surface, etc. The main challenge addressed by stakeholders is the exploration of the possible links between geothermal energy and CO2 capture, sequestration and storage. For R&D teams involved in EGS, the proceedings of the mid-term conference reveals a wide spectrum of themes like the reduction of the geological risk during exploration of deep resources, development of new stimulation strategies, mitigation of the induced seismicity, etc. These differences in establishing priorities are of course related to the fundamentally different missions of R&D and industrial projects. However, as mentioned above, the development of *a scientific exchange platform* is of common interest for both. *Definition of research projects* supported by the stakeholder committee should be a target for this platform that could be presented to the EU commission as a possible contribution for the future work programme of the FP7. Announcement done by the US Department of Energy's on 14th June 2007 of new funding opportunities for demonstrating the technical feasibility and economics from the naturally occurring geothermal fluids that are coproduced from oil and/or gas wells to generate electric power shows how innovative research projects can be defined from a common interest of scientists and stakeholders.

Stakeholders and R&D teams agree that the development of Enhanced Geothermal Systems still requires the definition of *an ambitious research program at the scale of Europe* that will optimize the research capacity and limit the financial risk by sharing the investment. Such a program, for example a *European geothermal drilling program,* requires an unified approach of both scientist and stakeholders and constitutes *a third point of convergence*. To achieve this goal, ENGINE, or another collaborative action after the end of ENGINE, must become a "political" platform that will have the technical and economic background to propose and support new projects. Among these new projects, the evaluation of the potential of former oil and gas field could also be one way to limit the risk and start new demonstration projects. Such a European geothermal drilling program could be promoted in parallel at the level of policy makers for implementing incentive politics for supporting geothermal energy as a contribution to achievements of EU objectives for renewable energies and greenhouse gas reduction.

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