The State of Geothermal Technology

Part II: Surface Technology


Power Plant Infrastructure at The Geysers (Source: Calpine Corp.) and Raft River (Source: U.S. Geothermal, Inc)

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EXECUTIVE SUMMARY

Geothermal surface technology, the subject of this report, is an important part of geothermal energy development.

Geothermal fluid—a hot, sometimes salty, mineral-rich liquid and/or vapor—is the carrier medium that brings geothermal energy up through wells from the subsurface to the surface. It is withdrawn from a deep underground reservoir, isolated from groundwater by thickly encased pipes, making the facility virtually free of water pollution. Once used, the water and condensed steam is injected back into the geothermal reservoir to be reheated.

A geothermal resource that uses an existing accumulation of hot water or steam is known as a "hydrothermal" resource. All geothermal electricity produced today derives from the hydrothermal resource base.

Characteristics of the geothermal fluid, including temperature, chemistry, and noncondensable gas content (NCG), can influence power plant design. Two substances sometimes found in geothermal fluid, hydrogen sulfide (H_2S) and mercury, are regularly abated at geothermal facilities, eliminating 90 to 99.9 percent of the substances.

Power Plant Basics

Like all conventional thermal power plants, a geothermal plant uses a heat source to expand a liquid to vapor/steam. This high pressure vapor/steam is used to mechanically turn a turbine-generator. At a geothermal plant, fuel is geothermal water heated naturally in the earth, so no burning of fuel is required.

Power Plant Size

Though the size of a power plant is determined primarily by resource characteristics, these are not the only determining factors. Factors that favor the development of larger geothermal plants include:

- Cost decreases when larger quantities of materials, including steel, concrete, oil, and fuel, are purchased at one time.
- High transmission costs, regardless of plant size, that can include land use and rights-of-way fees.
- Though some automated facilities require few personnel, a minimum number of people are typically required to run a geothermal power plant.

Factors that favor the development of smaller geothermal plants include:

- Developers may opt to start small and increase output as they come to understand the potential of the resource through continued use.
- Smaller plants require less time to permit.

- The production tax credit (PTC) induces developers to construct smaller plants that can qualify for the short timeframe of the PTC.
- A developer's power purchase agreement may require that he start with a small output and gradually increase production.

Conversion Technology

A conversion technology represents the entire process of turning hydrothermal resources into electricity. Four options are available to developers:

- **Dry steam plants,** which have been operating for over one hundred years, make use of a direct flow of geothermal steam.
- The most common type of power plant, a **flash power plant**, uses a mixture of liquid water and steam.
- **Binary geothermal plants** function as closed loop systems that make use of resource temperatures as low as 165^{o}F (74^{o}C). A **Rankine cycle** is the commercial binary cycle used in the United States.
- A combination of flash and binary technology, known as the **flash/binary combined cycle**, has been used effectively to take advantage of both technologies.

Cooling System

Most power plants, including most geothermal plants, use water-cooled systems – typically in cooling towers. In areas with scarce or expensive water resources, or where the aesthetic impact of steam plumes (produced only in water-cooled systems) are a concern, air cooling may be preferred. However, air-cooled systems are influenced by seasonal changes in air temperature.

Structuring Power plant to Minimize Impact

A geothermal developer mitigates potential impacts in a variety of ways. Developers may use noise muffling equipment, visual mitigation techniques, strategies to reduce potential effects on wildlife and vegetation, monitoring activities, and regular maintenance and upkeep activities.

Efficiency

The public interest in energy efficiency arose as a fossil fuel issue: that is, the less fuel used per output, the fewer emissions and the greater quantity of depleting fuel conserved. For renewable energy use, in contrast to fossil fuel use, efficiency is primarily an economic concern. This is because at renewable sites like geothermal power plants, the fuel source is not burned, and thus few emissions are released. Geothermal developers choose to discuss efficiency in a variety of ways, depending upon the context in which an efficiency measurement is needed and the characteristics of the resource and plant.

Non-Traditional Geothermal Systems

Several "non-traditional" technology applications have been considered, or are emerging, that could further expand geothermal potential:

- **Hybrid systems**: A hybrid system integrates another resource into a hydrothermal geothermal power plant, therefore creating more electricity without expanding the use of the geothermal resource. Geothermal can be used in combination with biomass, combined heat and power or CHP (geothermal electricity plus a geothermal direct use application), geothermal heat pumps, and geopressured resources (those that operate on both natural gas and geothermal fuel).
- **Enhanced Geothermal Systems (EGS)**: EGS resources could be harnessed using existing geothermal power systems.
- **Oil and Gas Co-production**: An oilfield co-produced resource makes use of wells already drilled by oil and gas developers. These wells are either deep enough to encounter hot water, or could be deepened into hot zones.

New Technology

Several surface technology applications look particularly promising for the future. These include:

Incremental Technology Improvements: Small-scale improvements can be commercially implemented more quickly than larger, more revolutionary advances, and can be incorporated into existing designs with comparatively lower risk.

Increasingly Standardized, Modular Geothermal Conversion Systems: Modular components and subcomponents reduce costs because they can be pulled from off-the-shelf designs that are mass-produced. They allow developers to move ahead more rapidly with plant development and, once a plant is established, capacity additions.

Mineral Recovery: Further research and development could make the separation of minerals from geothermal water, known as mineral recovery, a viable technology. Mineral recovery offers benefits such as reduced scaling and increased revenue.

Mixed Fluids: One working fluid especially suitable for lower temperature resources is an ammonia-water mixed fluid system as used in Kalina and other cycles. Studies have shown that mixed working fluids in binary-cycle geothermal power plants can reduce thermodynamic inefficiencies.

Hybrid Cooling: In an increasingly water-constrained world, air cooling will likely become the preferred cooling option. However, the relative inefficiency of air-cooled systems during the summer has proven in some cases to be a liability. Hybrid cooling systems seek to integrate the best of both systems, increasing seasonal efficiency while also reducing water use and aesthetic impact.

Coatings: Traditional materials used to reduce corrosion do not transfer heat well and can cost at least three times as much as traditional materials. Researchers have engineered less expensive "coatings" that can be applied to various power plant components to reduce scaling and fouling.

Direct Use

Geothermal resources have been utilized for centuries through "direct use." Direct use resources are tapped by drilling wells and bringing hot water to the surface directly for a variety of uses, primarily for space heating, but also for drying farm and timber products, aquaculture and industrial uses.

Geothermal Heat Pumps

According to the DOE, geothermal heat pumps (GHPs) use 25 to 50 percent less electricity than conventional heating or cooling systems. Geothermal heat pumps can reduce energy consumption—and corresponding emissions—from 45 to 70 percent when compared to traditional systems. They also improve humidity control. Because heat pumps do not require a geothermal reservoir, they can be used anywhere in the world.

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ACRONYMS AND ABBREVIATIONS

BLM	United States Bureau of Land Management
DOE	United States Department of Energy
DOI	United States Department of Interior
EGS	Enhanced Geothermal Systems
EERE	Energy Efficiency and Renewable Energy (of U.S. Department of Energy)
EIS	Environmental Impact Statement
EPA	United States Environmental Protection Agency
GEA	Geothermal Energy Association
KGRA	known geothermal resource area
INEEL	Idaho Engineering and Environmental Laboratory (previously INL)
LBNL	Lawrence Berkeley National Laboratory
LLNL	Lawrence Livermore National Laboratory
MCWD	Mammoth Community Water District
MPLP	Mammoth Pacific Limited Partnership
MIT	Massachusetts Institute of Technology
NCG	noncondensable gases
NREL	National Renewable Energy Laboratory
OEC	Ormat® Energy Converter
ORC	Organic Rankine cycles
PPA	Power Purchase Agreement
PTC	Production Tax Credit
R&D	Research and Development
RCRA	Resource Conservation and Recovery Act
RMOTC	Rocky Mountain Oilfield Testing Center
ROW	Rights of Way or Rights of Way

Introduction

This report, Part II of a larger guide to geothermal technology, focuses on surface technology.[+] Part I, published in November 2007, deals with subsurface technology.

Once a reservoir is found and characterized, surface technology, the power plant[^] and related infrastructure, must be designed and equipment selected to optimize the use and sustainability of the resource. The goal is to construct an energy efficient, low cost, minimal-impact plant.

Figure 1: Night at The Geysers

Source: Calpine Corp.

A basic definition offers a useful starting point for discussion: geothermal is, simply, heat from the Earth. It is a clean, renewable resource that provides energy in the United States and around the world. It is considered renewable because the heat emanating from the interior of the Earth—geothermal energy—is essentially limitless and is constantly being regenerated. The Earth's interior is expected to remain extremely hot for billions of year to come, generating heat equivalent to 42 million megawatts[*] of power.[1] If geothermal power plants are managed properly, they can produce electricity for decades or more.

[+] Technology is an important term that is often misunderstood. For more information about the term, along with a basic introduction with details about the significance and background of parts I and II of the technology guide, please visit http://www.geo-energy.org/publications/reports/Geothermal%20Technology%20Part%20I%20-%20Subsurface%20Technology%20(Nov%202007).pdf.

[^] A power plant is a central station where electricity is produced using turbines and generators (*This definition was obtained from The Geysers glossary, http://www.geysers.com/glossary.htm, which includes a variety of geothermal-related terms.*)

[*] One megawatt is equivalent to 1 million watts, and can meet the power needs of about 1,000 homes

ROAD MAP – TOPICS TO BE COVERED

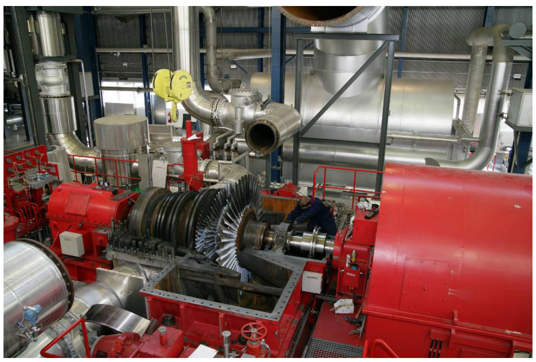
This paper is divided into eleven sections encompassing all major aspects of geothermal surface technology:

- **Geothermal Fluid**: Section 1 informs the reader about the temperature and pressure of the carrier medium, along with the associated impacts and benefits of injection.
- **Power Plant Basics**: Section 2 discusses factors that affect plant size, along with power plant design and construction.
- **Conversion Technologies**: Section 3 addresses the method of converting hydrothermal fluids into electricity.
- **Cooling Types**: Section 4 explores the two types of cooling options available to geothermal developers—air and water cooling.
- **Structuring Power Plant to Minimize Impact**: Section 5 details the mitigation options available to geothermal developers to reduce their power plant's impact.
- **Efficiency**: Section 6 provides an overview of the ways experts classify and discuss geothermal efficiency.
- **Non-Traditional Geothermal systems**: Section 7 offers examples of non-convention methods for producing electricity outside of the standard hydrothermal model.
- **New Technology**: Section 8 highlights some of the most promising new developments related to surface geothermal technology, some of which could usher in a new era of geothermal development.
- **Direct Use**: Section 9 provides a brief overview of one of the oldest methods for using geothermal resources: through direct use applications.
- **Geothermal Heat Pumps**: Section 10 offers information about geothermal heat pumps, which require only a stable underground temperature rather than a geothermal reservoir.
- **New Technology: the Path Forward**: Section 11 concludes with brief remarks about the future of geothermal development—not only related to surface technology, but also to all aspects of the development and production process.

GEOTHERMAL FLUID

Geothermal fluid—a hot, sometimes salty, mineral-rich liquid and/or vapor—is the carrier medium that brings geothermal energy up through wells from the subsurface to the surface. This hot water and/or steam is withdrawn from a deep underground reservoir and isolated during production, flowing up wells and converting into electricity at a geothermal power plant.[2] Once used, the water and condensed steam is injected back into the geothermal reservoir to be reheated. It is separated from groundwater by thickly encased pipes, making the facility virtually free of water pollution.

Figure 2: Turbine and Related Infrastructure at the Svartsengi Geothermal Plant in Iceland



Source: Sudurnes Regional Heating (Oddgeir Karlsson)

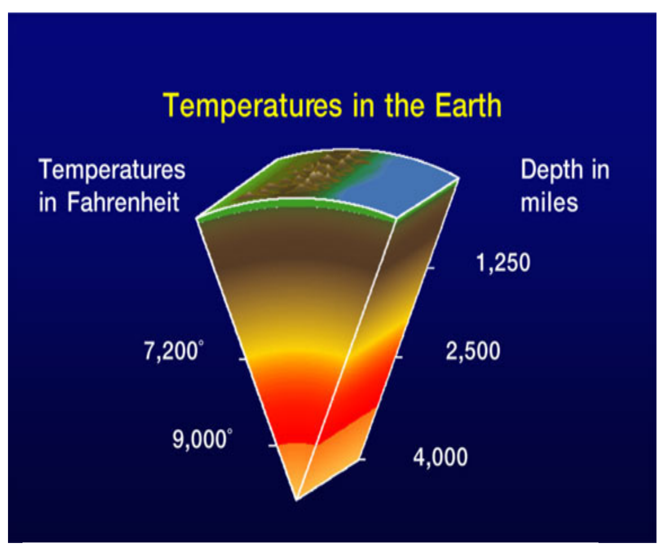
A resource that uses an existing accumulation of hot water or steam is known as a "hydrothermal" resource. While several other types of geothermal resources exist, all producing geothermal plants in the United States use hydrothermal resources.

Characteristics of the geothermal fluid, including temperature, chemistry, and noncondensable gas content (NCG), can influence power plant design.

I. Temperature

Each power plant is designed to optimize the use of the heat supplied by the geothermal fluid. Underground heat can reach thousands of degrees, as show in Figure 3 to the right.

Figure 3: Earth's Temperatures



Source: Geothermal Education Office (GEO)

Geothermal fluids suitable for hydrothermal electricity production generally occupy a range of 200°F, 93°C (low temperature) to 400°F, 204°C (high temperature). The type of conversion technology and size of various components, such as heat exchangers and cooling towers, is determined by the temperature of the carrier medium. As the temperature of the resource goes up, the efficiency of the power system increases (see "Efficiency" for more information).

II. Chemistry

Several chemical characteristics are addressed at the beginning of the power plant design phase, including the NCG content, corrosiveness, and geothermal liquid scaling potential, which may require additional equipment. While flash and dry steam plants may or may not produce gases as part of the conversion process, binary facilities, which function in closed loop systems, produce near zero gas emissions.

A. Noncondensable Gases

Geothermal fluids contain entrained noncondensable gases (NCGs) that may not be easily injected back into the reservoir (see "Injection" within this section for further details). These gases, which accumulate in the condenser, can decrease heat transfer and raise turbine backpressure, thereby lowering turbine performance. Steam is sometimes used in ejectors to remove NCGs, but this reduces the amount of steam available for use in the turbines.

Typically, either steam jet ejectors, vacuum pumps, or a combination are used to remove NCGs.[+] The system's "parasitic load[*]"—as steam in ejectors or electricity that operates vacuum pumps—is reduced through recent improvements in vacuum systems. Reductions in parasitic load will increase the overall efficiency of the system.[3] When parasitic load is decreased, more energy can be used to create electricity.

Steam jet ejectors produce lower plant efficiencies but cost less than vacuum pumps. Because jet ejectors require steam supply, the quantity of steam available for producing electricity is reduced compared with the quantity available using vacuum pumps.[4] Vacuum pumps tend to be more expensive and complex, but are more energy efficient. Therefore a cost-benefit analysis will best determine how and to what extent noncondensable gases should be removed from a geothermal system.

Figure 4: Engineers Working on Turbine at the Svartsengi Geothermal Plant in Iceland

Source: Sudurnes Regional Heating (Oddgeir Karlsson)

[+] For definitions of terms such as "steam jet ejector," "vacuum pump," and other terms, please see the glossary section in the last several pages of this document.

[*] At all plants, some of the electricity produced will be used to run the power plant itself – pumps, fans, and controls require a certain amount of electricity. These loads are often referred to as "parasitic loads."

Though some geothermal fluids contain noncondensable gases, emissions of each of these are significantly lower than those found at fossil fuel power plants.[5] Typically less than five percent of cooling tower noncondensable gases contain regulated toxic substances[6] such as hydrogen sulfide and mercury, discussed below.[+] Even in those reservoirs with regulated gases, developers have no trouble meeting California's stringent standards.

Hydrogen Sulfide

Hydrogen sulfide (H_2S) is a colorless gas that is harmless in small quantities, but is often regarded as an annoyance due to its distinctive rotten-egg smell. Anthropogenic (manmade) sources of hydrogen sulfide account for approximately five percent of total hydrogen sulfide emissions.[7] H_2S emissions vary with type and size of the plant and with the chemical quality of the resource.

During drilling and certain plant maintenance activities at some reservoirs, hydrogen sulfide gases can pose a worker safety issue. Appropriate plant design and drilling safety procedures developed through oil and gas and geothermal experience are therefore implemented, and standards and procedures are imposed by state and federal regulatory agencies.[8] In addition, H_2S is abated at some geothermal power plants where necessary to meet air quality standards. The two most commonly used vent gas hydrogen sulfide abatement systems are the Stretford and LO-CAT.[*] Both systems convert over 99.9 percent of the hydrogen sulfide from geothermal noncondensable gases[9] to elemental sulfur, which can then be used as a soil amendment and fertilizer feedstock. The cost to transport and sell the sulfur as a soil amendment is about equal to the revenue gained from the transaction (see "New Technology" for more information).

Mercury

While federal proposals related to mercury risk have focused on coal, state and local governments have also introduced measures to reduce mercury emissions from other sources. As a result, mercury abatement measures are already in place at most geothermal facilities where mercury is present (though mercury is not present at every geothermal resource). Abatement measures that reduce hydrogen sulfide also reduce mercury: after hydrogen sulfide is removed from geothermal steam, the gas is run through a mercury filter that absorbs mercury from the gas. After removing mercury, the sulfur created from the abatement process can then be used as an agricultural product. The rate of mercury abatement within a facility, which varies according to the efficiency of the activated carbon mercury absorber, is typically near 90 percent, and is always efficient enough to ensure that the sulfur byproduct is not hazardous. The activated carbon media is changed out periodically and is disposed of. Geothermal waste is considered non-hazardous under federal law, Resource Conservation and Recovery Act (RCRA); however it is regulated under California's hazardous waste laws.[10]

[+] More information about air emissions and NCGs can be found in GEA's Environmental report, accessible online at http://www.geo-energy.org/publications/reports.asp.
[*] For detailed information about LO-CAT systems, please visit http://www.gtp-merichem.com/

B. Corrosion

At some resource sites, geothermal liquids can gradually wear away power plant materials by chemical action, a process known as corrosion. Corrosion is particularly problematic at mineral rich resource areas, such as the Salton Sea. Much like rust corrodes a nail, geothermal liquids can corrode the metal components of a power plant (pipes, heat exchanger, tanks, etc.) if resistant materials are not used. Corrosion resistant materials such as stainless steel or titanium can be substituted for more corroded carbon steel. Protective coatings can also be applied to carbon steel at a lower cost than corrosion resistant steel alloys or titanium[11] (further explored under "New Technologies"). Though figures vary widely, using corrosion-resistant materials can reduce costs by around 0.25 cents per kWh.[12]

Figure 5: Corroded Steam Vent at the Old Cove Fort Plant

Source: National Renewable Energy Laboratory (NREL) (Keith Gawlik)

C. Scaling

At some resource locations, dissolved elements produce scaling. Scaling, a type of precipitation, occurs directly on a surface such as a heat transfer surface or pipe wall. Scaling results in dissolved materials that separate from solution, sometimes remaining suspended as small particles or attaching to a solid surface such as a pipe wall. Silica, a sand-like material, is the most common substance that scales out.[13] Other common materials include metallic carbonates and sulfides.[14]

Scaling can be induced by temperature and pH changes. When flashing a liquid to produce steam in separators,* the carbon dioxide (CO_2) originally dissolved in the geothermal liquid is naturally emitted in limited amounts. This creates a positive feedback loop, because the pH increases as a result of the CO_2 emission, which results in further scaling of dissolved liquids.

* See "Glossary" in the final section of this report for definitions.

Figure 6: Scaled and Corroded Tubes from Hoch Geothermal Facility

Source: NREL (Keith Gawlik)

Scaling can be dealt with in a variety of ways. A developer can reduce the heat captured from the geothermal liquid (thereby reducing plant efficiency), add scaling inhibitors, or acidify the geothermal liquid to maintain minerals in solution. More complex equipment may be required to clean the geothermal liquid and control mineral precipitation.[15]

Methods of scale control have improved in recent years, with technologies such as the Crystallizer-Reactor-Clarifier and pH Mod now successfully used at geothermal facilities.[16]

The Salton Sea power plant complex in Imperial County, California, deals with the severe scaling and corrosive potential of its geothermal water through a highly specialized power system. The complex's resource production facility is composed of geothermal liquid/steam separators, crystallizers, clarifiers, steam scrubbers and demisters, geothermal liquid injection pumps and precipitated solids disposal, and components of the steam gathering system. This equipment is virtually unneeded when the geothermal resource directly produces mineral-free dry steam.[17]

Figure 7: Imperial Valley Power Plant

Source: CalEnergy Operating Corp.

One of the advantages of the binary system is avoided scaling. By maintaining the geothermal water under pressure and injecting it at an elevated temperature (above 160^{o}F or 71^{o}C), the dissolved chemical constituents are maintained in solution. This mitigates/prevents scaling of heat exchangers, wells, and piping.[18]

III. Injection

Figure 8: Piping System at the Svartsengi Geothermal Plant in Iceland

Source: Sudurnes Regional Heating (Oddgeir Karlsson)

Hot water and steam gathering systems are the network of pipelines connecting the power plant with production and injection wells. The size and cost of a steam gathering system can be influenced by some or all of the following: site topography, slope stability, size and spread of the steam field, and temperature and pressure of the resource.

Production wells bring the geothermal water to the surface to be used for power generation, while injection wells return the geothermal water and steam condensate back into the geothermal system to be used again. In order to maintain a geothermal system and ensure the continued availability of a resource, geothermal liquids must be injected back into the system. Benefits of injection include enhanced recovery and safe disposal of geothermal fluids, reduced possibility of subsidence, and an increased operational lifetime of the reservoir.[19]

Figure 9: Transporting Geothermal Water at Imperial Valley Power Plant

Source: CalEnergy Operating Corp.

When geothermal water is injected, it runs through pipes and cools to a typical injection temperature of 180^{o}F (82^{o}C).[20] If the cooled geothermal liquid is injected too close to a production well, the resource may cool. If, however, the water is injected too far from the geothermal reservoir, it will not sufficiently replenish the system and reservoir pressure may decline.

Case Study – Injection at The Geysers[21]

One geothermal complex, The Geysers in California, has realized unique benefits from its injection activities. At The Geysers, injection serves the dual purpose of returning geothermal water back into the reservoir and providing an environmentally responsible method for disposing of reclaimed sewage water from surrounding communities. Reclaimed water—primarily sewage water—from Lake County is injected deep into The Geysers reservoir at a rate of approximately 2.8 billion gallons annually. Additionally, about 4 billion gallons annually (11 million gallons of treated wastewater per day) is pumped to The Geysers for injection from cities in Sonoma County.

Figure 10: Injection at The Geysers in California

Source: Calpine Corp.

If not for The Geysers project, the wastewater would be discharged onto fields or into local waterways, causing environmental hazards. This wastewater, normally expensive to manage, now rejuvenates geothermal reservoirs. Though the project has only been implemented at The Geysers, other geothermal sites could follow Calpine's example by partnering with municipalities to use "excess" or "waste" fluids to enhance geothermal facilities while simultaneously reducing waste products.[22]

Figure 11: Transporting Geothermal Water for Injection

Source: GEA (Alyssa Kagel)

POWER PLANT BASICS

Like all conventional thermal power plants, a geothermal plant uses a heat source to expand a liquid to vapor/steam. This high pressure vapor/steam is used to mechanically turn a turbine-generator. At a geothermal plant, fuel is geothermal water heated naturally in the earth, so no burning of fuel is required.

Figure 12: Aerial View of The Geysers

Source: Calpine Corp.

At many power plants, a steam turbine is used to convert the thermal energy extracted from pressurized steam into useful mechanical energy. Mechanical energy is then converted into electricity by the generator.[23] Geothermal plants rely upon one or a combination of three types of conversion technology – binary, steam, and flash – to utilize the thermal energy from the hot subsurface fluids and produce electricity. Each of these processes is described in greater detail in the next section of this report, "Conversion Technologies."

After the thermal energy has been used to turn the turbine, spent steam is condensed back to a liquid and injected into the ground where it is reused in the geothermal system,[24] prolonging the lifetime of a geothermal plant. Electricity is then transported by transmission lines into the regional grid.

Figure 13: Transmission Lines from a Geothermal Plant in Reykjanes, Iceland

Source: Sudurnes Regional Heating (Oddgeir Karlsson)

I. Design and Construction

As one expert notes in his survey of geothermal power plant technology, "Power generation from geothermal resources has been around for more than one hundred years; yet there continue to be advancements made that improve resource utilization, reliability, and economics.[25]"

Although funds for research and development have tended to focus on less advanced subsurface exploration techniques, new surface developments also shape the industry. Surface technology advances improve the viability of a geothermal resource and often provide short-term payback.

Figure 14: Steam Facility at Big Geysers

Source: Calpine Corp.

A power plant typically requires 6 to 9 months to build once the shovel hits the ground and construction begins.[26] However, when the time needed for exploration, discovery, permitting, and other hurdles is taken into account, the entire geothermal development process can last anywhere from three years to seven or more.[27]

A geothermal developer considers a number of factors when building a plant, particularly related to cost and the long-term viability of a project. Power plant designers must find the optimal size of power plant equipment and choose the best-suited technologies and construction materials that deal with site and resource specifics. Resource characteristics and those of the geothermal carrier medium vary in temperature, chemistry, and permeability. Site characteristics vary depending upon weather conditions, water availability, and geological factors such as ground and slope stability.

II. Recent Power Plant Developments – Turbines

Turbine efficiencies have improved in recent years, increasing as much as ten percentage points.[28] At The Geysers, for example, turbines have been designed to more appropriately match current steam conditions and to utilize more efficient and reliable turbine blade technology.[29]

Figure 15: Turbine at The Geysers

Source: Calpine Corp.

Turbines at steam plants (see next section, "Conversion Technologies," for further details) now benefit from longer lasting stage blades and a variety of other improvements.[30]

III. Factors Affecting Plant Size

A. Economies of Scale

Though the size of a power plant is determined primarily by resource characteristics, these are not the only determining factors. In some cases, a larger power plant proves more cost-effective than a smaller version due to economies of scale. A ten megawatt plant, for example, usually requires all the elements of a 50 megawatt plant. And though a few small plants are capable of running virtually by themselves with monitoring, a geothermal plant usually requires a minimum number of people to run, whether the plant is 50 or 100 megawatts.

Certain other construction, operation and maintenance costs must be borne independently of the project's capacity. Remote areas tend to have little existing infrastructure, so many geothermal power plants will require excavation, road building, and electric, phone and other connections.[31] Transmission costs can also be significant regardless of power plant size.

Figure 16: Imperial Valley Workers (Left), Power Plant (Right)

Source: CalEnergy Operating Corp.

B. Transmission

Because geothermal resources cannot be transported distances over more than a few miles without heat loss, geothermal plants must be built at the site of the reservoir and rely upon transmission systems. If new transmission lines are needed to access the regional grid, high costs can sometimes prohibit geothermal development. While larger transmission systems are traditionally more expensive than smaller versions, economies of scale still apply. For example, companies must negotiate and pay for easements and rights-of-way (ROW) if transmission lines cross private or public lands.

Figure 17: High Voltage Transmission Lines in Monterey County, California

Source: California Geothermal Energy Collaborative (CGEC) (Judy Fishchette)

Figure 18: Transmission Substation in Reykjanes, Iceland

Source: Sudurnes Regional Heating (Oddgeir Karlsson)

Transmission costs also depend upon topography, slope stability, site accessibility, and aesthetic sensitivities. The length of transmission lines from geothermal facilities to the grid delivery point can vary significantly. Extreme examples range from 220 miles from Dixie Valley, NV, to Bishop, CA; to two miles from Steamboat Hills, NV, to the delivery point on the Sierra Pacific system.[32] The voltage size of transmission systems can vary considerably as well, depending upon the power involved – from a low of 60 kilovolts (kV) to a high of 230 kV. A typical transmission line averages around 100 kV.

Figure 19: Transmission Infrastructure at Steamboat Facility in Reno, Nevada

Source: GEA (Alyssa Kagel)

C. Resource Uncertainty

All aspects of the power production process must be taken into account when choosing the megawatt capacity of a power plant, and this may lead to the preference for a smaller sized plant—regardless of economies of scale. Because the ultimate reservoir capacity characteristics and response to production can be uncertain at the start of a project, developers may opt to begin small and then gradually expand the use of the resource rather than risk (a) overusing the resource, or (b) spending money on costly power plant infrastructure only to find resource recovery is lower than expected due to misunderstandings of subsurface resource characteristics. In the past, some oversized projects have faced serious problems due to overuse.

The President of Iceland, in October 2007 remarks before the Senate Energy Committee, called the management of a geothermal resource one of the most critical—and often overlooked—elements needed to maintain a geothermal resource.[33] The power plant in the figure below, Nesjavellir, is part of one of the largest geothermal areas in Iceland.

D. Other Factors Promoting Small Size

Large plants can take longer to permit than their smaller counterparts and generally require longer environmental reviews. The production tax credit (PTC), a credit awarded for renewable energy generation, offers yet another incentive for developers to construct small plants. To be eligible for the PTC, developers' plants must begin operation within a challengingly short timeframe. The PTC, which has been cited by many experts as the most important policy needed to move the geothermal industry forward, incentivizes developers to create smaller plants with consequently smaller lead times.

Figure 20: Nesjavellir, Iceland Power Plants

Source: Glitnir Bank

Figure 21: Wineagle Power Plant – a Small 750 kW Plant in California

Source: Davis Power Consultants (Billy Quach)

One final factor promoting smaller units could come from a stipulation in a plant's Power Purchase Agreement (PPA)—the contract to buy the electricity generated by a power plant. A PPA could require a company to first develop a modest number of megawatts, and then gradually work up to a larger output.

E. Average Size

Considering these factors, some experts cite an economically viable geothermal power plant at 20 MW.[34] In practice, plants in the states range from less than one MW to just over 100 MW.

IV. Raw Materials

Geothermal power plants require a variety of raw materials. Some can be difficult and costly to obtain due to competition for limited resources. The cost of steel—which account for 10 to 20 percent of the cost of a geothermal power system – has increased substantially in recent years, particularly due to a demand from China.[35] The steel needs of the oil and gas industry also increase worldwide demand. Other raw materials critical to geothermal development include concrete, oil, fuel (for a drill rig) and lumber.* Some of these costs have doubled in recent years.

Figure 22: Imperial Valley Power Plant

Source: CalEnergy Operating Corp.

* Drill rigs, a component of subsurface technology are in high demand. As a result, they have become more expensive and difficult to secure. See Part I of the Technology report for further details.

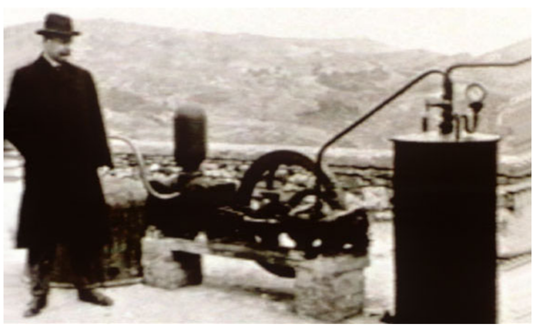
CONVERSION TECHNOLOGIES

A conversion technology represents the entire process of turning hydrothermal resources into electricity. Of the four available to developers, one of the fastest growing is the binary cycle, which includes a Rankine cycle engine.

I. Steam

"Dry steam" plants have been operating for over one hundred years—longer than any other geothermal conversion technology, though these reservoirs are rare. In a dry steam plant like those at The Geysers in California, steam produced directly from the geothermal reservoir runs the turbines that power the generator. Dry steam systems are relatively simple, requiring only steam and condensate injection piping and minimal steam cleaning devices. A dry steam system requires a rock catcher to remove large solids, a centrifugal separator to remove condensate and small solid particulates, condensate drains along the pipeline, and a final scrubber to remove small particulates and dissolved solids. Today, steam plants make up a little less than 40 percent of U.S. geothermal electricity production, all located at The Geysers in California.

Figure 23: First Geothermal Power Plant, 1904, Larderello, Italy

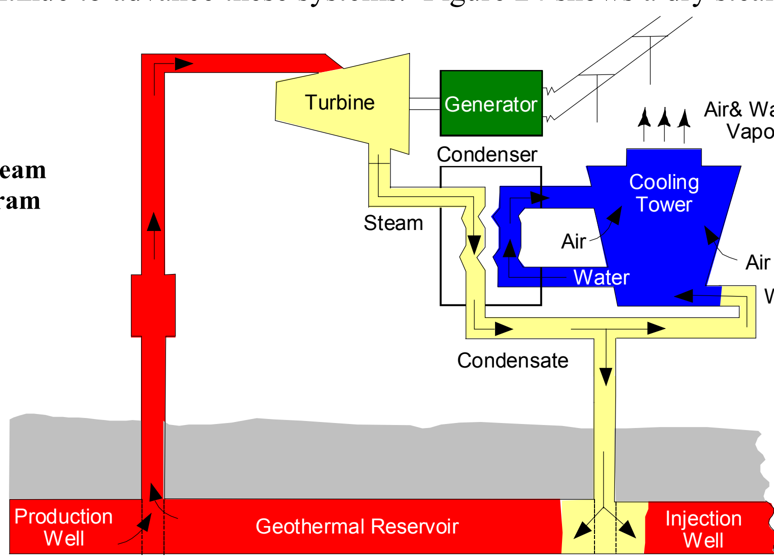


Source: Geothermal Education Office

The basic cycle for steam plants remains similar to the structure that first operated in 1904 in Larderello, Italy, pictured in the figure above. Even so, incremental technology improvements continue to advance these systems. Figure 24 shows a dry steam plant.

Figure 24: Dry Steam Power Plant Diagram

Source: Geo-Heat Center



II. Flash

The most common type of power plant to date is a flash power plant, where a mixture of liquid water and steam is produced from the wells. About 45 percent of geothermal electricity production in the U.S. comes from flash technology. At a flash facility, hot liquid water from deep in the earth is under pressure and thus kept from boiling. As this hot water moves from deeper in the earth to shallower levels, it quickly loses pressure, boils and "flashes" to steam.[36] The steam is separated from the liquid in a surface vessel (steam separator) and is used to turn the turbine, and the turbine powers a generator. Flash power plants typically require resource temperatures in the range of 350 to 500°F (177°C to 260°C).

A number of technology options can be used with a flash system. Double flashing, the most popular of these, is more expensive than a single flash, and could concentrate chemical components if they exist in the geothermal water. Even considering potential drawbacks, most geothermal developers agree that double flash is more effective than single flash because a larger portion of the resource is used.

Figure 25: Well Flowing Steam Through a Silencer at Coso, a Double Flash Plant in California

Source: U.S. Navy Geothermal. Program Office (Frank Monastero)

Figure 26: Imperial Valley Power Plant

Source: CalEnergy Operating Corp.

Steam processing is an integral part of the gathering system for flash and steam plants. In both cases, separators are used to isolate and purify geothermal steam before it flows to the turbine. A flash system requires three or more stages of separation, including a primary flash separator that isolates steam from geothermal liquid, drip pots along the steam line, and a final polishing separator/scrubber. A steam wash process is often employed to further enhance steam purity. All geothermal power plants require piping systems to transport water or steam to complete the cycle of power generation and injection.

Figures 28 and 29 below show schematics of single and double flash-type power plants.

Figure 27: Single Flash Steam Power Plant Schematic

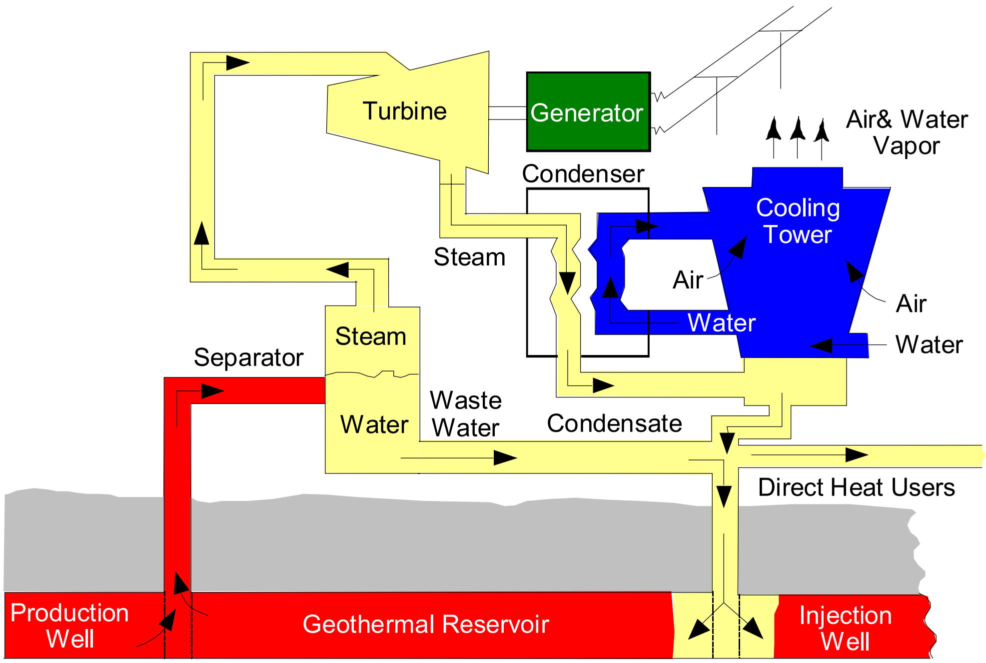
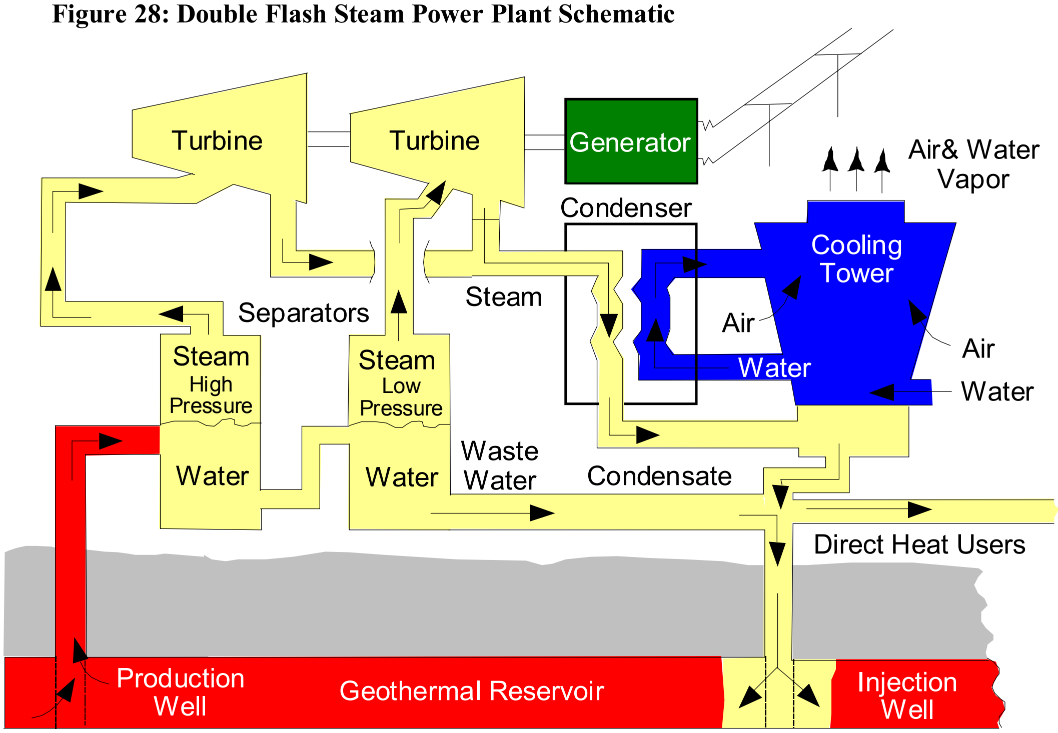


Figure 28: Double Flash Steam Power Plant Schematic



Source (Figures 28, 29): Geo-Heat Center

III. Binary

Technology developments during the 1980s have advanced lower temperature geothermal electricity production. These plants, known as “binary” geothermal plants, today make use of resource temperatures as low as 165°F, or 74°C (assuming certain parameters are in place) and as high as 350°F (177°C). Approximately 15 percent of all geothermal power plants utilize binary conversion technology.

In the binary process, the geothermal fluid, which can be either hot water, steam, or a mixture of the two, heats another liquid such as isopentane or isobutane (known as the “working fluid”), that boils at a lower temperature than water. The two liquids are kept completely separate through the use of a heat exchanger used to transfer heat energy from the geothermal water to the working fluid. When heated, the working fluid vaporizes into gas and (like steam) the force of the expanding gas turns the turbines that power the generators.

Figure 29: Binary Power Plant at Raft River in Idaho

Source: U.S. Geothermal, Inc.

Geothermal fluids never make contact with the atmosphere before they are pumped back into the underground geothermal reservoir. Because the geothermal water never flashes in air-cooled binary plants, 100 percent can be injected back into the system through a closed loop. This serves the duel purpose of reducing already low emissions to near zero, and also maintaining reservoir pressure, thereby extending project lifetime.[37*]

For lower pressure steam, a two phase binary cycle is sometimes used. Two-phase systems are similar to traditional binary cycles, except the steam flow enters the vaporizer/heat-exchanger, while the geothermal liquid is used to preheat the organic motive fluid. The steam condensate either flows into the pre-heater or is combined in the geothermal liquid after the pre-heater. Since the steam pressure in the vaporizer/heat-exchanger remains above atmospheric pressure, the noncondensable gases (NCG) can be reinjected together with cooled-geothermal fluid or simply vented without the need for a power consuming vacuum pump.[38]

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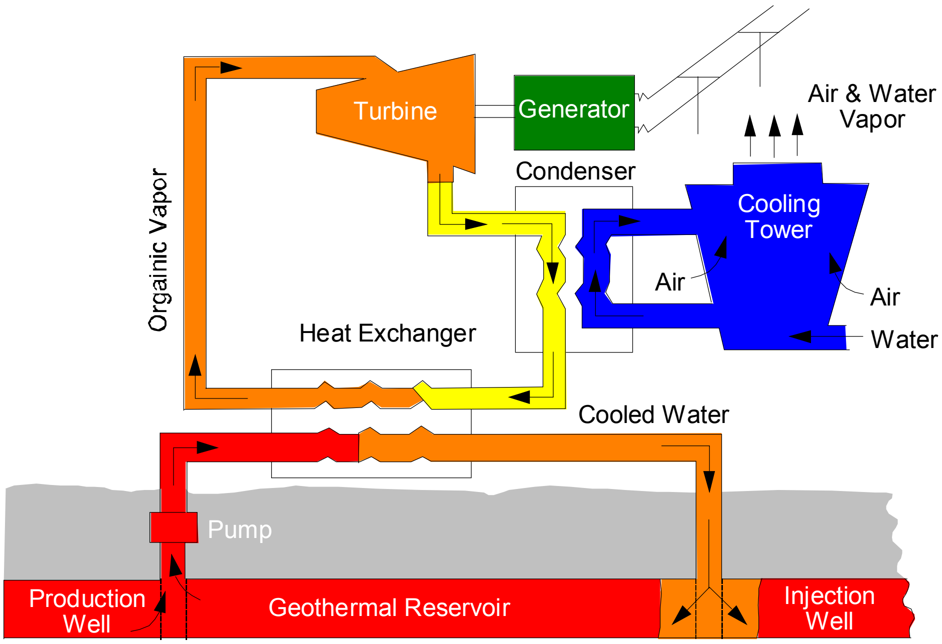
[*] This does not apply to a “two-phase” binary system with a vaporizer

Figure 30: Binary Power Plant Schematic

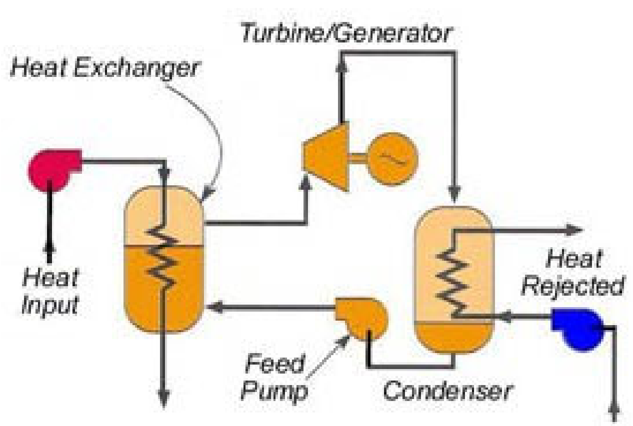


Source: Geo-Heat Center

A. Rankine Cycle

A Rankine cycle, the commercial binary cycle in the United States, converts heat into electricity. Rankine cycles require an organic-based working fluid with a lower boiling point than water, and are thus often used with lower temperature geothermal resources.[39] The four major pieces of the Rankine cycle include the boiler, turbine, cooling tower, and feed pump.[40] The working fluid in a Rankine cycle follows a closed loop and is reused constantly.

Figure 31: Rankine Cycle Schematic



Source: Barber-Nichols

The Rankine cycle, which includes four processes[+] that change the state of the working fluid, has been running geothermal power plants with success for over one hundred years.

Ormat Technologies, Inc.^

Ormat Technologies has led the effort to produce modular, binary Rankine power plants through their Ormat® Energy Converter (OEC) power generation unit. The company has supplied more than 800 MW of geothermal power plants. These power units vary in size, from 250 kW to 130 MW.[*] OECs are designed for outdoor installations within a wide variety of heat sources, including low temperature resources. For example, one of Ormat's small units in Thailand uses geothermal fluids at approximately 210°F.[41] An OEC's main components include a vaporizer/preheater, turbogenerator, air-cooled or water-cooled condenser, feed pump and controls. The OEC is a field-proven, mature commercial product used in 71 countries worldwide.[42]

Figure 32: 200KW OEC in Thailand

Source: Ormat Technologies, Inc.

UTC Power^

In 2000, UTC power engineered a new power system based on organic Rankine cycle (ORC) technology, known as PureCycle®. To understand the power conversion process, UTC suggests thinking of an air conditioner that uses electricity to generate cooling. The PureCycle® system reverses this process and uses heat to produce electricity. The system is driven by a simple evaporation process and is entirely enclosed (like all binary units), which means it produces virtually zero emissions. After the heat is extracted for power, the water is returned to the earth for reheating. UTC Power's PureCycle® system, in cold climates, can operate on 165°F geothermal water and by

Figure 33: Geothermal Power Plant at Chena Hot Springs, Alaska

Source: UTC Power

[+] Wikipedia provides a basic, easy to understand analysis of the four processes. Please follow the link for more information: http://en.wikipedia.org/wiki/Rankine_cycle.
[*] One megawatt is equivalent to 1 million watts (1 thousand kilowatts), and can meet the power needs of about 1,000 homes
^ Sections written with direct assistance from UTC Power and Ormat International, Inc.

varying the refrigerant can use hydrothermal resources up to 300ºF. Previously, experts had assumed that geothermal fluids needed to be in the range of 225ºF to produce economically viable power generation.*

Two PureCycle® 225 kW units are currently operating at Alaska's Chena Hot Springs resort. These are the first PureCycle® units to operate on geothermal energy.[43]

B. Outlook for Binary Systems

The ability to use lower temperature resources increases the number and type of geothermal reservoirs suitable for power production. According to some experts, lower temperature resources suitable for binary cycles will be the most common of all future hydrothermal resources developed.[44]

As binary use has increased, associated power technology has continued to improve. For example, advances in production pumps have allowed for sustained pump run time for years rather than months.[45] Also, binary systems can now operate at lower temperatures than scientists previously thought possible. Improvements will likely continue as conventional energy prices increase. The post-2001 hike in energy prices has led to the replacement and/or expansion of older geothermal generation systems using newer technology, particularly incrementally improved binary technology. In addition, several U.S. geothermal resources discovered in the 1980s are today undergoing their first commercial binary development. These new developments, while substantial, represent only a small fraction of the potential for new generation using binary technology that is being promoted by developers throughout the country.[46]

Figure 34: Puna Flash/Binary Geothermal Plant

Source: Ormat Technologies, Inc.

IV. Flash Binary Combined Cycle^

A combination of flash and binary technology, known as the flash/binary combined cycle,+ has been used effectively to take advantage of the benefits of both technologies. In this type of plant, the flashed steam is first converted to electricity with a steam turbine, and the low-pressure steam exiting the backpressure turbine is condensed in a binary system. This allows for the effective use of air cooling towers with flash applications and takes

* At Chena, the ambient temperature is near the freezing point of water, and the production pumping loads are extremely low due to unusually high reservoir pressure. Based on the climate conditions in the continental U.S., if these units were used in warmer climates than Chena's, they would likely require slightly higher temperature fluids.
+ This technology was pioneered by Ormat Technologies, Inc.

advantage of the binary process. The flash/binary system has a higher efficiency where the well-fields produce high pressure steam. This type of system has been operating in Hawaii since 1991 at the Puna Geo Venture facility.

For a high enthalpy water-dominated resource, the most effective power plant configuration may be integration of a combined cycle for the steam and a standard binary unit for the separated brine into one unified plant. In this case, each unit operates with common controls, fluid collection, and reinjection systems.[47] The developer must closely monitor the injection water temperature in combined cycle systems, as declines could occur that lead to scaling. As with any geothermal conversion technology, proper management is critical.

V. Choosing a Conversion Technology

Resource characteristics—temperature, pressure, volumes of fluid produced, and chemical properties of the geothermal reservoir—are the primary determinants of the size and type of power conversion equipment. Assuming sufficient volumes of fluid are produced, temperature determines the most efficient conversion design.[48]

While binary plants can utilize any temperature resource, low temperature resources are constrained to the binary model. Medium temperature resources can be economical by using either flash or binary systems.

Figure 35: Imperial Valley Power Plant

Source: CalEnergy Operating Corp.

High temperature resources are most economical when steam or flash systems are employed, as these are simpler and therefore less costly. Flash systems are less expensive than binary systems, but may not be as efficient at lower temperatures.

Steam plant equipment costs rise as temperature decreases (as a result of efficiency losses). Despite a more complex design, binary power systems are generally less expensive than steam systems for temperature close to 350°F. The cost of binary systems rises as temperature drops.[49] Binary systems may be preferred in highly sensitive environmental areas, since they operate as closed-loop, virtually emissions-free systems.

Figure 36: Aerial View, Imperial Valley Power Plant

Source: CalEnergy Operating Corp.

COOLING TYPES

A cooling system, which condenses the working fluid, is essential for the operation of any modern geothermal power plant. A cooling tower provides a greater temperature and pressure differential across the turbine to increase efficiency. The larger this differential, the greater the driving force across the turbine, and the greater the efficiency.[50] Since the earliest days of the industrial revolution, improving the condensing (cooling) process has been a prime concern of scientists and engineers.[51]

Advances during the past few years have improved the cooling process. For example, high efficiency fills* offer low-cost, compact towers that enhance air-to-water contact. New fills can improve the flow of the geothermal resource, reduce clogging, and assist with cleaning insoluble materials. The use of fiberglass structures rather than wood for cooling towers can improve both cost and fire resistance.[52]

Developers have two basic cooling options: water or air cooling. Hybrid air-water cooled systems have been demonstrated to a limited extent and are considered important for future advancement (see "New Technology" for more information).

Both air and water-cooled systems use cooling fan motors. Some maintenance is required, typically an annual check-up of fan motors and belts as well as system lubrication.

Figure 37: Power Plant and Water Cooling Towers at Aidlin Part of The Geysers Complex

Source: Calpine Corp.

* For definition, see "Glossary."

I. Water Cooled

Most power plants, including most geothermal plants, use water-cooled systems – typically in cooling towers. As these are more efficient, they generally require less land than air-cooled systems. Water-cooled systems are less expensive to build and operate if water is readily available and inexpensive to obtain. These systems lose most of the water to the atmosphere by evaporation in the form of water vapor,[53] while the remainder is injected back into the system. Emissions from a wet cooling tower (i.e. water vapor plus dissolved solids or minerals) depend upon the quality of the geothermal liquid injected back through the system.

Figure 38: Raft River Plant in Idaho

Source: U.S. Geothermal, Inc.

While today water cooling is mostly used in higher-temperature non-binary facilities due to the use of the geothermal fluid for cooling, a few existing and developing binary facilities in the U.S. utilize water-cooled systems. The binary plants at Heber, East Mesa and Wendel-Amedee, all in California, use water cooling. The Raft River geothermal plant, the first in Idaho, is a binary facility that uses water cooling.

II. Air Cooled

Because the efficiency of power generation is affected by the difference between the temperature of the fluid exiting the turbine and the temperature of the cooling medium, air-cooled systems are influenced by seasonal changes in air temperature. These systems can be extremely efficient in the winter months, but are less efficient in hotter seasons when the contrast between the air and water temperature is reduced. Plant efficiency typically increases by 15 percent during colder months and decreases by 15 percent during warmer months.[54] This means that an air-cooled plant is least efficient during summer peak energy demand, which typically takes place during the hottest hours of the day due to air conditioning.

Figure 39: Cooling Tower on Steam Plant

Source: The Ben Holt Co.

The ideal temperature difference between the air and the resource is 200°F (93°C) for an air-cooled system. Air cooling is beneficial in areas where extremely low emissions are desired, where water resources are limited, or where the view of the landscape is particularly sensitive to the effects of vapor plumes (as vapor plumes are only emitted into the air by water cooling towers). While air-cooled systems are only used at binary facilities today, these could theoretically be used with any geothermal conversion technology.

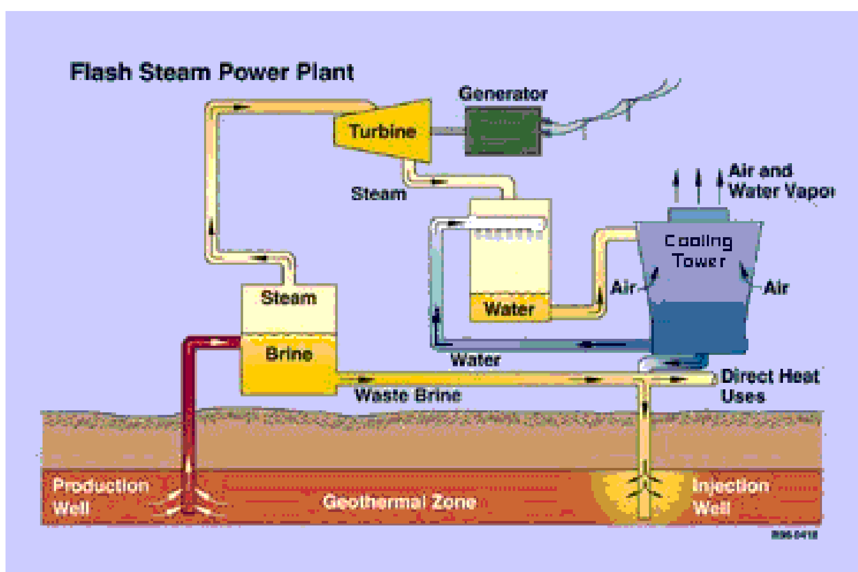


Figure 40: Diagram of Geothermal Power Plant with Water-Cooled System

Source: Idaho National Lab (INL)

III. Choosing the Right Cooling System for a Site

Climate and altitude can impact cooling technology. Water cooling is very efficient in hot dry climates; air cooling is most efficient in cool climates; and in hot humid climates where efficiency for both technologies is reduced, either may be applied.[55] Other factors to consider include water and land availability, value of power during hot months, aesthetics, and environmental issues.

Because water-cooled systems require biotic and sometimes chemical water treatment to prevent algae blooms or mineral deposition, some developers claim that operation costs of air-cooled systems are lower than those of water-cooled systems.[56] However, the upfront cost of an air-cooled system is higher per kilowatt than a water-cooled system. As is typically the case, a developer must consider upfront versus lifetime costs.

Figure 41: Sonoma Power Plant, Part of The Geysers Calpine

Source: Calpine Corp.

Figure 42: Imperial Valley Power Plant and Cooling Towers Alongside Farmland

Source: CalEnergy Operating Corp.

Structuring Power Plant to Minimize Impact

While a geothermal power plant's impact is relatively small compared to that of a fossil fuel plant, geothermal operators still take steps to mitigate any negative affects caused by development.[57]

I. Noise

A variety of noise muffling techniques and equipment are available for geothermal facilities. During drilling, temporary noise shields can be constructed around portions of drilling rigs. Noise controls can be used on standard construction equipment, impact tools can be shielded, and exhaust muffling equipment can be installed where appropriate. Turbine-generator buildings, designed to accommodate cold temperatures, are typically well-insulated acoustically and thermally, and equipped with noise absorptive interior walls.

Figure 43: Aidlin Drill Rig, The Geysers

Source: Calpine Corp.

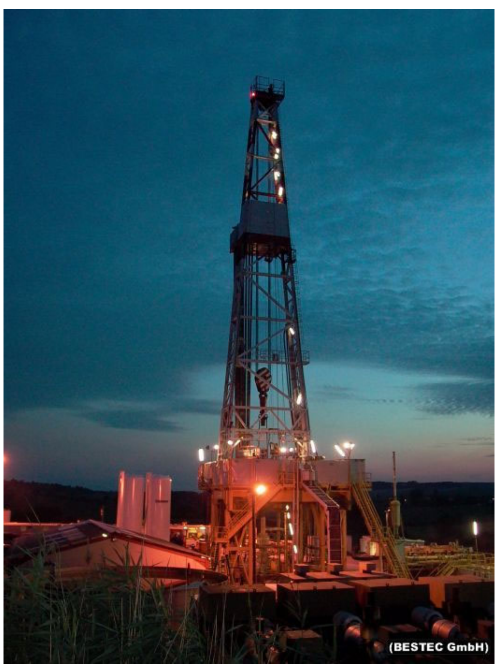
II. Visual Impacts

Visual impacts related to geothermal development include night lighting on the power plant, visibility of the transmission line, and the presence of plumes at facilities using water-cooled systems. Fossil fired power plants have all of these visual effects and more. Detailed site planning, facility design, materials selection, landscaping programs, and adjustment to transmission line routing are key aspects of geothermal operations that can reduce impacts. Developers may paint their power facility forest green to blend in with the surrounding landscape. Additionally, some companies use non-specular conductors, which reduce reflection and glare on transmission lines. As the Fourmile Hill Environmental Impact Statement found, even within a strictly managed recreational area, "with mitigation, which is an integral part of the project, the proposed project would be consistent with policies in the Klamath National Forest Land Resource Management Plan regarding visual resources."[58]

Figure 45: Steamboat Power Plant Blending into its Surroundings

Source: GEA (Alyssa Kagel)

Figure 44: Night Drilling at Geothermal Power Plant



Source: Geo-Heat Center

Other visual impacts, such as construction equipment, are only of concern on a temporary basis. Construction vehicles, drill rigs, and other heavy equipment impact the visual quality of an area for a limited amount of time.

III. Mitigation to Reduce Impact on Wildlife and Vegetation

Figure 46: Healthy Greenery at Steamboat Power Plant Site

Source: GEA (Alyssa Kagel)

Geothermal plants are designed to minimize the potential effect on wildlife and vegetation. Pipes are insulated, which prevents thermal losses and protects animals from burns if they contact the pipes. Spill containment systems are constructed, and areas with sensitive biological or cultural/archeological resources and threatened or endangered species are avoided. Pipelines are built high or low to help minimize impacts to wildlife movement. Geothermal plants do not cause additional disruption from offsite drilling, the construction of pipelines over long distances (as is typically necessary for natural gas transportation), and mining and transportation of coal and uranium ores.

Figure 47: Imperial Valley Power Plant and Productive Farmland

Source: CalEnergy Operating Corp.

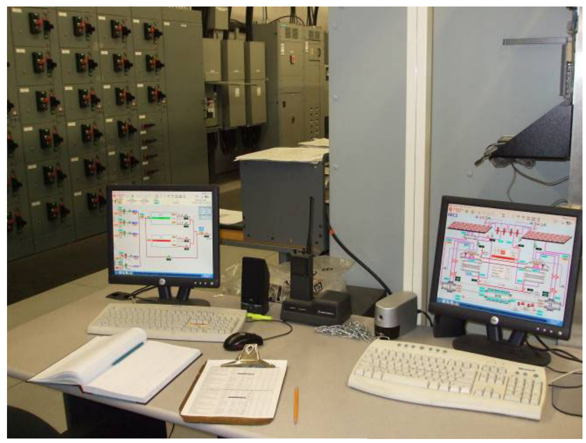
III. Monitoring Activities

Monitoring is a key component of geothermal maintenance and mitigation. Ongoing monitoring activities could include but are not limited to well pressure, water chemistry, surface site, subsidence, biological resources, and deep temperature monitoring. Most mitigation measures are set forth in permitting conditions and environmental documents available for public review.

IV. Maintenance

Geothermal plants are designed to fit the resource of the plant site. Reservoir chemistry can vary dramatically from one resource to another. California's Salton Sea area, for example, has some of the most mineral-rich geothermal water anywhere in the world. This can create challenges caused by corrosion and scaling. The facility at Mammoth Lakes, with a resource comparatively lower in mineral concentration, requires less maintenance.

Figure 48: Power Plant Control Room



Source: GEA (Alyssa Kagel)

Figure 49: Maintenance at The Geysers

Source: Calpine Corp.

On average, geothermal plants are available for power generation 97 percent of the time. Plants are typically off-line near three percent of the time due to routine scheduled maintenance as part of the power cycle management process.[59] By proactively inspecting parts, wear and tear-associated problems are kept to a minimum.

Like any facility, a geothermal plant can be impacted by fire, lightning, a wind storm, or other natural disasters. Geothermal developers are prepared for such unlikely occurrences, both in their mitigation and their maintenance techniques. Stop-gap emergency measures are typically put in place. For example, the Beowawe plant in Nevada automatically shuts down in case of emergency and can be operated remotely. Improvements in computers and digital instruments have lowered the cost and increased the capabilities of automation systems.[60] The Amedee plant, located in

California, runs by itself. If it detects a problem, it automatically radios the operator to come to the site.

Figure 50: Amedee Plant, Inside (Top) and Out (Bottom)

Source: Davis Power Consultants (Billy Quach)

EFFICIENCY

Efficiency is broadly defined as the ratio of the output to the input of any system. All thermal power plants have a fraction of "waste heat." While efficiency is an important measure of power generating facility performance, comparing efficiency values for geothermal and other renewable technologies, as well as for fossil fuels, poses significant challenges.[61]

The public interest in energy efficiency arose as a fossil fuel issue: that is, the less fuel used per output, the fewer emissions and the greater quantity of depleting fuels conserved. Burning fossil fuels to generate electricity contributes to climate change, health problems, and ecosystem damage. As fossil fuel resources become scarcer, costs skyrocket. That's why efficiency—maximizing the energy output from a quantity of burned fossil fuel—is so important for traditional power plants.[62]

The American Council for an Energy Efficient Economy (ACEEE) has pursued increased coal plant efficiency as a means for reducing emissions. According to ACEEE, coal plants grandfathered[*] by the clean air act "emit 3–5 times as much pollution per unit of power generated as newer, coal-fired power plants and 15–50 times as much nitrogen oxides and particulates as new combined-cycle natural gas power plants.[63]" Older and less efficient plants have 15 percent higher average heat rates per unit of generation than modern combined-cycle plants, according to ACEEE.

For renewable energy use, in contrast to fossil fuel use, efficiency is primarily an economic concern. Maximizing the output per input of available energy is still important, but the public issues are confined primarily to land use, not climate change, health and conservation issues. Unlike geothermal and other renewables, fossil fuel use is not sustainable even if managed properly and used efficiently.[64]

At a geothermal facility, the fuel source is not burned. That means air emissions are substantially lower than at a fossil fuel facility. Because the geothermal resource—the fuel source—doesn't have to be shipped from far-off locations, there is no environmental impact related to transportation as with traditional resources. The geothermal resource is continuously available and highly reliable. Geothermal power plants regularly inject geothermal liquids back through the reservoir, thereby improving the lifetime of the plants. While both conventional plants and geothermal plants must reject heat to the surroundings – a consequence of the Second Law of thermodynamics, discussed in further detail below – geothermal plants result in more heat rejection per unit of useful power output than conventional plants.[65]

Besides more obvious distinctions related to emissions and sustainability, other technology and resource differences must be considered when comparing efficiencies. Resource temperature is one important factor. At fossil fuel facilities, resources can

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[*] The 30-year-old U.S. Clean Air Act (CAA) allows old power plants built before the law to circumvent many air emissions standards because it was assumed that such plants would be decommissioned in the near term.

reach temperatures of 1,000°F (538°C) or higher. At geothermal power plants, in contrast, temperatures are lower because resources are heated naturally, within their natural confines, rather than through external heating. Because efficiency decreases with lower temperature resources, the quantity of heat input required to produce a given megawatt output increases, and so too does the percentage of that input that must be rejected as waste heat.[66] In geothermal plants, in contrast to fossil fuel plants, more of the energy resource is needed to produce the same output of electricity. That's because more low "quality" energy sources (e.g., resources at lower temperatures) are needed to produce the same electrical output,[67] and geothermal resource temperatures are lower than coal temperatures.

Figure 51: Steam Hood at the Hellisheiði Geothermal Plant in Iceland

Source: Reykjavik Energy (Gudmundur Sigurvinsson)

The geothermal industry has, over the years, worked to define geothermal efficiency in a way that can be easily understood by the general public and compared across technologies, while accurately and fairly characterizing the renewable energy resource.

The issue is further complicated because experts use a variety of efficiency categorizations, depending upon the context in which an efficiency measurement is needed and the characteristics of the resource and plant. Some of these efficiency measurements cannot be equitably compared.

What follows is a selection of some of the ways in which geothermal efficiency can be described. Rather than choosing any one efficiency description over another, this section seeks to identify several of the most popular ways of assessing geothermal efficiency.

I. First Law of Thermodynamics

The First Law of Thermodynamics states that energy cannot be created or destroyed; it can only be converted from one form to another.[68] The First Law is used to categorize "the performance of cyclic conversion systems like fossil-fired, steam power cycles or geothermal cycles. This efficiency is a measure of the portion of heat added to a power cycle that is converted to work, i.e., the ratio of net work produced to the heat added to the cycle."[69] The first law is a conservation law (Law of Conservation of Energy). Regarding geothermal power plants, "the 1st Law requires that any electricity that is generated (energy out) must balance with the energy extracted from the geothermal resource +/- any other energy uses and losses to the environment.[70]"

The First Law does not distinguish between the potential type and quality of energy that is received or delivered by a plant. This means that high quality, concentrated energy that can be used to produce electricity is not valued any more than dispersed, low-grade heat energy incapable of producing electricity.

II. Second Law of Thermodynamics

The Second Law provides direction to the First Law:[71] while energy can neither be created nor destroyed (First Law), important limitations exist in the capacity of energy to do useful work. The Second Law states, in simple, generalized terms, that heat can never be converted completely into work, because some of the energy must flow from high temperatures to a low temperature sink. This means that100 percent efficiency is impossible. Second Law efficiency is defined as the ratio of the net work to the available energy.[72]

Available energy, also referred to as exergy or availability, is the amount of work that can be completed using ideal thermodynamic processes to bring a fluid into equilibrium with a heat reservoir. "It differs from energy in that it is consumed or dissipated during processes that change a fluid's entropy," or measure of disorder of a system. These processes include heat transfer processes, pressure rises in pumps, compressors and fans, expansions in turbines, pressure drops in piping, etc. The Second Law efficiency measures how "efficiently the power cycle converts available energy into work.[73]"

Second Law efficiencies depend upon a number of factors, including the sink temperature of the power plant. The larger the temperature difference between the heating source and cooling sink, the more efficient a plant will be, assuming all other factors are the same.

Plant developers may purposely limit the temperature of the geothermal fluid leaving the plant to prevent mineral precipitation (primarily silica). "When this temperature limit is imposed, some define Second Law efficiency based on a modified available energy term that uses the minimum temperature instead of the ambient, or sink temperature as the reference condition. Second Law efficiencies defined in this manner will be higher in magnitude.[74]"

III. Comparing First and Second Law Efficiencies

Second Law efficiencies are generally, but not always, higher than First law because the available energy term (used in Second Law efficiency calculations) tends to be less than the quantity of heat removed from the geothermal fluid (First Law). Other, more subtle differences can sometimes mean that a plant at which Second Law efficiency is made higher through improvements or adjustments will actually result in a lower First Law efficiency.

IV. Carnot Efficiency

Carnot efficiency is often used to discuss geothermal power plants and heat engines in general. Binary plants, unique among geothermal conversion types, exist in closed power cycles. As such, power cycle definitions are often considered the most appropriate mechanism through which to categorize binary efficiency.

A. Carnot Cycle

An ideal, frictionless engine in a closed power cycle is known as a Carnot cycle. A Carnot cycle involves four processes[*] and represents the maximum First Law efficiency possible in a specified system.[75] A Carnot Engine is reversible and runs in a cycle, with all of its heat exchanges taking place at a source temperature and a sink temperature. A working engine operating between two heat temperature limits can never exceed Carnot efficiency. Even an ideal, frictionless engine can't convert 100 percent of its input heat into work.

Some geothermal experts prefer to use other vehicles to set the thermodynamic limit on cycle efficiency for geothermal binary plants. The main reason for this is that geothermal is a variable temperature process—a geothermal liquid enters a plant at a high temperature and cools off as it moves through the plant—while Carnot assumes a heat source operates at a constant temperature.

B. Triangular Cycle[76]

One expert has suggested that the Triangular cycle is the more appropriate ideal cycle upon which to base the maximum binary efficiency. A Triangular cycle recognizes that a heating source cools rather than remains at a constant temperature as it transfers heat. An ideal Triangular cycle will more closely mirror a working binary plant without imposing Carnot's "unreasonably high bar."[77] Carnot and Triangular cycles are identical in the first two processes. However, the Triangular cycle adjusts for temperature differences in the last half of the cycle: ideal Carnot efficiency assesses the difference between the heat source and heat sink as a fraction of the heat source; ideal Triangular efficiency assesses that same difference (i.e., heat sink subtracted from heat source) as a fraction of the heat

[*] For more information about Carnot and the four processes involved, please visit http://web.mit.edu/16.unified/www/SPRING/propulsion/notes/node23.html.

source considered *along with* the heat sink. The distinction is more succinctly represented in the equations below:[78]

Ideal Carnot Efficiency: $(T_H - T_L) / (T_H)$

Ideal Triangular Efficiency: $(T_H - T_L) / (T_H + T_L)$

Where T_H = absolute temperature of the heat source and T_L = absolute temperature of the heat sink.

Ideal Triangular cycle efficiencies will always be lower than ideal Carnot cycle efficiencies for the same temperature limits.[79]

Figure 52: Geothermal Geyser

Source: GEA

V. Efficiency Using Power and Flow Measurements

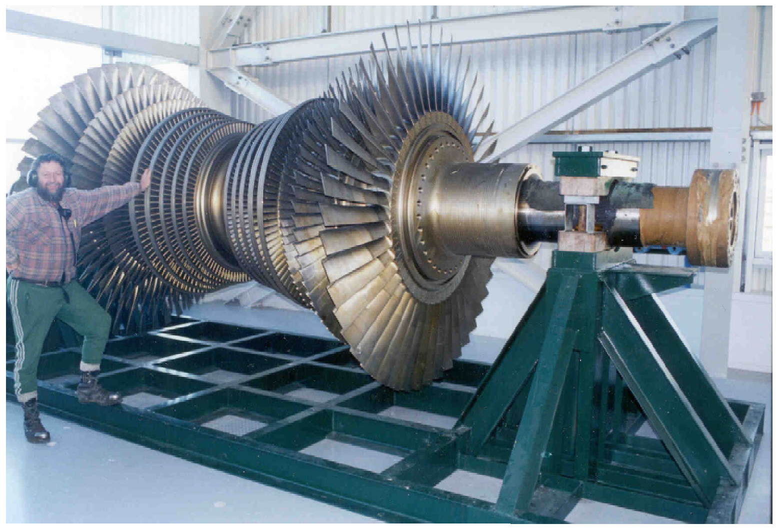
One way to measure efficiency without using the First or Second Law is through power and flow measurements.[80] Such measurements can be classified as either Specific Power Output (SPO) or Specific Geofluid Consumption (SGC).[81] SPO, which can be used for any type of geothermal power system, considers the amount of net power produced per unit flow of geothermal fluid. For given resource conditions, the higher the SPO—typically measured in watt hours per pound or kilogram of geothermal fluid—the more efficient a plant is. The geofluid flow rate needed to produce a certain net power is termed the SGC, which is the inverse of the SPO.[82] SGC measures the flow rate per unit power produced.[83]

Some experts consider this the simplest and most effective measurement of efficiency.[84] Dividing the SPO by the available energy is one way to measure the Second Law efficiency.[85]

VI. Turbine Efficiency[86]

Rather than considering the efficiency of the entire conversion system, another method for rating geothermal efficiency is to consider certain power plant components. The turbine, for example, provides a useful measurement. A turbine is a steam-powered machine that causes a shaft—a rotating rod that transmits power or motion from the turbine—to produce electricity through movement. Improvements in turbine design in the past several years have increased geothermal turbine efficiency to over 85 percent.[87]

Figure 53: Turbine Blade at Lardarello, Italy Geothermal Facility



Source: Geo-Heat Center

VII. Gross Versus Net Efficiency

When parasitic load is reduced at a facility, a plant will operate more efficiently. Gross plant efficiency includes the parasitic load in its assessment, while net plant efficiency only considers the electricity that can produce power (total power minus parasitic load). As a result, gross plant efficiency will always be higher than net efficiency.

VIII. Assessing Efficiency Measurements

While efficiency is important, it is only one characteristic among many that must be considered when choosing the most appropriate energy option for a particular location. Other factors, such as reliability, cost, environmental impact, and sustainability must also be considered.[88] A significant "energy cost," is associated with producing and transporting fossil fuel for use at a power plant,[89] while the associated costs at a geothermal facility are minimal.

When efficiency assessments must be made, a single number will be meaningless unless the calculations and assumptions used to arrive at that number are made transparent. For example, if a fossil fuel power plant developer cites its "efficiency" as 40 percent, and a geothermal developer cites a similar number, these two plants do not necessarily have the same efficiency.

To begin to assess efficiency values, an inquiry must be made into any calculations used. In many cases, two efficiency numbers should not even be compared because they measure two different types of efficiencies. As has been shown, efficiency can be represented in a variety of ways, all of which can be useful and accurate depending upon the situation and the needs of the developer. The point is not to choose one method of calculating efficiency over another. Rather, it is to consider efficiency as one of many factors that can influence power plant development preferences; and then to show which efficiency method is chosen, which calculations and adjustments are made, and why.

Figure 54: Geothermal Transmission Lines Reykjanes, Iceland*

Source: Sudurnes Regional Heating (Oddgeir Karlsson)

* The steam in the background comes from the Svartsengi geothermal plant.

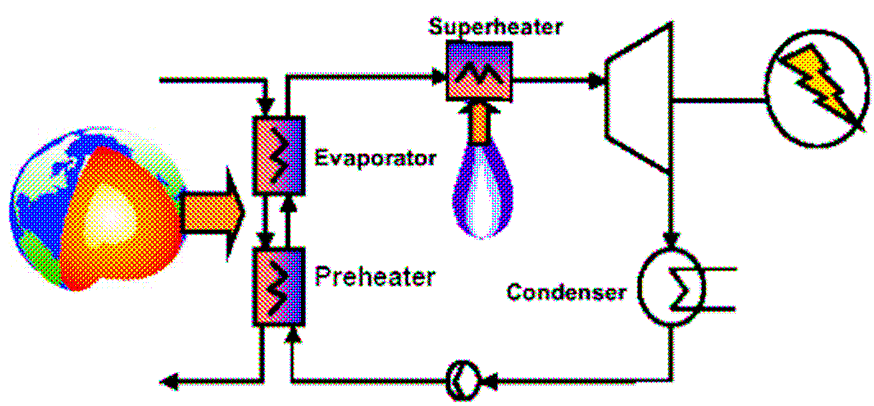
NON-TRADITIONAL GEOTHERMAL SYSTEMS

Most of today's geothermal electricity comes from traditional geothermal conversion technology that integrates no other types of resources into the system. While a significant undeveloped hydrothermal resource base is available, several other technology applications have been considered, or are emerging, that could further expand geothermal potential. Still other applications have already been successfully demonstrated and used commercially. What follows is a rundown of some of these applications, with particular focus upon power plant infrastructure.

I. Geothermal Hybrid Systems

Hybrid systems, which pair a geothermal hydrothermal resource with another type of resource, offer the flexibility of determining the optimal steam temperature independent of the geothermal source temperature. This adds increased reliability to the system design.[90] Hybrid systems can increase efficiency, and therefore create more electricity without expanding the use of the geothermal resource.[91] In figure 55 below, the energy source for the first two heat exchangers is geothermal; the energy source for the third (labeled "Superheater"), could come from any other source, including biomass, coal, or hydropower.

Figure 55: Geothermal Hybrid Power Plant System



Source: Workshop on Geothermal Reservoir Engineering (T. Kohl)

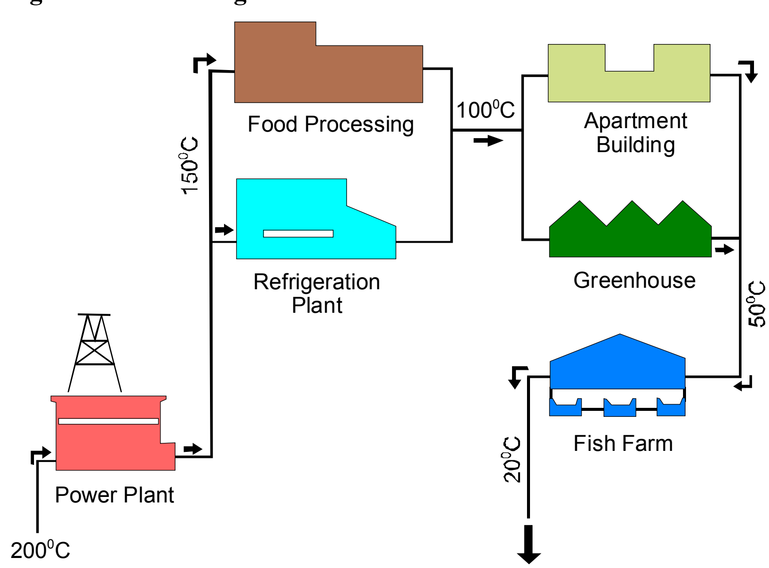
A. Biomass

Geothermal can be used in conjunction with biomass. The company Infinifuel Biodiesel, for example, has constructed a biodiesel processing facility at a small Nevada geothermal power plant in Wabuska. At this facility, camelina oil seed algae is transformed into diesel fuel. The facility is almost entirely self-contained, largely due to heat supplied by a geothermal plant. The plant works by growing algae, crushing or pressing these materials into vegetable oil and biomass, adding the biomass to alcohol, and, finally, mixing the biomass/alcohol combination with vegetable oil and heated it using geothermal power for the biodiesel plant. This geothermal facility, which uses 220°F (104°C) water, produces enough power to run the Wabuska facility and sell additional power. Infinifuel plans to expand to other locations in Nevada and beyond.[92]

B. Combined Heat and Power[93]

At certain resource locations and under favorable circumstances, geothermal resources can be used both to produce electricity and also for direct use purposes (see "Direct Use" for more information). This hybrid model is known as "combined heat and power," or CHP. CHP increases net efficiency, improves power plant economics, and creates jobs. CHP essentially takes the "waste" heat produced by geothermal electric plants and uses it for other useful purposes. Cascading water from a geothermal power plant provides energy for direct use projects such as district heating (and possibly cooling), greenhouse and fish pond heating, industrial applications, and spa and pool heating. CHP has been used on a commercial basis at several sites around the country. Figure 56 shows a diagram of a combined heat and power geothermal facility. [94]

Figure 56: CHP Diagram



Source: Geo-Heat Center

Figure 57: Svartsengi Geothermal Plant and Blue Lagoon, Iceland

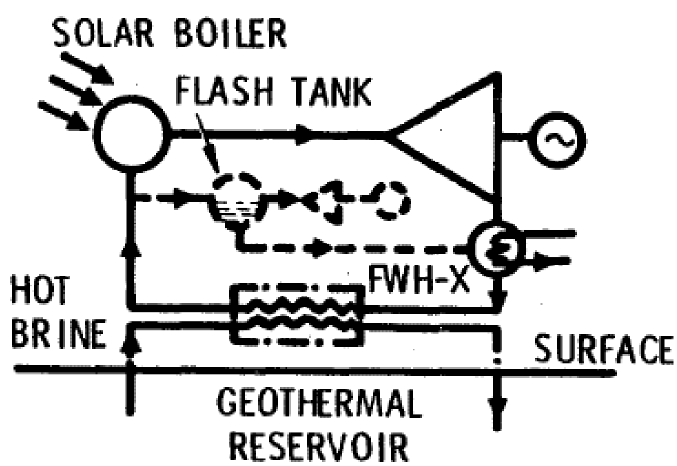
Source: Sudurnes Regional Heating (Oddgeir Karlsson)

Another example of the combined use of geothermal electricity and direct-use heating is highlighted in one of Iceland's top tourist attractions, the Blue Lagoon. At this location, geothermal water from a working geothermal power plant is piped directly to a large body of water, the Blue Lagoon. The water is said to offer healing properties due to its unique array of minerals, silica, and blue algae.[95] While the Blue Lagoon is a great success in Iceland, similar applications have not been constructed at large-scale U.S. power plants. In the figure above, the Blue Lagoon is pictured in the upper right-hand corner.

C. Solar

The U.S. Department of Energy (DOE) has considered solar-geothermal hybrid electric power systems on and off for decades. In 1979, a hybrid concept was considered where wellhead fluid was pressurized, with solar heat added prior to flashing. Such a system was assumed to provide higher quality steam and thermodynamic advantage over a conventional geothermal flash system, but the introduction of hotter than usual geothermal liquid resulted in increased scaling and corrosion. The study conducted by the DOE in 1979 concluded that while geothermal-solar hybrid systems would be comparatively more efficient than stand-alone geothermal plants, hybrids would not offer economic advantages over stand-alone systems. This conclusion has been replicated in subsequent years. Solar-geothermal hybrids may, however, be more cost-effective than stand-alone solar facilities. Figure 58 on

Figure 58: Solar-Geothermal Hybrid Facility



Source: U.S. Department of Energy (DOE)

the previous page shows the solar-hybrid configuration from the 1979 DOE Study. [96]

Solar has also been proposed as a means to hedge risk associated with geothermal production. In such solar-geothermal hybrid scenarios, a geothermal power plant capacity is proposed that is higher than the "proven capacity" derived from reservoir engineering assessments of the geothermal resource. A larger power plant size results in higher initial income but also a higher probability of more rapid resource depletion. To offset the risk that, after five or ten years of operation, resource depletion might impact generation, the power plant would be constructed so that its heat supply could be supplemented by solar, thereby maintaining generation. Although this kind of solar-geothermal hybrid was more widely discussed in 2007, its engineering and economics have not been published and no such project has been formally announced. [97]

One new idea that has been proposed, though not commercially implemented, involves the use of solar and geothermal energy to recover oil from depleting oil and gas fields. Solar Augmented Geothermal Energy (SAGE), according to an abstract presented at the University of Texas, converts depleting oil and gas fields and comparable reservoir strata to "synthetic geothermal" reservoirs over wider regions. SAGE stores/banks solar energy, using naturally occurring geothermal liquids, for geothermal power generation, while enhancing oil recovery.[98]

D. Hybrids with Heat Pumps

A separate application of geothermal energy, geothermal heat pumps, can be used in combination with any other electricity source. Geothermal heat pumps make use of the natural heat trapped below the surface of the earth that averages 65^{o}F (18^{o}C). This heat provides cooling in the winter and warming in the summer. Unlike hydrothermal electricity production, direct use systems do not require a geothermal reservoir. Geothermal heat pumps function like traditional heat pumps: they can heat, cool, and, if so equipped, supply a house with hot water, yet they are significantly more efficient that traditional heat pumps, allowing the user to become less dependent upon the electric grid for heating and cooling. Though any electricity source can be used to power a geothermal heat pump, using renewable power makes the pump 100 percent green.

E. Geopressured Resources

One particularly promising geothermal-fossil fuel hybrid is known as a "geopressured" system.[*] A geopressured geothermal facility operates on both natural gas and geothermal fuel. Geopressured geothermal resources have not been tapped since they were successfully demonstrated almost two decades ago, when oil and gas costs were low.[99] Today's increasing oil and gas costs make the economics of geopressured applications look particularly promising.

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[*] For more information about geopressured resources, please download GEA's *Subsurface Technology Report*, available at http://www.geo-energy.org/publications/reports.asp and review pages 61 – 62.

Demonstration Project: Pleasant Bayou

The Department of Energy embarked on a project to demonstrate geothermal geopressured resources in the 1980s at Pleasant Bayou in Texas. The original concept as defined in the DOE document was to tap into three forms of energy: heat from the geothermal resource (thermal energy), energy from natural gas in the reservoir (chemical energy), and well head pressure (mechanical energy). Due to cost considerations, in the Pleasant Bayou demonstration plant only the thermal and chemical energy were captured. Exhaust heat generated from the onsite burning of the natural gas was recovered to improve cycle efficiency.

Figure 59: Pleasant Bayou Facility

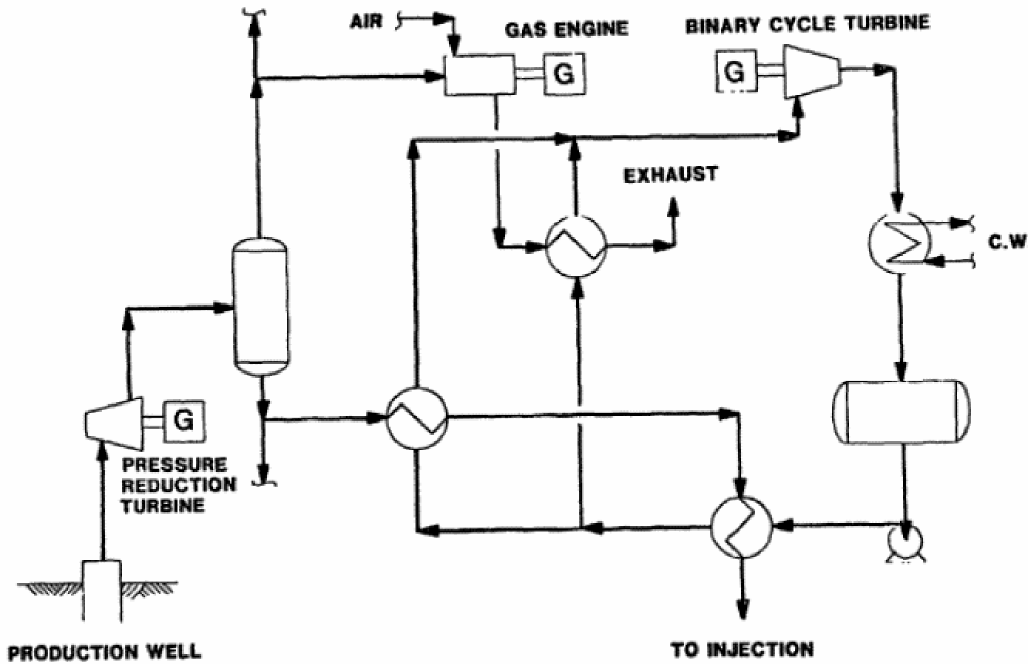
Source: The Ben Holt Co.

The one megawatt geothermal geopressured project was tested in October through December 1989. The demonstration ran January through May of 1990.[100]

The design power plant output was 905 kW, with slightly over half of the power derived from the gas engine. Though the capacity factor was decreased due to a 3-day plant outage and a 4-week turbine outage, the overall plant availability was 97.5 percent.

During the 121 days of operation, 3,445 MWh of electricity were sold to Houston Power and Light. According to experts associated with the project, there were no major technical problems—carbon deposits accumulated in the exhaust gas heat exchanger, but these were easily removed. Scale inhibitors were used successfully to control scale in the production well at the facility.[101] Figure 60 on the next page shows a geopressured geothermal use diagram.

Figure 60: Hybrid Cycle Flow Diagram



Source: The Ben Holt Co.

II. Enhanced Geothermal Systems (EGS)

Enhanced Geothermal Systems (EGS) have recently gained much attention as a promising application for geothermal energy. A Massachusetts Institute of Technology (MIT) report[102] discusses possible modifications to the design of a power plant that captures resources through EGS technology. According to the report, EGS technology could be used through existing geothermal power systems, including binary, flash-binary combined cycle, double-flash plant, or single flash plant (with several adjustments in power plant components). EGS resources are similar to traditional hydrothermal resources, except they include one or all of the following: (1) a dense rock reservoir through which liquid cannot easily pass (one that lacks the usual needed porosity and permeability), (2) insufficient quantities of steam and/or hot water and, (3) deeper than usual drilling depths.[103*]

Highest temperature resources, known as supercritical geothermal systems, would need so-called "triple-expansion systems." These are variations on double-flash, with the addition of a "topping" dense-fluid, back-pressure turbine. The turbine is designed to handle the very high pressures likely to be found with EGS geofluid. However, these systems would require great depths, deeper than 4.7 miles (7.5 km) except for very few

[*] For more information about EGS resources, please download GEA's *Subsurface Technology Report*, available at http://www.geo-energy.org/publications/reports.asp and review pages 53 – 58.

areas in the United States according to the maps in Tester et al.[104] Thus standard EGS systems utilizing binary or flash plants are more likely to be developed in the near term.[105]

Because EGS has not been successfully demonstrated to date, researchers can only postulate about the power plant that will be needed. However, certain aspects of EGS technology could impact power plant choice. These include:[106]

- Fluctuations in noncondensable gas content
- Temperature variations of the heat source
- Flow variations of the resource
- Size of the power plant

III. Oil and Gas Co-production

An oil field co-produced resource makes use of wells already drilled by oil and gas developers. These wells are either deep enough to encounter hot water, or could be deepened into hot zones.[107]

In certain water-flood fields in the Gulf Coast region of the United States, 95 percent of the production out of an oil and gas well is water. To the oil industry, producing hot water is at best a nuisance. It is difficult to handle, costs money to pump, and has to be reinjected at an additional cost. Capturing this waste heat and running it through a binary cycle offers the possibility of a revenue stream. Because most fluid produced at oil and gas wells is already passed to a central collection facility for hydrocarbon separation and water disposal, water can easily be run through binary geothermal cycles using existing infrastructure. This application is economic even on a small scale due to the elimination of upfront costs: wells are already drilled and the resource is known to exist. This geothermal application, using small-scale binary units, could significantly increase geothermal's national and global reach.[108]

Case Study: Rocky Mountain Oilfield Testing Center

Ormat Technologies, Inc. signed an agreement with the U.S. Department of Energy in December 2006 to explore the feasibility of oilfield co-production at the DOE Rocky Mountain Oilfield Testing Center (RMOTC), near Casper Wyoming. RMOTC contains unused hot water sources higher than 190°F (88°C) at flow rates sufficient for generation of roughly 200 kW. The Ormat unit that will be used is similar to the 250 kW air-cooled unit that has been producing electricity from 212°F (100°C) geothermal water for more than six years at an Austrian resort. Similar low temperature, small-scale Ormat units are in place in Nevada, Thailand, and Mexico (see figure 61).[109] The Ormat-supplied power unit at RMOTC is scheduled for delivery in January 2008.[110]

Some 8,000 wells similar to those at RMOTC have been identified in Texas by geothermal researchers.

Figure 61: 200KW OEC in Thailand, 300 kW OEC in Mexico

Source: Ormat Technologies, Inc.

IV. The Outlook for Non-Traditional Geothermal Power Systems

Some of the non-traditional systems discussed in this section, including EGS and oil and gas co-production, show great promise. Some have been demonstrated (geopressured) or even used commercially (CHP) but could be significantly expanded in the future. Still other non-traditional systems, such as solar-hybrids, are not as cost-effective as standalone geothermal systems, despite efficiency increases. The commercial and technological viability of each of these non-traditional systems requires not only research and development, but also demonstration projects. Geothermal investors are generally wary of incurring the extra risk associated with trying out a new system before any other developer, especially when the high upfront costs of traditional systems are taken into account. Many developers say they'll be the first in line to construct the second model, but they can't afford to take the risk to construct the first.

NEW TECHNOLOGY

The value of new technological innovations varies from site to site. At The Geysers, for example, where noncondensable gases influence electricity output, a major improvement for the future could be to upgrade the gas removal equipment for added flexibility, thereby handling a wider range of noncondensable gas concentrations in the steam.[111] At resource locations without noncondensable gases, such innovation would be of little value to developers.

What follows is a sample of some promising new developments in geothermal surface technology. It is not an exhaustive list, nor is it an evaluation of which technology is better than another. Rather, this section offers a selection based on discussions with geothermal experts.

I. Near Term Versus Long Term

Incremental technology improvements—those that marginally increase the efficiency of a particular power plant component, for example—might prove most valuable in the near term. Geothermal power plants can always benefit from reduced parasitic load, reduced power expenditures related to cooling fans, improvements to the power substation, and other modest technological advances. Incremental improvements can be commercially implemented more quickly than larger, more revolutionary advances, and can be incorporated into existing designs with comparatively lower risk.

Major surface technology advances, in contrast, typically require considerable research, field experience, and technology trials, along with multiple field applications, before industry and investors are willing to incur the added risk associated with large-scale innovations.[112] Major technology advances could be equally or even more valuable than incremental advances over the long term, but the former will likely be implemented commercially only after years of research, development, and field experience.

II. Increasingly Standardized, Modular Geothermal Conversion Systems

Modular energy conversion systems have already been engineered by existing geothermal companies. Even so, some experts believe modular systems continue to hold promise for further cost reductions. Modular components and subcomponents reduce costs because they can be pulled from off-the-shelf designs that are standardized and mass-produced. Once a plant site is established, a developer can move ahead more rapidly with plant development using modular systems. More costly custom-engineered modules tend therefore to be needed only on a limited basis. Modularity allows developers to more easily add capacity after a reservoir has been found to be capable of additional production.[113]

Increasing modularity does not necessarily indicate small size. Modular units can be in the hundreds of kilowatts or the hundreds of megawatts. Smaller power plants may be more promising in non-traditional power applications, such as oilfield co-production, but larger plants will continue to play a role as new technologies such as EGS become commercially viable.[114]

III. Mineral Recovery

Further research and development could make the separation of minerals from geothermal water, known as mineral recovery, a viable technology. Some geothermal fluids contain significant concentrations of dissolved minerals, while others are virtually mineral free. Mineral recovery offers several benefits, which generally fall into categories of either improving the function of the power plant (reducing scaling, allowing greater power production by lowering the injection temperature), or increasing profits (through the sale of mineral byproducts). Often a variety of benefits will result. Minerals found at geothermal power plants include zinc, silica, lithium, manganese, boron, lead, silver, antimony and strontium.

Figure 62: A Power Plant at the Salton Sea

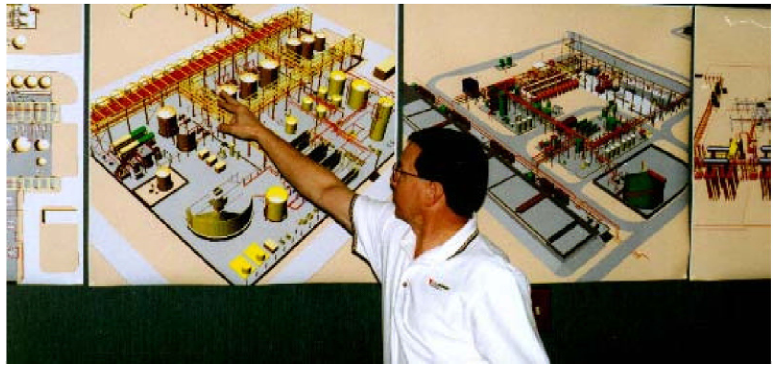
Source: CGEC (Judy Fischette)

A. CalEnergy Zinc Recovery

CalEnergy Operating Company embarked upon an ambitious mineral recovery project at one of its Salton Sea facilities, Elmore, through 1998. For a 10-month period, the company extracted 41,000 lbs of high-grade zinc, an abundant mineral in their geothermal liquid, at a demonstration facility. The facility used a combination of already existing technologies modified for the task: ion exchange, a solvent extraction, and “electrowinning” to extract zinc from the used geothermal liquid. After the metal was extracted, the geothermal liquid was injected back into the geothermal reservoir.[115]

In 2004, after months of operational and economic difficulties, the CalEnergy mineral recovery project ceased operation and liquidated its assets.[116] Still, most agree success is possible and even likely given adequate R&D and financial assistance. With the sharp rise in commodity prices over the last five years, mineral recovery projects look particularly profitable for the future.[117]

Figure 63: CalEnergy Vice President of Operations Jim Turner Describes Minerals Recovery Facilities

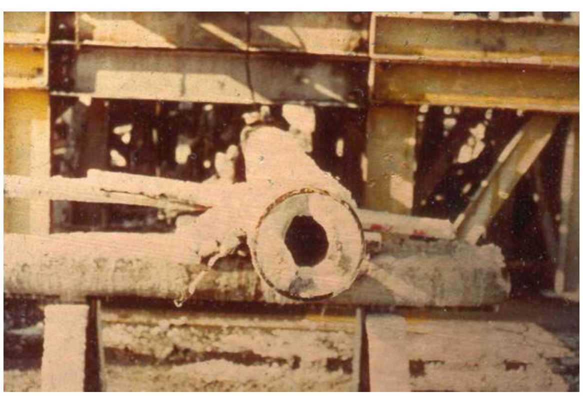


Source: GHC Bulletin (Ted Clutter)

B. Silica Recovery

While silica can be a useful additive in products such as paint, paper, tires, and toothpaste, it negatively impacts geothermal power plants by clogging pipes, wells, and heat exchangers. DOE has designated silica as one of the most promising minerals suitable for recovery due to its high commercial demand and its potentially negative impact on geothermal systems when not removed or reduced.[118]

Figure 64: Silica Scaling from the Lardarello Field in Italy



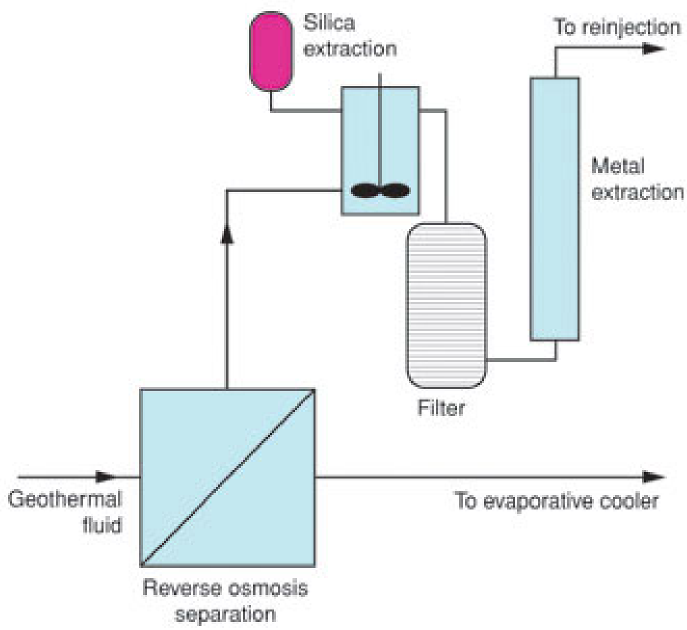
Source: Geo-Heat Center

Lawrence Livermore National Laboratory (LLNL) has developed a technology for extracting silica from geothermal water. Silica extraction increases the efficiency of a geothermal power plant, provides a marketable silica byproduct, and produces freshwater that can be used as a heat exchanger coolant. In the Livermore extraction process, geothermal water is separated into freshwater and concentrated brine (heavily salted water) by a reverse-osmosis separation process. The freshwater is used for evaporative cooling, and the concentrated brine is pumped into a reactor where chemicals are added and silica is extracted. If other minerals are present in the silica-free brine, these can be extracted, and the mineral-mined water is finally pumped to a surface pond and injected into the subsurface.

Case Study: Mammoth Pacific

In 2002, LLNL scientists, in collaboration with other agencies, worked with managers at the Mammoth Pacific power plant complex (known as MPLP) in Mammoth Lakes, California to remove silica from the geothermal water. Because the silica content of the geothermal water at MPLP is low compared to typical geothermal water, the co-produced silica is of high, marketable quality. However, the low silica content makes conventional methods for silica recovery less effective than at average geothermal facilities.

Figure 65: Silica Extraction Diagram



Source: Lawrence Livermore National Lab (LLNL)

To begin the silica extraction process at Mammoth, the geothermal water is tapped after passing through the heat exchanger and before injection, where it undergoes reverse osmosis. This process concentrates the silica, which then flows through a stirred reactor where salts or polyelectrolytes—synthetic chemicals used to clump solids—are added to induce silica precipitation. The simple silica molecules bond together to form colloids, which are silica particles about 10 to 100 nanometers in size. These larger molecules cluster to form particles that can be removed by filters downstream from the reactor.[119]

Figure 66: Silica Recovery at Mammoth

Source: LLNL

Preliminary results suggested in 2006 that silica recovery at Mammoth Lakes could reduce the cost of geothermal electricity production by 1.0¢/kWh. The market value of silica that could be produced from the Mammoth Lakes site if silica is removed from all geothermal liquid is estimated to total $11,000,000/year.[120]

LLNL is also considering using reverse osmosis to separate lithium, cesium, rubidium and tungsten. However, these activities have not yet been pursued.[121]

Case Study: Caithness Power Plants[122]

Brookhaven National Laboratory (BNL), in collaboration with several private and institutional partners, developed a method for extracting silica out of three geothermal sites owned by Caithness Operating Company—Dixie Valley and Steamboat Springs in Nevada, and Coso in California. BNL tested reaction parameters such as temperature, pressure, pH, concentration of reagents, and aging for their impacts on the properties of silica products. BNL also tested a silica surface modification process on produced silica to increase its marketability. The data was used to predict silica production and analyze projected costs. BNL won a 2001 R&D 100 Award[123] for developing the technology, but further research and development at BNL has since halted on the project. Experts involved in the Caithness demonstration project are confident commercialized mineral extraction has a viable future.[124]

Figure 67: Silica

Source: U.S. DOE

C. Future Outlook

Mineral recovery continues to be an issue of interest to the geothermal community. At many geothermal facilities, valuable mineral species may be available at high concentrations, but extraction of pure species tends to be difficult, expensive, and risky. For this reason, some combination of government and private sector funding is needed if this process is to occur more frequently and successfully in the U.S.[125] Recent increases in commodity prices over the past five years make the potential economics for mineral recovery even more promising then it has been in the past.

IV. Working Fluids for Rankine Cycle Power Plants

Studies at National Renewable Energy Laboratory (NREL), Idaho National Laboratory (INL), and elsewhere have shown that mixed working fluids in binary-cycle geothermal power plants can potentially reduce thermodynamic inefficiencies in the boiler and condenser, thereby improving overall plant efficiency. Researchers have investigated various pure and mixed working fluids to optimize power conversion efficiency. One potential working fluid, especially suitable for lower temperature resources, is ammonia-water as used in the Kalina cycle.

Figure 68: Kalina Power Plant in Husavik, Iceland

Source: Glitnir Bank

The Kalina cycle uses a mixture of 70% ammonia and 30% water as the working fluid. The fluid is vaporized using the geothermal water as the heat source. Because the ammonia-water mixture boils over a range of temperatures,[126] its temperature through the vaporizer aligns closely with the geothermal water temperature, improving the thermodynamic efficiency of the heat transfer process. However, this alignment can result in a smaller temperature differential between the geothermal water and the working fluid, which can require greater heat exchanger surface area. And while Kalina affords a higher thermodynamic efficiency because the cycle reduces so-called thermodynamic irreversabilities, the split ammonia and water streams add complexity to the system and may require additional pumping power.

Plant operators and developers offer differing views about the potential for the Kalina model to improve upon Rankine-type power plant performance. However, many experts see the possibility for marketability in the future. One challenge is that the Kalina cycle has not yet been commercially verified in the U.S., making it difficult for developers to secure investors. A solution may be for the government to provide cost-shared projects with industry, so as to verify the viability of any new power conversion cycle. This process of cost-sharing and verification is important for all emerging geothermal technologies.[127]

Kalina systems have so far been installed commercially at two facilities worldwide: the first, a 1.3 MW plant installed in 1998 at Sumitomo Metals Kashima Steelworks in Kashima, Japan, is a waste heat application. The second is a 1.8 MW plant installed in 1999 in Husavik, Iceland that continues to run successfully.[128]

Raft River and Rankine Cycle

The Raft River project developed by the company U.S. Geothermal is the first commercial geothermal plant to come online in Idaho. According to a Director at the company, U.S. Geothermal proposed using a Kalina cycle system after reviewing the available efficiency data. But investors, already wary of geothermal's high upfront risk, were unwilling to fund the project using a technology that hasn't been commercially proven in the United States. As a result, U.S. Geothermal's Idaho plant will use a Rankine cycle system.[129]

Figure 69: Raft River Power Plant in Idaho

Source: U.S. Geothermal, Inc.

V. Hybrid Cooling Systems

Experts site hybrid cooling as one of the most important areas for surface improvements. In an increasingly water-constrained world, air cooling will likely become the preferred cooling option. However, the relative inefficiency of air-cooled systems during the summer, when the temperature differential between the air and water is reduced, has proven in some cases to be a liability. On days with extremely hot conditions, some plants put out half the power they'd produce on a cold day. [130]

Figure 70: NREL Scientist Working on a Cooling System

Source: NREL

Due to the increasing demand for both efficiency and water resources, NREL and INL investigated ways to improve the heat transfer effectiveness of air-cooled condensers. The NREL concept, according to the lab's R&D website, "involves the use of perforated fins in which all air flows through the perforations. Tests of two prototypes at NREL and associated computer modeling indicated that 30 to 40 percent more heat transfer could be obtained for the same fan power with a hybrid as opposed to a stand-alone air-cooling system."

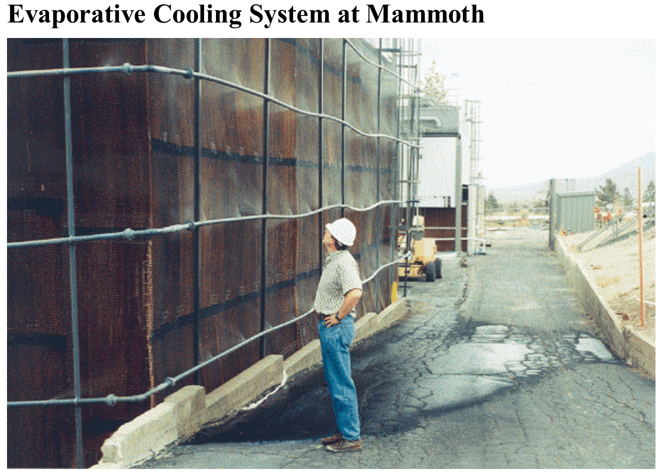
To investigate ways of using air and water cooling together, NREL analyzed the cost and performance of four different ways to augment air cooling with evaporative cooling.[131]

Case Study: Mammoth Pacific Cooling System[132]

Hybrid air-water cooling systems are in use today at Mammoth Pacific power plant complex, located in Mammoth Lakes, California. Though water-assisted air cooling is expensive, Mammoth's PPA rewards high output in the summertime, so the DOE-assisted air-water cooling system is especially beneficial to Mammoth developers. As an added incentive, tertiary treated sewage water of adequate quality became available from the Mammoth Community Water District (MCWD) that assisted with air cooling.

In 2001, the water-assisted air cooling project began. A pipeline brought MCWD wastewater to the Mammoth complex for use in systems of three different technologies designed to lower the dry bulb temperature. Systems were originally installed on all three power plants, but in 2001 the water-assisted cooling project was confined to the facility with smaller air condensers, so as to allow for small-scale testing. After large-scale testing and design improvements were subsequently implemented, developers

Figure 71: NREL Researcher Looks at Hybrid Evaporative Cooling System at Mammoth



Source: NREL (Keith Gawlik)

successfully tested geothermal fluid as a water supply for evaporative cooling in 2003. The hybrid cooling system is still in place at Mammoth; however it has not yet been installed at other geothermal facilities.

VI. Coatings[133]

Figure 72: Researchers Testing PPS Coatings at Puna Power Plant

Source: NREL (Keith Gawlik)

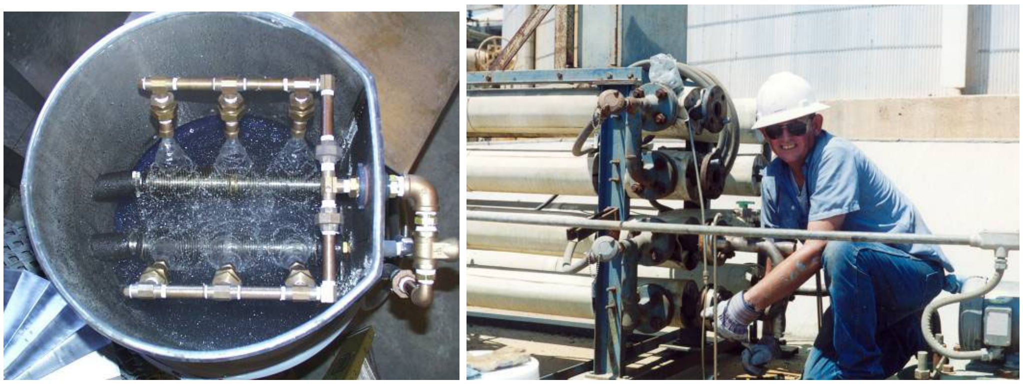
Corrosion and deposition of mineral scale (known as fouling) can occur at geothermal resource areas with high concentrations of dissolved and suspended solids, such as the geothermal water at the Salton Sea in California. When scale accumulates over time, it can clog pipes or vessels and decrease the effectiveness of heat exchangers. Fouling can be controlled by the use of chemical additives to keep scale from forming or by periodic cleaning fouled surfaces, but these practices add to operating costs. Traditionally, expensive materials such as high-alloy steel and titanium have been used to reduce corrosion. However, these do not transfer heat well, and can cost at least three times as much as traditional materials.

In order to reduce the cost of maintaining open flow paths and efficient heat transfer, Brookhaven National Laboratory (BNL) developed durable, scale-resistant polyphenyl sulfide-based coatings for carbon steel. These coatings can be used for heat exchangers—devices which transfer heat through a conducting wall from one fluid to another—as well as for binary cycle power plants, piping, flash vessels, and other plant components. Coatings applied to carbon steel are less expensive than alloys, deliver equivalent corrosion protection, and are easier to clean than stainless steel and titanium.[134]

When carbon steel tubes coated with a thermally-conductive coating variant were field tested by the National Renewable Energy Laboratory and compared to a high-alloy alternative, the coating variant resisted fouling and maintained heat transfer as well or better than the high-alloy. In locations where geothermal fluid is particularly mineral laden or corrosive, coated carbon steel may be a good alternative to more expensive construction materials.

In figure 73 below, coatings are being tested for resistance to direct brine spray (left); and coated heat exchanger tubes are being tested at the Hoch power plant in the Salton Sea known geothermal resource area (KGRA) (right).

Figure 73: Coatings Tested at Mammoth and Hoch Facilities



Source: NREL (Keith Gawlik)

Coatings are also useful with air-cooled systems. Spraying air-cooled condensers with water increases the efficiency of the system, but tends to corrode the heat exchanger fins. Researchers at BNL and NREL have therefore considered different coatings to apply to aluminum fins used in air-cooled heat exchangers to prevent corrosion. [135]

Figure 74: PPS (Polyphenylene Sulfide)-coated Replacements Being Installed

Source: NREL (Keith Gawlik)

In figure 74 to the left, a coated acidic steam vent is replacing a plain carbon steel component that corroded after only a few months. The new coated vent resisted corrosion after over a year of exposure to acidic steam.[136]

While coatings have been used commercially in military, nuclear, and petroleum facilities, they have not yet been applied commercially to geothermal applications.[137]

VIII. New Technology in Context

Some of the "new" geothermal technology discussed in this section has already been explored decades ago, during the 1980s. At this time, funding for the DOE Geothermal Technologies Program reached its peak, and large companies with oil and gas interests began to explore geothermal prospects. Much of the geothermal innovation in the 80s was driven by high energy prices. However, after the energy price collapse in 1986, a few projects were completed but very little geothermal development was pursued in the U.S. Some industry experts believe the initial promise of 1980s technology was under-exploited following the 1986 energy price collapse.[138] In today's world of skyrocketing energy prices and increased concerns over pollution, water, and greenhouse gases, developments in geothermal surface technology are shifting back into focus.

Figure 75: Mammoth Pacific Power Plant

Source: NREL (Keith Gawlik)

DIRECT USE[*]

Geothermal resources, through geothermal hot springs, have been used directly for centuries. Though hot springs are still used today, geothermal water can now be used directly (known as "direct use") for an expanded variety of uses, primarily related to heating and cooling. The main utilization categories are swimming, bathing and balneology; space heating and cooling, including district energy systems; agricultural applications such as greenhouse and soil heating; aquaculture application such as pond and raceway water heating; and industrial applications such as mineral extraction, food and grain drying.[139]

Direct uses work best with temperatures between 70 and 300^{o}F (21 and 149^{o}C). Resources in this range are widespread and exist in at least 80 countries at economic drilling depths. No conversion efficiency losses result when resources are used in this range, and projects can use conventional water-well drilling and off-the-shelf heating and cooling equipment (allowing for the temperature and chemistry of the geothermal water). Most projects can be online in less than a year.

Figure 76: Klamath Falls District Heating System

Source: Geo-Heat Center

Projects can be built on a small scale ("mom and pop operations") such as for an individual home, single greenhouse or aquaculture pond, but can also be built on a large scale such as for district heating/cooling, food and lumber drying, and mineral ore extraction.

In modern direct-use systems, a well is drilled into a geothermal reservoir to provide a steady stream of hot water. The water is brought up through the well, and a mechanical system—piping, a heat exchanger, and controls—delivers the heat directly for its intended use.[140]

Care must be taken to prevent oxygen from entering a direct use system, as geothermal water is normally oxygen free, and dissolved gases and minerals such a boron, arsenic, and hydrogen sulfide must be removed or isolated to prevent corrosion, scaling, and harm

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[*] Source for Section: Lund, John (June 2007). *Characterization, Development, and Utilization of Geothermal Resources.* Geo-Geat Center Quarterly Bulletin. Vo. 28, No. 2. ISSN 0276-1084. Retrieved November 16, 2007, from http://geoheat.oit.edu/bulletin/bull28-2/bull28-2-all.pdf.
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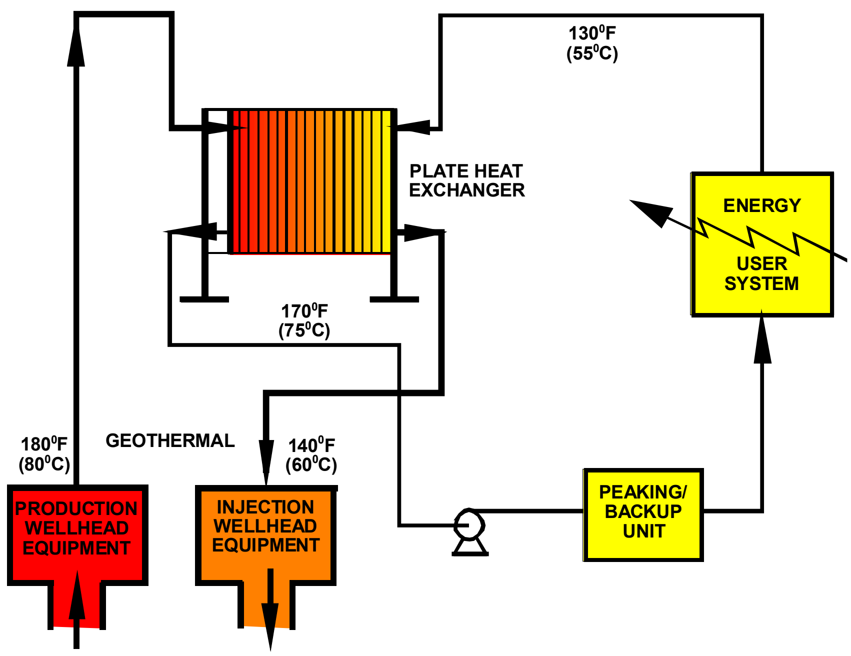
to plants and animals. Carbon dioxide, which often occurs in geothermal water, can be extracted and used for carbonated beverages or to enhance growth in greenhouses. The typical equipment for a direct-use system is illustrated in Figure 77 below, and includes downhole and circulation pumps, heat exchangers (normally the plate type), transmission and distribution lines (normally insulated pipes), heat extraction equipment, peaking or back-up generators (usually fossil fuel fired) to reduce the use of geothermal water and reduce the number of wells required, and water disposal systems (injection wells).

Figure 77: Typical Direct use Geothermal Heating System Configuration

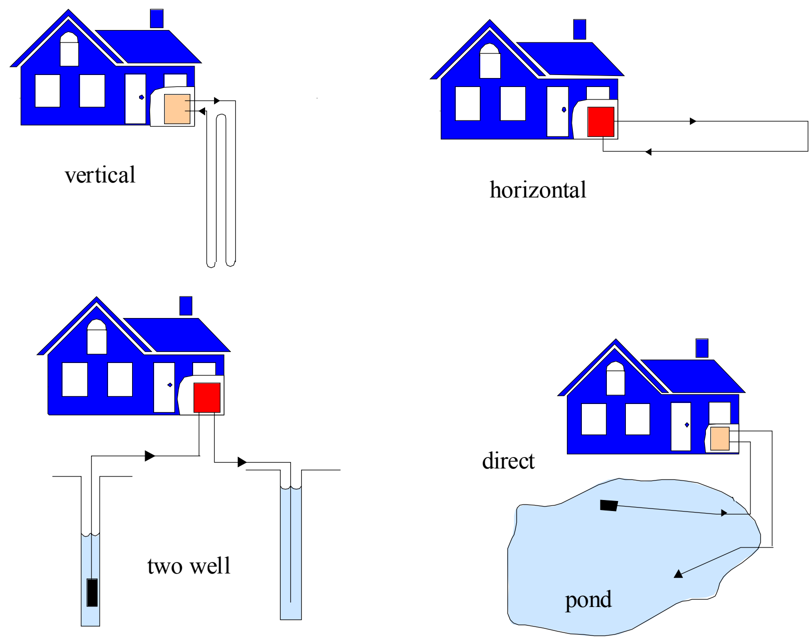


Source: Geo-Heat Center

GEOTHERMAL HEAT PUMPS

Geothermal heat pumps (GHPs) include both open (using ground-water or lake water) and closed loop (either in horizontal or vertical configuration) systems as illustrated in Figure 78 (for more information about heat pumps, see the previous section under "Hybrids with Heat Pumps"). According to the DOE, GHPs use 25 to 50 percent less electricity than conventional heating or cooling systems. Geothermal heat pumps can reduce energy consumption—and corresponding emissions—from 45 to 70 percent when compared to traditional systems.[141] They also improve humidity control. Because heat pumps do not require a geothermal reservoir, they can be used anywhere in the world.

Figure 78: Geothermal Heat Pump Diagram



Source: Geo-Heat Center

NEW TECHNOLOGIES: THE PATH FORWARD

Regardless of advances in geothermal technology, geothermal will not provide the silver bullet solution to our energy needs. Nor will any single resource. Instead, geothermal technology advances can help increase our country's share of renewable, sustainable geothermal energy. And that's important—today, only a fraction of the geothermal resource base is tapped. Surface technology developments, in particular, can increase energy production without impacting the resource base.

Technology, both surface and subsurface, can be developed a variety of ways. One of the most promising of these has been through federal initiatives such as The U.S. Department of Energy Geothermal Technologies Program. Unfortunately, the DOE program has faced funding challenges in recent years. Limited resources have resulted in loss of staff at national laboratories and universities. But a likely increase in FY2008 funding will help DOE to chart a long-term course for geothermal energy.

The U.S. will increasingly prioritize clean, plentiful, renewable, reliable, sustainable, and domestic energy sources—sources like geothermal energy. As geothermal energy use expands and technology develops, it will play an important role in helping meet the energy needs of the future.

Figure 79: Researchers Working in California's Lawrence Berkeley National Lab

Source: GEA (Alyssa Kagel)

GLOSSARY[142]

Algae blooms:[143] Elevated growth of one or more species of algae, which may result from excessive nutrient loading, in combination with adequate light, temperature and other environmental factors.

Aquaculture:[144] farming of organisms that live in water, such as fish, shellfish, and algae.

Binary-Cycle Plant: A geothermal electricity generating plant employing a closed-loop heat exchange system in which the heat of the geothermal fluid (the "primary fluid") is transferred to a lower-boiling-point fluid (the "secondary" or "working" fluid), which is thereby vaporized and used to drive a turbine/generator set.

Biofuels: Wood, waste, and alcohol fuels.

Biomass: Living or recently living biological matter that can be used as a fuel. Biomass usually refers to plant matter but can also refer to animal or waste materials.[145]

Biotic:[146] Pertains to living organisms.

Brine: A geothermal solution containing appreciable amounts of sodium chloride or other salts.

Btu (British Thermal Unit): A standard unit for measuring the quantity of heat energy equal to the quantity of heat required to raise the temperature of 1 pound of water by 1 degree Fahrenheit.

Capacity: The amount of electric power delivered or required for which a generator, turbine, transformer, transmission circuit, station, or system is rated by the manufacturer.

Capacity Factor: A percentage that tells how much of a power plant's capacity is used over time. For example, typical plant capacity factors range as high as 80 percent for geothermal and 70 percent for cogeneration.

Capacity, Installed (or Nameplate): The total manufacturer-rated capacities of equipment such as turbines, generators, condensers, transformers, and other system components.

Carbon Dioxide: A colorless, odorless, non-poisonous gas that is a normal part of the air. Carbon dioxide, also called CO_2, is exhaled by humans and animals and is absorbed by green growing things and by the sea.

Combined Cycle: An electric generating technology in which electricity is produced from otherwise lost waste heat exiting from one or more gas (combustion) turbines. The exiting heat is routed to a conventional boiler or to a heat recovery steam generator for utilization by a steam turbine in the production of electricity. This process increases the efficiency of the electric generating unit.

Coal: A readily combustible black or brownish-black rock whose composition, including inherent moisture, consists of more than 50 percent by weight and more than 70 percent by volume of carbonaceous material. It is formed from plant remains that have been compacted, hardened, chemically altered, and metamorphosed by heat and pressure over geologic time.

Cooling Tower: A structure in which heat is removed from hot condensate.

Condensate: Water formed by condensation of steam.

Conversion Technology: Represents the entire process of turning hydrothermal fluids or steam into electricity.

Consumption (Fuel): The amount of fuel used for gross generation, providing standby service, start-up and/or flame stabilization.

Corrosion: A state of deterioration in metals caused by oxidation or chemical action.

Cost: The amount paid to acquire resources, such as plant and equipment, fuel, or labor services.

Crust: Earth's outer layer of rock. Also called the lithosphere.

Debt: An amount owed to a person or organization for funds borrowed. Debt can be represented by a loan note, bond, mortgage or other form stating repayment terms and, if applicable, interest requirements. These different forms all imply intent to pay back an amount owed by a specific date, which is set forth in the repayment terms.

(U.S.) Department of Energy (U.S. DOE): The federal department established by the Department of Energy Organization Act to consolidate the major federal energy functions into one cabinet-level department that would formulate a comprehensive, balanced national energy policy. DOE's main headquarters are in Washington, D.C.

Demand (Electric): The rate at which electric energy is delivered to or by a system, part of a system, or piece of equipment, at a given instant or averaged over any designated period of time.

Demand (Utility): The level at which electricity or natural gas is delivered to users at a given point in time. Electric demand is expressed in kilowatts.

Deposition:[147] Deposition is the settling of particles (atoms or molecules) or sediment from a solution or suspension mixture, or the production of a solid on a pre-existing surface. It is also known by the particle model of matter as the process of gas changing form directly to a solid.

Dissolved Solids:[148] materials that enter a water body in a solid phase and dissolve in water.

Distribution: The delivery of electricity to retail customers (including homes, businesses, etc.).

Direct Use: Use of geothermal heat without first converting it to electricity, such as for space heating and cooling, food preparation, industrial processes, etc.

Drilling: Boring into the Earth to access geothermal resources, usually with oil and gas drilling equipment that has been modified to meet geothermal requirements.

Dry Steam: Very hot steam that doesn't occur with liquid.

Economics: The study of how the forces of supply and demand allocate scarce resources. Subdivided into microeconomics, which examines the behavior of firms, consumers and the role of government; and macroeconomics, which looks at inflation, unemployment, industrial production, and the role of government.

Economy of scale: Reduction in cost per unit resulting from increased production, realized through operational efficiencies. Economies of scale can be accomplished because as production increases, the cost of producing each additional unit falls.

Effluent: treated wastewater.

Efficiency: The ratio of the useful energy delivered by a dynamic system (such as a machine, engine, or motor) to the energy supplied to it over the same period or cycle of operation. The ratio is usually determined under specific test conditions.

Electric Plant (Physical): A facility containing prime movers, electric generators, and auxiliary equipment for converting mechanical, chemical, and/or fission energy into electric energy.

Electric Utility: A corporation, person, agency, authority, or other legal entity or instrumentality that owns and/or operates facilities within the United States, its territories, or Puerto Rico for the generation, transmission, distribution, or sale of electric energy primarily for use by the public and files forms listed in the Code of Federal Regulations, Title 18, Part 141. Facilities that qualify as cogenerators or small power producers under the Public Utility Regulatory Policies Act (PURPA) are not considered electric utilities.

Energy: The capacity for doing work as measured by the capability of doing work (potential energy) or the conversion of this capability to motion (kinetic energy). Energy has several forms, some of which are easily convertible and can be changed to another form useful for work. Most of the world's convertible energy comes from fossil fuels that are burned to produce heat that is then used as a transfer medium to mechanical or other means in order to accomplish tasks. Electrical energy is usually measured in kilowatt-hours, while heat energy is usually measured in British thermal units.

Energy Efficiency: Refers to programs that are aimed at reducing the energy used by specific end-use devices and systems, typically without affecting the services provided. These programs reduce overall electricity consumption (reported in megawatt-hours), often without explicit consideration for the timing of program-induced savings. Such savings are generally achieved by substituting technically more advanced equipment to produce the same level of end-use services (e.g. lighting, heating, motor drive) with less electricity. Examples include high-efficiency appliances, efficient lighting programs, high-efficiency heating, ventilating and air conditioning (HVAC) systems or control modifications, efficient building design, advanced electric motor drives, and heat recovery systems.

Energy Policy Act 2005 (EPAct): (Public Law 109-58) is a statute which was passed by the United States Congress on July 29, 2005 and signed into law on August 8, 2005 at Sandia National Laboratories in Albuquerque, New Mexico. The Act, described by proponents as an attempt to combat growing energy problems, provides tax incentives and loan guarantees for energy production of various types.

Energy Source: The primary source that provides the power that is converted to electricity through chemical, mechanical, or other means. Energy sources include coal, petroleum and petroleum products, gas, water, uranium, wind, sunlight, geothermal, and other sources.

Enthalpy: A thermodynamic quantity equal to the internal energy of a system plus the product of its volume and pressure; "enthalpy is the amount of energy in a system capable of doing mechanical work."

Environmental Impact Study: A document required by federal and state laws to accompany proposals for projects and programs that may have an impact on the surrounding area.
equity: Ownership interest in a corporation in the form of common stock or preferred stock. It is the risk-bearing part of the company's capital and contrasts with debt capital which is usually secured and has priority over shareholders if the company becomes insolvent and its assets are distributed.

Environmental Protection Agency: A federal agency created in 1970 to permit coordinated governmental action for protection of the environment by systematic abatement and control of pollution through integration or research, monitoring, standards setting and enforcement activities.

Energy Source: The primary source that provides the power that is converted to electricity through chemical, mechanical, or other means. Energy sources include coal, petroleum and petroleum products, gas, water, uranium, wind, sunlight, geothermal, and other sources.

Fills: These are structured surfaces placed inside a cooling tower to direct the flow of a fluid through it and enhance the effective vapor-liquid contact surface area.[149]

Facility: An existing or planned location or site at which prime movers, electric generators, and/or equipment for converting mechanical, chemical, and/or nuclear energy into electric energy are situated, or will be situated. A facility may contain more than one generator of either the same or different prime mover type. For a cogenerator, the facility includes the industrial or commercial process.

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Flash Steam: Steam produced when the pressure on a geothermal liquid is reduced. Also called flashing.

Fossil Fuel: Any naturally occurring organic fuel, such as petroleum, coal, and natural gas.

Fossil-Fuel Plant: A plant using coal, petroleum, or gas as its source of energy.

Fuel: Any substance that can be burned to produce heat; also, materials that can be fissioned in a chain reaction to produce heat.

Generating Unit: Any combination of physically connected generator(s), reactor(s), boiler(s), combustion turbine(s), or other prime mover(s) operated together to produce electric power.

Generation (Electricity): The process of producing electric energy by transforming other forms of energy; also, the amount of electric energy produced, expressed in watthours (Wh).

Generator: a machine that converts mechanical power into electricity by spinning copper wires (conductors) within a magnetic field.

Geology: Study of the planet Earth, its composition, structure, natural processes, and history.

Geothermal: Of or relating to the Earth's interior heat.

Geothermal Energy: Natural heat from within the Earth, captured for production of electric power, space heating or industrial steam.

Geothermal Heat Pumps: Devices that take advantage of the relatively constant temperature of the Earth's interior, using it as a source and sink of heat for both heating and cooling. When cooling, heat is extracted from the space and dissipated into the Earth; when heating, heat is extracted from the Earth and pumped into the space.

Geothermal Plant: A plant in which the prime mover is a steam turbine. The turbine is driven either by steam produced from hot water or by natural steam that derives its energy from heat found in rocks or fluids at various depths beneath the surface of the Earth. The energy is extracted by drilling and/or pumping.

Geothermal Steam: Steam drawn from deep within the Earth.

Geyser: A spring that shoots jets of hot water and steam into the air.

Geysers, The (note: "The" of "The Geysers" is always capitalized): A large geothermal steam field located north of San Francisco.

Gigawatt (GW): One billion watts.

Gigawatt-hour (GWh): One billion watt-hours.

Greenhouse Effect: The increasing mean global surface temperature of the Earth caused by gases in the atmosphere (including carbon dioxide, methane, nitrous oxide, ozone, and chlorofluorocarbon). The greenhouse effect allows solar radiation to penetrate but absorbs the infrared radiation returning to space.

Grid: The layout of an electrical distribution system.

Gross Generation: The total amount of electric energy produced by the generating units at a generating station or stations, measured at the generator terminals.

Hazardous Waste: Unwanted by-products remaining in the environment and posing an immediate potential hazard to human life.[150]

Heat Exchanger: A device for transferring thermal energy from one fluid to another.

Heat Pumps: *See Geothermal Heat Pumps*

Hot Dry Rock: A geothermal resource created when impermeable, subsurface rock structures, typically granite rock 15,000 feet or more below the Earth's surface, are heated by geothermal energy. The resource is being investigated as a source of energy production.

Hydrocarbon:[151] An organic compound containing only carbon and hydrogen. Hydrocarbons often occur in petroleum products, natural gas, and coals.

Hydrogen sulfide: Gas emitted during organic decomposition. Also a by-product of oil refining and burning. Smells like rotten eggs and, in heavy concentration, can kill or cause illness.

Injection: The process of returning spent geothermal fluids to the subsurface. Sometimes referred to as reinjection.

Injection well: Injection wells inject the brine back into the reservoir after using it in the power production process.

Insoluble: incapable of being dissolved.

Intermittent: Stopping and starting at regular intervals.

Kilowatt (kW): One thousand watts.

Kilowatt-hour (kWh): One thousand watt-hours.

Lead-time: The amount of time between the placing of an order and the receipt of the goods ordered.

Lease: A contract between a lessor and a lessee for the use of a vehicle or other property, subject to stated terms and limitations, for a specified period and at a specified payment.[152]

Levelized cost: The present value of the total cost of building and operating a generating plant over its economic life, converted to equal annual payments. Costs are levelized in real dollars (i.e., adjusted to remove the impact of inflation).

Load (Electric): The amount of electric power delivered or required at any specific point or points on a system. The requirement originates at the energy-consuming equipment of the consumers.

Magma: The molten rock and elements that lie below the Earth's crust. The heat energy can approach 1,000^{o}F (538^{o}C) and is generated directly from a shallow molten magma resource and stored in adjacent rock structures. To extract energy from magma resources requires drilling near or directly into a magma chamber and circulating water down the well in a convection- type system. California has two areas that may be magma resource sites: the Mono- Long Valley Caldera and Coso Hot Springs Known Geothermal Resource Areas.

Mantle: The Earth's inner layer of molten rock, lying beneath the Earth's crust and above the Earth's core of liquid iron and nickel.

Megawatt (MW): One thousand kilowatts (1,000 kW) or one million (1,000,000) watts. One megawatt is enough energy to power 1,000 average homes.

Megawatt-hour (MWh): One million watt-hours.

Mercury is not present in every geothermal resource, but where it is present, using that resource for power production could result in mercury emissions, depending upon the technology used.

Mitigation: Structural and non-structural measures undertaken to limit the adverse impact of natural hazards, environmental degradation and technological hazards

Molecule: The smallest particle of an element or compound which exists independently.

Nanometers: One billionth of a meter.

Noncondensable Gas (NCG): A gas from chemical or petroleum processing units (such as distillation columns or steam ejectors) that is not easily condensed by cooling; consists mostly of nitrogen, light hydrocarbons, carbon dioxide, or other gaseous materials.

Particulate Matter (PM): Unburned fuel particles that form smoke or soot and stick to lung tissue when inhaled. A chief component of exhaust emissions from heavy-duty diesel engines

Perforations:[153] Holes through casing and cement into the productive formation.

pH: A measure of the acidity of a solution. pH is equal to the negative logarithm of the concentration of hydrogen ions in a solution. A pH of 7 is neutral. Values less than 7 are acidic, and values greater than 7 are basic.

Plant: A facility at which are located prime movers, electric generators, and auxiliary equipment for converting mechanical, chemical, and/or nuclear energy into electric energy. A plant may contain more than one type of prime mover. Electric utility plants exclude facilities that satisfy

Pollution: Unwanted particles, mist or gases put into the atmosphere as a result of motor vehicle exhaust, the operation of industrial facilities or other human activity.

Power: The rate at which energy is transferred. Electrical energy is usually measured in watts. Also used for a measurement of capacity.

Power Plant (Note: Two separate words, not one word.): A central station generating facility that produces energy.

Power purchase agreement: The off-take contract from a large customer to buy the electricity generated by a power plant.

Precipitate: A substance separated from a solution or suspension by chemical or physical change.

Precipitation: the process of forming a chemical precipitate.

Price: The amount of money or consideration-in-kind for which a service is bought, sold, or offered for sale

Production well: A production well is a well drilled through a geothermal resource that produces geothermal brine.

Profit: The income remaining after all business expenses are paid.

Rankine Cycle:[154] The thermodynamic cycle that is an ideal standard for comparing performance of heat-engines, steam power plants, steam turbines, and heat pump systems that use a condensable vapor as the working fluid; efficiency is measured as work done divided by sensible heat supplied.

Rate of return: The annual rate of return on an investment, expressed as a percentage of the total amount invested. Also called return

Raw Material: Crude or processed material that can be converted by manufacturing, processing, or combination into a new and useful product.

Resource Conservation and Recovery Act (RCRA): a Federal law enacted in 1976, RCRA's goals are to protect the public from harm caused by waste disposal; to encourage reuse, reduction, and recycling; and to clean up spilled or improperly stored wastes.

Regulation: The governmental function of controlling or directing economic entities through the process of rulemaking and adjudication.

Reliability: Electric system reliability has two components--adequacy and security. Adequacy is the ability of the electric system to supply to aggregate electrical demand and energy requirements of the customers at all times, taking into account scheduled and unscheduled outages of system facilities. Security is the ability of the electric system to withstand sudden disturbances, such as electric short circuits or unanticipated loss of system facilities. The degree of reliability may be measured by the frequency, duration, and magnitude of adverse effects on consumer services.

Renewable Energy: Resources that constantly renew themselves or that are regarded as practically inexhaustible. These include solar, wind, geothermal, hydro and wood. Although particular geothermal formations can be depleted, the natural heat in the Earth is a virtually inexhaustible reserve of potential energy. Renewable resources also include some experimental or less-developed sources such as tidal power, sea currents and ocean thermal gradients.

Renewable Resources: Natural but flow-limited resources that can be replenished. They are virtually inexhaustible in duration but limited in the amount of energy that is available per unit of time. Some (such as geothermal and biomass) may be stock-limited in that stocks are depleted by use, but on a time scale of decades, or perhaps centuries, they can probably be replenished. Renewable energy resources include: biomass, hydro, geothermal, solar and wind. In the future, they could also include the use of ocean thermal, wave, and tidal action technologies. Utility renewable resource applications include bulk electricity generation, on-site electricity generation, distributed electricity generation, non-grid-connected generation, and demand-reduction (energy efficiency) technologies.

Reservoir: A natural underground container of liquids, such as water or steam (or, in the petroleum context, oil or gas).

Revegetation:[155] Regrowing native plants, mainly trees and shrubs, by active restoration, natural process restoration, or both.

Reverse osmosis: A type of pressurized filtration system in which water is forced through a semi-permeable membrane that allows the passage of water but restricts many contaminants.

Revenue: The total amount of money received by a firm from sales of its products and/or services, gains from the sales or exchange of assets, interest and dividends earned on investments, and other increases in the owner's equity except those arising from capital adjustments.

Rights-of-way (ROW): A ROW grant is an authorization to use a piece of land, over a period of time, for a specific facility.[156]

Rock Catcher:[157] In dry steam plants, the steam from the reservoir shoots directly through a rock–catcher into the turbine generator. The rock-catcher protects the turbine from small rocks that may be carried along with the steam from the reservoir.

Separator: A separator is a vertical cylindrical tank in which inflowing fluid is introduced tangentially (horizontally, but nearly parallel to the tank wall) to induce circular rotation inside the tank. The heavier particles collect in the outer wall and in the bottom of the tank near the drain, while the steam collects in the central and upper part, where it is withdrawn and sent to the turbine.[158]

Scaling:[159] (1) The formation at high temperatures of thick corrosion product layers on a metal surface, or, (2) The deposition of water-insoluble constituents on a metal surface.

Scrubber: Equipment used to remove sulfur oxides from the combustion gases of a boiler plant before discharge to the atmosphere. Chemicals, such as lime, are used as the scrubbing media.

Silica:[160] Silicon dioxide, the most abundant rock-forming compound on Earth.

Steam Jet Ejectors:[161] A device used to extract noncondensable gases from a pressure vessel by expanding high-velocity steam through the outlet of a nozzle connected to it, thereby creating a lower pressure at the ejector inlet and drawing in the gases along with the steam. Ejectors have been used for at least a century, are extremely inexpensive, simple and long-lived, but consume large amounts of energy relative to other options such as vacuum pumps.

Steam-Electric Plant (Conventional): A plant in which the prime mover is a steam turbine. The steam used to drive the turbine is produced in a boiler where fossil fuels are burned.

Sustainability:[162] Economic development that takes full account of the environmental consequences of economic activity and is based on the use of resources that can be replaced or renewed and therefore are not depleted.

System: A combination of equipment and/or controls, accessories, interconnecting means and terminal elements by which energy is transformed to perform a specific function, such as climate control, service water heating, or lighting.

System (Electric): Physically connected generation, transmission, and distribution facilities operated as an integrated unit under one central management, or operating supervision.

Transmission: The movement or transfer of electric energy over an interconnected group of lines and associated equipment between points of supply and points at which it is transformed for delivery to consumers, or is delivered to other electric systems. Transmission is considered to end when the energy is transformed for distribution to the consumer.

Turbine: A machine for generating rotary mechanical power from the energy of a stream of fluid (such as water, steam, or hot gas). Turbines convert the kinetic energy of fluids to mechanical energy through the principles of impulse and reaction, or a mixture of the two.

Turbine Generator: A device that uses steam, heated gases, water flow or wind to cause spinning motion that activates electromagnetic forces and generates electricity.

Utilization:[163] The fraction of a resource's total capacity that is being used.

Utility: A regulated entity which exhibits the characteristics of a natural monopoly. For the purposes of electric industry restructuring, "utility" refers to the regulated, vertically-integrated electric company. "Transmission utility" refers to the regulated owner/operator of the transmission system only. "Distribution utility" refers to the regulated owner/operator of the distribution system which serves retail customers.

Vacuum Pump:[164] A vapor pump capable of creating the degree of vacuum necessary to evaporate moisture near room temperature. It extracts noncondensable gases from the condenser by creating a lower pressure at its inlet than exists inside the condenser.

Vapor-Dominated: A geothermal reservoir system in which subsurface pressures are controlled by vapor rather than by liquid. Sometimes referred to as a dry-steam reservoir.

Watt: The electrical unit of power. The rate of energy transfer equivalent to 1 ampere flowing under a pressure of 1 volt at unity power factor.

Watt-hour (Wh): An electrical energy unit of measure equal to 1 watt of power supplied to, or taken from, an electric circuit steadily for 1 hour.

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