ENVIRONMENTAL IMPACTS OF GEOTHERMAL ENERGY

Based on "A Guide to Geothermal Energy and the Environment" GEA and "The Environmental Impact of the Geothermal Industry" CRES

Contents

Introduction

Geothermal energy is renewable resource. Unlike wind and solar resources, which are more dependent upon weather fluctuations and climate changes, geothermal resources are available 24 hours a day, 7 days a week.

Geothermal energy is the heat of the earth. Medium and/or high temperature geothermal systems are classified either as hydrothermal systems (low or high enthalpy), which are encountered in specific locations associated with the presence of fluids and permeability within the earth, or as enhanced geothermal systems, which can be engineered everywhere.

Introduction

Geothermal Heat Pumps

Geothermal heat pumps utilize the heat content of the upper part of the earth, and do not have any adverse environmental impact related to the geothermal energy itself. However, as heat pumps, they need considerable quantities of electricity for their operation and they contain refrigerants of very high greenhouse potential, in case they leak to the environment. Therefore, their environmental impact is limited to contribution to the greenhouse effect due to electricity consumption and due to possible refrigerant leakages. Due to the higher efficiency of the geothermal heat pumps (COP = 4 to 6) compared with air source heat pumps (COP = 2,5 to 3,5) and fossil fuels (efficiency = 80-90%), overall impact to the greenhouse effect is significantly less than burning fossil fuels or using air source heat pumps.

Introduction
Enhanced Geothermal Systems (EGS)

In the case of EGS, where water is initially injected and then circulates through the system, not only zero CO_2 emissions are foreseen, but also none of the other problems are anticipated. However, it pays to engineer EGS within or just outside the boundaries of a hydrothermal system, in order to benefit from bonuses in temperature, depth and limited natural permeability or fluid presence.

One problem that has been reported during engineering of enhanced geothermal reservoirs, is the occurrence of micro-seismic activity, probably associated with the hydraulic fracturing works. These micro-earthquakes have a magnitude up to around 2 in the Richter scale and pose no danger to existing buildings or structures. Whether they will also be present during exploitation, and how they will evolve overtime, remains to be identified in the field, but we anticipate that this micro-seismic activity should not be greater than the one encountered in hydrothermal systems.

Introduction

Low Enthalpy Hydrothermal Fields

The positive environmental impact of all geothermal plants is attributed to foregone CO_2 and other emissions (e.g. CO, carbon particles, NOx, SOx), had the same quantity of energy been produced by fossil fuels. However, in some low enthalpy geothermal fields the deep hot water may contain dissolved CO_2 in the form of bicarbonate ions. When these fluids are brought to the surface and their pressure is lowered, they tend to deposit calcite and release CO_2. Such fluids are usually located at the margins of larger hydrothermal systems. In Nigrita geothermal field of Serres prefecture, Greece, which produces CO_2 rich geothermal fluids of 60°C, the corresponding CO_2 emissions are 15-20 times less than the ones released by fossil fuels when producing the same amount of energy. The CO_2 emissions from a geothermal field can be minimized by engineering the exploitation scheme accordingly. For example, maximizing the energy extracted from a given flow rate by placing the users in cascade, results in minimum CO_2 emissions. In agricultural uses, the geothermal CO_2 can be directly released within the greenhouse, in order to increase the growth rate of the plants and save fossil fuels.

Introduction

Low Enthalpy Hydrothermal Fields

Adverse environmental impact may occur from low enthalpy geothermal utilization, associated with the chemistry of the geothermal fluid, which may include considerable quantities of chloride, small quantities of boron, and traces of arsenic, ammonia, mercury, or heavy metals, making it unsuitable for disposal to the surface. The problem is effectively solved by reinjecting all the produced geothermal fluid to the same deep reservoir it originated from. This practice also has benefits to the water replenishment of the deep system, improving sustainability and the economic life of the plant.

Other impact from long term low enthalpy geothermal utilization may be the dropping of water level of near surface aquifers and the flow reduction or dry-up of nearby springs and shallow water wells. The problem can be solved by reinjection, effective reservoir engineering and if the previous two measures do not solve the problem, by donating deep wells to affected water users.

Introduction
High Enthalpy Hydrothermal Fields

Like all forms of electric generation, both renewable and non-renewable, geothermal power generation has environmental impacts and benefits.

Geothermal energy—whether utilized in a binary, steam, or flash power plant, cooled by air or water systems—is a clean, reliable source of electricity with only minimal environmental impacts, even when compared with other renewable energy sources.

In high enthalpy hydrothermal systems, the steam phase of the geothermal fluid frequently contains small quantities of non-condensable CO_2, the quantity of which varies from field to field but it is limited to a few percentage units, usually in the range 0,05-5%.

Introduction
High Enthalpy Hydrothermal Fields

Comparison of CO_2 emissions between geothermal and conventional power plants

Plant	Net Power, MW_{el}	CO_2, % w/w	Conversion efficiency %	CO_2 emissions, kg/kWh_{el}
Milos, Greece	-	1,0 – 1,5	19,1*	0,10
Lago	8,30	1,7	13,3	0,16
Monterotondo	8,19	1,6	13,2	0,16
Molinetto	17,95	4	17,7	0,29
Gabbro	16,52	12	14,6	1,05
Radicondou	36,89	5	19,0	0,34
Travale	40,75	5	21,0	0,31
Natural Gas			50	0,38
Diesel Oil			33	0,75
Coal			33	0,90

*steam phase only

Introduction

Emissions

The visible plumes seen rising from some geothermal power plants are actually water vapor emissions (steam), not smoke. Because geothermal power plants do not burn fuel like fossil fuel plants, they release virtually no air emissions. A case study of a coal plant updated with scrubbers and other emissions control technologies emits 24 times more carbon dioxide, 10,837 times more sulfur dioxide, and 3,865 times more nitrous oxides per MWh than a geothermal steam plant.

Introduction

Emissions

Emission	Nitrogen oxide (NOx)	Sulfur Dioxide (SO_2)*	Particulate Matter (PM)	Carbon Dioxide (CO_2)
Sample Impacts	Lung irritation, coughing, smog formation, water quality deterioration	Wheezing, chest tightness, respiratory illness, ecosystem damage	Asthma, bronchitis, cancer, atmospheric deposition, visibility impairment	Global warming produced by CO_2 increases sea level, flood risk, glacial melting
Geothermal emissions (kg/MWh)	0	0 – 0.16	0	0 – 40.28
Coal emissions (kg/MWh)	1.95	4.71	1.01	993.82
Emissions Offset by Geothermal Use (per yr)	$32 \cdot 10^3$ tons	$78 \cdot 10^3$ tons	$17 \cdot 10^3$ tons	$16 \cdot 10^3$ tons

*SO_2 emissions derive from hydrogen sulfide emissions.

Introduction

Emissions

Hydrogen Sulfide (H_2S) is now routinely abated at geothermal power plants, resulting in the conversion of over 99.9% of the H_2S from geothermal noncondensable gases into elemental sulfur, which can then be used as a non-hazardous soil amendment and fertilizer feedstock. Since 1976, H_2S emissions have declined from 862 kg/hr to 91 kg/hr or less, although geothermal power production has increased from 500 megawatts (MW) to over 2,000 MW.

Mercury: Although mercury is not present in every geothermal resource, where it is present, mercury abatement equipment typically reduces emissions by 90% or more. The comparatively —highest mercury emitters, two facilities at The Geysers in California, release mercury at levels that do not trigger any health risk analyses under strict California regulations.

Introduction

Additional Environmental Issues

Noise Pollution: Normal geothermal power plant operation typically produces less noise than the equivalent produced —near leaves rustling from breeze, according to common sound level standards, and thus is not considered an issue of concern.

Water Use: Geothermal plants use 0.02 m^3 of freshwater per MWh, while binary air-cooled plants use no fresh water. This compares with 1.37 m^3 per MWh used by natural gas facilities.

Water Quality: Geothermal fluids used for electricity are injected back into geothermal reservoirs using wells with thick casing to prevent cross-contamination of brines with groundwater systems. They are not released into surface waterways. At The Geysers facility, around 42 thousands m^3 of treated wastewater from Santa Rosa are pumped daily for injection into the geothermal reservoir. Injection reduces surface water pollution and increases geothermal reservoir resilience.

Introduction

Additional Environmental Issues

Land Use: Geothermal power plants can be designed to fit into their surrounding, and can be located on multiple-use lands that incorporate farming, skiing, and hunting. A geothermal facility uses 404 m^2 of land per GWh, while a coal facility uses 3632 m^2 per GWh.

- Subsidence: Subsidence, or the slow, downward sinking of land, may be linked to geothermal reservoir pressure decline. Injection technology, is an effective mitigating technique.
- Induced Seismicity: While earthquake activity, or seismicity, is a natural phenomenon, geothermal production and injection operations have at times resulted in low-magnitude events known as —microearthquakes. These events typically cannot be detected by humans, and are often monitored voluntarily by geothermal companies.

Introduction

Additional Environmental Issues

Geysers, Fumaroles, and Geothermal Resources: While almost all geothermal resources currently developed for electricity production are located in the vicinity of natural geothermal surface features, much of the undeveloped geothermal resource base may be found deep under the Earth without any corresponding surface thermal manifestations. Geothermal surface features, while useful in identifying resource locations, are not used during geothermal development. (according laws and regulations to protect and preserve national parks and their significant thermal features).

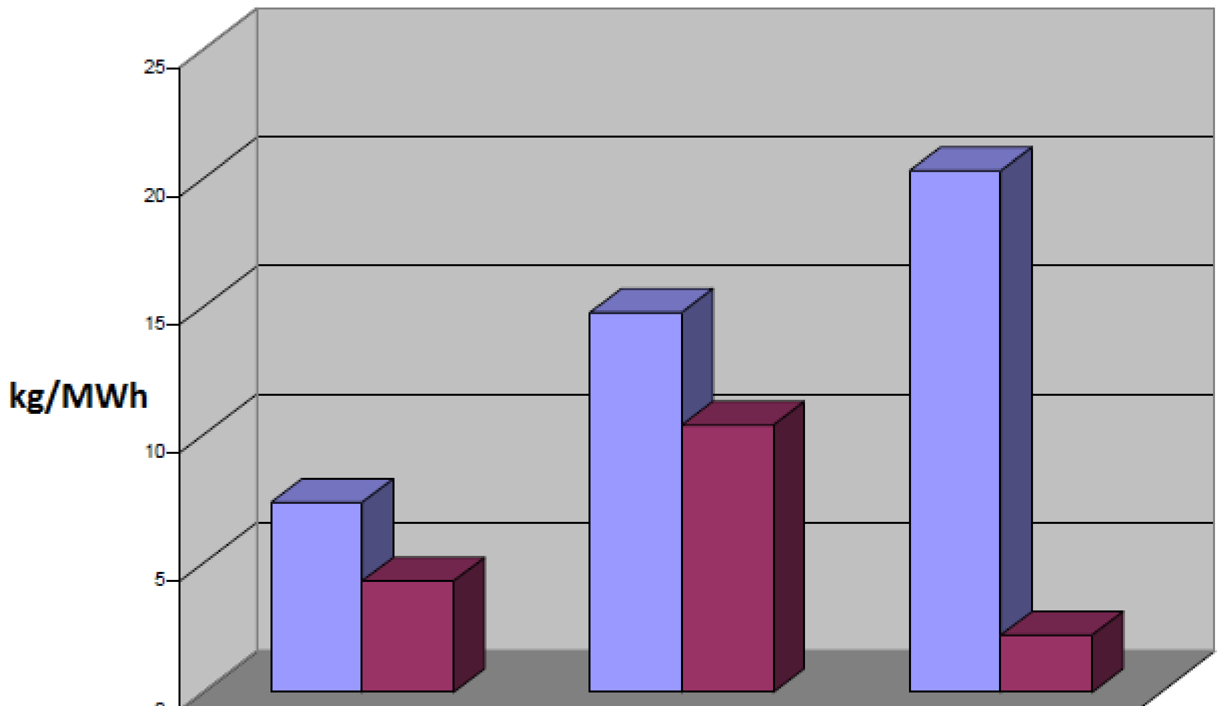
Impact on Wildlife and Vegetation: Before geothermal construction can begin, an environmental review may be required to categorize potential effects upon plants and animals. Power plants are designed to minimize the potential effect upon wildlife and vegetation, and they are constructed in accordance with the regulations of the host state that protect areas set for development.

Geothermal energy and the Environment
- Air Emissions -

Geothermal power plants (GPP) release very few air emissions because they avoid both environmental impacts associated with burning fuels as well as those associated with transporting and processing fuel sources. GPP emit only trace amounts of NOx, almost no SO_2 or particulate matter, and small amounts of CO_2. The primary pollutant some GPP must sometimes abate is H_2S, which is naturally present in many subsurface geothermal reservoirs. With the use of advanced abatement equipment, emissions of H_2S are regularly maintained below the valid standards.

Average life cycle emissions at coal facilities are substantially higher than their average operational emissions which do not consider the effects of coal mining, transport, construction, and decommissioning. Life cycle emissions from geothermal facilities, in contrast, generally remain in the same range as operational emissions.

Life Cycle versus Operational Emissions, Coal Power Plants

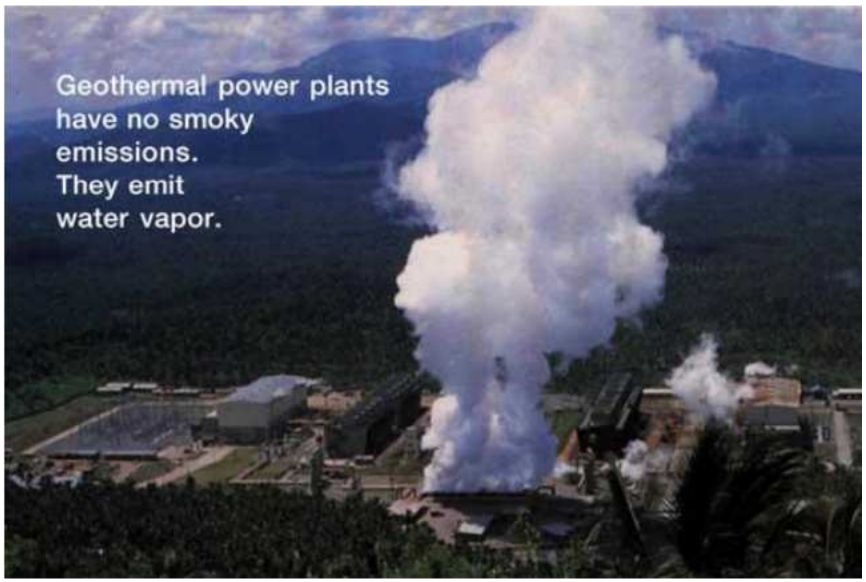


	NOx	SOx	PM
life cycle	3.35	6.71	9.21
operational	1.95	4.71	1.01

Plant by Plant Comparison

Plant Name	Year	Total MWh produced during specified year	Primary Fuel	NOx Emissions Rate (kg/MWh)	SO_2 Emissions Rate (kg/MWh)	CO_2 Emissions Rate (kg/MWh)
Cherokee Station*	1997	4,362,809	Coal	3.01	3.28	942.11
Cherokee Station	2003	5,041,966	Coal	1.82	1.06	977.03
Sonoma County at The Geysers**	2003	5,076,925	Steam Geo.	0.0005	0.0001	40.28
Mammoth Pacific***	2004	210,000+	Binary Geo.	0	0	0

Geothermal energy and the Environment
- Air Emissions -



The visible plumes seen rising from water cooled GPP are actually water vapor emissions (steam), not smoke, and are caused by the evaporative cooling system.

Air cooled systems emit no water vapor, and thus blend easily into the environment. In a water cooling process, 50% or more of the geothermal fluid that enters the cooling tower is emitted to the atmosphere as water vapor, while the remainder recycles back into the reservoir. Geothermal water vapor emissions contain only trace amounts of the pollutants typically found in much greater quantities in coal and gas power plant emissions.

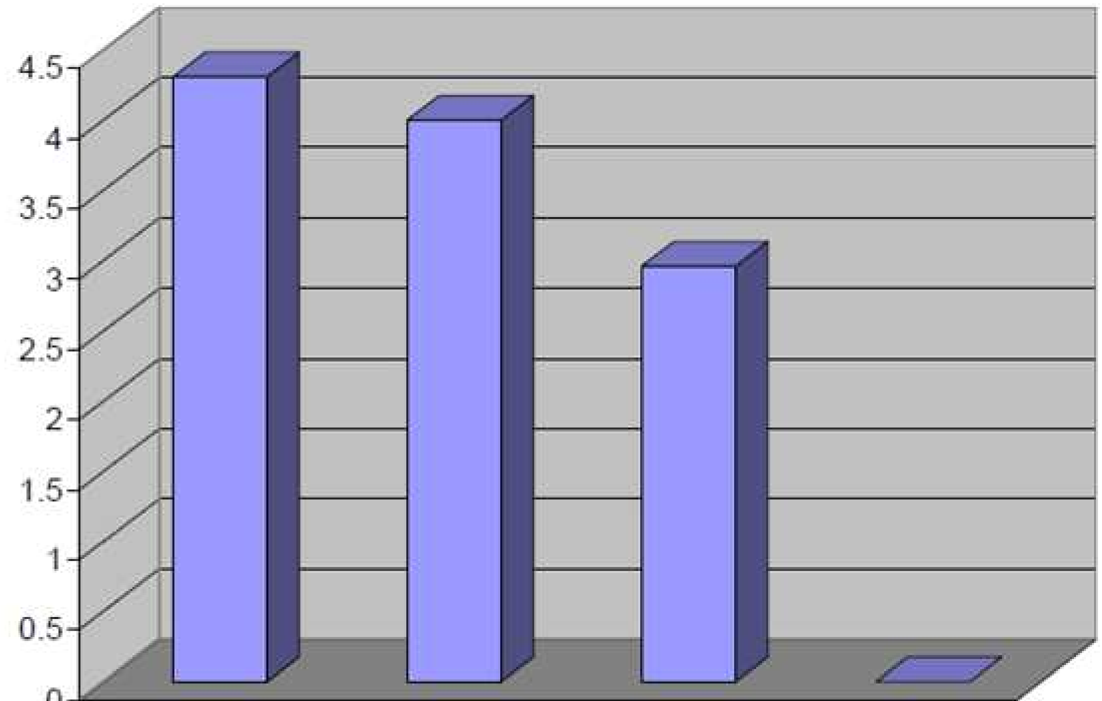
Nitrogen oxides (NOx)

NOx are often colorless and odorless, or reddish brown as NO_2. NOx form during high temperature combustion processes from the oxidation of nitrogen in the air. Motor vehicles are the major source of these pollutants, followed by industrial fuel-burning sources such as fossil fuel-fired power plants (responsible for approx. ¼ of NOx emissions).

NOx contribute to smog formation, acid rain, water quality deterioration, global warming, and visibility impairment. Health effects include lung irritation and respiratory ailments such as infections, coughing, chest pain, and breathing difficulty. Even brief exposure to high levels of NOx may cause human respiratory problems, and airborne levels of NOx above the EPA established average allowable concentration of 0.053 ppm can cause ecosystem damage.

NOx

Because GPP do not burn fuel, they emit very low levels of NOx. In most cases, geothermal facilities emit no NOx at all. The small amounts of NOx released by some geothermal facilities result from the combustion of H_2S. GPP are generally required by law to maintain H_2S abatement systems that capture H_2S emissions and either burn the gas or convert it to elemental sulfur. During combustion, small amounts of NOx are sometimes formed, but these amounts are miniscule. Average NOx emissions are zero.



	Coal	Oil	Natural Gas	Geothermal
kg/MWh	1.96	1.81	1.34	0

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.

Hydrogen Sulfide (H_2S)

H_2S is a colorless gas that is harmless in small quantities, but is often regarded as an —annoyance due to its distinctive - rotten-egg smell. H_2S can be lethal in high doses. Natural sources of H_2S include volcanic gases, petroleum deposits, natural gas, geothermal fluids, hot springs, and fumaroles. H_2S may also form from the decomposition of sewage and animal manure, and can be emitted from sewage treatment facilities, aquaculture facilities, pulp and paper mills, petroleum refineries, composting facilities, dairies, and animal feedlot operations. Individuals living near a gas and oil drilling operation may be exposed to higher levels of H_2S. Anthropogenic (manmade) sources of H_2S account for approximately 5% of total H_2S emissions. Health impacts from high concentrations include nausea, headache, and eye irritation; extremely high levels can result in death. H_2S remains in the atmosphere for about 18 hours. Though H_2S is not a criteria pollutant, it is listed as a —regulated air pollutant.

H_2S

H_2S remains the pollutant generally considered to be of greatest concern for the geothermal community. However, it is now routinely abated at GPP. The two most commonly used vent gas H_2S abatement systems are the Stretford and LO-CAT. Both systems convert over 99.9% of the H_2S from geothermal noncondensable gases to elemental sulfur, which can then be used as a soil amendment and fertilizer feedstock. The cost to transport and sell the sulfur as a soil amendment is about equal to the revenue gained from the transaction.

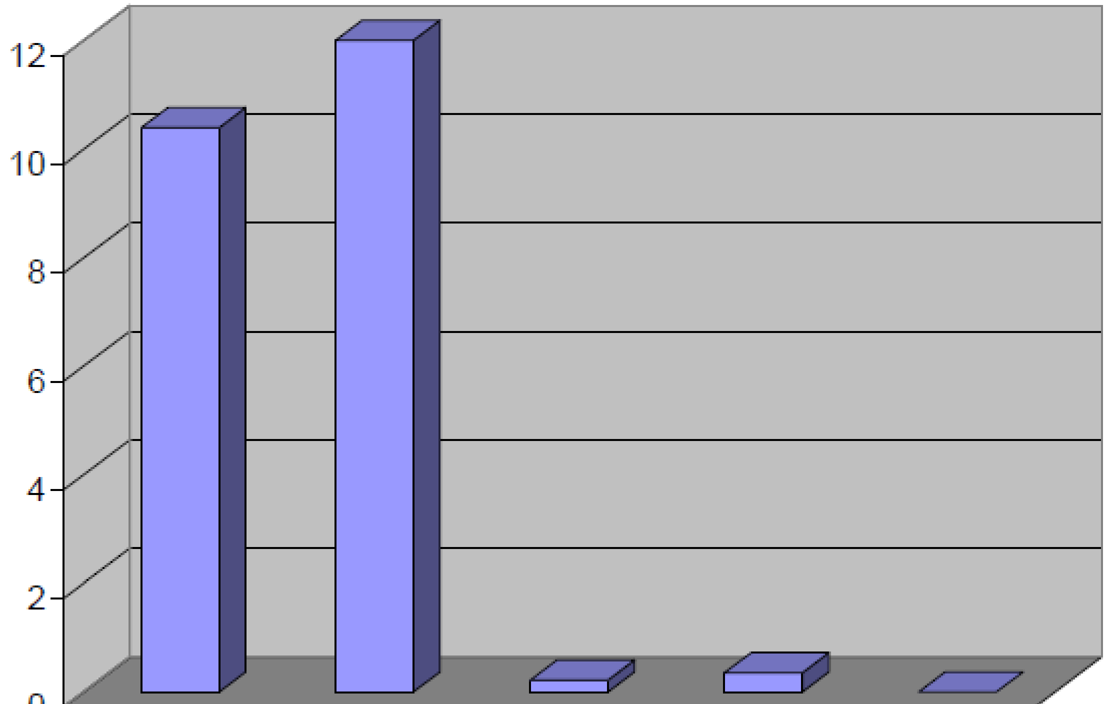
As a result of abatement measures, geothermal steam- and flash-type power plants produce only minimal H_2S emissions. Binary and flash/binary combined cycle GPP do not emit any H_2S at all.

Sulfur Dioxide (SO_2)

SO_2 belongs to the family of SOx gases that form when fuel containing sulfur (mainly coal and oil) is burned at power plants. Fossil fuel-fired power plants are responsible for the greatest part of the SO_2 emissions. High concentrations of SO_2 can produce temporary breathing impairment for asthmatic children and adults who are active outdoors. Health impacts from short-term exposures include wheezing, chest tightness, shortness of breath, aggravation of existing cardiovascular disease, and respiratory illness. SO_2 emissions injure vegetation, damage freshwater lake and stream ecosystems, decrease species variety and abundance, and create hazy conditions.

While geothermal plants do not emit SO_2 directly, once H_2S is released as a gas into the atmosphere, it spreads into the air and eventually changes into SO_2 and sulfuric acid. Therefore, any SO_2 emissions associated with geothermal energy derive from H_2S emissions. When comparing geothermal energy to coal, the average geothermal generation of 15 TWh avoids the potential release of 78000 tons of SO_2 per year.

SO_2



	Coal	Oil	Natural Gas	Geothermal (Flash)	Geothermal (Binary)
kg/MWh	4.71	5.44	0.1	0.16	0

SO_2 comparison

*Calculation converts H_2S to SO_2 for comparison only

Particulate Matter (PM)

PM is a broad term for a range of substances that exist as discrete particles. PM includes liquid droplets or particles from smoke, dust, or fly ash.

Primary particles such as soot or smoke come from a variety of sources where fuel is burned, including fossil fuel power plants and vehicles.

Secondary particles form when gases of burned fuel react with water vapor and sunlight. Secondary PM can be formed by NOx, SOx, and Volatile Organic Compounds (VOCs).

Large particulates in the form of soot or smoke can be detected by the naked eye, while small particulates (PM2.5) require a microscope for viewing. PM10 refers to all particulates less than or equal to 10 microns in diameter of particulate mass per volume of air.

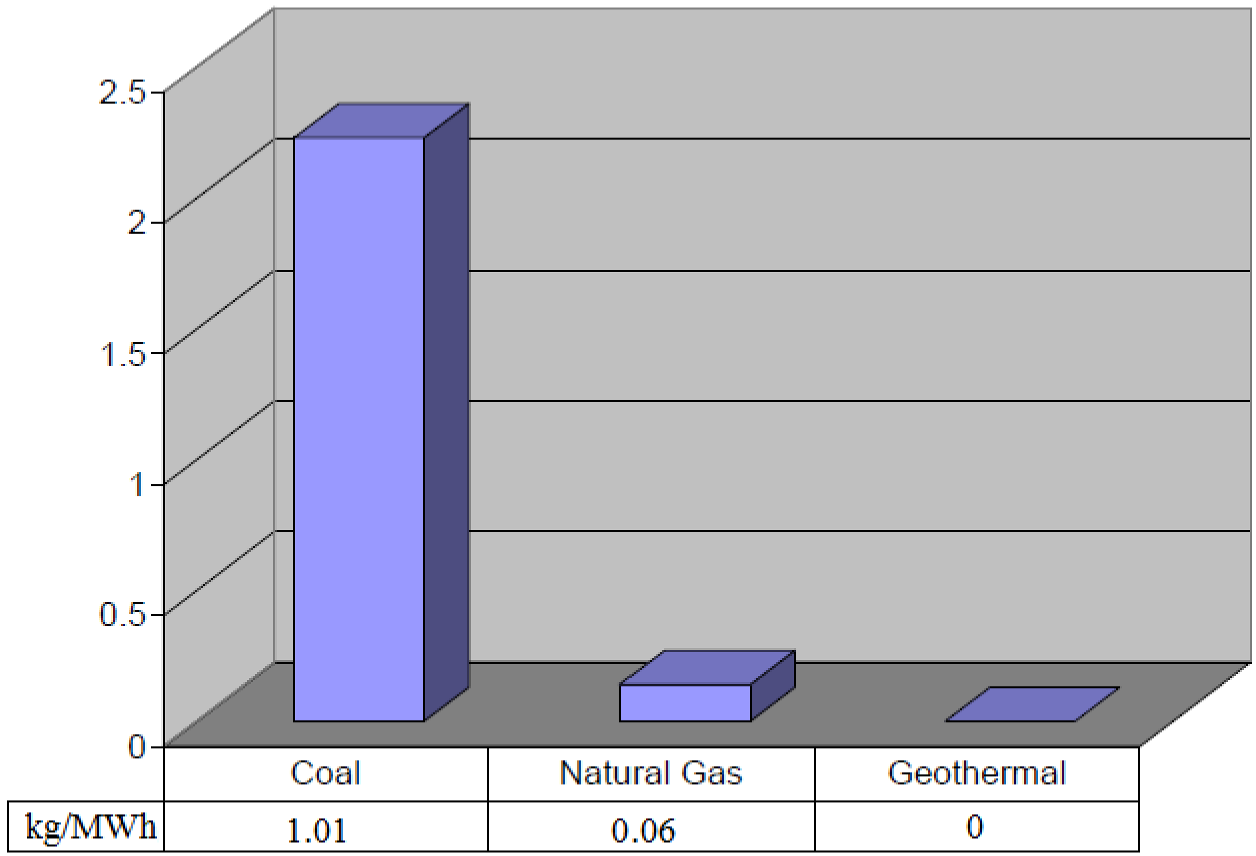
PM

PM is emitted through the full process of fossil fuel electricity production, particularly coal mining. Health effects from PM include eye irritation, asthma, bronchitis, lung damage, cancer, heavy metal poisoning, and cardiovascular complications.

PM contributes to atmospheric deposition, visibility impairment, and aesthetic damage.

Although coal and oil plants produce hundreds of tons on an annual basis, GPP emit almost no PM. Water-cooled GPP do emit small amounts of PM from the cooling tower when steam condensate is evaporated as part of the cooling cycle. However, the amount of PM given off from the cooling tower is quite small when compared to coal or oil plants which have burning processes in combination with cooling towers.

PM comparizon



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

Carbon dioxide (CO_2)

Carbon dioxide, a colorless, odorless gas, is released into the atmosphere as a byproduct of burning fuel. While CO_2 emissions are also produced by natural sources, most experts agree that increased atmospheric CO_2 concentrations are caused by human fossil fuel burning. Concentrations in the atmosphere have increased by approximately 20% since 1960. The increase in CO_2 is typically attributed to power plant (primarily coal) and vehicle emissions, and secondarily to deforestation and land-use change. About 37% of incremental CO_2 accumulation is caused by electric power generation, mainly from fossil fuels. While CO_2 does not pose any direct human health effects - humans exhale CO_2 with every breath – experts generally agree that global warming poses significant environmental and health impacts, including flood risks, glacial melting problems, forest fires, increases in sea level, and loss of biodiversity.

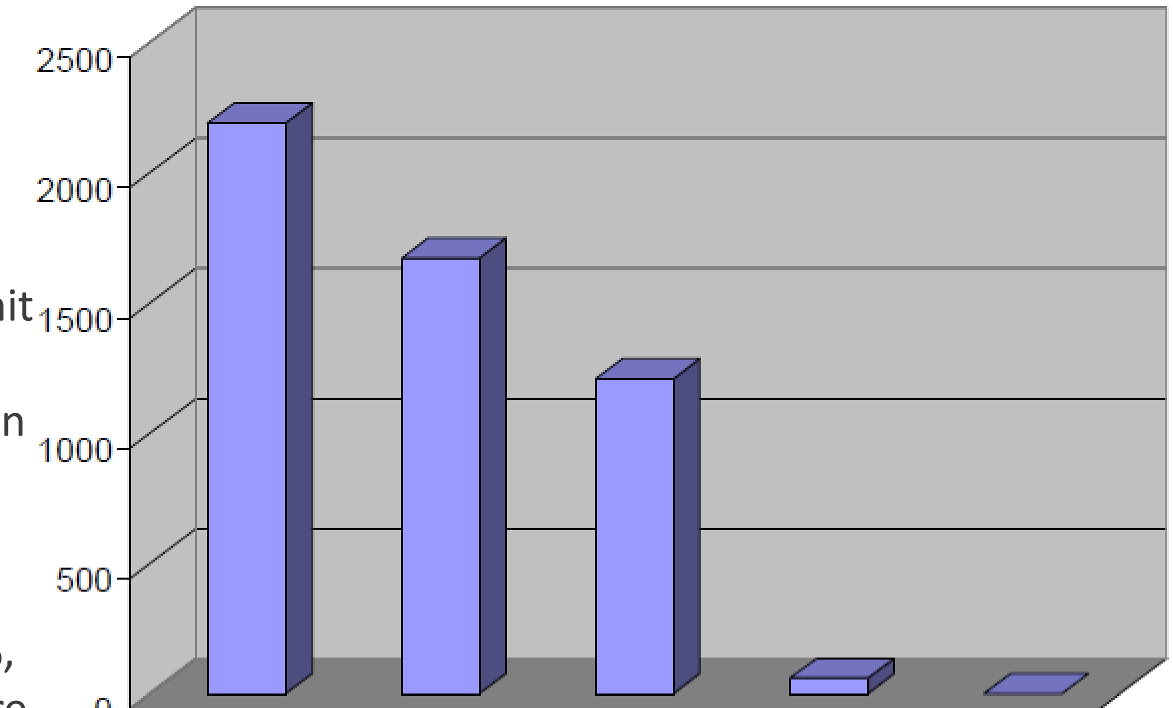
CO_2

Geothermal plants do emit CO_2, but in quantities that are small compared to fossil fuel-fired emissions. Some geothermal reservoir fluids contain varying amounts of certain noncondensable gases, including CO_2.

Geothermal steam is generally condensed after passing through the turbine. However, the CO_2 does not condense, and passes through the turbine to the exhaust system where it is then released into the atmosphere through the cooling towers. The amount of CO_2 found in geothermal fluid can vary depending on location, and the amount of CO_2 actually released into the atmosphere can vary depending on plant design. This makes it difficult to generalize about the amount of CO_2 emitted by an “average” GPP. For example, binary plants with air cooling are in a closed loop system and emit no CO_2 because in this system the geothermal fluids are never exposed to the atmosphere.

CO_2 comparison

Despite these disparities, GPP will emit only a small fraction of the CO_2 emitted by traditional power plants on a per-MWh basis. Noncondensable gases such as CO_2 make up less than 5% by weight of the steam phase of most geothermal systems. Of that 5%, CO_2 typically accounts for 75% or more of noncondensable gas by volume. Because of the low level of CO_2 emissions, geothermal power production currently prevents the emission of 22 million tons of CO_2 annually when compared to coal production.



	Coal	Oil	Natural Gas	Geothermal (flash)	Geothermal (binary)
kg/MWh	994	550	1212	27	0

Mercury (Hg)

The majority of mercury emissions derive from natural sources. Hg occurs naturally in soils, groundwater, and streams, but human activity can release additional Hg into the air, water, and soil. Coal-fired power plants are the largest source of additional Hg of any energy source, because the Hg naturally contained in coal is released during combustion. Currently, the coal industry contributes for 1/3 of the anthropogenic mercury emissions.

Mercury emissions from coal vary both day to day and from plant to plant. Snapshot Hg emissions information, taken over a 1-2 hour period, does not always accurately reflect long term Hg emissions-hourly averages can vary by almost an order of magnitude. In addition, Hg emissions from certain types of coal plants, such as bituminous plants, tend to be greater than from other types of coal plants. It is estimated that bituminous plants emit 52% of coal mercury emissions, while lignite coal plants emit only 9%. Those plants with emissions technologies in place, such as combined selective catalytic reduction (SCR) and wet flue gas desulphurization (FGD), tend to emit the lowest levels of mercury.

Hg

Hg emissions from power plants pose a significant risk to human health. When Hg enters water, biological processes transform it to a highly toxic form, methyl mercury, which builds up in fish and animals that eat fish. People are exposed to Hg primarily by eating fish or by drinking contaminated water. Hg is especially harmful to women.

Hg is not present in every geothermal resource. However, if Hg is present in a geothermal resource, using that resource for power production could result in mercury emissions, depending upon the technology used. Because binary plants pass geothermal fluid through a heat exchanger and then return all of it to the reservoir, binary plants do not emit any mercury.

Hg

Mercury abatement measures are already in place at most geothermal facilities. The abatement measures that reduce mercury also reduce the emissions of sulfur generated as a byproduct of hydrogen sulfide abatement: after hydrogen sulfide is removed from geothermal steam, the gas is run through a mercury filter that absorbs mercury from the gas. In removing mercury, the sulfur that is created from the abatement process can then be used as an agricultural product. The rate of mercury abatement within a facility, which varies according to the efficiency of the activated carbon mercury absorber, is typically near 90%, and is always efficient enough to ensure that the sulfur byproduct is not hazardous. The activated carbon media is changed out periodically and is disposed of as a hazardous waste. The amount of hazardous waste reduction is thousands of tons/year.

Total Organic Gases & Reactive Organic Gases

GPP may emit small amounts of naturally occurring hydrocarbons such as methane (CH_4). CH_4 is reported in Total Organic Gases (TOG). 10% of TOGs are assumed to be Reactive Organic Gas (ROG) emissions. TOGs consist of all compounds containing hydrogen and carbon, while ROGs consist of organics with low rates of reactivity. CH_4 is the primary TOG emitted by geothermal plants, followed by ethane and propane. The EPA's inventory of CH_4 emission from electric plants does not list geothermal, confirming that CH_4 emissions from geothermal are generally insignificant. In contrast, natural gas facilities emit 19% of domestic anthropogenic CH_4, while coal mining and production accounts for around 20%. Waste management accounts for the largest percentage of anthropogenic methane emissions, at over 26%. CH_4 emission estimates are uncertain, however, because they are usually accidental or incidental to biological processes, and they are not always present in geothermal systems.

TOGs and ROGs

Other ROGs, such as benzene, a known carcinogen, are generally not of concern to the geothermal community, as they are injected back into the system. Benzene emissions released at most geothermal facilities, including the Salton Sea in southern California, have never been high enough to trigger a risk assessment under California EPA exposure level standards. Although the Heber geothermal facility in southern California was required to conduct quarterly benzene cooling tower analysis as a stipulation in their permit agreement,90 analyses indicated that benzene comprises less than 1% of cooling tower gases.

Ammonia (NH_3)

Naturally occurring ammonia (NH_3) is emitted at low levels by geothermal facilities, with more concentrated amounts emitted by certain plants at The Geysers. While livestock is responsible for almost half of ammonia emissions, geothermal accounts for only a fraction of ammonia emissions, at substantially lower than one percent. Additional sources include fertilizers, crops, and biomass burning. Emitted ammonia can combine with water to form NH_4OH (ammonium hydroxide). If it lasts long enough in the environment, ammonia may combine with nitrogen oxide to form particulate (ammonium nitrate) or if there are no acid gasses present in the atmosphere, it will be absorbed into the soil and taken up by green plants. Experts generally concur that ammonia is released as hydrated ammonia, and depending upon the environment, is absorbed in soil to become part of the nitrogen cycle.

Boron

Boron, an element found in volcanic spring waters, does not exist naturally in its elemental form, but is commonly found as a mineral salt, “borax”, in dry lake evaporate deposits. Boron is only toxic when high concentrations are ingested. When present in soil at low concentrations, boron is essential to the normal growth of plants.

In geothermal steam systems, boron is present in the steam as highly soluble boric acid. When combined with ammonia, it often forms white crystalline salt deposits on equipment exposed to geothermal steam. Because of its high solubility, nearly all borate entering a geothermal plant will dissolve in the steam condensate, where it exits the plant through cooling tower blowdown and is injected back into the steam reservoir. New geothermal plants are now required to install high efficiency drift eliminators for particulate control regardless of boron content in the water, and these eliminators reduce boron emissions. Boron salt compounds may be emitted in cooling tower drift, but boron emissions are generally not regulated, as does not cause any environmental impact.

Air emissions - Conclusions

Total noncondensable gas emissions from geothermal resources typically make up less than 5% of the total steam emitted, whereas air emissions from facilities such as coal contain much higher percentages of emissions. Geothermal air emissions are significantly lower than those of an power plant. For example, the geothermal sulfur dioxide equivalent, derived from hydrogen sulfide emissions, is one of the most significant pollutants emitted from geothermal power plants. Even so, sulfur dioxide emitted by geothermal facilities, at 0.16 kg/MWh, represents only a fraction of the 2.74 kg/MWh of sulfur dioxide generated by the average power plant.

Air emissions summary

kg/MWh	NOx	SO_2	CO_2	PM
Coal	1.95	4.71	993.82	1.01
Coal, life cycle emissions	3.35	6.71	NA	9.21
Oil	1.81	5.44	758.40	NA
Natural Gas	1.34	1.00	550	0.06
EPA Listed Average of all U.S. Power Plants	1.34	2.74	631.62	NA
Geothermal (flash)	0	0.16	27.21	0
Geothermal (binary and flash/binary)	0	0	0	negligible
Geothermal (Geysers steam)	0.0005	0.0001	40.28	negligible

Solid and Liquid Waste

Generally, air emissions are the most significant environmental issue of concern. Solid wastes discharged from geothermal power plants are nonhazardous and in low quantities.

The substances listed are typically either too low to cause any concern, or are recycled through the system and do not make contact with water, land, or air. Solid and liquid waste substances are included to provide a comprehensive review of the environmental aspects of geothermal energy.

Solid and Liquid Waste

Arsenic

Arsenic, in its pure form, is a gray, crystalline solid, but can be found in various forms in the natural environment in combination with other elements. Arsenic is produced naturally in the Earth's crust and can be emitted during volcanic eruptions. It is also produced in fossil fuel processing and in the production of pesticides, wood preservatives, glass, and other materials. It is a known human carcinogen. Additional health effects include sore throat, irritated lungs, nausea, vomiting, decreased production of red and white blood cells, abnormal heart rhythm, damage to blood vessels, and skin pigmentation abnormalities.

Arsenic

Geothermal plants are not considered to be high arsenic emitters even though arsenic is common to volcanic systems. When arsenic is present in a geothermal system, it typically ends up in the solid form in the sludge and scales associated with production and hydrogen sulfate abatement. Arsenic emission levels have been well documented over the years through two emissions inventories in California: the Air Toxic "Hot Spots" Program and The Geysers Air Monitoring Programs (GAMP), both of which have shown limited arsenic emissions. Results of these programs have shown arsenic emissions levels from geothermal power plant to be very small, if they are even detectable. A study of The Geysers showed that arsenic emissions were not of significant concern: the average level at The Geysers, at around 1.6 ng m^{-3}, was found to be very close to the statewide average of 1.5 ng m^{-3}.

Solid and Liquid Waste

Silica and other waste products

Silica, an abundant element that is the primary component of sand, is a byproduct of geothermal power production from certain brine reservoirs. Silica is typically dewatered, and the silica sludge is disposed of off site. Silica is only considered a potential hazard when found in high concentrations in the workplace, but it poses no environmental risk. Silica is found in the effluents, or treated wastewaters, that are the byproducts of drilling operations in some resources. Concentrations of silica are low enough in geothermal facilities that workers are not at risk. Other geothermal effluents are generally considered to be harmless, and even, at times, beneficial to the environment.

The primary "waste" in geothermal operations is drilling cuttings, comprised primarily of bentonite, a naturally occurring clay. Wastes from drilling activities, mud and cuttings, are stored in what are known as “sumps” for disposal. Sumps provide secure storage for drilling mud and cuttings. They are typically lined with impervious materials to prevent leaching.

Noise Pollution

Common sound levels

Noise Source	Sound Level (dBA)
Geothermal normal operation	*15 - 28*
Near leaves rustling from breeze	25
Whisper at 2 m	35
Inside average suburban residence	40
Near a refrigerator	40
Geothermal construction	*51 - 54*
Geothermal well drilling	*54*
Inside average office, without nearby telephone ringing	55
Speech at 1 m , normal voice level	60
Auto (100 km per hour) at 30 m	65
Vacuum cleaner at 3 m	70
Garbage disposal at 1 m	80
Electric lawn mower at 1 m	85
Food blender at 1 m	90
Auto horn at 3 m	100

Sound is measured in units of decibels (dB), but for environmental purposes is usually measured in decibels A-weighted (dBA).
A-weighting refers to an electronic technique which simulates the relative response of the human auditory system to the various frequencies comprising all sounds.

Noise Pollution

Geothermal power plants can operate in compliance with the applicable regulations and are not considered a noise nuisance in surrounding residential communities. All power facilities must meet local noise ordinances according to the phase of construction and operation.

Noise pollution from geothermal plants is typically considered during three phases: the well-drilling and testing phase, the construction phase, and the plant operation phase.

During the construction phase, noise may be generated from construction of the well pads, transmission towers, and power plant. During the operation phase, the majority of noise is generated from the cooling tower, the transformer, and the turbine-generator building.

Noise Pollution

Construction is one of the noisiest phases of geothermal development, but even construction noise generally remains below the 65 dBA. Furthermore, noise pollution associated with the construction phase of geothermal development, as with most construction, is a temporary impact that ends when construction ends. Well pad construction can take anywhere from a few weeks or months to a few years, depending upon the depth of the well. In addition, construction noise pollution is generally only an issue during the daytime hours and is not a concern at night.

Noise Pollution

The well-drilling and testing phase of geothermal development generally does not exceed the noise regulations, they are temporary, and the noise pollution they produce is not permanent. However, well-drilling operations typically take place 24 hrs per day, seven days a week. This temporary noise pollution can last anywhere from 45 to 90 days per well.

Noise from normal power plant operation generally comes from the three components of the power plant: the cooling tower, the transformer, and the turbine-generator building. The produced noise is in range of whisper.

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

Water Quality and Use

Geothermal water (GW) is a hot, often salty, mineral-rich liquid withdrawn from a deep underground reservoir. The steam that is "flashed" from the hot water is used to turn turbines and generate electricity. The remaining water, along with the condensed steam, is then injected back into the geothermal reservoir to be reheated. In water cooled systems, 50% or more of the liquid is lost to the atmosphere in the form of steam, and the remainder is injected back into the system. Because the GW in a binary, air cooled plant is contained in a closed system, binary power plants do not consume any water. In a geothermal facility, GW is isolated during production, injected back into the geothermal reservoir, and separated from groundwater by thickly encased pipes, making the facility virtually free of water pollutants.

Water Quality and Use

Most geothermal reservoirs are found deep underground, well below groundwater reservoirs. As a result, these deep reservoirs pose almost no negative impact on water quality and use. Anyway, potable groundwater and clean surface water are important resources that require continued attention as the use of domestic geothermal resources grows.

Water Quality and Use

Geothermal steam and hot water can reach the surface in two ways: through naturally occurring surface features such as geysers and fumaroles, or through man-made wells that are drilled down into the reservoir to capture the Earth's energy for electricity. In either case, these natural geothermal fluids contain varying concentrations of potentially toxic minerals and other elements and are extremely hot when they reach the surface of the Earth. For these reasons, GWs can be dangerous to humans and surrounding ecosystems. This is just one of the reasons that geothermal fluids used for electricity are injected back into geothermal reservoirs and are not allowed to be released into surface waterways. When geothermal fluids are injected back into a geothermal system, the fluids are isolated from shallow groundwater by thick well casing. Injection typically takes place in separate wells that are designed to properly handle the chemistry of the injection fluids. In addition, geothermal developers manage geothermal fluids in order to minimize potential impacts. Benefits of injection include enhanced recovery of geothermal fluids, reduced subsidence and safe disposal of geothermal fluids.

Water Quality and Use

Occasionally, geothermal effluents, if stored rather than injected back into the system, deliver beneficial environmental effects. For example, injection was banned at the Amedee geothermal field in northeastern California because the effluent, stored in a holding tank, produced a diverse, thriving wetland. In another case, an evaporative pond at a Mexican geothermal facility was found to be occupied by 34 species of birds.

The Icelandic tourist attraction, the Blue Lagoon (a turquoise body of mineral rich water) was actually created by geothermal water discharged from a power plant. Not only is the Blue Lagoon safe for swimming, but the waters are also touted as "soothing" and as sources of "curative powers".

Although most geothermal community agrees that injection is the most environmentally beneficial method of disposing of geothermal fluids, there are instances where other beneficial approaches have been taken.

Water Quality and Use

Blue Lagoon: Tourist Attraction and Geothermal "Wastewater"

Wastewater injection

Geothermal plants have the potential to improve local water quality. So-called "waste water injection" projects serve the dual purpose of eliminating wastewater, which would otherwise be dumped into local waterways, and rejuvenating geothermal reservoirs with new water sources.

Although geothermal development does not contaminate groundwater, like any form of development, it has some impact on local water use. For geothermal developers, most water impacts occur during construction and are only temporary. However, regardless of the nature or degree of water use impacts, geothermal developers should prioritize sound reservoir management practices that benefit geothermal operation and preventatively minimize potential impact.

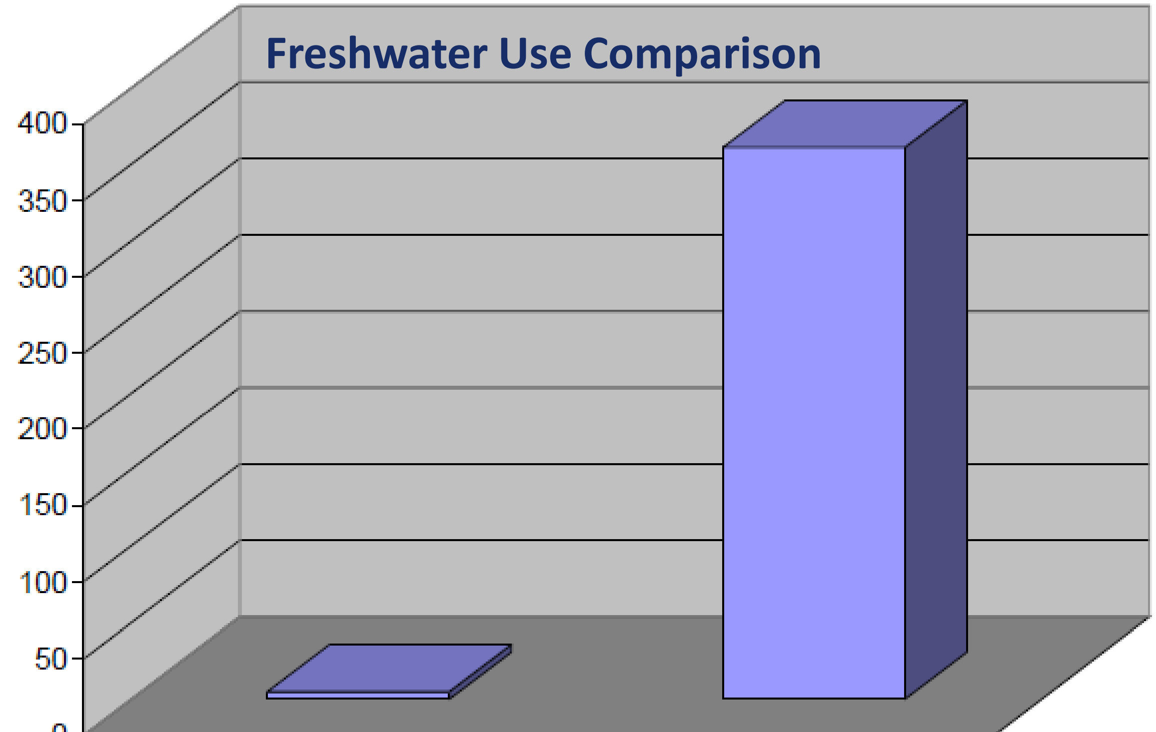
Wastewater injection

Geothermal power plants do use surface or groundwater during the construction and operation of the power plant as well as during well drilling to sustain operations. These uses, while typically not a significant concern as they do not dramatically decrease the amount of ground and surface water available for potable uses, should be taken into account during the development of geothermal resources.

Fossil fuel plants, in contrast to geothermal facilities, must contend with water discharge and thermal pollution throughout the life of the plant, and waste heat from fossil fuel and nuclear facilities can devastate the animals and plants that inhabit local water bodies. In addition, both coal and nuclear plants use more water per MWh than geothermal facilities in cooling their high-temperature fluids. Heated water is often dumped into local bodies of water, creating environmental disruption from the intake and heating processes.

Wastewater injection

The geothermal water use figure does not include geothermal fluid, as this liquid is injected back into the system and is not withdrawn from existing freshwater resources.



	Geothermal	Natural Gas
lit./MWh	2	1370

Wastewater injection

During normal operations, liquid wastes from drilling activities are stored in lined sumps before being properly disposed of in accordance with state regulations. Accidental spills of geothermal waters may occur due to well blowouts during drilling, leaking piping or wellheads, or overflow from well sumps. However, these incidents are rare, and are generally prevented through sound management practices by geothermal developers. Overall, any negative effect of geothermal development on surface waterways would be accidental, and even then, by following federal and state laws, their impact would be kept minimal.

Land Use

Flash/binary Puna Geo Venture facility, located in Hawaii. This plant blends into its surroundings and produces no steam plumes, while still utilizing high temperature resources.

Geothermal power plants can be designed to “blend-in” to their surrounding more so than many other types electricity-producing facilities. Binary and flash/binary power plants normally emit no visible steam or water vapor plumes, and flash and steam plants produce minimal visual impacts.

Land Use

Geothermal facilities are often located on lands that have multiple-use capabilities. Case study at the geothermal facilities of Salton Sea and Imperial Valley in Southern California - at these sites, several aquaculture operations use geothermal water to control the water temperatures, improve fish and fish culture facilities, and extend the fish growth season. In addition, these power plants in the Imperial Valley are surrounded by productive farm land.

Another geothermal plant, the Mammoth power plant in Northern California, is located only miles from the Mammoth Ski Resort and yet does not detract from the natural beauty of the area. In addition, The Geysers field teems with wildlife and still serves as a prime hunting ground for the individuals and hunting clubs that own much of the land. Finally, a 1995 study found that geothermal resource use can "beneficially influence the state of health of the population and the environment" by reducing deforestation and air emissions.

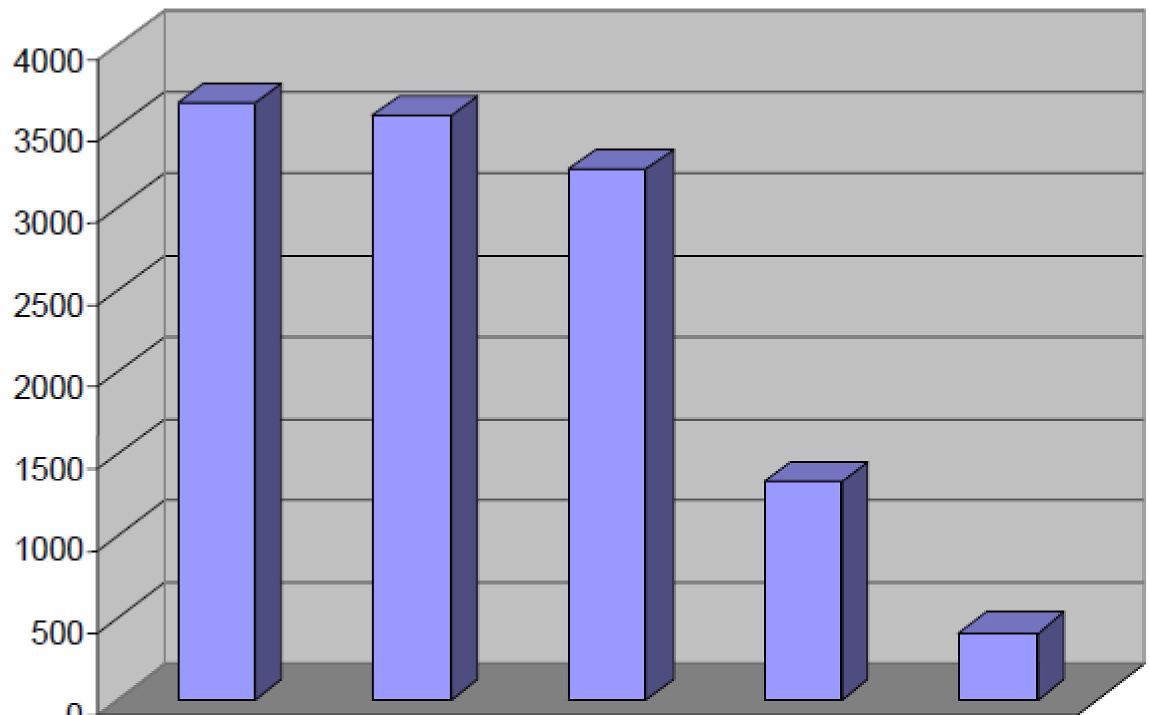
Land Use

Imperial Valley Power Plant Next to Productive Farmland

Land Use

While some fossil-fuel energy sources, such as coal, use up large swaths of land in the mining of their fuel, geothermal plants minimize the total amount of land used by only building the plant along with the number of well pads needed to support operation. It is important to keep in mind that the land impact of renewable energy development and use is much less damaging than the impact caused by fossil fuel development and use. Coal mining requires the transportation of huge amounts of dirt and rock, sometimes into streams, and causes disruption of water systems through acid drainage, deforestation, and damage to ecosystems. Nuclear facilities require the safe maintenance of huge amounts of radioactive waste. Over 30 years, the period of time commonly used to compare life cycle impacts of different power sources, geothermal uses less land than many other sources.

Land Use



	Coal*	Solar Thermal	Photovoltaics**	Wind***	Geothermal
m^2/GWh	3642	3561	3237	1335	404

* Includes mining.

**Assumes central station photovoltaic project, not rooftop PV systems.

*** Land actually occupied by turbines and service roads.

Land Use

GPP impose minimal visual impacts on their surroundings when compared to typical fossil-fuel plants. Some of the key visual quality effects related to geothermal development are the presence of steam plumes, night lighting on the wellfield and power plant, and visibility of the transmission line. Fossil fired power plants have all of these visual effects as well. The majority of geothermal visual impacts can be mitigated to reduce their effects. Detailed site planning, facility design, materials selection, revegetation programs, and adjustment to transmission line routing are all key aspects of geothermal operations that can reduce the visual impacts of the facility. Today, many geothermal operators already employ these mitigation techniques to reduce their facilities' visual impact.

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

Land Use

Subsidence

Subsidence is most commonly thought of as the slow, downward sinking of the land surface. Other types of ground deformation include upward motion (inflation) and horizontal movements. In some cases, subsidence can damage facilities such as roads, buildings and irrigation systems, or even cause tracts of land to become submerged by nearby bodies of water. Although it can occur naturally, subsidence can also occur as a result of the extraction of subsurface fluids, including groundwater, hydrocarbons, and geothermal fluids. In these cases, a reduction in reservoir pore pressure reduces the support for the reservoir rock itself and for the rock overlying the reservoir, potentially leading to a slow, downward deformation of the land surface. In most areas where subsidence has been attributed to geothermal operations, the region of Earth deformation has been confined to the wellfield area itself, and has not disturbed anything off-site.

Land Use

Subsidence

While subsidence can be induced by thermal contraction of the reservoir due to extraction and natural recharge, properly placed injection reduces the potential for subsidence by maintaining reservoir pressures. At fields produced from sedimentary rocks where the porosity and permeability is primarily between rock grains, injection can successfully mitigate for subsidence.

Naturally-occurring subsidence most frequently takes place in areas that are tectonically active such as volcanic regions and fault zones. Subsidence can also typically occur in areas where sedimentary basins are filled with unconsolidated sands, silts, clays and gravels. Most known geothermal resources are located in areas that are tectonically active, and may experience natural subsidence. Because geothermal operations occur at tectonically active sites, it is sometimes difficult to distinguish between induced and naturally occurring subsidence. Subsidence related to geothermal development is more likely in areas where the geothermal reservoir occurs in weak, porous sedimentary or pyroclastic formations.

Land Use

Subsidence

In cases where subsidence may be linked to geothermal reservoir pressure decline, injection is an effective mitigating technique. By injecting spent geothermal brines back into the reservoir from which they came, reservoir pressure is stabilized. This approach has helped to maintain the pressure of geothermal reservoirs and can prevent or mitigate for subsidence at geothermal development sites.

Injection technology has not always been utilized in other parts of the world, and therefore subsidence has been a larger issue at some geothermal developments overseas. The most commonly referenced case of major subsidence at a geothermal field is the Wairakei geothermal field in New Zealand. At this field, which has been operating since the late 1950s, geothermal fluids were not routinely injected back into the geothermal reservoir. Although limited injection began in the late 1990s at Wairakei, most subsidence had already occurred at this point. Long-term extraction of fluids without injection resulted in high subsidence rates in some areas near the production field, and a lower rate of subsidence across a much wider area. In the United States, as well as most other geothermal fields worldwide, injection of spent geothermal brines begins immediately after a plant comes on-line, and continues through the life of the plant.

Land Use

Induced Seismicity

Earthquake activity, or seismicity, is generally caused by displacement across active faults in tectonically active zones. An earthquake occurs when a body of rock is ruptured and radiates seismic waves that shake the ground. Although it typically occurs naturally, seismicity has at times been induced by human activity, including the development of geothermal fields, through both production and injection operations. In these cases, the resulting seismicity has been low-magnitude events known as "microearthquakes". Earthquakes with Richter magnitudes below 2 or 3, which are generally not felt by humans, are called microearthquakes. These microearthquakes sometimes occur when geothermal fluids are injected back into the system, and are centered on the injection site. The microearthquakes sometimes associated with geothermal development are not considered to be a hazard to the geothermal power plants or the surrounding communities, and will usually go unnoticed unless sensitive seismometers are located nearby.

Land Use
Induced Seismicity

Much like subsidence, seismicity typically takes place in areas with high levels of tectonic activity, such as volcanic regions and fault zones. Because geothermal operations usually take place in areas that are also tectonically active, it is often difficult to distinguish between geothermal-induced and naturally occurring events. Many regions where geothermal development has occurred or has been planned are known as areas with high levels of fault activity. These regions frequently experience earthquakes of various magnitudes, though few are felt by humans.

Land Use

Land slides

The extent to which geothermal development induces landslides is unclear, as landslides, which occur naturally in certain areas of geothermal activity such as volcanic zones, are produced by a combination of events or circumstances rather than by any single specific action. While field construction operations can "trigger" landslides, local geological preconditions must already exist in order for landslides to occur. Though landslides are rare, when they occur they are small enough to be confined entirely to the wellfield area of a geothermal facility. Geothermal areas with landslide hazards can be properly managed through detailed hazard mapping, groundwater assessment, and deformation monitoring, among other management techniques. Because landslides always present warning signs, such techniques ensure that landslides can be avoided on geothermal lands.

Geysers, Fumaroles and Geothermal Resources

Geothermal Surface Features

Geothermal resources are often discovered under certain land features such as geysers, fumaroles, hot springs, mud pools, steaming ground, sinter, and travertine. Geysers are hot springs where hot water, steam, or gas periodically erupts, while fumaroles vent gas and steam. The word “geyser” derives from the Icelandic word, “geysir”, which means, “the gusher”.

Geysers, Fumaroles and Geothermal Resources

There are concerns that such land features will be drastically altered or destroyed as a result of geothermal development. In some cases, both during past geothermal development and geothermal development overseas, it is true that land features have been altered by geothermal development. However, through the evolution of geothermal development, developers have come to understand the best management practices that reduce surface feature impact, and have employed preventative mitigation measures that reduce potential impact to surface features before they arise. In addition, monitoring programs for significant surface features are required by law, and geothermal development in areas where surface features may be adversely affected is forbidden. The current status of geothermal development shows that little alteration of land features has occurred in recent years as a result of sound geothermal management practices and law compliance.

Impact on Wildlife and Vegetation

Geothermal development poses only minimal impact to wildlife and vegetation in the surrounding area when compared with alternatives such as coal. It should be noted that geothermal facilities must sometimes be built in more sensitive areas than coal plants. However, increased sensitivity leads to increased mitigation and surveillance in these areas. Before geothermal construction can even begin, an environmental review may be required to categorize potential effects upon plants and animals. While any disruption of land that results from power plant construction has the potential to disturb habitat, geothermal plants, like any type of power plant, must comply with a host of regulations that protect areas set for development.

Impact on Wildlife and Vegetation

Geothermal plants are designed to minimize the potential effect upon wildlife and vegetation: pipes are insulated to prevent thermal losses, power plants are fenced in so as to prevent wildlife access, spill containment systems with potential to hold 150 percent of the potential maximum spill are put in place, and areas with high concentrations of wildlife or vegetation specific to an area are avoided. Because geothermal plants avoid much of the additional disruption caused by mining coal and building roads to transport it, the construction of a geothermal plant reduces the overall impact on wildlife and vegetation species from energy production. A typical 500 MW coal plant, for example, can disrupt 21 million fish eggs, fish larvae, and juvenile fish from water usage alone during normal operation, as the 8.3 millions m^3 of water required each year to create steam for turbine generation is extracted from nearby water bodies rich with fish species. Many species' habitats are restricted by road construction or eliminated altogether by mining activities related to fossil fuel production.

Summary

Despite improvements in coal, natural gas, and oil power plant technology, fossil fuel combustion continues to produce more air pollution than any other single source. They are main contributors for water pollution, SO_2 emissions and take great part in the NOx and CO_2 emissions. These pollutants have been widely documented to cause a host of environmental and health problems, and climate change.

Although green power pollutes significantly less than fossil fuel sources, it is important to note that all power generation impacts the environment, regardless of whether electricity is derived from the combustion of fossil fuel or renewable sources. Impacts such as land use, for example, cannot be avoided no matter what level of mitigation is employed. The goal, instead of eliminating all impacts, should be to minimize impacts.

Summary

Environmental Benefits of Geothermal Energy

Most important environmental benefits which support the expanded geothermal power generation:

- Geothermal energy is reliable
- Geothermal energy is renewable
- Geothermal energy produces minimal air emissions and offsets the high air emissions of fossil fuel-fires power plants
- Geothermal energy can offset other environmental impacts
- Geothermal energy is combustion free
- Geothermal energy minimally impacts land
- Geothermal energy is competitive with other energy technologies when environmental costs are considered

Conclusion

Abundant geothermal resources throughout the nations can provide an environmentally friendly source of energy. Data compiled from a variety of sources point to geothermal energy as an environmental option for new power and heat generation that is far better than other energy sources such as fossil fuels. In addition, geothermal remains as environmentally friendly as most other renewable sources, while simultaneously offering reliability and a source of baseload power that is unique among most other renewable options available.

While currently used at only a fraction of its potential, geothermal energy can substantially contribute to the energy needs of the twenty-first century.

As geothermal energy production is refined and expanded, the benefits continue to grow. With continued technological development, geothermal can be expanded all over the world, and the already negligible environmental geothermal impacts can be reduced to nearly zero. Geothermal energy can provide the clean, reliable, and plentiful renewable energy resource for the world.