8. ENVIRONMENTAL EFFECTS OF GEOTHERMAL ENERGY

Geothermal resources are considered renewable and "green" (Rybach, 2007); however, there are several environmental impacts that must be considered during utilization that are usually mitigated. These are emission of harmful gases, noise pollution, water use and quality, land use, and impact on natural phenomena, wildlife and vegetation (Kagel, et al., 2005).

8.1 Emissions

These are usually associated with steam power plant cooling towers that produce water vapor emission (steam), not smoke. The potential gases that can be released, depending upon the reservoir type are carbon dioxide, sulfur dioxide, nitrous oxides, hydrogen sulfide along with particulate matter.

8.1.1. Gaseous emissions

Gaseous emissions result from the discharge of non-condensable gases (NCGs) that are carried in the source stream to the power plant. For hydrothermal installations, the most common NCGs are carbon dioxide (CO_2) and hydrogen sulfide (H_2S), although species such as methane, hydrogen, sulfur dioxide, and ammonia are often encountered in low concentrations.

8.1.1.1 Carbon Dioxide (CO_2)

A colorless, odorless gas, CO_2 is released into the atmosphere primarily as a byproduct of burning various fuels. While carbon dioxide emissions are also produced by natural sources, most experts agree that increased atmospheric carbon dioxide concentrations are caused by human fossil fuel burning. Concentrations in the atmosphere have increased by approximately 20 percent since 1960. The increase in carbon dioxide is typically attributed to power plant (primarily coal) and vehicle emissions, and secondarily to deforestation and land-use change. About 37 percent of incremental carbon dioxide accumulation is caused by electric power generation, mainly from fossil fuels.

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

Geothermal steam is generally condensed after passing through the turbine, but CO_2 does not condense, and instead passes through the turbine to the exhaust system where it is released into the atmosphere through cooling towers. Amounts of CO_2 in geothermal fluids can vary depending on location, and the amount of CO_2 actually released into the atmosphere can vary depending on power plant design.

This makes it difficult to generalize about the amount of CO_2 emitted by an "average" geothermal power plant. For example, binary plants with air cooling are closed loop systems and emit no CO_2, because geothermal fluids are not exposed to the atmosphere. Despite these disparities, even the "dirtiest" geothermal power plant will emit only a fraction of the CO_2 emitted by thermal power plants on a per-MW basis. Non-condensable gases such as CO_2 make up less than 5 percent by weight of the steam phase of most geothermal systems. Of that 5 percent, CO_2 typically accounts for 75 percent or more of non-condensable gas by volume. Geothermal power production currently prevents the emission of 17 million tons of carbon annually when compared to the same amount of power produced by coal-fired power plants.

8.1.1.2. Nitrogen Oxides (NOx)

Because geothermal power plants do not burn fuel, they emit very low levels of NOx. In most cases, geothermal facilities emit no nitrogen oxides at all. The small amounts of NOx released result from the combustion of hydrogen sulfide (H_2S). During combustion, small amounts of nitrogen oxides are sometimes formed, but these amounts are miniscule. Geothermal facilities are generally required by law to maintain H_2S abatement systems that capture these emissions, and either burn the gas or convert it to elemental sulfur. During combustion, small amounts of NOx are sometimes formed, but these are miniscule. Average NOx emissions are zero. When comparing geothermal energy to coal, current U.S. geothermal power generation of about 15 billion kilowatt-hours (kWh) reduces NOx emissions by around 32,000 tons.

8.1.1.3. Hydrogen Sulfide (H_2S)

Identifiable by its distinctive "rotten-egg" smell, H_2S is the pollutant generally considered of greatest concern for geothermal power operations. Since 1976, H_2S emissions from geothermal power plants have declined from 861 kg/h to 90 kg/h or less, even though geothermal power production has increased from 500 megawatts (MW) to over 2,000 MW. The two most commonly used vent gas H_2S abatement systems are the Stretford system and the LO-CAT. Both systems remove over 99.9 percent of H_2S from non-condensable gases, and convert it to elemental sulfur for use as a soil amendment and fertilizer feedstock. Today, geothermal steam and flash power plants produce only minimal H_2S emissions. Binary geothermal power plants release no H_2S emissions at all.

8.1.1.4. Sulfur Dioxide (SO_2)

Geothermal power plants do not directly emit SO_2. Once H_2S is released, it spreads into the air and eventually changes into SO_2 and sulfuric acid. When comparing geothermal energy to coal, current geothermal generation of about 15 billion kWh avoids the potential release of 78,000 tons of SO_2.

8.1.1.5. Particulate Matter

Particulate matter (PM) is a broad term for a range of substances that exist as discrete particles. Particulate matter 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 particulate matter 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.

While coal- and oil-fired power plants produce hundreds of tons of particulate matter annually, geothermal power plants emit almost none. Water-cooled geothermal power plants give off small amounts of particulate matter from cooling towers when steam condensate is evaporated, but the amount is quite small when compared to coal- or oil-fired power plants. In a study of California geothermal power plants, PM10 is reported as zero. It is estimated that geothermal energy produced in the United States prevents the emissions of over 17,000 tons of particulate matter each year when compared to the same amount of power produced by coal-fired power plants.

8.1.1.6. Mercury

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

Mercury is not present in every geothermal resource. However, if mercury is present in a geothermal resource, using that resource for power production could result in mercury emissions, depending upon the technology used. In the United States, The Geysers is the main geothermal field known to emit small quantities of mercury, with 80 percent of mercury emissions concentrated at a few facilities where the installation of abatement equipment has been scheduled. The Geysers area was mined for mercury from 1850 to 1950, so it is likely that some degree of mercury emissions would exist independently of geothermal development.

Furthermore, mercury emissions from The Geysers are below the amount required to trigger a health risk analysis under existing California regulations. Because binary power plants pass geothermal fluid through a heat exchanger, then return all of it to the reservoir, they do not emit mercury.

While federal proposals related to mercury risk have focused on coal, state and local governments have also introduced measures to reduce mercury emissions from other sources. As a result, mercury abatement measures are already in place at most geothermal facilities. The abatement measures that reduce mercury also reduce sulfur emissions generated as a byproduct of H_2S abatement (after H_2S is removed from geothermal steam, the gas is run through a mercury filter that absorbs mercury from the gas). The rate of mercury abatement within a geothermal power facility, which varies according to the efficiency of its activated carbon mercury absorber, is typically near 90 percent, and is always efficient enough to ensure that the sulfur byproduct is not hazardous. The activated carbon media is changed out periodically and disposed of as a hazardous waste. The amount of hazardous waste reduction is thousands of tons/year.

8.1.1.7. Ammonia

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.

8.1.1.8. 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 vapor 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.

8.1.2. Solid and Liquid Waste

There is practically no chance for contamination of surface facilities or the surrounding area by the discharge of solids *per se* from the geofluid. The only conceivable situation would be an accident associated with a fluid treatment or minerals recovery system that somehow failed in a catastrophic manner and spewed removed solids onto the area.

8.1.2.1. 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.

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

8.1.2.2. 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.104 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.105 Concentrations of silica are low enough in geothermal facilities that workers are not at risk.

8.2 Noise

The majority of the noise produced at a power plant or direct-use site is during the well drilling operation, which normally shuts down at night. The noise from a power plant is not considered an issue of concern, as it is extremely low, unless you are next to or inside the plant. Most of the noise comes from cooling fans and the rotating turbines.

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 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.

Table 8.1: Common Sound Levels

Noise Source	Sound Level (dBA)
Geothermal normal operation	*15 - 28*
Near leaves rustling from breeze	25
Whisper at 1,8 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 0,9 m, normal voice level	60
Auto (96 km per hour) at 30,5 m	65
Vacuum cleaner at 3 m	70
Garbage disposal at 0,9 m	80
Electric lawn mower at 0,9 m	85
Food blender at 0,9 m	90
Auto horn at 3 m	100

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. According to the Telephone Flat EIS, noise from normal power plant operation at the site boundary would occupy a range of 15 to 28 dBA below the level of a whisper (table 8.1).

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.

8.3 Water quality and use

Geothermal projects, in general, require access to water during several stages of development and operation. Water use can be managed in most cases to minimize environmental impacts. Various aspects of water use in EGS projects are described below.

Well drilling, reservoir stimulation and circulation. Water is required during well drilling to provide bit cooling and rock chip removal. This water (actually a mixture of water and chemicals) is re-circulated after being cooled and strained. Makeup water is required to compensate for evaporation losses during cooling.

Fluids produced from the reservoir. Production of geofluids from a hydrothermal reservoir for use in power or thermal energy generation can lower the water table, adversely affect nearby geothermal natural features (e.g., geysers, springs, and spas), create hydrothermal (phreatic) eruptions, increase the steam zone, allow saline intrusions, or cause subsidence. EGS systems are designed to avoid these impacts by balancing fluid production with recharge.

Cooling water for heat rejection. Cooling water is generally used for condensation of the plant working fluid. The waste heat can be dissipated to the atmosphere through cooling towers if makeup water is available. Water from a nearby river or other water supply can also serve as a heat sink. There are opportunities for recovering heat from these waste fluids (and possibly from the brine stream) in associated activities such as fish farms or greenhouses.

Geothermal plants use about 20 liters of freshwater per MWh, while binary air-cooled plants use no fresh water, as compared to a coal plant that uses 1,370 liters per MWh. An oil plant uses about 15% less and nuclear about 25% more than the coal plant.

Geothermal water 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 percent 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 geothermal water in a binary, air cooled plant is contained in a closed system, binary power plants do not consume any water. In a geothermal facility, geothermal water 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.

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.

The 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, geothermal waters 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.

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.

8.4 Land use

Geothermal power plants are designed to "blend-in" with the surrounding landscape, and can be located near recreational areas with minimum land and visual impacts. They generally consist of small modular plants under 100 MWel as compared to coal or nuclear plants of around 1,000 MWel. Typically, a geothermal facility uses 404 square meters of land per GWh compared to a coal facility that uses 3,632 square meters per GWh and a wind farm that uses 1,335 square meters per GWh.

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.

Fig.8.4.1 Typical pipeline at Miravalles geothermal power plant, Costa Rica (photo by R. DiPippo)

Geothermal power plants 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, re-vegetation programs, and adjustment to transmission line routing are all key aspects of geothermal operations that can reduce the visual impacts of the facility.

Gathering pipelines are usually mounted on stanchions, so that most of the area could be used for farming, pasture, or other compatible use (see Figure 8.4.1). The footprint of the power plant, cooling towers, and auxiliary buildings and substation is relatively modest. Holding ponds for temporary discharges (during drilling or well stimulation) can be sizeable but represent only a small fraction of the total well field.

8.4.1. 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 well-field area itself, and has not disturbed anything off-site.

8.4.2. 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 "micro earthquakes". Earthquakes with Richter magnitudes below 2 or 3, which are generally not felt by humans, are called micro earthquakes. These micro earthquakes sometimes occur when geothermal fluids are injected back into the system, and are centered on the injection site. The micro earthquakes 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.

8.4.3. Landslides

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 well-field 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.

8.5 Impact on Wildlife and Vegetation

Plants are usually prevented from being located near geysers, fumaroles and hot springs, as the extraction of fluids to run the turbines, might impact these thermal manifestations. Most plants are located in areas with no natural surface discharges. If plants are located near these natural phenomena, the fluid extraction depth is planned from a different reservoir to prevent any impact. Designers and operators are especially sensitive about preserving manifestations considered sacred to indigenous people. Any site considered for a geothermal power plant, must be reviewed and considered for the impact on wildlife and vegetation, and if significant, provide a mitigation plan. Direct use projects are usually small and thus have no significant impact on natural features.

Fig.8.5.1 Imperial Valley Power Plant and Productive Farmland

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.

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.

8.6 Thermal pollution

Although thermal pollution is currently not a specifically regulated quantity, it does represent an environmental impact for all power plants that rely on a heat source for their motive force. Heat rejection from geothermal plants is higher per unit of electricity production than for fossil fuel plants or nuclear plants; because the temperature of the geothermal stream that supplies the input thermal energy is much lower for geothermal power plants. Considering only thermal discharges at the plant site, a geothermal plant is two to three times worse than a nuclear power plant, and the size of the waste heat rejection system for a 100 MW geothermal plant will be about the same as for a 500 MW gas turbine combined cycle (DiPippo, 1991a). Therefore, cooling towers or air-cooled condensers are much larger than those in conventional power plants of the same electric power rating.