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The IEA Geothermal Implementing Agreement- International Efforts to Promote Global Sustainable Geothermal Development and Help Mitigate Climate Change

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ABSTRACT

The Geothermal Implementing Agreement (GIA) provides a flexible and powerful framework for international cooperation on geothermal research and technology under the auspices of the International Energy Agency (IEA). It connects national and industry programmes for exploration, development and utilization of geothermal resources and establishes direct cooperative links among experts in the participating countries, industries and organizations, thus helping increase effectiveness. The GIA's activities are chiefly directed towards the coordination of national and industry geothermal programmes, with joint participation of members on specific studies. Emphasis is on sharing of information, developing techniques and best practices, and producing and disseminating authoritative information.

Current IEA scenarios indicate that unless governments implement energy saving and renewable energy options, energy security problems and a sharp increase in CO_2 emissions with related significant climate change effects are likely. The IEA recently extended the mandate of the GIA for a 3rd 5-year term (to 2012), and the IEA-GIA embraced these challenges in its new 3rd term mission: ***to promote sustainable use of geothermal energy worldwide by improving existing and developing new technologies to render exploitable the vast and widespread global geothermal resources, facilitating the transfer of know-how, providing high quality information and widely communicating geothermal energy's strategic, economic and environmental benefits***, and thereby contribute to the mitigation of climate change. To accomplish this mission, the GIA is concentrating its current efforts in four major areas, pursued in the following Annexes: I- Environmental Impacts of Geothermal Energy Development, II- Enhanced Geothermal Systems, III- Advanced Geothermal Drilling Techniques and VIII- Direct Use of Geothermal Energy. GIA's activities within these topics have grown significantly in the past few years with the addition of: induced seismicity studies associated with EGS reservoir development/production; investigation of sustainable use strategies; development of economic guidelines for EGS reservoir economic models; development of recommended procedures to create, test and evaluate EGS parameters, and development of new forms for geographic display of data on the internet.

Geothermal is gaining a growing recognition as one of the major renewable energy options, with vast worldwide potential and ability to make a significant contribution. As a result, worldwide geothermal development is now in a rapid state of growth. The IEA-GIA is increasing its efforts to support and help accelerate this growth in a sustainable manner, including: by convening international workshops on special topics like induced seismicity and sustainability, by attempting to determine the global development potential of geothermal energy (conventional, EGS, *etc.*) and estimating the contribution it could make towards the mitigation of climate change (useful as input for the IPCC 2010 renewable energy report), by producing a Geothermics Special Issue on Sustainability (2009); and by participating in international renewable energy conferences and workshops to raise awareness of geothermal energy and educate the public, government and finance decision makers, *etc.*

The IEA-GIA, now well into its 3rd 5-year term and 12th year of operation, is experiencing significant growth in membership, having nearly doubled in the past 3 years, and as of May 2009, with 19 members, including: 12 countries (Australia, France, Germany, Iceland, Italy, Japan, Mexico, New Zealand, Republic of Korea, Spain, Switzerland, United States), the EC, 4 industries (Geodynamics, Green Rock Energy, ORME Jeotermal, Ormat Technologies) and 2 national organizations (CanGEA and Geothermal Group [APPA]).

The current global energy scene and geothermal's potential contribution are outlined; brief reviews of the IEA and the GIA operation and structure are presented; and the GIA's current activities and achievements for supporting sustainable geothermal development and thereby aiding the mitigation of climate change are described. Comments on the GIA's future plans are also included.

1. INTRODUCTION

This paper provides a major update and amplification of the IEA-GIA paper presented at the WGC 2005 (Mongillo *et al.*, 2005) and other recent papers by Bromley *et al.* (2008) and Mongillo and Rybach (2007). More details about the IEA and the recent work of the IEA-GIA can be found in the GIA 2002-2007 End of Term Report (IEA-GIA EoT, 2006), Strategic Plan for 2007-2012 (IEA-GIA SP, 2006) and in the comprehensive IEA-GIA annual reports available on the IEA-GIA website. Note that all website addresses are included in the Reference section.

2. CURRENT GLOBAL ENERGY SCENE

The growth in global demand for energy is expected to continue well into the future, with fossil fuel likely to remain the dominant providing source. The IEA has recently examined several energy utilization and production scenarios (IEA, 2007; 2008a; 2008b) in attempts to forecast the situation to 2030, and beyond. The *Reference Scenario*, which assumes the continuation of current (as of mid-2008) government policies and measures, indicates that the total global primary energy need will grow by 45% between 2006 (11,740 Mtoe [492 EJ_{th}]) and 2030, with demand reaching 17,010 million tonnes of oil equivalent (Mtoe)

[712 EJ_{th}]; and the fossil fuel contribution reducing slightly from 80.9% to 80%. Though it seems that there will be sufficient fossil fuel to meet the 2030 demand, production will be controlled by fewer countries, many of which will be located in "unstable" parts of the world, thus causing energy security problems. Further, energy-related CO_2 emissions will increase from 28 Gt in 2006 to 41 Gt in 2030, an increase of 45%; with total greenhouse gas emissions (GHG) increasing by 35%, from 44 billion tonnes (Gt) CO_2-equivalent (CO_2-eq) in 2005 to 60 Gt CO_2-eq in 2030; leading to significant climate change effects. These global energy trends are socially, economically and environmentally unsustainable.

Urgent and strong action is needed to curb the GHG emissions growth and resulting rise in global temperatures predicted in the *Reference Scenario* (GHG concentration of 1,000 ppm and temperature increase of 6 °C relative to pre-industrial levels, by the end of the century). The IEA has developed two alternative climate-based scenarios to stabilize GHG concentrations at 550 ppm (550 Policy Scenario) and 450 ppm (450 Policy Scenario) CO_2-eq, resulting in a 50% chance of restricting global temperature increases to about 3 °C and 2 °C, respectively (*ibid.*). The total global primary energy demand in 2030 reaches 15,500 Mtoe (32% increase relative to 2006) for the 550 Scenario, and 14,400 Mtoe (23% increase) for the 450 Policy Scenario. The CO_2 and total GHG emissions in both of these scenarios are significantly less in 2030 than in the *Reference Scenario*, *vis*. energy-related CO_2 emissions: 32.9 Gt for 550 Policy Scenario and 25.7 Gt for the 450 Policy Scenario; and total GHG emissions: 48.2 Gt for the 550 Policy Scenario and 39.3 Gt for the 450 Policy Scenario. However, both of these climate-based scenarios require major efficiency gains; CO_2 capture and storage (CCS) deployment; a major decrease in the contribution of fossil fuels, to be replaced by nuclear and renewables; as well as considerable public and private RD&D spending.

Awareness of these possible outcomes, and the knowledge that energy-related CO_2 emissions comprise >65% of total global GHG emissions, provides a very strong incentive for expanding the use of clean, renewable energy resources. However, provision of such huge quantities of affordable, reliable and clean energy presents an enormous challenge. We are now truly at a global energy supply and climate change crossroads, which only international cooperation can overcome.

3. GLOBAL GEOTHERMAL POTENTIAL AND CURENT USE

Among the renewable energy options, geothermal resources have the potential to contribute significantly towards alleviating the world's energy-climate predicament. Geothermal resources essentially consist of the heat stored beneath the earth's surface and discharging from it. The main sources for geothermal energy are the heat flow from the earth's core and mantle (~40%), and that generated by the gradual decay of radioactive isotopes in the earth's crust (~60%); which together result in an average terrestrial heat flow rate of 44 TW_{th} (1,400 EJ/yr). This natural heat flow rate is nearly three times the 2006 worldwide total primary energy use, 492 EJ_{th} (136,600 TWh_{th}) (IEA, 2008c). Though it is clear that the world's geothermal heat resources are enormous and ubiquitous, the fact that they are, in the main, "hidden from view" (underground), makes it difficult to accurately determine potentials on a global basis. This uncertainty is accentuated because the technologies used to develop geothermal resources are evolving, extending capabilities and reducing costs, and thereby increasing technical and economic potentials. Consequently, there are considerable uncertainties in estimating worldwide geothermal resource potentials, and future revisions are likely as more information and new technologies become available.

In 2005, Stefansson (2005) estimated the *most likely* worldwide total technical potential for geothermal resources located along tectonic plate boundaries and near volcanic hot spots to be about 6.5 TW_{th} (205 EJ_{th}/yr), about 40% of the 2006 worldwide average annual consumption. Of this total, hydrothermal resources capable of development for electricity generation using conventional methods (T > 130 °C) made up about 240 GW_e (6.5 EJ_e/yr, or 65 EJ_{th}/yr), assuming a 10% electrical conversion efficiency. The remaining 4.4 TWh_{th} (140 EJ_{th}/yr), comprise lower temperature resources (T ≤ 130 °C) considered useful mainly for direct heat applications. Incorporating approximations for as yet hidden/unidentified resources increases these estimates by factors of 5-10 (*ibid.*). In addition, with current conversion efficiencies increasing, and now ranging up to 20%, power generation potentials are increasing.

In 2007, the worldwide geothermal installed power capacity was ~10 GW_e, distributed across 24 countries (Bertani, 2007); with > 56.8 TWh generated (IEA-GIA AP, 2008). Since the present installed capacity amounts to only 4% of the estimated total global *technically feasible* potential of 240 GW_e of identified hydrothermal resources (~0.5% if estimates of as yet hidden/unidentified resources are included), there is certainly potential for a large increase in conventional (hydrothermal) geothermal development in the future to meet growing demand for renewable energy in the tectonically or volcanically active regions. In fact, Fridleifsson *et al.* (2008) have recently estimated that by 2050, installed geothermal capacity from hydrothermal resources could reach some 70 GW_e, a 600% increase on the 2007 value.

The total direct use installed capacity at the end of 2007 was estimated to be about 35,570 MW_{th}, with a total thermal energy usage of about 329,270 TJ/yr (IEA-GIA AP, 2008.). In 2007, an estimated 1.6 million geothermal heat pumps (GHPs) were installed in more than 30 countries, and contributed > 19,000 MW_{th} of capacity and > 105,000 TJ/yr utilization (*ibid.*). As for power generation, the potential for increased direct use is huge, with only ~0.25% of *most likely* direct use technical potential (140 EJ_{th}/yr) currently used. Recent likely-case scenario estimates of future direct use indicate that by 2050, the total use could increase to 5.1 EJ_{th}/yr, with a GHP contribution of some 4.2 EJ_{th}/yr [83%] (Fridleifsson *et al.*, 2008). The dominance and expected significant growth in GHP use arises from their ability to be used for both heating and cooling almost anywhere on the earth's surface.

In addition to the abovementioned hydrothermal resources, there are several other potential significant geothermal sources capable of power generation and direct heat use, including: 1) the binary generation from the utilization of the hot water discharged from conventional plants (co-generation) and that available from the lower temperature geothermal resources (75 - 130 °C); 2) the cascaded use of hot water discharged from geothermal power stations for direct heat applications; 3) the huge geothermal energy potential available within drilling depths (3 - 10 km) in the earth's crust via enhanced geothermal systems (EGS) development; 4) the large energy resources in the form of super-critical fluids inferred to exist deep (3 - 5 km) beneath hydrothermal systems; 5) hot water produced from oil and gas wells; 6) hot water present in deep sedimentary basins and 7) off-shore (under-sea) hydrothermal resources located along the submarine rifts and identified by the presence of hydrothermal vents.

Of the above non-conventional resources, EGS is the first that has been identified as having an extremely large theoretical potential. Recent estimates indicate that the USA has over 200,000 EJ_{th} extractable heat via EGS techniques (about 2,000 times its 2005 annual primary energy consumption), with approximately 100 GW_e of cost-competitive generating capacity developable by 2050, given reasonable R&D investment (MIT, 2006). Estimates of EGS potential for the Rehai and Yangbajing geothermal fields of China (Wan *et al*., 2005) and for regions across India (Chandrasekhar and Chandrasekharam, 2007) also show capacities on the order of 100 GW_e, with further assessments of 35 GW_e for Germany (Paschen *et al*. 2003), 12 GW_e for 23% of Switzerland (Signorelli and Kohl, 2007) and 13 GW_e for 3 project areas of South Australia (Goldstein, pers. comm., 2008), making a total of $\geq$ 360 GW_e. A recent (2009) first-order estimate of global EGS theoretical potential of ~ 2 TW_e was obtained by assuming that the USA EGS capacity of 100 GW_e for the US continental area applied to the worldwide continental land mass. Comparison of this estimate with the $\geq$ 360 GW_e value suggests that the global estimate is low. However, Fridleifsson *et al.* (2008) have indicated that 70 GW_e of EGS could be available by 2050; and Rybach's (2010) recent discussion of geothermal potential and the challenges facing large-scale EGS deployment argues for the lower value. Hiriart *et al.* (2010) have recently examined the possibility of power generation from geothermal (hydrothermal) vents associated with active oceanic ridges, and with conservative assumptions, find a total potential production of 160 GW_e. Discussions at a joint GIA-GIA Workshop held in May 2009 highlight the continued uncertainties associated with the estimating geothermal potentials (Mongillo, in prep.).

Currently, geothermal development for electricity generation and direct use is in a high-growth phase worldwide (Figure 1), with future prospects looking very positive. It is not clear how the global financial crisis will affect geothermal in the near future, though USA President Obama announced on 27 May 2009, the American Reinvestment and Recovery Act to expand and accelerate the development, deployment, and use of geothermal energy throughout the United States, with a US$ 350 M stimulation package. This should not be surprising, since geothermal is a major renewable global energy resource, with a multitude of valuable characteristics, including its: extensive global distribution, environmentally friendly character, independence of season, immunity from weather effects, indigenous nature, contribution to development of diversified power, effectiveness for distributed application, sustainable development capabilities and small *foot-print*. Though geothermal usually operates as a baseload provider of electricity with availability and load factors typically well above 90%, it can also operate in a load-following capacity, albeit at lesser efficiency.

Clearly, there is the potential for geothermal resources to make a considerable contribution towards meeting the world's current and future energy needs well into the future, while contributing to reduced future emissions and to the mitigation of climate change. The global geothermal potential is enormous; however, more detailed studies are required to produce confident estimates of its possible contribution.

4. THE INTERNATIONAL ENERGY AGENCY (IEA) AND IMPLEMENTING AGREEMENTS

The International Energy Agency (IEA) is an autonomous intergovernmental organization based in Paris, France. Formed in 1974, in response to the 1973-74 oil crisis, the IEA now acts as an energy policy advisor to its 28 member countries: Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Japan, Korea, Luxembourg, The Netherlands, New Zealand, Norway, Poland, Portugal, Slovak Republic, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States; with the aim of helping ensure the provision of reliable, affordable and clean energy to their citizens. The Commission of the European Communities also participates in the work of the IEA.

In addition to its initial role of coordinating measures in times of oil supply emergencies, the IEA's mandate has broadened and now includes: energy security, economic development and environmental protection- the major components of balanced energy policy making. Significant joint measures include developing alternative energy sources, increasing efficiency of energy use and assisting with the integration of energy and environmental policies. IEA's current work concentrates on market reform, energy technology collaboration, climate change policies and outreach to the wider global community, especially the big energy consumers and producers: China, India, Russia and the OPEC countries. The IEA pursues an extensive programme of data compilation, energy research, publications and public dissemination of the most current energy policy analysis and good practices recommendations. See the IEA website for further information.

Only international technology cooperation can provide a cost-effective way to help guarantee energy security and address climate change issues. The IEA encourages such international energy technology collaboration in the areas of information centres and energy modelling, fossil fuels, renewable energy technologies, energy end-use technologies and fusion power through a network of 41 Implementing Agreements (IAs). The IAs provide a management framework and legal mechanism for guiding the IEA's collaborative program activities. IA Members are of two categories: Contracting Parties (representing countries), and Sponsors (industries and organizations); and typically consist of research institutions, utilities, industries and organizations.

IA activities, or *tasks*, are defined and organized in *annexes*, which specify task objectives, schedules and funding provisions (if any), and identify participants and define their obligations. An Executive Committee (ExCo), consisting of one representative from each Member, manages the activities of the IA and is responsible for disseminating results and reporting to the IEA. Each annex is led by an Operating Agent, usually an institution. Funding for IA annex activities can be of two types: *task-sharing*, wherein participants provide resources and personnel to conduct a portion of the annex work at their own expense; or *cost-sharing*, whereby participants contribute to a common fund that is used to pay for annex operation. A combination of these funding mechanisms may also be used.

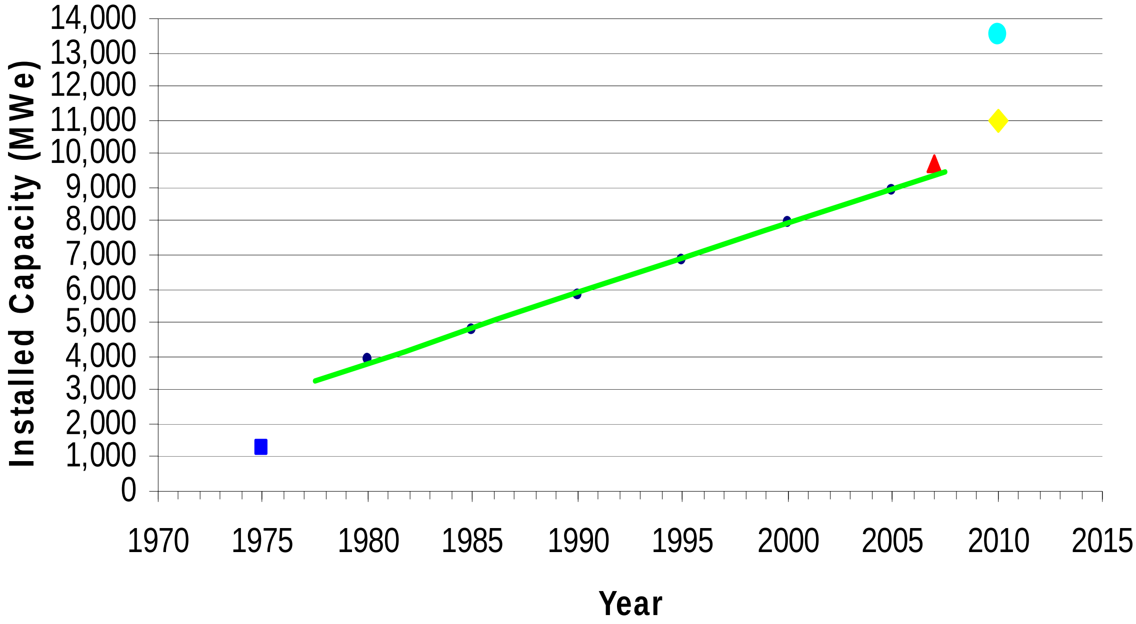

Figure 1. Worldwide geothermal installed capacity 1975-2010 (red triangle is installed capacity in 2007, yellow circle is Bertani (2007) estimate for 2010 and the blue circle is Gawell and Greenberg (2007) estimate for 2010).

5. THE IEA GEOTHERMAL IMPLEMENTING AGREEMENT (GIA)

5.1 Overview

Founded in 1997, the GIA is now well into its 3rd 5-year term of operation, which takes its activities to 2012. It provides a flexible structure for comprehensive international cooperation in geothermal R&D by linking national and industry programmes for exploration, development and utilization of geothermal resources. The emphasis is on enhancing effectiveness through establishing direct cooperative links among the geothermal experts in the participating countries, industries and organizations. The general scope of the GIA's activities consist of international collaborative efforts to: *compile and exchange improved information* on global geothermal energy R&D, *develop improved technologies* for geothermal energy use, and *improve the understanding of the environmental benefits* of geothermal energy utilization and ways to avoid or minimize its environmental impacts. Collaboration through GIA offers members the chance to participate in R&D projects, and assist with the development of databases, models and handbooks; as well as opportunities for information exchange via meetings, workshops and networking; and provides an international perspective on geothermal issues.

As of May 2009, there were 19 Members in the IEA-GIA, including: 12 countries (Australia, France, Germany, Iceland, Italy, Japan, Mexico, New Zealand, Republic of Korea, Spain, Switzerland, United States), the EC, 4 industries (Geodynamics Limited, Green Rock Energy Limited, ORME Jeotermal, Inc., Ormat Technologies, Inc.) and 2 national organizations (the Canadian Geothermal Energy Association [CanGEA] and the Geothermal Group of the Spanish Renewable Energy Association [GG-APPA]).

The GIA ExCo, which consists of one voting representative from each of the above 19 Members, supervises the overall operation of the organization. It meets twice each year to report on and discuss the organization's activities, especially those pursued in the annexes; and Members are stongly encouraged to attend. Country and Sponsor Members report on the status of their geothermal activities; and prospective new Members and invited guests describe their geothermal pursuits and interests. Separate Annex meetings are frequently held in association with the ExCo meetings. Members cover the travel expenses of their representatives to attend the GIA meetings and associated workshops. *etc.*.

The GIA ExCo has a Secretariat, currently based in New Zealand, which provides administrative and secretarial services, assists with publications, maintains the GIA website and provides other services as required for the organization. The operational expenses for the GIA Secretariat, including the Secretary's salary, and other common costs of the ExCo, are met from an ExCo common fund. Contributions to support the common fund are made by Members through a share apportionment system, with each share currently valued at US$ 3,500/year.

GIA membership provides many valuable benefits, including: increases R&D capabilities by combining the efforts of several nations and industry; helps avoid duplication and unproductive research; develops skills and knowledge; improves R&D cost effectiveness by sharing information, research costs and technical resources; provides wider and easier access to key information, research results and technological capabilities; provides impartial information and analysis to help guide national policies and programmes; provides the opportunity to review current issues, ongoing research and the need for future research; investigates barriers to implementation; and contributes to the development of energy policies.

5.2 Initiating GIA Sustainable Development Efforts

The IEA-GIA identified sustainable utilization as an important topic for consideration at the time of its formation; and in 2003, drafted Annex V- Sustainability of Geothermal Energy Utilization. The efforts of this proposed Annex were aimed at investigating alternative scenarios for energy production from representative geothermal resources with the goals of (1) defining methods and requirements for sustaining production from these resources, and (2) estimating the long-term economic sustainability of such production not only for representative resources but for the worldwide geothermal resource as a whole. To date, this Annex has remained inactive, awaiting two members to champion it.

In 2006, the ExCo decided to support an initial investigation into developing a GIA sustainability policy with the possibly of initiating the GIA's geothermal sustainability efforts, and a review paper that examined geothermal's renewable characteristics and its sustainable development with associated identified research needs was prepared (Rybach and Mongillo, 2006). This paper stimulated much useful discussion, and along with a paper that examined geothermal utilization strategies to promote beneficial environmental effects and optimize sustainability (Bromley *et al*., 2006), set the scene for the creation and official start-up of the GIA's sustainability studies in late 2006, in Annex I Task E-Sustainable Utilization Strategies.

The aim of Task E was to collate case histories of models of geothermal developments to see what strategies have worked; undertake modelling of long term reservoir behaviour to select optimum future strategies given different recharge and resource size scenarios; compare environmental gains with economic gains from different sustainable development scenarios; compare different conceptual and hypothetical reservoir model predictions, and investigate (with agreed scenarios) long term reservoir behaviour, recharge factors, recovery times, and optimised cyclic or staged operation strategies. Task E continues to be very active and productive (see below).

In the meantime, the ExCo had unanimously agreed to apply to the IEA to continue its operations for a 3rd Term (2007-2012). It identified the importance of promoting sustainable geothermal development for realizing geothermal's huge global potential as a clean, economic and secure energy resource that could contribute to the mitigation of climate change; and so adopted this goal as the core of its proposed 3rd Term mission.

5.2 3rd Term Mission and Objectives

To continue and expand global geothermal development, it is essential to improve and develop new technologies and to increase awareness of geothermal energy and the benefits of its sustainable utilization. The IEA-GIA sees itself as an organization that can take the lead in these efforts, and embraced them its 3rd Term Mission:

To promote the sustainable utilization of geothermal energy throughout the world by improving existing and developing new technologies to render exploitable the vast and widespread global geothermal resources, by facilitating the transfer of know-how, by providing high quality information and by widely communicating geothermal energy's strategic, economic and environmental benefits.

To accomplish this mission, the following six strategic objectives were designed:

- To actively promote effective cooperation in geothermal RD&D through collaborative work programmes, workshops and seminars
- To collect, improve, develop and disseminate geothermal RD&D policy information for IEA Member and non-Member Countries
- To identify geothermal energy RD&D issues and opportunities, and improve/develop geothermal energy technologies and methods to deal with them
- To increase membership in the GIA
- To encourage collaboration with other international organizations and appropriate IEA implementing agreements
- To broaden and increase the dissemination of information on geothermal energy and the GIA's activities and outputs to decision makers, financiers, researchers and the general public

Though the above mission and objectives were developed in late 2006 as part of the GIA's 3rd Term Strategic Plan, they still remain sound and continue to provide excellent guidance for the GIA's activities, even considering the more ominous IEA climate-based outlook (IEA, 2008b) and the financial crisis currently challenging the world.

6. CURRENT GIA ACTIVITIES

To help meet the above objectives and realize the GIA's mission, GIA participants take part in one or more of the current four major research areas, or Annexes. In addition, ExCo Members and the Secretary also contribute (see section 6.2 below).

6.1 The Annexes

The GIA's current major efforts are managed in the following four Annexes, with specific studies conducted in several Tasks within each Annex (See Table 1 for Annex information).

Annex I: Environmental Impacts of Geothermal Energy Development- to determine the environmental effects of geothermal development and develop and implement methods to avoid or minimize their impacts. Five tasks include: to examine the impacts on natural features; to study the problems associated with discharge and reinjection of geothermal fluids; to examine methods of impact mitigation and produce environmental guidelines; to investigate seismic risk from EGS fluid injection; and to develop sustainable utilization strategies (for further details, see Axelsson *et al.* (2010), Bromley (2010)).

Annex III: Enhanced Geothermal Systems (EGS)- to investigate new and improved technologies that can be used to artificially stimulate a geothermal resource to allow commercial heat extraction. Five tasks include: to develop EGS economic models; to review/modify application of conventional or new geothermal technologies; to collect information necessary for designing a commercial EGS plant; to compile effective tools for reservoir evaluation that can be applied to new EGS sites; and to conduct EGS R&D with emphasis on reservoir management and enhancement technologies (for further details, see Baria and Wyborn. (2010)).

Annex VII: Advanced Geothermal Drilling Techniques- to pursue advanced geothermal drilling research and investigate all aspects of well construction with the aim of reducing costs. Three tasks include: the compilation of geothermal well drilling cost and performance information; the production of a geothermal drilling "best practices" handbook; and the exchange of information on drilling technology development and new applications (for further details, see Bauer *et al.* (2010)).

Annex VIII: Direct Use of Geothermal Energy- to address all aspects of direct use technology with emphasis on improving implementation, reducing costs and enhancing use. Six tasks include: to define and characterize geothermal resources for direct use applications; to collect, analyze and disseminate cost and performance data and validate improvements; to initiate research to remove barriers, enhance economics and promote implementation; to identify, test and characterize performance of innovative equipment; to develop engineering standards; and to develop methods for presenting geothermal data on the internet using Google Earth (for further details, see Gunnlaugsson *et al.* (2010), Muraoka *et al*. (2010), Rybach (2010), Song (2010)).

GIA Members must participate in at least one of the Annex Tasks, though all current Members are participating in 2 or more Tasks. Funding for GIA Annex work has been of the *task-sharing* mode since the initiation of the GIA, and is expected to remain so for the foreseeable future.

Table 1. Annex Title, Operating Agent and Status of GIA Annexes at May 2009.

Annex Number	Title Operating Agent (OA) Task Leader (TL); Affiliation; Contact E-mail Participants	Status
I	Environmental Impacts of Geothermal Development OA: GNS Science (GNS), New Zealand TL: Chris Bromley; GNS, New Zealand; c.bromley@gns.cri.nz Participants: Australia, EC, France, Iceland, Italy, Japan, Mexico, New Zealand, Switzerland, USA	Active since 1997, Continuing through 2009
II	Shallow Geothermal Resources	Closed
III	Enhanced Geothermal Systems OA: Geodynamics Limited, Australia TL: Roy Baria, MIL-TECH UK (for Geodynamics); roybaria@onetel.com Participants: Australia, Canadian Geothermal Energy Association, EC, France, Geodynamics, Geothermal Group-Spanish Renewable Energy Association, Germany, Green Rock Energy, Italy, Japan, ORMAT, Spain, Switzerland, USA	Active since 1997, Continuing through 2009
IV	Deep Geothermal Resources	Closed September 2006
V	Sustainability of Geothermal Energy Utilization	Draft
VI	Geothermal Power Generation Cycles	Draft
VII	Advanced Geothermal Drilling Techniques OA: Sandia National Laboratories, United States TL: Steven Bauer; Sandia National Laboratories, USA; sjbauer@sandia.gov Participants: Australia, Canadian Geothermal Energy Association, EC, Iceland, Mexico, New Zealand, USA	Active since 2001, Continuing through 2009
VIII	Direct Use of Geothermal Energy OA: The Federation of Icelandic Energy and Waterworks, Iceland TL: Einar Gunnlaugsson; The Federation of Icelandic Energy and Waterworks, Iceland; einar.gunnlaugsson@or.is Participants: Canadian Geothermal Energy Association, France, Geothermal Group-Spanish Renewable Energy Association, Iceland, Japan, New Zealand, ORME Jeotermal, Republic of Korea, Spain, Switzerland, USA	Active since 2003, Continuing through 2011
IX	Geothermal Market Acceleration	Closed

Annex II- Shallow Geothermal Resources and IV- Deep Geothermal Resources, were closed after successful completion of their major tasks; and Annex IX was closed before it was initiated as the result of the IEA starting a special Implementing Agreement: Renewable Energy Technology Development.

6.2 The ExCo and Secretariat

In addition to supervising the overall operation of the GIA programme, the ExCo supports the IA's efforts through its Member's, and the Secretary's, general promotion and information dissemination on geothermal energy and the GIA through their participation at international renewable energy and geothermal conferences and workshops, with special effort made to support those sponsored by the IEA. Other activities include: publication, in international journals, of papers describing the GIA's activities; production of comprehensive GIA annual reports; maintenance of the public GIA website; and sponsorship of conference exhibition booths, where documents, posters and other material can be distributed.

7. RECENT GIA ACHIEVEMENTS IN SUPPORT OF SUSTAINABLE DEVELOPMENT

The GIA's sustainability activities have grown since the start of its 3rd Term in April 2007. A few examples which demonstrate the range of work and major accomplishments are presented here.

7.1 3rd Term Extension

The GIA identified sustainable geothermal development as one of the industry's most significant current, and future, issues, and so designed its 3rd Term mission and strategic objectives to deal with it. Following a rigorous review of the GIA's strategy, the IEA concurred and unanimously extended the GIA's activities for a 3rd 5-year Term, to March 2012.

7.2 Membership Growth

The ExCo recognizes the importance of increasing membership in order to enhance its expertise, extend its efforts and increase its influence in support of sustainable geothermal utilization worldwide; and so has emphasized its membership growth effort. In 2006, the GIA also broadened its membership base to include both industry and industry organizations, thus providing direct industry contact, perspective and input; thereby helping raise GIA's awareness of their concerns and needs. In the past 3 years, membership has nearly doubled to a total of 19 Members, with 12 Country Members, the EC and 6 Sponsor Members. At present, there is also interest from five prospective members: Norway, the European Geothermal Energy Council (Belgium), China, Russia, and Ireland.

7.3 Significant Information Dissemination

The GIA ExCo and Annexes have been particularly active and successful in their information dissemination endeavours since the start of the 3rd Term, with participation in several major international conferences, meetings and workshops, including: the European Geothermal Congress (2007), Unterhaching, Germany; and the 2008 New Zealand Geothermal Workshop (NZGW), Taupo, New Zealand, which was held in association with the 50th Anniversary of the commissioning of the Wairakei Geothermal Power Station. These conferences provided valuable opportunities for extensive discussion and information exchange with other geothermal professionals.

The GIA also had a major presence at the large Renewable Energy 2008 Conference, Busan, Korea, with the presentation of several geothermal papers about the IEA-GIA's efforts and geothermal utilization; and sponsorship of an exhibition booth that attracted good attention. The RE 2008 was especially valuable because it provided the opportunity for the GIA to raise awareness of geothermal as an important renewable energy source (amongst all the others), and explain and discuss it with non-geothermal participants, policy and decision makers, and the public. At the exhibition booth, many posters were displayed and computer presentations were projected continuously; hundreds of geothermal and GIA documents were distributed; and the GIA's work was discussed with a multitude of visitors, including scientists, business people and students.

The GIA has increased its participation in IEA workshops, meetings and seminars, through direct participation and the provision of GIA material for distribution. The GIA has participated at the China (Mongillo and Rybach, 2007) and Russia (Mongillo, 2008) IEA Networks of Expertise in Energy Technology (NEET) workshops designed to encourage these countries to increase their use of more environmental-friendly renewable energy. Both China and Russia have geothermal power and direct use developments and were interested in learning about the GIA's activities and how membership could help their geothermal programmes. The GIA also provided posters and several documents for the IEA Ministerial Fair held in Paris, France (2007), which many high-level government officials attended.

Information and data are regularly provided for IEA reports, thus raising the profile of the GIA and geothermal energy within the IEA, as well as on a global scale, and among the other renewable energy technologies. An example is the IEA bi-annual Energy Technologies at the Cutting Edge reports, which included highlights of the GIA's EGS activities in 2007, and will cover the GIA's sustainability efforts in 2009. The GIA has also contributed articles to IEA OPEN Bulletin, an electronic newsletter with over 12,000 subscribers, most recently dealing with induced seismicity associated with EGS (Bromley and Mongillo, 2008).

The GIA Annual Reports, and associated stand-alone Executive Summaries (2005, 2006 and 2007), have become the GIA's premier forms of information dissemination. They provide up-to-date information about the organization, member's geothermal activities and Annex efforts; and since the 2005 issue, CD-Roms including all GIA Annual Reports (1997-2007) and Executive Summaries have been produced for distribution at international conferences and upon request.

The GIA's comprehensive public website went on-line in late-2004 (www.iea-gia.org), and is being continuously developed and updated. It provides an important and easily accessible means for distributing and commenting on GIA documents and other international publications, as well making available up-to-date information about the GIA and geothermal energy to GIA Members and the public

The GIA has also expanded its activities by sponsoring/hosting several international technical workshops since 2005. In November 2008, Annex I sponsored an *International Geothermal Sustainability Modelling Workshop* in Taupo, New Zealand, in association with the 2008 NZGW and the 50th Anniversary of the Wairakei Power Station. There were over 40 participants; with 20 presentations examining geothermal development strategies and numerical modelling, which have been made available to the international community via the GIA website. Discussion and follow-up networking has lead to the development of a *Geothermics* Special Issue on Sustainable Geothermal Utilization, planned for publication in early 2010. It is to include case histories and modelling results illustrating various sustainable utilization methods for most of the major developed geothermal fields with long periods of power and direct use production. More recently, in May 2009, a joint GIA-IGA (International Geothermal Association) Workshop on *Geothermal Energy- Its Global Development Potential & Contribution to Mitigation of Climate Change* was held in Madrid, Spain. Over 60 participants from about 20 countries discussed these issues, and a proceedings consisting of a summary of workshop discussions and all presentations is being prepared.

In 2009, the GIA ExCo has, for the first time, been able to make funds available for specific GIA and Annex projects, such as the completion of specific studies and production of special reports. The first proposal funded is to support the publication of the *Geothermics* Special Issue on Sustainable Geothermal Utilization described above.

7.4 Recent Annex Efforts and Achievements

A few examples of the more important Annex-related efforts and achievements are described here.

Near the start of the 3rd Term, Annex III activities were significantly revised in recognition of the first EGS power stations approaching completion. New investigations were included to develop economic guidelines for EGS reservoir economic models and design recommended procedures to create, test and evaluate EGS parameters. These efforts will contribute to the development of sustainable EGS operation procedures.

Annex I's induced seismicity efforts- 3 international workshops held between 2005 and 2006, and other continuing investigations, culminated in the development of a *Protocol for Induced Seismicity Associated with EGS* (Majer *et al.*, 2008) which could serve as a guide for developers to use to address induced seismicity issues. In addition, a paper was produced which reviewed induced seismicity, presented up-to-date information, identified gaps in knowledge, and concluded that EGS-induced seismicity need not be a threat to EGS development (Majer *et al*., 2007). Annex I's important sustainability accomplishments were described above.

Annex VII continues to make progress on the development of a database of comparative well costs, downhole logging tool improvements, and production of a best-practices drilling handbook. The particular importance of reducing well drilling and completion costs is well recognized, and significant success here will provide a major boost to geothermal sustainable development.

A significant database of temperature and chemistry data for geothermal features from several countries has been assembled (and continues to grow) by Annex VIII, and will make a valuable contribution to the production of the planned *Atlas of World Hydrothermal Systems* and provide information useful for increasing direct use applications. Initial published results (Muraoka *et al.*, 2008) demonstrate the great value of having a comprehensive database from which data can be compared and geographically plotted; and indicate that surface feature discharge temperature mapping clearly depicts up-flow zones of hydrothermal systems and can be a useful tool for identifying prospective geothermal fields. Improved public accessibility to direct use data via Google Earth has been demonstrated, with full operation expected in the near future.

8. FUTURE DIRECTIONS, OPPORTUNITIES AND PLANS

Geothermal power and direct use development are currently in a period of major growth in many countries. However, in spite of geothermal's huge potential and valuable characteristics, this rate of development (< 2 GW_e/yr, Bertani (2009)) is far outstripped by those of solar PV (6 GW_e/yr) and wind (25 GWe/yr) (Renewables, 2009). Clearly, geothermal still faces serious obstacles, including technical, financial, political and perceived barriers that must be overcome if geothermal is to realize its huge potential and make the more rapid contribution it is capable of. The GIA believes its current strategy is sound and provides good direction to meet these challenges, however, it also sees opportunities to further its success and influence.

Information dissemination, exchange and communication will remain major activities for the GIA, and new opportunities have been identified for further developing these efforts, with the aim of expanding the communication of the benefits of geothermal energy and the GIA's activities and results to as wide an audience as possible. The GIA will continue to participate at major international renewable energy and geothermal meetings, conferences and workshops. Possibilities are being explored for holding more regular international workshops and seminars in association with ExCo meetings, in prospective Member countries and with other international organizations, such as the IGA. The GIA will be building on its already strong ties with its IEA parent, most immediately by producing a geothermal brochure (IEA Geothermal Technology Brief) with the IEA, which will provide recognition and wide circulation among the policy makers of the 26 IEA Member countries and EC, and provide a substantial document for distribution through GIA channels, international conferences, *etc.* The *Geothermics* Special Issue-Sustainable Geothermal Utilization, planned for release in early 2010, will be an important publication for informing the international community about current sustainable geothermal power and direct use operations, the various development options being used, and the IEA-GIA's efforts to promoting sustainable development. The GIA will also be sponsoring an exhibition booth at the WGC 2010, at which several posters describing the GIA, Annex studies and Member Country and Sponsor geothermal activities will be displayed, and many IEA and GIA documents made available.

The GIA has plans to produce a *proceedings* from the joint international GIA-IGA Geothermal Potential and Geothermal's Contribution to the Mitigation of Climate Change Workshop held in May 2009, consisting of a précis of the 2-day discussions plus copies of all presentations. The proceedings will be made available on CD-Rom and on the GIA website.

The GIA will continue to develop both its annual report as its premier GIA information product, and its public website as its most widely and easily accessible avenue for communication and information distribution. Plans for upgrading the GIA website are currently being considered, with outcomes to include making site updating/editing easier, downloading of documents/information from the site faster, assuring the GIA site appears more prominently on internet search lists, and providing more information about site visitors.

The GIA is always prepared to consider new collaborative activities and new proposals are encouraged where demand and needs exist. Interest is growing in sustainable geothermal development and several research needs have been identified, and if/when sufficient interest is demonstrated, the GIA is prepared to expand its efforts by initiating Annex V- Sustainability of Geothermal Energy Utilization. Similarly, the GIA has experienced a significant increase in requests for geothermal data and information over the past few years, and is now considering the creation of an Information Exchange and Dissemination Annex.

The GIA recognizes the need for continued growth, especially seeking those countries with significant geothermal resources and/or development whose membership would benefit both the GIA and them, including: Indonesia, the Philippines, and countries in East Africa and Central and South America. Potential members are encouraged to attend GIA ExCo meetings, workshops and Annex meetings to learn more about the GIA and the benefits of membership. At present, there is membership interest from Norway, the European Geothermal Energy Council (EGEC), Ireland, Russia and China; and continued growth is expected.

9. CONCLUSIONS

The worldwide demand for energy is expected to continue growing over the next several decades, irrespective of the current global financial crisis. Unless energy savings and renewable energy options are implemented, energy security problems and significant climate change effects are likely. To meet these challenges will require massive input from renewable energies, including that from the vast and ubiquitous geothermal resources.

However, to realize geothermal's huge potential contribution, it is necessary to improve existing and develop new technologies; and to promote the benefits of geothermal energy, its sustainable utilization and the contribution it can make toward climate change mitigation. Success will require considerable international effort.

The IEA-GIA, now well into its 3rd 5-year Term, and with a demonstrated record of success, is well placed to lead this essential international effort, and is confident that it can do so well into the future. The participants in the IEA-GIA extend an invitation to those national organizations, universities, industries and other groups who can contribute, to join us in our endeavours.

For more information about the IEA-GIA, contact the IEA-GIA Secretary and/or visit the GIA website.

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