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Status and Prospects of Geothermal Energy

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ABSTRACT

Although geothermal energy is well positioned within the renewables (in 2008 geothermal power production exceeded more than three times that of solar photovoltaics), current growth is only steady but rather slow. While wind and solar PV show exponential growth, geothermal power develops rather linearly, so far provided by hydrothermal resources, located in special geological settings. The universally deployable Enhanced Geothermal Systems (EGS) technology could speed up geothermal growth, although substantial R&D efforts are needed to solve still open problems. Possible approaches are outlined.

1. INTRODUCTION

Geothermal energy is one of the contributors to any future energy mix. The advantages of geothermal energy are numerous: great, still only marginally developed potential, available around the clock (=provides base-load power), ubiquitous, indigenous, environmentally friendly, economically rewarding energy. Its two main utilization categories power generation and direct use are already introduced in many countries around the globe; further, expanding distribution is possible and should be increasingly enforced.

In the following a comparison is presented between geothermal and the other renewable energies, in terms of both potential and power generation. Development growth in power generation is presented for wind, solar photovoltaic and geothermal power and compared for the time period 1995 – 2008. Future growth estimates –for power generation as well as for direct use– are also given.

Technologic developments like Enhanced Geothermal Systems (EGS) are envisaged as the key to accelerating growth in geothermal development. There are still open questions about the universal applicability, long-term performance, and economic viability of EGS systems.

Geothermal direct use development is nowadays governed by the increasing deployment of geothermal heat pump systems. In several countries such systems already exhibits exponential growth; it is anticipated that this trend continues.

The future prospects of geothermal energy in general, and of power generation in particular, will depend on the gear-change in further growth: only if exponential growth is achieved can geothermal energy become a real player in future energy supply schemes.

2. LARGE GEOTHERMAL POTENTIAL

A highly respected source (World Energy Assessment – a collaborative effort between UNDP, UNDESA and the World Energy Council) attests the largest potential value to geothermal energy among all forms of renewable energy sources. The comparison is given in Table 1.

The values are given in capacity units, i.e. energy per unit time. It is obvious that geothermal energy has the largest capacity, although the accuracy of the reported number is limited. This potential is so far only marginally developed.

Tab. 1: Potential of renewable energy sources (WEA 2000).

Energy source	Capacity (EJ/yr)
Geothermal	5000
Solar	1575
Wind	640
Biomass	276
Hydro	50
Total	7541

3. GROWTH COMPARISON OVER THE TIME PERIOD 1995 - 2008

The comparison geothermal – other renewables is made for power generation. Geothermal power development data is available for the time period 1975 – 2008. The growth is practically linear, with only small increase rate changes (Figure 1, after Bertani in Fridleifsson et al. 2008).

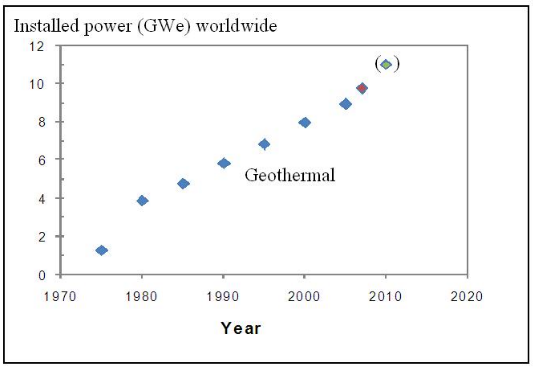

Figure 1: Growth in geothermal power development over the years 1975 – 2008. The number for 2010 (11 GWe) is estimated.

New data on the development of power generation from renewable sources is given in REN21 (2009). The installed capacity of wind power shows a clearly accelerating trend of an exponential nature (Figure 2).

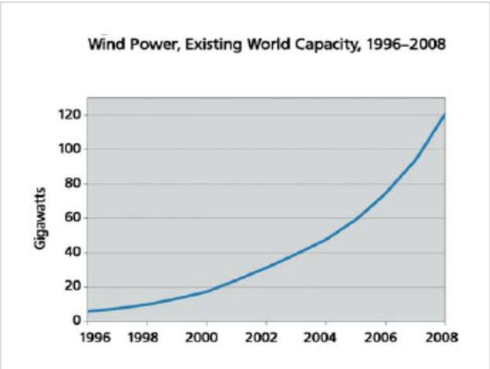

Figure 2: Growth in wind power development over the years 1996–2008. From REN21 (2009), modified.

A similar trend of exponential growth is reported for solar photovoltaic power, both grid-connected and off-grid production (Figure 3, from REN21, 2009). In Figure 3 the geothermal power growth -as depicted in Figure 1- is plotted for comparison. It is evident that geothermal had the lead over solar PV in the time before year 2006. Afterwards solar PV clearly takes over.

Here it must be emphasized that the plotted numbers refer to installed capacity, not to actual power production. Wind is not blowing all the time, the sun is shining only during daytime whereas geothermal production can go on at practically all times (except for production stops, for example during maintenance operations). This is reflected by the capacity factor (basically the percentage of yearly operating hours). Table 2 therefore clearly demonstrates that in terms of production geothermal is still by factors ahead of solar PV power generation.

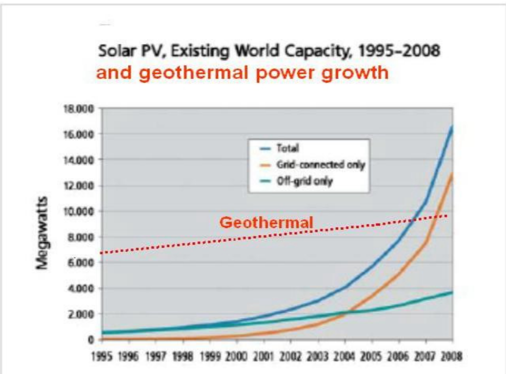

Figure 3: Growth in solar photovoltaic power development over the years 1995-2008 (from REN21, 2009). For comparison the geothermal growth trend is plotted (data of Figure 1).

From this comparison it is evident that currently geothermal power development is left behind wind and solar PV: whereas geothermal development growth is more or less linear (steady but slow growth – just a few percent increase per year), wind and solar PV exhibit accelerating growth with a clearly exponential tendency. To keep pace geothermal growth needs to be speeded up too; in the following some possible ways and means to accomplish this are addressed, primarily for power generation.

Tab. 2: Renewable electric power production comparison. Installed capacity from REN21 (2009), capacity factors from Fridleifsson et al. (2008).

Technology	Installed capacity in 2008 (GWe)	Capacity factor (%)	Electricity produced (TWh)
Wind	121	21	222.6
Solar PV	16	14	19.6
Geothermal	10	75	65.7

4. HOW TO SPEED UP GEOTHERMAL GROWTH?

In a study commissioned by the Intergovernmental Panel on Climate Change (IPCC) a team of authors estimated the growth curve in geothermal power development from the present to year 2050. Figure 4 from Fridleifsson et al. (2008) shows the result (installed capacity as well as power production). The curves in Figure 4 also exhibit exponential character.

How to achieve this accelerated growth? Until today the growth in installed geothermal power capacity originated entirely from “conventional”, hydrothermal resources. Such resources are found in numerous but special places, with high-temperature geothermal fluids present in the subsurface at relatively shallow depths (2 – 4 km). Such “anomalous” places can mainly be found in volcanic regions or in other regions, depending on their plate tectonic settings (details see e.g. in Fridleifsson et al. 2008). It can be expected that geothermal power development based on conventional high-enthalpy resources will remain more or less linear in the future; therefore some new technology is needed to provide the exponential growth component. In the following the case is made that EGS technology (Enhanced Geothermal Systems) could play this role.

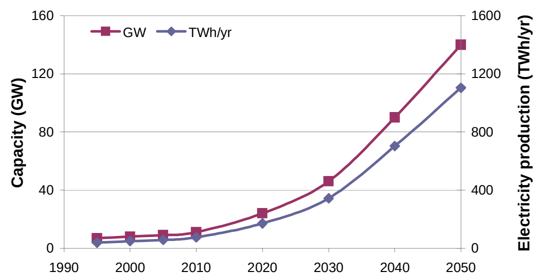

Figure 4: Installed capacity and electricity production 1995-2005 and forecasts for 2010-2050. From Fridleifsson et al. (2008).

5. ENHANCED GEOTHERMAL SYSTEMS – THE ACCELERATOR?

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) suggests that Enhanced Geothermal Systems will 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. The study M.I.T. study determined recoverable EGS resources > 200,000 EJ alone for the USA, corresponding to 2,000 times the annual primary energy demand.

The EGS principle 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.

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 3.

Tab. 3: 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 %

Although the minimum requirements for an economically viable EGS reservoir are herewith set, their realization in a custom-made manner to comply with differing site conditions is not yet demonstrated. The key issue is the development of a technology to produce electricity and/or heat from a basically ubiquitous resource, in a manner relatively independent of local subsurface conditions, i.e. to develop a technology for the creation of EGS downhole heat exchangers with the properties quantified above.

Therefore several still open questions about establishing and operating EGS heat exchangers need to be addressed and answered. Here some of the key issues are indicated.

- In creating EGS heat exchangers at several kilometers depth, questions of rock mechanics like the role of of anisotropy degree, stress change propagation/ transmission – fast / „dry“? slow / „wet“? (under different site conditions) – are unanswered;

- EGS induced seismicity (during stimulation in establishing the EGS heat exchanger but also during to production) becomes a real issue, also in terms of public perception. Social acceptance will be decisive (Majer et al. 2008).

- Uniform connectivity throughout a planned reservoir cannot yet be engineered;

- There is no experience with possible changes of an EGS heat exchanger over time.

A key property in this context is 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. Onsite experience is needed with 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. 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

So far the envisaged electric power capacity of an EGS installation (based on the properties of Table 3) is limited at a few MWe. But in order to play a significant role in local, regional and global electricity supply an EGS 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.

It is obvious that EGS is presently still at the "proof of concept" stage. More details about EGS status and problems can be found in Rybach (2010a).

6. R & D NEEDS, FINANCING

It is obvious from the above-described knowledge gaps that very substantial R & D efforts are still needed to make EGS become the future of geothermal energy. Whereas some of the problems could be tackled by broad-based international cooperation (the EU project ENGINE can be mentioned here; http://engine.brgm.fr), national R&D programs have to provide additional means for the challenge. Public funding, mainly by governmental agencies, will be indispensable. In Australia a veritable EGS boom is currently taking place (see e.g. Goldstein et al. 2009), its triggered only through through start-up financing, provided by the state budget.

Although envisaged for conventional geothermal resources, Ibrahim (2009) describes five steps to expedite development; four of them are based on fund allocations from national or regional governments. In any case it will be crucial to make rapid progress in tackling and solving the above-mentioned, still open problems.

7. GEOTHERMAL DIRECT USE

Geothermal direct use grows also steadily, but rather linearly (Table 4). The growth is increasingly dominated by the dissemination of geothermal heat pumps (GHP). This technology is versatile, can provide space heating as well as cooling and domestic hot water supply. Its world-wide growth is described in Rybach (2005).

Tab. 4: Growth of geothermal direct use world-wide. Data from Lund et al. (2005).

Year	MWth	TJ/yr
1995	8’660	112’441
2000	16’209	162’009
2005	27’825	261’418

Truly exponential growth is currently experienced in Switzerland. Here the borehole heat exchanger-coupled GHP systems are mainly used; their areal density is impressive (> 1 system per km^2) and so far the highest worldwide. The corresponding drilling activities (meters drilled per year) are shown in Figure 5. Remarkable is also the rapidly increasing share of GHPs in retrofitting; replacing customary oil-fired burners provide real CO_2 emission savings (Rybach, 2010b).

Geothermal heat pumps can be installed in most geologic situations (except in groundwater protection areas) all around the world, due to the ubiquitous geothermal resource present in the shallow ground. It can thus be expected that the coming decades will show a clearly exponential growth of GHP installations.

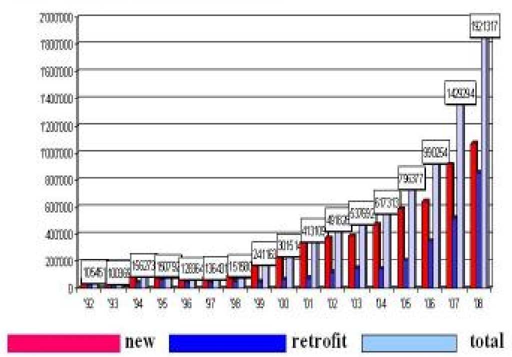

Figure 5: Development of borehole heat exchanger drillmeters in Switzerland 1992 – 2008. Data source: www.fws.ch

7. CONCLUSIONS, OUTLOOK

Enhanced Geothermal Systems have proven to have an immense theoretical potential. Presently EGS is still at the “proof of concept” stage; to reach the level of technical potential the it will be critical demonstrate that a technology can be created to establish 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 in 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 can 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 speeding-up geothermal development is obvious. Accelerating EGS development could provide a break-through, under the condition that the necessary significant funding needs can be met. This, in turn, will require heavy engagement of both the public and the private sector.

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