Geothermal Energy

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Abstract

Energy, a foundational resource in driving modern society, experiences increasing demand due to global population growth and improved living standards. Fossil fuels have historically, and even up until currently have dominated the energy landscape. The environmental concerns associated with fossil fuel use has led to the growth in research and development in renewable energy sources. Geothermal energy, derived from within the Earth, stands out as a clean and renewable option, however, one that lacks much application and research. Geothermal energy is abundant, and is an ever constant state of generation due to radioactive decay of particles, and the residual heat from Earth's formation. It is extracted through various technologies, such as power plants and direct-use systems, providing a predictable and reliable power output. There are many benefits to the environment using geothermal energy, especially considering with the expansion of it, we will be one step closer to decarbonization. Despite this, the recurring issue amongst geothermal energy is its location dependency, which limits where and when thermal energy can be extracted from and distributed to. With expanding research, such as Enhanced Geothermal Systems, limitations to geothermal energy will be overcome, and proven to be more accessible. The Imperial Valley Geothermal Project shows a substantial geothermal energy contribution. The area is rich in potential, and due to the size of the geothermal field, can play a huge part in the transition to sustainable energy.

Introduction

Energy is a fundamental resource that powers modern society and life as we know it. Increases in global population and improvements to the worldwide standard of living have caused a substantial increase in overall energy consumption. Currently the sources of energy include fossil fuels (such as coal, oil, and natural gas), nuclear power, and gaining recent popularity, inexhaustible renewable sources (such as wind, solar, and geothermal). Use of fossil fuels peaked during the Industrial Revolution and have been used as the main source of global energy since. In recent years, fossil fuels have supplied around 80% of the world's energy (Environmental and Energy Study Institute, 2021). There are many issues that arise with the use of fossil fuels, as they cause environmental harm by emitting greenhouse gasses, contributing to climate change, and as they are ultimately depleting since they are finite sources. As a result of these concerns, investment in renewable sources have increased for development and research: "As the demand for energy continues to grow, new energy-efficient technologies in power generation, delivery and conversion can play an increasingly important role in moderating the growth in future energy demands and reducing environmental impacts" (Gupta, 2006). Geothermal energy is one of these relatively clean and renewable sources, forming the question if using Earth's heat as a main energy source can be the answer to society's problems.

So what is geothermal energy? Geothermal energy is the thermal energy that is found throughout the Earth's interior (US Energy Information Administration, 2022). This energy comes from (i) the slow decay of radioactive particles from certain radioactive isotopes (typically isotopes of Uranium, Thorium, and Potassium) in the Earth's core and (ii) the residual heat from the formation of the planet. As radioactive isotopes go under decay processes, they release energy in the form of heat. Radioactive decay is a continuous process that produces an infinite source of thermal energy. An additional contributor to the energy within the planet is the residual heat from Earth's formation. In the early stages of Earth's formation there were many collisions with the mass of Earth and other small bodies; generating heat. The Earth's temperature eventually overtime started to decrease, however, the residual heat from the initial formation is still present. These two heat sources that contribute to the Earth's thermal energy create a heat gradient within the planet that can be viewed as a reservoir, which can be 'tapped' into.

Geothermal resources can differ in size, temperature, and depth depending on the location. There are two main types of resources: (i) high temperature (classified as > 200 C), found in volcanic regions and ice chains, and (ii) moderate-to-low temperature (classified as 50-200 C), typically found in almost all continental areas (Gupta, 2006). Higher temperature resources can on their own be utilized to generate electric power, as well as can moderate temperature resources with the assistance of a certain technology, the binary-cycle method power plant. Lower temperature reservoirs are commonly used for space heating in commercial, industrial, and residential buildings.

How GE is Extracted

Geothermal energy can be harnessed through the use of geothermal power plants or direct-use systems. Power plants convert the Earth's heat into electricity, while direct-use systems utilize the geothermal heat for direct use. They are used for generating electricity on a large scale, and are only built and used if a reservoir is above 100 C. There are three types of geothermal power plants: dry stream, flash stream, and binary-cycle. There are two factors in a reservoir, (i) temperature and (ii) accessibility to source, that determine which geothermal power plant is to be used in extraction. Dry stream plants are used for high temperature reservoirs that are found near the surface. Steam from the reservoir directly drives turbines connected to generators, which convert the thermal energy into electricity. Flash stream plants are used for reservoirs under high pressure that contain hot water, but not necessarily steam. The wells are drilled to bring hot water up to the surface, and then to go through a flash tank. This flash tank allows the high pressurized water to 'flash' into steam by releasing it into a lower pressure. This steam then drives turbines connected to generators, converting the thermal energy into electricity. A binary-cycle plant is used for low temperature reservoirs. This water from the reservoir is used to heat a secondary fluid with a lower boiling point, causing it to vaporize. This steam then drives turbines connected to generators, where the thermal energy is converted into electricity. Alternatively to the three types of power plants, hot water from geothermal sources can be used directly for heating things, such as buildings, greenhouses, hot springs, etc. and through geothermal heat pumps. This method is used for small scale applications, can be utilized anywhere, and is not limited to a certain temperature of reservoir, however, they are primarily used for low temperature reservoirs, as high temperature reservoirs are typically extracted via power plants. Direct-use heating also is most efficient and practical when the resource is in a close proximity to population centers or industrial facilities (Gupta, 2006). With a close proximity, large infrastructures for transportation of the energy is not needed, which saves money, the environment, and energy losses. Geothermal heat pumps (GHPs) are an example of a direct-use application for heating. They are a small-scale application of geothermal energy, and are used in residential, commercial, and industrial buildings. GHP systems utilize Earth-based heat exchange methods, including the Earth itself, groundwater, surface water, or other sources like sewer heat, as either a heat source or heat sink (Chiasson, 2016). Water wells and well pumps act to supply groundwater to either a direct application, or to a heat pump. Following this process, the 'used' groundwater is usually reinjected back into the ground or a sewer. GHPs are easy and efficient to use as the temperature beneath the Earth's surface is relatively constant year round, regardless of external climate. This allows for them to be utilized in either a heating or cooling mode. Compared to other conventional heating and cooling systems, GHPs emit less greenhouse gasses and do not rely on fossil fuels.

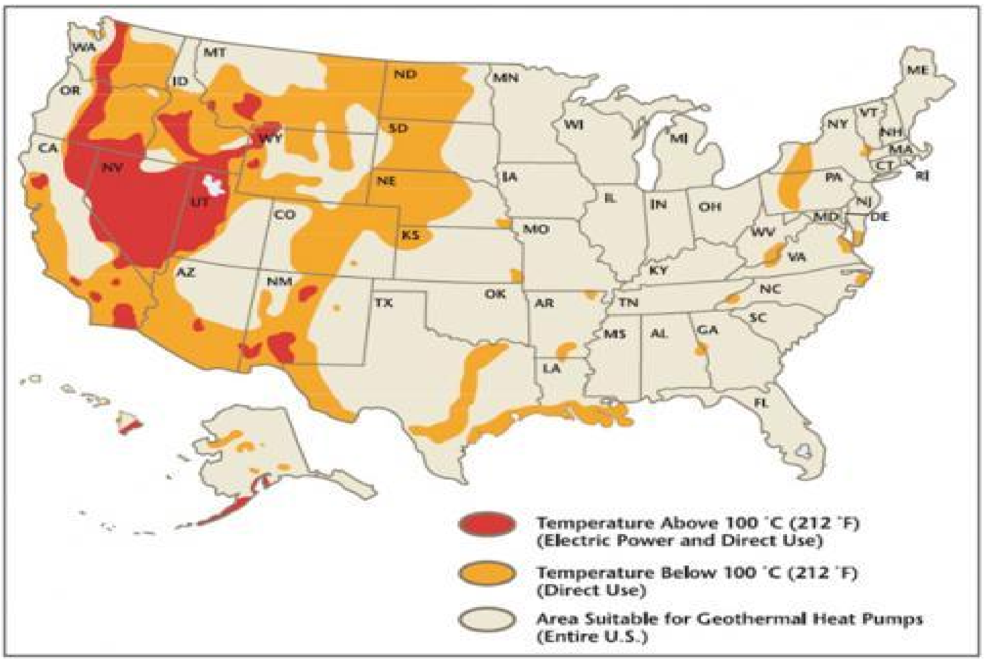
Advantages of Geothermal Energy

There are many advantages to using geothermal energy as a source of power. It is predictable, reliable, and doesn't face intermittency issues like other renewable energy sources do, such as wind and solar. As the residual heat from the formation of the planet and radioactive decay of particles are relatively constant, there is a consistent power output no matter the time, day, or season. This allows for baseload energy demand to be met, as enough energy is consistently generated and produced. Since geothermal energy comes from within the Earth, no collection setups over large areas of land surfaces are needed to be built in order to harness it.

This contributes to geothermal energy having a small land footprint (Energy Sage). Facilities for geothermal power plants that are needed to be built need approximately 88% less space compared to a solar farm to generate just one GW-h of energy (Marsh, 2021). With the demand for becoming a decarbonized economy and society and minimizing fossil fuel consumption, the geothermal industry and technologies are rapidly expanding. Currently only 0.4% of our energy consumption in the United States comes from a geothermal energy source (Center for Sustainable Systems, 2023). With an increase in the utilization of geothermal energy, its accessibility, efficiency, and applicability are also growing. Enhanced Geothermal Systems (EGS), is a recent advancement in the extracting process. It is still a young and developing technology, but has proven effective by creating permeability in rocks within reservoirs that previously weren't. Access to this 'man-made' reservoir is accomplished by the injection of fluids into pre-existing fractures, forcing them to reopen. This allows access to even more energy, which if all were to be extracted is estimated to have the potential to power 65 million American homes and businesses (US Department of Energy). Further research and development of how to access deeper, and currently unattainable resources will continue to expand with the growing field and interest in geothermal energy as a primary source of energy and electricity. Compared to other green energy solutions, geothermal heating and cooling systems have a long lifespan in their infrastructure. According to the US Department of Energy, there is an estimated 20 year lifespan for heat pumps, and up to 50 years for the underground infrastructure.

Disadvantages of Geothermal Energy

The biggest issue that geothermal energy runs into is its dependency on location. As previously mentioned, geothermal power plants can't be built everywhere. Reservoirs above 100 C are typically necessary for most large plants, which happen to only be found in specific locations, like near tectonic plate boundaries or hot spots. Additionally to this, when attempting to transport geothermal energy via pipeline, heat will be lost regardless by the time it reaches another destination (Barbier, 2002). This calls for more research and development, however, the technology needed to make this transfer more efficient could be both costlier, and less environmentally friendly.



This map displays the United States and where reservoirs have temperatures above 100 C, below 100 C, and where temperatures are negligible as they are low. As previously mentioned, power plants are built only when the temperature of a reservoir is above 100 C, below 100 C can geothermal energy only be extracted for direct-use. As depicted in the map, anywhere is suitable for geothermal energy pumps, as the ground is typically a constant temperature everywhere, at any time (*This map is attributed to Dictionary of Geological Terms, 3rd edtn., eds. R.L. Bates & J.A. Jackson, 2015).*

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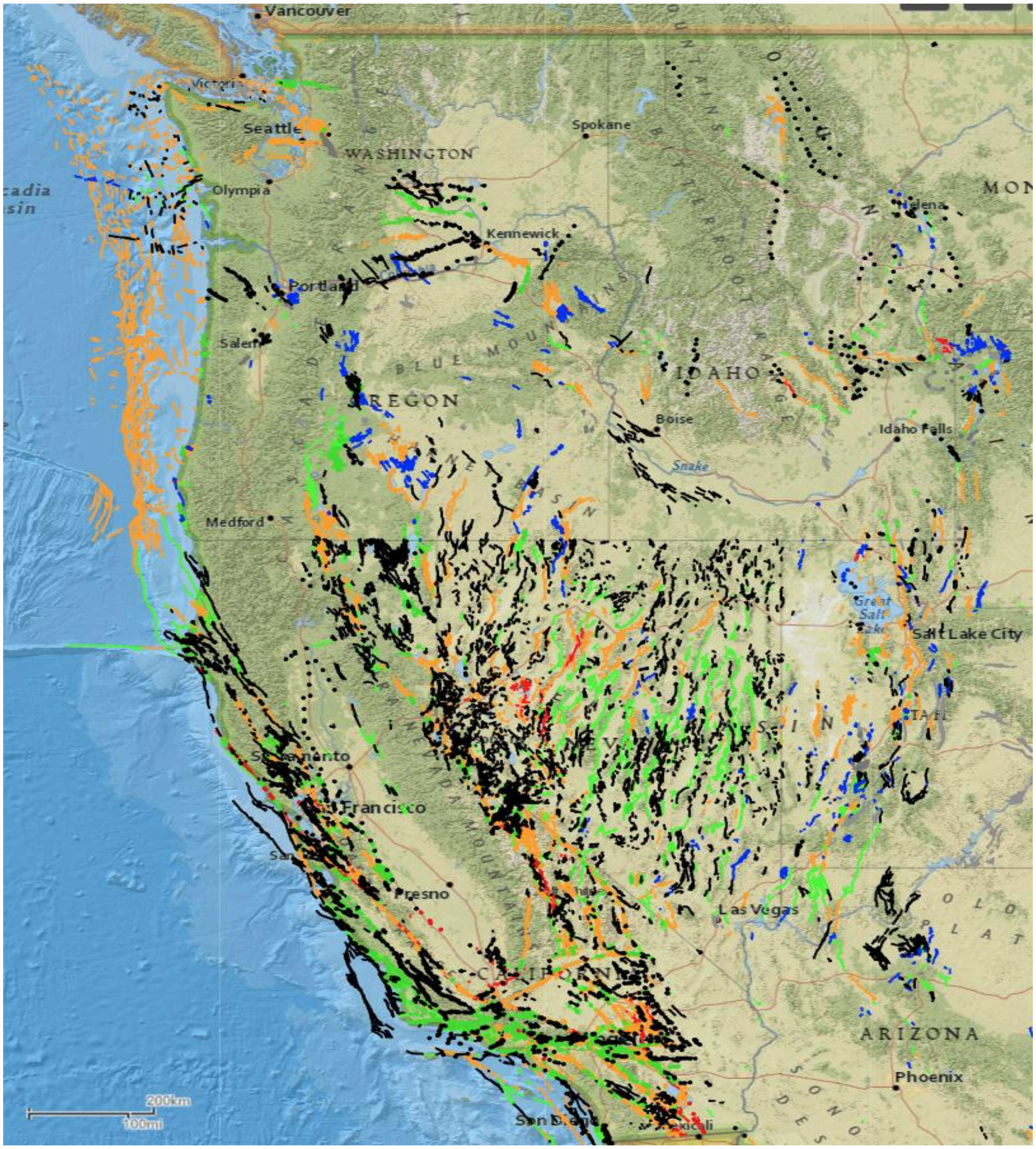


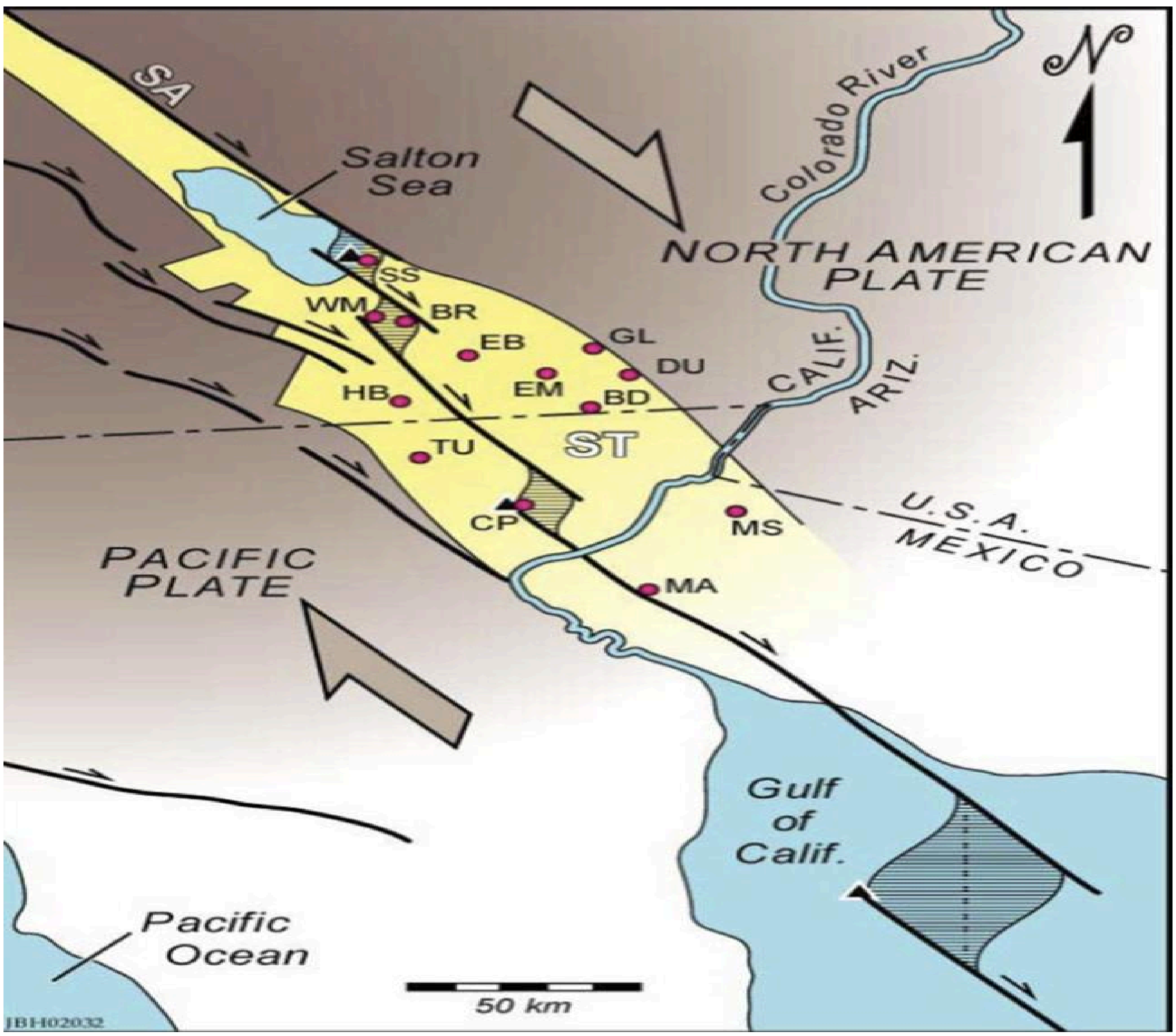
This map allows for a comparison to the previous map as it shows where the quaternary faults are on the West of the United States. The colors indicate different ages of earthquakes that have occurred in those areas, showing a relevance between plate activity, earthquakes, and geothermal activity. Compared to the previous map, areas where earthquakes are prominent, are also areas prominent in high temperature reservoirs (*This map is accredited to USGS, and is of Public Domain).*

Compared to other renewable energy sources, like wind and solar, geothermal energy facilities come in with having the highest upfront construction costs. High prices are due to the difficulty and expense of drilling deep into the Earth, however, there are no fuel purchasing costs once the plant is up and running. It costs about $4000-$6000 per kWh to build, where in comparison solar maxes out at $1250/kWh, and wind at $1550/kWh (Marsh, 2021). Although the use of geothermal energy can drive away the demand for fossil fuel based industries and ultimately be a cleaner choice for the environment, there are still some environmental issues that arise with geothermal power plants. Drilling deep within the Earth can cause instability underground, contributing to surface instability, and further, an increase in seismic activity. Considering that geothermal energy can only be extracted in certain areas, this could overtime have an impact on surface instability and seismic activity even moreso, leading to issues of environmental burdens to predominantly one area/community.

Imperial Valley Geothermal Project

The Imperial Valley Geothermal Project is a series of 11 geothermal power plants located in the Imperial Valley on the Salton Sea Geothermal Field (SSGF) in Southern California, United States. The plants that compile the project in the Imperial Valley make up the 2nd largest geothermal field in the US, following the Geysers Geothermal Project located North of San Francisco. The SSGF is one of the largest resources of geothermal energy in the world. There has been accessibility to access a lot of this resource, however, with the Saline Sea drying up, even more is becoming attainable to extract. What makes this area so incredibly rich in geothermal energy is its unique locational setting, and how the tectonic plates it lies on move. The SSGR falls within the Salton Trough, which is a pull apart basin formed by the movement of Earth's plates. The Salton Trough is located at the southern end of the San Andreas faultline, where

Pacific and North American plates meet. Movements of these plates resulted in the formation of the SSGF. Hot substances easily are able to surface here due to the thinning of Earth's crust that occurs in this region, leading to high geothermal activity. An additional contributor to the geothermal activity in the region is the saline lake within the Salton Trough. Geothermal reservoirs are associated with the sedimentary basin beneath the Salton Sea (Kaspereit, 2016). All 11 of the plants located in this area use dry stream technology power plants, which go to show how this field is in an optimal thermal energy location, as dry stream power plants are used for high temperature reservoirs that reach the surface, which is preferable.



The map above illustrates how the Pacific and North American Plates move. The red dots display geothermal active fields. A close proximity to the Salton Sea is depicted as a contributor to the activity in the area (*This map is attributed to Elders et al. (1982), Lachenbruch et al. (1985), and Elders and Sass (1988), from Hulen et al. (2002)).*

Conclusion

Currently there is a global race to find sustainable, green solutions to our energy demands to reduce the dependence on fossil fuels, and its implications causing climate change. Geothermal energy is an inexhaustible resource that is capable of meeting a portion of these demands, and with further development and technological advancement, could completely fulfill demands. Enhanced Geothermal Systems (EGS) is one of these technological advancements that is starting to take off, and would provide energy for electricity to an estimated 65 million households and businesses. The Imperial Valley Geothermal Project is a geothermal rich area, due to its location relative to its proximity to the saline lake, the Salton Sea, and it being on the Salton Sea Geothermal Field, which lies along important plates, contributing to the overall abundance in activity. Since geothermal energy is extremely location dependent, it isn't ideal on a global scale as of right now for geothermal energy to be transferred to places lacking huge access to it. This could increase emissions and costs, making geothermal energy less of a sustainable solution. However, if this issue were to be solved, the advantages to using geothermal energy are quite substantial, and would prove to be effective in helping our society become decarbonized.

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