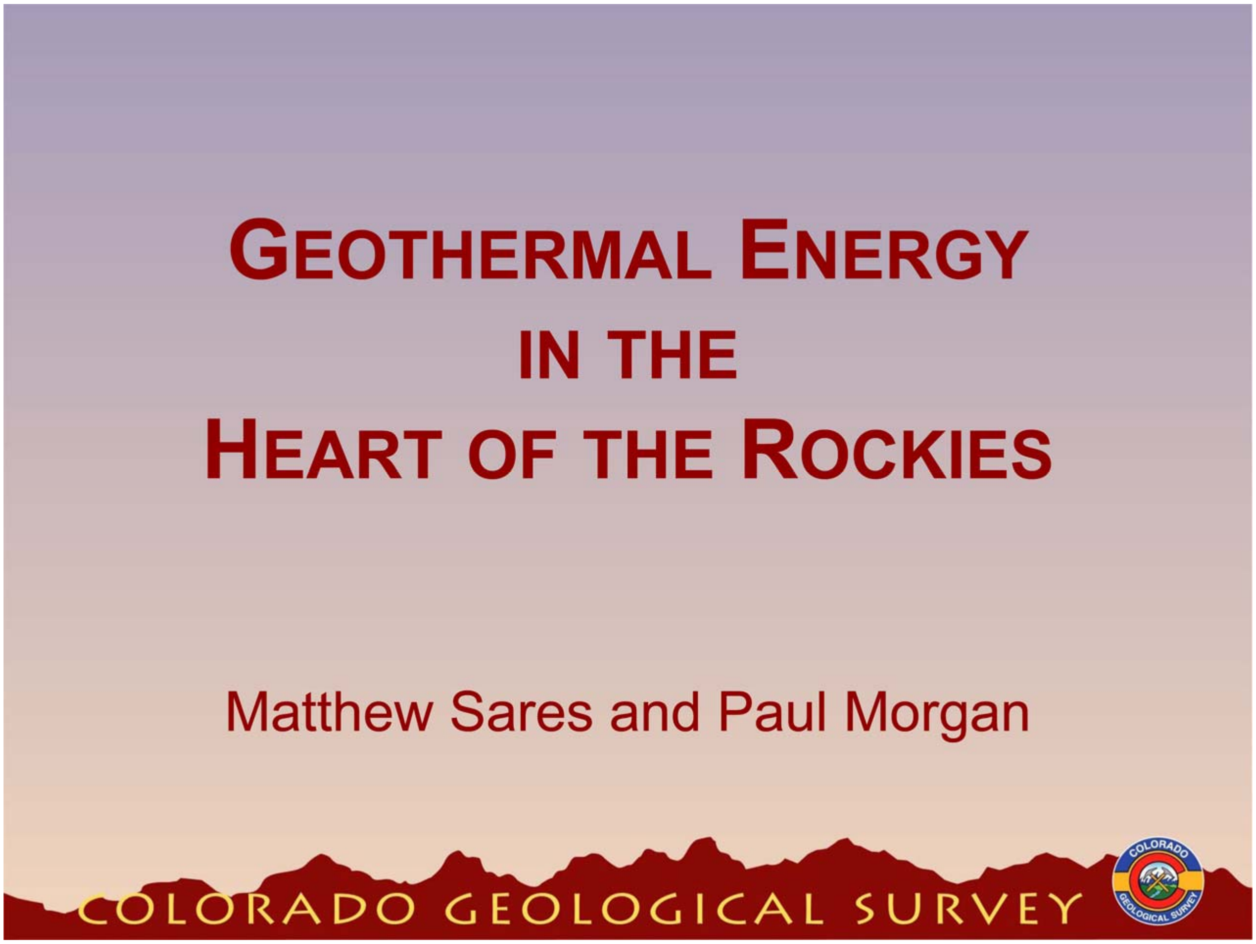


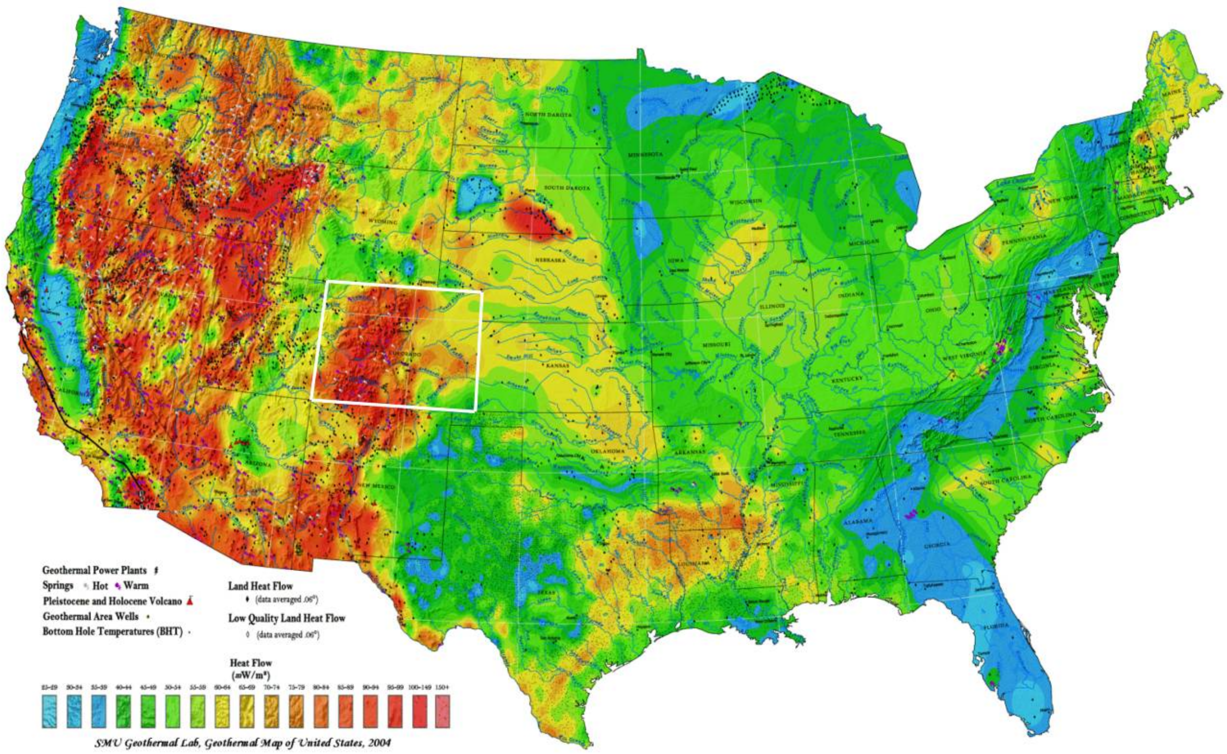
This document is derived from a presentation delivered at the Salida Sustainability Summit in Salida, Colorado on October 15, 2009. The meeting was held at the Salida Steam Plant. The meeting was an open forum for the general public to learn and ask questions about geothermal energy. It was organized by Kathryn Wadsworth of Incite Consulting, and sponsored by the municipal and county governments in Chaffee County, the Governors Energy Office, Dept of Local Affairs, and Alliance for Sustainable Colorado as part of the Chaffee County Energy Planning initiative.

"Geothermal Energy in the Heart of the Rockies" was a presentation introducing the subject of geothermal energy and covered the following topics:

- Geothermal resources of Colorado and the Chaffee County area.
- What is a geothermal power plant?
- What is required for one to be installed?
- Why here? Why now?
- What are the environmental impacts?

Questions were welcomed during and after the presentation.

Geothermal Resources of Colorado and the Chaffee County Area



Heat flow map of the conterminous United States[1]

Geothermal resources are defined as any resource that uses the natural heat of the Earth. Usually these are resources that are significantly hotter than surface temperatures and one measure of these resources is the amount of heat that is flowing out of the Earth. The map above shows this heat flow, based on measurements in drill holes: cold colors (blue and green) indicate low heat flow; warm colors (orange and red) indicate high heat flow. Colorado is outlined by the white square, and most of the mountainous regions of Colorado are indicated to have high heat flow. Other regions in Colorado may also have geothermal resources, but the areas indicated in orange and red are the areas most likely to have economic geothermal resources. The area of the heat flow anomaly is comparable to other states that currently produce electricity from geothermal resources, such as California, Nevada, Idaho, and Utah.

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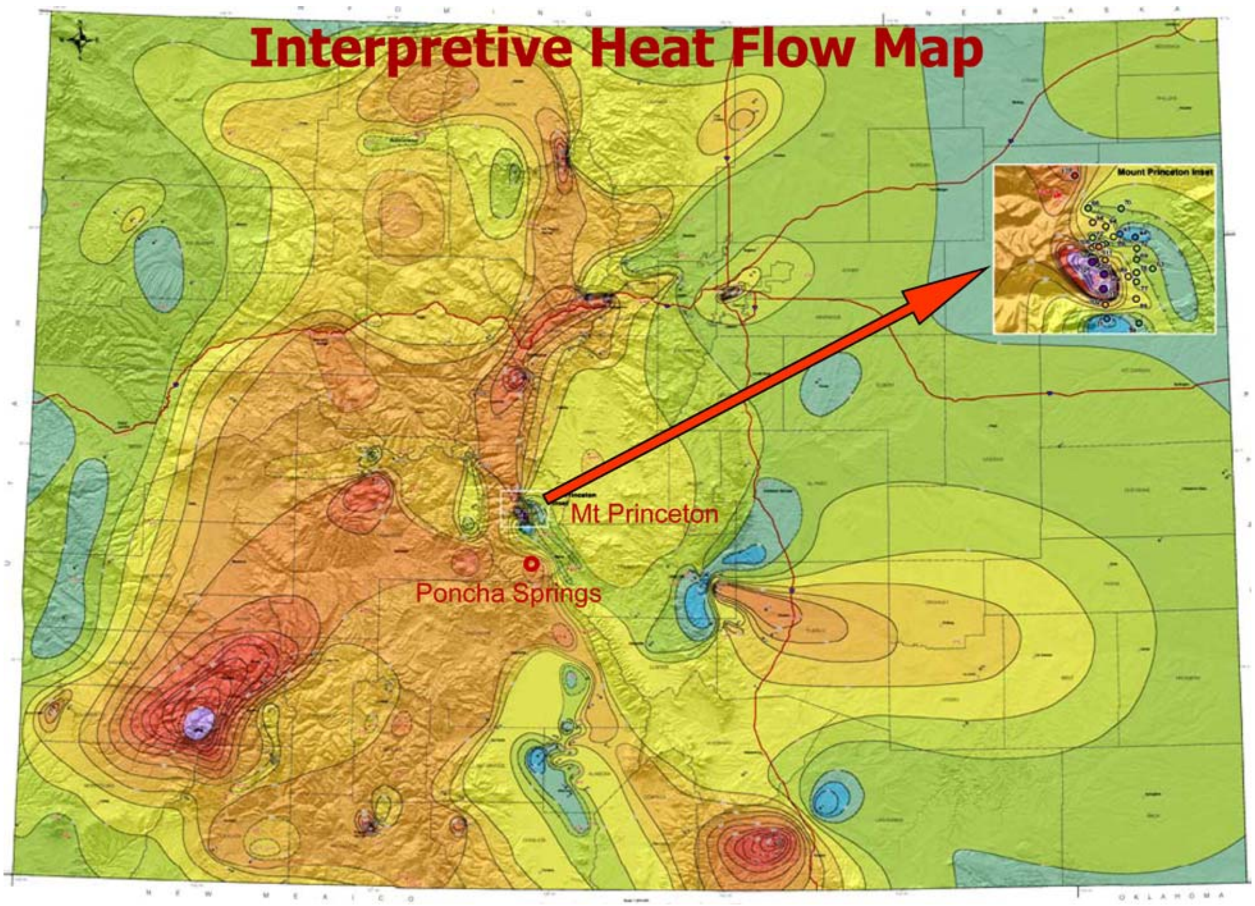
[1] (modified from Blackwell, D. D. and Richards, M., 2004, Geothermal Map of North America. American Assoc. Petrol. Geologists (AAPG), 1 sheet, scale 1:6,500,000. Web source: http://smu.edu/geothermal/heatflow/geothermal_all_us_clipped_150dpi_pagesize_legend.gif, last accessed 2009/10/27)

Heat Flow Map of Colorado

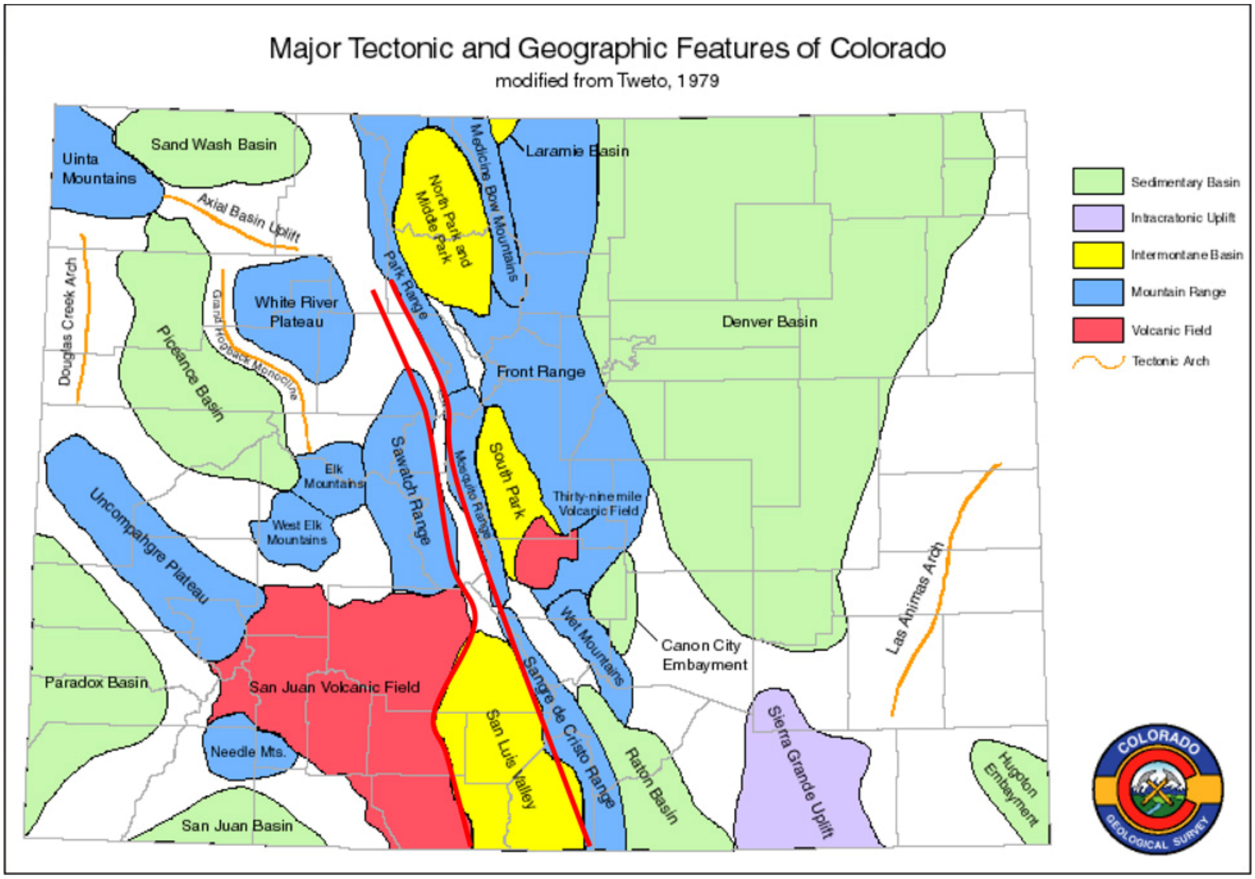


Heat Flow Map of Colorado[2]

The larger scale of this map shows more detail than the US Heat Flow Map, but many areas are without data and the contours are extrapolated. The same basic pattern is shown as on the US map, with high heat flow in the mountainous regions of Colorado. Two specific areas in Chafee County are labeled, Mt Princeton, which has the highest heat flow measured to date in Colorado, and Poncha Springs, a significant hot spring in the state.

[2] Modified from Berkman, F. E. and Carroll, C. J., 2007, Interpretive Geothermal Heat Flow Map of Colorado, Colorado Geological Survey, Map Series 45, Plate 1. The original version of this map may be downloaded at MS-45 Interpretive Geothermal Heat Flow Map of Colorado. This map was derived from much of the same data for Colorado as used in the US Heat Flow Map plus additional unpublished data and hot spring data were used in areas where heat flow data were not available.

Major Geologic Features in Colorado

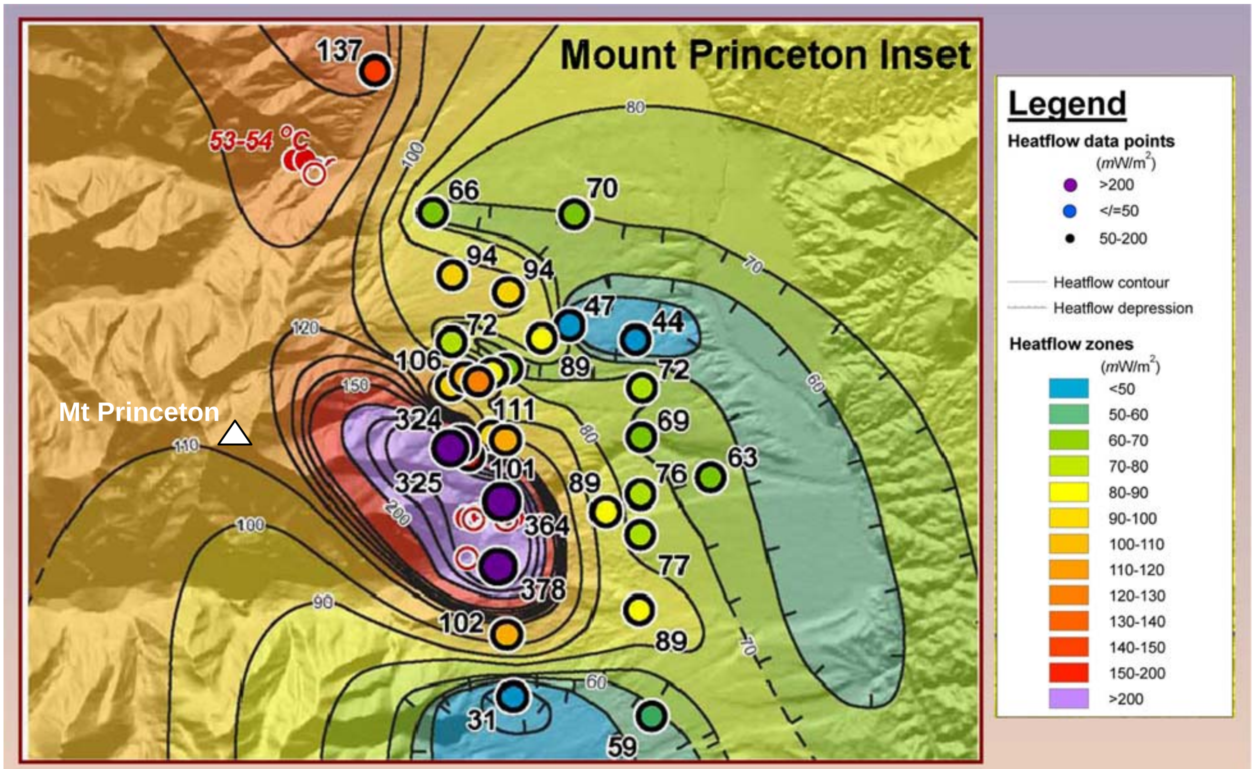


Map of Major Tectonic and Geographic Features in Colorado[3]

The mountain regions of Colorado have a variety of origins and ages which prevent detailed generalizations about the origins of geothermal resources in the state. The most that may be said without too many qualifications is that geothermal resources tend to be associated with geologically young (less than 30 million years) tectonic (mountain building) and volcanic activity. Even more favorable indications are very young (less than 2 million years) faults, but these are often difficult to identify, especially in mountain regions. Hot springs and hot wells are common surface manifestations of geothermal resources, just as oil seeps were indicators of oil reservoirs early in oil exploration. Lack of a hot spring, however, does not mean a lack of a geothermal reservoir. “Rift zones” are areas where the earth has been, or is being pulled apart. Around the world, rift zones contain important geothermal resources. The Mt Princeton and Poncha Springs geothermal areas are located within the northern extension of the Rio Grande Rift zone.

[3] Simplified and modified from Tweto, O., 1979, Geologic Map of Colorado, Colorado Geological Survey, MI-16, Map, scale 1:500,000. The red lines outline the trend of the Rio Grande rift, the youngest major tectonic feature in Colorado – the Upper Arkansas Valley is the northernmost basin in the Rio Grande rift.

Mt Princeton Area Heat Flow

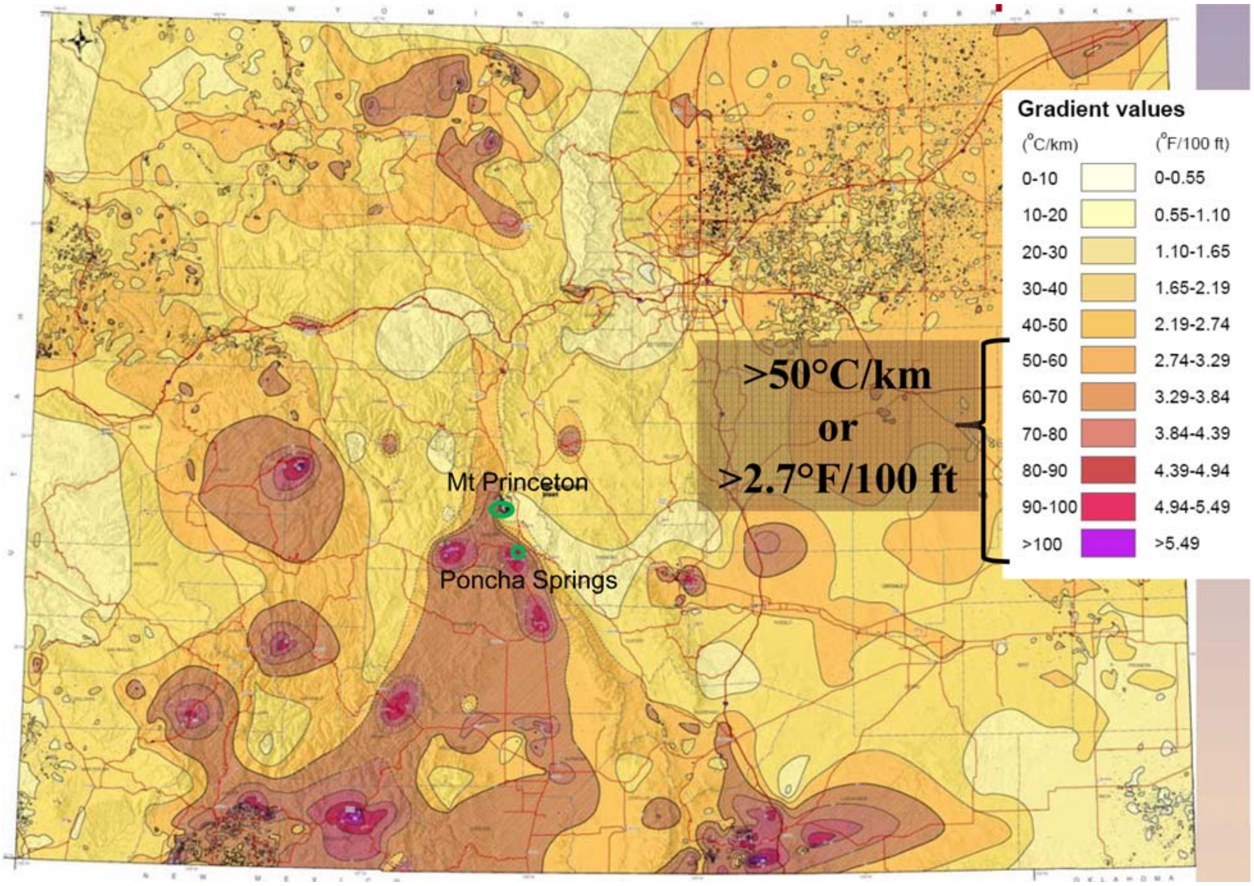


Heat Flow in the area of Mt Princeton, Chafee County, Colorado[4]

Chafee County has been of interest for geothermal exploration for over 35 years. There are three main hot springs areas in the county, Cottonwood/Charlotte Hot Springs west of Buena Vista (red dots at 53-53°C on map above, 127-129°F), Hortense and Mt Princeton Hot Springs in the Chalk Creek Valley, which include the hottest spring in the state (Hortense: 81-83°C, 178-181°F), and Poncha Hot Springs (~70°C, ~158°F). Extensive field exploration has been conducted around Mt Princeton and analysis of the hot spring waters indicate that the surface springs are a mixture of thermal waters at depth with a temperature probably around 150°C (around 300°F) and cooler shallow waters. Other similar hot springs exist in Colorado, but nowhere has the exploration been as intense.

[4] Taken from the inset on the Interpretive Geothermal Heat Flow Map of Colorado (2007 – see previous page). The shaded topography indicates the topography of the area: the smooth areas are the Upper Arkansas River valley. The colored dots indicate sites of heat-flow measurements and the number by each dot are the heat-flow values in milliWatts per square meter (mW/m2). A typical background heat flow would be 50-60 mW/m^2.

Geothermal Gradient Map of Colorado

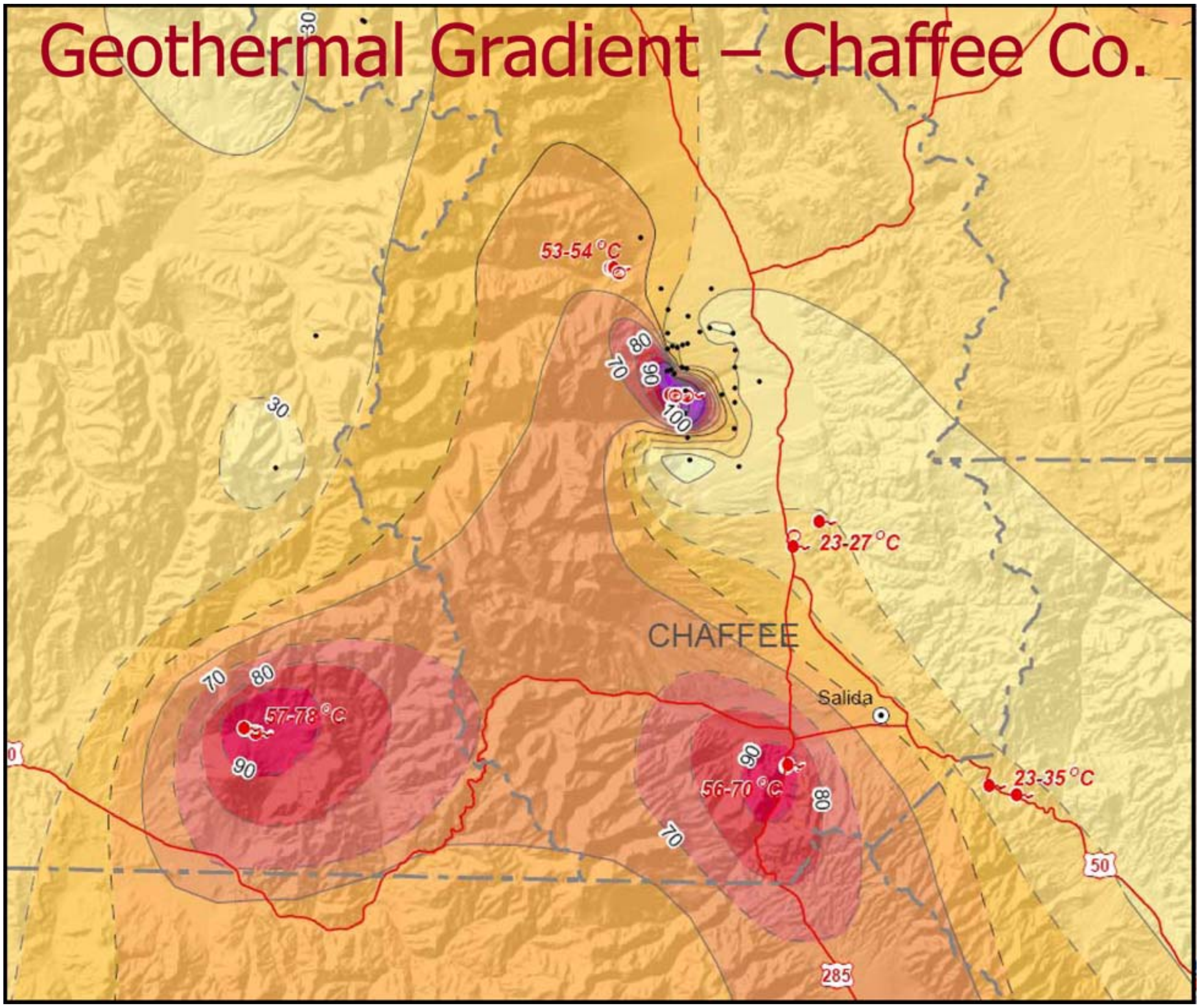


Geothermal Gradient Map of Colorado[5]

A second valuable regional method for assessing geothermal resources is to map the geothermal gradient, the rate at which temperature increases with depth. The map above shows the distribution of geothermal gradients in Colorado. Although this map mostly shows the highest geothermal gradients in the mountainous regions of Colorado, confirming the assessment of the heat-flow map, high and moderate geothermal gradients are shown east of the Rocky Mountain front in the Raton and Denver Basins indicating potential geothermal resources in these basins. Once again, Chafee County is shown to be a good prospect for geothermal resources.

[5] Modified from Berkman, F. E., in press, Interpretive Geothermal Gradient Map of Colorado, Colorado Geological Survey. This map was derived from some of the same data for Colorado as used in the US Heat Flow Map but a large additional data base of bottom-hole temperatures from oil and gas wells was also used in the compilation of this map, providing coverage in large areas where heat-flow data were not available.

Chafee County Geothermal Gradient



Geothermal Gradient Map of the Southern Portion of Chaffee County and Adjacent Areas.[6]

Geothermal gradient data for the southern portion of Chafee County and adjacent areas reinforce the conclusions from the heat flow data that Mt Princeton and Poncha Springs are good prospects for geothermal resources. Cottonwood/Charlotte Hot Springs are not ranked so highly by the geothermal gradient data, but the data are sparse. The large anomaly west of Poncha Hot Springs in Gunnison County is Waunita Hot Springs.

[6] Taken from the Interpretive Geothermal Gradient Map of Colorado (in press; see previous page). Small black dots indicate locations of data points. Temperatures of hot springs were used to estimate geothermal gradients where gradient data were not available.

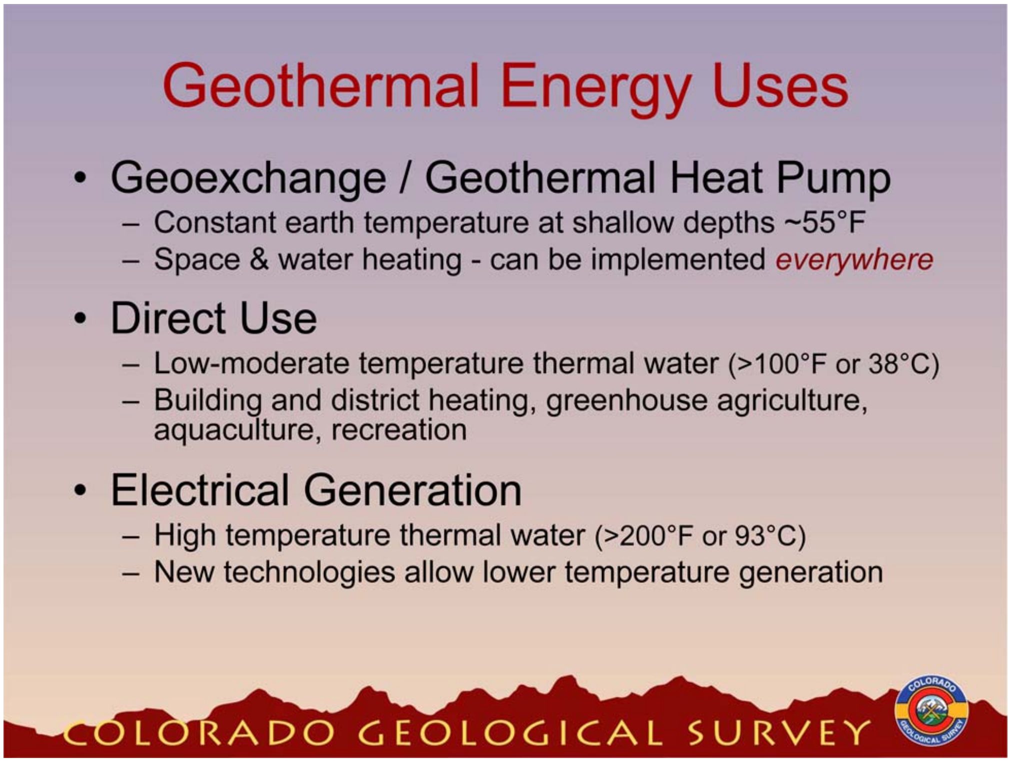
Overall Ranking of Hot Springs in Colorado Based on Published Spring Temperatures and Geochemistry

#	Spring Area	Comments
1	Waunita Hot Springs (Upper & Lower	Top ranking in all categories
2	Routt (Strawberry) Hot Springs	Second ranking without ionic geothermometers
3	Poncha Hot Springs	Next ranked for Quartz area ranking
4	Chalk Creek Hot Springs Area	Hortense H.S. hottest spring and high Individual rank
5	Penny Hot Springs	Approximate general ranking
6	Rico Area	Approximate general ranking
7	Wagon Wheel Gap	Approximate general ranking
8	Pagosa Springs	Approximate general ranking
9	Mineral Hot Springs	Approximate general ranking
10	Ouray and Orvis Hot Springs	Orvis approximate general ranking and Ouray highest ranked individual spring after Pagosa Springs

Ranking of Chafee County Hot Springs in Colorado[7]

Yet another method of assessing regional geothermal resources is to use information from hot and warm springs, which are surface seeps from subsurface heated water. We may examine just the surface temperatures, but the water may cool on its journey to the surface. Another technique uses experimental evidence that the solubility of minerals changes with temperature, but as the temperature drops the solution only slowly changes to the conditions of the lower temperature. The result is that a solution collected from a hot spring typically comprises a solution of minerals at the last hot reservoir temperature. By analyzing the solution chemistry, an estimate of the reservoir temperature may be calculated. This technique is called geothermometry. The table above is a ranking of the springs in Colorado that indicates the most promising reservoir temperatures based on surface temperatures and geothermometry. Poncha Hot Springs and the springs in the Chalk Creek Valley (Mt. Princeton) are numbers 3 and 4 in the ranking, again confirming the high potential for geothermal resources in Chafee County.

[7] Source: Morgan P., 2009, An Evaluation of Colorado's Thermal Springs with the Greatest Potential for High Temperatures Using Published Information, Colorado Geological Survey, unpublished report, 52 pp.

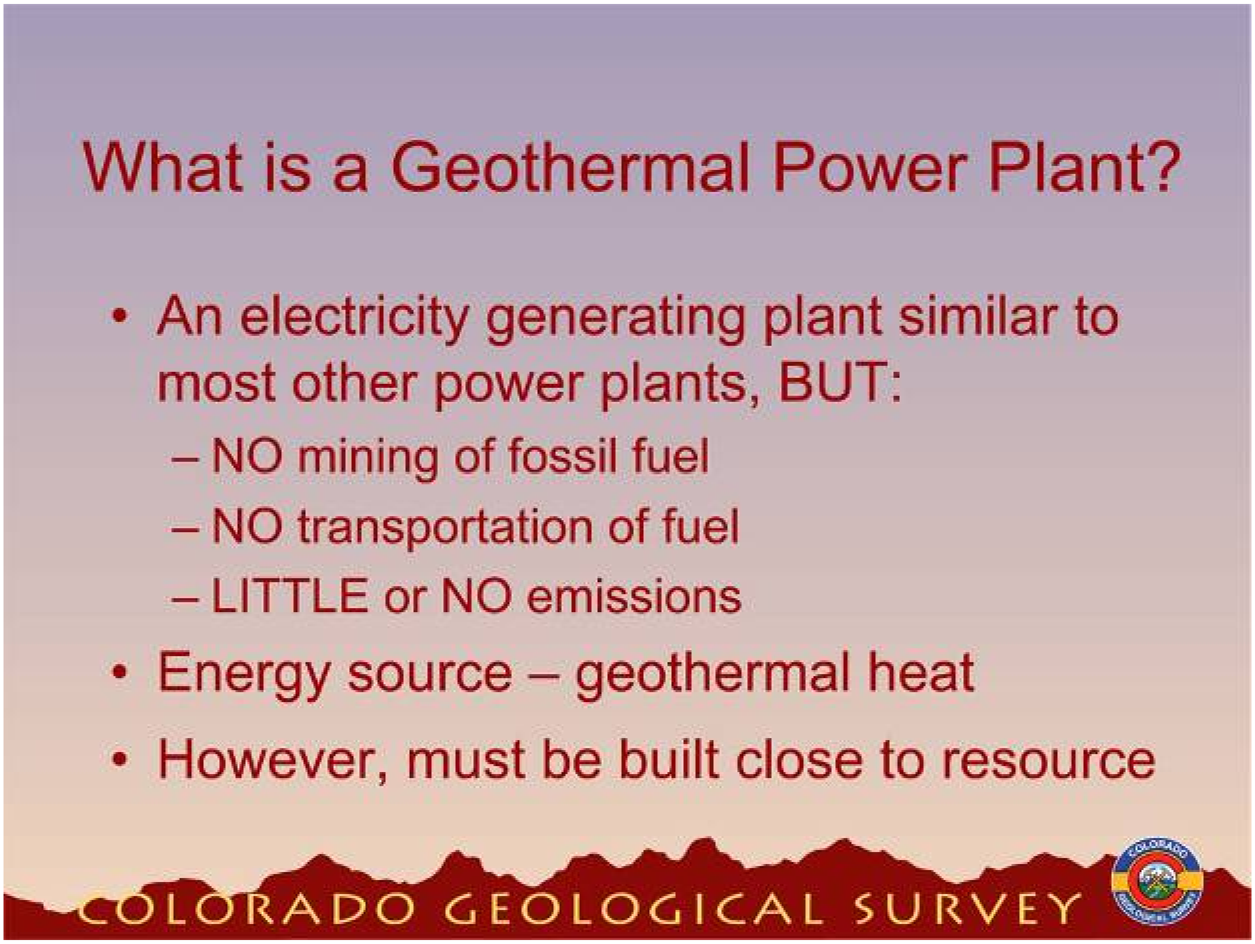


The Three Basic Uses of Geothermal Resources

There are three basic uses of geothermal resources:

- Geothermal Heat Pumps (also known as Geoexchange or Ground Source Heat Pumps). These systems work on the same principle as an air conditioner or a refrigerator with a compressor unit where the working fluid becomes hot and an expansion unit where the working fluid becomes cool. Heat from the compressor is taken for heating in the winter and cool from the expansion unit is used for cooling in the summer. The cool working fluid is heated in the ground in the winter and the hot working fluid is cooled in the ground in the summer. If more heating than cooling is required, hot water from a geothermal resource may be used to provide additional heat to the cool working fluid in the heating cycle. The heating cycle may also be used for water and other heating uses.
- Direct use is any use of geothermal hot water in which the water is used at or below the temperature that it comes from the ground. These uses include space heating, spas and bathing, greenhouse heating, and fish farming.
- When the geothermal resource is sufficiently hot (≥~200°F or 93°C) and with sufficient flow, electricity may be generated. The remainder of this document concerns Electricity Generation.

Geothermal Electricity Generation



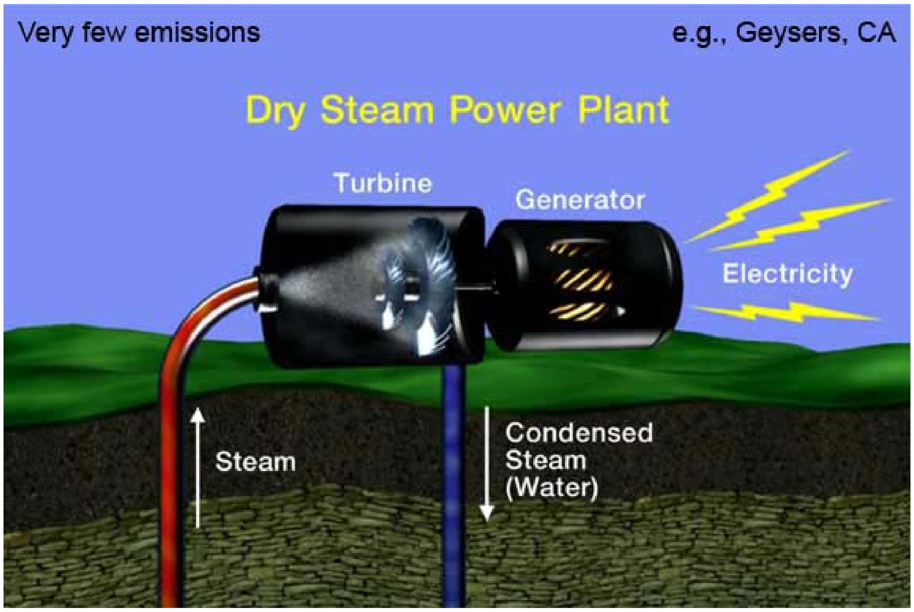
Features of a Geothermal Power Plant

A geothermal power plant is similar to most conventional power plants in that it has a turbine that drives a generator, but has no boiler and therefore needs no transported fuel to provide heat for the boiler. The turbine may be driven directly by geothermal steam or by vapor from a fluid that boils at a lower temperature than water and is heated by geothermal hot water in a heat exchanger. The geothermal steam and/or hot water are delivered to the power plant from boreholes through pipes, and no mining or traditional transportation is required. There is no combustion of fuel, and no combustion emissions. There are a few minor emissions of volcanic gases from some older power plants, but these have been reduced to zero in the latest plants.

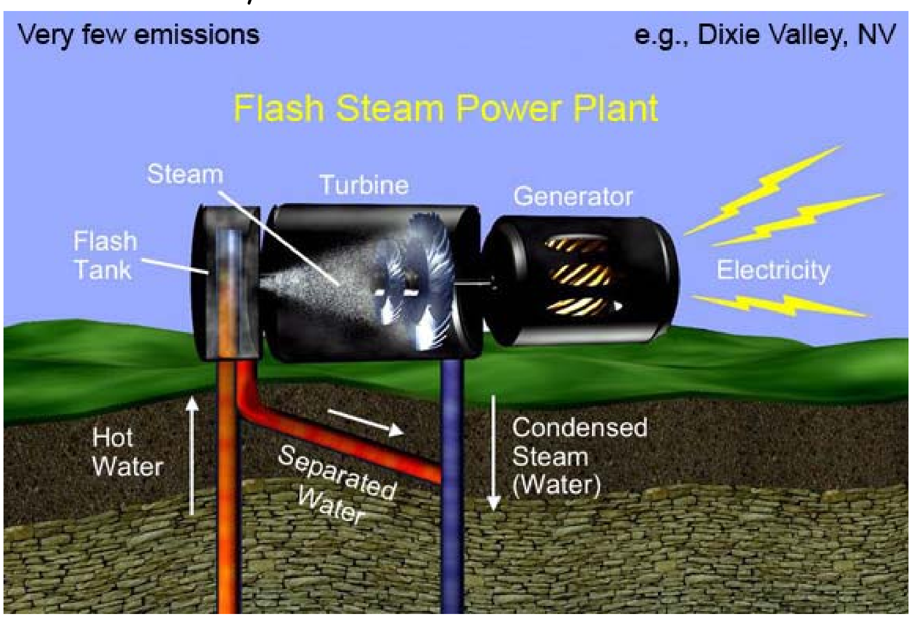
There are power plants where the geothermal hot water is piped about 7 miles (11 km) with a loss of only 1°C (2°F), but it would probably be impractical to site a power plant more than a few miles from the center of a geothermal resource.

Basic Types of Geothermal Power Plant

There are three basic types of geothermal power plant with additional hybrid designs.

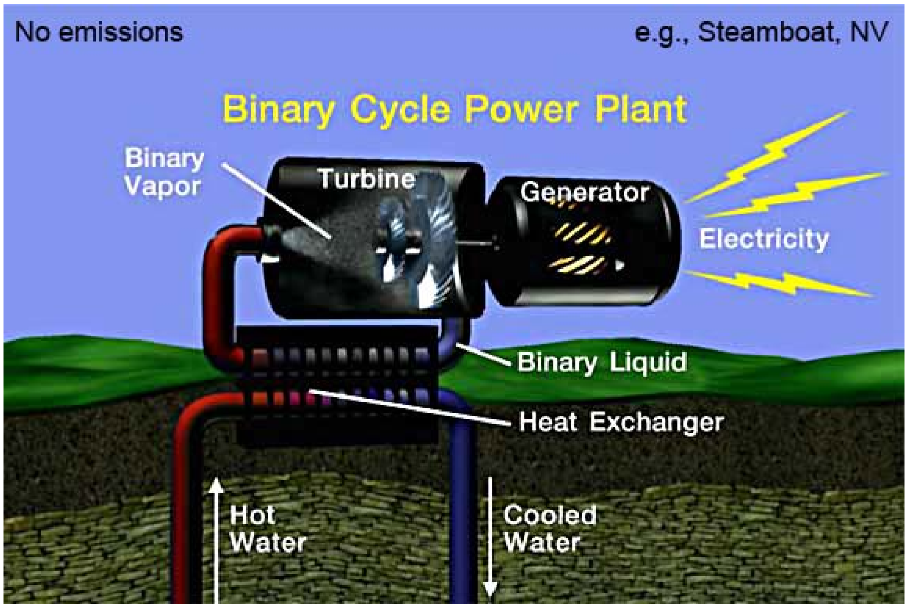


Dry Steam Geothermal Power Plant[8]



Flash Steam Geothermal Power Plant[8]

[8] Modified from Geothermal Education Office, 2000, Introduction to Geothermal Energy Slide Show, http://geothermal.marin.org/Geopresentation/, © 2000-2001 Geothermal Education Office.

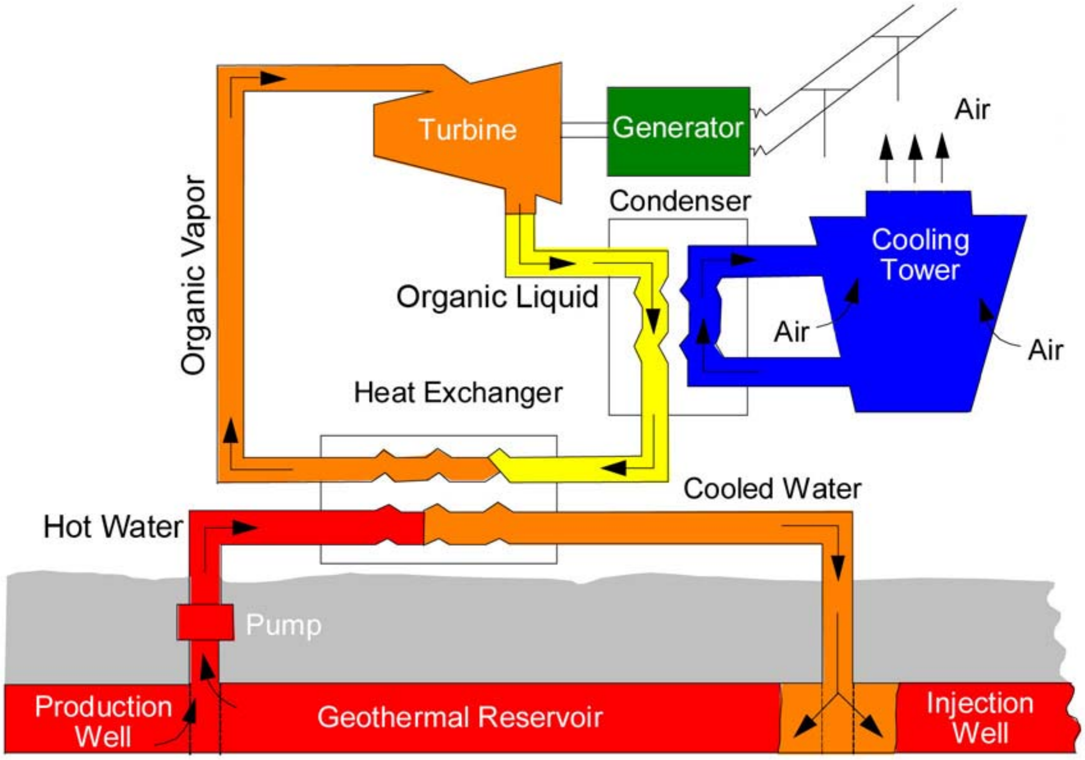


Binary Cycle Geothermal Power Plant[8]

There are very few locations where dry steam may be tapped from a geothermal reservoir and Dry Steam Geothermal Power Plants are rare. Most reservoirs produce hot water that is above its boiling temperature at atmospheric pressure and flashes to a mixture of water and steam when the water pressure is reduced at the surface. In a Flash Steam Geothermal Power Plant this flashing to steam is controlled in a chamber, the steam is fed to the turbine, and the hot water is typically returned to the reservoir. If temperatures are lower, little steam is produced by the flashing process, so the hot water is used to convert a fluid with a lower boiling temperature than water to vapor, and this vapor is used to drive the turbine in a Binary Cycle Geothermal Power Plant.

Not shown in these diagrams is the cooling system that must be used with any turbine generating unit to cool the vapor after it exits from the turbine to increase the amount of energy that is extracted in the turbine. These cooling units are most commonly water towers and are the large tapering concrete cylinders seen at power plants with white clouds of water vapor issuing from their tops. With binary power plants air cooling is also an option which requires no water and these units are generally much shorter than water cooling towers.

Advantages of Binary Geothermal Power Plants



Binary Cycle Geothermal Power Plant Showing Basic Operating Components.[9]

- Binary cycle geothermal power plants can use geothermal resources with temperatures lower than 200°F (93°C), although higher temperatures are more efficient;
- There are no emissions from the geothermal resources as the geothermal waters are not exposed to the atmosphere;
- Binary cycle power plants can be water cooled or air-cooled. With air-cooling, there is no primary water use for the power production.
- Heat from the geothermal resource may be cascaded for other direct heat uses: after using the hot water in the heat exchanger to vaporize the binary fluid, it may be passed through a second heat exchanger to heat water for direct heat uses.

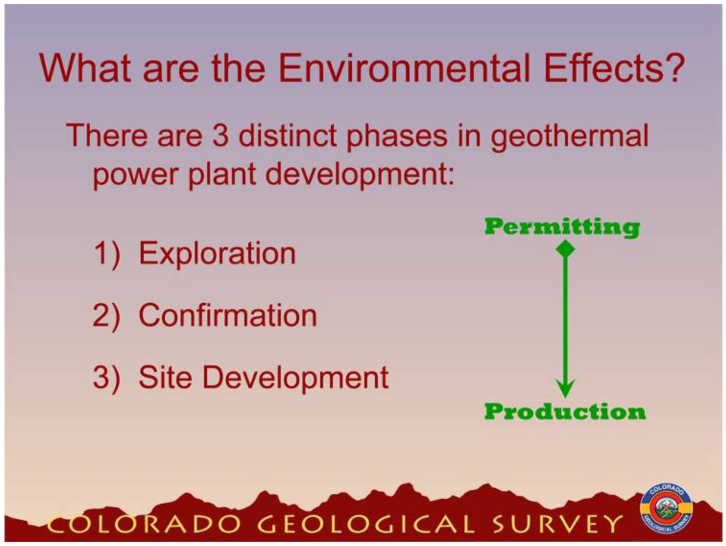
[9] Modified from Idaho National Laboratory, 2009, What is Geothermal Energy? Schematic of the binary cycle power plant. Web source: https://inlportal.inl.gov/portal/server.pt?open=512&objID=422&&PageID=3453&mode=2&in_hi_userid=2&cached=true. Original diagram © 2009 Idaho National Laboratory.

What is Required for a Geothermal Power Plant?

- There are two basic requirements from a geothermal resource to generate electricity:
  - High temperature at a relatively shallow depth (up to about 10,000 feet, but typically less). Temperatures must be at least high enough for a binary cycle power plant.
  - High porosity and permeability. The reservoir must be capable of producing high volumes of hot water, generally more than 500 gallons per minute per well. Energy is being extracted from the reservoir and converted into electricity, and the energy effectively extracted is related to the temperature of the water and the water flow.

- However:
  - Water from the geothermal reservoir is not consumed; it is recycled back into the reservoir through one or more injection wells to maintain the volume of the reservoir.
  - The water used from the reservoir does not need to be high-quality potable water: often the water is from deeper aquifers and may be more saline than shallower potable aquifers. Care is taken to prevent cross-contamination of aquifers.

The Environment and Safety



Environmental and Safety in the 3 Phases of Geothermal Development

There are 3 distinct phases in the development of a geothermal power plant: 1) exploration; 2) confirmation; and 3) site development. Depending on the ownership of the land (*e.g.*, private, State, or Federal), the regulations enforced at each phase of development are different, but at or before the stage of site development a full environmental impact statement is always required in Colorado including compliance with extensive environmental and safety regulations.

An Example of Federal and State Regulations Applied to Geothermal Development

1. Exploration

For geothermal electricity production, a shallow, high-temperature reservoir of hot water or steam must be found. This activity is call exploration

Exploration activities may include:

- Review of existing information, locations of hot springs, large-scale geological mapping, published information, *etc.*
- Seeking land access (permitting is usually not required at this stage, although permits may be required in National Forest Lands)
- Geological Mapping
- Geophysical Surveys (gravity, magnetic, resistivity, electromagnetic techniques, self-potential, active and passive seismic techniques, *etc.*)
- Geochemistry (spring and well water analyses, soil gas analysis)
- Hydrogeology (also known as hydrology – study of ground water flow)
- Remote Sensing (Analysis of photographs and other images from airborne and satellite sensors)
- Shallow Temperature Surveys (temperature measurements at depths up to about 3 m (about 10 feet)
- Temperature gradient drilling (drilling boreholes specifically for temperature gradient measurements to a depth of ~100 m [~300 feet], or in areas of more rugged topography ~150 m [~500 feet]). Temperature gradient boreholes are typically permitted as non-consumptive water wells and are cased with 1 to 1½ inch PVC pipe with the annulus between the pipe and the borehole wall backfilled to prevent water circulation in the hole.

2. Confirmation

Geothermal Drilling Rig.[10] Shown here is a large rig, capable of drilling more than 3 km (more than 10,000 feet). Significantly smaller rigs could be used for shallower wells.

If exploration indicates sub-surface conditions favorable for a geothermal resource at an economic depth and permitting is successful, one or two test wells may be drilled into the resource to confirm the temperature and hydraulic flow properties of the potential resource.

Drilling is usually performed by specially trained geothermal drilling crews using an oil rig modified for safety and geothermal-well drilling conditions. Geothermal drilling differs from oil and gas drilling in that, commonly, the drilling is through harder crystalline rocks than typical oil and gas sedimentary rock drilling, and temperatures may be significantly higher at shallow depths requiring additional caution and modified equipment to prevent hydrothermal blowouts from the well.

As in oil and gas drilling, more than one well may be drilled from the site using directional-drilling techniques.

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[10] Source: Geothermal Education Office, 2000, Introduction to Geothermal Energy Slide Show, http://geothermal.marin.org/Geopresentation/, © 2000-2001 Geothermal Education Office.

Confirmation – Flow Testing

Flow testing of a reservoir after drilling.[11]

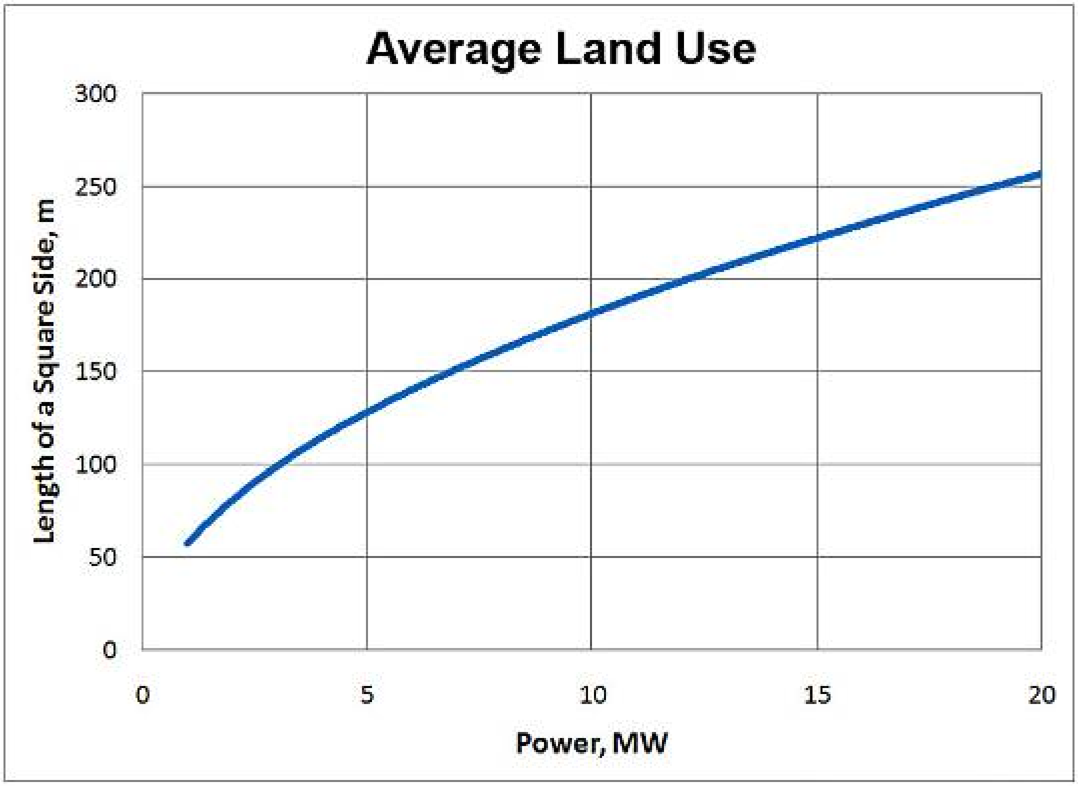
<u>If</u> drilling indicates a reservoir with sufficient temperatures for electricity generation, the flow properties of the reservoir are determined by "flow testing" the well. During a flow test, the rate of flow, the percentage of the flow flashing to steam, temperature, pressure, and changes with time are measured, and the length of the flow test is typically from a week to a few weeks.

During drilling and testing all "environmental" and other regulations apply, *e.g.*:

- No uncontained surface discharges
- Excess water either returned to reservoir (if permitted), or removed from site
- Roads upgraded for heavy equipment and repaired as necessary
- Site cleanup
- Noise barriers erected as necessary
- *etc.*

[11] Source: Geothermal Education Office, 2000, Introduction to Geothermal Energy Slide Show, http://geothermal.marin.org/Geopresentation/, © 2000-2001 Geothermal Education Office.

Site Development



Average Land Use for Geothermal Electricity Production[12]

<u>IF</u> flow tests indicate sufficient flow from the reservoir and all other factors are positive, site development will begin. Site development includes:

- Site selection and construction of the power plant
- Drilling and flow testing of additional wells (if required. They may be drilled at a later date)
- Drilling of injection well(s)
- Routing and construction of pipelines

In English units: 60 x 60 yd^2 per MW; for a 10 MW plant and wells=~8 acres
(10 MW=32,400 m^2; 1 acre ~ 4,000 m^2)

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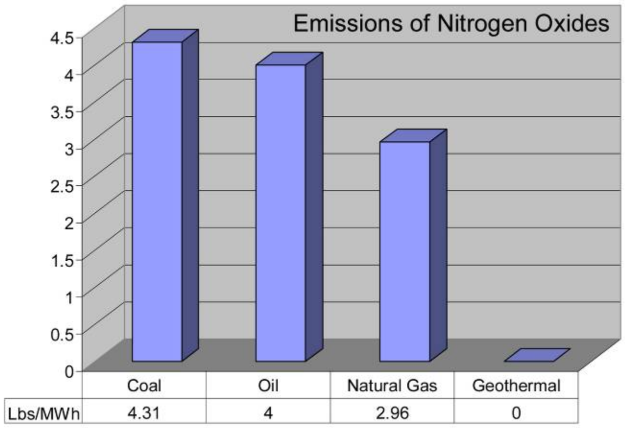
[12] Land use varies among power plants – these numbers include power plant, wells and pipelines. I estimate that the power plant is, on average, about 2/3 of the total. The land use is given in terms of a square, if all of the land use were put together on a square, the length of the side of the square is given. 1 m = 3.28 feet. Data derived from Kagel, A., D. Bates, and K. Gawell, 2007, A Guide to Geothermal Energy and the Environment, Geothermal Energy Association, 75 pp. http://www.geo-energy.org/publications/reports/Environmental%20Guide.pdf.

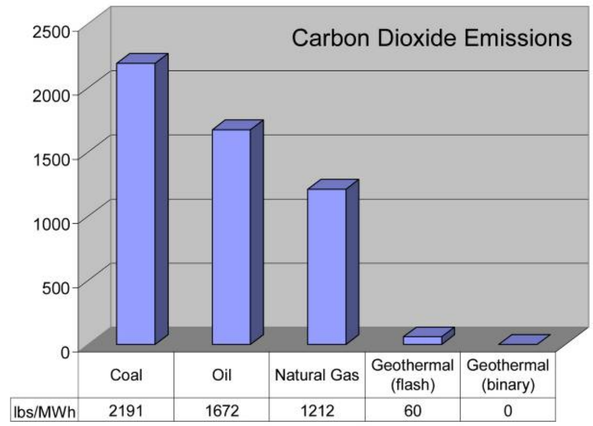
Some of the Many Factors to be Considered in Any Major Development

In any development project economic, regulatory, environmental, safety, engineering, and other factors are included in the design process. The consequences of some of these factors may be varied within only small limits according to the nature of the development project, for example, a geothermal power plant must be close to a geothermal resource. The following pages examine features of geothermal electricity generating plants and, where appropriate, compare them with the same features through other modes of electricity generation.

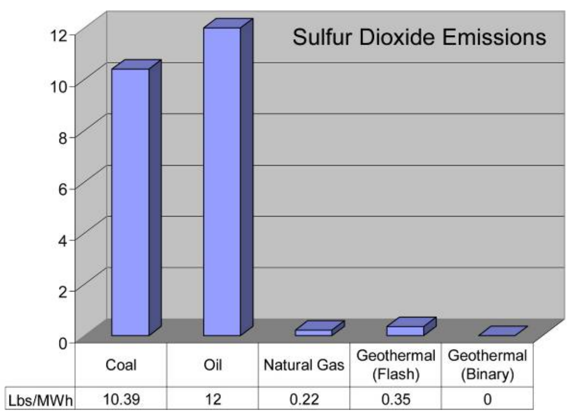
Atmospheric Emissions



Coal, oil, and geothermal reported as average existing power plant emissions; natural gas reported a average existing steam cycle, simple gas turbine, and combined cycle power plant emissions.

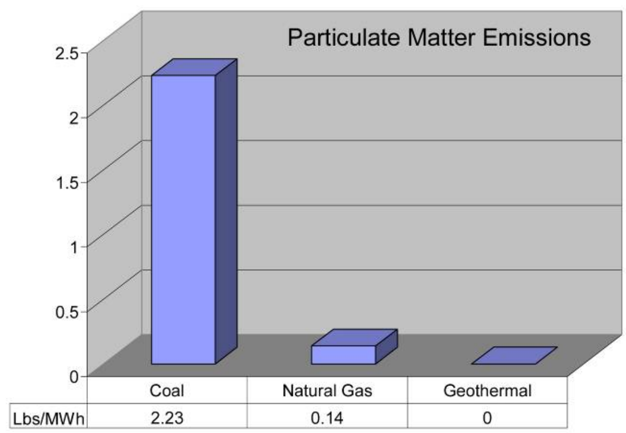


Coal, oil, and geothermal reported as average existing power plant emissions; natural gas reported as average existing steam cycle, simple gas turbine, and combined cycle power plant emissions.



*Calculation converts hydrogen sulfide to sulfur dioxide for comparison only

Coal, oil, and geothermal reported as average existing power plant emissions; natural gas reported as average existing steam cycle, simple gas turbine, and combined cycle power plant emissions.



Comparing pulverized coal boiler, natural gas combined cycle, and average existing power plant, geothermal.

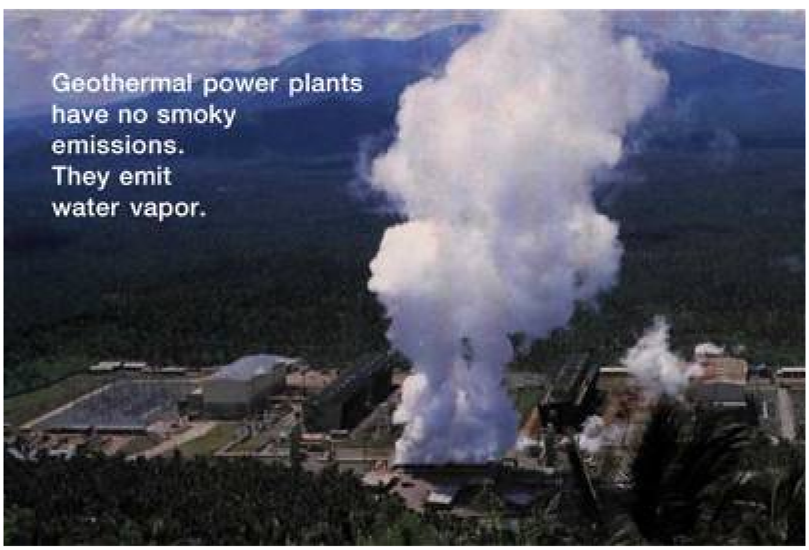
Comparison of Atmospheric Emissions from Different Types of Electricity Generation.[13]

Geothermal Power plants have no emissions of nitrogen oxides (NO_x) or particulate matter. Dry-steam and flash-steam geothermal power plants have small emissions of sulfur dioxide and carbon dioxide, varying from field to field. Binary cycle geothermal power plants have no atmospheric emissions.

[13] Modified from Kagel, A., D. Bates, and K. Gawell, 2007, A Guide to Geothermal Energy and the Environment, Geothermal Energy Association, 75 pp. http://www.geo-energy.org/publications/reports/Environmental%20Guide.pdf.

(A) With a binary cycle, air-cooled geothermal power plant there are no air emissions -- not even water vapor.

(A) Geothermal power plant with no water vapor emissions at Puna, Hawaii. This power plant produces ~25% of the electricity for the big island and consists of ten 2.5 MW units.[14]

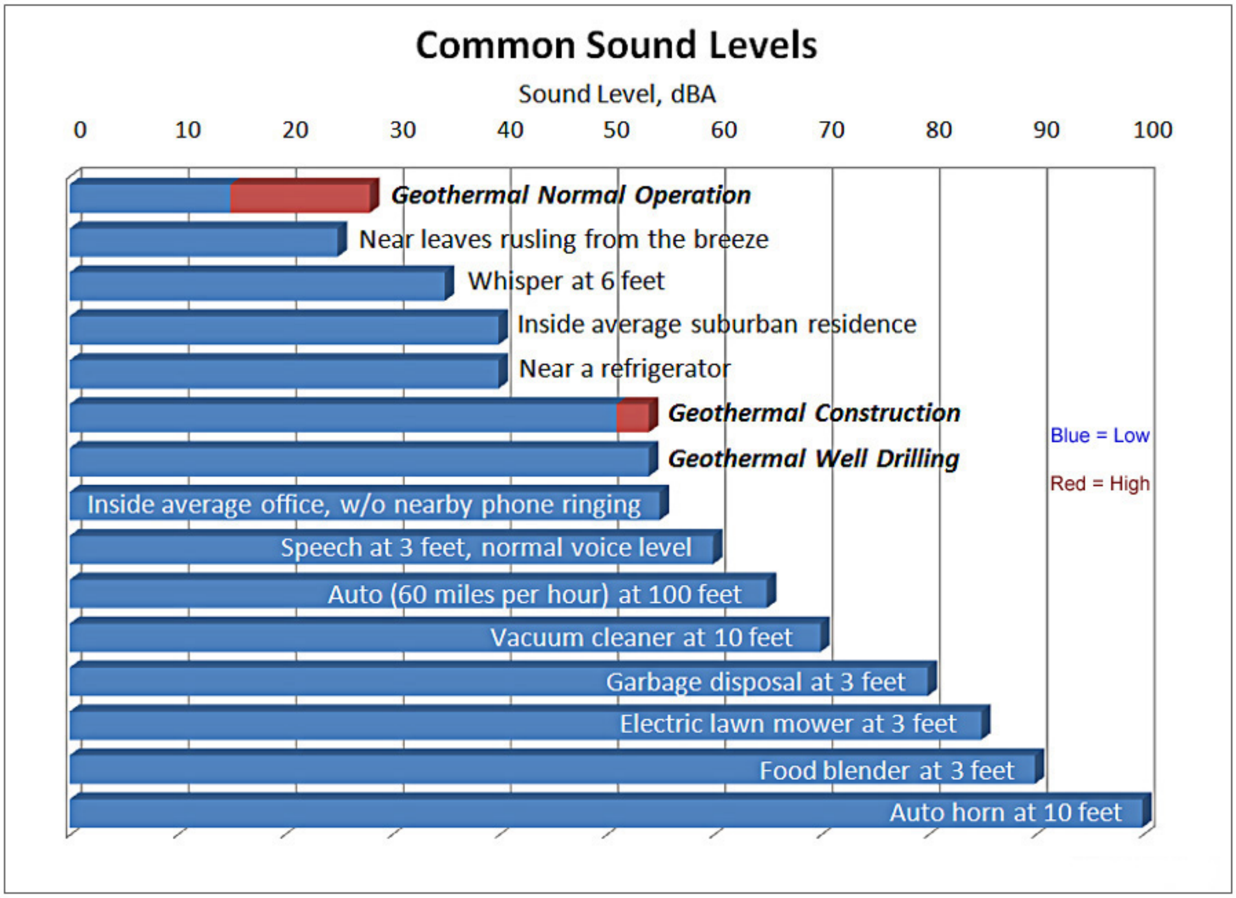


At water-cooled power plants, water vapor is emitted from the plant's cooling towers as a part of the process.

(B) Water vapor from a water-cooled geothermal power plant.[14]

[14] Image source: Geothermal Education Office, 2000, Introduction to Geothermal Energy Slide Show, http://geothermal.marin.org/Geopresentation/, © 2000-2001 Geothermal Education Office.

Noise Pollution



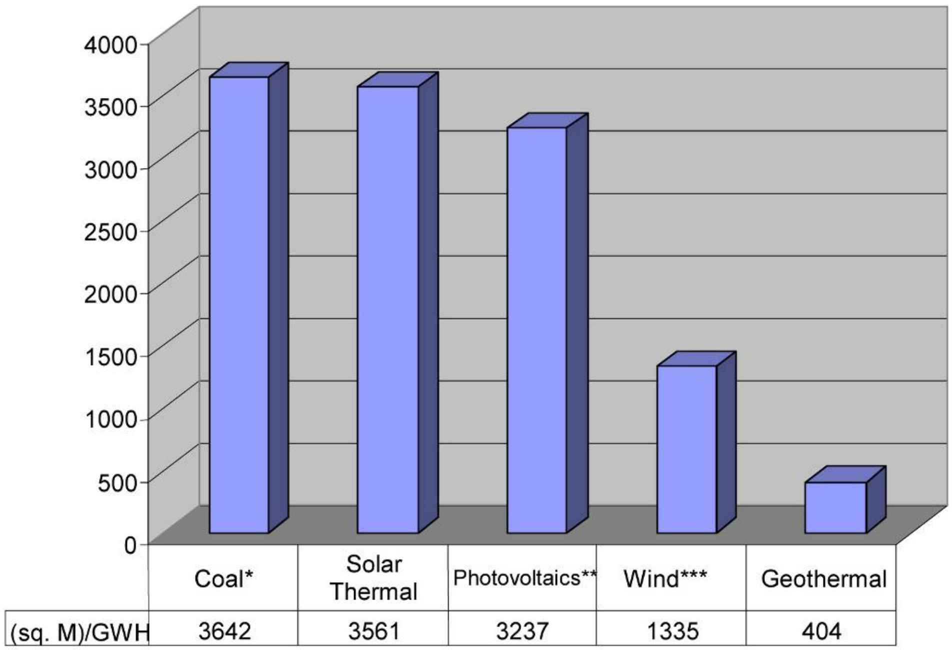
Noise Levels as Perceived by the Human Ear[15]

At ½ mile from the actual construction or drilling site, noise levels associated with site development are approximately the same as those encountered in a busy office.

At ½ mile from the fence of on operating geothermal power plant, noise levels are typically only slightly above background with a slight breeze.

[15] Sound level in dBA is a weighted or filtered dB level adapted to respond as a normal human ear responds to different frequencies, *i.e.*, these are noise levels as they are perceived by the human ear. Data source: Kagel, A., D. Bates, and K. Gawell, 2007, A Guide to Geothermal Energy and the Environment, Geothermal Energy Association, 75 pp. http://www.geo-energy.org/publications/reports/Environmental%20Guide.pdf.

Comparison of Land Use



* Includes mining.
**Assumes central station photovoltaic project, not rooftop PV systems.
*** Land actually occupied by turbines and service roads.

Geothermal Land Use in Square Meters per GigaWatt Hour of Electricity Generated Compared with Land Use for Selected other Energy Sources.[16]

As geothermal power plants have no furnaces and boilers, they are smaller per unit of power produced than other conventional turbine power plants. In addition, their fuel collection system is compact and close to the power plant site and no land use for mining or additional fuel production is required. Geothermal energy is more concentrated than wind or solar, so land use for a geothermal power plant is significantly less than for equivalent power production from wind or solar sources.

[16] One square meter = 10.76 square feet. Source: Kagel, A., D. Bates, and K. Gawell, 2007, A Guide to Geothermal Energy and the Environment, Geothermal Energy Association, 75 pp. http://www.geo-energy.org/publications/reports/Environmental%20Guide.pdf.

Geothermal Pipelines

Typical Geothermal Pipelines, at the Miravalles Geothermal Power Plant, Costa Rica. These pipelines are elevated to allow cattle free access to pasture.[17]

Pipelines for geothermal fluids are heavily insulated to prevent heat loss, are cold to touch, and safe for plants, animals and humans. They may be painted to blend with the environment, and routed to cause the minimum visual impact and raised to allow cattle or wild-life access and/or arched to provide human and vehicle access.

[17] Source: DiPippo, R., 2007, Geothermal Power Plants: Principles, Applications, Case Studies and Environmental Impact (2nd edn.), Butterworth-Heinemann, Oxford, 493 pp.

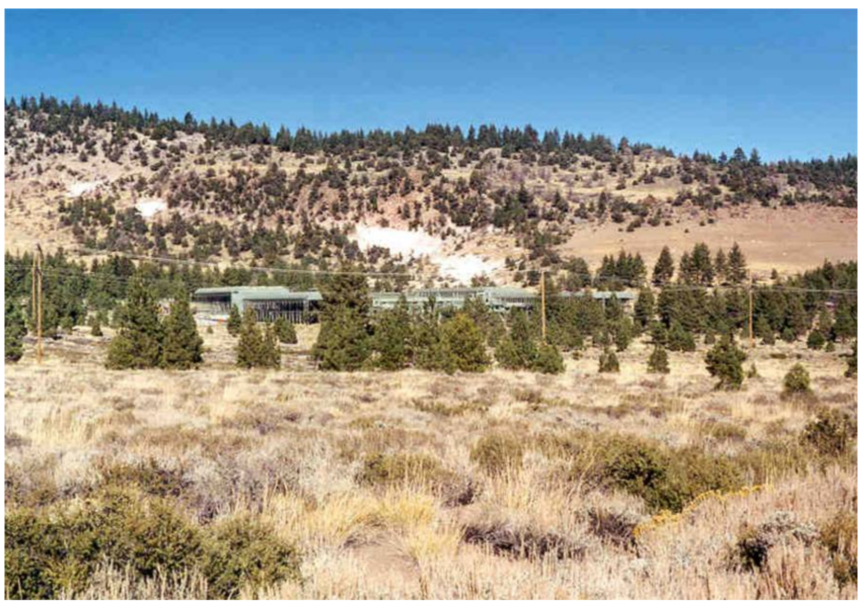
Examples of Geothermal Power Plants

Soda Lake II Power Plant, Nevada. Two binary-cycle air-cooled units producing a total of 12 MW. The two units are seen in the foreground; the air cooling fans are at the top (yellow); a geothermal pipeline is visible in the background to the left.[18]

Binary Power Plant at Wendell-Amadee, California. This unit produces 1.9 MW and is air-cooled: the air-cooling units are the large grey structures in the top of the plant. This plant runs automatically and calls an operator to come to the site if a problem is detected.[18]

[18] Image source: Geothermal Education Office, 2000, Introduction to Geothermal Energy Slide Show, http://geothermal.marin.org/Geopresentation/, © 2000-2001 Geothermal Education Office.

300 kW Binary Power Plant at Fang, Thailand. After passing through the heat exchanger in the binary power plant, the geothermal water is cascaded for use at a refrigeration (cold storage) plant, for crop drying, and at a spa.[18,19]

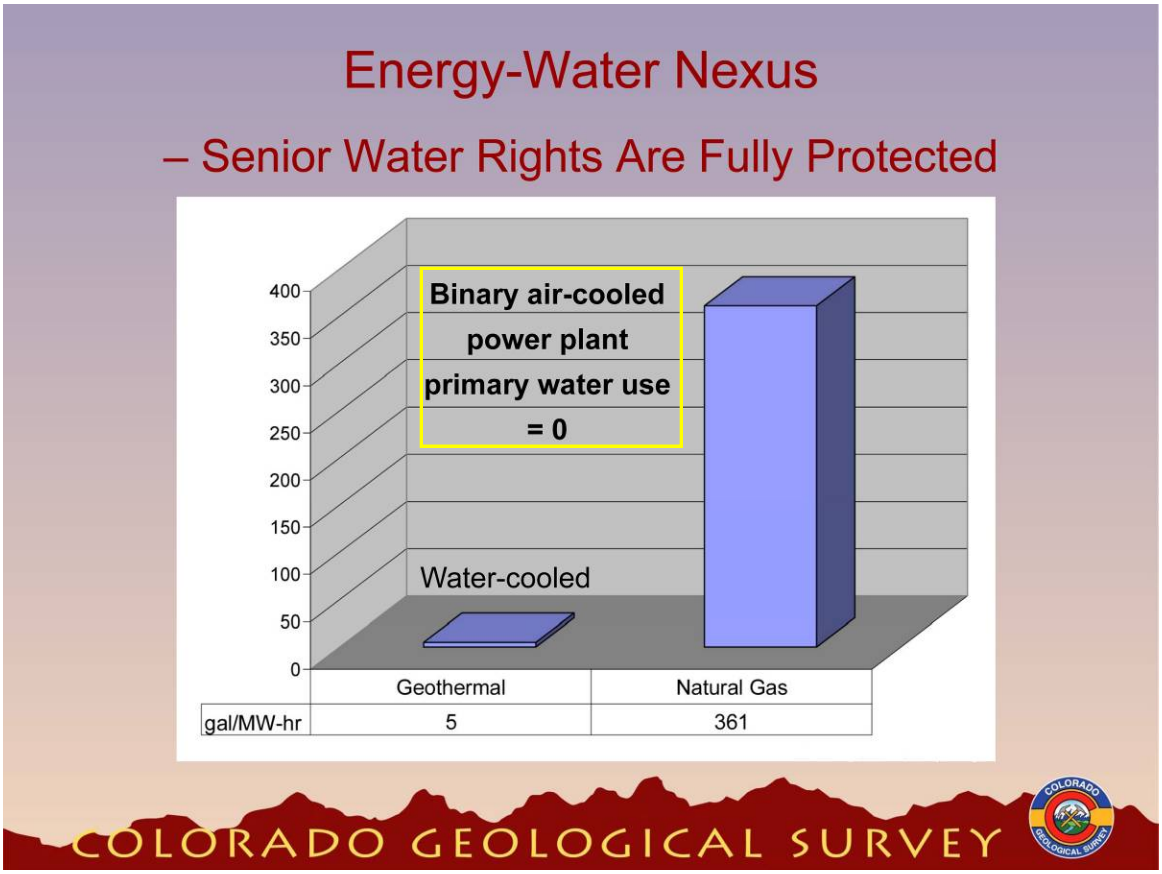


Mammoth Pacific 10 MW Binary Power Plant, California, ground-level view.[20]

[19] Information from Lund, J. and T. Boyd, 1999, Small Geothermal Power Project Examples, Geothermal heat Center Bulletin, v. 20, n. 2.

[20] Image credit: Keith Gawlik, NREL; source: Kagel, A., D. Bates, and K. Gawell, 2007, A Guide to Geothermal Energy and the Environment, Geothermal Energy Association, 75 pp. http://www.geo-energy.org/publications/reports/Environmental%20Guide.pdf.

Water Use

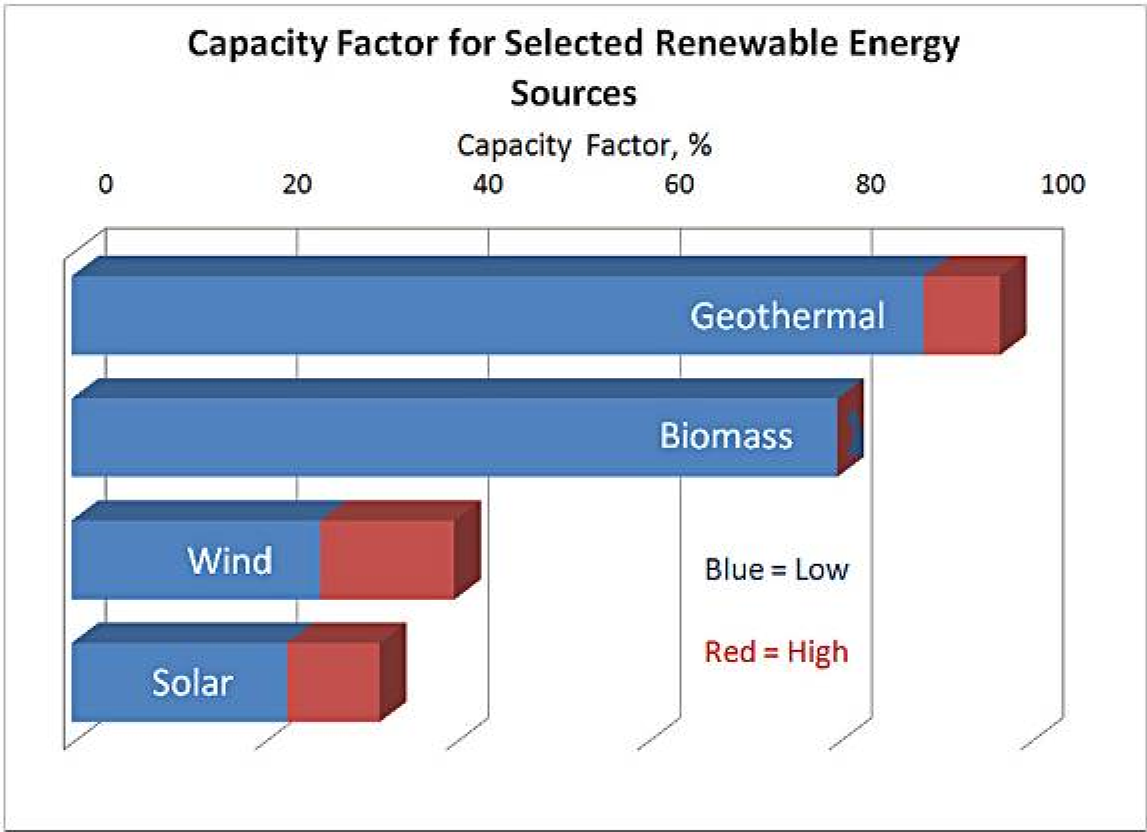


Comparison of Water Use Between Geothermal and Gas Power Plants (in gallons of water used per megawatt-hour of energy produced).[21]

Power-plants are large consumers of water, which is why they are commonly situated on the banks of rivers or have large lakes or ponds. The only primary use for water in a geothermal power plant -- apart from the hot water that provides the energy and is recycled back into the ground -- is when water cooling is used in the process. In an air-cooled binary cycle power plant there is no primary water use. They are, therefore, well suited to arid climates such as the western US.

[21] Source: Kagel, A., D. Bates, and K. Gawell, 2007, A Guide to Geothermal Energy and the Environment, Geothermal Energy Association, 75 pp. http://www.geo-energy.org/publications/reports/Environmental%20Guide.pdf.

Capacity Factor

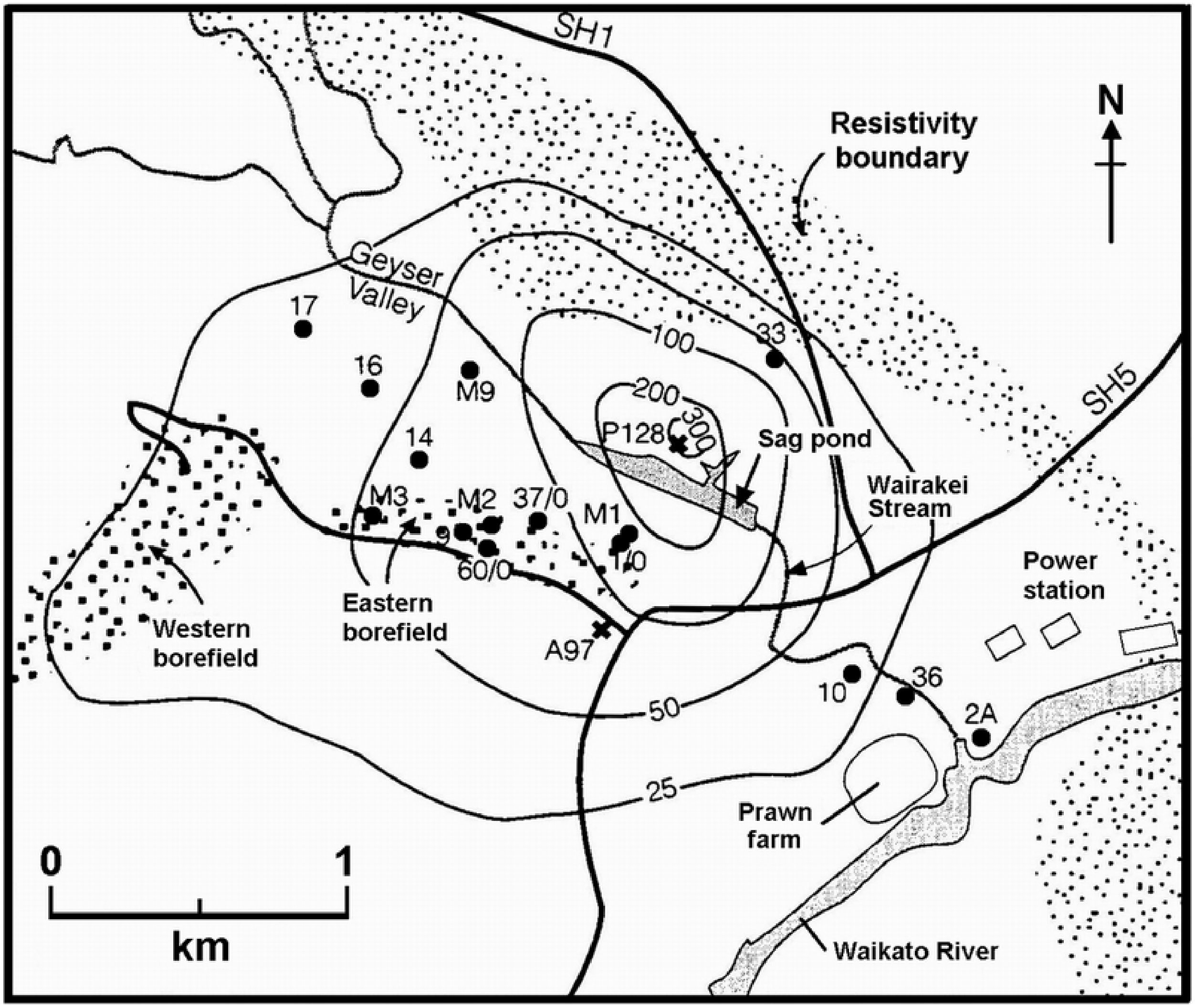


Capacity Factor, or Percentage of Time That a Power Plant is Producing Electricity, for Selected Renewable Energy Sources.[22]

Geothermal power plants have a track record of being on-line producing electricity for a higher percentage of time than any other generating source, with the possible exception of hydroelectric power. Wind and Solar have very low capacity factors; they generate electricity less than 25 to 40% of the time due to the intermittent nature of wind and solar energy. Biomass and fossil-fuel turbine systems, including nuclear power plants, require significant maintenance that results in them having capacity factors in the range of 80 to 90%. With relatively little maintenance required, geothermal power plants are typically producing electricity up to 95% of the time.

[22] Data source: Kagel, A., D. Bates, and K. Gawell, 2007, A Guide to Geothermal Energy and the Environment, Geothermal Energy Association, 75 pp. http://www.geo-energy.org/publications/reports/Environmental%20Guide.pdf.

Hazards from Geothermal Site Development



Subsidence in the Wairakei Geothermal Field, New Zealand, 1986 to 1994. The subsidence contours are labeled in mm (25.4 mm = 1 inch). The maximum subsidence is approximately 1 foot over half a mile. (horizontal scale, 1 km = 5/8 mile).[23]

Any withdrawal of material from the ground may result in surface subsidence. This has occurred in areas where groundwater, oil, or gas have been pumped and, as shown here, in geothermal areas. Experience has shown that in geothermal areas subsidence occurs only if withdrawal is greater than return. If all thermal water is returned to the subsurface reservoir after extraction of heat, subsidence does not occur.

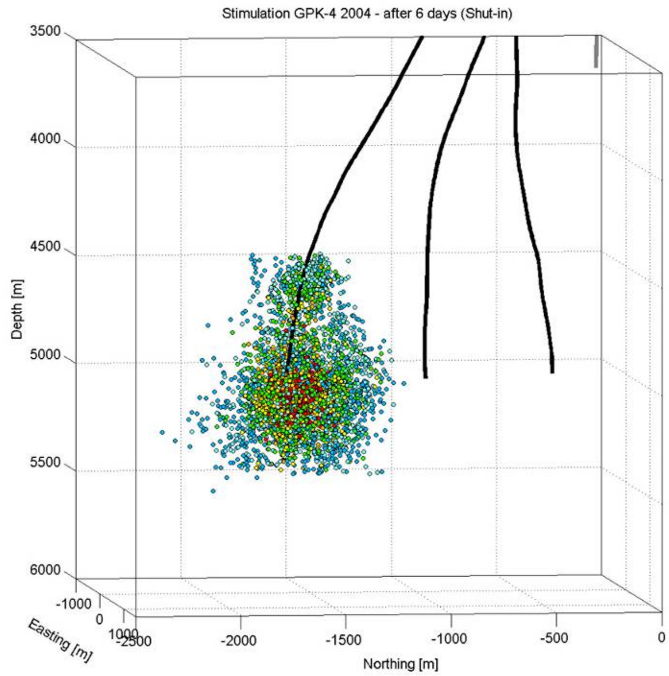
[23] Source: DiPippo, R., 2007, Geothermal Power Plants: Principles, Applications, Case Studies and Environmental Impact (2nd edn.), Butterworth-Heinemann, Oxford, 493 pp.

Landslide at Zuni Geothermal Field, Guatemala, probably at least partially caused by poorly designed geothermal extraction well field.[24]

At least one landslide has been reported to have been associated with geothermal site development. However, this development included road cuts into the hill slope, and analyses of the causes of the landslide concluded that this event would have been prevented if the requirements of an adequate environmental impact study had been followed during site development.

[24] Image modified from Goff, S., 2000, The effective use of Environmental Impact Assessments (EIAs) for geothermal development projects, Proceedings World Geothermal Congress 2000, Kyushu – Tohoku, Japan, May 28 – June 10, 2000, p. 597-602.

Induced Earthquakes



Induced small earthquakes from Fluid Injection in Well GPK4 in 2004 at the European Hot Dry Rock Site at Soultz, France.[25]

Geothermal resources are commonly located in areas of geologically young mountain building and volcanic activity, which are also the areas in which earthquakes are common. There is no evidence, however, that when withdrawal and return of water to the geothermal reservoir are maintained in balance, that operations associated with geothermal electricity generation cause induced earthquakes.

For many decades, due to lessons learned from the Denver earthquakes which started in April 1962 and continued for six or more years, there has been a known association of induced earthquakes and the injection of fluids at very high pressures. The image above is from a deep (5,000 m; ~16,400 feet) engineered geothermal system (EGS) that injected water under high pressure to fracture rock. It shows a clustering of small earthquakes progressing outward with time.

Conversely, conventional geothermal operations do not re-inject water under high-pressure and maintain a balance between water withdrawal and injection.

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[25] Image source: Baria, R., R. Jung, T. Tischner, J. Nicholls, S. Michelet, B. Sanjuan, N. Soma, H. Asanuma, B. Dyer, and J. Garnish, 2006, Creation of an HDR reservoir at 5000 m depth at the European HDR project, Proceedings, Thirty-First Workshop on Geothermal Reservoir Engineering, Stanford University, Stanford, CA, January 30- February 1, 2006, SGP-TR-179, 8 pp. Colors show locations as a function of time during pumping: red – 6 hours (pumping heavy brine); 12 hours – orange (fresh water pumped from this time); 1 day – yellow; 2 days – green; 3 days – light blue; and 6 days dark blue. Distances given in meters (1 m = 3.28 feet) from surface position of wells.

Concluding Remarks

- Geothermal Energy is a clean, safe, renewable, sustainable energy source. It has been in direct use since prehistoric times and producing electricity for more than a century. It is mature technology.
- The United States is the largest producer of geothermal energy, and until a few years ago, when large subsidies were introduced for wind and solar, geothermal was the largest producer of renewable energy in the United States after hydroelectric power.
- Geothermal mapping in Colorado indicates that this State has a much greater potential for direct use of geothermal energy than is currently realized and significant potential for geothermal electricity generation.
- The average land use for a geothermal power plant, including wells and pipelines, is about 60 x 60 square yards per megawatt, which is less than for any other energy source when fuel and other land access needs are considered.
- In Colorado (as in most other States), all senior water and geothermal rights are fully protected from future geothermal development by existing statutes. However, water use by geothermal power plants is very low compared to other conventional turbine plants, and is essentially zero using an air-cooled binary cycle geothermal power plant.
- Conventional air-cooled binary-cycle geothermal power plants:
    - Do NOT produce any atmospheric emissions, including water vapor,
    - Do NOT contaminate surface or subsurface water systems (only heat is extracted from the geothermal water)
    - Do NOT have any primary net water use
    - Do NOT cause subsidence
    - Do NOT induce earthquakes
- Environmental, safety, and other studies are required prior to development with permitting and public input to identify any issues of concern and to ensure that if development is allowed to proceed, any potential problems are identified and mitigated.

CGS Geothermal Web Page:
Follow the links on our home page to geothermal:
https://coloradogeologicalsurvey.org/energy/e-geothermal/