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**Comments on IPCC Geothermal Paper**  
**23 June 2008**

These comments are made with the hope that they will be helpful during the review phase of the geothermal contribution (Fridleifsson, et al., 2008) to the IPCC Report.

1) Abstract- I think the statement in the abstract beginning on line 7: “It is considered possible...from current 10 GWe to 70 GWe with present technology, and to 140 GWe with enhanced technology.” Does the “present technology” include the contribution from binary generation using low temperature resources and heat recovery from “waste/separated” water from conventional developments? It should also be made clear that the 140 GWe includes 70 GWe of EGS. What about potential contributions from deep geothermal (which has the potential of wells producing up to 10 times more than current 2 km deep wells as stated in this paper)? What about enhancement techniques applied to hydrothermal development (e.g. creating permeability in the hotter, tight portions of developed reservoirs)? It is important that these specifics be mentioned, and this should not take up too much extra space.

I think would be extremely valuable to provide a little more information about the huge geothermal potential available if deep geothermal development is successful, if EGS becomes the success many of its proponents believe it will, if binary plants are used on low temperature systems and for generating power using “waste/separated” water. Just indicating the “potential” from these methods will demonstrate the wide possibilities for geothermal. However, in doing this, it is also important to point out the challenges to such development, what technical issues need to be overcome, “...with further vigorous R&D effort” as noted in the Wind Energy paper for the IPCC Scoping Meeting Proceedings (p.116). I suggest that section “IV. Challenges and Perspectives” in the Wind contribution be examined to see what I am suggesting. As I mention below, I suggest that such a section be included in this paper.

Perhaps this geothermal paper is a little too “conservative” in its estimates?

2) I disagree with the comment on page 3, para 2, lines 2-3 about the 800 MWe during the 3-year period 2005-2007, following the rough standard linear trend of 200/250 MWe per year”. The slope of the 1980-2005 data is actually 202 MWe/year with an  $R^2 = .0.9986!$  The slope from 2005 to 2007 is ~265 MWe/year, a significant increase, which is signalling a new period of accelerating worldwide geothermal development. Gawell and Greenberg (2007) also conclude that worldwide geothermal development appears to be accelerating (GEA website, report 1 May 2007). They also estimate the worldwide installed capacity to be 13,500 MWe by 2010! I think it is important to point this out to those decision makers who will read this report.

3) Page 6;

para 3: replace the word “too” in “...due to the presence of too many uncertainties.” with “so”: “...due to the presence of **so** many uncertainties.” “Too” does not provide the right connotation, in my opinion.

Also, the next sentence states that it is possible to identify a “range of estimations (perhaps “**estimates**” would be a better word)”- this is a key phrase. Here is where the “high end” of estimates can be more clearly stated.

para 4: Includes some interesting and important information, but really requires a strong concluding few sentences that ties things together and clearly provides a “high-end” figure for

the total global geothermal potential. In the 2<sup>nd</sup> line the phrase: "...a method that seems to be realistic the expected ... is estimated to be between a minimum of 35-70 GW and a maximum of 140 GW..." The 140 GW seems to come from Gawell (1999) and arises from "permeability enhancement and drilling improvements." It is not clear why Stefansson's (2005) estimates, which include a value of 240 GWe for most likely value for technical potential (without including binary or EGS) are not given more consideration, or somehow used to produce final hydrothermal potential estimates.

para 4: There is a little confusion in sentence 4- I suggest it be slightly changed to something like: "The MIT study (Tester et al., 2006) indicates an EGS potential of more than 100 GW for USA alone, with Paschen et. al. (2003) obtaining an estimate of 35 GW for Germany."

para 4 (beginning with: "Bertani (2003)..." is a good start...', but I think it would be useful to include more information on the EGS assessments that have been published to date (see the information in my comment 10 below referring to page 18). I think it would be useful to include more information on the EGS assessments that have been published to date and provide a short review of the current global EGS activities. This would give more validity to the seriousness with which this type of geothermal development is being considered and investigated as well as the international attention it has.

Also, I did not see a contribution to geothermal from the binary generation potential available. This is proven technology, and power can be generated using fluid temperatures as low as 72 °C (Chena Hot Springs, Alaska)!

4) Page 7, para 1: I think this paragraph should be removed from the document. There are no numbers or discussion included to back up this statement. We don't know what geothermal resources it is based on (does it include EGS, binary, deep [3-5 km] resources, etc.).

5) Page 8, Type d) Resources in hot dry rocks, or EGS, should be added and discussed here.

6) Page 10: para.1, lines 5-6: El Salvador (22%) and Guatemala (3%) should be removed from the statement that: "Geothermal power stations provide about 12% of the total electricity generation of..." according to Figure 6. This could be replaced with: "Geothermal power stations provide over 10% of the total electricity generation of El Salvador, Costa Rica and Nicaragua."

7) Page 10, para 1, line 7: Is the 4 GWe of geothermal potential for Central America only for conventional hydrothermal geothermal? I think that in light of the fact that substantial potential for electricity generation is possible using binary, deep geothermal and EGS, it is now important that the type of resource/development be identified when quoting potentials.

8) Page 11, para 1, end of last line: the figure referred to should be Figure 8.

9) Page 17, para 4, bullet 2: temperatures from 80 °C are referred to as "medium" temperature, while on page 8, "low temperature" fields are defined as temperatures < 180 °C. This is a bit confusing.

10) Page 18, para 1: I recommend that this paragraph be moved in front of the previous paragraph, i.e. it should follow the bullet points at the bottom of page 17.

para 2, lines 7-8: The EU project "EGS Pilot Plant" in Soultz-sous-Forêts (started in 1987) was commissioned in early June 2008 (1.5 MWe) to utilize..."

The following information should be included in the first paragraph of page 18, before the current 2<sup>nd</sup> paragraph, as it sets the scene for the investigations currently being pursued.

Current assessment information I am aware of: 1) USA (100 GWe; MIT Report)- [this is included], 2) Germany (35 GWe from the German Parliament Document 15/1835 (2003), in German; is this the Paschen et al. 2003 report referred to in Fridleifsson et al.?), 3) Switzerland (12 GWe for an area covering 23% of the country; report by Signorelli and Kohl, 2007), 4) China (100 GWe from two regions in China; Wan, et al., 2005: Forecast and evaluation of hot dry rock geothermal resource in China, Renewable Energy 30 (2005), 1831-1846), 5) India (100 GWe from Chandrasekhar and Chandrasekhar, 2007, Enhanced Geothermal Resources: Indian Scenario, GRC Trans. 31, 271-273), 6) Australia (12.2 GWe, B. Goldstein, pers com. 20 June 2008), ENGINE project (any final EGS estimate numbers available?).

Therefore, for numbers in these few cases, we have: USA: 100 GWe; Germany: 35 GWe; Switzerland: 12 GWe; China: 100 GWe; India: 100 GWe; Australia (Cooper Basin Area, Paralana Project and Limestone Coast Geothermal Project; B. Goldstein, pers. comm. 20 June 2008): 12 GWe; thus a total estimate from these 6 countries of: 359 GWe.

Perhaps it would be a good idea to provide a range for the possible future contribution of EGS, which indicates its vast potential tempered by “challenges” that need to be met. The current estimated total geothermal contribution is 140 GWe, of which 70 GWe is from hydrothermal and 70 GWe is from EGS (I think). It may be more appropriate to indicate (current value in Fridleifsson et al. 2008) 70 (this seems extremely low, compared to the total of the current estimated potentials) to  $\geq 500$  (?) GWe for EGS alone?

Update on current EGS projects in:

A. Germany- Landau, producing electricity and heat, has been operating since November 2007. Other German developments: Unterhaching at the beginning of 2008 (?).

B. Australia- Cooper Basin, three wells (Habanero 1, 2 and 3) completed. Plans (Doone Wyborn, pers. comm., 12 June 2008) are to begin long term closed loop circulation test to start by end June 2008; and install steam turbine (output potential 2.2 MWe) in January 2009, expecting to generate ~ 1MWe (maximum local load at present). Now drilling first well, Jolokia 1, in second area, 9 km from Habanero field. Wyborn estimates 5-10 GWe from the Cooper Basin location (1,000 km<sup>2</sup>)

C. France- Soultz, the EGS power station has been connected to the grid and was commissioned in the 2<sup>nd</sup> week of June 2008! Perhaps there will be some useful data available from this first 100% EGS development that could be included before the final version is completed?

Page 18, para 3: Sentence 1: I suggest that the “huge contribution of EGS” also be mentioned here, along with the “expected...great environmental benefits...” Perhaps something like: “EGS plants, once operational, can be expected to provide 100s of GWe of power plus significant quantities of heat for district heating and other direct uses. In addition, they can be expected to have great environmental benefits like avoiding additional CO<sub>2</sub> emission. To realize this important potential, certain challenges must be overcome (see my comments below on adding a section on Challenges and Perspectives).

The word “satisfactorily” could be replaced with “accurately” or “confidently” in the statement that EGS impacts “...cannot yet be satisfactorily quantified” is. However, it is still important to provide some sort of “estimate” (or range) as an indication of the “potential”

importance of EGS. Such an estimate should be made, with the recognition that certain “challenges/barriers” must be overcome to attain it- but what benefits when realized!

The Wind chapter in the IPCC Scoping Proceedings included quite “positive” potential estimates and included a section to discuss challenges, etc. in order to meet these challenges. Their estimates are in the range 39-58,000 TWh/year potential generation. As a comparison, for geothermal 140 GW/year at 90% capacity factor equates to about 1,110 TWh/year. If deep geothermal could increase this by a factor of 5, and EGS contributes another 500 GWe, then geothermal would be producing about 1,200 GWe, or > 9,000 TWh/year(!). In addition, the direct use of the “left-over” energy in the discharged/separated hot water following power generation could be used for heat applications (cascade operation)- something wind cannot do!! It might be a good idea to include an estimate of the total heat available for direct use from these sources.

I think it is important to add a section(s) on: Challenges and Perspectives, Barriers to Development (that discusses hydrothermal/conventional, deep geothermal and EGS) to place the extremely large potential available for geothermal energy (power and heat) and associated environmental contributions in perspective. This would be a better approach than “under-play” the contribution that geothermal could make; i.e. be too conservative. This section should be near the end of the paper.

para. 4: line 6: Though “energy security” is mentioned, perhaps it should be emphasized a little more- the indigenous nature of geothermal, hence its importance in “energy security”, especially in light of the contribution it could make to several of the smaller, developing nations (large help with their economies). This is especially important now with oil prices reaching very high levels of >US\$ 135/barrel!

para 4, Line 8: I also suggest that the word “too” in the phrase “...systems are too localized...” be removed or replaced by a word like “very”, so: “...systems are (very) localized...”. This has a less “negative” implication, but still explains the situation.

I suggest that the comments on CO<sub>2</sub> in paragraph 4 be removed and included in the later section of the paper where environmental aspects are considered.

11) Page 19, para 2, line 3: change “...three developed drill fields...” with “...three developed geothermal fields...”

Page 19, section: Environmental issues- A brief introduction describing the natural occurrence of CO<sub>2</sub> in geothermal areas should begin this section, e.g. like in the section: Natural Greenhouse Gas Emissions from Geothermal Areas in Bertani & Thain (2002).

12) Page 20, para 1, last sentence: It might be a good idea to explain why the measurable decrease in natural CO<sub>2</sub> emission should be subtracted from the measured plant emission (this should go along with my comment immediately before this one).

Page 20, para 2: Move the first line of this paragraph to the end of the previous paragraph; then move the remainder of the paragraph to the beginning of the first paragraph under: CO<sub>2</sub> emission reduction by heat pumps, since it refers to heat pumps.

13) Page 23, para 4, last sentence: “...and for tap water also in the summer.” This is confusing. Does it mean for providing hot tap water in the summer, in addition to the other uses in the summer?

14) Page 24, Table 5: It is not clear what the second column: “Average annual growth rate from 2005” refers to. Is it installed capacity (MWth) or heat used (TJ/yr)? In either case, I think that the % growth numbers do not agree with the data shown. These % figures need to be checked.

15) Page 25, para 1: The first sentence should have “for” added: “...as long as GHPs substitute **for** fossil energy.” and in the 2<sup>nd</sup> sentence, “fuel” should be added: “...fossil **fuel** provided electricity...”

I find that sentences 2 and 3 of para 1 are quite confusing. It is not clear where the scenario of 1 Million TJ/year comes from?

Page 25, para 2, 2<sup>nd</sup> sentence: El Salvador produces 22% and Guatemala 3% of their energy from geothermal (see page 10, figure 6). So they cannot be included as “about providing 12 % of the total ...” The average of Nicaragua (10%) and Costa Rica (15%) is about 12%

Page 25, para 2, lines 8-9: It should be made clear that this Central American potential of 4,000 MWe is from hydrothermal resources (does it include any binary use?).

Pages 25 (last para) -26, (first para): These estimates are quite conservative. See my comments regarding pages 6 and 18 above. It could be important to include a good estimate of what binary plants (which are now “conventional technology”) utilizing the separated and waste water from “conventional” hydrothermal power stations could generate.

16) Page 26, para 3: It should be clearly stated that the “capacity factor” numbers, 64% and 73%, quoted are average values for many operating geothermal fields. As mentioned, many geothermal developments now have capacity factors of 90%.

Page 26: Table 6: The last column should indicate “**Average** Capacity Factor”. As I commented above, the installed capacity and electricity production appear very conservative.

17) Page 30, Figure 22: water level is indicated by “blue” line, not black line.

Page 30, section: “Discussion of geothermal energy and other renewables”- I think that many of the numbers in this section should be updated, or removed, since there have been major changes since 2004 (the date for which the quoted data refers), especially as regards wind power. For example, in the Wind contribution for these IPCC proceedings, it is stated that at the end of 2007, 94,000 MW were operating in 60 countries! This is significantly higher than the 74,000 MW estimated for 2010 as mentioned on page 32 of this geothermal paper.

What is the reference date for the cost figures included in this section?

18) Page 32, last para, line 10: “...geothermal...is site specific.” Again, this ignores EGS. So, care must be taken to clearly refer to today’s “hydrothermal” characteristics.

19) Page 33, para 4, line 6: “...(EGS) technologies, where heat is extracted from deep hot rock almost anywhere, or from deeper, less permeable, parts of hydrothermal reservoirs than conventional systems currently access, are under development.”

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