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Harnessing power from non-renewable sources has been one of the leading forces in innovation over the past century. While there are positives to this form of energy generation, its impacts on the climate and resources are detrimental. Due to this, researchers and scientists have found methods to harness power from natural and renewable energy sources, more commonly known as "clean energy". These include sources such as solar energy, wind energy, hydro energy, geothermal energy, and many others. While many of these sources are being used to replace the long-standing tradition of using nonrenewable energy sources, using geothermal energy is of particular interest. Geothermal energy uses the heat produced within the earth's core to yield usable power. One of the main benefits of using this renewable energy source, when compared to others, is the small land footprint and its reliability. Unfortunately, there are some downsides to this energy source, which include the production of pollutants that then affect the surrounding environment.

The purpose of this project is to address the specific effects of pollutants released from geothermal power plants. By doing so, efforts to diminish those pollutants can be focused on along with ideas to better the overall geothermal power plant mechanism. By doing so, future power plants can be created with reduced output of pollutants. This will be better for both the environment and future generations as innovation helps the betterment of energy sources.

Mechanisms of Geothermal Power Plants

Within the earth, there exist four major layers: the crust, the mantle, the outer core, and the inner core. The boundary between the mantle and the earth's crust reaches temperatures of approximately 4000°C (U.S. Energy Information Administration, 2016). The heat from this boundary transfers through the rock layers and heats underground aquifers. These pools of water that are being heated from the magma below are called geothermal reservoirs.

To harness energy from these reservoirs, three main types of geothermal energy plants have been developed: dry steam power plants, flash steam power plants, and binary cycle power plants (National Renewable Energy Laboratory, 2022). All these turbines utilize the same mechanism for the generation of energy. When steam is generated, a turbine is spun which allows a generator to be activated to produce electricity. How these turbines differ is how they generate steam (Gobler, 2022). Dry steam power plants utilize hot steam that comes from underground and is piped directly into the turbines. Flash steam power plants pump the hot water from the underground aquifer to a cooler reservoir. The water in the cooler reservoir, as it is heated up from the hot water, turns to steam and is then piped to the turbines. The last type of geothermal power plant, the binary cycle power plant, utilizes a tank, containing a secondary liquid, that has a pipe that runs through it which contains the underground hot water. As the hot water runs through the pipe, heat exchange occurs between the hot water and the liquid in the tank via the pipe. As heat exchange occurs, the secondary liquid turns to its gaseous form and is piped to the turbines.

Currently, flash steam power plants are the most common, but it is the binary cycle plants that are expected to be the most used geothermal power plant (University of Calgary, 2017). This is because the secondary liquid that is used contains a fluid that has a low boiling point such as organic compounds like butane and pentane. This allows geothermal energy to be utilized even if the location of the power plant is outside of a primary hot spot. This also ensures that contamination is minimized as the hot water from the underground aquifer does not combine with the liquid we provide.

While geothermal plants provide a relatively efficient way of harnessing renewable energy, some of the main environmental concerns are surface disturbances, the physical effects

of fluid withdrawal, noise, thermal effects, chemical pollution, biological effects, and disruptions in the protection of natural features. The initial setup of the plant requires drilling. While the area used for a drill site is relatively small and the landscape can be reshaped, the impact of drilling can still affect wildlife and surrounding areas. The physical effects of fluid withdrawal and surface disturbances combined can cause the formation of fumaroles that can cause further damage. In addition to this, the chemicals that compose the liquid fraction are hydrogen sulfide, arsenic, boron, mercury, lead, cadmium, iron, zinc, manganese, lithium, ammonia, as well as aluminum, which are all toxic to many plants and animals and can therefore cause detrimental effects if this water seeps into other areas. Lastly, another major production of pollution in the harnessing of geothermal energy is the gases that are released into the air. One of the main chemicals found in the released gas is carbon dioxide. While research has found that the CO_2 released would have been released into the atmosphere naturally, it is still a result of geothermal power plant exhaust. Essentially, the multitude of environmental changes that are directly and indirectly due to a geothermal plant must be considered and analyzed carefully before proceeding (Turgeon & Morse, 2022).

Pollutants and reactions of geothermal power plants

Carbon Dioxide

As stated earlier in the paper geothermal energy is a renewable source that can be used to produce power or heat. Even though it produces lower pollution emissions than its nonrenewable counterparts, its expansion is beginning to raise some issues (Fridriksson et al., 2017). Three of the biggest issues from these plants are carbon dioxide, methane, and hydrogen sulfide. Power plants, however, generate little to no methane, so the focus would be on Carbon Dioxide and Hydrogen Sulfide. Emissions of the greenhouse gas CO_2 to the atmosphere is one of the top

negative environmental effects of geothermal power production (Armannsson, 2017). The reason why CO_2 is considered so detrimental to the environment is because of its ability to absorb energy at a variety of wavelengths. When the surface of the earth absorbs sunlight, it radiates the sunlight back as infrared waves (heat). These waves would be able to return to the atmosphere if it was uninterrupted. Molecules such as oxygen do not interfere with these waves because they only interact with waves 200 nanometers or lower. However, carbon dioxide absorbs energy at a wavelength of 2,000 and 15,000 nanometers which interferes with infrared energy (Sadatshojaie & Rahimpour, 2020). This causes CO_2 to absorb and does not allow infrared radiation to exit the atmosphere. This is what creates the greenhouse effect. CO2 absorbing radiation in the winter may be beneficial, high amounts of CO_2 would allow for too much radiation to be kept in the atmosphere (Fecht, 2021).

Hydrogen Sulfide (Sulfur Dioxide)

Another one of the pollutants of greater concern that is expelled from geothermal power plants is hydrogen sulfide. Hydrogen sulfide is dangerous to humans as well as the environment as it is slightly soluble in water and can form sulfhydric acid. This can add to the effects of acid deposition in soil and water while being corrosive to metals. Individuals suffering from respiratory illnesses, such as asthma, are affected most by hydrogen sulfide released into the environment (*Hydrogen Sulfide & Health | California Air Resources Board*, n.d., 2022). However, hydrogen sulfide is not a greenhouse contributor, so it oxidizes to form sulfur dioxide (Kristmannsdóttir & Ármannsson, 2003). Sulfur dioxide is a water-soluble compound that can react with water to form sulfurous acid. It can also react with air or ozone to form sulfuric acid (Dean, 2001). Sulfuric acid is the main contributor to acid rain, which can acidify lakes and soils.

However, ammonia can neutralize the effects of sulfuric acid and spread it throughout the atmosphere (Spiro et al.,2012).

The two main ways that are currently used focus on removing the hydrogen sulfide before it reaches the turbine and after it reaches the turbine. The first method is to allow the hot water steam and hydrogen sulfide to come in contact with copper sulfate which results in a reaction producing elemental sulfur. The second method is to use an alkaline solution like sodium hydroxide. There are many ways that the hydrogen sulfide can be removed after the steam reaches the turbine. The three categories are off-gas methods, condensate water methods, and hybrid systems. Off-gas methods use a non-condensable gas removal system to remove hydrogen sulfide from the gas, while condensate water methods use either a hydrogen peroxide treatment or waste steam treatment to remove the hydrogen sulfide. Lastly, hybrid systems can treat either the steam that exits the condenser or the condensate steam to remove the hydrogen sulfide. All these methods are highly advanced and based on each situation, one is chosen to remove the pollutant. For example, the use of a waste stream to remove the hydrogen peroxide after it has reached the turbine is cheap which makes it optimal for larger power plants. Since this study has been conducted in 2014, many other methods have been developed which are more optimal and innovative (Rodríguez et al., 2014).

Another issue with using and converting to geothermal energy as a renewable source is scarcity. While it has been, in the past, difficult to identify areas where geothermal energy can be harnessed, new research has found an innovative way to find areas that are less environmentally sensitive. Researchers take samples from surface wells and look for high ratios of Helium 3 to Helium 4. A greater ratio indicates that there is a potential geothermal heat source that could be used for energy (Kennedy & van Soest, 2007).

In conclusion, while using geothermal energy is of great use and is a much better alternative to nonrenewable energy sources, there are still many aspects that must be altered before using it to completely replace nonrenewable energy. The impact on the surrounding ecosystems and land formations as well as the pollutants released which then cause an indirect impact on the environment are both important factors that must be altered. In addition to this, finding methods to identify heat sources without having to use environmentally sensitive areas, such as Yellowstone National Park in the US and specific areas in Iceland, is also important. Along with this idea, further research can be done to improve the efficiency of building these power plants, lessening the impact of drilling into the earth, removing pollutants from the exhaust emitted from the power plants, identifying other methods to isolate, discovering areas of geothermal heat sources without disturbing ecosystems, and more.

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