

Geothermal Power Production: Steam for Free

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An Exercise in Imagination

Imagine this: a source of non-polluting, non-greenhouse-gas-emitting energy that is storable, reliable, almost 100% available, astonishingly cheap over a 30-year project cycle, exploitable by 19th-century power plant technology, using an un-shippable mineral resource with absolutely no market value, apparently inexhaustible, indifferent to weather or diurnal cycles, hardly smelly or noisy, non-hazardous, and conveniently available for use in many countries where high load growth and vigorous industrial development are beacons for investors looking for high returns. So where are we? In Sandia Labs? Battelle? Lawrence Livermore? A Jules Verne mini-series? The fictional planet Tatooine? Well, no. Reader, look between your feet – welcome to the very real world of geothermal power.



A 100 MW geothermal plant – like the four-unit Cerro Prieto project pictured above – is a substantial power plant, because it needs to handle a generous masses of low-pressure steam.

A Power Plant Person's Wildest Dream – Cheap Steam –Occasionally Comes True

According to geologists and the Discovery Channel, the inner regions of the Earth are very hot, while the surface, where humans operate, remains comparatively cool. A juicy ΔT , as we all

know, is a sign of a potential energy production opportunity. And certain places on the Earth's surface lend themselves to convenient use of this ΔT – between up here and down there – to generate electricity, generally using hot water or steam obtained from wells. Pioneer geothermal power developments have taken place over the last century in the great steamfield of Lardarello, Italy, in the Geysers region in Northern California, in Iceland, in México, and in Japan.

Although the Earth's heat is abundant anywhere underfoot if we venture deep enough, geothermal resources that lend themselves to profitable extraction are inequitably distributed. Profitable geothermal opportunities appear where there exists an improbable combination of things: shallow volcanic or magmatic presences, an impermeable cap-layer, abundant groundwater recharge, and a permeable underground reservoir to allow rapid transfer and extraction of hot resources.

Where these conditions are fulfilled – in places such as Iceland, Italy, Costa Rica, México, El Salvador, New Zealand, the Rift area of Africa, and the circum-Pacific region known as the Ring of Fire – it is often feasible to build varieties of traditional Rankine Cycle steam power plants without boilers – plants that profitably exploit the heat from below. Today, these sites are responsible for a significant contribution to the world's inventory of renewable and “green” energy sources. As of early 2000, 21 nations now play host to geothermal power plants, and world installed capacity is now a little more than 8,000 MW.

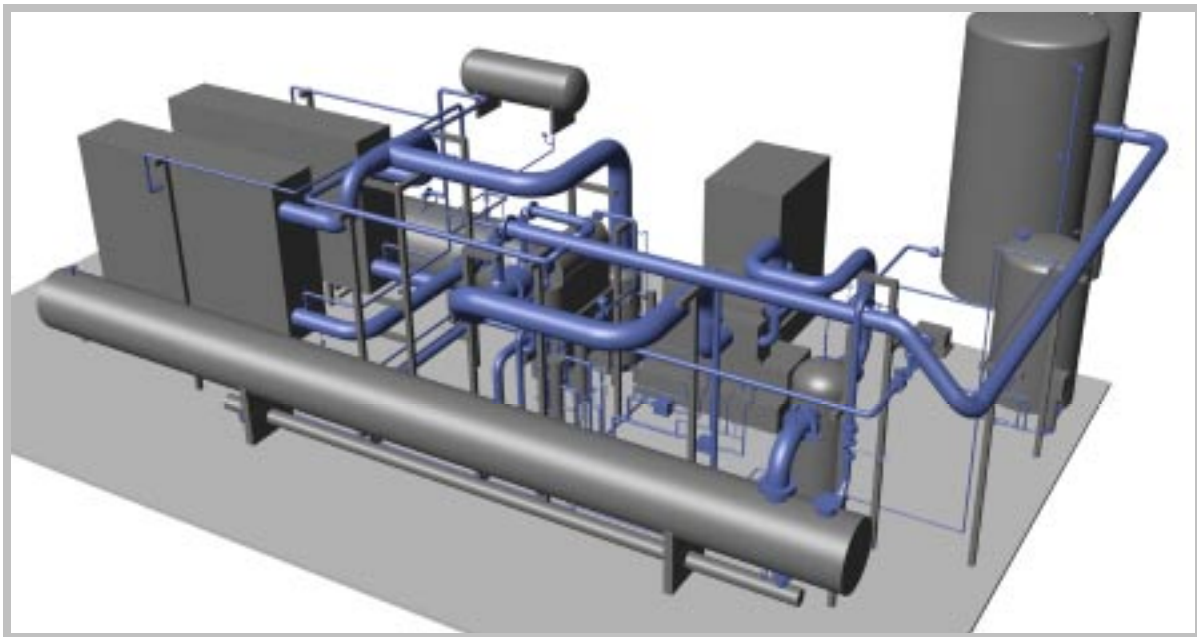
The Technology – Modest and Comforting

Geothermal power plant operations tend to be of three general kinds: dry steam plants and “flash” plants, applied to high-energy geothermal resources, and binary plants, typically used in lower-temperature resource situations:

- **Dry Steam Plants:** In a few places on earth – Lardarello and the Geysers are the best-known instances – wells yield comparatively high-quality steam. At the Geysers, according to folklore, even pipe fenceposts and gateposts sometimes vent free steam, recalling the generous though fanciful place celebrated in the old hobo song where cigarettes grow on trees. Calpine Corporation, which owns and operates the sprawling Geysers geothermal complex, has an excellent visitor center at the site to celebrate and explain this phenomenon. In these prodigious places, power plants have the comparative luxury of being old-fashioned steam plants minus the tricky bits such as combustion systems and boilers. Steam produced from the wells is collected, polished and used to drive turbines directly. Geothermal steam turbines are typically designed and fabricated to make effective use of the comparatively low pressures and high volumes produced in these resources. Geothermal dry steam plants usually use condensing turbines, and condensate is usually reinjected or evaporated in a wet tower cooling scheme or both.
- **Flash Plants:** Though geothermal dry steam resources represent the acme of thermodynamic possibility and cost-effectiveness for geothermal projects, most hard-working geothermal plants get their energy from liquid-dominated resources such as those underlying the Imperial Valley in California. These plants get their steam from a process of separation in which superheated fluids accessed by wells are “flashed” in wellbores and separators. The resulting steam is routed to a turbine or turbines, and the resulting fluids are routed to reinjection or

further flashing in lower-pressure regimes. Like dry steam plants, flash plants tend to be used to extract energy from high-temperature geothermal resources. The fluid fraction of well products exiting the separators, as well as steam condensate (except for the condensate evaporated in a wet cooling system) is usually reinjected.

- **Binary Plants:** Binary plants are usually applied to lower-temperature resources. In these plants – which have been cheerily described as “refrigerators running backwards” – the resource fluid is used, via heat exchangers, to heat a closed loop of working fluid with vaporization and condensation properties better matched to the resource temperatures than those of water. This working fluid is flashed to vapor, drives a turbine, and is condensed and recirculated to do its job over and over again. Ammonia/water mixtures and hydrocarbons are working fluids commonly used in binary cycle plants. (Ammonia/water plants have been receiving keener attention lately after the completion of the 2 MW Kalina Cycle™ plant in Húsavík, Iceland in 2000. Húsavík has provided a convincing demonstration of the efficiency of this innovative mixed-fluid-based cycle for low-temperature geothermal heat exploitation.) Binary plants generally reinject all the resource fluids produced and used in the plants, complete with all original constituents, so these plants have the additional advantage of being (or approaching) true zero-discharge operations.



This view is from the 3D engineering model for the innovative Husavik Kalina Cycle power plant in Iceland, which began commercial operation in 2000. This binary cycle plant uses an ammonia/water mixture as the working fluid.

- **Hybrid Plants:** There are a number of recent geothermal plants – Puna in Hawaii and Rotokawa in New Zealand, as prominent examples – which use traditional Rankine cycle technology on the topping end and a binary cycle on the bottoming end. Plants such as these offer an aggressive approach to energy extraction balanced by the additional development and operational considerations of building and running two distinct kinds of power plants in series.

However, There are Some Tricky Spots

One notable fact about geothermal plants is that they use a wild geological product as “fuel.” This has some advantages to the owner, in that nobody else would probably want it or steal it away or compete for its use. But this fuel is also implacable and beyond negotiation: if the resource falls short of the desired productivity, the operator’s options are limited. The operator can hardly go to a lower-bid supplier or order up a better grade of fuel. Smart geothermal operators generally plan for a resource’s production degradation over time and schedule the drilling of make-up wells in their life-cycle capital plans.



The photo above shows construction on an NCG system at one of Calpine’s dry steam plants at the famous Geysers geothermal area in California. Calpine is the largest geothermal power producer in the world.

Another notable difference between conventional steam plants and geothermal plants is the NCG extraction requirement. Geothermal steam usually has higher noncondensable gas concentrations to deal with. The range of concentrations reported for geothermal steam spreads from something like a few tenths of a percent by mass to up to 2-3% or even somewhat higher. The noncondensable gas (NCG) contained in geothermal steam is primarily CO₂ although it typically has H₂S and small fractions of other gases.

The high NCG content means that a geothermal flash plant will have a much larger and more complex gas extraction system than one would find in a typical gas turbine combined cycle plant

where the noncondensables are primarily small quantities resulting from in-leakage. Therefore, instead of the small, relatively inexpensive steam jet system you would see in a gas turbine combined cycle project, you have a large, expensive, multiple-stage system which commonly use two stages of jets followed by a vacuum pump or three stages of jets.

Still another particular requirement faced by designers of geothermal plant systems is the importance of canny resource piping design, particularly if two-phase flow is involved. In two-phase systems, the sizing and routing of the pipe, and the design of the separation system, have a crucial bearing on the output of the plant and, often, the happiness of the investors.

Geothermal's Contribution to the World's Renewable Generation Capacity is Respectable

Increasing concern in recent years about global warming has globally turned up the heat on investor and developer interest in non-carbon-emitting renewable energy production. Until recently, geothermal plants, as a class, were the leading contributors to the world's inventory of non-fired, non-hydro renewable capacity. This distinction was lost in 1999 or so when new wind farms in Europe – Germany, Denmark and Spain, in particular – began spinning out kWhs with hurricane force.

Despite this startling sudden domination (at least in terms of raw capacity) of the non-hydro renewables segment by the upstart windmill industry, recent progress in geothermal baseload capacity development has been steady and substantial. The U.S. Geothermal Energy Association reports that world geothermal generation capacity has increased 50 percent in the past decade.

For example, in the past few years, new plants have been installed and started up in Russia, El Salvador, Kenya, New Zealand, Indonesia, México, Austria, and Nicaragua. In addition to these, POWER Engineers and Mitsubishi Heavy Industries of Japan have teamed over the past six years to design and install more than 300 MW of geothermal generation capacity including two 52 MW stations in the Philippines, one 100 MW plant in México, a 27.5 MW unit in Costa Rica, and a two-unit 64 MW plant now under construction in Kenya. Plans are afoot for major new plants in California, Utah, and Nevada in the U.S., and in Costa Rica, Kenya, Chile, Iceland, Philippines, and Indonesia.

Most of these recent plants use high-temperature resources and employ conventional flash technology. Some employ binary technology, and a few use a hybrid or “combined cycle” flash-and-binary combination favored by Ormat International to impressive effect. Ormat is a very interesting company, active both as a geothermal IPP and as the engineer and power conversion module supplier for binary energy conversion units in service throughout the world.

The Fiercest Squirrel in the Forest?

One very recent commercial and technological development in the geothermal industry has been the successful application of the Kalina Cycle to geothermal power production, at a hybrid power and heating plant at Húsavík, in northern Iceland. This cycle is a proprietary ammonia-water-

based energy conversion cycle marketed as a more efficient competitor to the more traditional Organic Rankine Cycle (ORC), using hydrocarbon working fluids, heretofore used almost exclusively in binary geothermal service.

The Húsavík plant entered service in 2000 and appears to have decisively borne out the production and efficiency claims of its advocates. So the stage seems set for lively competition in the upcoming years for low-temperature geothermal applications by the Kalina and ORC camps, both of which have shown a keen interest in nabbing or keeping market share in this small but fiercely contested market.

Cost-Per-kWh Reports for Geothermal – The Tale of the Tape

Initial capacity costs for geothermal plants tend to look high: \$900 to \$1,200 per kW for recent flash plant installations, for example. But recent geothermal history provides some useful figures regarding the ongoing cost of power production from some geothermal plants. The CFE Cerro Prieto IV project in México is reported to produce power at a cost of 2.81 cents per kWh, a gloriously attractive rate. CFE geothermal director Dr. Gerardo Hiriart explains this remarkably low cost reckoning – “comparable with the cost of highly efficient gas-fired plants” – pointing out that as a publicly owned plant operating in a highly evolved wellfield complex, CP IV is spared significant cost burdens that plants elsewhere might have to tuck into their debit columns. CFE has an impressive stable of other geothermal plants, and Hiriart reports a cost/kWh range of 3.29-3.42 cents for the earlier plants in México’s geothermal inventory.

With fuel costs virtually eliminated, cost/kWh figures for geothermal plants can be decisively lower than their initial cost/kW capacity bottom line might suggest. On a dollar-per-kWh basis, geothermal plants provide thoroughly competitive power, as indicated in the following World Bank survey summary.

	Unit Cost (U.S. cents/kWh): High Quality Resource	Unit Cost (U.S. cents/kWh): Medium Quality Resource	Unit Cost (U.S. cents/kWh): Low Quality Resource
Small Plants (< 5 MW)	5.0-7.0	5.5-8.5	6.0-10.5
Medium Plants (5-30 MW)	4.0-6.0	4.5-7.0	Normally not suitable
Larger Plants (> 30 MW)	2.5-5.0	4.0-6.0	Normally not suitable

Note: Unit cost in the table above includes wellfield costs but not costs for transmission lines.

The quality categories noted above refer primarily to the temperature or energy content of the resource. At lower temperatures, a geothermal resource is generally not suitable for development using a flash-type plant. Instead, a binary cycle, where the hot water heats an intermediate working fluid, would be used.

Specific Geothermal Benefits: Robust, Highly Available, Green

Geothermal plants are, as a species, tough, reliable and clean. High-temperature geothermal plants employ proven steam power plant technology – old-fashioned technology, in many ways – modified according to the specific characteristics of the site and the general characteristics of geothermally produced steam. Geothermal steam turbines typically operate at low pressures by steam plant standards, below 10 bara, and are robust and reliable. Geothermal plants, because of their low pressures and comparatively few auxiliary systems, are also typically simple and safe to operate and maintain, as well.



This lofty site, at~ 4,500 meters[14,600 feet] above sea level in the Andes, is being developed for geothermal power production, using a futuristic plant design to take advantage of the exotic climatic conditions.

Geothermal power can also offer an economic premium in areas where petrochemical resources are hard or expensive to come by, as in El Salvador. El Salvador, with no indigenous natural gas sources and no gas transmission line nearby amid an exceptional volcanic landscape testifying to the abundant heat below, maintains an inventory of sophisticated geothermal plants and plans to develop more.

How Renewable is Renewable?

With much of the activity taking place out of sight, deep within the ground, renewable energy advocates have occasionally gnawed their knuckles while pondering to what extent geothermal energy production may be regarded as “renewable.” Clearly, underground reservoirs are unlikely to experience anything like an annual charging cycle. Recent study and modeling of reservoir performance have shed interesting light recently on the view of geothermal as a renewable resource, positing a charging cycle perhaps clockable over decades or centuries, but apparently renewable.

What Next? The Crystal Ball is Cloudy but Interesting

Peering intently into our geothermal crystal ball (somewhat clouded with a deposit of silica precipitate), we can dimly see portentous shapes of future geothermal plants. It seems likely that in the lifetimes of many of us now working in the field, the world may approach something like a mature build-out of easily convertible high-energy geothermal resources with flash-plant development in Indonesia, the Philippines, Latin America and Africa, places where load growth rates will inevitably compel the canny use of indigenous resources.

Our future may see construction of a few gargantuan desert-based geothermal minerals recovery and power production projects, 100-500 MW in capacity, where resource fluids are cleanly stripped of energy and valuable metals.



This view shows beachside construction underway for the 10 MW Bouillante II geothermal plant on the Caribbean island of Guadeloupe. Geothermal plants can often offer power at highly competitive rates to island grids, particularly on islands of volcanic origin.

Far in the distance, we see the hazy shapes of deep geothermics, the promise of heat recovery many kilometers below today’s range of play, sometimes envisioned taking place below the seabed. We also see possibilities for HDR, or hot dry rock, the much-studied technology for mining shattered high-temperature rock far below the surface for heat recovery. (HDR offers the

promise, perhaps, of an ultimate binary technology application because it offers a controlled, manufactured heat-exchange zone way down below for heating a working fluid.) And the first decades of the 21st Century may witness a stirring competition between competing binary-cycle technologies if climbing fossil fuel prices and advancing well-drilling technologies coincide to extend the competitive range of low-temperature geothermal power production.

In the end, we in the geothermal world await the auguries and pronouncements of the two priestly classes – the drillers and the bankers – who hold us in their sweaty but steady hands. There is abundant and generous energy beneath our feet, and interesting technology for sharing it around. ■

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A ceiling-walking gecko on site at the Bouillante geothermal plant, Guadeloupe