National Renewable Energy Laboratory

A national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy

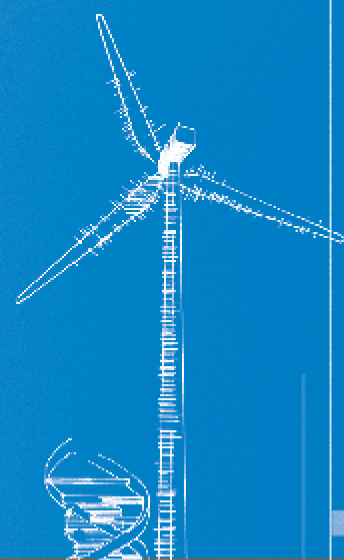
Innovation for Our Energy Future

Geothermal— The Energy Under Our Feet

Geothermal Resource Estimates for the United States

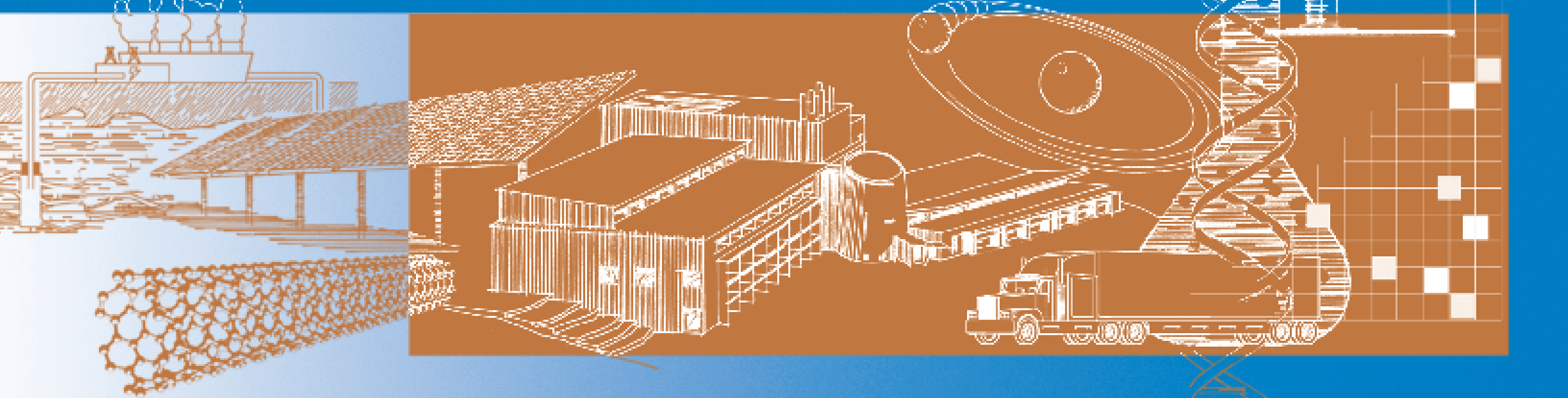
Bruce D. Green and R. Gerald Nix,
National Renewable Energy Laboratory

Technical Report
NREL/TP-840-40665
November 2006



NREL is operated by Midwest Research Institute • Battelle

Contract No. DE-AC36-99-GO10337

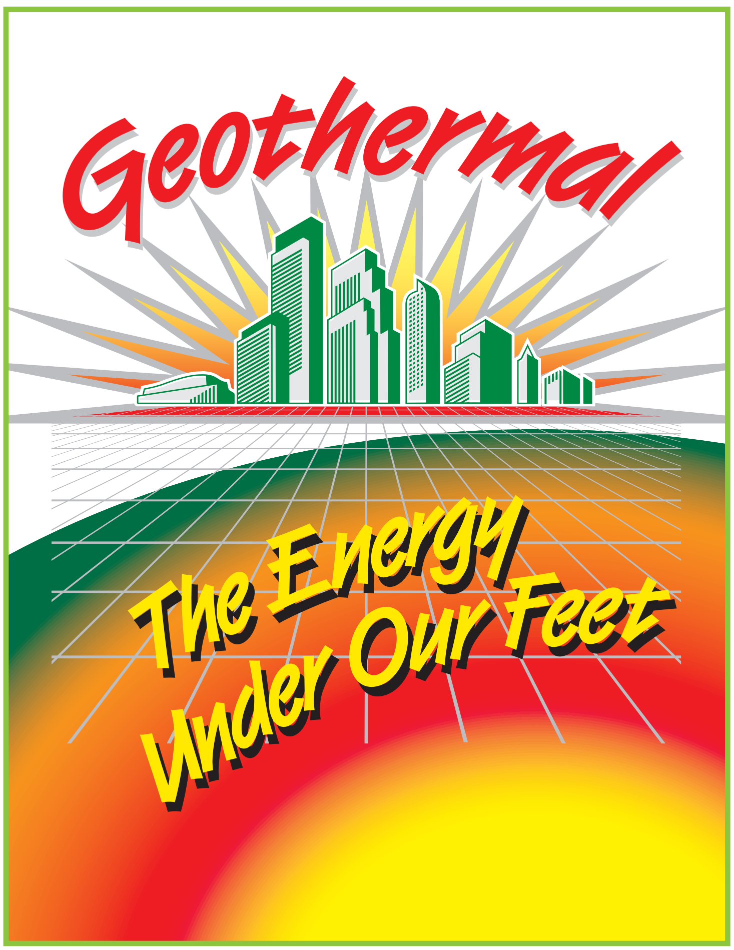


Geothermal—
The Energy Under Our Feet

Geothermal Resource Estimates for the United States

Technical Report
NREL/TP-840-40665
November 2006

Bruce D. Green and R. Gerald Nix,
National Renewable Energy Laboratory



National Renewable Energy Laboratory
1617 Cole Boulevard, Golden, Colorado 80401-3393
303-275-3000 • www.nrel.gov

Operated for the U.S. Department of Energy
Office of Energy Efficiency and Renewable Energy
by Midwest Research Institute • Battelle

Contract No. DE-AC36-99-GO10337

Executive Summary

The Earth houses a vast energy supply in the form of geothermal resources. Domestic resources are **equivalent to a 30,000-year energy supply at our current rate for the United States!** In fact, geothermal energy is used in all 50 U.S. states today. But geothermal energy has not reached its full potential as a clean, secure energy alternative because of issues with resources, technology, historically low natural gas prices, and public policies. These issues affect the economic competitiveness of geothermal energy

On May 16, 2006, the National Renewable Energy Laboratory (NREL) in Golden, Colorado hosted a geothermal resources workshop with experts from the geothermal community. The purpose of the workshop was to re-examine domestic geothermal resource estimates. The participating experts were organized into five working groups based on their primary area of expertise in the following types of geothermal resource or application: (1) Hydrothermal, (2) Deep Geothermal Systems, (3) Direct Use, (4) Geothermal Heat Pumps (GHPs), and (5) Co-Produced and Geopressured.

Geothermal resources are categorized in several layers of accessibility and feasibility, from broadest criteria (i.e., total physically available), to criteria that includes technical and economic considerations. The total resource base is scaled downward to accessible resource, and finally to a category called developable resource (see p. 4 for explanation).

The table below shows estimates for the different geothermal resource categories, as compiled by the workshop experts. **These estimates show the enormous potential of the U. S. geothermal energy resource.** New low-temperature electric generation technology may greatly expand the geothermal resources that can be developed economically today.

Findings by Resource Category

			Estimated Developable Resource*		
	Estimated Accessible Resource (MWe)	2006 (Actual MWe)	2015 (MWe)	2025 (MWe)	2050 (MWe)
Shallow Hydrothermal[1] (Identified) >90˚C/194˚F	30,000	2,800	10,000	20,000	30,000
Shallow Hydrothermal[1] (Unidentified) >150˚C/302˚F	120,000		TBD	TBD	TBD
Co-Produced & Geopressured[2]	>100,000	2[3]	10,000 to 15,000	70,000	>100,000
Deep Geothermal[4]	1,300,000 to 13,000,000	0	1000	10,000	130,000
Thermal Uses	(MWt)	(MWt)	(MWt)	(MWt)	
Direct Uses[5]	>60,000	620	1600	4,200	45,000
Geothermal Heat Pumps[6]	>1,000,000	7,385	18,400	66,400	>1,000,000
GHP[6] Avoided Power	120,000	880	2,100	8,000	120,000

** Please note that these resource estimates represent a consensus of a group of experts who considered existing resource assessments (referenced on next page). There is considerable uncertainty in the estimates as many resources are hidden and exploration to date has been relatively limited. The figures shown above are not a resource assessment, but, even with uncertainty,* ***clearly show that the U.S. geothermal resource is a very large and important domestic energy source.***

References

1. *Assessment of Geothermal Resources of the United States – 1978*, USGS Circular 790 (p. 41 and 157). Includes identified and unidentified resources; 2015 and later estimates are a consensus of the experts at the workshop. Estimated accessible figure includes identified (~30,000 MW) and unidentified (~120,000 MW) (i.e., hidden or showing no surface manifestations) hydrothermal resources.
2. "Geothermal Electric Power Supply Possible from Gulf Coast, Midcontinent Oil Field Waters," *Oil and Gas Journal,* September 5, 2005, and SMU Geothermal Laboratory *Geothermal Energy Generation in Oil and Gas Settings Conference* findings, March 13 – 14, 2006, and USGS Circular 790.
3. Based on Mafi Trench Unit on offshore platform now in operation.
4. *Energy Recovery from Enhanced/Engineered Geothermal Systems* (EGS), Massachusetts Institute of Technology (MIT), September 2006.
5. OIT Geo-Heat Center, using analysis based on USGS Circulars 790 and 892.
6. Geothermal Heat Pump Consortium, based on Energy Information Administration data and projections. The 'avoided power' figure represents the peak power not required or offset through use of GHPs. Thus, GHPs act as a proven demand and growth management option for utilities.

Bruce Green, NREL, PIX 14846

Dr. Roy Mink, DOE Geothermal Technologies Program manager, making opening comments.


Bruce Green, NREL PIX 14843

The geothermal heat pump working-group during their resource deliberations. John Geyer (l), Wael El-Sharif (c), and Jack DiEnna (r) made up this working group.

Introduction

The United States possesses vast underground stores of heat whose full potential has yet to be realized. The Earth's interior reaches temperatures greater than 4,000°C (>7,200°F), and this geothermal energy flows continuously to the surface. The energy content of domestic geothermal resources to a depth of 3 km (~2 mile) is estimated to be 3 million quads, **equivalent to a 30,000-year supply of energy at our current rate for the United States!** While the entire resource base cannot be recovered, the recovery of even a very small percentage of this heat would make a large difference to the nation's energy supplies. New low-temperature electric generation technology may greatly expand the geothermal resources that can be developed economically today.

Geothermal resources could meet a substantial portion of the nation's energy needs in the 21st century. In fact, when including geothermal heat pumps (GHPs), geothermal energy is used in all 50 U.S. states today. The U.S. Department of Energy's (DOE) Geothermal Technologies Program seeks to make geothermal energy the nation's environmentally preferred baseload energy alternative. The Program's mission is to work in partnership with U.S. industry to establish geothermal energy as an economically competitive contributor to the nation's energy supply.

The purpose of the workshop was to re-examine domestic geothermal resource estimates. There were two guiding questions: what is the total potential accessible resource in the United States, and, given favorable circumstances and using existing practices with improved technology, and with institutional issues solved, how much of the resource is developable by 2015, 2025, and 2050? Resource types include hydrothermal, deep geothermal systems, co-produced, geopressured, direct use, and GHPs.

The goal of the workshop was to *gather and summarize* expert opinions about the potential of various geothermal resources for generation of electricity and utilization of heat energy. The workshop was not a formal assessment, but a recorded discussion by a group of experts who collectively state their opinions based on their experiences, knowledge, and interpretations of various detailed assessments (e.g., USGS Circular 790).

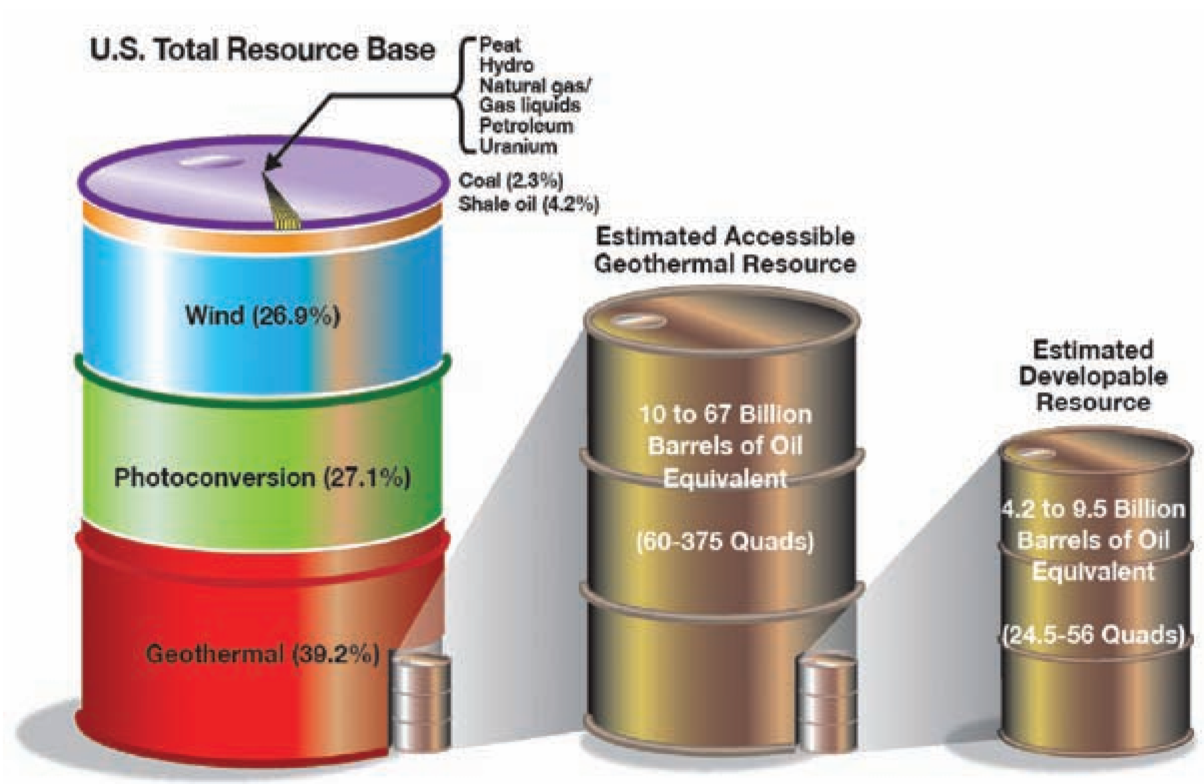


Figure 1. U.S. Energy and Geothermal Resources

Note: U.S. Total Resource Base from Characterization of U.S. Energy Resources and Reserves, December 1989, U.S. Department of Energy, DOE/CE-0279. Data for "Estimated Accessible Geothermal Resource" and "Estimated Developable Resource" are from Table 4 of this report.

Resource Definitions

The *total resource base* in the United States, both renewable and non-renewable, is very large, with an energy content of over 657,000 billion barrels of oil equivalent (BBOE), or nearly 50,000 times the annual current rate of national energy consumption. Figure 1 shows graphically what the *total resource base* looks like, and in descending order, the values for the estimated accessible geothermal resource and estimated developable resource.

Energy resources are traditionally classified according to the degree of certainty and the economic feasibility of exploiting the particular resource. The U.S. Geological Survey (USGS) and the U.S. Department of Energy (DOE) have used such identifying terms for resource classification. Following are simple definitions of these classification terms:

U.S. Total Resource Base – Resource base is all of a given material in the Earth's crust, whether its existence is known or unknown and regardless of cost considerations[a].

Estimated Accessible Geothermal Resource– The accessible resource base for geothermal energy is that part of the resource base shallow enough to be reached by production drilling in the foreseeable future[a].

Estimated Developable Resource – This category is the subset of the accessible resource base that the workshop experts believe likely to be developed in future years.

[a]**Source:** Assessment of Geothermal Resources of the United States – 1978, USGS Circular 790 (p. 4).

NREL, PIX03698

Geothermal resources are available throughout the entire U.S.

Description of Geothermal Resource Categories

Hydrothermal

A hydrothermal system is defined as a subterranean geothermal reservoir that transfers heat energy upward by vertical circulation of fluids driven by differences in fluid density that correspond to differences in temperature (see Figure 2). Hydrothermal systems can be classified into two types—vapor-dominated and hot water—depending on whether the fluid is steam or liquid water, respectively.

Most high-temperature geothermal resources occur where magma (molten rock) has penetrated the upper crust of the Earth. The magma heats the surrounding rock, and when the rock is permeable enough to allow the circulation of water, the resulting hot water or steam is referred to as a hydrothermal resource. Such resources are used today for the commercial production of geothermal power. They benefit from continuous recharge of energy as heat flows into the reservoir from greater depths.

Deep Geothermal Systems

Deep geothermal systems (a.k.a. enhanced geothermal systems or EGS) are defined as engineered reservoirs that have been created to extract heat from economically unproductive geothermal resources. The deep geothermal/EGS concept is to extract heat by creating a subsurface fracture system to which water can be added through injection wells. The water is heated by contact with the rock and returns to the surface through production wells, just as in naturally occurring hydrothermal systems.

Hydrofracturing and stimulation techniques are used widely in the oil and gas industry to extend production, and can be used to greatly extend and expand use of geothermal resources. Figure 3 gives a graphic idea of the domestic scope of geothermal resources at just 6 kilometers (3.7 miles), a nominal drilling depth in the oil and gas industry.

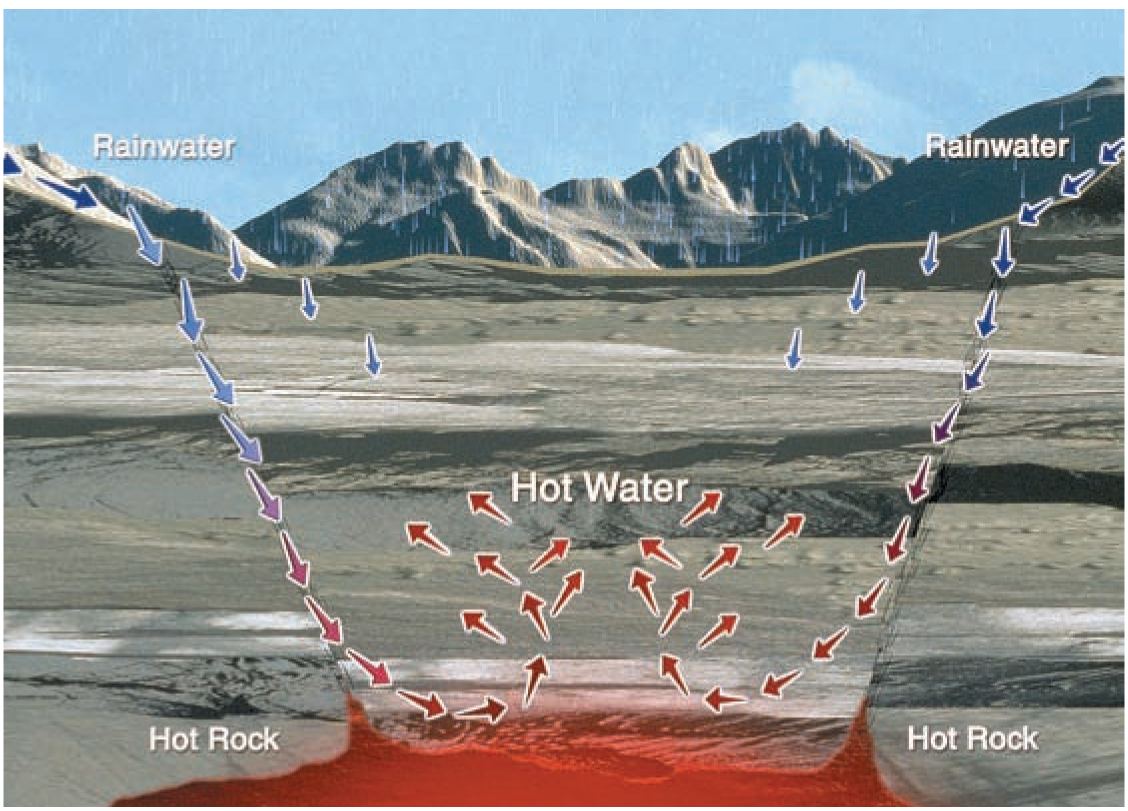


Figure 2. Illustration of a hydrothermal reservoir, showing the natural recharge, fractures, and heat source.
Courtesy: Geothermal Education Office

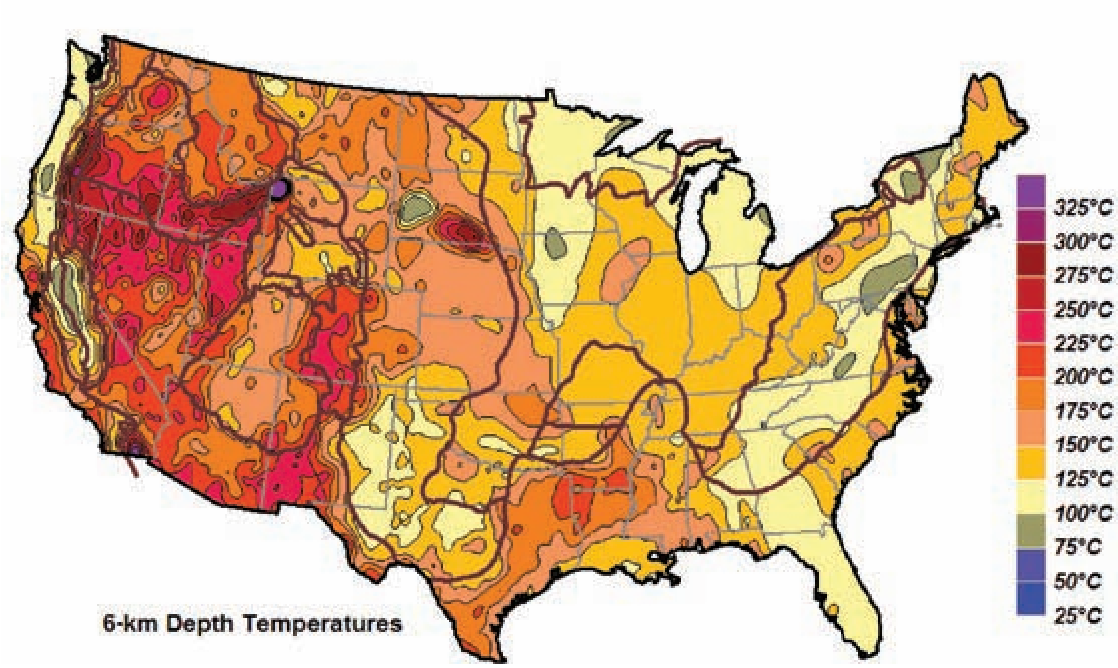


Figure 3. Estimated Earth temperature at 6-km (3.7-mile) depth. Courtesy: Southern Methodist University Geothermal Laboratory.

Direct Use

Hot water from geothermal resources is used directly to provide heat for buildings, crop and lumber drying, industrial process heat needs, aquaculture, horticulture, ice melting on sidewalks, roads, and bridges, and district heating systems. In direct use applications, a well (or series of wells) brings hot water to the surface; a mechanical system— piping, heat exchanger, pumps, and controls—delivers the heat to the space or process.

Often, direct use applications use geothermal fluids not hot enough for electricity generation. To improve efficiencies, used water from geothermal power plants can be 'cascaded' down for lower temperature uses, such as in greenhouses or aquaculture. Flowers, vegatables, and various fish species and alligators are examples of products from greenhouse and aquaculture systems.

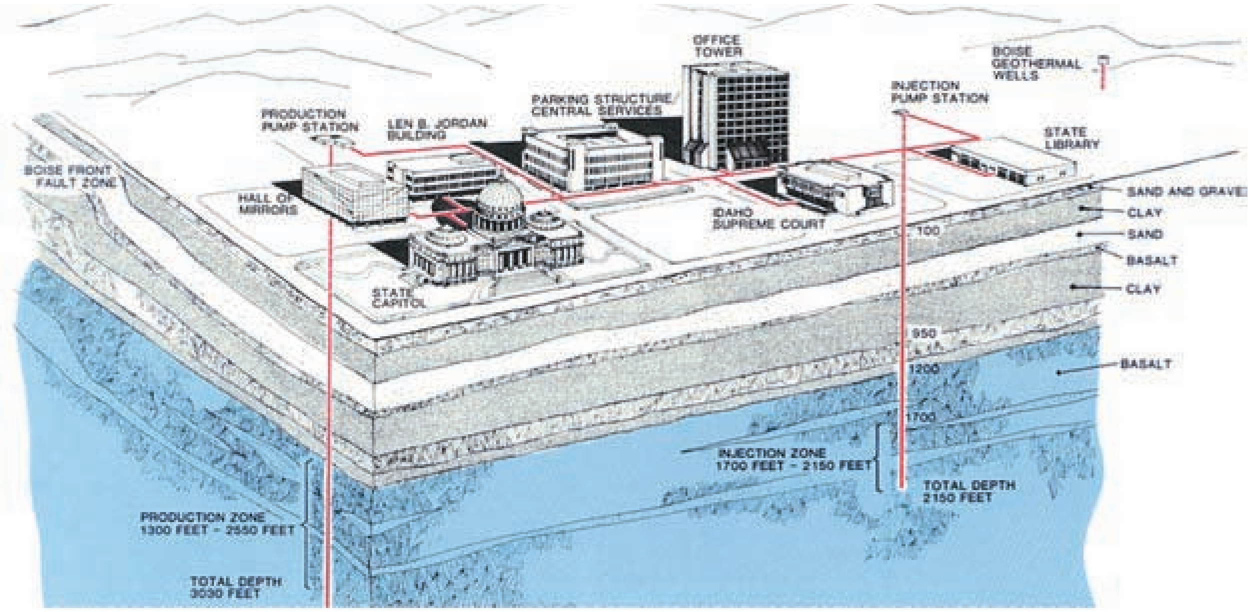


Figure 4. An illustration of the State Capitol geothermal district-heating system, Boise, Idaho.

Geothermal Heat Pumps

Geothermal heat pumps (GHPs) use the Earth's huge energy storage capability to heat and cool buildings, and to provide hot water. GHPs use conventional vapor compression (refrigerant-based) heat pumps to extract the low-grade heat from the Earth for space heating. In summer, the process reverses and the Earth becomes a heat sink while providing space cooling (see Figure 5). GHPs are used in all 50 U.S. states today, with great potential for near-term market growth and savings.

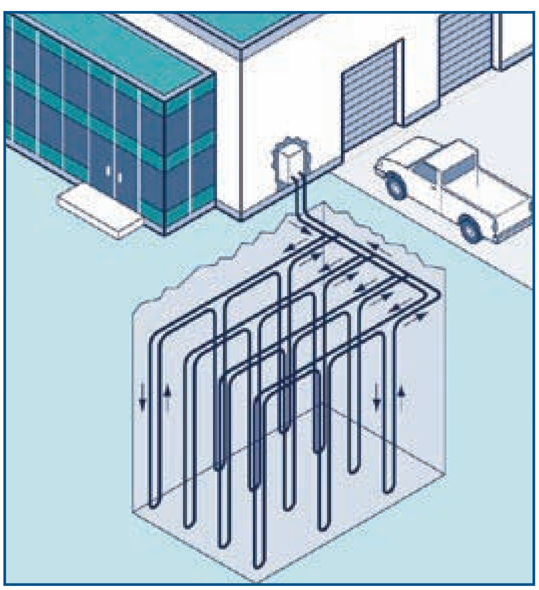


Figure 5 - Geothermal heat pump (GHP) illustration for a commercial application.

Geopressured Resources

The geopressured resource consists of deeply buried reservoirs of hot brine, under abnormally high pressure, that contain dissolved methane. Geopressured brine reservoirs with pressures approaching lithostatic load are known to occur both onshore and offshore beneath the Gulf of Mexico coast, along the Pacific west coast, in Appalachia, and in deep sedimentary basins elsewhere in the United States.

The resource contains three forms of energy: methane, heat, and hydraulic pressure. In the past, DOE conducted research on geopressured reservoirs in the northern Gulf of Mexico sedimentary basin, and operated a 1-megawatt (MW) power plant using the heat and methane from the resource (i.e., Pleasant Bayou, TX, 1989 – 1990).

Co-Produced Geothermal Fluids

Sometimes referred to as the 'produced water cut' or 'produced water' from oil and gas wells, co-produced geothermal fluids are hot and are often found in waterflood fields in a number of U.S oil and gas production regions (See Table 1). This water is typically considered a nuisance to the oil and gas industry (and industry is accountable for proper disposal), but could be used to produce electricity for internal use or sale to the grid.

Like geopressured resources, co-produced geothermal resources can deliver near-term energy savings, diminish greenhouse gas emissions, and extend the economical use of an oil or gas field. New low-temperature electric generation technology may greatly expand the geothermal resources that can be developed economically today.

Table 1. Co-Produced Geothermal Fluids

Estimated equivalent geothermal power from processed water associated with existing hydrocarbon production, using 140°C (285°F) as a nominal fluid temperature.

State	Total Processed Water, 2004 (bbl)	Power, MW @ 140˚C (285)˚F)
Alabama	203,223,404	47
Arkansas	258,095,372	59
California	5,080,065,058	1169
Florida	160,412,148	37
Louisiana	2,136,572,640	492
Mississippi	592,517,602	136
Oklahoma	12,423,264,300	2860
Texas	12,097,990,120	2785
Total	**32,952,140,644 bbl**	**7,585 MW**

Courtesy: Dr. David Blackwell, Southern Methodist University

Process Used

The participating experts were organized into five working groups based on their primary area of expertise in the following types of geothermal resource or application: (1) Hydrothermal, (2) Deep Geothermal Systems, (3) Direct Use, (4) Geothermal Heat Pumps, and (5) Co-Produced and Geopressured. Because of similarities (e.g., oil and gas industry involvement), the co-produced and geopressured resource working groups were combined.

Through opening comments and guidance, Dr. Roy Mink of DOE and Dr. Gerry Nix of NREL introduced the participants to the task, purpose, goals, and approach of the workshop. The facilitator provided each working group with a set of guiding questions to help obtain results consistent with stated purpose, goals, and approach to this workshop. These included: what is the total potential accessible resource in the U.S., and, given favorable circumstances and using existing practices with improved technology, and with institutional issues solved, how much of the resource is developable by 2015, 2025, and 2050?

The working groups answered the guiding questions and formulated their responses, then presented their findings to the other participants. During the final stage of the workshop, the participants discussed data integration and related issues. See Table 2 for the findings of the working groups.

The Gulf Coast region of the U.S. is rich in geopressured and co-produced energy resources.

Bruce Green, NREL, PIX 14845

Workshop participants during data integration discussions – Dr. John Lund makes a point.

Table 2. Findings by Resource Category

			Estimated Developable Resource*		
	Estimated Accessible Resource (MWe)	2006 (Actual MWe)	2015 (MWe)	2025 (MWe)	2050 (MWe)
Shallow Hydrothermal[1] (Identified) >90°C/194°F	30,000	2,800	10,000	20,000	30,000
Shallow Hydrothermal[1] (Unidentified) >150°C/302°F	120,000		TBD	TBD	TBD
Co-Produced & Geopress[2]	>100,000	2[3]	10,000 to 15,000	70,000	>100,000
Deep Geothermal[4]	1,300,000 to 13,000,000	0	1000	10,000	130,000
Thermal Uses	(MWt)	(MWt)	(MWt)	(MWt)	
Direct Uses[5]	>60,000	620	1600	4,200	45,000
Geothermal Heat Pumps[6]	>1,000,000	7,385	18,400	66,400	>1,000,000
GHP[6] Avoided Power	120,000	880	2,100	8,000	120,000

* Please note that these resource estimates represent a consensus of a group of experts who considered existing resource assessments (referenced below). There is considerable uncertainty in the estimates as many resources are hidden and exploration to date has been relatively limited. The figures shown above are **not** a resource assessment, but, even with uncertainty, ***clearly show that the U.S. geothermal resource is a very large and important domestic energy source.***

Table 3. Co-Produced and Geopressured Resources (Estimated Developable Resources)[2]

	2015	2025	2050
Co-Produced	5,000 MWe	10,000 to 20,000 MWe	30,000 to 40,000 MWe
Geopressured	5,000 to 10,000 MWe	50,000 to 60,000 MWe	70,000 to 80,000 MWe

Bruce Green, NREL, PIX 14847

Chena Hot Springs Resort (Alaska) geothermal power plant dedication in August 2006. New technology such as that being used at Chena could greatly extend the feasibility of using geothermal resources.

Table 4. Energy Equivalents by Resource Category (see appendices for calculation method)

Resource Category	Estimated Accessible Resource	Estimated Developable Resource – 2050
Shallow Hydrothermal[1] (Identified) >90˚C/194˚F	0.81 Quads 135 million BOE	0.81 Quads 135 million BOE
Shallow Hydrothermal[1] (Unidentified) >150˚C/302˚F	3.2 Quads 540 million BOE	–
Co-Produced & Geopressured[2]	2.7 Quads 450 million BOE	2.7 Quads 450 million BOE
Deep Geothermal[4]	35.1 to 351 Quads 5.8 to 58.5 BBOE	3.5 tp 35 Quads 0.58 to 5.8 BBOE
Direct Use[5]	0.88 Quads 150 million BOE	15 Quads 112.5 million BOE
Geothermal Heat Pumps (GHP)[6]	15 Quads 2.5 billion BOE	15 Quads 2.5 BBOE
GHP[6] Avoided Power	1.8 Quads 300 million BOE	1.8 Quads 300 million BOE

References

1. USGS Circular 790 (p. 157), includes identified and unidentified resources; 2015 and later estimates are a consensus of the experts at the workshop. Estimated accessible figure includes identified (~30,000 MW) and unidentified (~120,000 MW) (i.e., hidden or showing no surface manifestations) hydrothermal resources.
2. USGS Circular 790, *Geothermal Electric Power Supply Possible from Gulf Coast, Midcontinent Oil Field Waters,* “Oil and Gas Journal,” September 5, 2005, and SMU Geothermal Laboratory *Geothermal Energy Generation in Oil and Gas Settings Conference* findings, March 13 – 14, 2006.
3. Based on Mafi Trench Unit on offshore platform now in operation.
4. *Energy Recovery from Enhanced/Engineered Geothermal Systems* (EGS), Massachusetts Institute of Technology (MIT), September 2006.
5. OIT Geo-Heat Center, using analysis based on USGS Circulars 790 and 892.
6. Geothermal Heat Pump Consortium, based on Energy Information Administration data and projections. The ‘avoided power’ figure represents the peak power not required or offset through use of GHPs. Thus, GHPs act as a proven demand and growth management option for utilities.

Energy Comparison Information

U.S annual energy consumption equals about 100 quads (EIA, 2004).

U.S annual electricity production equals about 40 quads (EIA, 2004).

U.S. petroleum demand equals about 21 million bbl/day, 7.67 billion bbl/yr (EIA, 2004).

World petroleum demand equals about 84 million bbl/day, 30 billion bbl/yr (EIA, 2004).

Energy Equivalents

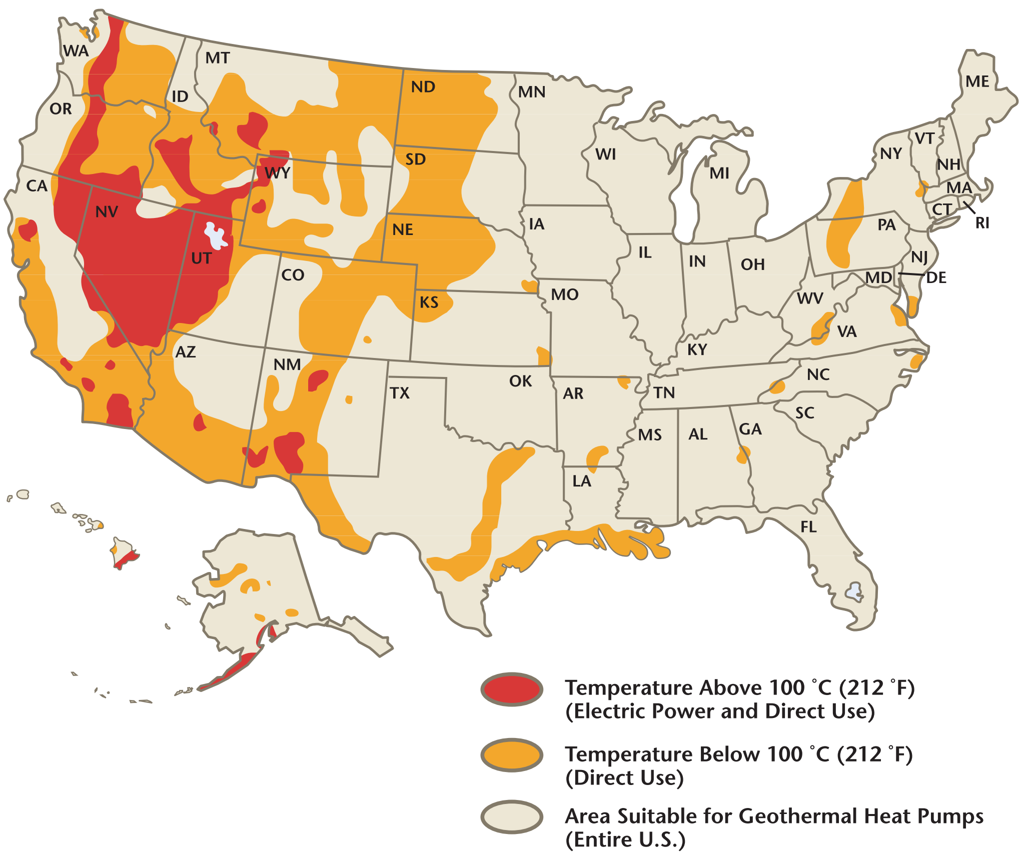
1 Quad = 0.170 billion barrels of oil, 170 million barrels of oil
1 Quad = 45 million short tons of coal
1 Quad = 1 trillion cubic feet of dry natural gas

1000 KWh = 0.59 barrels of crude oil
1000 KWh = 0.15 short tons (300 pounds) of coal
1000 KWh = 3,300 cubic feet of dry natural gas

1 barrel of crude oil = 1,700 kWh
1 barrel of crude oil = 5,600 cubic feet of dry natural gas
1 barrel of crude oil = 0.26 short tons (520 pounds) of coal

Appendices

- Present Development
- Benefits
- Strategic Value
- Profile of a Geothermal Project
- List of Workshop Participants and Staff
- How Energy Equivalent Calculations Were Made
- References and Supporting Documents



The Nation's geothermal resources represent a huge and viable energy resource, providing the U.S. with various ways to use them and enhance national security, and economic and environmental health.

Today's U.S. geothermal industry is a $2-billion-per-year enterprise involving over 2800 MW of electricity generation capacity, about 620 MW of thermal energy capacity in direct-use applications such as indoor heating, greenhouses, food drying, and aquaculture, and over 7,300 MW of thermal energy capacity from geothermal heat pumps. The international market for geothermal power development could exceed a total of $25 billion for the next 10 to 15 years. At the present time, U.S. technology and industry stand at the forefront of this international market.

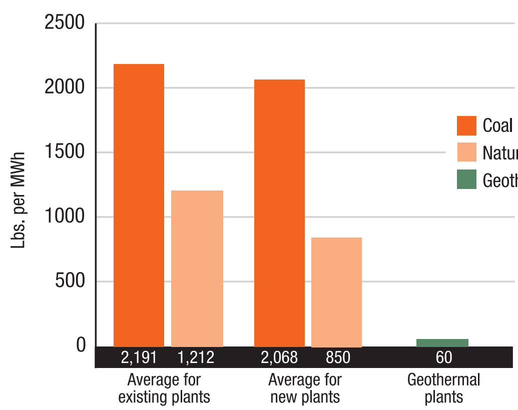
Benefits

Geothermal energy benefits the nation by helping to solve three problems— energy reliability and security, economic development, and air quality. Geothermal resources can help address the shortage of new electricity generating capacity in the United States cited in the National Energy Policy Act of 2005. As a baseload generation source, geothermal energy is well proven and reliable.

Geothermal power plants emit little carbon dioxide, very low quantities of sulfur dioxide, and no nitrogen oxides. U.S. geothermal generation annually offsets the emission of 22 million metric tons of carbon dioxide, 200,000 tons of nitrogen oxides, and 110,000 tons of particulate matter from conventional coal-fired plants. See Charts 1, 2, and 3 for details on comparative emissions.

Chart 1. Carbon Dioxide (CO_2) for U.S. Power Plants

(Pounds per Megawatt-hour)



Existing - For all existing U.S. coal power plants; natural gas averages include steam cycle, simple gas turbine and combined cycle.

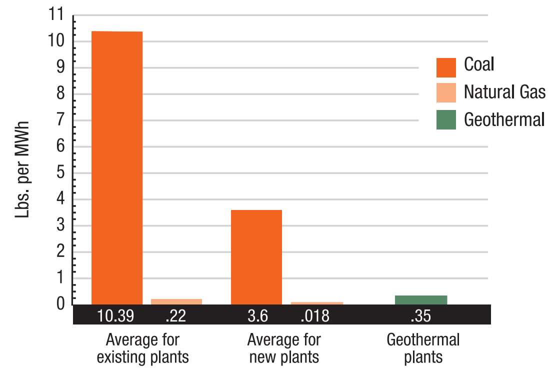
New - Coal plants built in 1990s; natural gas combined cycle plants built in 2002.

Geothermal - 60 lbs./MWh for flash plants; 0 lbs./MWh for binary plants.

CO_2 is not classified as a pollutant by the U.S. Environmental Protection Agency.

Chart 2. Sulfur Dioxide (SO_2) for U.S. Power Plants

(Pounds per Megawatt-hour)



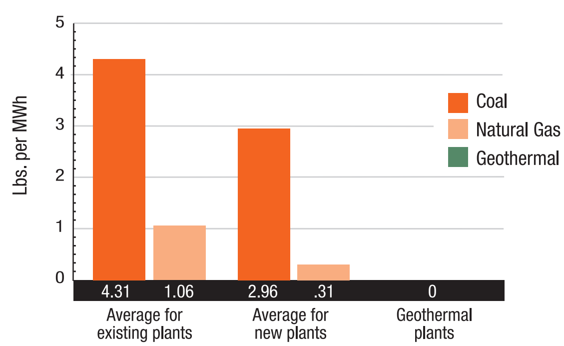
Existing - For all existing U.S. coal power plants; natural gas averages include steam cycle, simple gas turbine and combined cycle.

New - Coal plants built in 1990s; natural gas combined cycle plants built in 2002.

Geothermal - .35 lbs./MWh for flash plants, 0 lbs./MWh for binary plants. SO_2 from geothermal plants is from hydrogen sulfide contained in geothermal fluids. Modern systems return 90 percent of the hydrogen sulfide to the reservoir.

Chart 3. Nitrogen Oxide (NO_X) for U.S. Power Plants

(Pounds per Megawatt-hour)



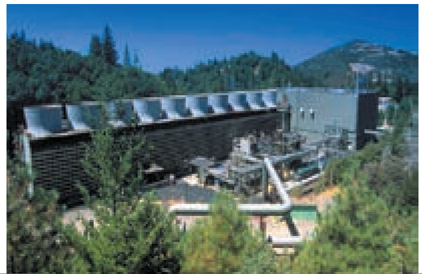
Existing - For all existing U.S. coal power plants; natural gas averages include steam cycle, simple gas turbine and combined cycle.

New - Coal plants built in 1990s; natural gas combined cycle plants built in 2002.

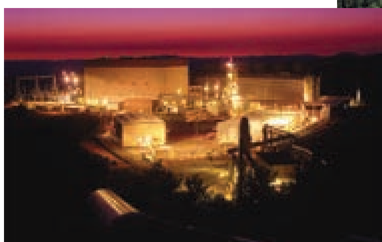
Source: Coal and natural gas emissions information from Platts Research and Consulting, based on data from the Environmental Protection Agency's Continuous Emissions Monitoring Systems, 2003; geothermal information from U.S. Department of Energy, 2000

Strategic Value

Use of domestic geothermal energy resources has substantial strategic value for the nation. Geothermal resources can contribute to:



◀ Clean electricity generation



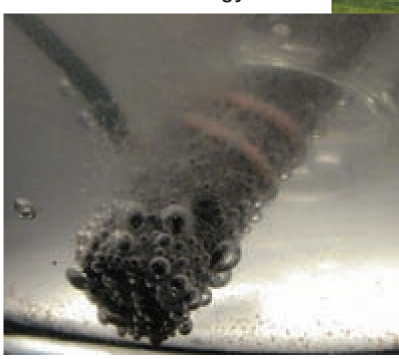
◀ Baseload power production, having established high capacity factors

▶ Coproduction and enhanced oil recovery, thus gaining more oil

◀ Distributed energy systems with modular and shorter development timeframe advantages

▶ Direct-use for building energy needs

▼ Ethanol and biodiesel production – thermal energy requirements



▲ Hydrogen production – via off-peak electrolysis

▲ Mineral recovery, such as silica and zinc – both strategic minerals in short supply.

▲ Rural economic development – aquaculture and horticulture, and lumber drying

◀ Climate change mitigation – by offsetting needs for fossil-fueled power plants

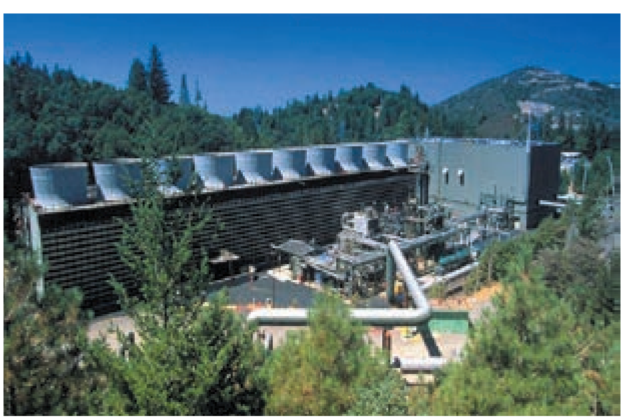
Profile of a Geothermal Project

Geothermal power and direct use development begins with exploration to locate an economic reservoir, using a variety of techniques. Wells are drilled to measure subsurface temperatures and flow rates and to produce and inject the hydrothermal fluid. Once the reservoir has been proven, the site is developed either for power generation or a direct use application.

Geothermal projects are capital-intensive, and the major expenses are incurred before the project produces revenue. Exploration represents only about 10% of the total cost of a successful project, but many projects can fail at this stage. A high degree of risk evolves from the need for success on the first wells drilled into the reservoir. The extent to which these wells produce hot fluids influence subsequent investment decisions. Although the most expensive element of a power generation project is surface plant construction, drilling to create a well field involves higher risk due to uncertainties in reservoir characteristics. Direct use applications are usually less costly than power generation, because the resource is shallower, the fluids are less difficult to manage, and the technology less complex.

Typically, geothermal power plants are baseload facilities, but they may be operated in a load-following mode. Power conversion options include (1) the transformation (flashing) of hot geothermal fluids to steam which drives a turbine or (2) transfer of heat from the geothermal fluids to a secondary (binary) working fluid which drives a turbine. Geothermal plants have very high availabilities and capacity factors, exceeding 90%. Liquids produced from the reservoir are reinjected to sustain production pressures.

Courtesy: GRC



Clean, baseload, distributed electricity is being produced from geothermal resources today. Big Geysers, a 75-MW geothermal power plant located in northern California, is shown above.

Bruce Green, NREL/PIX13079

Horticulture represents a rapidly growing domestic industry that lends itself well to rural economic development.

Courtesy: Geothermal Heat Pump Consortium

Residential application of a geothermal heat pump.

Geothermal heat pump (GHP) systems use highly durable heat exchangers that are placed into the ground, a water source, or a well, and deliver heating and cooling very efficiently, as well as providing hot water. Commercial and institutional GHP installations are often cost-competitive today, achieving substantial energy savings for building owners and tenants. Once connected to the ground (or water), the GHP system is typically integrated with traditional HVAC equipment. Only accredited designers and installers (see: www.igshpa.okstate.edu) should be used for GHP installations. There are federal tax benefits for use of GHPs, and some states also offer incentives (see: www.geoexchange.org).

List of Workshop Participants and Staff

Hydrothermal
Jim Lovekin, GeothermEx, Inc., CA
Al Waibel, Columbia Geoscience, OR
Matthew Sares, Colorado Geologic Survey, CO

EGS
Susan Petty, Black Mountain Technology, WA

Direct Use
John Lund, Oregon Institute of Technology, Geo-Heat Center, OR

Co-Produced (combined w/Geo-Press.)
David Blackwell, Southern Methodist University, Geothermal Laboratory, TX

Richard Erdlac, University of Texas Permian Basin, TX
Mark Milliken, Rocky Mountain Oil Testing Center, WY

Geopressured
Chip Groat, University of Texas – Austin, TX

Geothermal Heat Pumps
Wael El-Sharif, Geothermal Heat Pump Consortium, D.C.
Jack DiEnna, Geothermal Heat Pump Consortium, PA
John Geyer, JG&A, Inc., WA

DOE, INL, and NREL Staff
Roy Mink, DOE
Ray Fortuna, DOE
Jay Nathwani, DOE
Sandy Glatt, DOE
Joel Renner, INL
Gerry Nix, NREL
Bruce Green, NREL

Observers
Colin Williams, USGS
Marshall Reed, USGS
Kermit Witherbee, BLM

Facilitators
Kathleen Rutherford, The Keystone Center
Jody Erikson, The Keystone Center

Courtesy- Calpine Corp.

Several geothermal power plants are visible at The Geysers in northern California.

Bruce Green, NREL, PIX 14844

Members of the entire workshop group during discussions about resource data integration.

How Energy Equivalent Calculations Were Made

Electricity as the equivalent energy content of the produced electricity –

Barrels (bbls) of oil equivalent (BOE)

[(electricity production potential/MWe) (1000 kW/MW) (8760 hrs/yr.) (0.9 capacity factor) (3413 BTU/kW-hr)] 1 bbl oil equivalent/6 x 10^6 BTU = BOE/yr. for a minimum of 30 years.

Quads (Q)

[(electricity production potential/MWe) (1000 kW/MW) (8760 hrs/yr.) (0.9 capacity factor) (3413 BTU/kW-hr)] 1/10^{15} BTU/Q

NOTE: If properly designed, plants are sustainable.

Thermal calculations assumed a duty cycle of 50% –

BOE

[(MWt) (1000 kW/MW) (8760 hrs/yr.) (0.5 duty cycle) (3413 BTU/kW-hr)]
(1 bbl oil equivalent/6 x 10^6 BTU)

Quads (Q)

[(MWt) (1000 kW/MW) (8760 hrs/yr.) (0.5 duty cycle) (3413 BTU/kW-hr)] 1/10^{15} BTU/Q

NOTE: Actual fuel displacement for alternative production sources is somewhat larger.

Supporting Documents

1. *Assessment of Geothermal Resources of the United States* – 1978, USGS Circular 790 (p. 157), includes identified and unidentified resources; 2015 and later estimates are a consensus of the experts at the workshop.

2. *Geothermal Electric Power Supply Possible from Gulf Coast, Midcontinent Oil Field Waters*, "Oil and Gas Journal," September 5, 2005, and *Geothermal Energy Generation in Oil and Gas Settings Conference* findings, March 13 – 14, 2006, and SMU Geothermal Laboratory. Available at: *http://www.smu.edu/geothermal/publications/Oil&GASJ2005_McKenna.pdf*

3. *Energy Recovery from Enhanced/Engineered Geothermal Systems* (EGS), Massachusetts Institute of Technology (MIT), September 2006. Available at: *http://www1.eere.energy.gov/geothermal/egs_technology.html*

4. *Characterization of U.S. Energy Resources and Reserves*, December 1989, U.S. Department of Energy, DOE/CE-0279.

Geothermal

Energy from Our Earth

Available electronically at http://www.osti.gov/bridge

Available for a processing fee to U.S. Department of Energy
and its contractors, in paper, from:

U.S. Department of Energy
Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831-0062
phone: 865.576.8401
fax: 865.576.5728
email: reports@adonis.osti.gov

Available for sale to the public, in paper, from:

U.S. Department of Commerce
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
phone: 800.553.6847
fax: 703.605.6900
email: orders@ntis.fedworld.gov
online ordering: http://www.ntis.gov/ordering.htm

Printed on paper containing at least 50% wastepaper, including 10% postconsumer waste.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
10/2006	Technical Report	2006

4. TITLE AND SUBTITLE
Geothermal -- The Energy Under Our Feet

5a. CONTRACT NUMBER
DE-AC36-99-GO10337

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Bruce Green and Gerry Nix, National Renewable Energy Laboratory

5d. PROJECT NUMBER
NREL/TP-840-40665

5e. TASK NUMBER
GT06.1000

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
National Renewable Energy Laboratory
1617 Cole Blvd.
Golden, CO 80401-3393

8. PERFORMING ORGANIZATION REPORT NUMBER
NREL/TP-840-40665

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR'S ACRONYM(S)
NREL

11. SPONSORING/MONITORING AGENCY REPORT NUMBER

12. DISTRIBUTION AVAILABILITY STATEMENT
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

13. SUPPLEMENTARY NOTES
NREL Technical Monitor: Gerry Nix

14. ABSTRACT *(Maximum 200 Words)*
On May 16, 2006, the National Renewable Energy Laboratory (NREL) in Golden, Colorado hosted a geothermal resources workshop with experts from the geothermal community. The purpose of the workshop was to re-examine domestic geothermal resource estimates. The participating experts were organized into five working groups based on their primary area of expertise in the following types of geothermal resource or application: (1) Hydrothermal, (2) Deep Geothermal Systems, (3) Direct Use, (4) Geothermal Heat Pumps (GHPs), and (5) Co-Produced and Geopressured. The workshop found that the domestic geothermal resource is very large, with significant benefits.

15. SUBJECT TERMS
Geothermal; resources; hydrothermal; geopressured; co-produced, geothermal heat pump; GHPs; earth energy; deep geothermal systems; EGS; enhanced geothermal systems; direct use; and energy resources.

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
Unclassified	Unclassified	Unclassified	UL		19b. TELEPHONE NUMBER *(Include area code)*

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18

F1146-E(12/2004)