

# GeoNow

## A novel approach to geothermal energy in Alberta

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Authors: Kendra Leavitt  
Ryan Saunders  
Jason Boddez  
Shawn Grant  
Karen Robinson

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## Introduction

Geothermal energy is heat that is derived from the Earth. It is the thermal energy contained in the rock and fluid that fills fractures and pores within the Earth's crust. This energy is generated in the Earth's core, 6500 kilometers below the surface. Temperatures hotter than the surface of the sun are continuously produced by the slow decay of radioactive particles. It is considered a renewable energy because the heat emanating from the interior of the Earth is essentially limitless and is constantly being regenerated.

Worldwide, Canada is dwarfed by many other countries when it comes to the direct use of geothermal power. In 2000, Canada was ranked 25<sup>th</sup> in the world using only 284 GWh/yr of geothermal energy (most of which was direct heating and virtually no electrical applications) as compared to China, which is at close to 9000 GWh/yr [1].

Historically, the economics of geothermal energy projects failed due to the high costs associated with drilling and completing wells. GeoNow focuses on the potential energy locked within the large number of abandoned oil and gas wells in Alberta. Geothermal waters found in the Western Canadian Sedimentary Basin (WCSB) represent an abundant and cheap energy source that is sequestered in underground aquifers. It is found that over 90,000 of the abandoned wells in Alberta lie within part of the WCSB called the Viking Aquifer. The Viking formation is one of many prolific oil and gas reservoirs in Alberta that is buried from east to west and varies between 1,000 to 3,000 meters deep. The Viking's geothermal aquifers range in temperature from 33 to 99°C. The potential energy locked in Alberta's geothermal waters is the equivalent of two to five trillion barrels of oil equivalent [2].

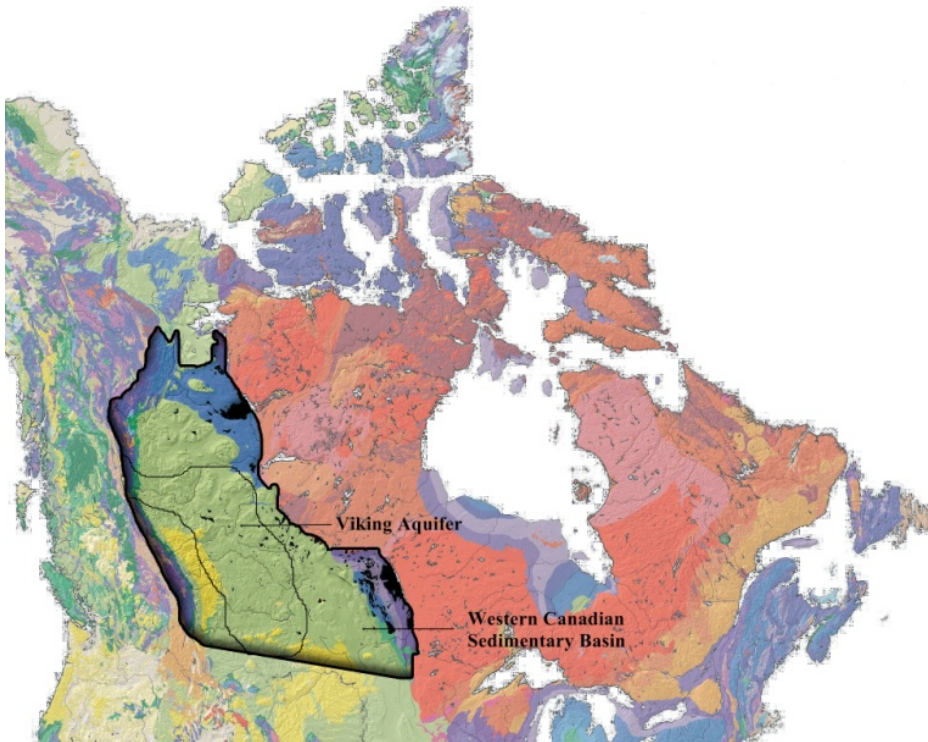


Figure 1: Western Canadian Sedimentary Basin and Viking Aquifer

The primary considerations that GeoNow focuses on for this proposal include the following:

- Locate and explore the prospect of uncapping recently abandoned oil and gas wells to substantially reduce the capital cost
- Re- injection of one hundred percent of the geothermal fluid for conservation and balance of the geothermal fluid
- Matching the power plant and working fluid to the heat flow and temperature of the available resource
- Eliminate atmospheric discharge and utilize air cooling, as opposed to water cooling, to minimize environmental impact
- To maximize the cost effectiveness in terms of the real production cost of a kilowatt-hour of energy and not limited to short term equipment capital cost

- To effectively use low enthalpy geothermal energy to produce enough clean power to sell to the AESO (Alberta Electric System Operator)
- Explore the social uptake and political acceptance of low temperature geothermal power stations

## **Abandoned Well Selection & Power Plant Siting**

Siting of a geothermal power plant requires consideration of many variables, and using the concept of abandoned wells requires the incorporation of even more considerations. Traditionally, geothermal power plant siting requires consideration of underground thermal gradients, an understanding of the underground geology (rock permeability, porosity, and reservoir recharge rates), and proximity to electrical transmission lines and electrical demand. Examining abandoned wells as sources for production and re-injection of geothermal fluid requires extra siting variables, including the location of abandoned wells and their associated type, depth, and date of abandonment. Most important to the successful siting is that all traditional and novel considerations must align perfectly.

To begin, Alberta was examined as to its potential for geothermal energy. Previous studies have examined geothermal conditions in Alberta, primarily for a depth of 5 km, but also at a depth of 2 km. The underground temperature isotherms can be seen in Figure 2, which displays the great potential for geothermal energy in Alberta. In Figure 2a, seven specific locations were highlighted for their high source temperatures. All such locations were investigated as potential candidates for the GeoNow project, and should also be considered for future expansion.

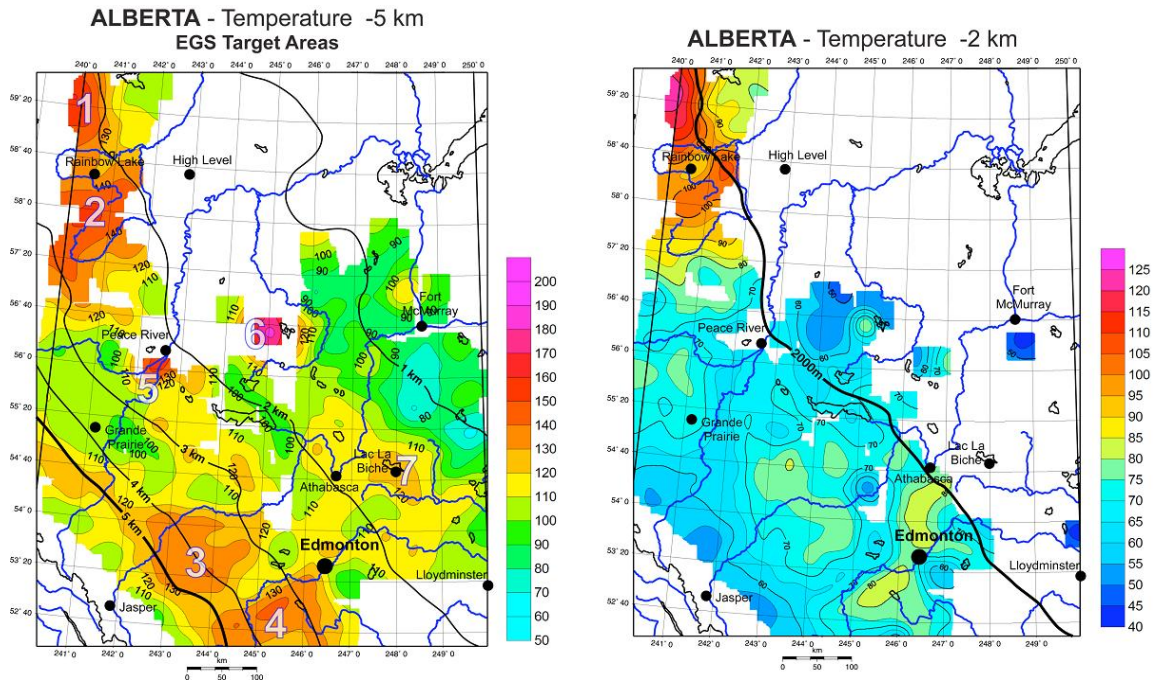


Figure 2: Underground temperature isotherms for the northern portion of Alberta (a) at a depth of 5 km (b) at a depth of 2 km. [3]

After Alberta's geothermal potential was verified, it was required to examine the abandoned wells in Alberta to ensure a large selection pool existed. In total there are 128,722 abandoned wells in Alberta at the time of the lists publication in 2008 [3]. These wells are broken down into three categories: abandoned unreclaimed wells, reclamation exempt abandoned wells, and reclamation certified abandoned wells. For the purpose of this work, abandoned unreclaimed wells were targeted for examination, providing a total of 41,310 potential wells.

Now, each of the seven previously discussed locations in Figure 2a had their abandoned unreclaimed wells examined. While locations 1 & 2 have excellent thermal potential, they contain only 32 and 219 unabandoned wells, respectively, and are relatively far away from electrical demand and transmission. In addition, site 6 is relatively far away from electrical demand and transmission. As a result, attention was focused on sites 3, 4, 5 and 7, with a total of 233, 700, 37, and 267 abandoned wells per site, respectively. The low amount of abandoned wells in site 5 excluded it from further consideration. The

remaining three sites had their average depth examined to determine further consideration for each site. It was found that hardly any abandoned wells in these regions reached a depth of 5km; however, a noticeable portion reached a depth of 2 km. This required a major shift in attention away from temperature isotherms at 5km, Figure 2a, to temperature isotherms at 2km, Figure 2b. After examination of Figure 2b, two very specific locations north of Edmonton and south-west of Edmonton are apparent as possible siting locations. After thorough discussion with the team, the location at site 4 was chosen for further examination.

Site #4 spans a considerable area, while still providing underground temperatures high enough to implement geothermal technology. There are 700 unreclaimed abandoned wells within Site #4, as shown in Figure 3. These wells are dispersed throughout the area, with three locations showing a slight clustering of wells together. All of these wells had their maximum depth and date of abandonment examined [4, 5]. It was decided that abandoned wells must have a depth of at least 2 km, and that these wells must have been abandoned in 1995 or later. This abandonment date was chosen to ensure that only newer wells would be selected, which would facilitate with well identification, reopening, and required repairs. After these two requirements were applied, a total 72 abandoned wells were identified within Site #4, as seen in Figure 4.



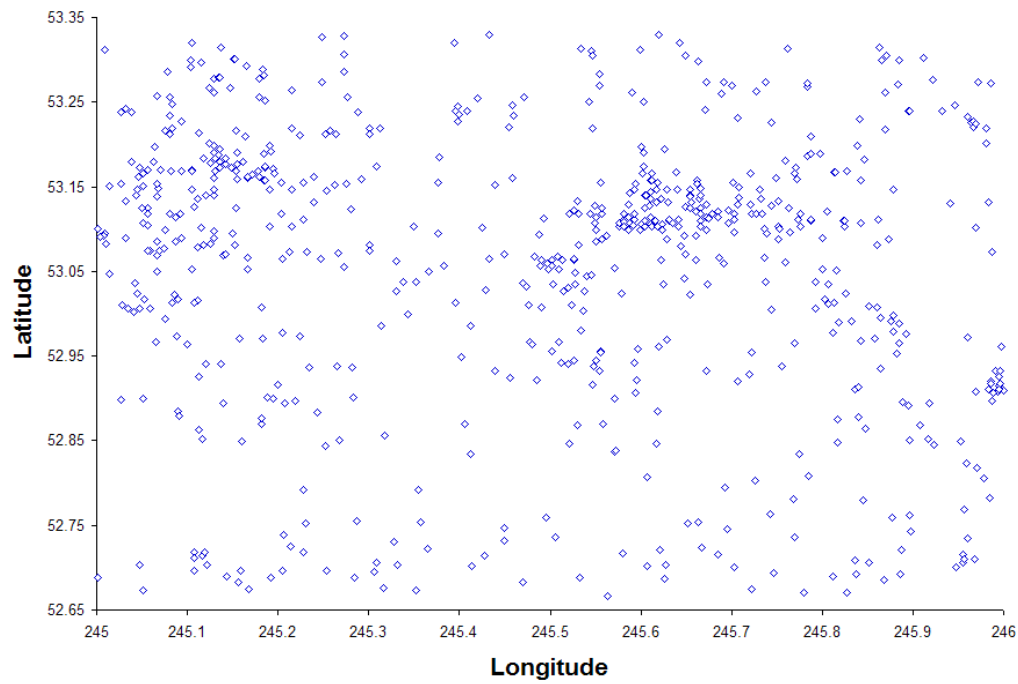


Figure 3: All abandoned wells within the boundaries of Site #4.

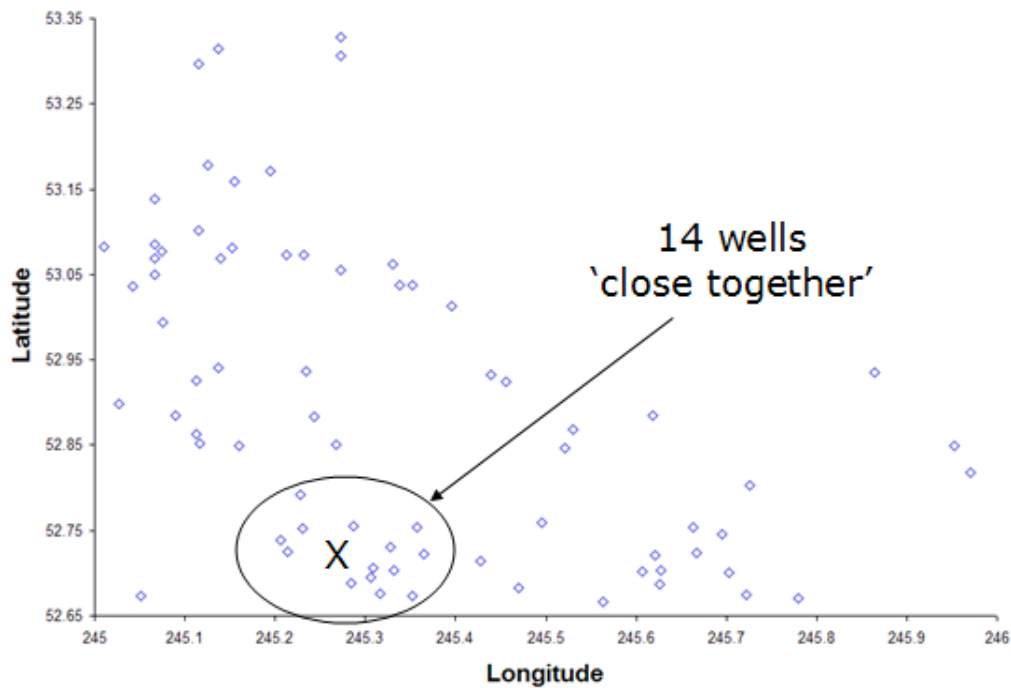


Figure 4: All abandoned wells deeper than 2 km, with abandonment dates later than 1995.

A large size (MW) power plant would require a number of active wells to draw upon in order to achieve the desired geothermal fluid flow rates. Figure 4 was examined for any cluster of wells, and one location was deemed more suitable than the others, as marked in Figure 4. This location would have 14 wells that are ‘close together’, attempting to minimize the amount of piping required to connect the wells with the generation facilities. In addition, Site #4 can be seen from a larger perspective in Figure 5, which shows the proximity to Edmonton and the comparative area spanned. The white rectangle represents the entirety of Site #4, while the circular region identifies an area where the wells are ‘close together’. Depending on the initial performance of the geothermal power plant based on these 14 wells, additional abandoned wells could be brought into the system if necessary.

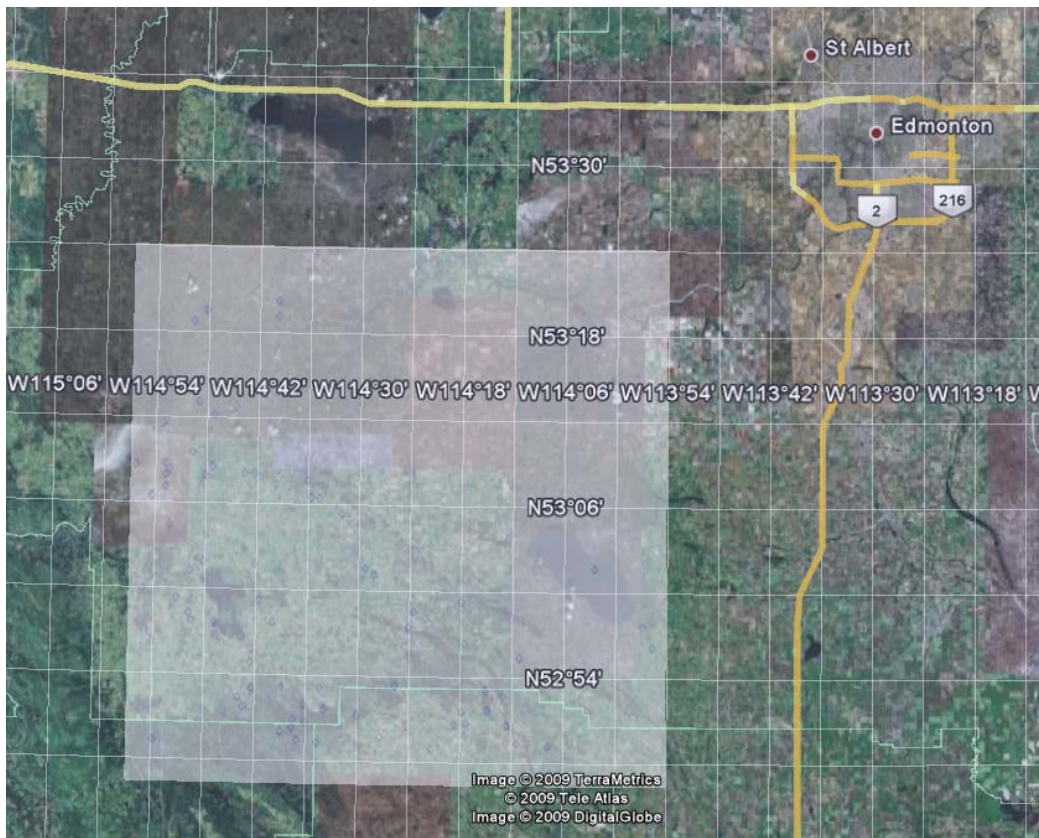


Figure 5: A broader perspective of Site #4 in comparison with Edmonton.

## Technical

Recent technological developments have advanced low enthalpy geothermal electricity production. Binary geothermal power plants make use of resource temperatures as low as 74°C and as high as 177°C. In the binary process, the geothermal fluid, which can be either hot water, steam, or a mixture of the two, heats another liquid such as ammonia or isobutene. This ‘working fluid’ boils at a temperature lower than water, allowing a standard Rankine cycle, as outlined in Figure 6, to be used and in essence extends the usable range of geothermal source temperatures. The two liquids are kept completely separate through the use of a heat exchanger that transfers heat energy from the geothermal water/steam to the working fluid. When heated, the working fluid vaporizes and the force of the expanding gas turns a turbine that can power a generator. The binary system operates in a closed loop system that allows for very little working fluid to be lost to the atmosphere [6].

A geothermal power plant does not need to burn fuel to generate electricity; it is, therefore, virtually emission free once operational and insusceptible to fluctuations in fuel cost. While wind power can only operate when the wind blows and solar power only works when the sun shines, geothermal power is nearly 100 % reliable and provides dependable base load power. This makes GeoNow’s system of low temperature geothermal production a sustainable and environmentally benign way to help power the Alberta grid.

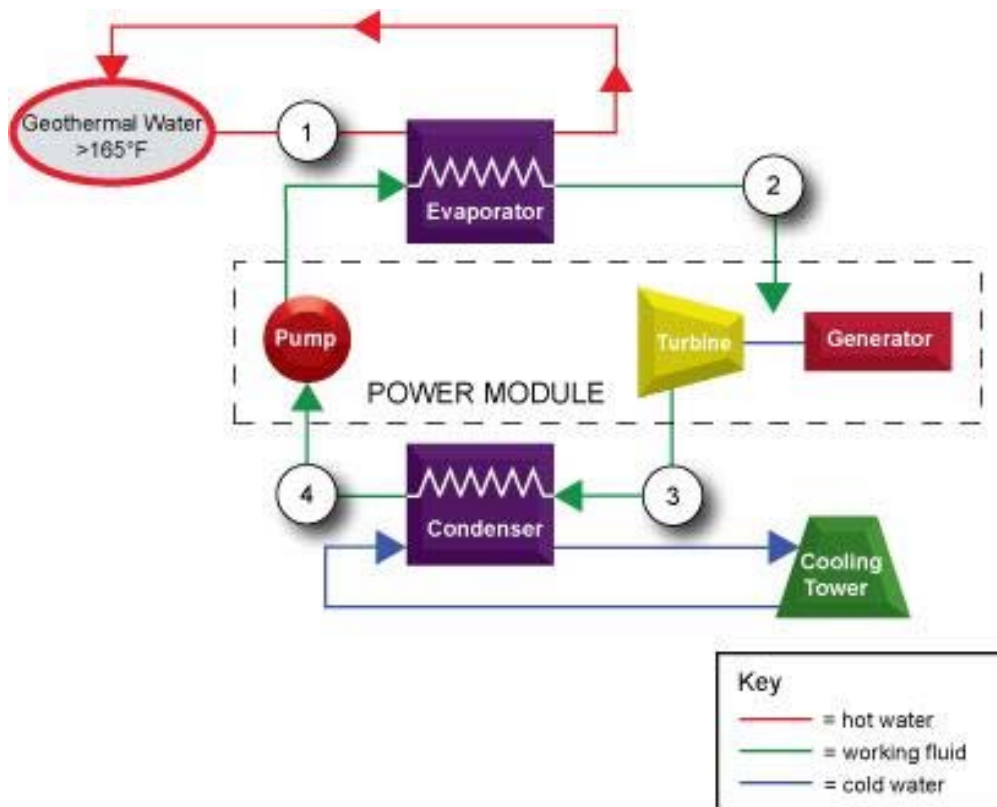


Figure 6: Geothermal Rankine Binary Cycle [7]

GeoNow will be using existing abandoned oil and natural gas wells as the source for hot geothermal fluid to power a Rankine cycle as outlined in Figure 6 above. In order to achieve the desired plant output, several parameters were taken into consideration when choosing a location such that the necessary source temperature and heat flow rate is available. Also of interest is the cooling source necessary for plant operation. The GeoNow installation is expected to use air coolers instead of water coolers for the condenser, as this avoids the use of cooling water allotments from rivers or lakes, and allows for much more flexible plant siting [8].

Cost remains a significant factor for geothermal power plants, as with all other types of electricity production, with the initial capital cost governed by the output capacity of the plant being installed. GeoNow has determined that using a number of small independent units to convert heat to electricity would provide several advantages over the traditional method of designing one large unit: various plant sizes can be accommodated by varying

the number of units installed, which leads to reduced design cost for every installation since identical units are used repeatedly; maintenance or breakdowns can be dealt with individually while all remaining units operate unaffected; and economy of scale is exploited as parts are produced in bulk instead of on a one-off basis. A 280 kW unit produced by United Technologies Corporation (UTC), an American multinational conglomerate based in Hartford, Connecticut has been selected for further investigation to fill this requirement for the GeoNow project.

Based in South Windsor, Connecticut, UTC Power is a full-service provider of environmentally advanced power solutions. UTC Power is a leader in innovative, renewable energy solutions and combined cooling, heating and power solutions for the distributed energy market. Their PureCycle® Model 280 energy solution harnesses the Earth's heat to power a turbine, turning a renewable resource into 280 kW of electrical power with zero emissions. UTC Power's geothermal power system was recognized in 2007 by R&D Magazine as one of the 100 most technologically significant products introduced during the past year.

UTC Power has recently teamed with Raser Technologies to rapidly deploy low-cost modular power generation plants. The advantages of this type of modular design are numerous:

- Premanufactured for economy in high volume
- Delivered and deployed rapidly avoiding costly on-site engineering delays
- Flexible modular design can be connected into larger power generation "farms"
- The entire plant can be operated remotely, with no personnel on site.

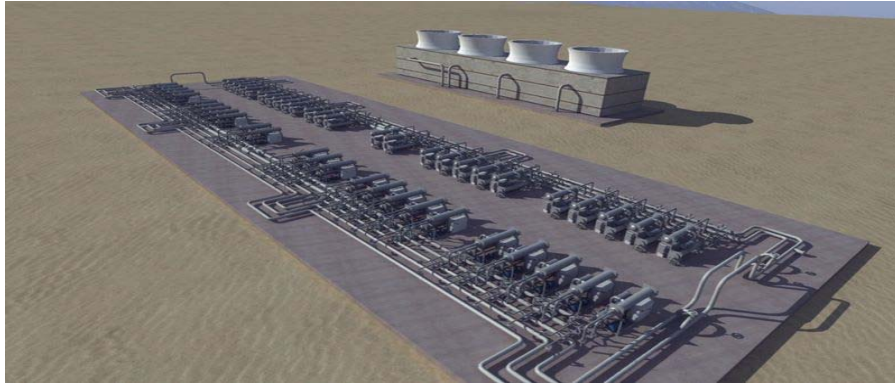


Figure 7: Raser Technologies 10 MW modular power generation plant using forty-five of UTC's PureCycle® units. [9]

## ***Calculations***

Preliminary calculations have been carried out to determine ballpark figures for plant setup requirements and performance. Due to the complex nature of underground rock formations, water reserves, and geothermal activity, it is difficult to accurately predict performance before actual flow testing has been carried out.

Appendix A: CO<sub>2</sub> Emissions Reduction presents the CO<sub>2</sub> emissions savings when comparing an operational geothermal power plant to traditional coal generation plants. A reduction of 1640 tonnes CO<sub>2</sub>/yr per 200 kW unit is determined based on average coal power plant data and vehicle statistics [10, 11]. This equates to an equivalent reduction of 315 cars operating per year for each 200 kW unit installed [12]. Looking forward, when the GeoNow project expands and replaces the equivalent of the Wabamum coal power plant, quoted at 279 MW, the equivalent vehicle reduction would be approximately 440,000 cars/year, or 58% of all Edmonton's cars and light trucks registered in 2006 [13]. These numbers only incorporate the operating emissions from the two plant types, but since the GeoNow project will use abandoned wells instead of drilling new ones, the construction emissions from the geothermal power plant will result in even lower total emissions than previous lifecycle analyses. Regardless of this improvement, the aforementioned lifecycle analysis comparisons between coal and

geothermal power strongly favor geothermal power with average quoted values of around 910 CO<sub>2</sub>/MW<sub>e</sub>h for coal power and 75 CO<sub>2</sub>/MW<sub>e</sub>h for geothermal power [14].

In order to have a specified plant output, there must be sufficient geothermal heat flow to replenish the reserve temperature underground. Using data for estimated underground heat flux, it is shown in Appendix B: Heat Flow Calculation that the required area for 20 MW of heat flow is approximately 286 km<sup>2</sup> [3, 15]. The selected region (site 4 in Figure 2) has a total area of approximately 5000 km<sup>2</sup>, so there is more than sufficient area in the entire region to provide the required heat flow. However, when narrowing the area down to the specific region indicated in Figure 4, the approximate area covered is only 310 km<sup>2</sup>. This may pose problems due to the efficiency of the geothermal units used to generate electricity (requiring a larger amount of thermal energy to achieve the desired electrical energy), but due to the potential for uncertainty, flow testing would have to be carried out. If the thermal output is found to be inadequate, then the region over which abandoned wells are utilized for the plant will have to be increased.

Geothermal fluid flow is used to carry thermal energy from underground to the power plant to generate electricity. As mentioned before, the thermal energy available must be sufficient to produce the desired power with the available efficiency of the setup being used. Appendix C: Geothermal Fluid Flow Analysis goes through some basic calculations to show that the required geothermal fluid flow may range from as low as 160 kg/s (50% efficiency, 60 °C temperature drop across geothermal units) to as high as 1590 kg/s (15% efficiency, 20 °C temperature drop across geothermal units). The actual value is expected to be much closer to the high end of this range since a binary cycle is used, which will have a lower efficiency than typical steam-based geothermal units [16]. Again, to verify actual operating parameters, flow testing of the selected wells is required.

It is obvious that only limited parameters can be calculated using basic temperature data obtained from previous data. Heat flow data is essential to determine the number of wells required, and the area over which they must be spread in order to supply the required amount of thermal energy. Also, the composition of the geothermal fluid (including

dissolved solids) is necessary to determine the materials necessary for construction to avoid rapid corrosion, and also the minimum temperature that must be maintained in the ground loops to avoid scaling in the pipes that would restrict flow and reduce plant output. On the other hand, the available data is able to provide ball-park figures that can be used to begin studies of various other aspects of the plant design, including environmental impact, appropriate policy, and economic potential.

## **Environmental**

Through the use of geothermal technologies utilizing abandoned well sites we are ensuring a cleaner healthier environment. By implementing these types of power plants, the energy requirement of coal burning plants would be diminished by the equivalent of taking 31,500 cars off the road with the production of a 20 MW plant, as shown in Appendix A: CO<sub>2</sub> Emissions Reduction. This means a significant reduction in the production of noxious chemicals such as hydrochloric acid, sulfuric acid, ammonia and hydrogen fluoride, along with heavy metal compounds such as lead, nickel and Mercury often associated with coal power plants. These chemicals have the potential to cause cancer and linger in human tissues and the environment for an extended period of time. Not only will GeoNow improve the impact of energy production on the environment, but it will also reduce the release of cancer causing agents into our air. GeoNow is a healthier alternative that may supply base load power, giving rise to the possibility that solar, wind, hydro or other forms of renewable energy could be utilized at peak hours when energy demands are the greatest. This would reduce the demand for building new coal power plants and nuclear reactors to supply the population with energy.

GeoNow would utilize air cooling as opposed to water cooling, as used by nuclear and coal power plants. This reduces the amount of water needed and also eliminates the effects that cooling ponds have on surrounding ecosystems. Furthermore, the lifetime of geothermal units can be very long depending on the heat sustainability of the area. This



reduces the frequency of major renovations, decommissioning, and rebuilding of additional systems, all of which require significant amounts of emissions to accomplish.

It is the basis of the GeoNow concept to utilize abandoned oil wells as the site for geothermal power plants. This means that not only the cost of drilling, but the energy and materials required to drill these holes are not required. This can be a huge savings as drilling requires heavy equipment and a large quantity of fuel to complete each well. It is GeoNow's goal to use abandoned wells' geothermal potential to provide energy that is efficient, sustainable, and logical.

## **Policy**

After the release of the Canadian Federal Budget 2009 it appears that implementation of renewable energies falls to the bottom of the priority list. Although the government has allotted significant funding, \$250 million, for a full scale commercial demonstration of carbon capture and storage in the coal-fired electricity sector, little is being done to reduce this carbon that we are producing at such an astounding rate. Only \$10 million is set aside over two years for scientific research and analysis on biofuels emissions, while \$300 million is spent on nuclear energy, including the development of the advanced CANDU reactor. Instead of funding more research and implementing solar and wind power generation, the government is only extending GST/HST relief to land leased to situate wind or solar-powered equipment for the production of electricity. Although these are all small steps to a cleaner power supply, they are not on a large enough scale to reduce our dependence on coal, nuclear and other environmentally unfriendly, inefficient, and hazardous methods.

The implementation of GeoNow as a successful base load power supply would greatly reduce the overall CO<sub>2</sub> emissions in the area of implementation. Because Alberta imposes a carbon levy system, valuable carbon offsets available from a geothermal plant could be sold to large emitters for a fee, or used by our partner company. Currently, Alberta is the province producing the highest CO<sub>2</sub> emissions in Canada, being estimated

at ~205 Mt/yr in 1999. A carbon levy of 15\$ a tonne is imposed on producers that emit over 100,000 tonnes for every tonne above 88% of their 2007 CO<sub>2</sub> levels. Alberta was the first jurisdiction to impose such a tax in Canada. GeoNow would qualify for offsets to sell to large emitters to use in place of carbon levies.

Geothermal technology is a huge area of interest in the renewable energy sector around the world, and is already being implemented in numerous areas. Germany seems to be a leader in the implementation of geothermal as it allots approximately \$250/MWh for geothermal projects (includes heat integration bonus and enhanced geothermal system bonus). In Australia, the governments have committed more than \$100 million in grants that have paid for 25% of the projects to date. If the Alberta government could subsidize even a small percentage of the startup costs associated with GeoNow, this could become a viable source of base load energy.

## **Business**

Even with the economic down turn, the demand for electricity in Alberta is increasing [17]. Presently, the electricity demand in Alberta frequently exceeds the generating capacity [18]. In 2020, the predicted peak energy shortage is 2000 MW [19]; hence, the Alberta market will want to buy all of the electricity our anticipated geothermal plant can generate. We propose to partner with EPCOR or ENMAX in order to provide the infrastructure and capital needed for what will be a commercially viable project.

Due to numerous variables, the exact construction and operating cost of our geothermal power plant is impossible to predict. However, we will employ a number of strategies to facilitate a lower construction cost, lower operating cost, and increased profit margin by targeting the appropriate market segment.

Using abandoned wells instead of drilling holes *de novo* saves in construction costs as well as lowering the risk of the project significantly since we have an estimate of the temperature of the wells [3, 20]. The total amount of initial capital investment that will

be saved is approximately 30 to 60 million dollars [16, 20]. This amount is an incredible 40% reduction in construction costs for a typical 20 MW geothermal plant [20, 21]. With this reduction in price, construction cost for the geothermal plant is competitive with a traditional gas or coal based plant [22]. Having a construction cost lower than average will also lower our operating cost compared to a typical geothermal plant, as we have less debt to service.

To further lower our operating costs, GeoNow will apply for a protocol to sell carbon offsets under Alberta's existing Carbon levy system. Under this system, large emitters must reduce their CO<sub>2</sub> emissions to 88%, pay into a technology fund for every tonne of CO<sub>2</sub> at \$15/tonne, or buy offsets. Companies are able to sell offsets when they have either reduced their own emissions to less than 88% of their 2007 levels, or have changed their business as usual practices to reduce greenhouse gas emissions. An example of this is the offsets a wind farm produces because it supplies electricity to the grid without burning any fossil fuels [23]. Our geothermal plant will similarly supply electricity without emitting any greenhouse gases; furthermore, we will be able to qualify for even more offsets than a wind farm because our capacity will be much higher at around 90 to 95% compared to 35% for the wind farm. Although \$15/tonne would only lower our operating costs by at most 1.5 cents/kWh, there is speculation that the offsets will increase to \$25-30 within the next 2 years and \$65 within the next five [24]. On occasion, the speculation alone increases the price of the offsets to above the price of the levy. Additionally, a federal government plan may also be introduced. This plan would only increase the value of the offsets, especially if firms are limited to the amount of levies they can purchase.

If our operating costs are still above the market price of electricity, a market segment that would be willing and able to pay more for carbon free electricity would be the oil sands projects. Presently, oil from the oil sands is labeled 'dirty oil' because it requires more energy to extract than conventional oil. Often this energy is in the form of natural gas to make steam or gasoline for the large vehicles used in the mining operations. However, *in situ* techniques are available to extract the oil using electricity [25]. Power supplied from

our clean geothermal plant could be used for this procedure to reduce the overall emissions associated with oil sands extraction.

Initially, the carbon free electricity GeoNow sells to the oil sands projects would only help to power their plants and not extract the oil. Although this would still lower the carbon content of a barrel of synthetic oil, the impact would not be too significant. More importantly, with further geothermal plants being installed and either their redesigned or new projects, GeoNow offers the oil companies the chance to drastically improve the carbon cost of their product, possibly by implementing electric heaters instead of natural gas, or through *in situ* techniques as suggested above. The oil companies would be willing to pay a premium for our product as it ensures their end product, oil, is more competitive in the American market. With the oil sands as our target market, GeoNow will be set to expand with multiple 20MW plants after we have proven success with our initial plant.

A possible concern with using abandoned oil wells is the liability that comes with them. To circumvent this problem, we will explore the possibility of leasing rather than buying the oil wells and having the liability remain with the original owners. The original owners are likely now the main players in the oil sands; hence, they would have a vested interest in GeoNow's success. An equitable arrangement might be to offer to pay a small percentage variable cost in rent if they agree to keep the liability of the oil wells.

## **Future and Alternative Considerations**

### **1. Detailed analysis of conditions at selected wells for underground temperature and water composition**

- Non-combustible gas content, corrosiveness, scaling potential, dissolved solids and pH should be analyzed for special operating, maintenance, and design considerations.
- One of the advantages of a binary system is the avoidance of scaling. By maintaining the geothermal water under pressure and injecting it at an elevated temperature (as dictated by its composition), the dissolved chemical constituents are maintained in solution. This can mitigate/prevent scaling of heat exchangers, wells, and piping [6].

### **2. Flow testing the wells to determine the buoyancy flow rate and thermal output.**

- A temperature gradient analysis would be conducted to determine the actual temperatures of each prospect well and determine if sufficient heat flow is present.
- The depths of the wells have already been determined, so the goal would be to figure out if the wells are deep enough for an adequate fluid flow and replenishment of heat in the underground reservoir. Characteristics of the well and the reservoir are tested by ‘flowing’ the well [25].

### **3. Further investigation of the UTC Purecycle geothermal units to ensure suitable operation at selected site.**

- Work in collaboration with UTC to deploy a strategic plan to develop a power plant that will suit the characteristics of the plant site and surrounding environment.
- Currently UTC does not offer units that operate below 90 °C, so our best option (if the geothermal source has a low heat content) would be to work with UTC to develop a system that can operate below 90 °C. The ‘proof

and concept' of this collaboration is seen in the Chena Geothermal Power Plant project in Alaska, where Chena Hot Springs Resort entered into a partnership with UTC to develop an ORC system that operates at temperatures as low as 74 °C simply by changing the working fluid and design of the turbine [26].

- It may also be of interest to investigate drilling existing abandoned wells deeper to take advantage of higher temperatures to increase plant output and allow for easier incorporation of existing UTC units. Of course, the budgetary impact of this approach will need to be evaluated against the aforementioned design modifications.
- UTC is looking into developing a 1 MW modular power system. This system could save space and money during the implementation phase.

#### **4. Complete budgetary analysis to determine setup and operating costs for the geothermal plant.**

- The cost of the project is a key aspect to making it feasible. A complete budgetary analysis would allow us to potentially develop partnerships with other companies. We would have a better understanding of our capital cost, the operational and maintenance costs and our rate of return.
- Part of this analysis can come from UTC as they provide pricing once the application has been evaluated. This pricing includes equipment and service only. Engineering, construction, and balance of plant are not offered by UTC and separate price quotes would have to be acquired.

#### **5. Small mobile systems**

- Small mobile plants can help in meeting the energy requirements of isolated areas. The standard of living of many communities could be considerably improved were they able to draw on local sources of energy. Electricity could facilitate many important operations such as pumping

water for irrigation or freezing fruit and vegetables for longer conservation.

- The convenience of the small mobile plants is most evident for areas without ready access to conventional fuels, and for communities where it would be too expensive to connect to the national electric grid [27].
  - Half a million dollars for step-down transformers needed to tap electricity from high voltage lines
  - \$20,000/ km for electricity distribution using wooden poles
  - 100 kW could serve 100 – 500 people
  - 1 MW could serve 1000 – 5000 people

## **6. Water/air cooling hybrid system**

- Sole air-cooled systems are influenced by seasonal changes in air temperature. These systems can be extremely efficient in the winter months, but are less efficient in hotter seasons when the contrast between the air and water temperature is reduced. Plant efficiency typically deviates by 15 percent between colder and warmer months.
- To counteract the efficiency fluctuation, a cold water cooling system would be used to supplement the air cooling in the summer months, while the air cooled system would be used solely in the winter months, taking full advantage of Alberta's frigid winters [6].

## **7. The Kalina cycle**

- A newly developed binary system which utilizes a water-ammonia mixture as the working fluid.
- The system incorporates reheat and regeneration processes into the basic Rankine cycle to improve efficiency.
- Because the ammonia mixture acquires heat more efficiently than water, the Kalina Cycle provides more electric output per unit of heat input, but it is of more complex design than existing geothermal ORC binary power plants [27].

## Conclusion

GeoNow proposes using abandoned oil wells as a source of geothermal energy for its power plant. Our site, situated southwest of Edmonton, features close proximity to high voltage power lines in addition to recently abandoned oil wells closely spaced with appropriate depth, temperature and heat flow. Our geothermal power plant will be composed of one hundred, low temperature, 0.2 MW Rankine cycle generator units, each complete with the necessary heat exchangers. The high number of generators will allow for economies of scale to be used in terms of maintenance. Additionally, two separate fluid loops will be used (geothermal and working), enabling our plant to utilize much lower temperature wells than previously used. To further reduce our environmental impact and increase our flexibility for future siting, we will employ air cooling rather than water cooling. By using abandoned oil wells, carbon offsets, and target markets, GeoNow's power plant will be economically viable. Alberta requires electricity; having geothermal power plants provides this electricity and greatly reduces the toll on the environment that a power plant can cause.




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## Appendix A: CO<sub>2</sub> Emissions Reduction

	Feb. 23, 2009	Appendix A CO <sub>2</sub> Emissions Reduction	Boddez, Jason	1/2
	<p>Evaluate the reduction in emissions in using geothermal power as a substitute for coal generated electricity.</p> <p>Source: "Clean Coal Technology" presentation from BARC Dec. 4 2007</p> <p>↳ obtained data from CEA, 2006, Thermal performance report</p> <p>Average CO<sub>2</sub> emissions: 1.04 kg/kWh</p> <p>(377 plants sub-critical pulverised coal (535-575 °C, 175-230 bar))</p> <p>Find the amount of CO<sub>2</sub> emissions avoided by implementing one 200 kW geothermal electricity generation unit.</p> <p>Assume: Uptime = 90% of 365 days/year</p> <p>Operating Time = 365 days/year × 24 hours/day × 0.90 = 7884 hours/year</p> <p>Power Produced = 7884 hours/year × 200 kW = 1,576,800 kWh/yr</p> <p>CO<sub>2</sub> emissions avoided = 1,576,800 kWh/yr × 1.04 kg/kWh = 1,639,872 kg CO<sub>2</sub>/yr = 1640 tonne CO<sub>2</sub>/yr per geothermal unit</p> <p>Average CO<sub>2</sub> emissions = 5.2 metric tons/year = 5.2 tonne/yr</p> <p>↳ For an average passenger vehicle from a fleet with 63.9% cars and 36.6% light trucks (includes SUVs &amp; minivans)</p> <p><a href="http://www.erasecarbonfootprint.com/cor2emissionlist.html">http://www.erasecarbonfootprint.com/cor2emissionlist.html</a></p> <p>∴ Car equivalence = <math>\frac{1640 \text{ tonne CO}_2/\text{year}}{5.2 \text{ tonne CO}_2/\text{car} \cdot \text{year}} = 315.38 \text{ cars/year}</math> = 315 cars/year·unit</p> <p>Hence for a 20 MW geothermal plant (100 units)</p> <p>Emissions reduction = 315 cars/unit·year · 100 units = 31,500 cars/year</p> <p>Wabamun Replacement: 279 MW/(0.2 kW/unit) = 1395 units 315 cars/unit·year · 1395 units = 439,425 cars/year</p>			



Feb. 23, 2009

Appendix A.

CO<sub>2</sub> Emissions Reduction

Boddez, Jason

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Total vehicles on the road in Edmonton (July, 2006): 752,958

$$\frac{439,425}{752,958} \times 100\% = 58.36\% = 58\% \text{ of Edmonton vehicles taken off the road}$$

(assuming Edmonton vehicles are a fleet of 63.4% cars and 36.6% light trucks)

Reference: <http://www.oma.canada.ca/en/market/edmonton/default.oma>

## Appendix B: Heat Flow Calculation



Mar. 13, 2009

Appendix B  
Heat Flow Calculation

Boddez, Jason

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Using Map 2 on P. 15 of the "EGS Potential in the Alberta Basin" document from IEEE 2008, the approximate area required to extract thermal energy for a geothermal power plant can be estimated.

In region of interest, heat flow ( $\dot{q}$ )  $\approx 70 \text{ mW/m}^2$

$$70 \text{ mW/m}^2 \times \frac{1 \text{ W}}{1000 \text{ mW}} \times \frac{(1000 \text{ m})^2}{(1 \text{ km})^2} = 70,000 \text{ W/km}^2 = 70 \text{ kW/km}^2$$

To find required area, divide desired output by heat flow

Desired Output (kW)	Required Area (km <sup>2</sup> )	Square Edge Length (km)
1000	14	3.8
5000	71	8.5
10,000	143	12.0
20,000	286	16.9

Site 4 on isotherms presented in the report covers the following approximate area:

Latitude:  $52^\circ 46' - 53^\circ 24' \text{ N} \rightarrow 70.5 \text{ km}$   
 Longitude:  $113^\circ 54' - 114^\circ 57' \text{ W} \rightarrow 70.7 \text{ km}$   
 $\text{Area} = 4984 \text{ km}^2$

Use an online calculator to calculate side distances of a rectangle of this size, then calculate the area.

Reference: <http://jan.ucc.nau.edu/~cvm/latlongdist.html>

Narrowing the area down to the circled region presented in the report as the selected plant area, the land area reduces to the following values:

Lat:  $0.25 \times 70.5 \text{ km} = 17.6 \text{ km}$   
 Long:  $0.25 \times 70.7 \text{ km} = 17.7 \text{ km}$   
 $\text{Area} = 311 \text{ km}^2$

## Appendix C: Geothermal Fluid Flow Analysis



Mar. 22, 2009

Appendix C

Geothermal Fluid Flow Analysis

Boddez, Jason

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Determine the amount of flow required in the geothermal loop (provided by production wells, and returned with re-injection wells) for various temperature differences between production and re-injection wells.

Pilot plant electricity capacity: 20 MW = 20,000 kW

Specific heat capacity of water:  $C_p \approx 4.2 \frac{\text{kJ}}{\text{kg} \cdot \text{K}}$

$$\dot{Q} = \dot{m} C_p (T_{\text{prod}} - T_{\text{inject}}) \eta_{th} = \dot{m} C_p \Delta T \eta_{th}$$

Efficiencies of geothermal plants have been found to vary between 25-50% depending on specific site conditions ("The Future of Geothermal Energy", MIT Report, 2006). Both of these limits will be used to provide a reasonable range to be expected.

Isotherm given for 2km depth in the region of interest indicate temperatures of approximately 80°C ("Enhanced Geothermal Systems (EGS) Potential in the Alberta Basin", IEEE Research Paper, 2008). Since dissolved solids are unknown in the underground region of interest (which impact the minimum allowable reinjection temperature to avoid scaling), reinjection temperatures of 20°C, 40°C, and 60°C will be used.

Temperature Difference (°C) ( $T_{\text{prod}} - T_{\text{inject}}$ )	Geothermal Loop Flow Rate (kg/s)	Plant Thermal Efficiency (%)
20	952	25
40	476	25
60	317	25
20	476	50
40	238	50
60	159	50
20	1587	15
40	794	15
60	529	15

Included since binary cycle may operate at a lower efficiency than typical steam based geothermal plants.