ENEE 355 Final Report

Geothermal Energy in Alberta

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Abstract

The following report explores and discusses the possibility of replacing Alberta's current coal energy source with a renewable alternative that is new to Canada - geothermal energy. Geothermal energy is heat energy that can be found within the earth's crust. Alberta currently has no geothermal plants despite its world class geothermal potential. Given that coal-fired plants account for just over 85% of total CO_2emissions in Alberta, and considering geothermal energy is one of the cleanest sources of energy, the transition to a cleaner, healthier, and more economical way of harnessing energy to produce electricity can be easily justified. While considering the social, economical, technical, and environmental impacts of this transition, along with the calculations to estimate the reduction of CO_2emissions and the cost of energy, once fully transitioned, it is demonstrated that such a proposal is feasible. For all these reasons, we recommend Alberta to invest in a closed-loop, binary geothermal plant, which will replace coal plants over the next 40 years.

Introduction

With the planet's global temperature increasing (currently by 0.9 degrees celsius according to NASA Global Climate Change), the need to reduce CO_2 emissions becomes an increasingly significant world issue. According to our previous study, the total calculated CO_2 emissions in Alberta came out to be $0.9995 kgCO_2/kWh$. The production of electricity from coal accounts for over 85% of the total CO_2 emissions in Alberta. By introducing geothermal energy as a clean alternative to coal, total overall CO_2 emissions will be reduced over time.

Currently there is zero geothermal plants in Canada so there is a huge amount of untapped potential in geothermal energy.

Purpose

The following report addresses issues regarding coal-based electric plants in Alberta, while also discussing why geothermal energy is a more suitable energy resource for Alberta. Geothermal energy is clean and sustainable heat energy that can be found within the Earth's crust. Transitioning to geothermal-based electric plants will reduce Alberta's dependence on coal plants. The results from implementing this change will primarily be environmentally beneficial in Alberta, but also has great potential to be economically and socially beneficial as well.

Background

Geothermal energy is widely utilized around the world. Certain parts of the earth are geologically younger than others which results in a higher outflow of geothermal energy; the Pacific Rim's Ring of Fire is a great example of this. Canada is fortunate to be the location of many active hotspots that have potential for harnessing energy geothermally. When referring to the geothermal map as shown in figure 3 of the Appendices section, the majority of these locations can be found in Western Canada. This is mostly due to the fact that Canada's western coast coincides with the Ring of Fire.

This report aims to accomplish the following:

- *Calculate the amount of reduction of CO_2 emissions once fully transitioned into geothermal energy*. To accomplish this, we calculated the amount of CO_2 emissions from coal-based electric plants. Assuming we are transitioning fully from coal to geothermal for electricity, we concluded that all of the emissions from these coal-based electric plants equal the reduction of CO_2 emissions in Alberta.
- *Calculate the cost of energy once fully transitioned into geothermal energy.* To accomplish this, we calculated values such as the annual capital cost and the fixed operations and maintenance cost and used these values.
- *Verify whether geothermal energy is more suitable in Alberta than coal energy.* Research and calculations justified the outcome and recommendation of this report.

Calculations and Results

Findings from prior research and reports were analyzed to identify potential issues in Alberta's current day energy production and consumption. To verify the potential solution that geothermal energy harnesses, this section shows calculations for the total CO_2 emissions per kWh in both cases when running (1) coal-based electric plants (2) geothermal plants as primary electricity supplier in Alberta; and, cost of energy for both coal electric plants and geothermal plants.

Calculation for CO_2 emissions per kWh

According to our first report, the total CO_2 emissions was $0.995\ kg\ CO_2/kWh$ in 2015 when running coal electric plants in Alberta . Now, we will calculate the total CO_2 emissions in the case when Alberta transitions from running coal-based electric plants to geothermal plants.

Assuming geothermal plants will replace all current coal-based electric plants in Alberta, we can first subtract the CO_2 emissions of coal plants from the total CO_2 emissions in Alberta . This yields

$$CO_2\, emissions/\, kWh\, (without\ coal\ plants)\ =\ total\ CO_2\, emissions/kWh\ -\ coal\ CO_2\, emissions/kWh$$

$$CO_2\, emissions/\, kWh\, (without\ coal\ plants) \ = \ 0.995 kg\, CO_2/kWh \ - \ 0.85\, kg\, CO_2/kWh$$

$$CO_2\, emissions/\, kWh\, (without\ coal\ plants) \ = \ 0.145\, kg\, CO_2/kWh$$

Now, we will add the CO_2 emissions from the geothermal plants that will replace the coal electric plants.

According to Nowicki (2018), geothermal plants have little to none CO_2 emissions. For the sake of simplicity, we will assume that geothermal plants are zero emission plants. Therefore,

$$CO_2\, emissions\ after\ replacing\ coal\ plants/\, kWh\, (with\ geothermal\ plants) \ = \ 0.145\, kg\, CO_2/kWh$$

Calculation for cost of energy

According to our first report, the cost of energy for coal-based electric plants in 2015 was around $0.1/kWh in Alberta. Now, we will calculate the cost of energy for geothermal plants. We will model our geothermal plant from the United States, since according to Tonya L. Boyd on their report titled 'The United States of America Country Update 2015' (2015), the United States leads the world in geothermal development.

We will divide the calculation into four parts: (a) capital charge factor (CCF), (b) annual capital cost per unit energy, (c) operations and maintenance cost per unit energy, and (d) levelized cost of energy.

(a) Capital charge factor (CCF)

To calculate the CCF, we need to make assumptions. First, according to an article on geothermal sustainability on the Scientific American (2018), there is an indefinite amount of geothermal resources underneath the Earth. Because of this, we can assume that geothermal plants can stay operational for a long time and can last even longer if proper maintenance is in place. However, for the sake of this calculation, we will assume a geothermal plant life of 50 years. Secondly, we will assume an interest rate of 18%, which is around what Dr. Nowicki would use in class (2018). The formula for CCF is

$CCF(r, n) \ = \ r * (1 + r)^n \, / \, (1 + r)^n \ - \ 1$ where r - interest rate, n - plant life (in years).

Then,

$$CCF(0.18,\ 50) \ = \ 0.18 * (1 + 0.18)^{50} \, / \, (1 + 0.18)^{50} \ - \ 1$$

$$CCF = 0.18 / year.$$

(b) Annual capital cost per unit of energy (ACC)

Before we calculate this, we need three things: capital cost, power output and utilization factor. According to Valgardur Stefansson, the capital cost of a geothermal plant with an output of 40 MWe is US$57.6M, or $76.04M in Canadian dollars (2001). Secondly, according to the Office of Energy Efficiency and Renewable Energy, a geothermal plant can have a utilization factor of 90% or more, easily (2018). With these we can calculate the ACC.

$$ACC = \frac{\$76.04*10^6}{40*10^6 J/s * 0.9} * \frac{0.18}{year} * \frac{1\ year}{365.24\ days} * \frac{1\ day}{24\ hrs} * \frac{1\ hr}{60\ min} * \frac{1\ min}{60\ s} * \frac{3,600,000\ J}{1\ kWh}$$

$$ACC = \$0.043 / kWh.$$

(c) Operations and maintenance cost per unit of energy (O&M)

Note here that we will only consider fixed O&M since we will assume that geothermal plants will be the baseload producer of electricity in Alberta, as other electrical plants will compensate fluctuations in power demand ie. natural gas plants.

According to the US Department of Energy Federal Energy Management Program(2016), O&M costs range from US$0.01 - $0.03 per kWh, which is $0.013 - $0.04 Canadian dollars. We will use this range of values for the calculation of the levelized cost of energy.

(d) Levelized cost of energy (LCOE)

Finally we can calculate the LCOE for geothermal plants. To do this, we add the ACC and O&M costs. So,

$$LCOE = ACC + O\&M$$

$$LCOE\ (low\ range) = \$0.043 / kWh + \$0.013 / kWh$$

and

$$LCOE\ (high\ range) = \$0.043 / kWh + \$0.04 / kWh.$$

Therefore,

$$cost\ of\ of\ energy\ /\ kWh\ (geothermal\ plants)\ =\ \$0.056\ /\ kWh\ to\ \$0.083\ /kWh.$$

Discussion

Besides coal being a nonrenewable energy source; Reserves-to-Production ratio (R/P) of 250 years (Nowicki, 2018)—CO_2emissions associated with the production of electricity through coal-fired plants are dangerously high, ultimately having a negative impact on the environment. The decision to convert Alberta's dependence on coal-fired plants to geothermal plants for energy would decrease CO_2emissions significantly. Along with R/P increased to an indefinite amount with proper maintenance. Our proposal is to introduce geothermal energy in Alberta, eventually resulting in the complete phase out current coal-fired power plants. To understand how this shift in energy source will be better suited for Alberta, we will explore four different aspects that will be affected: environmental, economical, social, and technical sectors.

Environmental impacts

The environment would benefit from Alberta's transition from coal sourced energy to geothermal energy as it would decrease the CO_2 emissions from $0.995 CO_2/kWh$ to $0.145\ kg\ CO_2/kWh$as demonstrated in the Findings and Calculations section. Resulting in a beneficial change to the surrounding environment and ecosystems. Additionally, the previous section also states that the CO_2 emissions associated with geothermal power plants are negligible—the systems utilize naturally occuring thermal energy sourced from the earth to heat water vapour, then utilizes the resulting steam to create energy for localized power. However, there are still particulates released such as hydrogen sulfide, nitrous oxide, and sulfur dioxide emissions from the plant (Clean Energy BC, 2018). The surrounding environment is affected significantly less when using geothermal energy because the water from the geothermal plants cooling tower is reinjected into the system for an efficient negative feedback loop, eliminating the need to inject hot water into the surrounding ecosystems. This is what is called a closed loop geothermal plant, where fluids working the plant are recycled, and replaced only when necessary. Currently, Canada has zero working geothermal power plants (Grasby, S.E., 2012), but the United States (US) can act as a sufficient example for Canada. Thus far, there has been zero reported cases in which the surrounding area has been contaminated with waste water used in the geothermal process in the US (Union of Concerned Scientists, 2018) .The energy plants are built very close to the reservoir, although the plants are usually farther from the final target; where the energy is being actively consumed. This can unfortunately increase transportation processes which can negatively impact the environment. Although the geothermal power plants need to inject water into the system to maintain a constant volume, it does not necessarily have to be potable water. The use of waste water injections to recharge the power plant is a great opportunity to utilize waste water injections as shown in the geothermal reservoirs in Northern California (Calpine Corporation, 2018). This would not only get rid of potentially toxic water, but also would help preserve clean water that could be used towards other projects.

Economical Impacts

Due to the dependance Alberta has on our coal-fire plants, it is important to address the potential economic impacts the transition to geothermal would have. According to Alberta's 2018 fiscal budget (Ceci, 2018) the Alberta government has decided to invest approximately $680 million dollars on the energy transition away from coal-generated energy services, as well as $662 million dollars on energy efficiency. This would allow some of Alberta's budget to be contributed to the slow introduction of geothermal plant construction and maintenance. If our plan was to be implemented, we would aim to be granted a larger portion of the province's budget overtime. With government subsidies, geothermal energy has the potential to be a high revenue power production system. This is due to the fact that production cost fluctuations do not apply as heavily to the geothermal energy sector (Deep Earth Energy Production, 2018). There is much profit to be made as the LCOE of geothermal calculated above is $\$0.056\ /\ kWh\ to\ \$0.083\ /kWh$, comparatively lower to coal which is assumed to be$\$0.100\ /\ kWh$ (Atutubo, R. et al., 2018). However, building a large scale geothermal plant is more costly than a coal plant as estimates can be shown that the capital cost of a 100 MW geothermal plant, and its associated facilities in South Meager, BC, is estimated at $400 million dollars (Clean Energy BC, 2018). When looking at a smaller scale pilot plant in Southeast Saskatchewan, which has similar geothermal reservoir temperatures to Alberta, the project has a net output of 5MW and a total estimated cost of $50 million dollars (Deep Earth Energy Production, 2014). The Shepherd Natural Gas Energy Power Plant in Calgary is valued at $1.4 billion dollars to produce 800 MW of energy. Comparatively, to build a geothermal plant of similar scale it would have a price tag 3 times larger (Bakx, 2015). When comparing the economic benefits, Washington was estimated in 2006 to profit $740 million dollars during a 30-year economic output from a new power capacity in geothermal energy of 50 MW (Geothermal Energy Association, 2014). However, the cost of a geothermal energy power plant is significantly lower when comparing profitability to lifetime of more traditional sources of power; refer to figure 2 of the Appendices section. As we slowly transition away from coal-powered energy, the initial investment in geothermal power plants would be more costly. With the arising problem of abandoned oil wells, many of which are a result of bankrupt companies, it will cost taxpayers to clean up (Seskus, 2018). With the utilization of these wells it would not only benefit Albertans but also the companies interested in starting geothermal. They would be able to greatly reduce the initial capital cost of drilling as the estimated cost to drill is roughly $1.5-$2million per kilometer whereas utilizing an abandoned oil well can cut cost by over 85% (Banks, 2015). Although, the potential profitability from geothermal energy being a primary resource, while also having a indefinite lifetime compensates for its capital cost.

Social impacts

The process of phasing out coal plants, occurring simultaneously with the implementation of geothermal plants, creates susceptible change to Alberta's social sector. Geothermal plants require less employees due to reduced amount of upkeep. On average, 53 ("Coal and jobs in the US", 2018) full-time personnel are needed to operate a coal-fired power plant, while a geothermal power plant requires about 30-40 (Clean Energy BC, 2018). This will result in the termination of many current employees. Luckily, the Alberta Government has acknowledged this issue and is providing services which include financial support programs to help re-employ, relocate, and even offer tuition for education for the individuals that have been laid off from the coal plants (Government of

Alberta, 2018). Unfortunately, the harsh reality is that Alberta is infamous for a large carbon footprint. A positive impact could be an increase in the quality of life and health resulting from the decrease in CO_2 emissions by just over 85% from our calculations. Particulate pollution from coal combustion is five times as dangerous as the average pollutant to human cardiovascular health, risk of cancer, respiratory illness, and stroke. (Climate Nexus, n.d.). This is because a fraction of the particulate matter has a diameter of less than 2.5 micrometers ($PM_{2.5}$), therefore it can easily enter into the human body (Goodarzi, 2006). Another positive impact resulting from this change would be increased motivation for younger generations to make greener shifts in Alberta's energy division. Citizens can also benefit from adopting a positive outlook for the future of the provinces reputation and standing in the renewable energy sector.

Technological Impacts

Alberta has the reservoirs capable of generating electricity from geothermal plants, while utilizing abandoned oil wells to aid in a smooth transition. (Tam, 2018). Unfortunately, Alberta has not yet taken advantage of this opportunity. According to Banks (2015), there are geothermal reservoir temperatures in Alberta that are above 150°C. This suggests that Alberta has enough geothermal energy potential to power a sufficient number of plants, because plants with reservoirs above 150°C are able to generate electricity profitably (Cartographic and Geological Institute of Catalonia, n.d.). The potential of geothermal energy is encouraging companies and governments to expend their efforts into doing research towards improving the geothermal energy sector. The US Department of Energy and Google are examples of credible entities that are currently investing in geothermal energy (Merchant, 2012).

Alberta is committed to improving renewable energy research. In 2016, the federal government invested $75 million into the U of A's Future Energy Systems initiative (Tam, 2018). This initiative is dedicated to investing time into researching how to provide global renewable energy solutions to meet the current energy demand. Their goal is to also find local solutions, and geothermal is one of the most likely for Alberta given our geothermal potential and abundance of abandoned oil wells (Tam, 2018).

An example of a technological breakthrough in geothermal energy is the binary geothermal plant. These plants have been proven by scientists to give off zero CO_2emissions while emitting only water vapour. (Yan, 2011).

Another discovery indicates that in the future, advances in HDR (hot dry rock) technology could mean that geothermal plants could be located anywhere, and no longer restricted to places where there are geothermal reservoirs (Yan, 2011). This would take geothermal energy from just impacting the areas who have access to a geothermal reservoir to impacting the global scale.

Recommendation

As discussed previously in this report, geothermal energy is a greener, more economical, and a reliably sustainable form of energy in comparison to Alberta's current coal energy source. For this reason, we recommend and encourage the province's shift to geothermal power, as opposed to coal electric plants as primary producers of electricity.

A closed-loop, binary geothermal plant is the most practical model that Alberta is suggested to invest in. The balancing feedback nature of these particular plants guarantee that the steam operating the turbines (which consequently work to power the generators) are returned underground for future applications; as shown in figure 3 of the Appendices section. Additionally, it prohibits the release of steam into the surroundings which avoids the negative environmental impacts associated, as discussed previously in this report. By doing so, Alberta can reduce total CO_2emissions from the electricity sectors initial value of $0.995\ to\ 0.145\ kg\ CO_2/kWh$. We recommend that these geothermal power plants be installed not only near Alberta's active hot springs, but also our province's abandoned oil fields. By doing so, the province can reduce capital costs by $1.5 to $2 million dollars per kilometer of drilling for every abandoned oil wells in Alberta. Due to the province's conventional nature, a transition towards a renewable energy source could be easily dismissed as implausible. For this reason, we recommend a slow transition—a 20% initial reduction of coal power plants. Furthermore, we suggest the construction and operation of small scale geothermal power plants initially, eventually following with bigger scale geothermal plants later as budget and resources become more accessible. Fortunately for our province, it is a reasonable goal to be fully transitioned by 2060; forty years from today.

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Appendices

Appendix A: Time sheet

Name	Amount of time spent (in hours)			
	Planning and Scoping	Data Collection and Research	Modeling and Calculations	Report Writing and Editing
Brandon	5	4	2	8
Shaylynne	8	5	1	20
Ronald	4	9	0	7
Mark	8	6	4	17
Nathan	8	8	0	11
Cormac	7	7	3	7
Daniela	8	3	3	8

Appendix B: List of figures

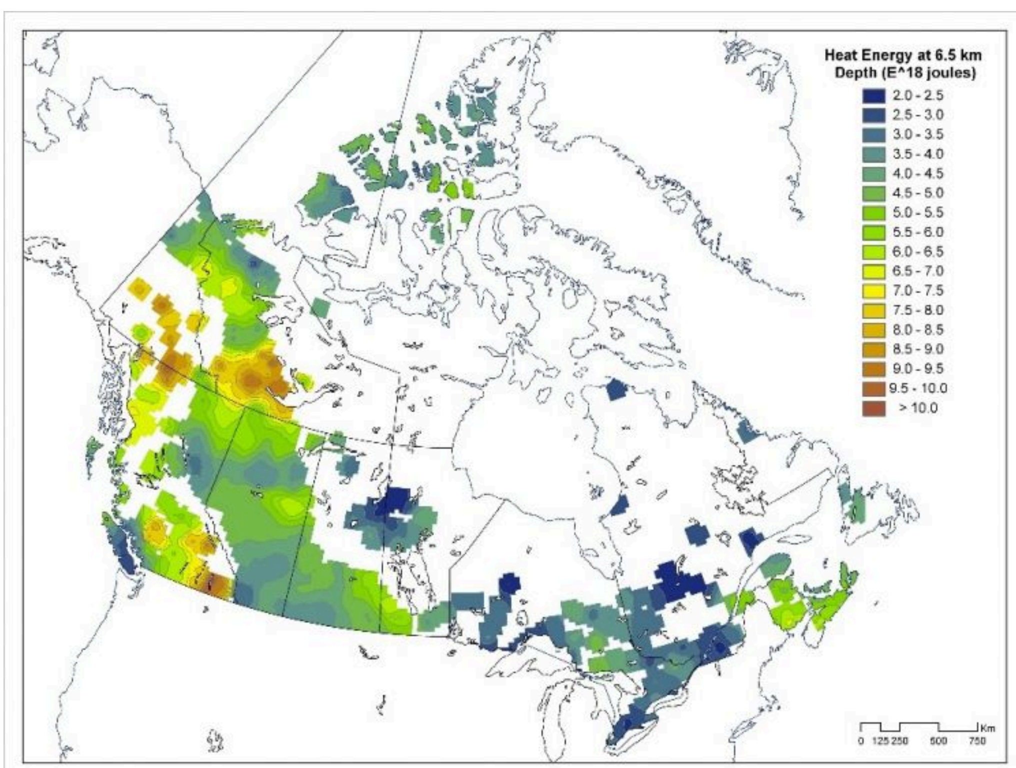

Figure 1. Geothermal map of Canada. Retrieved from http://energytransitions.ca/wp-content/uploads/2015 /04/Energy-Production-and-Potential-in-the-Peace-River-Region.pdf

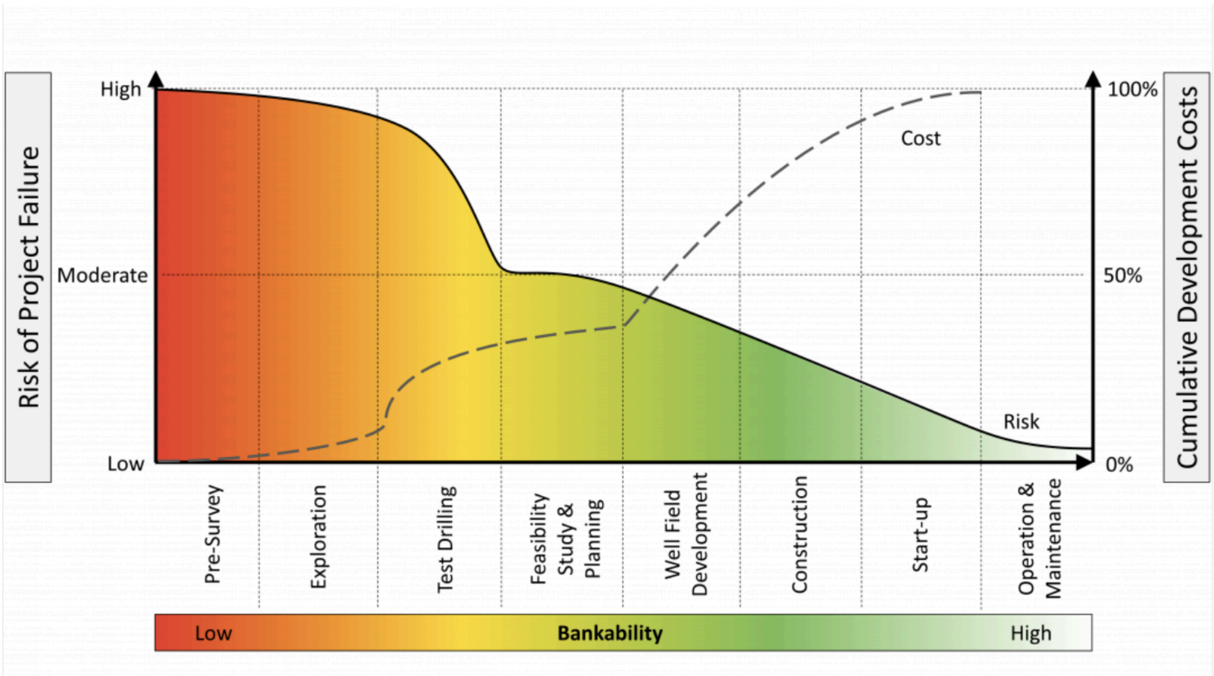

Figure 2. Cumulative development costs. Retrieved fromhttps://onlineacademiccommunity.uvic.ca/2060project/ 2017/06/29/why-arent-we-using-geothermal-energy-for-electricity-in-canada/

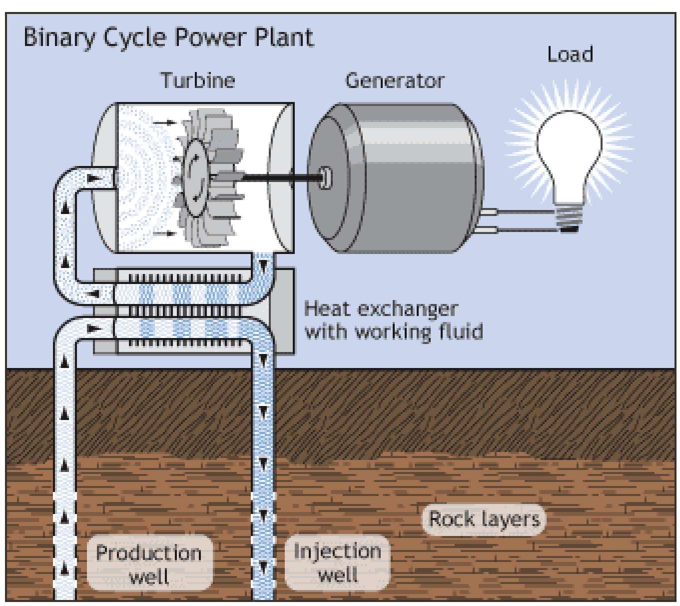

Figure 3. Binary cycle geothermal power plant. Retrieved from www.energy.gov./eere/geothermal/electricity-generation.

Making the switch from coal-fired power plants to geothermal power plants for Alberta's primary source of energy will have resulting impacts in Alberta’s social sector. Geothermal power plants require on average about 10-20 less full-time employees to operate smoothly. Although this is economically beneficial, it will result in the termination of many current employees in the energy sector. Thankfully, the Alberta government has implemented a program specifically to offer support for the workers affected by the coal plant phase out. This program works to relocate, re-employ, and even offer tuition for people who may want to pursue a new education or further their current one. The current energy sector in Alberta can be considered unstable when providing reliable jobs. Having a more consistent form of primary energy, like geothermal, can help the workers to have a reliable source of income.

Also, reduced carbon dioxide emissions means less pollution which will result in an increased quality of life for those living in Alberta. Fossil fuel pollution contributes to health issues that compromise an individual's cardiovascular and/or respiratory health, and also their risk of developing cancer.

Making the change to a greener and more environmentally favorable energy source can empower future generations to continue to make decisions that are innovative and leave a positive impact. Citizens can also benefit from adopting a more positive outlook for the future of Alberta’s reputation and standing in the renewable energy division.