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Geothermal Analysis

Whitecourt

Study by Terrapin Geothermics

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Executive Summary

In the spring of 2018, Terrapin Geothermics was engaged to evaluate the geothermal resources available to northern Alberta municipalities. Geothermal energy refers to the heat available from within the earth and is classified as a renewable energy resource. Based on Alberta's sub-surface geology, the highest quality geothermal resources in the province are in the northern and western regions, making the geothermal industry the only source of renewable energy that is better in the northern part of the province than in the south. The majority of wind and solar projects have been developed in southern Alberta due to the fact that the solar and wind resource in Alberta happens to be stronger in those regions.

As with all energy developments, before any active project development and direct investment can take place, you must start with understanding the resource available.

The primary focus for this particular project was to provide northern Alberta communities with a high-level understanding of the geothermal resource available within a 25-kilometer radius. This information can then provide a starting point for municipalities that are keen to develop their resource further.

One of the unique aspects of geothermal energy developments is that you can use geothermal energy for a variety of different things depending on the quality of the resource. The hotter the temperature available, the greater the number of possibilities exist for using this resource.

In general, the projects you can develop in this industry break down into a few main categories:

1. **Geo-Exchange:** A few feet beneath the surface, the earth's temperature remains fairly constant, about 4-6°C year-round in Canada. Geo-exchange takes advantage of this constant temperature to provide extremely efficient heating and cooling for houses, commercial buildings or light industrial facilities. In winter, a water solution circulating through pipes buried in the ground absorbs heat from the earth and carries it into the home or building. The Geo-exchange system inside the home uses a heat pump to concentrate the earth's thermal energy and then to transfer it to air circulated through standard ductwork to fill the interior space with warmth. In the summer, the process is reversed: heat is extracted from the air in the house and transferred through the heat pump to the ground loop piping. (Taken from Canadian GeoExchange Coalition). Geo-exchange projects are typically focused on individual houses or commercial buildings with costs in the thousands of dollars range. Geo-exchange projects are not extracting geothermal energy from the earth; they are using the earth as a heat battery.
2. **Electricity Generation.** Deep geothermal resources with temperatures above 90°C can be used to produce electricity. Electricity generation projects are highly valuable developments to pursue as the power generated can be connected to Alberta's electricity grid to be sold anywhere in the province. Geothermal electricity projects require drilling relatively deep (1,500 metres – 4,500 metres) to extract hot water that is trapped sub-surface. This hot water is called a geo-fluid and is almost exclusively salt water in sub-surface aquifers. The higher the temperature of the geo-fluid, the better the economics of a power generation project will be.
3. **Direct Heat Use.** Even if a geothermal resource is below the threshold for power generation (90°C), there is a significant opportunity to use the hot water as a direct heating source, often

displacing natural gas being used for heating. Hundreds of examples of direct heat use projects exist across the world including district heating systems, industrial facility heating projects, greenhouse heating, snow melting, pool heating, crop drying, timber drying and many more. The higher the temperature, the more options exist to develop a direct heat use project.

This report has analyzed your region's geothermal resource with a focus on temperature mapping in order to frame which category of projects would be worth further exploration. In general, the broad steps required to develop a geothermal energy project in your region are as follows:

1. **Temperature Mapping (This document):** This report is focused exclusively on temperature mapping and is a desktop study that uses the wealth of pre-existing data available from existing energy developments in the province to estimate the quality, quantity and location of the best geothermal resource in your region.
2. **Resource Evaluation:** For municipalities and regions keen to pursue geothermal development in their region, the recommended next step is a more in-depth resource evaluation exercise. High quality geothermal resources require three things, strong temperatures, a heat transfer fluid (hot water) and geological formations that are porous and permeable so you can actually move fluid through the reservoir. With this initial report only focusing on temperature, it is key to analyze water production potential, porosity, permeability and existing infrastructure to fully understand the geothermal resource available.
3. **Project Decision**: Once a more complete understanding of the geothermal resource is developed in the resource evaluation phase, a decision on what type, and size of project should be developed is made.
4. **Project Development**: Upon selecting the specific project to develop, the traditional project development process takes over and focuses on completing the technical, economic and regulatory work needed to bring the brainstormed project from concept to reality.

How to Read This Document

Below you will find a technical report prepared by Terrapin Geothermics that will walk through a number of key things:

1. Glossary of key geothermal terms
2. A visualization of the typical project development process
3. A more detailed technical description of geo-exchange, direct heat use and power generation project categories
4. An overview of how this project was completed
5. Research results that showcase the specific geothermal hot-spots within your region, the number of data points analyzed, how your geothermal resource compares to global averages and a list of recommendations and notes from Terrapin's geology team.

The final two pages of this document are the most practical as they provide actionable, specific data on the quality and location of the geothermal resource in your region. This information can be valuable for land-use planning, energy strategy development and investment attraction. If you have any questions about your research results, please don't hesitate to contact Terrapin Geothermics for a more detailed explanation. Their contact information is on the cover page of this document.

Glossary

Aquifer	An underground layer of water-bearing permeable rock, rock fractures or unconsolidated materials (gravel, sand, or silt).
Devonian	A geological period/age lasting from 419.2 to 358.9 million years ago.
Formation	An individual geological unit with a well-defined age, stratigraphic horizon and rock type.
Frostline	The depth to which groundwater in soil freezes. The temperature in ground deeper than the frost line is always above $0^{o}C$.
Permeability	The state or quality of a material or membrane that causes it to allow liquids or gases to pass through it. Greater permeability allows for greater fluid flows within a reservoir.
Porosity	A measure of the void (i.e. "empty") spaces in a material and is a fraction of the volume of voids over the total volume, between 0 and 1, or as a percentage between 0% and 100%. High porosity generally correlates with high permeability.
Reservoir	A regional scale, resource-rich formation.
Sedimentary Layers	Rock layers formed by the accumulation and consolidation of mineral and organic fragments that have been deposited by water, ice, or wind.
Stratum (plural: strata)	A single bed of sedimentary rock, generally consisting of one kind of matter representing continuous deposition.

Development Path

Preliminary Survey (this document)

Examine the temperatures and geological conditions of a location. Identify potential geothermal reservoirs in the study areas.	Widest overall focus. Desktop study based on existing data. Provides a targeted location for future study and development options based on temperature readings

Resource Evaluation

Technical study which examines porosity and permeability of identified reservoirs, examines the potential water content of a reservoir, provides estimations as to the energy content of the reservoir, and seeks to confirm the temperature data uncovered during the preliminary survey.	More targeted research. Combination of desktop and in-field activities. Provides greater level of clarity as to the available heat and/or electricity potential of the reservoir. Allows for a decision as to what style of geothermal project to pursue.

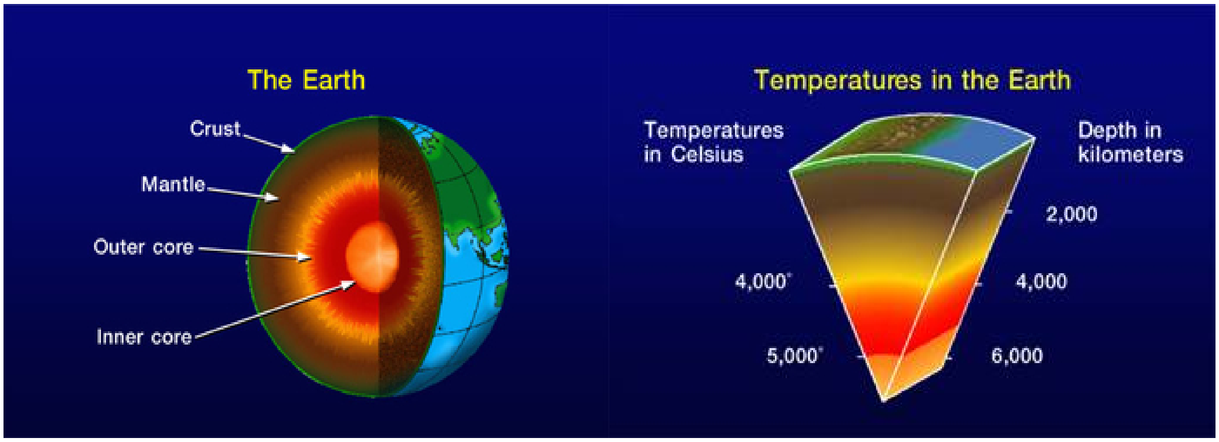
Project Decision

Geo-exchange	Direct Use	Power Generation

Project Development

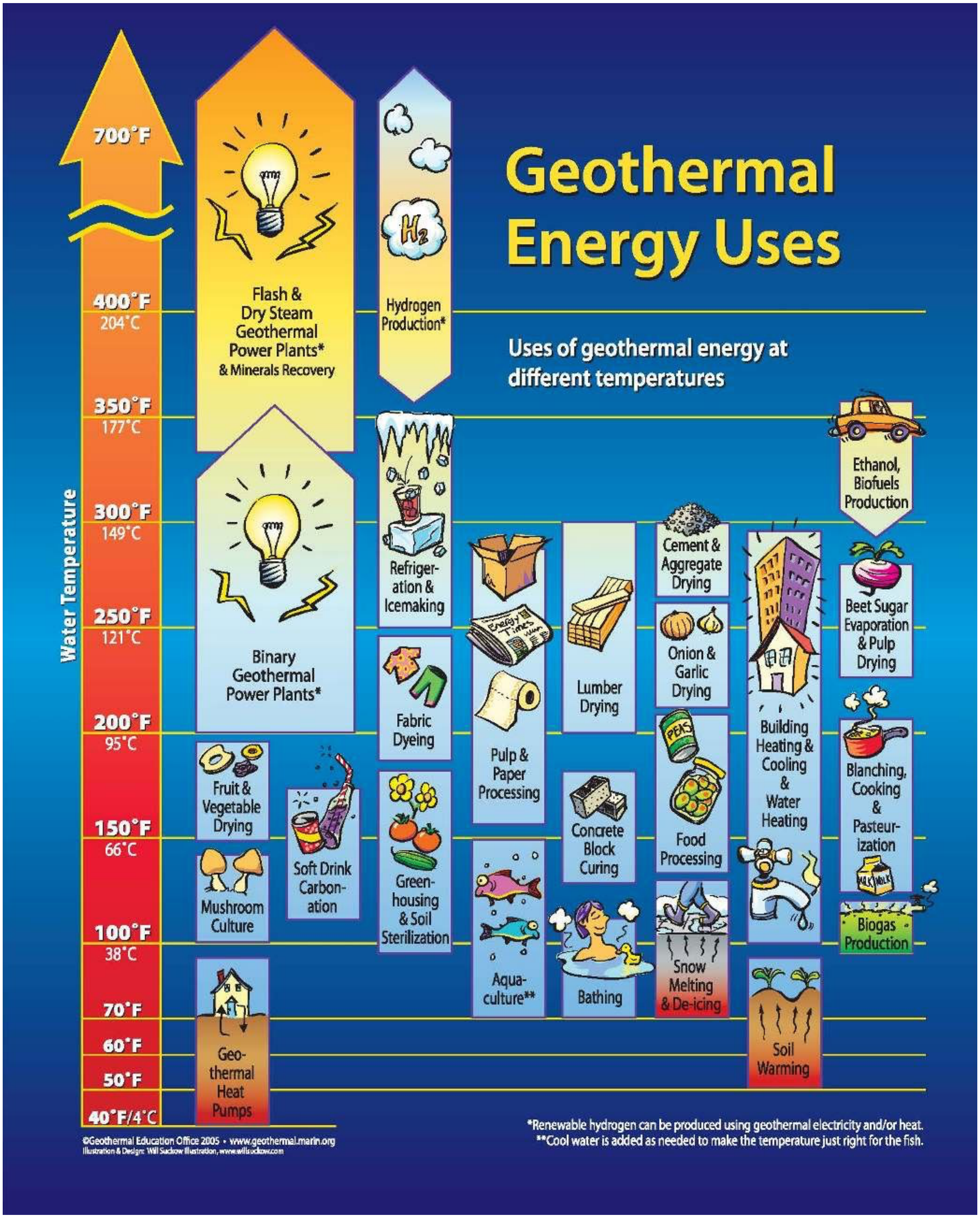
Front End Engineering Design (FEED) Study	Test Well Drilling/Well Testing	Project Construction (including well field development)	Commissioning & Operation

What is Geothermal Energy?



Simply put, geothermal energy is the heat generated and stored underneath the surface of the Earth. It is a clean and, with appropriate reservoir management, sustainable source of energy. Heat is constantly generated by the slow decay of radioactive particles, such as potassium-40 and thorium-232, in the Earth's core. Temperatures in the Earth's solid inner core can rise to almost 6,000ºC, for comparison, the temperature on the surface of the sun is approximately 5,500ºC. This heat then radiates outwards towards the Earth's crust creating, at extremely high temperatures, molten rock (magma) and, at progressively lower temperatures as the heat approaches the Earth's surface, hot water and hot rocks. The visible manifestations of this radiating heat are volcanoes, hot springs, geysers, and fumaroles. However, this romantic idea of geothermal energy use as the capping of volcanic vents that are spewing jets of steam into the air is not a reality in Alberta. Outside of a few mountainous hot springs, in the protected National Parks, Alberta's geothermal resources are locked under layers of sedimentary rock in subsurface aquifers, between 1 and 6km below the surface, waiting to be accessed in what is known as the Western Canadian Sedimentary Basin (WCSB). This basin underlies much of Western Canada including southwestern Manitoba, southern Saskatchewan, Alberta, northeastern British Columbia and the southwest corner of the Northwest Territories. The WCSB contains massive reserves of petroleum, natural gas, and coal along with water-saturated subsurface geological formations, known as Hot Sedimentary Aquifers (HSA). Much of the WCSB has been extensively explored and drilled to facilitate petroleum and natural gas production. However, the potential of the geothermal resources in the Basin to be used as both a source of direct heat and as baseload power generation is, as of now, still untapped.

How can geothermal energy be used?



Geo-exchange

Geo-exchange, or ground-source heating, is the process of extracting low-grade heat from the Earth and transferring it, through the use of a heat pump, into a space in order to provide heating for requirements such as building water or space heating. Geo-exchange systems can also be reversed during warmer periods and leech heat from water or air and discharge it back into the Earth, providing cooling. The geo-exchange process is often called geothermal heating/cooling but does not technically use traditional geothermal energy. Instead, the solar radiation from the sun is absorbed into the first few hundred meters of the Earth's surface, providing a near constant temperature below the frostline. Though the heat pumps do require a small amount of electricity to run, the use of this thermal energy for both heating and cooling in Alberta can provide utility bill savings by replacing heat generation through the burning of natural gas. Geo-exchange systems can be installed in individual residences but have also been installed at a larger scale in a number of residential and commercial developments in Alberta including the Mosaic Center in Edmonton and the International Terminal at the Calgary International Airport.

Edmonton's Mosaic Centre utilizes a geo-exchange system of 32 boreholes of 70m depth to provide heating and cooling to the building.

Direct Use

"Direct use" refers to a myriad of applications for geothermal resources that all share a common point: they require the heat present in geothermal fluids but do not require the conversion of this heat into electricity. Direct use applications are distinguished from geo-exchange as they access deeper and higher temperature resources that are geothermal rather than solar-thermal resources and generally do not require the use of a heat-pump to enhance the fluid temperature. The up-front capital costs of these geothermal systems can be higher than other forms of heating, due to the need to drill production and injection wells, but the ongoing operational costs are minimal due to the lack of any necessary fuel inputs. As well, because the use of geothermal energy for heating eliminates the need to generate heat through the burning of fossil fuels, particularly natural gas, direct use applications generate negligible carbon emissions and can be eligible for carbon offsets. An example of large-scale direct use is district heating in Iceland. District heating provides heat to 90% of Iceland's homes and the district heating utility in Reykjavik serves approximately 60% of Iceland's population.[1] A further example of direct use is the 5,000-acre Oserian Development Company's flower farm in Kenya. This farm, near the Olkaria Geothermal Field, utilizes both geothermal heating from a single well with temperatures between 130-160ºC and geothermal electricity from a pair of 2MW geothermal power plants. Oserian exports almost 400 million flowers to Europe annually, accounting for over 30% of the European cut-flowers market.

Oserian Flower Farm, Kenya.

[1] Gunnlaugsson, Einar et al., "85 Years of Successful District Heating in Reykjavík, Iceland", *Proceedings of the World Geothermal Congress 2015*, Melbourne, Australia, pg. 1-2

Electricity Generation

The energy contained in geothermal resources can be converted into electricity in dedicated geothermal power plants. At the end of 2016, the global installed geothermal generation capacity was 12.7GW or 0.3% of total global electricity generation.[2] There are currently three basic types of geothermal power plants, with hybrid plants that combine these basic technologies beginning to emerge. The choice between plant types is tied to the type of geothermal resource and the temperature of the geothermal fluid (geofluid). Geofluids are generally classified as high (180°C and above), medium (100-180°C), and low (80-100°C) temperature resources with fluids under 80°C being suitable for direct uses but currently unable to be used for electrical generation. The three types of geothermal power plants are: dry-steam plants (directly using geothermal steam at 235°C or above); flash plants (turning geothermal fluids of at least 150°C into steam to drive a turbine); and binary power plants (using hot waters above 80°C to encourage a working fluid to undergo a phase change into steam to drive a turbine). However, technological advancements are continually expanding the useful temperature range of geothermal resources and may lead to future expansions in the usage of lower temperature resources. Canada currently generates no electricity from geothermal power.

Hellishedi Geothermal Power Plant, Iceland. 303MW electrical capacity and up to 400MW thermal capacity from 500l/s steam at 180°C.

[2] IRENA (2017), *Geothermal Power: Technology Brief*, International Renewable Energy Agency, Abu Dhabi, pg. 6

Northern Alberta Opportunity

Geothermal energy is playing an increasingly important role as a source of baseload and emission-free renewable energy around the world. By the end of 2016, there was 12.7 GW of installed global geothermal electrical generation capacity and 23 GW of geothermal heating capacity.[3] This global rise in large-scale geothermal energy use has not yet translated to large-scale geothermal adoption in Alberta or Canada. Utilizing geothermal energy can reduce Alberta's GHG emissions, contribute to the diversification of the Alberta energy market, and increase innovation in green technology. The development of geothermal energy projects can position communities as environmentally-responsible, technologically innovative, and being at the leading-edge of the global energy transition.

The adoption of geothermal energy to replace existing power or heat production from carbon-based fuels, particularly coal and natural gas, could help Alberta achieve its goals of adding 5000 megawatts of renewable energy capacity and having 30% of the province's electrical load supplied by clean sources of electricity generation by 2030. Much of the renewable capacity will be taken up by wind and solar power. However, these resources suffer from intermittency, they only provide power when the wind is blowing or the sun is shining. A constant (base-load) source of power is needed to balance the energy mix as a hedge against intermittency. Geothermal energy is the only baseload renewable power source, providing constant power without contributing any GHG emissions to the Alberta energy mix.

Not only would a bourgeoning geothermal energy industry help Alberta succeed with its Climate Leadership Plan, but it would also create economic opportunities for the communities where geothermal facilities were located. The development and operation of geothermal heat and/or power facilities require many of the same positions as required for fossil fuel power plants, a diverse mix of jobs including drilling rig crews, engineers, geologists, management, administrative personnel, carpenters, plumbers, and construction labourers. The development of geothermal heat and/or power facilities would provide new opportunities, with little to no retraining, for the already highly skilled workforce previously employed in the Northern Alberta's oil and gas sector. Geothermal facilities also have a long lifespan. Power facilities generally contract to sell power for periods of 20 years, and a single plant has a life-cycle of at least 30 years. For the smaller communities that would likely supply the manpower for the construction and these facilities, new full-time positions would provide welcome

[3] IRENA (2017), *Geothermal Power: Technology Brief*, (International Renewable Energy Agency, Abu Dhabi), pg. 6 and REN21. 2017., *Renewables 2017 Global Status Report,* (Paris: REN21 Secretariat), pg. 54-55

employment stability. District heating facilities are generally even longer lasting, with the city of Boise, Idaho having the oldest continuously operating geothermal district heating system in the United States. Boise has used geothermal district heating continuously since 1892 to heat homes in the Warm Springs Water District and installed a separate, larger system in 1983 to provide heat for 81 buildings in the downtown (353,000 m^2 of floor space). This extensive lifespan for geothermal facilities results in stable on-site employment not tethered to fluctuating electricity costs or the cessation of resource extraction like in various coal communities across Alberta.

Research Project

A key issue for communities in determining their development opportunities is to have access to comprehensive, up-to-date, and geographically organized information on resources in their locality. When assessing the geothermal resource potential of Alberta, there are a number of considerations that need to be investigated: the depth of the resource, resource temperature, specific geological characteristics including the porosity of rock or sediment, and flow rate of any geothermal fluids. Knowledge of the temperature at depth, the depths and thicknesses of various geological formations and the likelihood of these formations containing large amounts of accessible fluids can substantially de-risk expensive exploratory activities. Terrapin has been contracted to conduct an initial geothermal resource evaluation for a representative sampling of northern Alberta communities.

The focus of this project is to create location-specific research reports that provide a high-level technical overview of the geothermal resource potential of the studied areas, considering both the potential temperatures to be found and unique geological considerations in the study locations. These reports will contain a location-specific resource overview investigating both the temperature and geology within the study area. The reports will also include a subsurface temperature map indicating potential hotspots/development opportunities to aid in future land-use planning. They will also include a temperature gradient map, which shows the increase in subsurface temperature in relation to increased depth. A list of representative wells with their current status and current operator listed will be provided along with a discussion as to any unique geological features of the study regions. Then recommendations as to the best course of action to utilize the geothermal resources of the study regions will be presented (i.e. geo-exchange, direct use, or power generation). These recommendations will also include next steps to be taken in order for municipalities to evaluate potential geothermal resource development opportunities.

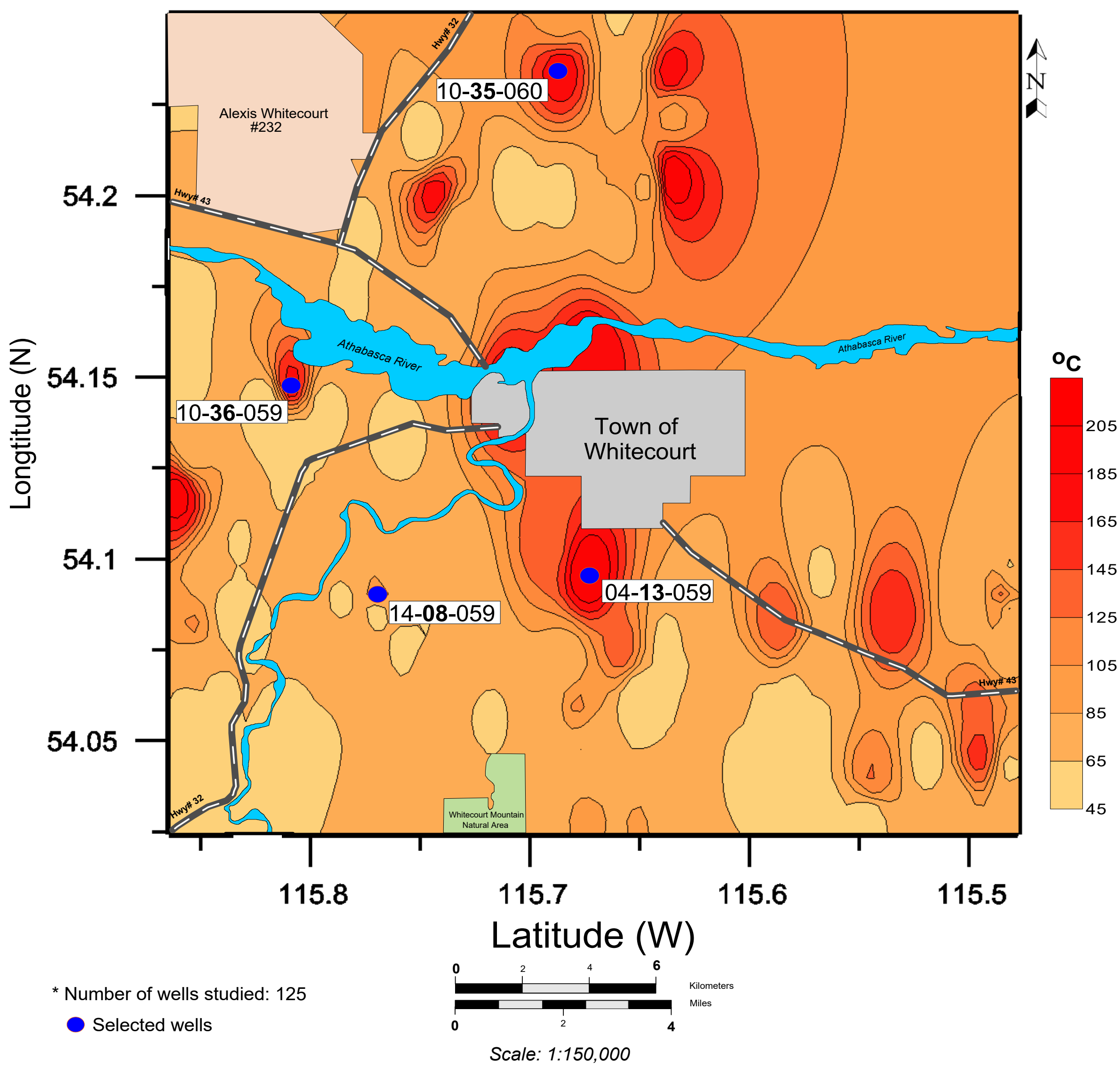
RESEARCH RESULTS: WHITECOURT

CONTEXT

Terrapin Geothermics was engaged to evaluate the leading geothermal energy development opportunities in Alberta. This report outlines key technical data on your region's geothermal potential:

HEAT MAP

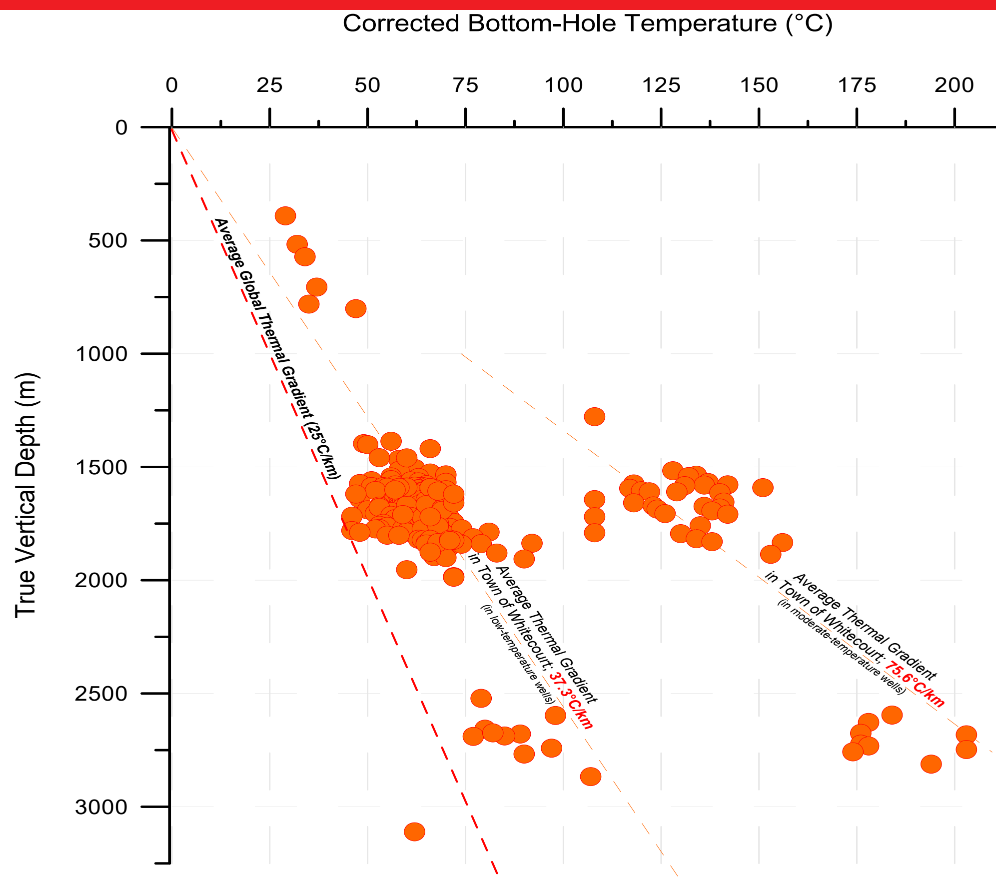
Corrected Bottom-Hole Temperature Map
(at Depths Greater than 1.7km - Town of Whitecourt)



RESEARCH RESULTS: WHITECOURT

TEMPERATURE GRADIENT

The geothermal gradient refers to the expected increase in temperature for each kilometer deeper you drill. The higher the geothermal gradient, the better the economics of a potential project will be.



TOP 4 REPRESENTATIVE WELLS

Well ID	Current Depth (mVD)	Depth to Hot Formation-Swan Hill F. (m)	Corrected Bottom-Hole Temperature (˚C)	Expected T. at Base of the Target Formations (˚C)	Current Operator
100/04-13-059-12W5/00	2746.2	-55.2	203	215	Devon Cda Corp
100/10-35-060-12W5/00	2730.4	-123.2	178	200	-
100/10-36-059-13W5/00	2756.3	-139.9	174	200	Outlier Rsrcs Ltd
100/14-08-059-12W5/00	2865.7	-172.9	107	120	Progress Enrg Cda Ltd

KEY TAKEAWAYS

- The ideal formation for geothermal production in your area is the **Swan Hills** formation.
- There are two temperature data sets surrounding the town of Whitecourt. The low-moderate data set indicates a temperature gradient of **37.3ºC/km** with an average bottom hole temperature of **62ºC**. The moderate-high data set shows a gradient of **75.6ºC/km** with an average bottom hole temperature of **142ºC**.
- The moderate-high data set indicates the potential for **geothermal power generation** in the Whitecourt area.

RECOMMENDATION & NOTES

Our research of Whitecourt and the surrounding area has identified two distinct data sets related to Bottom Hole Temperature measurements: a low-moderate grouping and a moderate-high temperature grouping. The moderate-high grouping is amongst the strongest geothermal potential that our geology team has discovered in Alberta and the linear pattern in the distribution of hotter wells is indicative of possible geological anomalies in the area. It is very strongly recommended that Whitecourt pursue further research in this area. Specific studies should expand the scope of work to the surrounding areas, seek to validate this initial temperature and geological data, map fluid flows within target formations and create detailed energy potential models to assess the magnitude and viability of this seemingly large opportunity.