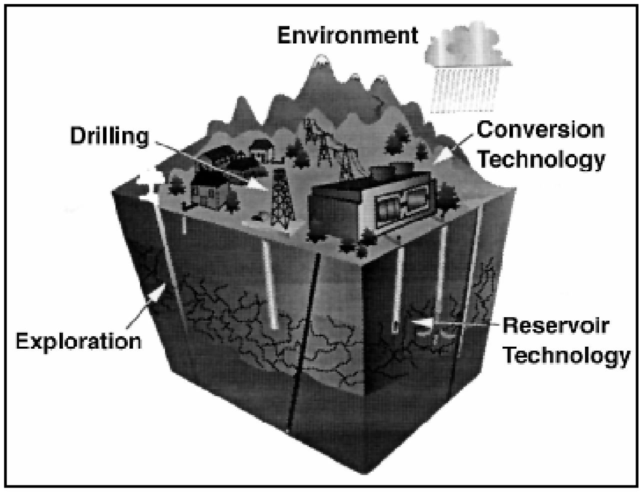
Geothermal Energy

Technology Description

Geothermal energy is heat from within the Earth. Hot water or steam are used to produce electricity or applied directly for space heating and industrial processes. This energy can offset the emission of carbon dioxide from conventional fossil-powered electricity generation, industrial processes, building thermal systems, and other applications.

System Concepts



- Geophysical, geochemical, and geological exploration locates resources to drill, including highly permeable hot reservoirs, shallow warm groundwater, hot impermeable rock masses, and highly pressured hot fluids.
- Well fields and distribution systems allow the hot fluids to move to the point of use, and afterward, back to the earth.
- Utilization systems may apply the heat directly or convert it to another form of energy such as electricity.

Representative Technologies

- Exploration technologies identify geothermal reservoirs and their fracture systems; drilling, reservoir testing, and modeling optimize production and predict useful lifetime; steam turbines use natural steam or hot water flashed to steam to produce electricity; binary conversion systems produce electricity from water not hot enough to flash.
- Direct applications use the heat from geothermal fluids without conversion to electricity. Geothermal heat pumps use the shallow earth as a heat source and heat sink for heating and cooling applications.
- Coproduction, the recovery of minerals and metals from geothermal brine, is being pursued. Zinc is recovered at the Salton Sea geothermal field in California.

Technology Applications

- With improved technology, the United States has a resource base capable of producing up to 100 GW of electricity at less than 5¢/kWh.
- Hydrothermal reservoirs are being used to produce electricity with an online availability of up to 97%; advanced energy-conversion technologies are being implemented to improve plant thermal efficiency.
- Direct-use applications are successful throughout the western United States and provide heat for space heating, aquaculture, greenhouses, spas, and other applications.
- Geothermal heat pumps continue to penetrate markets for heating/cooling (HVAC) services.

Current Status

- The DOE Geothermal Program sponsored research that won two R&D 100 Awards in 2003: Acoustic Telemetry Technology, which provides a high speed data link between the surface and the drill bit; and Low Emission Atmospheric Monitoring Separator, which safely contains and cleans vented steam during drilling, well testing, and plant start-up.
- A second pipeline to carry replacement water has been completed through the joint efforts of industry and federal, state, and local agencies. This will increase production and extend the lifetime of The Geysers Geothermal Field in California. The second pipeline adds 85 MW of capacity.

Technology History

- The use of geothermal energy as a source of hot water for spas dates back thousands of years.
- In 1892, the world's first district heating system was built in Boise, Idaho, as water was piped from hot springs to town buildings. Within a few years, the system was serving 200 homes and 40 downtown businesses. Today, the Boise district heating system continues to flourish. Although no one imitated this system for nearly 70 years, there are now 17 district heating systems in the United States and dozens more around the world.
- The United States' first geothermal power plant went into operation in 1922 at The Geysers in California. The plant was 250 kW, but fell into disuse.
- In 1960, the country's first large-scale geothermal electricity-generating plant began operation. Pacific Gas and Electric operated the plant, located at The Geysers. The resource at The Geysers is dry steam. The first turbine produces 11 megawatts (MW) of net power and operated successfully for more than 30 years.
- In 1979, the first electrical development of a water-dominated geothermal resource occurred at the East Mesa field in the Imperial Valley in California.
- In 1980, UNOCAL built the country's first flash plant, generating 10 MW at Brawley, California.
- In 1981, with a supporting loan from DOE, Ormat International Inc. successfully demonstrated binary technology in the Imperial Valley of California. This project established the technical feasibility of larger-scale commercial binary power plants. The project was so successful that Ormat repaid the loan within a year.
- By the mid-1980s, electricity was being generated by geothermal power in four western states: California, Hawaii, Utah, and Nevada.
- In the 1990s, the U.S. geothermal industry focused its attention on building power plants overseas, with major projects in Indonesia and the Philippines.
- In 1997, a pipeline began delivering treated municipal wastewater and lake water to The Geysers steamfield in California, increasing the operating capacity by 70 MW.
- In 2000, DOE initiated its GeoPowering the West program to encourage development of geothermal resources in the western United States by reducing nontechnical barriers.
- The DOE Geothermal Program sponsored research that won two R&D awards in 2003, advancing this renewable energy.
- With approval of the federal production tax credit and with support from state-level renewable portfolio standards, U.S. geothermal power is poised to double in capacity within the next couple of years.

Technology Future

The levelized cost of electricity (in constant 1997$/kWh) for the two major future geothermal energy configurations are projected to be:

	2000	2010	2020
Hydrothermal Flash	3.0	2.4	2.1
Hydrothermal Binary	3.6	2.9	2.7

Source: *Renewable Energy Technology Characterizations*, EPRI TR-109496, 1997.

- Costs at the best sites are competitive at today's energy prices – and investment is limited by uncertainty in prices; lack of new, confirmed resources; high front-end costs; and lag time between investment and return.
- Improvements in cost and accuracy of resource exploration and characterization can lower the electricity cost; demonstration of new resource concepts, such as enhanced geothermal systems, would allow a large expansion of the U.S. use of hydrothermal when economics become favorable.

Market Context

- Hydrothermal reservoirs have an installed capacity of about 2,133 MW electric in the United States and about 8,000 MW worldwide. Direct-use applications have an installed capacity of about 600 MW thermal in the United States. About 300 MW electric are being developed in California, Nevada, and Idaho.
- Geothermal will continue production at existing plants (2.1 GW) with future construction potential (100 GW by 2040). Direct heat will replace existing systems in markets in 19 western states.
- By 2015, geothermal could provide about 10 GW, enough heat and electricity for 7 million homes; by 2020, an installed electricity capacity of 20,000 MW from hydrothermal plants and 20,000 MW from enhanced geothermal systems is projected.

Source: National Renewable Energy Laboratory. *U.S. Climate Change Technology Program. Technology Options: For the Near and Long Term*. DOE/PI-0002. November 2003 (draft update, September 2005).

Geothermal

Market Data

Cumulative Installed Capacity

Source: U.S. electricity data from EIA, *Annual Energy Review 2004*, DOE/EIA-0384(2004) (Washington, D.C., August 2005), Table 8.11a; world totals from *Renewable Energy World*/July-August 2000, page 123, Table 1; 1998 world totals from *UNDP World Energy Assessment 2000*, Tables 7.20 and 7.25; 1997 world electricity and U.S. and world direct-use heat data from Stefansson and Fridleifsson 1998, "Geothermal Energy: European and World-wide Perspective."

	1980	**1985**	**1990**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**
Electricity (MW_e)													
U.S.	909	1,580	2,666	2,968	2,893	2,893	2,893	2,846	2,793	2,216	2,252	2,133	2,133
Rest of World	1,191	3,184	3,166	3,829		5,128	5,346		5,181				
World Total	2,100	4,764	5,832	6,797		8,021	8,239		7,974				
Direct-Use Heat (MW_{th})													
U.S.						1,905							
Rest of World						7,799							
World Total	1,950	7,072	8,064	8,664		9,704	11,000		17,175				

Cumulative Installed Capacity

Source: International Geothermal Association, http://iga.igg.cnr.it/index.php

	1980	**1985**	**1990**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**
Electricity (MW_e)												
U.S.			2,775	2,817					2,228			2,020
Rest of World			3,057	4,016					5,746			6,382
World Total			5,832	6,833					7,974			8,402
Direct-Use Heat (MW_{th})												
U.S.				1,874					3,766			4,350
Rest of World				6,730					11,379			
World Total				8,604					15,145			

Annual Installed Electric Capacity (MW_e)

Source: *Renewable Electric Plant Information System (REPiS)*, Version 7, NREL, 2003.

	1980	1985	1990	1995	1996	1997	1998	1999	2000	2001	2002	2003*
U.S.	251.0	352.9	48.6		36.0				59.9			

Cumulative Installed Electric Capacity (MW_e)

Source: Renewable Electric Plant Information System (REPiS), Version 7, NREL, 2003.

	1980	1985	1990	1995	1996	1997	1998	1999	2000	2001	2002	2003*
U.S.	802	1,698	2,540	2,684	2,720	2,720	2,720	2,720	2,779	2,779	2,779	2,779

* 2003 data not complete as REPiS database is updated through 2002.

Installed Capacity and Power Generation/Energy Production from Installed Capacity

Source: Lund and Freeston, *World-Wide Direct Uses of Geothermal Energy 2000*, Lund and Boyd, Geothermal Direct-Use in the United States Update: 1995-1999, J. Lund, *World Status of Geothermal Energy Use Overview 1995-1999* http://www.geothermie.de/europaundweltweit/Lund/wsoge_index.htm, Sifford and Blommquist, *Geothermal Electric Power Production in the United States: A Survey and Update for 1995-1999*, and G. Huttrer, *The Status of World Geothermal Power Generation 1995-2000.* Proceedings of the World Geothermal Congress 2000 http://geothermal.stanford.edu/wgc2000/SessionList.htm, Kyushu-Tohoku, Japan, May 28-June10, 2000.

Cumulative Installed Capacity

	1980	1985	1990	1995	1996	1997	1998	1999	2000
Electricity (MW_e)									
U.S.				2,369	2,343	2,314	2,284	2,293	2,228
Rest of World				4,464					5,746
World Total	3,887	4,764	5,832	6,833					7,974
Direct-Use Heat* (MW_{th})									
U.S.									4,200
Rest of World									12,975
World Total	1,950	7,072	8,064	8,664				16,209	17,175

Annual Generation/Energy Production from Cumulative Installed Capacity

	1980	1985	1990	1995	1996	1997	1998	1999	2000
Electricity (Billion kWh_e)									
U.S.				14.4	15.1	14.6	14.7	15.0	15.5
Rest of World									33.8
World Total									49.3
Direct-Use Heat* (TJ)									
U.S.				13,890				20,302	21,700
Rest of World				98,551				141,707	163,439
World Total		86,249		112,441				162,009	185,139

* Direct-use heat includes geothermal heat pumps as well as traditional uses. Geothermal heat pumps account for 1854 MW_{th} (14,617 TJ) in 1995 and 6849 MW_{th} (23,214 TJ) in 1999 of the world totals and 3600 MW_{th} (8,800 TJ) in 2000 of the U.S. total. Conversion of GWh to TJ is done at 1TJ = 0.2778 GWh.

Annual Generation from Cumulative Installed Capacity

Source: U.S. electricity data from EIA, *Annual Energy Review 2004*, DOE/EIA-0384(2004) (Washington, D.C., August 2005), Table 8.2a; world electricity totals from *Renewable Energy World*/July-August 2000, page 126, Table 2; 1997 world electricity and U.S. and world direct-use heat data from Stefansson and Fridleifsson 1998, “Geothermal Energy: European and World-wide Perspective.” 1998 world totals from UNDP World Energy Assessment 2000, Table 7.25; 1995, 2000, and 2003 direct-use heat and 1999 electricity world total from International Geothermal Association, http://iga.igg.cnr.it/index.php.

	1980	1985	1990	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Electricity (Billion kWh_e)													
U.S.	5.1	9.3	15.4	13.4	14.3	14.7	14.8	14.8	14.1	13.7	14.5	14.4	14.4
Rest of World	8.9	7.7	3.6	6.6		29.0	31.2		35.2				
World Total	14	17	19	20		43.8	46	49	49.3				
Direct-Use Heat (billion kWhth)													
U.S.				3.9		4.0			5.6			6.2	
Rest of World						31.1							
World Total				31.2			40		53.0				
			27.4					47.3					
					35.1								

Annual Geothermal Energy Consumption for Electric Generation (Trillion Btu)	Source: EIA, *Annual Energy Review 2004*, DOE/EIA-0384(2004) (Washington, D.C., August 2005), Table 8.4a.												
	1980	**1985**	**1990**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**
U.S.	110	198	326	280	300	309	311	312	296	289	305	303	302
Rest of World													
World Total													

Annual U.S. Geothermal Heat Pump Shipments, by type (units)	Source: EIA, *Renewable Energy Annual 2004*, DOE/EIA-0603(2004) (Washington, D.C., June 2006), Table 58.									
	1995	**1996**	**1997**	**1998**	**1999**	**2000**	**2001***	**2002**	**2003**	**2004**
ARI-320	4,696	4,697	7,772	10,510	7,910	7,808	N/A	6,445	10,306	9,130
ARI-325/330	26,800	25,697	28,335	26,042	31,631	26,219	N/A	26,802	25,211	31,855
Other non-ARI Rated	838	991	1,327	1,714	2,138	1,554	N/A	3,892	922	2,821
Totals	32,334	31,385	37,434	38,266	41,679	35,581	N/A	37,139	36,439	43,806

* No survey was conducted for 2001.

Capacity of U.S. Heat Pump Shipments (Rated Tons)	Source: EIA, *Renewable Energy Annual 2004*, DOE/EIA-0603(2004) (Washington, D.C., June 2006), Table 59.									
	1995	**1996**	**1997**	**1998**	**1999**	**2000**	**2001***	**2002**	**2003**	**2004**
ARI-320	13,120	15,060	24,708	35,776	27,970	26,469	N/A	16,756	29,238	23,764
ARI-325/330	113,925	92,819	110,186	98,912	153,947	130,132	N/A	96,541	89,731	100,317
Other non-ARI Rated	3,935	5,091	6,662	6,758	9,735	7,590	N/A	12,000	5,469	20,220
Totals	130,980	112,970	141,556	141,446	191,652	164,191	N/A	125,297	124,438	144,301

1 One Rated Ton of Capacity equals 12,000 Btu's.
2 No survey was conducted for 2001.

Annual U.S. Geothermal Heat Pump Shipments by Customer Type and Model Type (units)	Source: EIA, *Renewable Energy Annual 2004*, DOE/EIA-0603(2003) (Washington, D.C., June 2006), Table 61, REA 2003 Table 40, REA 2002 Table 40, REA 2001 Table 40, REA 2000 Table 38, REA 1999 Table 38, and REA 1998 Table 40.								
	1996	**1997**	**1998**	**1999**	**2000**	**2001***	**2002**	**2003**	**2004**
Exporter	2,276	226	109	6,172	784	N/A	1,165	945	1,092
Wholesale Distributor	21,444	29,181	14,377	9,193	9,804	N/A	20,888	16,167	23,647
Retail Distributor	8,336	829	3,222	2,555	2,272	N/A	552	1,145	355
Installer	18,762	25,302	18,429	24,917	20,491	N/A	10,999	10,784	13,562

End User	689	657	994	66	63	N/A	207	1,103	397
Others	13	1,727	1,135	6,259	2,167	N/A	3,328	6,295	4,753
Total	51,520	57,922	38,266	49,162	35,581	N/A	37,139	36,439	43,806

Annual U.S. Geothermal Heat Pump Shipments by Export & Census Region (units)

Source: EIA, *Renewable Energy Annual 2004*, DOE/EIA-0603(2003) (Washington, D.C., June 2006), Table 60, REA 2003 Table 39, REA 2002 Table 39, REA 2001 Table 39, REA 2000 Table 37, REA 1999 Table 37, and REA 1998 Table 39.

	1996	**1997**	**1998**	**1999**	**2000**	**2001***	**2002**	**2003**	**2004**
Export	4,090	2,427	481	6,303	1,220	N/A	3,271	2,764	2,984
Midwest	11,874	13,402	12,240	13,112	10,749	N/A	12,982	12,042	14,650
Northeast	6,417	9,280	5,403	6,044	4,138	N/A	3,903	5,924	8,060
South	25,302	26,788	16,195	20,935	17,403	N/A	13,660	12,543	14,674
West	3,837	6,025	3,947	2,768	2,071	N/A	3,323	3,166	3,438
Total	51,520	57,922	38,266	49,162	35,581	N/A	37,139	36,439	43,806

Technology Performance

Source: *Renewable Energy Technology Characterizations*, EPRI TR-109496, 1997.

Efficiency		**1980**	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2020**
Capacity Factor (%)	Flashed Steam			89	92	93	95	96	96
	Binary			89	92	93	95	96	96
	Hot Dry Rock			80	81	82	83	84	85
Cost		**1980**	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2020**
Capital Cost ($/kW)	Flashed Steam			1,444	1,372	1,250	1,194	1,147	1,100
	Binary			2,112	1,994	1,875	1,754	1,696	1,637
	Hot Dry Rock			5,519	5,176	4,756	4,312	3,794	3,276
Fixed O&M ($/kW-yr)	Flashed Steam			96.4	87.1	74.8	66.3	62.25	58.2
	Binary			87.4	78.5	66.8	59.5	55.95	52.4
	Hot Dry Rock			219	207	191	179	171	163