

The Values of Geothermal Energy:

A Discussion of the Benefits Geothermal Power Provides to the Future U.S. Power System



Puna Expansion, U.S., 13 MW, 2010



McGinness Hills, Nevada, U.S., 30 MW (2012)



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Introduction

Geothermal power offers both firm and flexible solutions to the changing U.S. power system by providing a range of services including but not limited to baseload, regulation, load following or energy imbalance, spinning reserve, non-spinning reserve, and replacement or supplemental reserve. It is well known that geothermal plants can operate 24 hours a day with a steady output, regardless of environmental conditions, and are not subject to the unpredictability and voltage swings that variable energy resources (VER) face and, hence, can fulfill the necessary role as a renewable baseload power source. As aging baseload fossil fuel plants retire, geothermal plants can provide the generation these plants have historically provided to the power system.

Geothermal plants can also ramp up or down quickly, allowing them to adjust to the changing needs of the power system and act as a flexible power source in addition to baseload. The increasing percentage of electricity produced from VER, such as solar and wind, is placing an escalating level of stress on an aging power system designed for fossil fuels. The varying output can cause voltage swings in transmission lines, potentially creating power surges and blackouts.

This combination of firm and flexible power positions geothermal energy as an ideal candidate to fill several roles historically performed by emission-heavy fossil fuels, such as baseload, regulation, load-following, and reserve functions typically reserved for coal and/or natural gas plants. In addition to considerable environmental advantages over fossil fuels, geothermal plants generally lack the fuel costs of other baseload sources, or the ancillary and transmission costs associated with variable energy resources that often equate to the long-term stability in energy costs.

Looking beyond these specific benefits, geothermal has a number of other attractive features, including:

- Geothermal power production has a positive impact on local economies, and creates significantly more jobs per megawatt than natural gas.
- Geothermal power has a smaller land footprint than most other energy sources, particularly when compared with other renewables.
- Geothermal power has very low emission levels. Binary plants produce near-zero GHG emissions while flash and dry steam plants represent a significant reduction compared to fossil fuel based generation.
- Geothermal power's established history of consistent output demonstrates a level of reliability unmatched by other renewables and fossil fuel based generation.

Relevant Terms and Definitions

Ancillary services are defined by FERC as the services necessary to support the transmission of electricity from a supplier to a purchaser, given the obligations of a control area and that area's transmitting utilities to maintain reliable operations of the interconnected transmission system. There are six different kinds of ancillary services: scheduling and dispatch, reactive power and voltage control, loss compensation, load following, system protection, and energy imbalance.

Balancing Authority Area is a metered segment of the electric power system in which electrical balance is maintained. In a balancing authority area, the total of all generation must equal the total of all loads (as supplemented by electrical imports into and exports out of the area).

Baseload Power (Firm Power) is the minimum amount of power that a utility or distribution company must generate for its customers, or the amount of power required to meet minimum demands based on reasonable expectations of customer requirements. Baseload values typically vary from hour to hour in most commercial and industrial areas. Large baseload units also tend to have lower operating costs relative to other fossil-fueled facilities.

Capacity Factor/Value of a power plant is the ratio of its actual output over a period of time to its potential output if it were possible for it to continuously operate at full nameplate capacity. To calculate the capacity factor, the total amount of energy produced by the power plant during a period of time is divided by the amount of energy the plant would have produced at full capacity. Capacity factors vary greatly depending on the type of fuel that is used and the design of the plant. The capacity factor should not be confused with the availability factor, capacity credit (firm capacity) or with efficiency.

Contingency Spinning Reserve is generation (or responsive load) that is poised, ready to respond immediately, in case a generator or transmission line fails unexpectedly. Spinning reserve begins to respond immediately and must fully respond within 10-15 minutes. Enough contingency reserve (spinning and non-spinning) must be available to deal with the largest failure that is anticipated.

Demand response is not a single technology or rate which a power plant can be activated. Rather, Demand Response is any technology that controls the rate of electricity consumption rather than the rate of generation. FERC defines the term Demand Response to include “consumer actions that can change any part of the load profile of a utility or region, not just the period of peak usage.”

Dispatchable energy is closely related to load following and ramping. However, dispatchable energy focuses on the energy consumption at times of peak capacity requirements and minimum load while Load Following focuses on the rate of change in generation and consumption, i.e., the ramping requirements. Both can be obtained from sub-hourly and hourly energy markets and/or the movements of the marginal generators or loads.

Distributed generation refers to electricity generated from many small energy sources. Most countries generate electricity in large centralized facilities powered by fossil fuels or hydropower. Distributed generation allows energy to be collected from many sources and may result in a lower environmental impact and improved security of supply.

Dry Steam, Flash, and Binary are the three main types of geothermal power conversion technologies. In dry steam technology, steam is withdrawn directly from a subsurface geothermal reservoir and used to run the turbines that power the generator. In flash plants, high-pressure and high - temperature geothermal fluids separate (“flash”) into steam and water either in the reservoir, in the well, or in a surface separator as a result of pressure decrease. The steam is delivered to a turbine that powers a generator and the resulting liquid is injected back into the reservoir. In binary plants, geothermal fluid is prevented from flashing by maintaining the pressure and is used to heat a secondary liquid called a working fluid, which boils at a lower temperature than water. Heat exchangers are used to transfer the heat energy from the geothermal fluid to vaporize the working fluid. The vaporized working fluid, like steam in flash plants, turns the turbines that power the generators. The geothermal water is injected back into the reservoir. The binary configuration is a closed-loop system with zero emissions that maintains complete separation from groundwater sources.

Energy Imbalance Service is a market service that provides for the management of unscheduled deviations in individual generator output or load consumption.

Intermediate and Peaking Units are power plants that have fast ramp rates and relatively lower minimum generation levels and can be shut down and started up relatively quickly. Intermediate and peaking units are most often used to provide load following generation service due to their ability to ramp up and down quickly.

Load Following is a slower response (from several minutes to a few hours) whereby available resources are dispatched to follow system ramping requirements. Load following is not a defined FERC service, but is obtained from intra-hour and hourly energy markets. Furthermore, a load following power plant is a power plant that adjusts its power output as demand for electricity fluctuates throughout the day and typically falls between baseload and peaking power plants in efficiency, speed of startup and shutdown, construction cost, cost of electricity, and capacity factor.

Non-Spinning Reserve is similar to spinning reserve, except that response does not need to begin immediately. Full response is still required within 10 minutes, however.

Organic Rankine Cycle (ORC) is named for its use of an organic, high-molecular mass fluid with a liquid-vapor phase change, or boiling point, which occurs at a lower temperature than the water-steam phase change. The fluid allows Rankine cycle heat recovery from lower temperature sources such as biomass combustion, industrial waste heat, geothermal heat, solar ponds, etc.

Power Purchase Agreement (PPA) is a contract between two parties, one who generates electricity (the seller) and one who is looking to purchase electricity (the buyer). The PPA defines all of the commercial terms for the sale of electricity between the buyer and the seller, including when the project will begin commercial operation, the schedule for delivery of electricity, penalties for under delivery, payment terms, and termination of the agreement. The PPA is the principal agreement that defines the revenue and credit quality of a generating project and is thus a key instrument used in project finance. There are many forms of PPAs in use today and they vary according to the needs of buyer, seller, and financing counterparties

Peaking power plants, also known as “peakers,” are power plants that generally run only when there is a high demand for electricity, often referred to as peak demand. Although these plants supply only occasional power, the power supplied commands a much higher price per kilowatt hour than a plant supplying baseload power.

Ramp Rate is essentially the speed at which a generator can increase (ramp up) or decrease (ramp down) generation. Generating units have different characteristics making some more suited to supplying certain needed functions.

Regulation is the time frame during which generation (and potentially load) automatically responds to minute-by-minute deviations in a supply-demand balance. Typically, signals are sent by an automatic generation control (AGC) system to one or more generators to increase or decrease output to match the change in load. The frequency regulation control portion of the AGC system is typically called the load frequency control (LFC). Changes in load during the regulation time are typically not predicted or scheduled in advance and must be followed by generation reserve capacity that is online and grid-synchronized.

Replacement or Supplemental Reserve is an additional reserve required in some regions. It begins responding in 30 to 60 minutes. It is distinguished from non-spinning reserve by the response time frame.

Unit commitment typically covers several hours to several days. Unit commitment involves the starting and synchronizing of thermal generation so that it is available when needed to meet expected electricity demand.

Variable Energy Resources (VER) are any sources of energy that are not continuously available due to some factor outside direct control of the resource operator (solar, wind, tidal, etc.). The VER may be predictable, for example, tidal power, but cannot be dispatched to meet the demand of a power system.

The Changing U.S. Power Market

Until recently, renewable energy technologies represented only a small fraction of the U.S. power system. However, in recent years, renewables have become an increasing contributor to the grid, generating approximately 14% of the electricity of the United States as of June 2013 with wind, solar, and geothermal power generating about 5% of that electrical power.¹

Wind and solar generation are important and innovative technologies that will play a prominent role in the transition to a clean energy economy and help alleviate the significant consequences of a warming planet. However, wind and solar photovoltaic rely heavily on the prevailing weather conditions for their generation. Changes in wind patterns or a cloudy day can affect the availability of these generation technologies. As a result, reliability of the overall power system can fluctuate. Geothermal energy is a renewable power source that can provide baseload and flexible power, quickly adjusting to fit the needs set by variable renewable energy technologies.

In addition, President Obama's climate goals encourage new opportunities for geothermal power to provide clean electricity to communities across the U.S. Unfortunately, natural gas is used in many scenarios rather than geothermal power, but not all the externality and ancillary costs associated with natural gas are factored into the price of electricity. This misconception creates the illusion that natural gas power plants are a viable alternative to geothermal power.

Other actions by President Obama, such as directing the U.S. Environmental Protection Agency to work expeditiously to complete carbon pollution standards for both new and existing power plants, will create new opportunities for geothermal power. In 2012 the President set a goal to issue permits for 10 gigawatts (GWe) of renewables on public lands by the end of the year. With approximately half of geothermal power plants on public lands this new goal should accelerate geothermal development. Also, the Department of Defense – the single largest consumer of energy in the United States – is committed to deploying 3 GWe of renewable energy on military installations, from solar, wind, biomass, and geothermal sources, by 2025. Federal agencies are setting a new goal of reaching 100 megawatts (MWe) of installed renewable capacity across the federally subsidized housing stock by 2020.

¹ U.S. EIA 2013a

Lastly, state Renewable Portfolio Standards (RPS), require electric utilities and other electric service providers to derive a certain percentage of their retail sales, consumption, or some other metric, from eligible renewable energy resources. These standards should increase demand for geothermal power and other renewables. However, not all state RPS requirements treat all renewables equally. For example in California, the bidding process adjusts prices for the "time of day" which devalues technologies that would otherwise provide power as baseload and does not value capacity or integration costs, which historically were given value in the procurement process.

Firm Power: Geothermal the Clean, Cost Effective, Baseload Resource

Even though growth in annual demand for electricity is slowing (currently about .7% a year growth rate), EIA still expects electricity demand to grow by 24% from 2011 to 2040.² Baseload will be a substantial part of this growth within any balancing area's power supply. A typical power producer keeps 35-40% of maximum load throughout the year as baseload. Geothermal power is a reliable and economical option to provide baseload power for the growing U.S. power system.

Replacing Baseload Coal

Geothermal power is a firm power source because it runs 24 hours a day regardless of extraneous conditions. Geothermal plants, when built and managed responsibly, can last up to half a century or more. Power plants built in the 1970's, such as at The Geysers in California, still operate today extracting geothermal steams and brines to generate electricity. Additionally, geothermal power is a technically and commercially proven technology, unlike many other renewable energy technologies that are still relatively new and that involve a significant degree of technological risk. Geothermal plants are scalable to over 50 MW with a fraction of the land and environmental impact of other technologies.

Over 40% of the U.S. electric power generation comes from burning coal.³ With their relatively low fuel cost and predictable output, coal-fired plants have historically been used as one of the primary sources of baseload power. Most of the coal-fired plants in the U.S. were built over 30 years ago; the average lifespan of such a plant is 40 years. Because of this fact, as well as the changing economic and regulatory environment, it has been estimated that 59 – 77 GW of existing coal plants will be retired by 2016.⁴

The impending void created by these retirements presents an opportunity to replace some of these emission-heavy plants with more environmentally-friendly options. Among energy sources which are suitable for baseload production, geothermal power has the smallest carbon footprint. Geothermal power has negligible CO₂ emissions (59-396 lbs/MWh) when compared with coal (2200 lbs/MWh) or natural gas (861 lbs/MWh)⁵. Burning biomass materials actually releases even more CO₂ into the atmosphere than fossil fuels. Since much of this CO₂ would be released eventually anyway, it is difficult to assess biomass' net carbon footprint. In contrast to the ambiguity surrounding biomass emissions, geothermal power offers an undeniable carbon-mitigation advantage compared to traditional fossil fuels.

In addition, geothermal power offers a degree of economic advantage compared to other baseload options once the full lifecycle costs of a plant is taken into account. Unlike biomass and fossil sources,

² U.S. EIA 2013d

³ U.S. EIA 2013c

⁴ Celibi et al. 2012

⁵ U.S. EPA 2011

there is minimal ongoing fuel cost associated with geothermal power. This lack of a fuel cost helps to balance the relatively high initial capital investment. A recent report issued by the U.S. Energy Information Administration (EIA) formulates the levelized cost per megawatt-hour for various energy sources. The estimated average levelized cost for geothermal power (\$89.60/MWh) comes in significantly lower than coal (conventional or advanced), nuclear, or biomass.⁶

A Substitute for Natural Gas

Natural gas is likely to provide a substantial amount of firm power in the future and be a significant alternative to other fossil fuels. However, geothermal power should be taken seriously as a viable, cost effective, and cleaner alternative to natural gas when power purchasers are considering multiple procurement contracts. Given the 30 to 60 year lifetime of most new power plants, choices made today will influence the ability to meet U.S. climate goals in the future. In addition, while natural gas can be seen as an economic alternative to geothermal power, the external and ancillary costs associated with extracting and burning natural gas to generate electricity are often forgotten.

To elaborate, the expectation is often that dispatchers will rely on natural gas-fired units for load and resource following. These units will help cushion against the variability caused by VER as a non-firm, power source. In reality, load following using gas-fired generation is more costly. Geothermal power can provide these services as a least cost option. A report from Aspen Environmental Group listed several reasons:⁷

- Since gas moves slowly, deliveries are scheduled in advance. As a result, gas scheduling to support load following is inconsistent with current practices making securing gas for load following more difficult and costly.
- A utility's gas fleet is not capable of providing ancillary services that will be most desired with high penetration levels of VER. For example, PG&E noted that more than 50% of the existing [presumably gas-fired] fleet requires 5 or more hours to start. For these resources to be effective at supporting VER they would have to continually be placed in service hours before they are needed.
- The existing gas supply infrastructure for power generation works because ramp is predictable and VER penetration levels are low. When larger, more frequent and sudden ramps become commonplace it will be harder to accommodate for changes without notice to gas suppliers making gas plants less economical.
- Owners of both gas-fired base-load and peaking units often do not hold gas transportation rights. Peaking generation units are understandably reluctant to commit to annual charges in reserve capacity all the time that they expected to be used in only a handful of hours during the year. Even if generators do commit, state end-use priority rules and cost allocation policy make delivery of gas to electricity generators lower priority than deliveries to other customers.
- Gas requirements for ramping patterns to support VER are inconsistent with gas utility and pipeline tariff provisions requiring ratable hourly takes.
- Operating gas-fired peaking units for reliability purposes requires specific natural gas transportation capacity arrangements. Unfortunately, these specific transportation capacity arrangements are quite different from gas peaking units that are only operated during the

⁶ U.S. EIA 2013b

⁷ Linvill et al. 2013

summer. The latter can use spare gas transport capacity because summer is an off-peak season for gas transportation capacity.

- Geothermal power provides stable electricity prices as opposed to natural gas which can cause prices to fluctuate. The price of electricity from natural gas spiked three times over the last decade in 2003, 2006, and 2008. Stable electricity prices are a result of a diverse portfolio of energy resource technologies. Geothermal power adds to stable electricity prices since it's disconnected from fuel costs. Power plants are locked into long term fixed contracts where "fuel costs" are paid upfront during the plant's construction in the form of high capital costs.⁸

The Union of Concerned Scientists describes in their latest report that the transition from a coal to a natural-gas-dominated electricity system would not be sufficient to meet U.S. climate goals. A natural-gas-centered power system still carries significant economic, environmental, and public health risks such as its impact on climate change as well as environmental consequences from extraction. Even if direct smokestack pollutants could be controlled or reduced with carbon capture storage technologies, they are not the only global warming emissions associated with natural gas. The extraction of the fuel from wells, and its distribution in pipelines, results in the leakage of methane—a primary component of natural gas that is 25 times stronger than carbon dioxide at trapping heat over a 100-year period. While there is still uncertainty about the precise quantity of these so-called fugitive methane emissions, preliminary studies and field measurements range from 1 to 9 percent of total natural gas production.⁹

Flexible Power: Geothermal Power's Ability to Adapt to Variability

The changing power markets have ignored or undervalued geothermal power and its ability to be both a firm and flexible resource that can address the challenges faced by the further integration of VER into a changing power market. Geothermal power can supplement variable resources to counteract and balance some of the changes needed to transition to a clean energy economy by acting as a firm and flexible power source.

The Need for a Flexible Power System

Electricity market participants are concerned that the increased presence of renewable VER without flexibility means current resources will not be sufficient to meet the reliability needs of the U.S. power systems. For example, the California Independent System Operator (CAISO) expects 12,079 MW of flexible resources to be retired by 2020 and the risk of power shortages is unacceptably high without flexibility.¹⁰ CAISO expects that with the addition of new, non-firm renewable resources coupled with the retirement of existing plants, there will be a much greater need for flexible power resources. Specifically, the following three issues will increase the need for flexible power system:

- The once-through-cooling (OTC) policy will reduce the number of flexible resources available because of power plant retirements.
- Variable resource additions will quickly displace flexible capacity in meeting resource adequacy obligations.
- Flexible resources will retire prematurely due to revenue insufficiency unless there are enhancements to the resource adequacy program.

⁸ U.S. EIA 2013f

⁹ UCS 2013

¹⁰ CAISO 2012

Overall CAISO's fundamental concern is that new VER and distributed resources will displace existing flexible dispatchable capacity and that without sufficient flexible resources in the fleet, the ISO will be unable to reliably operate the grid.¹¹

The Realities of a 21st Century Power System & Variability

Variable energy resources are important and feature innovative technologies that will play a prominent role in the transition to a clean energy economy and the reduction of global greenhouse gas emissions. However these technologies are variable, meaning that although some systems can be fairly predictable, they are not continuously available due to some factor outside direct control of the power plant operator.

Solar photovoltaic (PV) systems are growing in popularity and abundance as prices fall. A recent white paper and a letter to public officials from the Western Electrical Industry Leaders Group (WEIL), described some of the changes PV variability causes to the U.S. power system. PV generation power output is variable, injecting power at various points along electric distribution lines, which increases the voltage of the distribution lines at the point of interconnection. The output can change significantly over short periods of time due to environmental conditions like cloud movement and fog burn off. As a PV system output fluctuates, it causes voltage swings on these distribution lines.¹²

Wind power is also an increasingly prominent source of U.S. electricity and an important technology needed for building a clean energy economy to reduce global greenhouse gas emissions. However, it also is a variable source of electricity. A number of factors contribute to the variability of wind generation, including actions to reduce the danger to wildlife around the spinning blades. More commonly, matching demand and supply instantaneously alters generation when more energy is produced than the power grid can handle.¹³

The reality is that today's energy infrastructure was built for yesterday's technology, i.e., mostly fossil fuels. The process of synchronizing fluctuating wind or solar power in ever increasing amounts is a challenge to grid operators. The fear is that a power surge could overload and shut down the wires, leading to a drop in voltage on the system, and potentially spreading blackouts through the region and to other parts of the country.¹⁴

Flexible Power

Despite previous misconceptions, geothermal power has the ability to operate in a flexible mode that can quickly adapt to variability in the power system. Geothermal power plants can provide regulation, load following or energy imbalance, spinning reserve, non-spinning reserve, and replacement or supplemental reserve. In fact, 8 of the 16 MW of geothermal capacity at the Puna Geothermal Venture facility in Hawaii is currently used only to provide ancillary services for grid support and provides identical services as oil-fired resources on the Big Island.¹⁵

¹¹ *Ibid*

¹² *WEIL 2013*

¹³ *Cardwell 2013*

¹⁴ *Ibid.*

¹⁵ *Linville et al. 2013*

Geothermal power plants have minimal fuel costs. After the upfront capital investment for the well field construction, the operational costs of a geothermal power plant are nearly constant. As a result, the nominal flow of hot fluid can be circulated in the system even when only partial power is required. It does not affect operating costs to operate the plant at partial mode, as there is no cost for the unused geothermal fluid, or “fuel,” of a geothermal plant.

Some geothermal power plants can ramp up and down multiple times per day to a minimum of 10% of nominal power and up to 100% of nominal output power. The normal ramp rate for a geothermal ORC turbine is 15% of nominal power per minute (by heat source valve). The ramp rate for dispatch in Flexible Operation Mode is 30% of nominal power per minute. A geothermal plant can operate as Real Power Regulation, allowing the geothermal plant to support the grid frequency during disturbance (up to $\pm 5\%$ of nominal frequency), thereby improving the ability of the utility system to ride through the disturbance.¹⁶

Ancillary Services, Integration, Transmission Costs

As VER achieve higher levels of penetration in the Western electricity market, industry participants and regulatory agencies are recognizing the importance of quantifying integration and transmission costs associated with them. Failure to include these costs and the value of ancillary services results in an imprecise price per MWh comparison between energy technologies. The most common integration costs include those for transmission upgrades and ancillary services. These costs can vary depending on the type, penetration levels and supporting infrastructure of the resources that are selected to fulfill a power purchase agreement. An accurate cost comparison of renewable energy resources would include the total integration cost of each resource.

Calculating the integration cost is a very complex task, and to date these calculations have not been completed in a satisfactory manner. The complexity does not come from an inability to model the power system or from an inability to calculate system costs with or without variable energy resources. Instead, the complexity comes from trying to establish what conditions to compare, as well as from the complex and numerous interactions between generation resources as their aggregate output is adjusted to maintain load balance.¹⁷ Power System operators need to find a way to effectively and fairly compare VER to geothermal power.

Recently, in decision D. 11-04-030, the California Public Utilities Commission (CPUC) mandated that a “zero” adder for integration costs be used in evaluating bids in its 2011 RPS Solicitation. This hidden fee required to integrate a VER can cost millions of dollars to the ratepayer. When selecting renewable resource additions, regulators must recognize the costs associated with integrating resources into the electric system and the attributes these resources provide. Including an integration cost component that recognizes the ancillary service value provided by renewable energy resources is imperative to cost containment.¹⁸

Furthermore, geothermal power uses already existing transmission capacity efficiently because of its high capacity factors averaging 92%. Meanwhile, VER capacity factors average 20-34%.¹⁹ Therefore, a 100 MW VER needs to consume 100 MW of transmission even though the VER may seldom use the full

¹⁶ *Ibid.*

¹⁷ *Milligan et al. 2011*

¹⁸ *Thomsen 2013*

¹⁹ *U.S. EIA 2013b*

capacity of that line. As a result existing transmission capacity becomes unavailable to other generators. Geothermal power on the other hand will almost fully use the transmission capacity that it reserves from that same line. For congested transmission lines, the integration of VER resources can raise costs as more transmission infrastructure is built to accommodate the same amount of power. Transmission infrastructure is not cheap. Cost can range \$1-\$4 million dollars per mile²⁰ and often high-quality VER are distant from areas of high electric power demand. Therefore, they require investment in additional transmission infrastructure to accommodate new VER into the grid, raising costs.

Other Benefits of Geothermal Power

In addition, when considering solutions to specific challenges facing the evolving power market environment, geothermal energy has a number of other attributes that make it an attractive piece of the energy puzzle. It contributes to the labor market, not just by creating jobs directly, but also indirectly affecting employment in a variety of supporting industries. With near-zero emissions and a small land footprint, geothermal power’s impact on the environment is small, particularly when compared to other baseload power sources. Its high capacity value and capacity factor display a level of reliability generally not found in renewable energy sources, and its history of successful exploitation demonstrate both the longevity of the resource and the dependability of the technology.

Employment and Economic Development

Geothermal power production creates a variety of jobs throughout its lifecycle. Consultants and geoscientists perform the initial exploration; drilling engineers and construction teams develop the facilities; and an O&M staff ultimately runs the power plant. These steps, and many more in the process, create quality, professional positions. In addition to the jobs created directly, geothermal development also indirectly increases employment in a variety of industries that provide services to the companies performing exploration, construction, or operation and maintenance. Examples of these indirectly- created jobs include equipment service personnel, security guards, lawyers, and government regulators.

As Table 1 demonstrates, geothermal power creates significantly more jobs per megawatt than natural gas.²¹

Table 1: Comparative Job Creation

Power Source	Construction Employment (jobs/MW)	O&M Employment (jobs/MW)	Total Employment for 500 MW Capacity (person-years)
Geothermal	4.0	1.7	27,050
Natural Gas	1.0	0.1	2,460

Source: U.S. DOE 2006

Examples of jobs created during each stage of geothermal development include:

- Start-up phase: archeologists, hydrologists, wildlife biologists, geologists, lawyers, NEPA coordinators

²⁰ AEP 2008

²¹ U.S. DOE 2006

- Exploration phase: geologists, geochemists, geophysicists, GIS specialists, exploration drillers, engineers, sample analysts, consultants, management staff, clerical staff
- Feasibility drilling phase: drilling engineers, rig hands, site managers, mud loggers, drilling fluids personnel, cementing personnel, casing crews, rig transportation, fuel transportation, welders, safety managers
- Drilling and construction phase: engineers, power plant designers, document controllers, project managers, administrative support, safety managers, welders, steel erectors, concrete placers, assembly mechanics, inspection personnel
- Operation and Maintenance: plant managers, engineers, technicians, site operators, service repair

Many of these jobs are in rural communities, which have their own unique set of challenges. Such communities are often plagued with high unemployment rates that are well above the national average. Seasonal employment is also a common practice in many rural locations. Because geothermal developers typically negotiate long-term agreements with power purchasers, many of the jobs they create can be guaranteed for decades. The development of geothermal resources in rural areas offers a vehicle for educating, training and employing the local population, in addition to, increasing the diversity and stability of the local economy.²²

Small Land Footprint

Geothermal power has a very small land usage compared to other energy sources, particularly when weighed against other renewables. Unlike solar, wind, and biomass sources, which are predicated upon gathering diffuse ambient energy over large tracts of land, geothermal exploits a concentrated, subterranean resource. This plant design equates to less planetary surface area needed to produce comparable levels of power.

A recent paper estimates the intensity of land use associated with various energy sources based on the anticipated state of technology in the year 2030. Geothermal power's estimated usage of 7.5 km²/TWh-year is better than coal (9.7), solar thermal (15.3), natural gas (18.6), solar voltaic (36.9), petroleum (44.7), hydropower (54.0), wind (72.1), and biomass (543.4).²³

Near Zero Emissions

Geothermal power boasts extremely low emission rates, especially when compared with traditional fossil fuels that involve direct combustion of the primary resource. Binary power plants, which represent most of the geothermal plants that have come online recently, have near-zero GHG emissions and minimal particulate matter emissions.²⁴ When considering life cycle emissions, Argonne National Laboratory found binary geothermal power plants to be one of the cleanest forms of energy.²⁵ Flash and dry steam power plants also represent a significant improvement over coal and natural gas, as shown in Table 2:

²² Jennejohn 2010

²³ McDonald et al. 2013

²⁴ Matek 2013

²⁵ Sullivan et al. 2010

Table 2: Estimated Emission Levels by Pollutant and Energy Source of Power Plants

[lbs/MWh]	Dry Steam	Flash	Binary	Natural Gas	Coal
CO ₂	59.82	396.3	-	861.1	2200
CH ₄	0.0000	0.0000	-	0.0168	0.2523
PM _{2.5}	-	-	-	0.1100	0.5900
PM ₁₀	-	-	-	0.1200	0.7200
SO ₂	0.0002	0.3500	-	0.0043	18.75
N ₂ O	0.0000	0.0000	-	0.0017	0.0367

Source: Climate Registry 2012, EIA 2013e, EPA 2009, EPA 2011, NRC 2010

The emission most frequently associated with geothermal power production is hydrogen sulfide, a naturally occurring gas in geothermal systems, which oxidizes into sulfur dioxide and sulfuric acid when released into the atmosphere. Known for its distinctive “rotten egg” smell, hydrogen sulfide is a natural component of many volcanic and geothermal systems. Today, hydrogen sulfide abatement systems, such as LO-CAT and Stretford, are used extensively throughout the industry and have demonstrated a removal efficiency of more than 99.9%²⁶. Through such systems, hydrogen sulfide is converted to elemental sulfur, which can be used as a feedstock for fertilizers or as a soil amendment.

Reliability: Predictable and Long-lasting

Geothermal power production represents predictable output and long-lasting resources.

Having no reliance upon transitory environmental states such as wind and sunlight, geothermal facilities can produce electricity 24 hours a day, 7 days a week. As a result, geothermal power plants have a high capacity factor, demonstrating a level of consistency not found in other sources. The EIA report lists geothermal power as having the highest capacity factor (92%) of all the energy sources discussed, higher even than coal (85%), gas (87%), or biomass (83%). For comparison’s sake, the capacity factors for wind, solar and solar PV are listed as 34%, 20%, and 25% respectively.²⁷

Geothermal power’s reliability is also demonstrated by the longevity of the resource and its history of successful exploitation. The first electricity from geothermal steam was produced in 1904 by Prince Piero Ginori Conti in Larderello, Italy, and it went into operation as the first commercial geothermal power plant in 1913. This field is still producing today. In fact, with the exception of a few years during World War II, this field has been producing continuously for more than a century. Similarly, The Geysers field in California has been exploited consistently since the 1960s, and thanks in part to the wastewater injection practices which were enacted to sustain the resource, this field accounts for approximately one-fifth of the clean energy produced in California today²⁸

Examples such as these demonstrate the dependability of the resource, and the technology used to exploit it. Since geothermal exploitation is focused on harvesting a fluid, underground resource, much of the technology involved is similar to that which has been successfully used for decades in oil and gas drilling. Also, geothermal power is not burdened by many of the integration issues which plague variable energy sources and is compatible with existing transmission technology.

²⁶ Nagl 2009

²⁷ U.S. EIA 2013b

²⁸ Calpine 2012

Conclusion

Geothermal power is a reliable, economical, and clean option to provide baseload power for the growing U.S. power system.

- Retirement of emission-heavy coal plants will provide opportunities for more environmentally-friendly geothermal power plants. Among energy sources which are suitable for baseload production, geothermal power represents arguably the smallest carbon footprint. Geothermal power has significantly lower CO₂ emissions than coal or natural gas.
- The U.S. Energy Information Administration (EIA) formulates the levelized cost per kilowatthour for various energy sources. The estimated average levelized cost for geothermal power (\$89.60/MWh) comes in significantly lower than coal (conventional or advanced), nuclear, or biomass.²⁹
- Baseload or Load Following using gas-fired generation is more costly than geothermal power when factoring in ancillary costs of natural gas electrical generation.³⁰
- The transition from a coal to a natural-gas-dominated electricity system would not be sufficient to meet U.S. climate goals. A natural-gas-centered power system still carries significant economic, environmental, and public health risks from methane's impact on climate change as well as environmental consequences from natural gas extraction.³¹

Despite previous misconceptions geothermal power has the ability to operate in a flexible mode that can quickly adapt to uncertainties in the U.S. power system. Geothermal power offers flexible solutions to provide a range of services including, but not limited to, baseload, regulation, load following or energy imbalance, spinning reserve, non-spinning reserve, and replacement or supplemental reserve.

- Geothermal power plants can ramp up and down very quickly, multiple times per day to a minimum of 10% of nominal power and up to 100% of nominal output power. The normal ramp rate for a geothermal ORC turbine is 15% of nominal power per minute.³²
- As VER achieve higher levels of penetration in the Western electricity market, market participants and regulatory agencies are realizing the importance of quantifying integration and transmission costs associated with them. Failure to include these costs and the value of ancillary services results in an imprecise price-per-MWh comparison between energy technologies. Well-established inaccurate procurement comparisons increase ratepayer costs on a power system built for older, baseload energy technologies.³³
- Geothermal power uses already existing transmission capacity efficiently because of its high capacity factors averaging 92%. Meanwhile, VER capacity factors average 20-34%. Therefore, a 100 MW VER needs to consume 100 MW of transmission even though the VER may seldom use the full capacity of that line. As a result, existing transmission capacity becomes unavailable to other generators. Geothermal power on the other hand will almost fully use the transmission capacity that it reserves from that same line.

Geothermal power has a number of other attributes which make it an economical and attractive resource for electrical generation including:

²⁹ U.S. EIA 2013b

³⁰ Linvill et al. 2013

³¹ UCS 2013

³² Linvill et al. 2013

³³ Thomsen 2013

- Geothermal power production has a positive impact on local economies, and creates significantly more jobs per megawatt than natural gas.³⁴
- Geothermal power has a smaller land footprint than most other energy sources, particularly when compared with other renewables.³⁵
- Geothermal power has very low emission levels. Binary plants produce near-zero GHG emissions while flash and dry steam plants represent a significant reduction compared to fossil fuels based generation.³⁶
- Geothermal power's established history of consistent output demonstrates a level of reliability unmatched by other renewables and fossil fuel based generation.³⁷

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³⁴ Jennejohn 2010

³⁵ McDonald et al. 2013

³⁶ Matek 2013

³⁷ U.S. EIA 2013b

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