To: Dr. Seagrave
From: The Significant Figures
Subject: Technology Report
10 Pages

The purpose of this memo is to inform you about a binary cycle geothermal power plant. It will go over the history, science, manufacturing process, industry, and future of this technology.

Industry

The geothermal industry has invested in the technology of a binary cycle plant. This industry seems to be under appreciated and it is an absurdly unkown source of clean, renewable energy. The geothermal industry has invested greatly in this technology because it allows for cooler geothermal reservoirs to be used in comparison with other widely used geothermal plants. These other technologies, the dry steam and the flash steam plants, require that the reservoir in which the water is retrieved to be hot already. The geothermal industry is a buried industry. This can be mainly blamed on the up front cost of starting one of these operations.

Mammoth Pacific is a company located in the Sierra Nevada mountain range in California. It has three power plants that generate 29 Megawatts of electricity. This much electricity is capable of powering about 22,000 homes. This company produces and utilizes the binary cycle power plants in their world renowned geothermal complex. This award winning complex simply helps generate clean energy. The production of the binary cycle plant, and the maintaining of these facilities is their main involvement in the technology. Mammoth Pacific built and now manages this facility. Using the energy they get from their binary cycle plants they're able to harbor electricity. They then sell the electricity they generate to Southern California, Edison, and to Pacific Gas & Electric under long-term contracts.

These companies articulate the technology's sustainability by using it to generate clean energy. In our day and age, we need a cleaner source of energy to combat the mass products of carbon dioxide from coal and gasoline burning. From Mammoth Pacific's code of ethics, "We're committed to supporting our quality of life here in the Eastern Sierra. We recognize the importance of protecting our unique natural resources..."[1] This shows that their view of sustainability is important because their power plant is where they live. This demonstrates how they believe in their technology, and how it helps their environmental sustainability.

The Science

The geothermal Binary Cycle Generator is an extremely clean and efficient system of producing energy by utilizing the heat generated by the core of the earth. The process is an entirely closed system and can produce consistent and great quantities of energy and could compete with fossil fuel methods of energy production in area where geothermal wells are readily available. [2][3][4]

geothermal Binary Plants can be created anywhere where we can drill down into wells of superheated water. These wells can be hundreds or thousands of feet into the earth. Once a well is located it is drilled in and pipes are laid down into the wells. Once the pipes and the generators are in place then the hot water is pumped out of the well and into pipes to the surface and into the generators. Inside the generators the pipes containing the superheated water passes through a tank containing a secondary fluid. The choice of fluid is based on the temperature of the water because the secondary fluid needs to have a much lower boiling point than the temperature of the water as it passes through the secondary fuel tank. [2][3][4]

This difference in the temperature of the water and the boiling point of the working fluid results in the heat transfer between the two causing the working fluid to vaporize and, because heat rises, the steam flows through a pipe from the tank into a turbine. As the steam rises it turns the turbine, generating energy. Once the steam passes through the turbine it is pumped through a cooling tank where the steam becomes liquid again and flows back into the main tank. This allows the process to continue indefinitely without producing any carbon emissions. [2][3][4]

History

The known history of geothermal Energy, discovery, and production begins with ancient Indigenous people from around the globe. These people used the natural heat from hot springs for bathing, heating, and cooking. The usage of geothermal energy in ancient times can be found in the American, Asian, and Roman territories. [5][6][7]

The first industrial development of geothermal energy was performed by Italians in 1904. Their goal was to harness the subterranean heat into a form of electricity that could power homes and cities. Prince Piero Ginori Conti was the first individual who was able to successfully generate sufficient electrical energy to power 4 lightbulbs. While this original prototype wasn't very powerful, it did inspire serious investigation into advancing geothermal energy. [5][6][7]

These early developments were exciting to the scientific community, however, it wasn't until 1960 that a large scale geothermal plant was finally erected by Pacific Gas & Electric in San Francisco, CA. This plant was capable of generating 11 megawatts of energy. [5][6][7]

The oil crisis of 1973 helped to propel the idea of alternative energy. As a result of this, the 1980s saw many advances in geothermal power. Geothermal pumps became popular due to their low cooling and heating costs. [5][6][7]

The United States is still currently the leader in geothermal Energy. Indonesia has the second highest usage. Many other nations are also seeking ways to utilize alternative, cleaner energy sources like geothermal power. Today, only about 1% of power generated is from geothermal sources. However, experts expect that number to raise to 10-20% by 2050. [5][6][7]

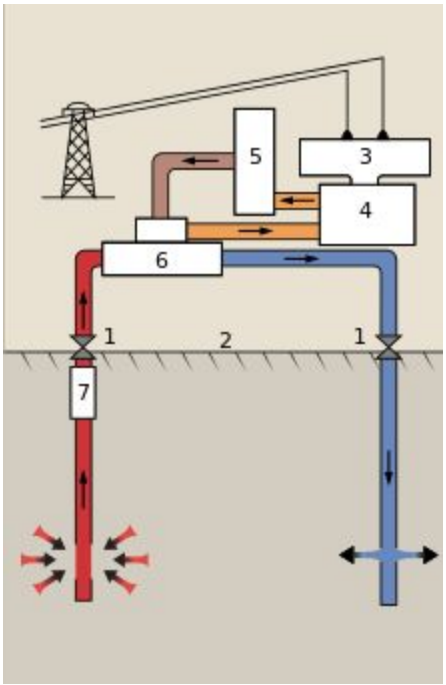
How the technology works

A binary cycle geothermal power plant works like this (as depicted in figure 1): A pump is drilled miles below the earth's surface into some type of natural hot spring or geothermal well where hot water can be accessed. The hot water is pumped to the surface and goes through a heat exchanger. A heat exchanger is a device that transfers heat between a solid object and a fluid, or between two or more fluids. These two fluids are separated by a wall to prevent mixing 3[8]. In this case, the plant uses the natural hot water to "flash vaporize" a secondary or "binary" fluid (hence the term *binary* cycle [11]) with a boiling temperature lower than water; typically the fluid is a butane or pentane hydrocarbon. It's the use of this secondary fluid that sets the binary cycle apart from the other types of geothermal plants like dry steam and flash steam. Because it doesn't need such a high boiling temperature, the binary cycle plants can be opened up on more locations that have a cooler geothermal reservoir than is necessary for the rest [9].

Once the secondary fluid turns into vapor, the steam goes through blades in a turbine that generates rotary motion that in turn drives an electrical generator and creates electricity [10]. The steam that exits the turbine is directed to a condenser where it is condensed back into the secondary fluid by cold air radiators and cycled back to the heat exchanger. Meanwhile, the natural water is cooled and sent back down to the natural spring in a second pump [9].

The binary cycle does not produce any gas emissions into the atmosphere as well as avoids all the issues around releasing emissions of all sorts of chemicals that mess up the

balance of nature because it is a closed system. Meaning, the only thing being released from the plant is the return of uncontaminated, natural water back to its underground reservoir [11].



Key: 1 Wellheads **2** Ground surface **3** Generator **4** Turbine **5** Condenser **6** Heat exchanger **7** Pump

Hot water

Cold water

Isobutane vapor

Isobutane liquid

Figure 1 [9]

Manufacturing

The manufacturing process of a binary cycle geothermal energy plant varies depending on many factors. These factors largely depend on both the amount of thermal resources available in the aquifer. Another major contributor to the design of a plant is the environment and location of the plant, and the social and economic capital invested into it.[12]However, the construction often follows this general process (see figure 1):

1. Predict where an aquifer with most ideal conditions is located
2. Drill an exploratory well into the location determined
    a. If there is no aquifer present or it is inadequate, repeat steps 1 and 2.

3. Drill the full wells
    a. Extraction well
    b. Injection well
4. Casing and Cementing
5. Depending on the thermal energy available in the well, determine a working fluid
6. Install a piping system for both the heated water and the working fluid.
7. Install the machinery (Heat exchanger, condenser, turbine, etc.)
8. Connect to a power grid

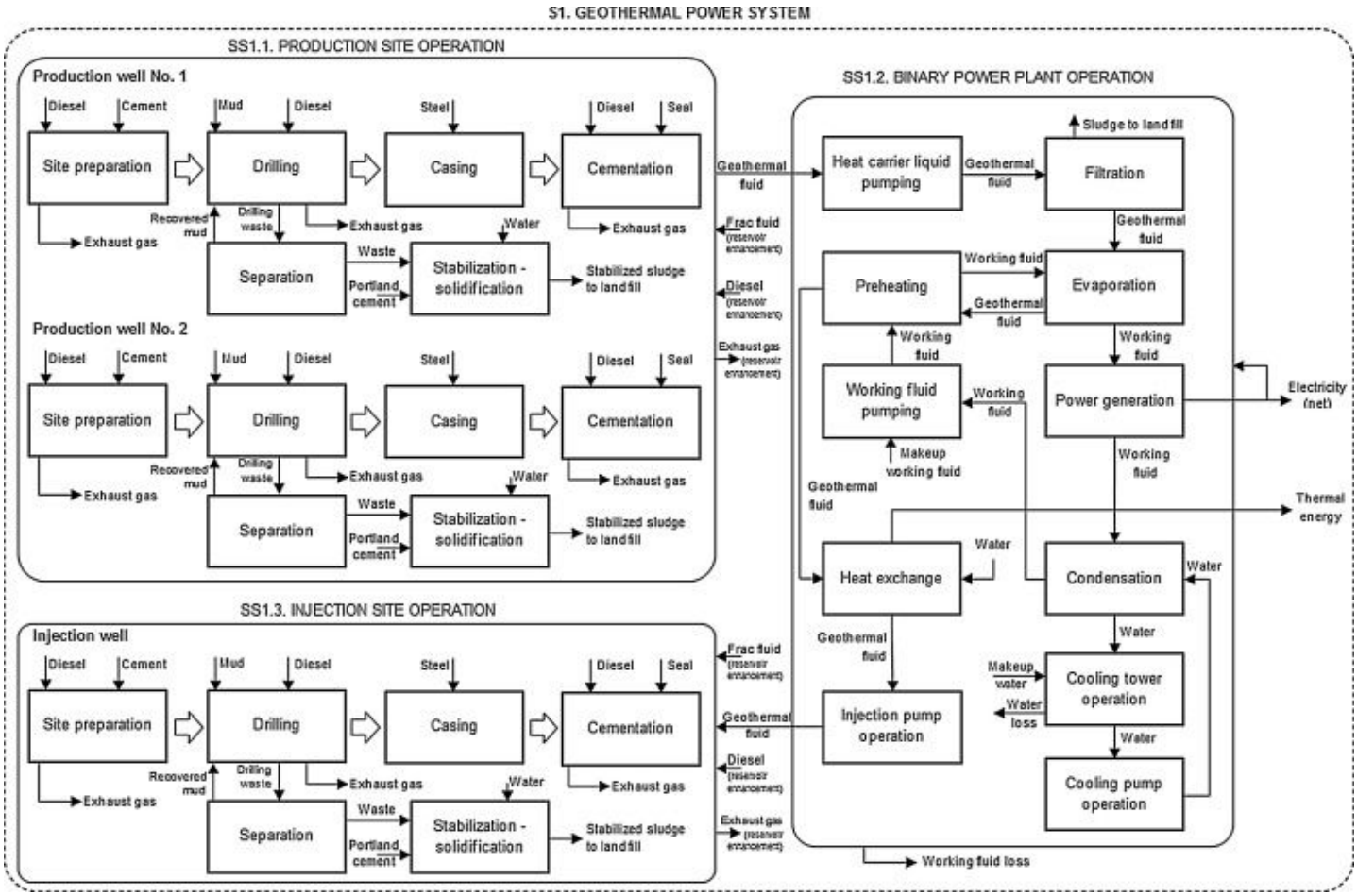


Figure 1 [2]

While the binary cycle system itself is closed and has no environmental impact, the process of constructing a plant has some environmental issues. The major issues occur in the drilling and casing phase of construction. Drilling produces waste material in two forms: mud and drill waste. The mud can be safely disposed of, but the waste material, which consists of drill fragments and drilling fluid, must be put in a reserve pit and treated. This process must be done for both the injection and extraction wells (note: the exploratory well is redrilled as one of the final wells if the aquifer is sufficient). Casing and cementing involves injecting a material around the borehead to support the well and having it cement there. Depending on the material used and the process employed, it can be damaging. One final problem to be mentioned is that once a facility is decommissioned, the remaining structures must be taken care of which is considered environmentally harmful. [13]

A big issue related to the construction of a binary plant is the monetary cost. As with other forms of geothermal plants, a high amount of capital is required for land rights, drilling, and construction. What sets binary cycle power plants apart is the costs associated with the additional equipment required by the binary cycle. Another expense is high operating costs. According to NASA [14], the average operating costs of a plant is 22% of its capital cost. However, as with the the manufacturing process, this varies greatly depending on environmental factors.

Development of geothermal Energy

The concept of geothermal energy is most certainly not new. It is common knowledge that thousands of years ago, resources such as hot springs were being used in a commercial setting. Their particular use was not for generating power, but rather for cleansing or therapeutic reasons. Many old age "spas" would charge for customers to soak in these naturally-heated wells, thus turning the discovery into quite a business. From there, communities started to form around the hot springs for the purpose of easier accessibility. It became clear early on that these heated pools had advantageous commercial value and could be utilized in versatile ways. Even as societies grew, there was a system eventually invented for the purpose of pipelining this water to buildings' and homes' main water systems during the early 1900s. [15]

Not only did systems like these provide the water itself to individual homes, it also generated a form of heating for these households. True use of geothermal-produced energy and the establishment of geothermal plants began in 1960 in California. Though, like any new invention, the first plants were not near as efficient as those constructed today. [16] Geothermal generators have developed drastically since the first Italian experimental model which only had the ability to gain enough power to light four light bulbs in 1904. In fact, other countries such as Italy, New Zealand and Mexico all had their foot in the door with this technology before the United States. [17] The American desire for commercialism and marketing is likely what eventually brought about the investment in geothermal energy's numerous benefits.

Works Cited

[1] "Welcome To The Mammoth geothermal Complex Website," *Ormat Technologies*. [Online]. Available: http://www.mammothpacific.com/. [Accessed: 27-Oct-2017].

[2] Z. Yan, "Binary Power Plants," 03-Dec-2011. [Online]. Available: http://large.stanford.edu/courses/2011/ph240/yan2/. [Accessed: 27-Oct-2017].

[3] "geothermal Power Plants," *geothermal Power Plants - Energy Explained, Your Guide To Understanding Energy - Energy Information Administration*. [Online]. Available: https://www.eia.gov/energyexplained/index.cfm?page=geothermal_power_plants. [Accessed: 27-Oct-2017].

[4] Raser Technologies, *YouTube*, 27-May-2009. [Online]. Available: https://www.youtube.com/watch?v=_AwiQs_CSB0. [Accessed: 27-Oct-2017].

[5] J. Bratley. [2016, Aug] *A History of geothermal Energy - Clean Energy Ideas*. [online] Available at: https://www.clean-energy-ideas.com/geothermal/geothermal-energy/history-of-geothermal-energy [Accessed 27 Oct. 2017].

[6] Conserve Energy Future. (2017). *geothermal Energy History*. [online] Available at: https://www.conserve-energy-future.com/geothermalenergyhistory.php [Accessed 27 Oct. 2017].

[7] The Earth Project (2017). *Everything You Need to Know about geothermal Energy*. [online] The Earth Project. Available at: http://theearthproject.com/everything-geothermal-energy/ [Accessed 27 Oct. 2017].

[8] "Heat exchanger," *Wikipedia*, 20-Oct-2017. [Online]. Available: https://en.wikipedia.org/wiki/Heat_exchanger. [Accessed: 27-Oct-2017].

[9] "Binary cycle," *Wikipedia*, 07-Sep-2017. [Online]. Available: https://en.wikipedia.org/wiki/Binary_cycle. [Accessed: 27-Oct-2017].

[10] "Steam turbine," *Wikipedia*, 16-Oct-2017. [Online]. Available: https://en.wikipedia.org/wiki/Steam_turbine. [Accessed: 27-Oct-2017].

[11] Z. Yan, “Binary Power Plants,” *Binary Power Plants*, 03-Dec-2011. [Online]. Available: http://large.stanford.edu/courses/2011/ph240/yan2/. [Accessed: 27-Oct-2017].

[12] G.V.Tomarov, and A.A.Shipkov. (2016). *Modern geothermal power: Binary cycle geothermal power plants (vol. 64)* [online]. Avaliable FTP:https://link.springer.com/article/10.1134%2FS0040601517040097

[13] M. Martin-Gamboa, D. Iribarren, and J. Dufour. (2014). *On the environmental suitability of high- and low-enthalpy geothermal systems* [online]. Available FTP: http://www.sciencedirect.com/science/article/pii/S0375650514000364?via%3Dihub

[14] B.Holt and J. Brugman. (2017).*Investment and Operating Costs of Binary Cycle geothermal Power Plants* [online]. Available FTP: https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19750012783.pdfdkfhhdjfh,jh

[15] "A History of geothermal Energy in America." Office of Energy Efficiency and Renewable Energy. [Online] Available: https://energy.gov/eere/geothermal/history-geothermal-energy-america. [Accessed October 19, 2017].

[16] R. DiPippo. [July 31, 2014]. "geothermal power plants: Evolution and performance assessments." Geothermics. [Online] Available: http://www.sciencedirect.com/science/article/pii/S0375650514000820. [Accessed October 19, 2017].

[17] Q. Hubert, M. Joachim, H. Heiko and A. Ulvi. “History of International geothermal Power Plants and geothermal Projects in Germany.” Proceedings World geothermal Congress 2010. [Online] Available: https://www.geothermal-energy.org/pdf/IGAstandard/WGC/2010/0605.pdf. [Accessed October 19, 2017].