Geothermal Energy as Replacement for Oil and Gas - A Proven Option among the Renewables

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***Abstract*—This paper describes the properties and benefits of geothermal energy as renewable, clean and cost effective means to meet depleting resources of conventional fuels for heat and power generation. The history of commercial utilization of geothermal energy for electric power generation spans a century, and it has proven to be the most cost effective of all the renewables. Currently the installed capacity of geothermal electricity generation totals 10 GW_e in 24 countries, and this could be increased tenfold by 2050 if existing plans are successful.**

I. EU TARGETS FOR RENEWABLE ENERGY

In January 2008 the European Commission introduced extensive plans to promote renewable energy to fight climate change. The target is to increase the share of renewables in energy use to 20% by 2020. Many EU nations are looking to indigenous energy resources such as geothermal to meet their targets.

II. RENEWABLE ENERGY AND SUSTAINABLE USE TARGETS FOR RENEWABLE ENERGY

The terms “renewable” and “sustainable” are often mixed up in the discussion of energy resources. In essence, renewable describes the property of an energy resource, whereas sustainable refers to the mode of utilization the energy from the resource is harnessed. In order to throw a light on the meaning of these terms with special attention to geothermal energy, it is useful to consider the following definitions (Stefansson and Axelsson, 2003):

“Renewable energy sources are in one way or another linked to some continuous energy process in nature. The conditions must be such that the action of extracting energy from the natural process will not influence the process or energy circulation in nature. A simple definition of a renewable energy source can be as follows:

> *The energy extracted from a renewable energy source is always replaced in a natural way by an additional amount of energy, and the replacement takes place on a similar time scale as that of the extraction.*

It could be argued that oil and gas are renewable on a geological time scale, but this time scale is so long in relation to the human time scale that there is a common agreement to classify oil and gas as finite energy sources. Furthermore, the term sustainable production of geothermal energy from an individual geothermal system can be defined in the following way (Axelsson et al., 2001):

> *For each geothermal system, and for each mode of production, there exists a certain level of maximum energy production, **E0**, below which it will be possible to maintain constant energy production from the system for a very long time (100-300 years). If the production rate is greater than **E0** it cannot be maintained for this length of time. Geothermal energy production below, or equal to **E0**, is termed sustainable production, while production greater than **E0** is termed excessive production”.*

III. ORIGIN AND POTENTIAL OF GEOTHERMAL ENERGY

The part of the Earth’s internal heat that is accessible and harnessable as geothermal energy stems mainly from radioactive decay of minerals such as uranium, thorium and potassium in the Earth's crust and mantle. The geothermal energy emerges on the Earth’s surface as flow of hot water and steam, naturally in hot springs and geysers or through man-made boreholes. According to the World Energy Assessment (2000), geothermal energy has the highest potential of technically harnessable renewables, Figure 1.

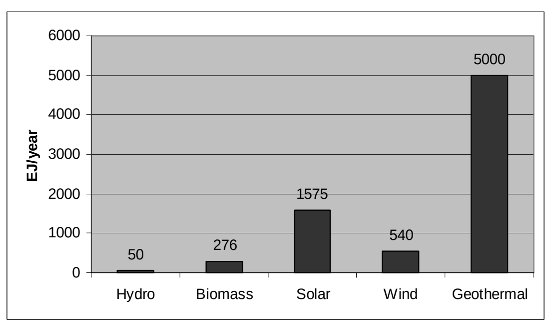

Figure 1. World’s technically harnessable renewable energy, from WEA (2000)

The first commercial geothermal electric power plant was commissioned in Larderello, Italy, in 1911. The geothermal power industry has since evolved to produce electricity from geothermal sources in 24 countries and the total installed capacity in 2007 was about 10 GW_e,

Figure 2. It is estimated that a total of 70 to 100 GW_e could be produced with conventional geothermal systems, i.e. with natural hydrothermal circulation. Where water is lacking but heat is abundant as in hot dry rock (HDR), by fracturing the rock and injecting water into the system, the resulting hot water and steam can be used in conventional geothermal power plants. Such systems, called Enhanced Geothermal Systems (EGS), are now being developed in the USA and Australia and other places around the world where hot dry rock is found at reasonable depth. Recent report shows that 100 GW_e of economically viable EGS electric capacity could be developed in the USA by 2050 (MIT, 2007). The largest EGS system currently being planned is in Cooper Basin in Australia where the electricity production potential is estimated between 5 and 10 GW_e. Already, some small HDR demonstration plants have been constructed and tested in Germany, France and Switzerland.

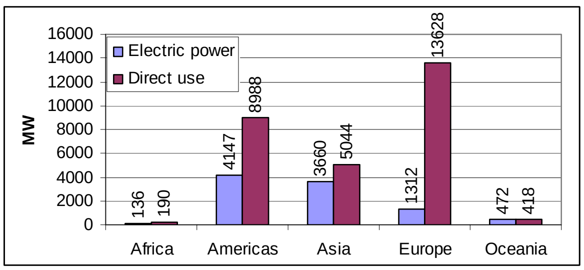

Figure 2. Installed capacity for conventional geothermal electric production and direct use (heating) in different continents in 2007, (adapted from Fridleifsson and Ragnarsson, 2007)

Another novelty in the geothermal energy sector is the Iceland Deep Drilling Project (IDDP). This project aims at drilling 5 km deep boreholes down into a reservoir with supercritical hydrous fluids at 450-600°C. High-enthalpy steam from such a reservoir would, for the same steam flow rate, produce ten times more power than a conventional 250°C hot reservoir, or 40 to 50 MW compared to typically 4 to 4,5 MW pr. well. If the IDDP project will be successful, it would mean that much more energy could be obtained from presently producing high-temperature geothermal fields from fewer wells (Fridleifsson et.al, 2003).

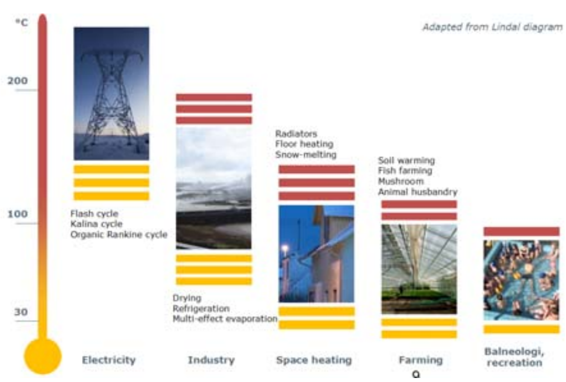

Figure 3. Examples of multiple uses of geothermal energy (based on Lindal diagramme)

While geothermal electric generation totaled 10 GW_e. in 2007, direct use of geothermal energy for heating came close to 28 GW_t,. Half of the installed heating capacity is accounted to Europe, Northern America come second with 9 GW_t. followed by Asia with 5 GW_t., Figure 2. The direct use of geothermal energy comprises multiple applications, such as space and district heating, swimming pools and balneotherapy, aquaculture, agriculture and various industrial processes, examples of which can be seen in Figure 3.

Typical exergic efficiency in electric generation lies between 15 and 20%, but for direct heating the efficiency is much higher, or 60 to 90% depending on the reservoir enthalpy. Where geothermal can be found near a large heating market, the use of the geothermal energy for district heating should be given due attention. Where possible, combined heat and power plant could be the ideal solution.

IV. GEOTHERMAL COMBINED WITH OIL/GAS FOR DISTRICT HEATING

For the reasons of fighting global warming and due to the dwindling sources of oil and gas, much emphasis is now laid on finding alternative energy sources. One of the best options is geothermal energy, cost effective and with low rate of greenhouse gas emissions. For district heating, the capital investment of geothermal boreholes is rather high compared to conventional boilers, so for the most economical solution a combination of geothermal base load with fossil fuel peak-load boilers is often recommended. This is especially true in places where the heat load factor is low.

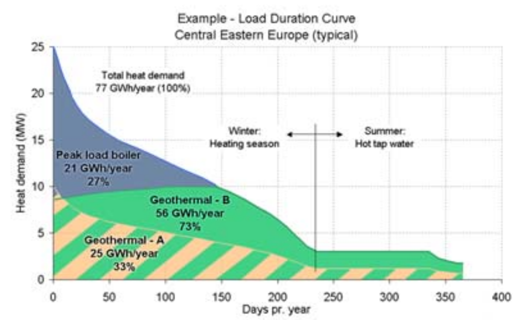

Figure 4. Heat load duration curve – typical for Central and Eastern Europe

A typical energy duration curve for Central and Eastern Europe with low load factor is depicted in Figure 4. A boiler plant requires a comparatively low capital investment but is expensive to operate. This in turn makes boiler plants for heat generation typically more economical for intermittent peak load applications, than would the provision of additional geothermal well.

Following example demonstrates how a peak load boiler can lower the overall production cost of heat energy (Elíasson and Björnsson, 2003). It is assumed that the heating market is large in relation to the available geothermal resource. The price of geothermal energy is normalized for a system of 4400 equivalent peak-load hours pr. year where the cost is estimated 1 UScent/kWh (this reflects a typical situation in Iceland, where the heat load factor is high).

First let us consider a situation where geothermal covers all the heat demand of a specific heating market with 10 MW peak load (this is shown as the striped area on Figure 4). The area under the load duration curve represents annual energy demand, in this case 25 GWh, all of which is provided with geothermal energy. The corresponding peak-load hours are 2500 pr. year and the specific geothermal energy price is 1,7 US cent/kWh.

If a peak load boiler is installed that covers 60% of the maximum load demand, the market that can be served is increased from 10 MW to 25 MW (total area under the topmost curve on Figure 3). The load duration curve demonstrates that although geothermal only provides 40% of the maximum **power** demand, it will cover 73% of the annual **energy** demand. This means that for 10 MW geothermal power installed, 56 GWh of geothermal energy will each year replace another energy source (usually fossil fuel) compared to 25 GWh if a peak load boiler is not installed. The overall production cost of energy is reduced by 25 to 30%, or from 1,7 to 1,25 US cent/kWh.

This is an example of how a peak load boiler can influence a geothermal district-heating project, both the size of the market that can be served and the cost of the produced heating energy. In a real project it is important to optimize the size of the peak-load boiler, taking into account the marginal cost of installed geothermal power, cost of peak-load boiler, cost of fuel and the cost and benefits of an increased heating market.

V. Environmental Aspects of Geothermal Energy

Geothermal energy is an important alternative for replacing depleting oil and gas resources. Not only is it renewable and indigenous, geothermal provides one of the most environmentally friendly solutions for generating electric power and for space heating. The atmospheric pollution so avoided is considerable.

To put geothermal electricity generation in context with conventional power plants, the International Geothermal Association, IGA, conducted a survey of CO_2 emission rates from existing geothermal power plants (Bertani and Thain, 2002). The total installed power of the plants surveyed was 6700 MW_e,, which represented about 85% of the global geothermal electric generation capacity at the time. The results showed a wide spread in the CO_2 emission rates. The weighted average was 122 g/kWh, however for two-thirds of the plants surveyed, the MW_e weighted average was 50 g/kWh or less.

In Iceland, CO_2 emission rates from major geothermal plants range from 26 to 181 g/kWh for electric production. In combined heat and power plants as in Nesjavellir and Svartsengi, when counting the total energy produced, the CO_2 emission figures are much lower, or 10 to 74 g/kWh (Ármannsson, 2003).

It has been argued that CO_2 emitted from geothermal power plants, especially in high temperature areas, is already part of the natural CO_2 release. So new CO_2 is not being produced as is the case in fossil fuel plants. It may be added that as a consequence of geothermal exploitation natural emission of CO_2 might be reduced. Such a result has been recorded in Larderello, Italy. It has been suggested, that any measurable decrease in natural emission resulting from power development should be subtracted from the measured plant emission rate (Bertani and Thain, 2002).

VI. Benefits of Geothermal Energy

The major attractions of geothermal energy may be summarized as follows:

- Low cost of generated electricity and heating of domicile and industrial space
- Insignificant atmospheric pollution
- Highest capacity factor of natural energy options
- Low land use and recoverable
- The resource is indigenous
- Geothermal facilities are unaffected by long-term fluctuations in fuel costs
- Improved public health, hygiene and quality of living

A. *Lowest cost by geothermal*

Two recent reports, by Credit Suisse (2009) and ESMAP World Bank Group (2007), conclude that geothermal energy offers the least expensive option for generating electricity, Figure 5 and Figure 6.

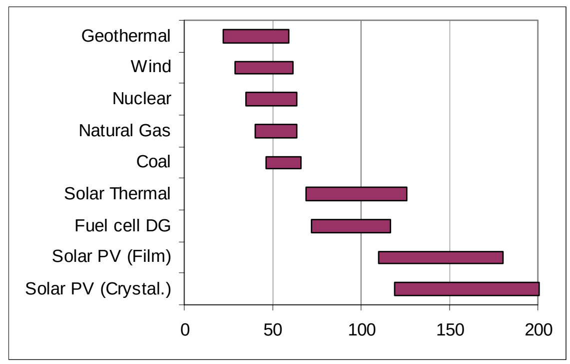

Figure 5. Levelized cost of electricity generation (US $/MWh), source: Credit Suisse, January 2009.

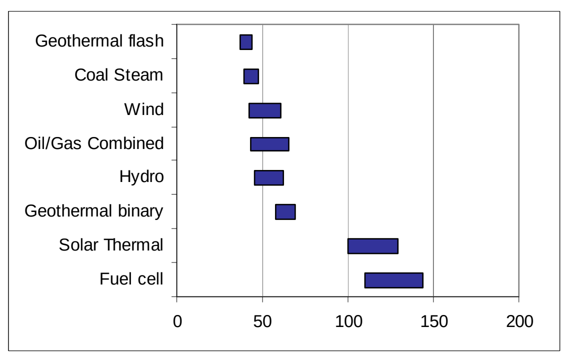

Figure 6. Levelized electricity generation costs (US $/MWh), adapted from ESMAP the World Bank Group 2007

Both reports conclude that the least expensive electricity comes from geothermal flash cycle plant (50 MW), ahead of modern large coal fired plants (300 to 500 MW). Wind (100 MW) is the second least expensive of the renewables, but their major drawback is the low capacity factor, especially when compared to geothermal. The reports also show that electricity generated from geothermal binary cycle plant (20 MW) is 50 to 60% more expensive than electricity from conventional flash cycle.

B. Clean energy

The benefits for the environment of using geothermal energy become obvious when the CO_2 emission rates for conventional fossil fuel energy and geothermal are compared (data from IGA, 2002).

CO_2 emissions from electric power plants

Typical CO_2 emission data for fossil fuelled power plants are in the order of:

- Coal, in a power plant operating at 35% efficiency, 915 g/kWh
- Fuel oil, in a power plant operating at 35% efficiency, 760 g/kWh
- Natural gas, in a combined cycle power plant at 60% efficiency, 315 g/kWh.

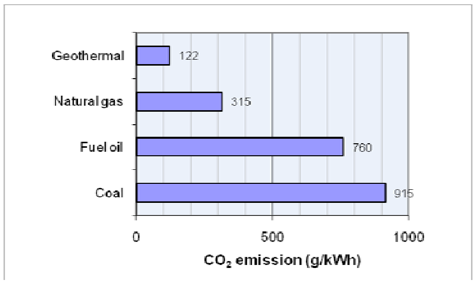

Figure 7. Comparison of CO_2 emissions from electric power generation from different energy sources (IGA. 2002)

CO_2 emissions from heating plants

Typical CO_2 emission data for geothermal and fossil fuelled heating plants are shown in Figure 8.

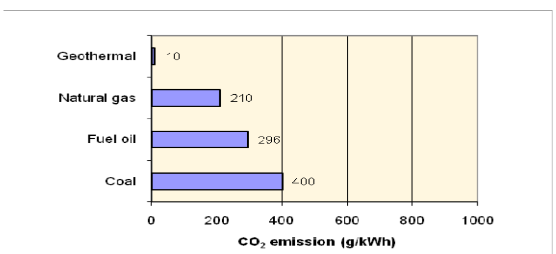

Figure 8. Comparison of CO_2 emissions from heat generation from different energy sources

This demonstrate that geothermal has a distinct environmental advantage over fossil fuels.

C. High capacity factor by geothermal

According to the ESMAP report (2007), modern geothermal power plants have the highest capacity factor of all power plants, or 90%, while for example wind power plants only reach 30%. This is due to the fact that geothermal power plants are independent of transient weather conditions, unlike wind, wave and solar. The present world average for geothermal plants is however only 73%, but is expected to rise to 90% or higher with improved reservoir management, reinjection, better knowledge of corrosion and scaling etc. (Fridleifsson et. al, 2008). In many cases, for example in Iceland, the capacity factor, or availability, has been even higher, or 95 to 98%, the plants only requiring a one week service and maintenance stop each year. Geothermal energy therefore constitutes a very reliable base load.

D. Indigenous resource with low land use

Geothermal power plants require less land than many other renewable energy installations and the land is recoverable if it is decided to rest the geothermal field or terminate energy utilization in the area for other reasons.

Utilizing an indigenous resource for energy and heat generation is important from the standpoint of national and economic security. Furthermore, geothermal facilities are unaffected by fluctuations in fuel costs and potential irregularities in fuel deliveries across boundaries, that add risk to conventional power generation such as coal, oil and natural gas

E. Health and recreation

Cleaner atmosphere as a result of geothermal heating instead of burning gas, oil or coal has many positive effects on the public health and wellbeing. Access to inexpensive heating promotes the construction of public swimming pools, hot spas, heated pavements and even heated sport grounds. In Iceland, special low-cost tariff is offered for heating of recreational facilities. The cost benefit for the public health system is obvious.

Figure 9. Outdoor swimming pool in Reykjavík Iceland during winter season. Geothermal hot water provides the heating of the pavement.

VII. CONCLUSION

Much knowledge and experience has accumulated in Iceland and many other countries were geothermal energy has been utilized for commercial heating and electric power generation since early in the last century. Geothermal energy is indigenous, clean, has low CO_2 emission rate, is renewable and cost effective, which, if used in a sustainable manner, will last indefinitely measured on the Homo sapiens timescale. Successful utilization of geothermal energy requires in-depth knowledge of the properties and behavior of hydrothermal reservoirs, their geophysics and fluid chemistry, as well as borehole technique and wellhead engineering and conversion equipment for power and heat production. When complemented with years of operational experience the end result will be a high capacity-factor geothermal installation that will fulfill the targets needed to fight climate change in the most cost effective manner available.

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