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CO_2 Emission Mitigation by Geothermal Development – Especially with Geothermal Heat Pumps

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ABSTRACT

Geothermal technologies for power generation or direct use operate with little or no greenhouse gas emissions. Geothermal energy development has thus great CO_2 emission reduction potential when substituting fossil sources of energy. Geothermal development estimates for 2050 indicate that power generation could mitigate CO_2 emissions by 100's of Mt/yr, direct use >300 Mt/yr, most of it by geothermal heat pumps. These need electricity; its source must be considered. Real CO_2 emission reduction results only when fossil-fired installations are being replaced; otherwise only additional emission can be avoided. Environmental and societal benefits are thus obvious.

1. INTRODUCTION

Climatic warming is a fact; it endangers the environmental living conditions as well as global economy. The global average surface temperature increased from 1900 to 2006 by at least 1.0 °C; during the same time period the CO_2 content of the atmosphere doubled (IPCC 2007). Although it is widely recognized that the most probable cause of climatic warming is the increasing content of greenhouse gases (foremostly CO_2) in the atmosphere, some people still debate a connection, Nevertheless the ice core data from the Vostok site in Antarctica show a 1:1 correlation between CO_2 content and temperature change, according to the widely recognized paper of Petit et al. (1999).

Any CO_2 reduction can counteract climate change. So far the main CO_2 emitters: power generation, buildings, traffic operate mainly by burning fossil fuel. Any change to low-emission technologies in these sectors can thus counteract global warming.

Geothermal technologies for power generation or direct use operate with little or no greenhouse gas emissions. Since no burning processes are involved they are low in CO_2 emissions. Geothermal energy development has thus great CO_2 emission reduction potential when substituting fossil sources of energy. Further development –depending on future growth rates– could reduce CO_2 emissions even more significantly. The current and future potential contributions to reduce CO_2 emission by geothermal power generation and direct use have been assessed in a study carried out for the Intergovernmental Panel on Climate Change, IPCC (Fridleifsson et al. 2008). In the following the main results are summarized, separately for geothermal power generation and direct use.

2. GEOTHERMAL POWER GENERATION

Geothermal electricity generation started in Italy more than 100 years ago. Today 24 countries generate base-load electricity. Five of these countries obtain 15-22% of their national electricity production from geothermal (Costa Rica, El Salvador, Iceland, Kenya and the Philippines). In 2008 a world-wide geothermal capacity of 10 GWe produced 65 TWh electricity (Rybach, 2008a).

When compared to other energy source of power generation, geothermal power plants have much lower CO_2 emission, see Fig. 1.

CO_2 emission from geothermal power plants in high-temperature fields is about 120 g/kWh (weighted average of 85% of the world power plant capacity). With the present engineering solutions it could be possible to increase geothermal power from the expected value of 11 GW for year 2010 up to a maximum of 70 GW in 2050; the gradual introduction of the new developments (binary plants, EGS systems) may boost the growth rate with exponential increments, thus reaching the global world capacity of 140 GW in 2050. The corresponding electricity production of about 1000 TWh/yr in 2050 will mitigate (depending on what is substituted) hundreds of million tons CO_2/yr. Future technology including reinjection will result in negligible emissions (10 g CO_2/kWh). The extrapolations to year 2050 are given in Figs. 2 and 3.

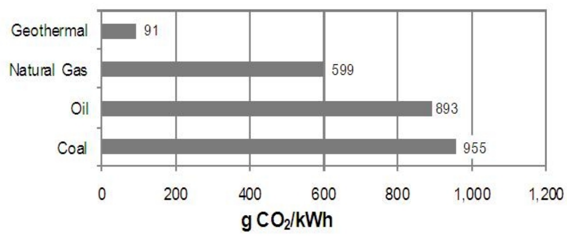

Figure 1: Comparison of CO_2 emission from electricity generation from different energy sources in the USA. Data from Bloomfield et al. (2003).

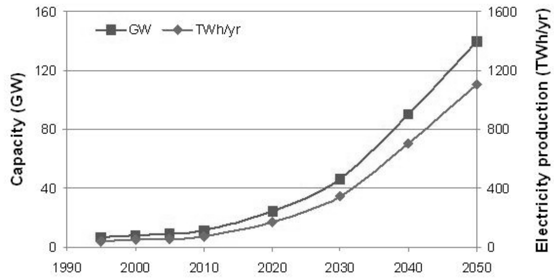

Figure 2: Installed global geothermal capacity and electricity production 1995-2005 and forecasts for 2010-2050 (from Fridleifsson et al. 2008).

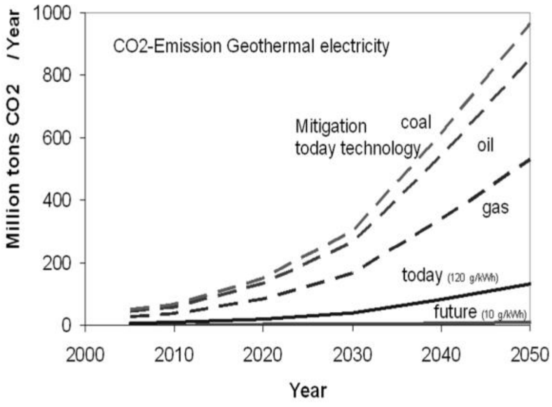

Figure 3: Mitigation potential of geothermal power plants in the world and assumptions for emission of 120 g CO_2/ kWh for today and 10 g CO_2/ kWh for future technology (from Fridleifsson et al. 2008).

Here it must be emphasized that new geothermal power plants do not reduce CO_2 emission unless the replace fossil-fueled ones. When the geothermal plants operate besides the existing fossil-fueled plants only additional emission can be avoided ("mitigation").

3. DIRECT USE

The worldwide direct use of geothermal heat is currently about 300 PJ/yr, produced by a total capacity of about 30 GWth. The usage is distributed as follows: space heating 52% (thereof 32% using heat pumps), bathing and swimming (including balneology) 30%, horticulture (greenhouses and soil heating) 8%, industry 4%, and aquaculture (mainly fish farming) 4% (Lund et al., 2005).

In Fridleifsson et al. (2008) the direct use production growth was estimated by extrapolation to year 2050 (Fig. 4), the corresponding CO_2 mitigation effect is given in Fig. 5.

The largest contribution as well as the highest growth rate is with geothermal heat pumps (GHP), one of the fastest growing renewable energy technologies (Rybach, 2005). World-wide production by GHPs increases (in PJ/yr): 14.6 in 1995, 23.3 in 2000, 87.5 in 2005. GHPs provide space heating, cooling and also domestic hot water.

4. GEOTHERMAL HEAT PUMPS

Since the main fraction of direct use development and CO_2 mitgation effect is due to GHPs their role and uniqueness in Europe was specially treated (Rybach, 2008b). Again here the main findings are summarized.

GHP installations need no fossil fuel, do not use combustion processes to generate heat, and thus produce no air polluting substances. This is the environmental advantage of GHP systems, like in the case of geothermal power generation.

The subsurface has basically two heat carriers for GHPs: the heat stored in the earth materials, and the heat content of groundwater (if present). GHPs come in various configurations, which are installed horizontally and vertically (see Figure 6). The type chosen depends upon the soil and rock type at the installation, the land available and/or if a water well can be drilled on site.

The heat pump (HP), a basic system component, relies on auxiliary power to accomplish the temperature rise needed in the system. In most cases, HPs are driven by electric power.

The property that describes the efficiency of a heat pump system (i.e. the ratio of heat output to electric energy input) is defined by the Coefficient Of Performance, COP. The higher the COP the more heat can be provided per unit of electricity input. The Seasonal Performance Factor (SPF) is the ratio of heat output to total electricity input (incl. that for circulation pumps).

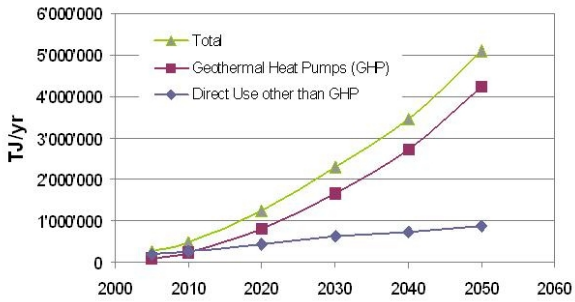

Figure 4: Likely case scenario for growth in direct use and GHP energy production (from Fridleifsson et al. 2008).

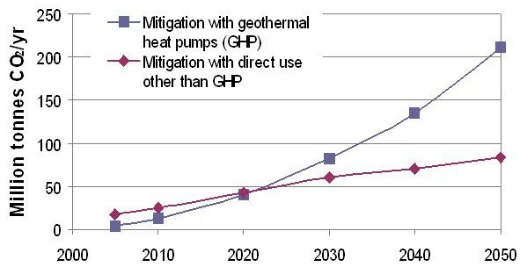

Figure 5: Mitigation potential of geothermal direct heating use in the world based (from Fridleifsson et al. 2008).

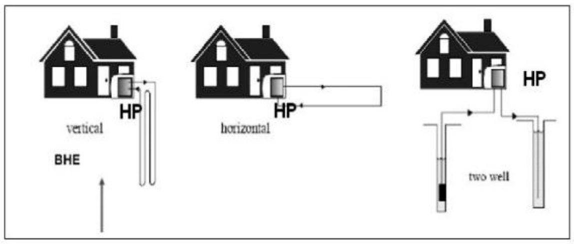

Figure 6: Ground-source or geothermal heat pump (GHP) systems. The arrow indicates the most common system, with borehole heat exchangers (BHE). HP: heat pump (after Fridleifsson et al. 2008).

When the issue of CO_2 emissions is considered then heat pumps systems have the great advantage that they can replace fossil-fired systems. Table 1 shows the heat content of fossil fuels along with the CO_2 emission values that result while burning fossil fuels. Such emissions can be avoided when heat pump systems are used instead of fossil-fuelled systems.

In the following the issue will be addressed as to what extent GHP systems can contribute to the reduction of CO_2 emissions in the building sector. It is obvious that, when GHP systems are used instead of fossil-fired systems, the source of the electricity that drives the heat pumps must be carefully considered.

5. CO_2 EMISSION OF ELECTRICITY PRODUCTION

Numerous technologies are in use world-wide to produce electricity. Whereas some technologies like hydropower are characterized by low CO_2 emissions, others –like coal-fired power plants– emit lots of CO_2. In a given country there is a specific "mix" that gives an average value of CO_2 emission per produced kWh electricity. Table 2 shows the wide range of country mix values.

Obviously there are large differences in the national mix values; Norway has the lowest number (thanks to hydropower electricity supply), Poland the highest (only coal-fired power plants).

Table 1: Heat content and CO_2 emission of traditional fossil fuels (Data from Swiss Federal Office of Energy, 2008)

Fuel	**Heat content (GJ/t)**	**CO_2 emission (t CO_2/TJ)**	**CO_2 emission (t CO_2/t fuel)**
Coal	28.1	94.0	2.64
Oil light	42.6	73.7	3.14
Natural gas	46.5	55.0	2.56

6. CO_2 EMISSION AVOIDANCE AND SAVINGS BY GEOTHERMAL HEAT PUMPS

The heat pump (HP), a basic GHP system component, needs auxiliary power to accomplish the temperature rise needed in the system. In most cases, HPs are driven by electric power. With proper system design, seasonal performance coefficients in the heating mode of 4.0 (heating energy supplied by the GHP system / electricity input for HP and circulation pumps) can be reached. This means that GHP systems need 75 % less fuel than fossil-fired systems.

This represents the "saving" of fossil fuels – and the corresponding CO_2 emission. But one should not fall into the trap to think that it would mean also CO_2 emission reduction, it only avoids additional emission. It must be emphasized that new GHP installations do not provide any emission reduction – unless they replace old, fossil-fuelled systems or electric heaters/boilers. Therefore it needs to be stressed that

- New heat pump systems need new (additional) electricity
- The production of this electricity is usually accompanied by CO_2 emission
- Not even systems installed during renovations fully reduce CO_2 emission (except when the electricity comes from completely CO_2-free sources).

Let's assume the installation of 10'000 new GHP units per year (easily done in many European countries), each with a standard heating capacity of 12 kWth. Further assumption: heat pump COP = 4.0, thus the electric power needed per unit is 3 kWe.

With a heat pump running time of 1,500 hours/year the electricity demand for the new GHPs is 45.106 kWh. When the electricity is produced by a reasonable national "mix" (emits 500 g CO_2/kWhe, cf. Table 2) then the additional CO_2 emissions amount to 45.106 * 0.5 = 22.5.106 kg = 22,500 tons of new CO_2 per year.

Therefore, true CO_2 emission reduction results only when heat pump systems are mainly installed during renovations.

Table 2: National CO_2 emission values in Europe (from Nowak, 2008)wide range of country mix values

Country	**kg CO_2 per kWh electricity produced**
Austria	0.239
Belgium	0.311
Cyprus	0.974
Czech Republic	0.922
Denmark	0.680
Estonia	1.015
Finland	0.403
France	0.108
Germany	0.626
Greece	0.882
Hungary	0.695
Ireland	0.706
Italy	0.565
Latvia	0.443
Lituania	0.367
Luxembourg	0.367
Netherlands	0.619
Norway	0.015
Poland	1.108
Portugal	0.630
Slovak Republic	0.382
Slovenia	0.392
Spain	0.493
Sweden	0.076
Switzerland	0.041
United Kingdom	0.558
EU average	**0.486**

When GHPs are used for space cooling in the "free cooling mode", there is even more fossil fuel savings: since the heat pump is bypassed, there is no need for electricity during this time. But again here real CO_2 emission reduction can only be achieved when an “old” air-conditioning system fed by “dirty” electricity gets replaced. In any case the source and CO_2 emission characteristics of the electricity consumed by the heat pump needs to be carefully considered.

7. CONCULSIONS

Geothermal technologies produce little or no greenhouse gas emissions since no burning processes are involved. Geothermal development estimates for 2050 indicate that power generation could mitigate CO_2 emissions by 100’s of Mt/yr, direct use >300 Mt/yr, most of it by geothermal heat pumps. These need electricity, its source must be considered.

New geothermal installations do not reduce CO_2 emissions; only additional emission can be avoided. Real CO_2 emission reduction is achieved when “old” heating and/or air-conditioning systems -fed by “dirty” electricity- get replaced e.g. by geothermal heat pumps, i.e. in renovation. When complemented by measures in improved construction solutions like efficient thermal isolation to reduce the energy consumption of buildings, the geothermal heat pump systems to provide space heating, cooling and domestic hot water can and will contribute in the future significantly to avoiding or reducing CO_2 emissions.

The environmental benefits of geothermal development are obvious: increasing development can help to mitigate the effects of global warming. The societal benefits are developing in parallel: the positive effects are also increasing, regionally and globally.

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