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"The Future of Geothermal Energy" and Its Challenges

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ABSTRACT

The widely renowned M.I.T. study "The Future of Geothermal Energy" (2006) determined recoverable EGS resources > 200,000 EJ alone for the USA, corresponding to 2,000 times the annual primary energy demand. To universally and globally utilize these immense resources exciting R&D problems need to be tackled: 1) Development of a technology to produce electricity and/or heat from a basically ubiquitous resource, independent of site subsurface conditions ("EGS technology"); 2) Acquiring experience about possible changes of an EGS heat exchanger with time; 3) Upscaling EGS power plant capacity from the currently few MWe to several 10 – 100 MWe.

1. INTRODUCTION

The widely renowned M.I.T. study "The Future of Geothermal Energy – Impact of Enhanced Geothermal Systems (EGS) on the United States in the 21th Century" (Tester et al., 2006) envisages Enhanced Geothermal Systems to be the future of geothermal energy utilization. Enhanced Geothermal Systems is an umbrella term for various other denotations such as Hot Dry Rock, Hot Wet Rock, Hot Fractured Rock. In the following the prospects of EGS to become the future of geothermal energy are highlighted.

The principle of Enhanced Geothermal Systems (EGS) is simple: in the deep subsurface where temperatures are high enough for power generation (150-200°C) an extended fracture network is created and/or enlarged to act as new fluid pathways and at the same time as a heat exchanger. Water from the surface is transported through this deep reservoir using injection wells and recovered by production wells as steam/hot water. The extracted heat can be used for district heating and/or for power generation.

While conventional geothermal resources cover a wide range of uses for power production and direct uses in profitable conditions, a large scientific and industrial community has been involved for more than 20 years in promoting Enhanced Geothermal Systems. The enhancement challenge is based on several conventional methods for exploring, developing and exploiting geothermal resources that are not economically viable yet. This general definition embraces different tracks for enlarging access to heat at depth and its recovery:

- stimulating reservoirs in low permeability systems and enlarging the extent of productive geothermal fields by enhancing/stimulating permeability in the vicinity of naturally permeable rocks
- improving thermodynamic cycles in order to ensure power production from water resources at medium temperature (from 80°C)
- improving exploration methods for deep geothermal resources
- improving drilling, reservoir assessment and stimulation technology.

Recent efforts along these lines have been undertaken by a multi-national team within the ENGINE Project. From the 1st of November 2005 to the 30th of April 2008, the ENGINE co-ordination action gathered 35 partners from 16 European and 3 non-European countries including 8 private companies. ENGINE was supported by the 6th Research and Development framework of the European Union. Its main objective was to coordinate research and development initiatives for Enhanced Geothermal Systems from resource investigation to exploitation through socio-economics impacts assessment. The results, and especially a Best Practices Handbook, can be downloaded from the ENGINE website http://engine.brgm.fr

The M.I.T. study (Tester et al., 2006) determined a large potential for the USA: recoverable resources > 200,000 EJ, corresponding to 2,000 times the annual primary energy demand (Tester et al., 2006). An EGS power generation capacity of >100,000 MWe could be established by the year 2050 with an investment volume of 0.8 - 1 billion USD. The report presents marketable electricity prices, based on economic models that need to be substantiated by EGS realisations. Similar studies came up with comparably large numbers (Paschen et al. 2003). When presenting potential numbers it needs to be clearly defined what potential is in question; some related considerations are given below. Furthermore the EGS challenge to become the future of geothermal energy is addressed and the still open questions are discussed.

2. SOME REMARKS ON GEOTHERMAL POTENTIAL

Whenever there is a need to express in a quantitative way the amount of not yet developed geothermal energy, then potential is one option, but then it must be clearly defined what potential: Theoretical? Technical? Economic? Sustainable? Developable? The other way of description is by resources and reserves. Here a clear distinction must be made between resources (Inferred? Indicated? Measured?) and reserves (Probable? Proven?), in the sense of the Australian Geothermal Reporting Code (2008). Since the "potential" and "resources" approaches are distinctly different, the term "resource potential" is misleading and should not be used.

In renewable energy considerations it is customary to refer to different potential categories. Here some considerations and definitions are given, partly based on Piot (2006).

The theoretical potential describes the physically usable energy supply (e.g. the in the total biomass stored energy) over a certain time span in a given region. It is defined solely by the physical limits of use and thus marks the upper limit of the theoretically realizable energy supply contribution. Due to insurmountable technical, structural and administrative limitations only small fractions of the theoretical potential can actually be used. Therefore the theoretical potential has no practical relevance in assessing the practical usability of renewable energies.

The technical potential describes the fraction of the theoretical potential that can be used under the existing technical restrictions (currently available technology). In addition, it considers the given structural and ecologic restrictions as well as legal and regulatory allowances, since these are –similar to technical limitations– of insurmountable character. Thus it describes the time and location dependent possible contribution of a renewable energy to the energy demand. Since this potential depends mainly on technical boundary conditions it is less subject to temporal variations than the economic potential.

The economic potential describes the time and location dependent fraction of the technical potential that can be economically utilized within the actually considered energy system: the total costs (investition, operation, and decommissioning of a renewable energy installation) are in the same range as the total costs of competing systems. Since various approaches exist to assess the economy of a technology for energy supply there are different economic potentials. In addition several economic boundary conditions exist (e.g. oil price changes, changing taxations, write-offs, feed-in tariffs).

The sustainable potential is a fraction of the economic potential; it describes the fraction that can be utilized by applying sustainable production levels (see e.g. Rybach and Mongillo, 2006).

The economically developable potential describes the fraction of the economic potential that can be developed under realistic conditions. Therefore it is usually smaller than the economic potential. It can be greater when administrative measures like promotion programs exist for renewable energies.

In general terms each potential is a fraction of the previous potential. Figure 1 illustrates the relations.

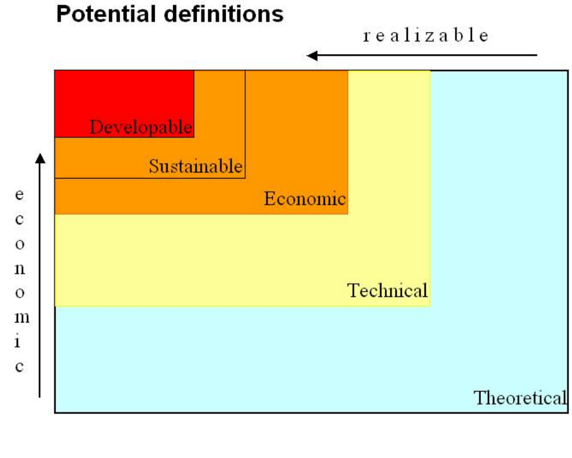

Figure 1: Potential definitions for renewable energy; they also apply to geothermal energy.

As it is shown below the EGS potential cannot yet be termed "technical"; it is still very much "theoretical".

3. THE EGS CHALLENGE

The core piece of an EGS installation is the heat exchanger at depth. It is generally accepted that it must have a number of properties in order to be technically feasible and economically viable. These refer to the total volume, the total heat exchange surface, the flow impedance, and the thermal and stress-field properties. The key properties are summarized in Table 1.

The challenge is that the heat exchanger needed is located at several kilometres depth; there is no way to detect and change its properties by direct observations and/or manipulations. Therefore some kind of “remote sensing” and “remote control” is needed, based on actions and interventions at wellhead.

There are already some tools available to perform such operations:

- to detect downhole data and their changes with time the software package HEX-B can be used to evaluate in-situ conditions from wellhead data (Mégel et al. 2005, Mégel and Kohl 2007);
- to plan and evaluate hydraulic stimulation the software package HEX-S can be used, especially to trace the evolutions of permeability distribution in space and time (Kohl and Mégel 2007).

Both tools have been successfully applied at the European HRD Project Soultz (ENGINE Best Practice Handbook 2009).

Definitely more tools for data processing and interpretation are needed to come up with best solutions.

4. THE REMAINING TASKS

Several still open questions need to be addressed and answered. The report “An Evaluation of Enhanced Geothermal Systems Technology” (DOE 2008) critically assessed the knowledge gaps; here some main issues are indicated.

4.1 Engineering an EGS Reservoir

In most cases this needs some stimulation (hydraulic, chemical) in order to achieve the needed reservoir properties as given in Table 1. Experience with thermal and chemical stimulation is beginning to accumulate.

Table 1: Required properties for an EGS reservoir (after Garnish, 2002)

Fluid production rate	50 - 100 kg/s
Fluid temperature at wellhead	150 - 200°C
Total effective heat exchange surface	> 2 x 10^6 m^2
Rock volume	> 2 x 10^8 m^3
Flow impedance	<0.1 MPa/(kg/s)
Water loss	< 10 %

The possible environmental effects of hydraulic stimulation like induced seismicity (during stimulation but also due to production) become increasingly a real issue. Social acceptance will be decisive (Majer et al. 2008).

Many questions of rock mechanics like the degree of stress anisotropy, stress propagation/transmission (whether it happens fast, in “dry“ state? Or slow, in „wet“ state?) are unanswered. Connectivity throughout a planned reservoir cannot yet be engineered.

The key issue will be to develop a technology for the creation of EGS downhole heat exchangers with the needed properties independent of site conditions. Before this fundamental question is not solved and the corresponding technology developed, the EGS potential cannot be termed “technical”.

4.2 Long-Term Behaviour

There is no experience about possible changes of an EGS heat exchanger with time. The thermal output will generally decrease with time; so far there are only model calculations to get a handle on this effect (see e.g. Sanyal and Butler 2005).

A key property is here the recovery factor (fraction of extractable heat/heat in place). The recovery factor can change with time: permeability enhancement (e.g. new fractures generated by cooling cracks or dissolution of mineral species) could increase the recovery factor, while permeability reduction (e.g. due to mineral deposition) or short-circuiting could reduce recovery.

Without having field-scale experience with long-term EGS production the economic estimates about installation, production, and maintenance costs remain unsubstantiated. Obviously the economic balance is most favorable when the waste heat of an EGS-based power plant can be sold locally, e.g. to an already existing district heating network

4.3 How to Upscale EGS Power Production?

So far the envisaged electric power capacity of a EGS installation (based on the properties of Table 1) is limited at a few MWe. But in order to play a significant role in local, regional and global electricity supply a system capacity of at least several tens or hundreds of MWe would be essential.

One of the main future R&D goals will be to work out how the EGS power plant size could be upscaled. So far there are only some theoretical calculations available; see e.g. Vörös et al. 2007. In this publication an EGS scheme with 24 injection and 19 production wells is modelled, providing a net power output of around 60 MWe.

Geodynamics Ltd (Australia, www.geodynamics.com.au) repeatedly announced to have at Habanero, Cooper basin a commercial-scale 50 MWe power plant up and running by 2011.

In any case, a large-scale dissemination of EGS technology will need considerable time (presumable some decades).

5. CONCLUSIONS, OUTLOOK

Enhanced Geothermal Systems have proven an immense theoretical potential. Presently EGS is still at the “proof of concept” stage; to reach the level of technical potential the key proof needs to be demonstrated: development of a technology for the creation of EGS downhole heat exchangers with the needed properties independent of site conditions in the subsurface.

In addition, experience is needed about the production behavior of EGS heat exchangers at depth on the long-term, not least for acquiring economic data about installation, production, and maintenance costs. This is especially needed to judge the cost/benefit ratio of EGS power plants.

The future of geothermal energy will strongly depend on to what extent can geothermal power plant deployment be accelerated. Other sources of renewable energy are developing rapidly (wind energy recently accomplished to install 25 GWe additional capacity per year; solar PV reached 6 GWe/yr; Renewables – Global Status Report 2009) whereas geothermal power growth remains clearly below 2 GWe/yr (Bertani 2009). Even when one takes into account the higher geothermal capacity factor the need for speed-up in geothermal development is obvious. Accelerating EGS development could establish a break-through, provided that a strong financial involvement can take place. This would need correspondingly strong engagement of the public and private sector.

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