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Contribution of Geothermal Energy to Climate Change Mitigation: the IPCC Renewable Energy Report

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ABSTRACT

A special report on renewable energy has been commissioned by the IPCC (Inter-Governmental Panel on Climate Change) to provide guidance on future mitigation options for climate change through reducing CO_2 emissions. To achieve this, a better understanding is required of potential global and regional geothermal resources. These range from convecting high-grade hydrothermal to conduction-dominated stored thermal energy, and are hosted in volcanic, sedimentary or crystalline crustal rocks. Important issues affecting future utilisation include: energy security and sustainability, status of current applications, future technology advances, cost predictions, projected deployment rates, energy integration and infrastructure requirements, environmental risks and benefits, technology transfer, and policy options.

Increased geothermal energy development is well suited to climate change mitigation because it provides base-load power and heating (or cooling) from a large energy resource that is well-distributed globally. It has a good track record of sustainable production using existing technology, applicable to both developed and developing countries, and for generating cost-effective and highly-dispatchable power. Geothermally-heated fluids are available for space heating and cooling and a variety of other industrial applications, ranging from small-scale to district-wide installations. In addition, geothermal heat pumps (GHPs) are deployed worldwide, enabling substantive gains in heating and cooling efficiency of buildings. Relative to other renewable energy technologies, geothermal resources are utilised at high average availability factors (typically > 90% for electricity generation).

Overall, geothermal has been shown to be socially acceptable with some positive social and environmental impacts, including a relatively small land-use footprint. Adverse impacts are manageable using best practice reservoir management practices, including water resource conservation. Wider deployment of existing technology and application of new technologies under demonstration will significantly increase the use of geothermal resources at all temperatures. Enhanced or Engineered Geothermal Systems (EGS) offer the potential for global scale utilization when and where it is needed. For this potential to be realised, research and field testing at commercial scale is required with multi-year government and private support and investment. The benefits will include mitigation of climate change through provision of CO_2 offsets at competitive costs, and improved energy security.

1. INTRODUCTION

Despite the short-term economic situation, long term growth rates in global energy demand are expected to continue, with fossil fuels maintaining dominance in the energy supply for the next few decades. A 2008 IEA study (IEA, 2008), which incorporates the effects of current (mid-2008) government policies and measures (Reference Scenario), shows that the global primary energy demand will increase by 45% during the period 2006-2030, raising demand to 712 EJ. Fossil fuel contribution is expected to remain at about 80%, but will be controlled by fewer countries, creating energy security problems. In addition, green house gas (GHG) emissions will increase by 35%, from 44 to 60 Gt CO_2-equivalent, leading to significant climate change effects. These global energy trends are socially, economically and environmentally unsustainable.

Two alternative climate-policy based scenarios have been developed to stabilize GHG concentrations at 550 and 450 ppm CO_2-eq, thereby containing global temperature increases to about 3°C and 2°C, respectively. In both scenarios, the total emissions are significantly less in 2030 than in the Reference Scenario. However, both scenarios require major efficiency gains, CO_2 capture and storage (CCS) deployment, a marked decrease in the contribution of fossil fuels, and replacement by nuclear and renewable energy sources, including geothermal. This will require considerable public and private investment and R&D spending. We are truly at a cross-road in terms of decisions over future global energy supply and climate change consequences. Only international cooperation can overcome the obstacles ahead.

Geothermal energy has several significant characteristics that make it suitable for climate change mitigation. These include: global-wide distribution; indigenous resource; production independent of season; immune from weather effects and climate change impacts; effective for on and off grid developments and for provision of base-load power. In off-peak periods this base-load generation can also be used to recharge battery-powered vehicles, helping to mitigate CO_2 emissions from fossil-fuelled transportation.

2. GLOBAL ELECTRICITY GENERATION AND DIRECT USE RESOURCE CAPACITY

Installed global geothermal electricity capacity has surpassed 10 GWe, and generation is approximately 60 TWh per annum, at an average of 6 GWh/MW_e. Geothermal power provides a considerable share of total electricity demand in several countries, in particular, Iceland (30%), El Salvador (24%), Kenya (19%), the Philippines (19%), and Costa Rica (15%).

Geothermal energy is used in more than 70 countries for direct heat applications, including: space, greenhouse and aquaculture pond heating; crop drying; industrial processes; bathing; cooling; snow melting, and GHPs. The total thermal energy use in 2007 was about 330 PJ, 20% greater than in 2005. The GHP market continued its significant growth worldwide through 2007, with a total of about 1.6 million units installed, >19 GW_{th} capacity and >105 PJ of use.

3. GEOTHERMAL RESOURCE POTENTIAL

The maximum technical potential for global geothermal energy resources is extremely large, by any measure, because of the high heat content of the earth's crust, and the high natural flow of heat to the earth's surface. Technical potential will not be the limiting factor in future deployment; growth rates will instead be determined by economics, demand, material constraints and social factors. By 2050, the estimated global electricity generation from known hydrothermal resources is predicted to grow from 10 GWe to 140 GWe, of which 70 GWe is confidently anticipated to be achievable using current technology and the balance will be achieved if new technology develops as expected (Figure 1). Successful development of (as yet) undiscovered geothermal resources (with no obvious surface expression), and off-shore resources, could further increase this to 1500 (± 500) GWe at some time in the future. Global EGS technical potential (by fracturing and extracting heat from deep crustal rocks anywhere) is also estimated at 1000 - 2000 GWe. [In the western USA, alone, the technical potential resource for EGS (> 150°C and < 6 km depth) has been estimated to be at least (95% confidence level) 345 GWe (USGS, 2008)]. However, the future deployment rate of EGS across the globe is uncertain because the technology is relatively new, and the economics and sustainability are not yet well established. Consequently, with a conservative, probability-based estimate of EGS deployment, it is suggested that the total geothermal generation could increase to 170 GWe by 2050.

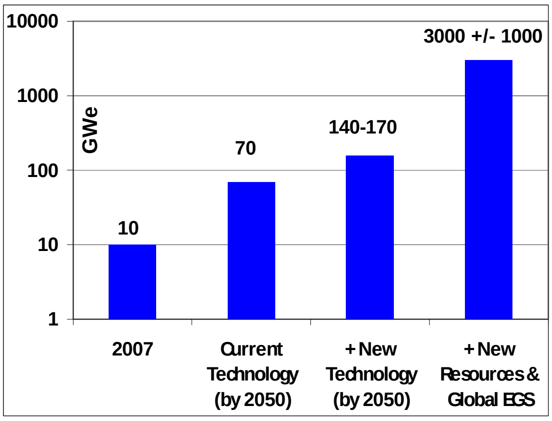

Figure 1: Global geothermal resource estimates.

The technical potential of low-temperature (<130°C) geothermal resources is estimated to be 140 EJ_{th}/yr. Such resources may be used for binary cycle power generation and direct heat applications. The total direct use could exceed 5 EJ_{th} /yr by 2050, with GHPs contributing over 80%.

4. ECONOMICS AND COSTS

As noted above, one of the primary drivers that will determine future geothermal deployment potential is economics. At present, the situation is favorable for rapid acceleration in growth rates. Investment has grown significantly in the past few years, surpassing US$ 2.5 billion in 2008, a 40% growth from 2007, and a 570% increase since 2005. The recent US administration geothermal research budget of US$ 400 million is an example of significantly increased global investment. Geothermal development costs depend on many variables. These include: resource temperature and pressure, reservoir depth and permeability, fluid chemistry, location, drilling market, size of development, number and type of plants used (dry steam, flash, binary or hybrid), and whether the project is green-field or an expansion (10-15% less). Commodity prices (oil, steel and cement) strongly affect development costs, and the decreases in oil and gas prices since 2008 have resulted in reducing geothermal capital and drilling costs, and improved drilling rig availability.

In 2008, the capital costs of a green-field geothermal power development were about US$ 2000 – 4000/kW_e for flash plant developments and US$ 2400 – 5900/kW_e for binary developments (Figure 2). By 2020, total capital costs are expected to decrease by about 5%. The distribution of costs is approximately as follows: a) exploration and resource confirmation (10-15%), b) drilling (20-35%), c) surface facilities (10-20%), d) power plant (40-60%).

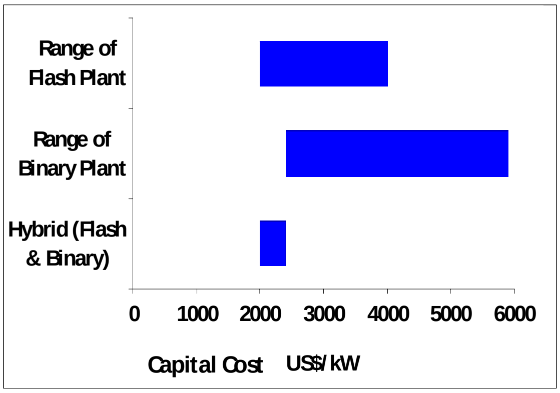

Figure 2: Capital costs (2008 US$) of geothermal developments. (Data from IEA-GIA, 2008).

In Europe, small binary developments (a few MW_e each), which use medium temperature resources and deep wells, are expected to increase in number, if economics remain favorable. The total investment costs for these smaller power plants are estimated to be in excess of US$ 5900/kW_e. The availability of renewable energy feed-in tariffs and the sale of heat from CHP development (e.g. district heating) increases economic viability for these projects significantly.

Power generation operation and maintenance (O&M) costs are a comparatively low percentage of the total cost of generation because geothermal relies on a fuel that is essentially free (once developed), as well as being sustainable (if not over-exploited), and relatively low maintenance (if fluids are benign). Typical O&M costs depend on location and size of the facility, type and number of plants, and use of remote-control. They range from US$ 9/MWh for large flash plants to US$ 25/MWh for small binary plants, excluding the costs for drilling replacement wells. The cost of replacement well drilling is dependant on development size relative to sustainable resource capacity. It typically increases towards the end of a cycle of energy extraction as reservoir pressures and temperatures in a bore-field decline. Hot fluid recharge and conductive heating will gradually restore pressures and temperatures, especially after extraction is suspended, if continued operation and replacement drilling is no longer economic. The rates of recharge increase in proportion to the extraction-induced pressure and temperature decline.

Levelized cost calculations depend strongly on several basic assumptions. For example, the planned economic lifetimes of geothermal plants are typically 20-30 years, although in practice, they usually operate for much longer (Wairakei and Larderello now exceed 50 years). Levelized cost calculations that distribute capital costs across a standard 20-30 year plant life can prove to be quite conservative. A recent example from the USA consists of a 30 MW_e binary development which has estimated levelized generation costs of US$ 72/MWh for a 15 year debt, 6.5% interest rate and power purchase agreement of 20 years. The levelized cost would be less if these time scales were increased to reflect probable actual plant life. New plant generation costs for expanded development of proven geothermal fields in some countries are competitive with fossil-fuelled power plants (even without subsidies) at US$ 50-70/MWh for known high temperature resources. For new green-field developments, where drilling costs are higher, levelized costs range up to US$ 120/MWh. In more difficult settings, where temperatures and productivity are lower, and drilling depths and parasitic pumping costs are greater, costs can range up to US$ 200/MWh, and economic operation is only possible with the help of subsidies or feed-in tariffs. Estimated EGS development production costs using current power plant technology range from US$ 75/MWh (300°C resource at 4 km depth) to US$ 150/MWh (200°C resource at 5 km) in a typical USA or Australian setting, while estimates for some northern European settings are much higher at US$ 270-400/MWh (Figure 3).

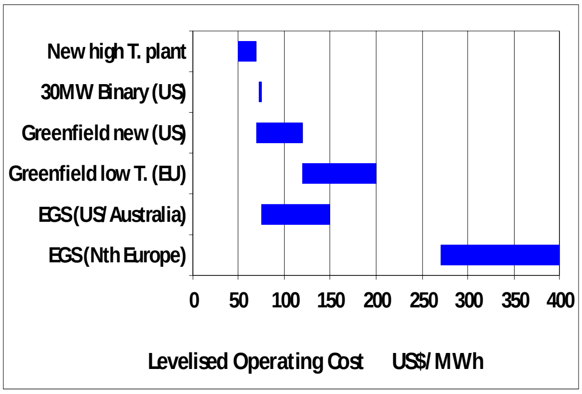

Figure 3: Production costs (source : IEA-GIA, 2008).

Direct use of geothermal energy for heating purposes is currently competitive with conventional energy sources. In Europe, geothermal district heating costs an average US$ $68/MWh_{th}$. The average cost for GHP operation is about US$ $79/MWh_{th}$ and savings in the cost of energy can recover capital cost over a period of 4-8 years.

5. GEOTHERMAL DEPLOYMENT FACTORS, BARRIERS, AND FUTURE OUTLOOK

The drivers for cost reductions in geothermal electricity generation include the following: reduced well drilling costs; more reliable high temperature and pressure downhole pumps and logging tools; more accurate estimates of resource potential prior to well drilling; better methods of creating fractured hot reservoirs; and methods for controlling or mitigating adverse environmental effects, such as large induced seismicity. In Europe, targets have been set for the following cost reductions by 2030: US$ 29/MWh for conventional geothermal; and US$ 74/MWh for low-temperature and EGS production. Cost reductions for ‘direct use’ and GHP deployments will be driven by economies of scale related to the rapid global growth in demand. In Europe, there is expected to be a 10% decrease to US$ $74/MWh_{th}$ by 2030. The district heating target is US$ $89/MWh_{th}$, a decrease of about 5%.

One of the strongest geothermal growth drivers, at present, is the potential impact of climate change and other negative environmental impacts of fossil-fuelled power and heat production. This has raised awareness of the need to use renewable energies, such as geothermal. Several countries have developed incentive schemes, such as feed-in tariffs and Green Certificates. These make geothermal power generation and GHPs more economic to install and operate. Other drivers include the desire for energy independence and security, increasing fossil fuel costs, and rapidly growing energy demand.

Some of the barriers to geothermal development acceleration include the following: lack of awareness and information about geothermal energy technology and its options and advantages for power and direct use; uncertainty in the future of incentive schemes; lack of trained geothermal scientists and engineers; and perceived environmental issues (e.g. hot spring interference, induced seismicity, and subsidence). For GHPs, technical issues, such as standards and quality control and legal security (licensing, regulation) are important.

The outlook for accelerated growth of geothermal power and direct use (especially GHPs) is extremely promising. The baseline scenario in IEA Energy Technology Perspectives (ETP) 2008 suggests that geothermal technology could feasibly provide 1% (approximately 350 TWh) of global electricity in 2050. Furthermore, the IEA’s advanced “BLUE” scenario, which requires significant technology innovation, indicates that 3% (or about 1060 TWh) could be feasible by 2050. Fridleifsson et al. (2008) obtain similar results (Figure 4). They also suggest that the maximum power generation potential from geothermal resources could be 10-times larger if the vast potentials of EGS and other advanced geothermal technologies (e.g. super-critical temperature resources and off-shore resources) are fully realized in the same time frame.

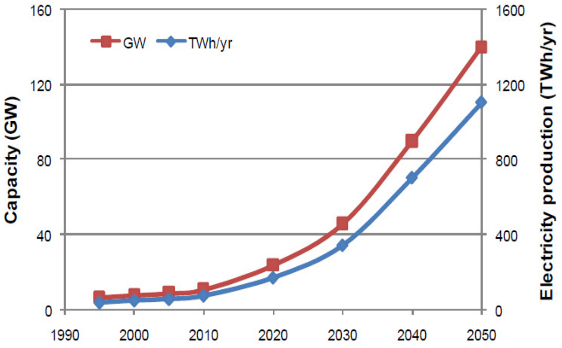

Figure 4: Electricity capacity and production (from Fridliefsson et al., 2008).

Fridleifsson et al. (2008) also estimate that, by 2050, using current technology, the total geothermal direct use could amount to 5.1 EJ_{th}/year, with GHPs contributing 83%.

6. ENVIRONMENTAL IMPACTS

Geothermal developments have relatively minor environmental impact. Indeed, relative to other energy options there are distinct advantages, such as a relatively small footprint for surface facilities (power plant, pipelines etc), of about 0.35 km^2/100 MW_e. Nevertheless, the disposal of waste water containing small quantities of chemicals (boron, mercury and arsenic) and gases (H_2S and CO_2) is an important issue, and various methods are used for dealing with it, including: total reinjection of separated water, condensate and gases; chemical treatment and mineral extraction. Treatment costs typically amount to 1-2% of generation cost. Natural CO_2 emissions from high temperature systems, when exhausted from steam turbines, are typically less than 10% of those emitted by burning coal in an equivalent power plant (averaging 100 g/kWh), while those from low temperature resources are negligible (0 - 1 g/kWh). Most binary systems, district heating, EGS and CHP schemes typically operate by keeping fluids in a closed-loop, hence have zero emissions. GHPs reduce CO_2 emissions by at least 50%, relative to other modes of heating and cooling, depending on the source of the electricity used.

Induced seismicity (felt earthquakes) has become an environmental and social issue at some EGS projects. However, an international protocol has been developed for dealing with it (Majer et al., 2008). To date, although small earthquakes are sometimes felt, induced seismicity has caused no significant damage to buildings and structures. Land subsidence from pressure decline has occurred and caused concern at a few high temperature developments, however, monitoring identifies potential effects which can usually be remedied, and targeted injection is sometimes used to minimize it.

7. POTENTIAL TECHNOLOGICAL ADVANCES

Several advances in technology have the potential to significantly increase the deployment of geothermal in the coming decades. For example, in active volcanic areas, the use of supercritical temperature fluid (373-600°C) from depths of up to 5 km, close to molten magma chambers or dykes, has the potential to increase the power output per well by a factor of up to 10 (~50 MW_e/well), hence reducing development costs by decreasing the number of wells required. Also the development of technology to utilize off-shore geothermal resources, particularly high temperature fluids in fractured zones at shallow depth along mid-ocean ridges (active spreading zones, ocean-floor volcanoes, hydrothermal vents, seamounts, etc), promises to provide yet another very large source of geothermal energy for future use.

Advances in power plant design and improvements in utilization efficiency are expected to continue. Recent advances have resulted in power production from fluids with temperatures as low as 73°C. Development of combined heat and power plants, more efficient space heating and cooling systems, use of deep sedimentary fluids, co-produced hot water from oil/gas wells, and EGS fracture stimulation technology, will hopefully facilitate a significant increase in geothermal use almost anywhere on earth. Better tools for logging high temperature and pressure geothermal wells will produce more reliable and accurate data faster, so reducing logging costs. Modern drill rigs, with better control equipment and drill bits, will make it possible to drill more accurately, more successfully, to deeper levels, and at faster rates, thus reducing costs.

Some of the R&D topics that require more research in the short term to achieve the expected long-term growth outcomes, include the following: more refined resource assessment; better reservoir simulation; methods for more accurately characterizing geothermal resources prior to drilling; techniques for defining sustainable production levels at an early stage; methods for determining dynamic recovery factors; better understanding of permeability enhancement; techniques for controlling the magnitude of induced seismicity; improved fluid zonal isolation; reliable high temperature and pressure submersible pumps, logging tools and monitoring sensors; predictive stimulation models; drilling methods and equipment to reduce rig time.

8. CONCLUSIONS

World geothermal energy installed capacity by 2007 had exceeded 10 gigawatts (GW_e) for electricity generation and 35 GW_{th} for direct use. Approximately 60 Terawatt hours (TWh) of baseload electricity were generated with an average capacity factor >75%. More than 330 PJ of direct heat was used, with geothermal heat pumps (GHPs) the largest contributor at about 30%.

Geothermal investment worldwide exceeded US$ 2.5 billion in 2008, up 40% on 2007, the highest growth renewable for the year. In 2008, the global geothermal sector employed about 25,000 people, and more than 6 GWe of new projects were under development. Capital costs for green-field geothermal flash plant developments in 2008 ranged from US$ 2000-4000/kW_e; with lower temperature binary developments at US$ 2400-5900/kW_e.

Recent production costs for flash plant developments range from US$ 50 - 120/MWh for higher temperature resources and US$ 70 /MWh (USA) to US$ 200/MWh (Europe) for lower temperature binary developments. Current estimates for enhanced geothermal systems (EGS) range from US$ 75 - 200/MWh for higher temperature resources, and US$ 270-400/MWh for lower temperature resources. Production costs for district heating range from US$ 50 - 110/MWh; with an average GHP cost of US$ 79/MWh.

Geothermal plants typically operate with high capacity (75-95%), load (84-96%) and availability (92-99%) factors. Geothermal developments have planned (economic) lifetimes of 20-30 years; although ~50% of the current global installed capacity has been in operation for >25 years, and two developments for >50 years. Depletion in reservoir pressure and temperature occurs with time, but recovery through natural heat recharge allows depleted resources to be re-used after a rest period. Surface footprints of typical geothermal power developments are relatively low providing a distinct advantage in optimizing land use.

Geothermal power production is projected to increase to 350 TWh by 2050 under IEA's baseline scenario, and to 1060 TWh by 2050 under IEA's BLUE scenario. With an assertive attitude to increased exploration and deployment, an even greater geothermal production potential is achievable by 2050 and beyond. Major barriers to growth include initial capital cost, lack of awareness about geothermal energy, uncertainty regarding incentive schemes and perceived environmental issues.

With the right attitude and approach by policy makers, investment agencies and power companies, geothermal is capable of contributing a significant component of the global renewable energy supply by 2050 that is needed to displace fossil fuel generation and thereby mitigate the impact of climate change from green house gas emissions.

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