Geothermal Energy

Clean

Sustainable

Energy

for

the

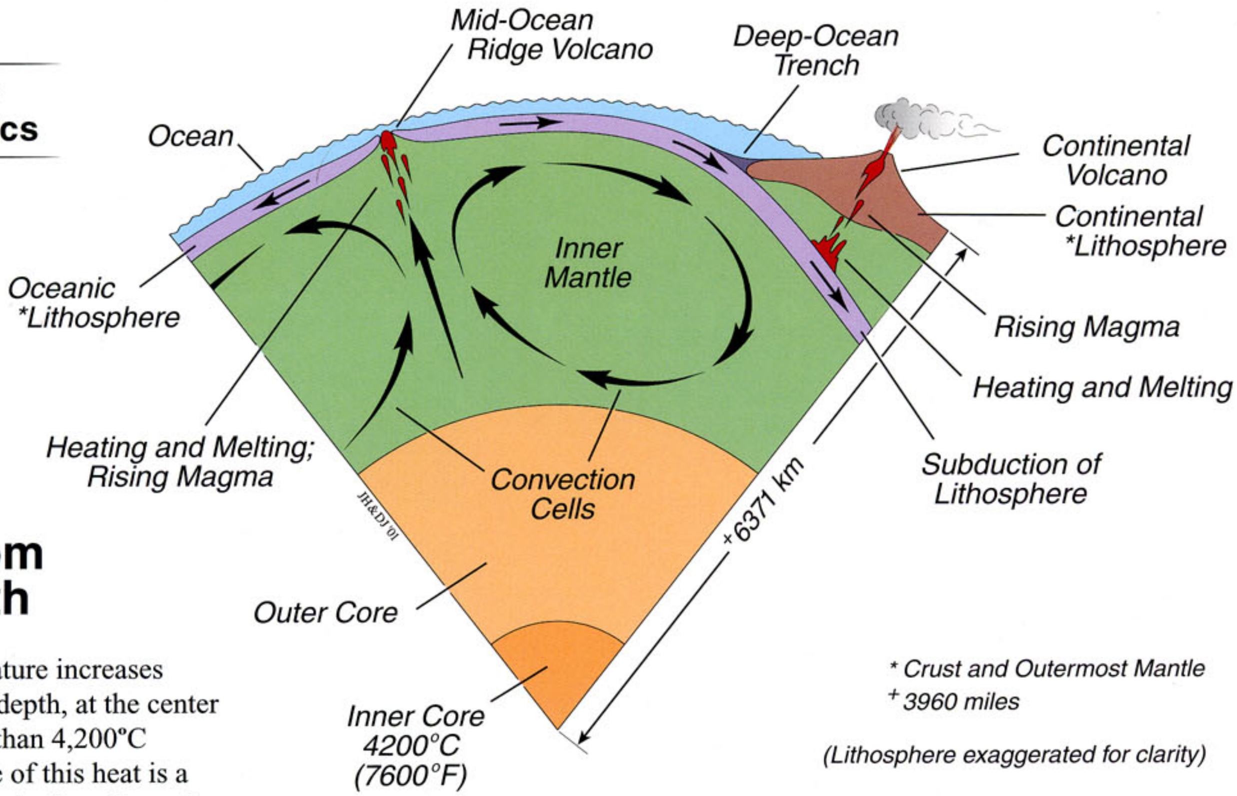
Benefit of Humanity

and

the Environment

Geothermal energy – literally, heat from the earth – is a clean, abundant, and versatile natural resource ready to meet an ever greater share of the world's steadily escalating energy needs. Geothermal steam and hot water are now routinely utilized for the generation of electric power with the gentlest of environmental impacts. Thermal waters piped directly from the ground support greenhouses, fish farms, and municipal heating systems. Geothermal heat pumps can be installed almost anywhere, and are widely considered the ideal means for heating and air conditioning schools, homes, and workplaces. Our rich geothermal endowment has scarcely been tapped, but there is growing awareness of its genuine value and near-limitless potential. With continually improving technology for development, geothermal energy is destined to become a major factor in solving the world's increasingly complex energy equation.

Earth Dynamics



Heat from the Earth

Earth's temperature increases gradually with depth, at the center reaching more than 4,200°C (7600°F). Some of this heat is a relic of the globe's fiery formation about 4.5 billion years ago, but most has been generated by the decay of radioactive isotopes. As heat naturally moves from hotter to cooler regions, so Earth's heat flows along a *geothermal gradient* from the center to the surface, where an estimated 42 million thermal megawatts (42 X 10^{12} watts) are continually radiated into space. The bulk of this immense heat supply cannot be practically captured, because it arrives at the surface at too low a temperature. Fortunately, the fundamental geologic process know as *plate tectonics* (responsible for seismicity, mountain building, and volcanism) ensures that some of this heat is concentrated at temperatures and depths favorable for its commercial extraction.

The planet's thin *lithosphere* – its rigid shell of crust and outermost mantle – has been broken into 12 large and several smaller moving plates by thermally- and gravitationally-driven convection of the underlying mantle, at rates measured in millimeters per year. The world's geothermal provinces are conspicuously concentrated at the margins of these jostling slabs. Where plates move apart, along globe-encircling mid-ocean ridges, basaltic magma rises in the fissures to form vast undersea volcanoes. Where two plates collide, one is commonly thrust (subducted) beneath the other, causing formation of a deep ocean trench and occasionally inducing powerful earthquakes. At great depth just above the downgoing plate, temperatures become high enough to melt rock. The resulting magma bodies are less dense than surrounding rocks, and ascend buoyantly through the upper mantle into the crust, where they sometimes give rise to explosive volcanoes, and are always profound shallow pools of heat. Under the right conditions, these near-surface heat anomalies can be harnessed for commercial production of geothermal energy.

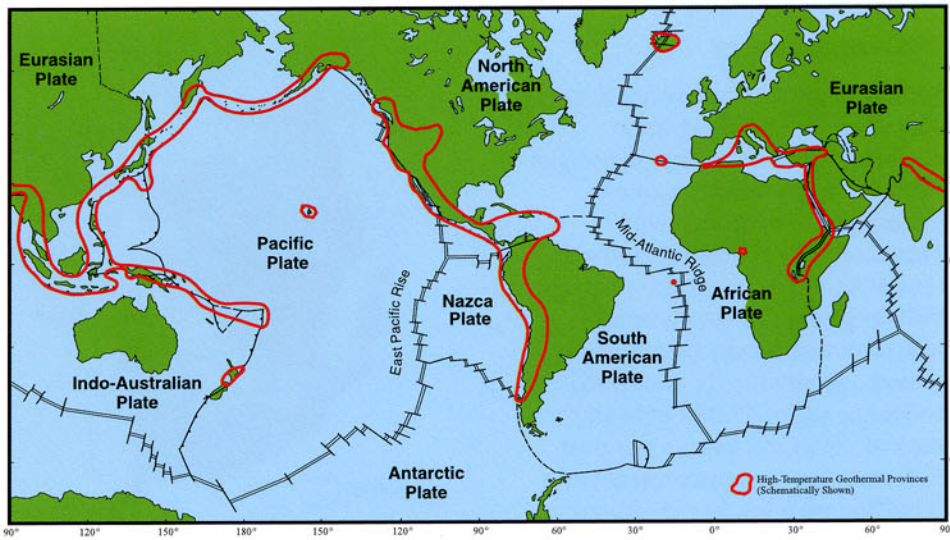
Geothermal Resources

Hot springs and thermal pools, among the more familiar clues to Earth's shallow heat anomalies, have been used since the dawn of mankind for swimming, bathing, and cooking, as well as for healing the body and soul. These and related phenomena – geysers, boiling mud pots, and fumaroles (steam vents) – are the surface expressions of natural *hydrothermal systems,* now widely developed for such diverse applications as electric-power production and roadway snow melting.

Sou Hot Springs, Dixie Valley, Nevada

In addition to a persistent heat source, two other critical components are necessary for the birth and maintenance of a hydrothermal system: (1) a copious supply of water in a network of permeable (able to transmit fluid), interconnected fractures (and other open spaces); and (2) a caprock, or peripheral seal, that inhibits both thermal-fluid escape and cool groundwater incursion. The process begins when the waters are heated at depth. The heat source may be a partially molten or recently solidified but still hot magma body, commonly associated with volcanic activity. Alternatively, along especially permeable fracture zones, the heating may simply be due to deep and rapid fluid circulation in regions with higher than normal geothermal gradients.

World Geothermal Provinces



The heated fluids are less dense than surrounding cooler waters, and therefore rise in the fracture networks as buoyant geothermal plumes. Small portions of these plumes may leak to the surface through the caprocks to form hot springs and related phenomena. Most of the thermal waters, however, remain confined and gradually cool as they migrate away from the heat source. As they do so, their resulting density increase allows them to descend once again to their source regions, where they reheat and rise anew to perpetuate this *hydrothermal convection*. Large hydrothermal systems of this sort are very stable features, persisting naturally for several hundred thousand to more than a million years.

Hot springs and other surface thermal emissions account for only trivial fractions of the parent hydrothermal systems, which can have volumes of tens or even hundreds of cubic kilometers (km). Effectively concealed, the subsurface nature and extent of these systems must be mapped using modern geological, geophysical, and remote-sensing techniques. The combined results of these methods are used by geothermal explorationists to determine where production wells can be drilled with the highest probability for discovering deep thermal fluids at commercially high temperatures and flow rates.

Other Geothermal Resource Types

The conventional geothermal resources introduced above only hint at the vast amounts of heat everywhere present in Earth's upper crust. As one example, many of the world's deep, commonly petroleum-bearing sedimentary basins include deep thermal aquifers – shale-capped and warm-water-filled formations such as sandstone and cavernous carbonate. There are also countless young igneous intrusions that have not engendered hydrothermal systems but are nonetheless vast shallow reservoirs of heat. Some of these intrusions are still molten, and this *magma* is an immense repository of heat awaiting only visionary technology for extraction.

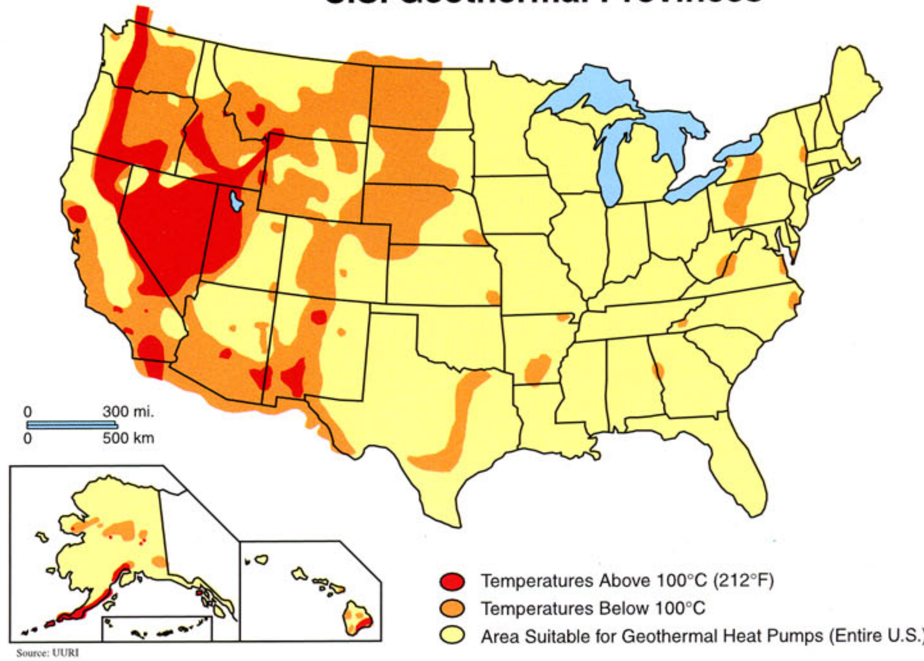
Recovering Earth's heat at high temperatures and rates is a challenge of daunting complexity in the absence of a natural hydrothermal system. Even so, the potential resource base is so enormous that researchers in the United States, Japan, and Europe are striving to develop the means. These research programs show great promise to vastly increase the availability of geothermal energy for future generations.

Current Utilization of Geothermal Energy

Modern usage of geothermal energy falls naturally into three main categories, corresponding in general to progressively lower resource temperature – electric power generation, direct heating, and geothermal heat pumps. Approximately 8000 megawatts of geothermal electric-power production capacity are now installed in 21 countries, producing about 49,000 gigawatt-hours of electrical energy per year (sufficient for the requirements of 30 million people). In the United States alone, the installed capacity is about 2600 megawatts, with an annual yield of about 16 billion kilowatt-hours. The state of California (which would have the world's sixth largest economy if it were a sovereign nation) derives 5% of its electrical energy from geothermal resources. Northern Nevada's electric-power supply is 10% geothermal, and Utah's geothermal riches, by most accounts and if fully developed, could serve the needs of at least a third of the state's households.

Direct-heat uses for geothermal waters are no less impressive. There are about 16,000 thermal megawatts of installed direct-heating capacity in 55 countries, with an annual output of 45,000 gigawatt-hours. Among myriad applications, these thermal waters are used to heat homes, factories, and greenhouses; to nurture plants and animals under otherwise adverse conditions; and to dry foodstuffs, lumber, and bricks. Hot springs and spas, of course, remain popular worldwide for recreational and therapeutic bathing, swimming, and soaking. Geothermal heat pumps, which exploit ubiquitous, low-temperature ground heat rather than natural hot water, are increasingly popular as efficient home heating and cooling installations.

U.S. Geothermal Provinces



The Geothermal Resource Base

Earth's currently and potentially available reserve of geothermal energy is a quantity of astonishing magnitude – vastly greater, in fact, than the resource bases of coal, oil, gas, and nuclear energy combined. As an example, the chart below compares the modern and potential worldwide (and U.S.) geothermal energy resource base with that of domestic and global oil. Although only a fraction of this geothermal bounty can now be tapped, with innovative technology it will remain available for our descendants long after the last drop of oil is produced.

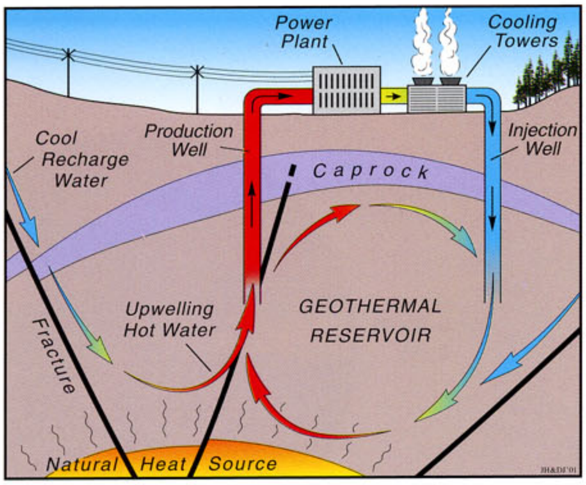
Geothermal Energy Resource Base Compared with Oil Reserves

Geologic Regime	U.S. Resources (10⁹ barrels of oil equivalent)	World Continental Resources (10⁹ barrels of oil equivalent)
Magmatic Systems (surface to 10 km)	160,000	2,400,000
Crustal Heat (3 km to 10 km)	2,300,000	79,000,000
Thermal Aquifers (0.1 to 4 km)	9	130
Known Oil Reserves (for comparison)	890	5,300

Sustainability

Geothermal energy is a renewable resource by any rational measure. Large, magmatically-heated geothermal systems are driven by partially molten or crystallized but still hot igneous intrusions that yield their heat gradually over hundreds of thousands of years. Similarly, systems heated by deep circulation along highly permeable fracture zones are supported by Earth's constant outward flux of thermal energy. Not a single geothermal field has been exhausted to date, although reservoir pressures and temperatures have slowly declined in response to production. Large fields at The Geysers (California, USA) and Wairakei (New Zealand) have been producing electric power continuously for 40 years; Italy's pioneering Larderello field has been similarly productive since 1904. Carefully managed with modern scientific and engineering techniques, geothermal systems can be sustained commercially for decades or even centuries.

Geothermal Energy for Electric Power



Hydrothermal systems of two main types are currently utilized for electric power production. The rarest and most valuable systems are exemplified by those at The Geysers and Larderello. These *vapor-dominated* systems yield nearly pure, high-temperature (>235°C, or 455°F) steam through production wells typically 1-4 km in depth. The steam is processed to remove particulates and non-essential fluids, then is piped to turbines that spin generators to create electricity. More common are systems dominated by hot water at temperatures in the range 150-300°C (300-700°F). For these systems, flash-steam power plants are required. Again, the geothermal fluids are brought to the surface through production wells as much as 4 km deep. At these depths, the hot waters are highly pressurized, but as pressure is reduced in transit to the power plant, 30% to 40% of the water *flashes* (explosively boils) to steam. The steam is separated from the remaining hot water and fed to a turbine/generator unit to produce electricity. The residual water is returned to the reservoir through injection wells to help maintain pressure and prolong productivity.

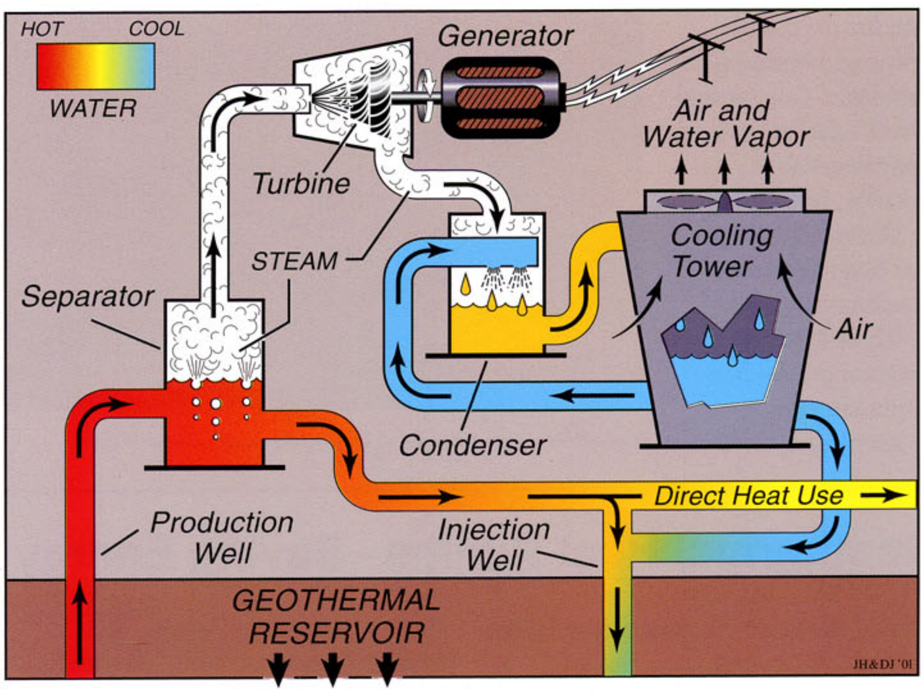
For lower-temperature geothermal reservoirs (those between approximately 100°C [212°F] and 150°C), binary-cycle power plants are the preferred installations. In a binary plant, geothermal waters are passed through a heat exchanger to heat a secondary working fluid (for example, isopentane) that vaporizes at a lower temperature than water.

In a closed-loop cycle, the working-fluid vapor spins the power-producing turbine/generator unit, then is condensed back to liquid before being revaporized at the heat exchanger. As in a flash-steam cycle, the spent (heat-depleted) geothermal water exiting a binary plant is injected back into the reservoir.

Flash and binary cycles can be combined in sequence for the most efficient conversion of thermal to electrical energy. In these hybrid power plants, hot water from production wells is first flashed to steam that is used to rotate a primary turbine/generator unit. Steam condensate from the flash cycle is then mixed with the residual, unflashed water and routed to a binary unit for further generation of electricity.

Geothermal electric-power plants are typically available for generation 95% of the time. They are modular, and can be installed incrementally on an as-needed basis. Moreover, construction of these plants is a relatively rapid procedure – as little as half a year for 0.5 to 10 megawatt units, and 1-2 years for clusters of plants with capacities of 250 megawatts or more.

Flash-steam power plant



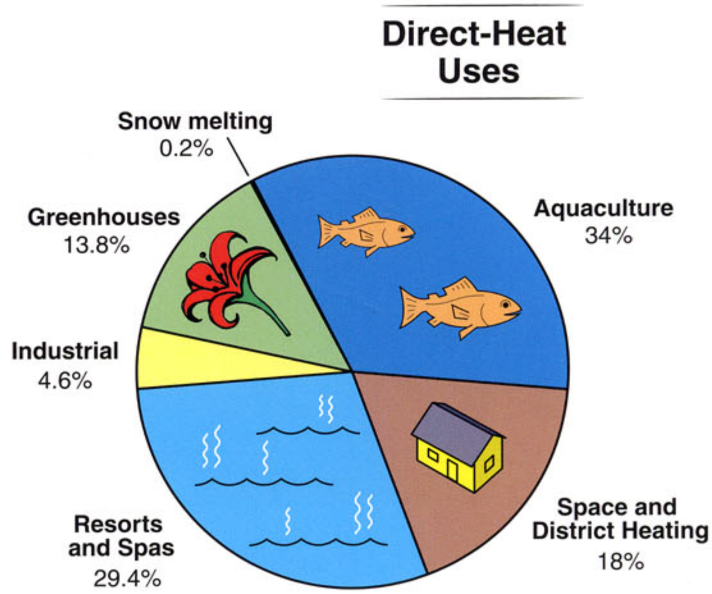
Power for Developing Countries

Indigenous energy sources are urgently needed in developing countries, and geothermal energy is ideally suited to provide the required thousands of megawatts of electric power with the least environmental impact. High-temperature hydrothermal systems occur throughout the world, and are notably abundant in many developing countries, where judicious utilization of these resources can displace construction of power plants requiring more traditional fuel sources.

Readily available in these countries for large-scale, base-load electric-power generation, geothermal energy also shows great promise for supplying small amounts of power to local transmission grids for rural electrification.

Geothermal Heat for Direct Use

From earliest times, hot waters from geothermal springs have been used for bathing, cooking, and heating. Applications of low- to moderate-temperature (35°C [95°F] to 150°C) geothermal waters have expanded dramatically in the modern era (by 50% in just the last five years). In the U.S., the principal applications are fish-farming (aquaculture); resorts and spas; greenhouses for the growing of vegetables, fruits, and flowers; and discrete (space) and district (tract) heating of homes, workplaces, and other facilities. U.S. geothermal greenhouses today cover more than 110 acres, and domestic aquaculture annually yields an impressive 17,545,000 kilograms (38,600,000 pounds) of fish. Geothermal waters are also employed for a variety of industrial applications, including enhanced heap leaching of precious-metal ores and the drying of crops and building materials. Geothermal direct-heating systems are remarkably durable; one system in Boise, Idaho, has been operating continuously since 1892, and its two original production wells are still in service.



Source: Geo-Heat Center, 2000


photo © Robert E. Blackett

A geothermal greenhouse at Newcastle, southwestern Utah

With allowances for the nature of hot water and steam, standard and readily available equipment is perfectly suitable for geothermal direct-use projects. The primary components of a direct-use system are downhole and circulation pumps; transmission and distribution pipelines; peaking, or backup plants; and various heat-extraction mechanisms. Depending upon water quality, the local environment, and project-permitting requirements, the spent geothermal waters are either discharged at the surface or reinjected into the subsurface reservoirs from which they were derived.

Geothermal Heat Pumps – Saving Energy

One of the most efficient technologies for home and workplace heating is the ground-source geothermal heat pump (GHP). These installations reduce energy consumption by 30% to 60% relative to conventional electrical heating and cooling systems. Domestic hot water is produced essentially free by the GHP during the air-conditioning season, and for half the usual cost in winter. GHP systems also require very little maintenance while providing exceptionally reliable energy streams.

The GHP operates on the same principal as a home refrigerator. However, unlike the refrigerator (in essence a one-way heat pump), the GHP can move heat in either direction. In the winter, heat is extracted from the earth and delivered to the building (heating mode). In the summer, heat is removed from the building and delivered for storage into the earth (air conditioning mode). Admittedly, the GHP is electric-powered, but the electricity is used only to move heat, not to produce it. As a result, the pump delivers three to four times more energy than it consumes.

Minimal Environmental Impact

Because of burgeoning populations and expanding economies, the world's appetite for energy is inexorably increasing. At the same time, there is growing awareness of the fragility of the global environment. The seemingly paradoxical need to produce more power while reducing pollution clearly depends on changing the present energy mix to include a greater proportion of clean and safe geothermal energy. When compared to conventional power sources, geothermal energy has enormous environmental advantages; far fewer and more easily controlled atmospheric emissions; readily maintainable groundwater quality; minimal amounts of troublesome waste; and generally more modest land requirements for power-production facilities.

Clean Air

The comparatively minute quantities of gases (such as carbon dioxide) emitted from geothermal electric power plants are not created during power production but are natural trace constituents of all geothermal systems. These gases would vent to the atmosphere even in the absence of geothermal development (although at far slower rates). Strictly in this sense, gaseous emissions from geothermal power plants can be considered essentially "net zero".

Clean Water

Technology for the safe, non-polluting use of geothermal water has been carefully developed and rigorously tested. Production and injection wells are lined with steel (or titanium) casing and cement to isolate fluids from the environment. Spent thermal waters are injected back into the reservoirs from which the fluids were derived. This practice neatly solves the water-disposal problem while helping to bolster reservoir pressure and prolong the resource's productive existence.

Land Use

Geothermal installations are justifiably lauded for blending harmoniously with other land uses. For example, the Imperial Valley of southern California not only is one of the most productive agricultural areas in the world, it also encompasses some 15 large geothermal power plants producing more than 400 megawatts of electric power. One of these plants, at the southern end of the Salton Sea, is neighbor to a popular national wildlife refuge sheltering hundreds of species throughout the year.

Improving Geothermal Technology

Today, only the highest-grade geothermal resources can be utilized economically. The principal barrier to more rapid worldwide geothermal development is costly and inadequate technology. Improving this technology requires focused research, particularly in the disciplines of exploration, drilling, and power plant design.

Exploration

A major problem confronting geothermal companies is how to predict, efficiently and economically, where drill holes can be sited with the best chance to intersect productive thermal-fluid channels and reservoir rocks deep in the subsurface. Current geological, geochemical, and remote-sensing techniques have enabled many discoveries, but can still be improved to further minimize costly but nonproductive "dry holes".

Drilling

Because geothermal fluids are high-temperature, can be corrosive, and tend to occur in hard and abrasive reservoir rocks, geothermal drilling is much more difficult and expensive than conventional petroleum drilling. Each geothermal well costs $1 million to $4 million, and there may be 10 to 100 or more wells in a fully-developed field. Drilling can readily account for 30-50% of a geothermal project's total financial outlay. Currently ongoing, U.S. Department of Energy-sponsored research has yielded numerous innovations that have lowered geothermal drilling costs in the U.S. and around the world.

Power Plants

The viability of geothermal power production is strongly influenced by two important variables at the plant: (1) the efficiency of converting a fluid's thermal energy to electricity; and (2) the cost of equipment and construction. Increasing the former and lessening the latter inevitably will lead to more profitable geothermal developments. To address these twin goals, applied geothermal research programs are being carried out successfully at national laboratories and universities under the auspices of the Department of Energy's Office of Wind and Geothermal Technologies, and with the essential support of the U.S. geothermal industry. Strong research programs are also underway in Japan, the European Community, New Zealand, Iceland, Italy, Indonesia, the Philippines, Mexico, and Central America. As a result of this research and consequently improved technology, the cost of generating power from geothermal resources has decreased by about 25% over the past two decades. Even so, further improvements and cost reductions are necessary for full realization of geothermal energy's unquestionably immense potential.

Geothermal Energy—*The Low-Cost Alternative*

It is less than widely appreciated that geothermal power plants have comparatively low lifetime costs when compared with facilities other-wise fueled. All power plants have high start up expenditures, but after that, and unlike the others, geothermal plants use fuel essentially free for the taking (operational and maintenance costs are comparatively minor). Since geothermal installations can function efficiently for 30 years or more before replacement, and since geothermal systems can yield the requisite fluids for decades or even centuries, the average lifetime cost of energy from a geothermal resource can be a surprisingly modest sum. Nonetheless, modern economies are prone to take the short-term view, in which even essentially guaranteed long-term profitability does not offset the reasonable risk that a start-up is obliged to assume.

Geothermal resources have undeniably great potential to meet an increasing share of the world's expanding energy needs. Geothermal energy is our plentiful, clean, reliable, and renewable energy alternative – a bargain in every sense of the word.

Sources of further information on geothermal energy are –

U.S. Department of Energy
Office of Wind and Geothermal Technologies, EE-12
1000 Independence Ave, S.W.
Washington, DC 20585
http://www.eren.doe.gov/geothermal

Geo-Heat Center
Oregon Institute of Technology
3201 Campus Drive
Klamath Falls, OR 97601-8801
http://www.oit.edu/~geoheat

Energy & Geoscience Institute*
Dept. of Civil and Environmental Engineering
University of Utah
423 Wakara Way, Suite 300
Salt Lake City, Utah 84108
http://www.egi.utah.edu
** Formerly University of Utah Research Institute (UURI)*

Geothermal Resources Council
2001 Second Street, Suite 5
Davis, CA 95617-1350
http://www.geothermal.org

Geothermal Education Office
664 Hilary Drive
Tiburon, CA 94920
http://geothermal.marin.org

Geothermal Energy Association (GEA)
209 Pennsylvania Avenue, S.E.
Washington, D.C. 20003
http://www.geo-energy.org

Geothermal Heat Pump Consortium
701 Pennsylvania Ave., N.W.
Washington, DC 20077
http://www.ghpc.org

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Fly Ranch Hot Springs, Nevada: travertine mounds from flowing well (photo © Joel Renner)
Power plant at Cove Fort-Sulphurdale, Utah (photo © Joe Moore)
Power plant in The Geysers geothermal field, California
Geothermal greenhouse at Radium Hot Springs, New Mexico