Geothermal Technologies Program Blue Ribbon Panel Recommendations

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Office of Energy Efficiency and Renewable Energy

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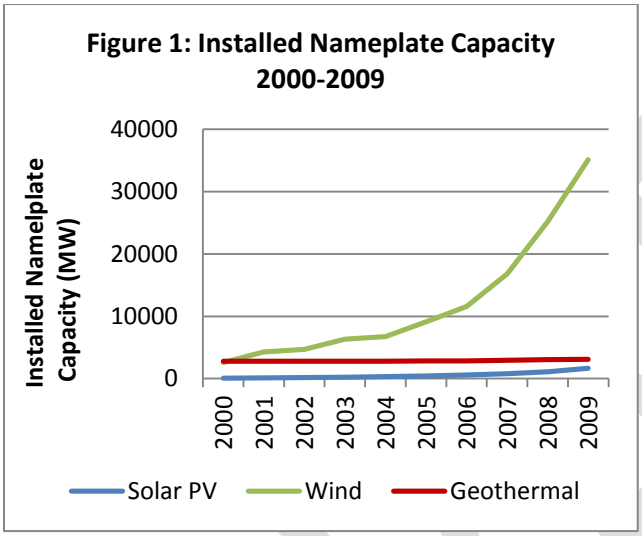
Introduction

While the United States currently leads the world in installed geothermal capacity and generation, the majority of the industry's growth occurred prior to 1990. In recent years, the growth of geothermal capacity has lagged that of the U.S. solar and wind industries, which have both made significant gains [Figure 1]. Solar PV installed capacity (on and off-grid) rose from 85 MW in 2000 to 1,677 MW in 2009. Wind installed capacity rose from 2,578 MW in 2000 to 35,159 MW in 2009. In that same time period, geothermal installed capacity increased by less than 300 MW from 2,798 MW to 3,087 MW.



Year	Geothermal	Wind	Solar PV
2000	2.20%	2.60%	26.90%
2001	0.00%	65.80%	31.70%
2002	0.00%	9.60%	39.20%
2003	0.00%	35.60%	44.80%
2004	0.00%	5.90%	38.00%
2005	1.10%	35.60%	35.80%
2006	0.10%	26.90%	33.40%
2007	3.70%	45.20%	36.20%
2008	3.50%	50.10%	43.50%
2009	1.50%	39.30%	51.60%

Source: DOE EERE Renewable Energy Data Book 2009, Page 23: Renewable Electricity Nameplate Capacity (MW) and Percent Cumulative Increase from Previous Year. August 2009. Available at: www1.eere.energy.gov/maps_data/pdfs/eere_databook.pdf

On March 22 and 23, 2011, the U.S. Department of Energy's (DOE) Office of Energy Efficiency and Renewable Energy (EERE) assembled a panel of geothermal experts in Albuquerque, New Mexico for a guided discussion on the future of geothermal energy in the U.S. The purpose of the meeting was to identify the obstacles to geothermal energy growth, discuss the appropriate role of DOE in enabling geothermal energy, and recommend priority research and development (R&D) areas for the EERE Geothermal Technologies Program. The 15 panelists included experts from the geothermal and oil/gas industry, finance institutions, utilities, universities, and national laboratories [Appendix 1].

Panel members expressed the view that the role of DOE is to support a portfolio of R&D activities addressing the short-term (2020) and the longer term (2050), but they noted that the two objectives are not mutually exclusive and that many of their technology development recommendations will benefit in both timeframes.

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They recommended that DOE efforts be focused on identifying hidden resources that can increase current geothermal capacity while developing the technology to optimize these resources, and accelerating the development of enhanced geothermal systems (EGS).

Panel members suggested that the Program focus its R&D resources in two major areas:

1. Exploration - Reduce the cost of confirming known hydrothermal resources and identifying undiscovered hydrothermal resources to accelerate the growth of the industry in the near term.

2. Enhanced Geothermal Systems (EGS) - Prove the technical and economic feasibility of EGS to enable geothermal resources to be a significant contributor to the U.S. energy supply in the long term.

They also recommended that the Program allocate some R&D resources to reducing operations and maintenance (O&M) costs of hydrothermal systems, e.g. more efficient dry or hybrid cooling technologies, and consider creating a dedicated field laboratory to test new technologies, validate reservoir engineering techniques, and gather empirical data on EGS and other geothermal systems.

Panelists did not believe the Program should invest in research, development and demonstration of low temperature, coproduced, geopressured, or sedimentary resources due to the absence of any major technological challenges in those areas. And they felt that investment by DOE in geothermal education and workforce development is unnecessary.

Finally, citing the difficulty they have in getting financing for geothermal projects, industry members of the Panel expressed the need for policy in the form of a government-assisted drilling program.

This report describes the discussions and recommendations of the Geothermal Blue Ribbon Panel.

Accelerate Near-Term Growth through Exploration

The lack of prospects, the high cost and risk of exploration, and the difficulty of securing financing at early development stages are major barriers for the U.S. geothermal industry. To overcome these barriers, Panelists recommended that DOE take a two-pronged approach: use current tools in the near-term to locate and characterize new and known resource prospects while developing innovative tools to decrease exploration cost and risk over the next 20 years.

Develop an Inventory of Prospects using Existing Technology

An inventory of high-grade geothermal prospects should be developed by identifying new resources and fully exploring known geothermal resource areas (KGRAs). The U.S. Geological Survey estimated in 2008 that 30 GWe of undiscovered geothermal resources could be found in

the western United States.[1] This provides an opportunity for a 10-fold increase compared to today's installed capacity. Panel members recommended that the DOE geothermal program focus on locating these resources in the near term using rapid reconnaissance surveys, surface exploration, stress measurements, fracture mapping, temperature gradient drilling or even cost-shared exploration drilling. The Program should also partner with other agencies, including the Department of the Interior, the U.S. Geological Survey (USGS), and the Nevada Bureau of Mines to share knowledge and data.

Panel members noted that drilling is the most difficult part of geothermal project development to finance and that many of the current geothermal prospects were identified through past government-assisted drilling programs. Many panel members felt strongly that the best way to accelerate geothermal energy growth is through cost-shared drilling projects to confirm undiscovered conventional resources.

However, a few panelists expressed that funding conventional drilling is not an appropriate use of government R&D funds, and that the government should not fund activities that could reduce fair competition in the market nor support drilling efforts just to help the industry stay alive. Those in support of cost-shared drilling felt that the DOE should support industry's efforts to better understand the geographic distribution and quality of resources available for development. In exchange for cost-shared drilling, industry would be able to provide "field laboratories" for the DOE, providing publicly accessible data that would benefit the entire geothermal community. Industry members suggested that one of the national laboratories could lead the data collection and dissemination effort, and identify best practices and lessons learned. These lessons could then be implemented across the cost-shared drilling program and throughout the industry to improve performance and reduce costs.

Improve and Develop Advanced Exploration Technologies

Panel members noted that geothermal exploration technologies and methods must also be improved. The lack of ability to accurately predict temperature and permeability at depth from the surface is the major cause of exploration risk. Drilling, which is currently quite costly, is always needed to confirm resources before debt financing can be secured. Cost-effective drilling tools are lacking, particularly for smaller resources, which make it more difficult for developers to recoup exploration costs through power sales.

There was general agreement that DOE should develop both drilling and non-drilling exploration technologies. New exploration drilling techniques that enable small diameter wells could potentially replace conventional drilling in well field development. Non-drilling technologies such as seismic tools that image fractures at depth, and niche technologies adapted from mining, oil and gas industries could significantly reduce the cost of exploration.

[1] Williams, Colin F., Reed, Marshall J., Mariner, Robert H., DeAngelo, Jacob, Galanis, S. Peter, Jr., 2008, Assessment of moderate- and high-temperature geothermal resources of the United States: U.S. Geological Survey Fact Sheet 2008-3082, 4 p.*2008-3082*. 2008. http://pubs.usgs.gov/fs/2008/3082/

Panelists noted that many of the objectives of exploration overlap with the objectives of EGS development, e.g. identification of potential EGS sites may be a spin-off of hydrothermal exploration.

Measuring Success - Goals and Metrics for Exploration
Panel members suggested that the DOE program consider establishing two goals:

1) Validate new technologies and approaches to assist industry in evaluating and developing up to 30 GWe of currently uncharacterized or undiscovered resources. The metrics for success would be to identify a number (to be determined) of prospects capable of producing a number of MW (also to be determined) by a specific year.

2) Develop technologies and approaches that reduce the cost of confirming a productive reservoir. The metrics for success would be based on reducing the number of drilled wells needed to confirm the resource and reducing the cost of drilling each hole.

Determining the correct metrics will require establishing a baseline of current exploration costs and successes, which tend to be site-specific and can be difficult to obtain. Some data, including drilling rig day rates, can be readily obtained from the industry but other data, such as performance data for exploration wells can be hard to access. A company may not be willing to share all of its information related to drilling costs unless it is part of a government-sponsored cost-shared drilling program. Furthermore, it may not be possible to obtain information on the expected megawatt capacity of a resource because industry often does not definitively know the size of the resource until water is flowing and production begins. Additionally, more information is needed on the probabilities of success when using various exploration tools.

Data required to establish cost and success baselines includes:

- Drilling costs
- Tested production rates
- Number of dry holes
- Total number of wells drilled
- Expected MW capacity of the resource

To address the issue of proprietary data, the DOE could “black box” the data - that is, collect data from industry and store it without attribution while maintaining confidentiality.

Secure the Future by Developing Enhanced Geothermal Systems

Panel members agreed that the successful development of enhanced geothermal systems (EGS) – a potentially ubiquitous resource - would significantly increase the inventory of viable prospects available for geothermal development and enable geothermal resources to become a major contributor to the U.S. energy supply. They recommended that DOE pursue EGS development in parallel with exploration, and with an emphasis on demonstrating the technical and economic feasibility of EGS. Panelists noted that the lack of operational data is a major

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barrier both for setting realistic goals and milestones and for the development of EGS. The DOE should investigate the need for reservoir stimulation as well as well stimulation.

Panel members recommended that DOE:

Determine the optimal conditions for EGS. The parameters analyzed should include temperature, depth, geology, mineralogy and the characteristics of natural fractures that are desirable for EGS reservoir creation. The information would then be used to identify the best prospective sites in the U.S.

Study the feasibility of reservoir creation. The DOE should conduct a geomechanical study of the feasibility of creating a reservoir with conventional technology. This would be an iterative process, using computer simulation to model reservoir creation and operations. Operational data collected from demonstration efforts can be used to validate and improve the models. The geomechanical models should be employed to conduct case studies of sites with promising conditions for EGS.

Develop tools to optimize power production and reduce cost. These would include tools to improve the predictability of stimulation, packers and zonal isolation technologies to enable engineering of reservoirs with more control and precision, and diversion tools to help prevent reservoir short-circuiting. Panel members also recommended that DOE evaluate stimulation fluids other than water to maximize stimulation potential. New working fluids, including carbon dioxide, may have significant efficiency advantages over water. Improving reservoir stimulation and behavior models will help optimize reservoir performance. Many of these tools could also be used in hydrothermal power production. Some panelists suggested that investment in supporting technologies (drilling research, generation, alternative fluids, etc.) should be at a low level until reservoir creation demonstrating commercial circulation rates is successful. They recommended a phased long-term program of tool development and demonstration.

Demonstrate the ability to create and sustain a reservoir. Panel members recommended that DOE conduct a series of EGS demonstrations in different geologic environments and perform long-term flow tests. The DOE could establish one location as a long-term site with a series of satellite locations to conduct flow tests for two to three years. The overall purpose of these demonstrations would be to establish technical feasibility, collect long-term performance data, and make the data publicly available.

Milestones needed for each demonstration would include creating a fracture network, drilling interconnecting wells, conducting a long-term circulation test, and determining the temperature decline over time. To achieve these milestones, actual power production might not be necessary. For instance, water could be circulated through a doublet and monitored for several years. However, it is important to note that an alternative method for cooling the geofluid would be required, as cooling is usually accomplished through energy extraction.

The reservoir size and performance needed (in terms of flow rate and reservoir life) could be calculated from the economic requirements. For example, if the desired LCOE is 10 cents/kWh, then it would be possible to calculate the associated reservoir size and flow rate required to

achieve that LCOE. The reservoir size would need to approach one cubic kilometer to sustain production over 30 years and flow rates would likely need to be 50-100 kilograms/second.

These demonstrations should be government-owned due to the high cost and the need to work closely with scientists throughout every stage of development. Following a two to three year demonstration phase, ownership could be transferred to industry or the site could be used for additional research. Ongoing research could include whole reservoir stimulation, drilling additional wells and expanding the fracture stimulation, and experimenting with using new geofluids such as carbon dioxide.

Cross-Cutting Recommendations

Reduce Operations and Maintenance Costs

Panelists pointed to the need for reducing the operation and maintenance (O&M) costs of geothermal plants to lower the levelized cost of geothermal energy. The development of hybrid cooling systems was cited as an example. Traditional cooling systems have high water requirements and securing the necessary permits and water rights is difficult, particularly in western states. Panel members recommended that DOE conduct an analysis of O&M costs and technology needs.

Create a Field Laboratory

Panel members noted that while a field laboratory would have EGS as a major focus, it would also provide a science and engineering site for conducting rock physics experiments and flow tests, validating geophysical models, and testing tools and technologies for all geothermal resources. Currently, there is no such field location open to both developers and scientists. The site could be comprised of 16 to 20 wells, each approximately 6,000 feet deep with an estimated total cost of $100 million.

Panelists noted that this field laboratory could be a partnership effort modeled after similar sites established for oil and gas and/or physics research. One model cited was the DOE-funded Multi-Well project, a research-oriented field laboratory in the 1980s that successfully assisted industry in its ability to produce natural gas from tight sandstone formations. Another example mentioned was the Power Systems Development facility supported by the DOE Office of Fossil Energy.

Several panel members pointed out, however, that while a dedicated field laboratory would be useful, it is critical that DOE demonstrate reservoir creation and operation in multiple locations. They suggested that the field laboratory could be used as a central location for this purpose, with smaller sites employed as satellites in different geologic conditions.

Support Policy Improvements

In addition to the technical challenges described above, permitting and financing are major barriers to geothermal development. Panelists felt that these could be addressed through new or modified policies in the bidding process, exploration insurance programs, and financial incentives.

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Members noted that the Bureau of Land Management (BLM) bidding process is lengthy and that bid prices and resource quality are highly uncertain. They suggested that streamlining and improving the bid process could shorten project development time by approximately two years.

Providing industry with more information on a parcel prior to auction would reduce the upfront risk of exploration. This information could be provided by allowing developers to have first right of refusal after successful exploration drilling on a site before it is leased. Alternatively, prior to auction the DOE and USGS could drill slim holes to validate temperatures and thermal gradient holes to validate reservoir volume. An environmental assessment could be performed and water rights could also be secured by the BLM prior to auction. Developers would pay a higher bid price, but would have more certainty regarding the resource and fewer permitting delays.

Panel members suggested that an exploration re-insurance program in the U.S. would also help reduce risk. Similar programs have been implemented in Europe. For example, a developer could insure and drill five wells; if any of the drilled wells do not meet previously specified criteria for success, the developer would receive a cash payment.

Industry panel members noted that financial incentives drove geothermal exploration in the 1980s. Through Standard Offer 4 under the Public Utilities Regulatory Policy Act of 1978,[2] utilities were required to pay renewable energy sources higher fixed electric prices as a hedge to the rising cost of oil. Private industry was willing to take more drilling risk because of the higher electricity price. Currently, production tax credits (PTCs) and investment tax credits (ITCs) are available for geothermal projects. However, since ITCs are calculated based on qualified property expenses, there is no incentive to maintain production over the long term. An attractive option is the PTC on a cash basis (currently available through the 1603 program under ARRA).

Conclusion

The Blue Ribbon Panel members provided clear recommendations on how the Department of Energy can support the near- and long-term growth of geothermal energy in the United States. Panelists recommended that the Department work to reduce risk in investment in geothermal projects, conduct cost-shared drilling with industry, explore known geothermal resource areas (KGRAs), increase resource information and certainty, and invest in technology development for EGS due to its huge potential.

Overall, panel members recommended that the DOE Geothermal Technologies Program focus its resources and activities in two major areas:

1- Exploration to confirm known and undiscovered hydrothermal resources and to develop technologies that reduce cost and risk;

2- Enhanced geothermal systems (EGS) to enable long-term growth of geothermal energy.

[2] 16 U.S.C. Sections 2601-2645.

In addition, panel members suggested that the Program develop technologies that can reduce the O&M costs of geothermal plants.

Due to the lack of technical barriers associated with low temperature, coproduced, geopressured, and sedimentary resources, panelists recommended against DOE investment in those resources. They also suggested that DOE not invest in geothermal education and workforce development, as there is not a workforce shortage in the industry.

On the policy front, panel members expressed the need for a more streamlined permitting process and that the Federal government establish a program to share with industry the cost of drilling.

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Appendix

The Geothermal Blue Ribbon Panel meeting included a facilitated discussion among the Panel members and representatives of the DOE and the USGS. A representative from the BLM was invited but was not able to attend. The majority of the meeting was led by a facilitator, allowing panelists to engage in a guided discussion on the barriers and opportunities for geothermal development in the United States, and the role of the DOE. This Appendix provides information on the Panel members.

Panelists

1. Robert (Bob) Banack, Founder, Banack Capital Group
2. Douglas (Doug) Blankenship, Geothermal Research Manager, Sandia National Laboratory
3. Carol Bruton, Director of Resource Development, Simbol Materials, Inc.
4. Richard Campbell, Vice President of Engineering, CH2M Hill
5. Thomas (Tom) R. Fair, Vice President, Renewable Energy, NVE
6. Joseph (Joe) Greco, Senior Vice President, Terra-Gen Power, LLC
7. Recep Kendircioglu, Senior Managing Director, John Hancock Financial Services
8. Ernest (Ernie) Majer, Scientist, Deputy Division Director, Earth Sciences Division, Lawrence Berkeley National Laboratory
9. Karsten Pruess, Senior Scientist, Lawrence Berkeley National Laboratory
10. Subir Sanyal, President and Manager of Reservoir Engineering Services, GeothermEx, Inc. (a Schlumberger Company)
11. William (Bill) Teplow, Vice President of Exploration, U.S. Geothermal, Inc.
12. Paul Thomsen, Director, Policy & Business Development, Ormat Technologies, Inc.
13. Herbert (Herb) F. Wang, Professor Rock Physics and Geodynamics, University of Wisconsin – Madison
14. Norman (Norm) Warpinski, Director of Technology, Pinnacle – A Halliburton Service
15. Kenneth (Ken) Williamson, Independent Consultant and International Expert

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ROBERT (BOB) BANACK
Founder
Banack Capital Group

Robert Banack has significant experience in advising and financing clean energy companies across a variety of sectors and technologies, including geothermal, wind, solar, wave power and waste-to-energy. Prior to launching Banack Capital Group, he served as Managing Director, Investment Banking in the Clean Energy Group of Imperial Capital, LLC. Banack has been involved in transactions with Nevada Geothermal Power Inc., U.S. Geothermal Inc., AltaRock Energy and Finavera Renewables (now Finavera Wind Energy, Inc.). Previously, Banack served as Vice President, Investment Banking and Vice President, Institutional Sales at Dundee Securities Corporation. He was also an associate in the distressed bank loan trading group at Goldman, Sachs, & Co. Banack has an M.B.A. from Schulich School of Business and an L.L.B. from Osgoode Hall Law School.

DOUGLAS (DOUG) BLANKENSHIP
Geothermal Research Manager
Sandia National Laboratory

Douglas Blankenship is the manager of the Geothermal Research Department at Sandia National Laboratories, a group that focuses on R&D activities related to geothemal well construction and reservoir completion and operations. He has 30 years of experience in the development, testing, and monitoring of drilled and mined openings in subterranean environments, approximately ten years with Sandia's geothermal program and the remainder in the private sector supporting mining, oil and gas and civil industries. He has been involved in a wide variety of technical and managerial efforts, including basic R&D associated with the development of high-temperature drilling tools (e.g., Diagnostics-While-Drilling), the planning, development and supervision of grassroots drilling exploration programs, in-situ stress measurements and well testing in deep boreholes, coordination and development of an underground drilling program, the design and installation of instrumentation systems for underground and surface excavations, and numerical analyses of drilled and mined excavations in geologic materials. He has a B.S. in civil engineering and a master's in geological engineering from the University of California, Berkeley.

CAROL BRUTON, PH.D.
Director of Resource Development
Simbol Materials, Inc.

Dr. Carol Bruton is a co-founder of Simbol Materials, an award-winning, early-stage company focused on the production of lithium and other commodity metals using clean, zero waste production processes from brines and effluent streams. Based on that proprietary cleantech process, the company aims to become the leading provider of lithium carbonate, a key component of batteries for electric vehicles and energy storage technology. She previously served as a geochemist with Lawrence Livermore National Laboratory where she led the

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Geothermal Program. Bruton holds an M.S. in geochemistry from the New Mexico Institute of Mining and Technology and a Ph.D. in geology from the University of California, Berkeley.

RICHARD CAMPBELL
Vice President of Engineering
CH2M Hill

Richard Campbell has an extensive background in geothermal development and in the design, procurement, construction support and start-up of geothermal power plants. He is also a director of the Geothermal Resources Council (GRC) and served as GRC's president from 1995-1996. He received the Joseph W. Aidlin Award (2000) for outstanding contribution to the development of geothermal energy. He previously managed the technical and engineering services division at The Industrial Co. (TIC) and was President of The Ben Holt Company. Campbell received his B.S. in chemical engineering from UC Davis and his master's in chemical engineering from Caltech.

THOMAS R. FAIR
Vice President, Renewable Energy
NV Energy, Inc.

Thomas R. Fair was named Vice President, Renewable Energy at NV Energy Inc. in February 2009. He is responsible for procurement and development of green power sources such as geothermal, solar and wind for both the northern and southern Nevada utilities. Fair was previously Executive, Renewable Energy, a position he obtained in February 2006 after having served as Director of Environmental Services since October 2004. Fair spent five years developing wind energy projects, initially as a project director at FPL Energy and then as a development director at Renewable Energy Systems North America, LLC. He was responsible for various stages of the development of more than 400 megawatts of wind projects now in operation. In August 2006, Fair was appointed to the Nevada Renewable Energy and Energy Conservation Task Force and to the Governor's Renewable Energy Transmission Access Advisory Committee in 2007. In addition to several other executive-level environmental affairs and planning positions, he also served as Staff Assistant to the Assistant Secretary for Water and Science at the U.S. Department of the Interior under the President's Executive Exchange Program. Fair holds a B.S. in architecture from the University of Cincinnati, a master's degree in urban planning from the University of Michigan, and an M.B.A. from the University of Miami.

JOSEPH (JOE) C. GRECO
Senior Vice President
Terra-Gen Power, LLC

Joeseph Greco is responsible for asset management and expansion of Terra-Gen's geothermal and solar portfolio as well as Terra-Gen's governmental affairs efforts. He joined the Terra-Gen team following acquisition of the Caithness Energy renewable portfolio in December 2007. While at Caithness, Greco held the position of Vice President – Western Region with

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responsibility for the geothermal and solar portfolio, as well as natural gas facility development. Prior to joining Caithness in January 2001, Greco served for six years at UAE Energy Operations Corp. (now Enpower Corp.), an independent energy producer focused on fossil and biomass power generation technologies. His responsibilities at UAE included asset management, operations and maintenance management, and he served as Vice President of Development for the West Coast. Prior to joining UAE, Greco held various management positions at Consolidated Edison of New York. He holds a B.S. in mechanical engineering from Manhattan College.

RECEP KENDIRCIOGLU
Senior Managing Director
John Hancock Financial Services

Recep Kendircioglu is senior managing director in John Hancock's Power and Project Finance Group and is responsible for origination and execution of debt and equity investments in the infrastructure and utility sectors. He currently manages $2.5 billion of the Power Team's Portfolio and has invested over $1 billion to date in various transactions. Prior to joining John Hancock, Kendircioglu worked for Enel North America (ENA) for three years where he was involved in the company's acquisition and development of renewable energy projects in the United States and Canada including those in wind, geothermal, and hydro power. Kendircioglu holds a B.S. in computer engineering from Bogazici University and an M.B.A. from Rice University.

ERNEST (ERNIE) MAJER, PH.D.
Scientist, Deputy Division Director, Earth Sciences Division
Lawrence Berkeley National Laboratory

Dr. Ernest Majer is a leading expert in the field of geophysics. He currently focuses on utilizing geophysical methods for recovery of conventional and alternative energy sources, environmental cleanup, nuclear waste disposal and CO_2 sequestration. His research encompasses all aspects of the technology including instrumentation, data acquisition, processing and interpretation. Majer's work has specifically focused on complex geologic environments such as fractured reservoirs, heterogeneous environments and multiphase/multifluid reservoirs. His recent research emphasis has been on using geophysical methods to allow improved energy efficiency for extraction of resources from tight gas sands, oil sands, through application of alternative methods such as seismic stimulation, microbial enhanced oil recovery, and high-resolution imaging of in-situ processes. Majer holds bachelor's degrees from Whitman College and Columbia University, and an M.A. and Ph.D. from the University of California, Berkeley in geophysics.

KARSTEN PRUESS, PH.D.
Senior Scientist, Lawrence Berkeley National Laboratory
Research Leader: Advanced Process Modeling

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Hydrogeology Department

Dr. Karsten Pruess is a senior scientist in the Earth Sciences Division of the Lawrence Berkeley National Laboratory which he joined in 1977. Pruess has conducted research in multiphase, non-isothermal, and chemically reactive flows in porous media, including mathematical modeling, analysis of field data, and laboratory experiments. His interests include geothermal energy recovery, nuclear waste isolation, oil and gas recovery and storage, environmental remediation, and geologic storage of carbon. He has published over 130 publications in peer-reviewed journals and is the chief developer of the TOUGH family of general-purpose simulation codes used in approximately 300 organizations in over 30 countries. He has taught classes in numerical simulation at the University of California, Berkeley. Pruess is a member of the Society of Petroleum Engineers (SPE), the Geothermal Resources Council (GRC), and a Fellow of the American Geophysical Union (AGU) and the Geological Society of America (GSA). He was recently elected to the National Academy of Engineering. A native of Germany, Pruess received a Ph.D. in theoretical physics from the University of Frankfurt, Germany in 1972.

SUBIR SANYAL, PH.D.
President and Manager of Reservoir Engineering Services,
GeothermEx, Inc. (a Schlumberger Company)

Dr. Subir Sanyal has been a leader in the geothermal industry for decades, with knowledge and expertise in the areas of geothermal project financing, management, economic analysis, property appraisal, reservoir engineering, numerical simulation, training and software development. For the past three decades, Sanyal has managed major geothermal projects in the United States, the Philippines, Japan, Costa Rica, Indonesia, Mexico, Nicaragua, Guatemala and Italy. He has conducted technology transfer and evaluated geothermal fields in more than two dozen countries. In addition, he has assisted clients in sales negotiations, property appraisals, market studies and economic analysis. He has authored more than 100 technical publications. Sanyal earned his M.S. degree in applied geology at the Indian Institute of Technology. He later received a post-graduate diploma (equivalent to M.S.) in petroleum engineering at Birmingham University (England) and a Ph.D. in petroleum engineering at Stanford University.

WILLIAM (BILL) TEPLOW
Vice President of Exploration
U.S. Geothermal, Inc.

William Teplow has more than 30 years of successful geothermal exploration experience covering the western United States, Hawaii and Central America. His expertise includes the design, costing, and execution of integrated geophysical exploration programs, production and injection well targeting, wellsite geologic management and 3-D geologic modeling of geothermal reservoirs. He has a bachelor's degree from the University of California and is a California Registered Geologist.

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PAUL THOMSEN
Director, Policy & Business Development
Ormat Technologies, Inc.

Paul Thomsen manages Ormat's federal, state and local legislative programs as well as its geothermal project development activities in the United States. He serves as Ormat's principal liaison with organizations and advocacy groups involved in renewable energy sector. In addition to his positions at Ormat, Thomsen is the President to the Board of Directors of the Geothermal Energy Association, he serves as past-chairman of the United States Clean Heat and Power Association, and he sits on Senator Harry Reid's Blue Ribbon Council on Renewable Energy. Thomsen also currently serves as the president of the Nevada Geothermal Council and is on the boards of the Economic Development Authority of Nevada, the Nevada Mining Association and the Nevada Conservation League. He was appointed by former Nevada Governor Jim Gibbons to the Transition Team for Energy and Natural Resources. Prior to joining Ormat, Thomsen worked for U.S. Senator Richard Bryan, and U.S. Senator Harry Reid, where he handled public lands and energy issues. Thomsen received a bachelor's degree in political science and a master's degree in public administration from the University of Nevada, Reno.

HERBERT (HERB) F. WANG, PH.D.
Professor Rock Physics and Geodynamics
University of Wisconsin - Madison

A professor and member of the faculty at University of Wisconsin-Madison since 1972, Dr. Hebert Wang's projects include examining the effects of fracture deformability on reservoir production and to examine the effects of poroelastic response in a fractured, dual porosity reservoir. Previous research was sponsored by the Geosciences Program in the Office of Basic Energy Sciences at the U.S. Department of Energy. In addition, Wang is interested in quantifying geodynamical processes that result from various interactions. He has developed numerical models to interpret thermal histories based on diffusion profiles in minerals and his research has shown that the double porosity model for fracture flow can be used in problems of cation and oxygen isotope diffusion. Wang has served as spokesperson for the GEOXTM collaboration for monitoring rock deformation using fiber-optic and tilt meter sensors in the Deep Underground Science and Engineering Laboratory (DUSEL) in Lead, South Dakota sponsored by the National Science Foundation. Wang holds a bachelor's degree from the University of Wisconsin-Madison, a master's from Harvard and a Ph.D. in geophysics from MIT.

NORMAN (NORM) WARPINSKI, PH.D.
Director of Technology
Pinnacle Technologies

Dr. Norman Warpinski is the Director of Technology for Pinnacle – A Halliburton Service in Houston, Texas, where he is in charge of developing new tools and analyses for hydraulic fracture mapping, reservoir monitoring, hydraulic fracture design and analysis, and integrated

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solutions for reservoir development. He joined Pinnacle in 2005 after previously working at Sandia National Laboratories from 1977 to 2005 on various projects in oil and gas, geothermal, carbon sequestration, waste repositories, and other geomechanics issues. Warpinski has extensive experience in various types of hydraulic fracture mapping and modeling and has been involved in large-scale field experiments on both the hardware and software sides. He has also worked on formation evaluation, geomechanics, natural fractures, in situ stresses, rock behavior and rock testing. Warpinski received his M.S. and Ph.D. in mechanical engineering from the University of Illinois, Champaign/Urbana and holds a BS in mechanical engineering from Illinois Institute of Technology.

KENNETH (KEN) WILLIAMSON, PH.D.
Independent Consultant and International Expert

A renowned expert in geothermal systems, Dr. Kenneth Williamson has more than 25 years of experience exploring and developing geothermal resources with Unocal Corporation, a U.S. company that developed a quarter of the world's geothermal capacity. Within Unocal, Williamson established a multi-disciplinary geothermal center of excellence and successfully restructured the group through challenging business cycles. He currently is a geothermal consultant, and has worked with Chevron Corporation. His work includes significant experience in the United Kingdom, the United States, Southeast Asia, Central and South America, the Caribbean, Africa and Europe. Williamson testified before Congress in 2007 on a bill to establish a National Geothermal Initiative. He also worked in geothermal research and exploration for five years with the British Geological Survey. Williamson recently chaired the Enhanced Geothermal Systems IV working group at the 36th Stanford Workshop on Geothermal Reservoir Engineering. Williamson holds a Ph.D. from Imperial College, London where his doctoral thesis involved a study of heat flow from the earth in East Africa.

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