10/16/2018

# FEED Study: Hinton Geothermal District Energy System

Epoch Energy Development Inc.

REPORT PREPARED AND SUBMITTED BY
EPOCH ENERGY DEVELOPMENT

# Executive Summary

Epoch Energy is pleased to provide this Front-End Engineering Design (FEED) report to the Town of Hinton. The purpose of this FEED project is to evaluate the economic and technical viability of a geothermal-based District Energy System.

Goals of the study

The Town of Hinton is investigating the opportunity to provide its citizens with a clean, long-term heating option for its main municipal facilities via a District Energy System, with expansion capability to include other commercial/industrial buildings. The study aims to determine the viability of supplying the District Energy System with geothermal heat sourced from repurposed oil and gas wells. The development of a District Energy System would reduce Hinton area greenhouse gas (GHG) production and provide long term stable heat energy pricing.

Key Findings

1. The original scope of the FEED project had to be modified due to the increased complexity encountered. Hinton has a tremendous subsurface heat and geothermal resource potential, but with a higher degree of technical complexity for development than other locations in Alberta. The technical complexity of developing the geothermal resource increases the capital required, which at the current market conditions does not make it viable for a stand-alone heat project. Developing the geothermal heat resource for the District Energy System was meant as a first step to de-risk the environment for larger, more capital-intensive geothermal electricity generation development. Since the pre-FEED was performed, the power market in Alberta has changed significantly and created a new opportunity for Hinton. Power is attractive in that the combined energy and transmission power prices are forecasted to almost double to $130/MWhr by 2022. Since new drilling is required, and because power prices have structurally increased, evaluating a combined heat and power project is now the best first step forward for Hinton's geothermal development strategy. **Based on this, it is recommended that a study be undertaken to review a combined geothermal heat and power plant to justify the capital required to develop the technically complex but significant heat resource in Hinton.**

2. For a successful District Energy System, a substantial heat load from its customers in a concentrated area is imperative. The Town of Hinton is laid out in such a way that the buildings with significant loads are fairly spread out. Additionally, there is a change in elevation through the town from north to south that increases the complexity of designing a District Energy System due to handling pressure changes within the pipe. Combined, these issues are substantial compared to the energy requirements of the Town of Hinton, which is relatively low. A District Energy System was designed for the Town of Hinton that encompassed all of the identified potential customers. The project team took the design one step further and developed an Optimized District Energy System to improve project financials by removing the least profitable areas of the system. The Optimized design consisted of only a portion of the total customer base, and subsequently the overall cost. **The energy density in the core of Hinton is low, but with infrastructure planning utilizing open and available land for future heat-**

**intense industries (i.e. greenhouse, brewery, etc.) this energy density can be increased in the core of Hinton.**

3. To properly design and cost a District Energy System, customer buildings need to be accessed to assess their current heating systems and infrastructure. Obtaining utility bills that demonstrate actual heating energy load is also greatly beneficial. Lack of access to buildings and information in Hinton was a key issue that forced a number of assumptions to be made. **Further studies and detailed engineering will require confirmed building specifics to satisfy design needs.**

4. Geothermal was not shown to be an easily accessible, viable heat source. **If the Town is solely interested in providing low-carbon, sustainable heating, an alternative viable heat source will need to be identified to supply the designed District Energy System.**

Upstream - Geothermal Resource Production Summary

The purpose of the Upstream portion of the FEED project was to determine the technical feasibility of repurposing existing oil and gas wells near the Town of Hinton for geothermal heat extraction. Due to the large number of wells that exist near the Town, the project team was able to complete a detailed geological assessment of reservoirs varying from about 2,000m to more than 6,000m, covering four different geological reservoirs. Based on the detailed geological assessment, by reviewing data within an approximate radius of 17 km of the Town of Hinton the project team determined that the necessary technical conditions needed to produce geothermal heat, such as porosity, permeability, areal extent, water saturation and flowrates did not exist within the immediate vicinity of the town. In addition, there is significant risk of encountering dangerous levels of hydrogen sulfide ($H_2S$) in many geological formations. Also, the changes in formation type over a short distance (<100m) means there would be a lack of communication between an injection and production well that would prevent the use of reservoir enhancement, i.e. fracking, to improve the technical conditions. Finally, the most favourable wells, in terms of location to Hinton, are not available due to the current well owner's interest in maintaining them as solely oil and gas wells.

The option of drilling new wells was explored, including a two-well injection/production system and the case of a single well injection/production system. Several well depth and shape profiles were explored. It was determined that the most feasible configuration was a single well system, using closed-loop circulation, that has a total length of 4300m, with a 500m long horizontal section, resulting in a vertical depth of 3650m. The approximate cost of this system is $6 million. This cost is approximately 10-20 times more than repurposing an existing well, which makes the project economics more difficult to satisfy when based solely on District Energy System heat supply.

The final conclusion based on the technical analysis is that there are no viable oil and gas wells that can be repurposed to produce geothermal heat in the immediate vicinity of Hinton. Local geological complexity and pursuant high drilling costs make a stand-alone heat project not economically viable. These findings expose a local phenomenon specific to the Town of Hinton do not reflect the quality of the geothermal resource elsewhere in Alberta.

Midstream - District Energy System Summary

The objective of the Midstream portion of the FEED project was to design the District Energy System. The design includes all of the components necessary to transport the heat from a District Energy Centre to customer buildings. The design of the Midstream portion is heat agnostic and can be applied to any town or city. A District Energy System for Hinton that is heated by other sources (biomass, natural gas, waste heat recovery) is both technically feasible (as shown in the Midstream Section) and economically feasible (as shown in the Financial Analysis).

There are factors that make designing a District Energy System more complicated, such as lack of concentration of heating loads, profitability of areas within the system, and topography. It is important to balance these potentially costly factors with the heating needs of a location in order to justify their cost. Hinton's heating loads are spread out over a large area and there is a marked elevation change between the southern and northern ends of the townsite. The elevation change would require piping able to handle large changes in pressure, and additional pumping, which further impacts the economics of the system.

The scope of the FEED project was expanded to 53 buildings from the initial 12 covered by the pre-FEED study, resulting in a total heat load of 11,940kWth (discussed further in the Downstream section). However, as this heat load is dispersed throughout the downtown core and not concentrated in one area, 11 iterations of the pipe network were tested to determine the optimal layout for the system. The final pipe network design has consumers located along four primary branches, centered at the Friendship Centre where the District Energy Centre would be located.

This design with all 53 buildings was called the "Complete" District Energy System (see Figure 1), which consisted of four branches going NW, NE, SE and SW from the District Energy Centre. The Complete system was then optimized to eliminate areas that were unprofitable. This "Optimized" District Energy System configuration (see Figure 2) involved only branches going NW and NE only.

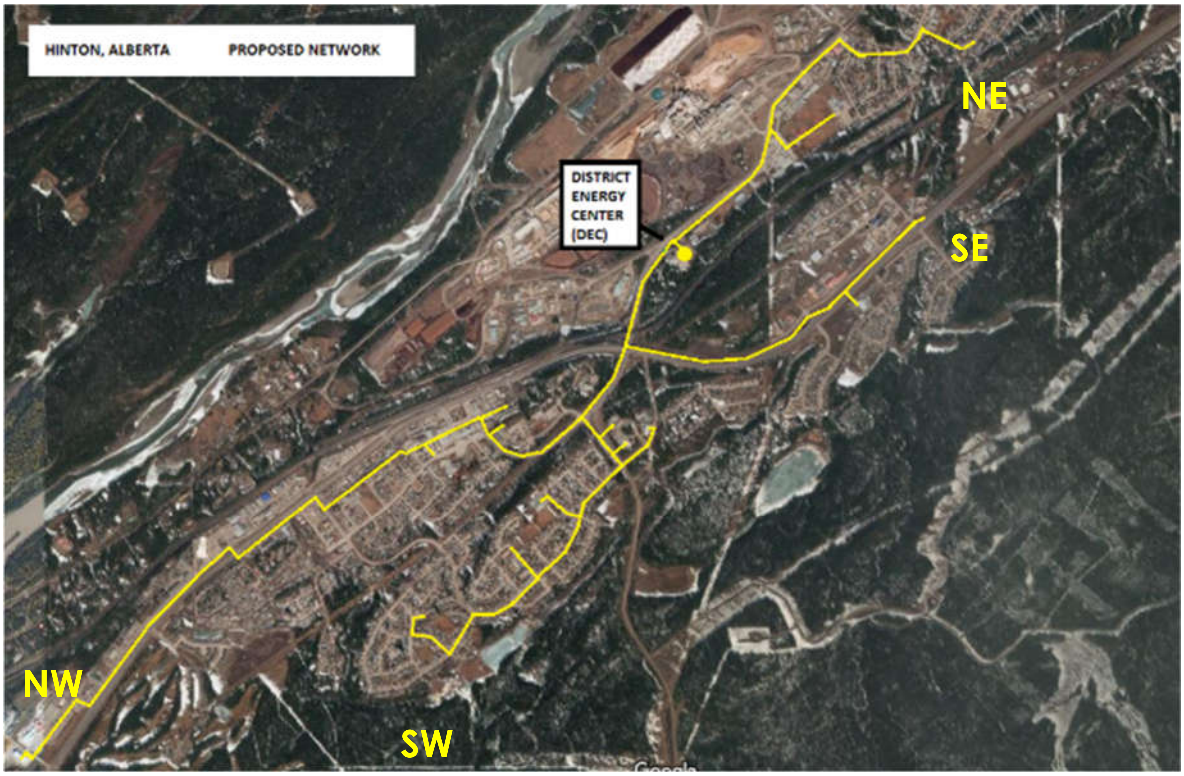



**Figure 1 – Complete Hinton District Energy System, Proposed Distribution Network (53 Consumers, ZONES 1 to 4)**


**Figure 2 – Optimized Hinton District Energy System Distribution Network (38 Consumers, ZONES 1 and 2)**

Downstream – Building Interconnection Summary

The objective of the Downstream analysis was to define the components required to connect each building to the District Energy System and to determine the overall tie-in design. For buildings to tie into the system they will require a hydronic system, which uses the circulation of hot water for space heating. For building systems that do not currently have a hydronic system and are therefore incompatible with a District Energy System, building modifications were also determined. In addition, cost estimates for each building were calculated, accounting for both the estimated cost required for the building to connect to the District Energy System, and the estimated cost to convert to a hydronic system where necessary. Based on the 53 buildings used within this project, individual building loads were determined, and the subsequent total required system load was used within the Midstream section to design an appropriately sized system.

The project team sought access to the 53 buildings included in the project in order to view existing heating components. The team was only able to obtain access to 16 of the buildings, the majority of which were municipally owned. Eight of the buildings accessed provided their monthly heating load requirements in the form of utility bills. Access to the remaining 37 buildings required permission from non-regional management or levels of government, which was not granted or provided in time for this project.

For the buildings accessed, both hydronic and non-hydronic heating systems were observed and the monthly heat load varied from 20kW to 1024kW. The project team was able to approximate that at least 16 buildings had hydronic systems and would be able to directly connect to the District Energy System. The team confirmed that two of the buildings had non-hydronic systems and it was conservatively assumed that the remaining 35 also had non-hydronic systems as well and would need additional tie-in components. The final heating load was determined based on 38 buildings of the Optimized system design and found to be approximately 9,090kW.

The total cost for the Downstream section was estimated to be $11.8 million for the Optimized System of 38 buildings, including $560,000 for tie-in costs and $11.3 million for costs to convert existing systems to hydronic.

Financial Analysis Summary

The purpose of the Financial Analysis was to assess the financial viability of the project. Upstream, Midstream and Downstream sections were analyzed individually.

*Upstream*

The Upstream geotechnical analysis showed that a new well would need to be drilled in order to access the deep geothermal heat to supply the Hinton District Energy System. Drilling a new well is much more expensive than repurposing an existing well and makes project economics challenging to satisfy. Based on the heat requirements of the final design of the Complete Hinton District Energy System with all 53 buildings, the total cost of the Upstream section is approximately $9.4 million dollars. This estimated cost is based on one deep well providing the heat for the entire system, and a system heat load of approximately 117,715 GJ/yr with potential for expansion and additional sidewalk heating loads.

It was determined that at the current market conditions, drilling a technically complex geothermal well strictly for a stand-alone heat project is not viable.

*Midstream*

The Midstream section compared a District Energy System to the natural gas heating system currently utilized by Hinton, and provided key financial measures such as payback period, net present value, and internal rate of return. It also compared the financial performance of the Complete District Energy System to the Optimized system.

The key findings are:

- To increase the viability of the project, the borrowing cost and capital cost would need to be decreased. Decreasing the borrowing cost can be achieved through issuing municipal bonds to reduce the interest rate below 4%.
- Increasing revenue (i.e. raising the Price per GJ charged to customers) will decrease the payback period. Increasing pricing above existing natural gas costs may, however, be perceived negatively by potential consumers as they will no longer have any financial incentive to enroll in this project.

Based on the midstream financial analysis, the best scenario is if municipal bonds are used at an interest rate of 2%, with a price of heat of $10/GJ and a capital cost reduction of 30% due to grants and cost sharing such that the payback period is 15 years. This is midstream-specific and does not include the cost of the well or the individual downstream building infrastructure.

*Downstream*

The Downstream section explored costs of buildings tying into the District Energy System. Cost estimates for all 53 customers were developed based on whether they had a hydronic or non-hydronic system. The cost of tying in a building with an existing hydronic system ranged from $5,000 to $37,000. Tie-in cost is based upon the load of the consumer and goes up accordingly with increasing load. Buildings without hydronic systems will require retrofitting for conversion to a hydronic system with the estimated cost dependent upon the size of the building (i.e. Price per Square Foot). These costs ranged from around $133,000 to upwards of $1.6 million. Only rough estimates could be made since information was not provided for all of the buildings.

Acknowledgements

This FEED project involved a number of leaders in their field of expertise; we are grateful to have such a breadth of knowledge on the project.

Project development was led by Epoch Energy Development.

The FEED project team was led by TM Gunderson with Epoch Energy.

On the Upstream aspects of the research, we would like to thank Shannon Acton, Christine Wennekers with OTC Consulting Inc., Dave Brown with Frontier Project Solutions Ltd., Michael Skaf with Enerpro Engineering, including policy assistance from Stephanie Nichols at Enerpro Engineering.

Midstream analysis and design was provided by the following at Enerpro Engineering: Ujay Kim, Steven England, Michael Skaf and Saul MacPherson.

Analysis on the downstream interconnection was provided by Jill Pederson with Williams Engineering, Michael Skaf of Enerpro Engineering; on-location support was provided by Flurina Deagle.

Regulatory and policy assistance was provided by Stephanie Nichols at Enerpro Engineering.

Financial Analysis was completed by Boris Stojanov with Stream Systems.

The report was compiled by Ashley Derry with Epoch Energy.

This FEED project was financially supported by the Government of Alberta, Western Economic Diversification and Alberta Innovates.

Disclaimer

This report was prepared by Epoch Energy for the Town of Hinton. The material in it reflects our professional judgement based on previous experience, research, engineering principles, and visual observation. Assumptions presented in this report should be reviewed, and any discrepancies brought to the attention of the appropriate Epoch contact. All results are estimates with a margin of uncertainty and are not guaranteed. Any use which a third party makes of this report, or any reliance on or decisions made based on it are the responsibility of such third parties. Epoch Energy accepts no responsibility for damages, if any, suffered by any third party as a result of the decisions made or actions based on this report.

Some assumptions have been made for parameters of the operation or performance of equipment and materials. The use of these values and parameters shall in no way imply endorsement of a specific product or manufacturer.

This report involves matters that cannot be precisely determined. Calculations generally depend on subjective judgements and uncertainties that increase with forecasting into the future. Much of the information available is based on estimates and assumptions provided by third parties. Accordingly, this report should not be relied upon as guaranteeing a specific result; instead, it is a means of assessing the relative desirability of alternative course of action, a range of investment requirements, and anticipated income or cash flow, as the case may be.

Epoch Energy reserves the right (but will be under no obligation) to review all calculations referred to in this right and, if considered necessary by us, to revise them in light of any new facts, trends, or changing conditions that become apparent to us after the report is published.

Interested parties are cautioned that decisions of whether to rely on the accuracy and completeness of the information in this report, and whether to invest or provide financing, are theirs alone and Epoch Energy will not assume any responsibility for losses resulting from such decisions. Decisions to invest or provide financing will likely require additional information beyond the information contained within this report.

Alberta Innovates and Her Majesty the Queen in right of Alberta make no warranty, express or implied, nor assume any legal liability or responsibility for the accuracy, completeness, or usefulness of any information contained in this publication, nor for any use thereof that infringes on privately owned rights. The views and opinions of the author expressed herein do not reflect those of Alberta Innovates or Her Majesty the Queen in right of Alberta. The directors, officers, employees, agents and consultants of Alberta Innovates and the Government of Alberta are exempted, excluded and absolved from all liability for damage or injury, howsoever caused, to any person in connection with or arising out of the use by that person for any purpose of this publication or its contents.

# Glossary & Acronyms

AER – “Alberta Energy Regulator”. “A regulatory body with a mandate to provide for the efficient, safe, orderly, and environmentally responsible development of Alberta’s energy resources.” [1]

BHT – “Bottom Hole Temperature”. The temperature measured at the total depth of a drilled well.

Casing – “A pipe that is assembled, inserted and cemented into a section of a recently drilled wellbore.” [2]

$CO_2$ – “Carbon dioxide”. It is a naturally occurring, colourless, odourless gas that is vital to life on Earth.

CSP – “Community Sustainability Plan”. The “Hinton Community Sustainability Plan builds on the positive aspects of [the] community today and addresses the challenges [the] community will encounter in the future” [3]. It is a living document that provides the means and strategy for managing change and steps to move forward.

DE – “District Energy”. It is a means of transmitting thermal energy sourced from a number of potential heat supplies through an underground piping loop connecting and supplying multiple buildings. Compared to conventional heating systems, district heating is more efficient, has fewer emissions and is more cost-effective.

Dead head pressure – A situation that occurs when the pump's discharge is closed either due to a blockage in the line or an inadvertently closed valve. This will cause the pump to go to its maximum shut-off head and the fluid will be recirculated within the pump resulting in overheating and possible damage.

DEC – “District Energy Centre”. The central plant that receives hot water sourced from deep wells and delivers it to the distribution system (District Energy System, or DES).

DES – “District Energy System”. The distribution system of underground piping and interconnections (heat exchangers) that transmits the thermal energy coming from the District Energy Centre (DEC).

Direct Use – a term used to describe when geothermal energy is used to deliver heat directly for its intended use for applications such as greenhouse food production, building heating, industrial/commercial processes, etc.

Downstream – In a District Energy System this term refers to the portion of the system responsible for delivery of heated water directly to the buildings via units such as heat exchangers.

Facies – A geological term used to describe a body of rock that has consistent properties and characteristics.

FEED – “Front End Engineering Design”. A basic engineering study conducted in order to define technical issues and estimate investment cost.

Formation Top – A geological term used to describe the location/depth at which the uppermost extent of a geological formation can be found.

GeoDH - “Geothermal District Heating”. The term is analogous to District Energy System (DES) but is used instead by Europeans.

Geothermal – “Earth heat”.

Geothermal gradient – The increase in temperature with increasing depth beneath the Earth’s surface.

GHG – “Greenhouse Gas”. Greenhouse Gases are a group of compounds that are able to trap heat in the atmosphere.

GJ – “gigajoule”. A measure of energy, the equivalent of 1,000,000 Joules.

HVAC – “Heating, Ventilation and Air Conditioning”.

Hydronic – A heating system in which heat is transported by circulating water.

IRR – “Internal Rate of Return”. A discount rate that makes the NPV of all cash flows from a project equal to zero.

LCOE – “Levelized Cost of Energy”. “The LCOE determines how much money must be made per unit of [energy]… to recoup the lifetime costs of the system. This includes the initial capital investment, maintenance costs, the cost of fuel for the system (if any), any operational costs and the discount rate.” [4]

Midstream - In a District Energy System this term refers to the portion of the system responsible for receiving heated water at the District Energy Centre and distributing it throughout the network via underground piping.

MD – “Measured Depth”. The total length of the well.

MW – “megawatt”. A measure of energy, the equivalent of 3.6 gigajoules.

MWth – “megawatt thermal”. Quantifies the rate of thermal energy transfer.

NPV – “Net Present Value”. The difference between the present value of cash inflows and the present value of cash outflows.

O&G – “Oil and Gas”.

Peak Heating – Times during which the heating load on the system is at its maximum, when the temperature outside is at its coldest.

Perforations – A term referring to holes that are created in well casing that connects the well to the reservoir.

Permeability – A geological term used to describe the amount of resistance to the flow of a fluid through a rock. High permeability allows water to flow easily through a rock body.

Porosity – A geological term used to describe the percentage of void space in a rock; the small spaces between the mineral grains forming a rock that hold substances such as air, water, oil/gas, etc. High porosity allows a rock to contain more water.

Production Liner (or tie-back string) - A type of casing that is inserted inside of a previously set casing that has already been cemented in place.

Radiogenic Heat Production – One of the two main sources of heat found within the Earth. Through this process heat is produced via the natural radioactive decay of isotopes present within the Earth's crust.

Repurposing/ Recompletion – A term used for wells where modification will be performed on the well bore to access a different formation than was originally produced from.

Sour – Refers to natural gas or other gas containing $H_2S$, or hydrogen sulfide.

Static pressure – The amount of pressure exerted by a fluid that is not moving.

Tie-back string (or production liner) - A type of casing that is inserted inside of a previously set casing that has already been cemented in place.

TVD – "True Vertical Depth". It is the measurement from the surface of the Earth where a well is located in a straight, perpendicular line down to the bottom of the well.

Upstream - In a District Energy System this term refers to the portion of the system responsible for the production of heated water from wells or other heat sources.

Wellbore – A term used to describe the actual hole that forms a well.

# Table of Contents

# 1 Introduction

## 1.1 Background

The Town of Hinton is located in west-central Alberta and lies in the foothills at the eastern edge of the Rocky Mountains. Self-described as the “hub of the Northern Rockies” [5], Hinton’s economy is based on industries taking advantage of abundant natural resources in the area. The community takes their responsibility for managing these resources seriously, as demonstrated by the existence of respected and in-demand local educational and training institutions, as well as their Community Sustainability Plan.

In 2011 the Town of Hinton released the initial version of the comprehensive and progressive Hinton Community Sustainability Plan, which is in essence the true origin of this project. The Plan is a living document that lays out the ideal vision that members of the community would like to realize by year 2040. Furthermore, the plan outlines the goals and steps necessary to meet those ideals. The Hinton community has taken steps to meet its sustainability goals by investigating the feasibility of installing a geothermally-heated District Energy System (DES)- a system that supplies heat via a piping network to numerous buildings using heat sourced from deep within the Earth. Research conducted by the University of Alberta highlighted Hinton as one of the best sources of geothermal resource potential in Alberta. DES are one of many uses for geothermal heat, including but not limited to power generation, industrial and commercial heating applications such as timber drying, fish farming, beer brewing, and sidewalk/road snow and ice melting.

On October 12, 2016, the Town of Hinton approved this report’s predecessor, the District Heating Pre-FEED (Front End Engineering and Design) study, as part of the community’s investigation into reducing its energy costs, energy consumption and greenhouse gas (GHG) emissions associated with a number of the key municipal buildings. The pre-FEED was instigated as part of the larger analysis ongoing by the University of Alberta’s regional research on the geothermal resource potential in the Hinton area. It provided a high-level evaluation of the economic and technical viability of a geothermal-based DES. The pre-FEED study concluded that further investigation was warranted and moving into a FEED (front end engineering and design) project was recommended.

On February 6, 2018, Western Economic Diversification Canada, Alberta Innovates and the Government of Alberta announced joint funding for a FEED project. This FEED project is a more in-depth analysis of the technical and economic feasibility of developing a geothermal-sourced DES for the Town of Hinton. It includes determining the character and extraction of the subsurface heat source, finalizing the scope of the district heating facilities, developing a detailed capital and operating cost model, and building a comprehensive financial model.

A municipal DES for heating can operate utilizing any number of low-carbon heat sources and has the potential to significantly reduce GHG emissions and provide long-term stable pricing compared to the current heating infrastructure dominated by natural gas supply. The concept of a DES that is supplied with a renewable energy resource is well aligned with the Town of Hinton’s Sustainability plan for a “bold & vibrant future” [6]. The long-term nature of developing a sustainable district energy system is synergistic with the community vision: "We want to leave our grandchildren a community that will sustain them, and their grandchildren to come." [6]

Past and present research suggests the Hinton area is one of the most attractive locations in Alberta for geothermal project development, specifically for larger-scale projects such as power generation*. In addition, the large amount of local oil and gas (O&G) activity provides real subsurface knowledge, which eliminates speculation of the deep geological environment. Furthermore, nearby wells near the end of their gas producing life present the opportunity to be repurposed for geothermal heat extraction, thus avoiding expensive drilling costs. However, this opportunity necessitates that appropriate wells are in close proximity to Hinton, and the willingness of operators to release those wells.

This FEED project has three main technical sections: Upstream, Midstream and Downstream. Upstream involves the subsurface research into the geothermal resource, including the geology, reservoir engineering and drilling engineering, and also the process by which the heat is extracted and transmitted to the District Energy Centre (DEC). The Midstream section begins at the DEC where heat gets distributed to the piping network, the piping network itself, and individual heat exchanger stations located at customers sites. The Downstream section includes all components required to connect each building to the DES loop.

## 1.2 Objectives & Scope of Study

The original scope of this FEED project was specifically limited to the following:

- District Energy System (DES) design for the Town of Hinton,
- Source of heat would be geothermal from the subsurface,
- The heat would be obtained by repurposing pre-existing oil and gas wells.

As detailed in the Upstream section (Section 2), procurement of existing wells in the Hinton area is impractical due to both geological constraints and inability to obtain wells from current owners. To adapt to these obstacles the project's scope was broadened to include assessing the feasibility of drilling new wells to source geothermal heat for the DES.

The following list of Technical, Economic and Strategic Objectives were identified as needing to be met in order for the FEED project to be considered successful, and were identified in accordance with the initial well-repurposing scope in mind. As the scope changed to different well configurations and capabilities, many of the Technical Objectives were no longer directly applicable.

Technical Objectives

1. Well heat extraction of 3 MWth
2. Flow rate ability of 5 L/s
3. Uptime of 90%
4. Casing thermal rating and condition to handle 120°C of brine fluid with a specific gravity of 1.20

---

* *The leftover waste heat from geothermal power generation provides the opportunity for supplying heat to supply a DES and/or other heat-intensive ventures.*

5. Within 5 km of Heat Substation crossing crown land or Transportation Utility Corridor
6. Water Zone – abandon the hydrocarbon zone, re-perforate in water zone, area geological review
7. Downhole Heat Exchanger – if not perforating the water zone to surface, the ability to acquire heat to reach 3 MWth
8. Optimization of the heat distribution loops to balance cost per km with heat load customers to meet objective of $750/m installed

Economic Objectives

1. Confirmation of 5-7% IRR at 100,000 GJ
2. Committed customers to achieve minimum heat load of 100,000 GJ
3. Project costs identified, with vendors quotes +/- 20%
4. Dollar value of sales tied to the knowledge-based product, process, service or technology commercialized
5. Small and medium enterprises (SME) employment growth
6. Number of SMEs assisted

Strategic Objectives

1. Alberta Energy Regulator (AER) approval of/regulation of project's plan to allow start of construction in Q2 of 2019
2. Attraction of new industry with a long-term heating cost (greenhouse installation)
3. Discussion of lessons learned, technical gaps and further opportunities

## 1.3 District Energy Overview

A district energy system (DES) is a thermal energy distribution system that distributes heat to multiple buildings at a community scale. The process involves using a closed network of pipes to circulate heated fluid throughout the community delivering heat to buildings attached to the system. The DES provides heat for multiple uses beyond space heating. The DES is attractive for heat intensive commercial and industrial processes, such as timber drying, fish farming, beer brewing, and for melting of snow/ice on sidewalks and roads.

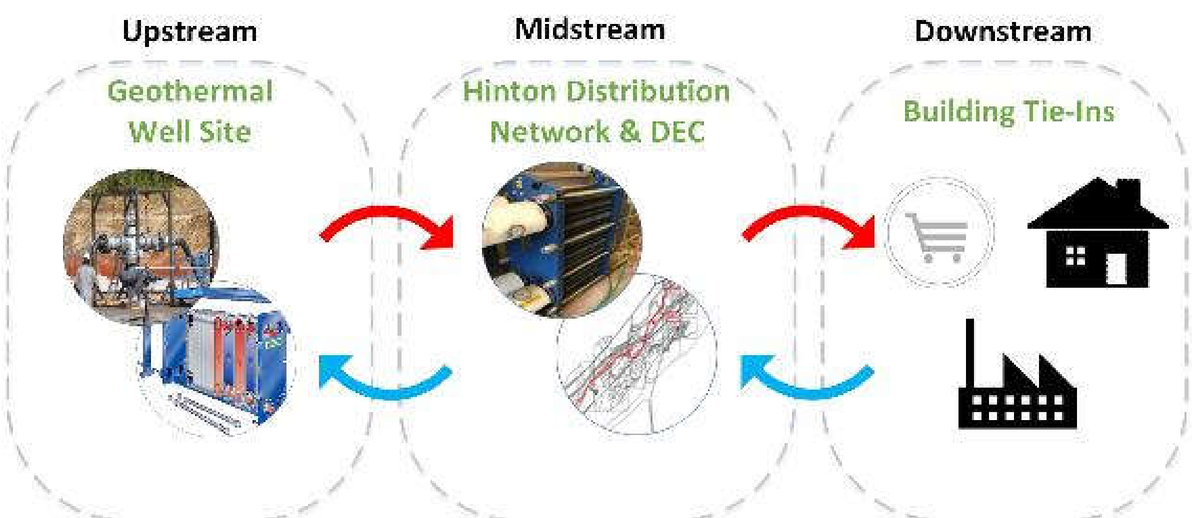



**Figure 3 - District Energy System Overview**

A DES consists of: a heating and/or cooling centre, referred to as the district energy centre (DEC), a thermal network of pipes connecting groups of buildings, and, in the case of the geothermal-sourced DES, the piping from the wellhead to the DEC.

A conventional DES are heat source agnostic, meaning it does not matter by what means the heat is produced. As such it can utilize natural gas or low-carbon energy sources such as geothermal energy, solar thermal, sewer heat, biogas, and biomass (like timber waste). In all cases, the proximity of the heat source to end users is a crucial factor to attractive economic return in DES.

District energy is a reliable and proven technological approach used by cities all around the world, including many in North America. Development of DES is a growing opportunity for cities and communities with a concentration of buildings and residents, like downtown cores, medical and educational campuses, and government and military installations.

For a successful project, the following key variables must be weighed when considering the installation of a DES:

1. Large heating loads located in a centralized area.
2. Proximity of heat source, geothermal or otherwise, to the DEC
3. Community engagement
4. Infrastructure Plan with Utility Line Assignment that DES can be incorporated into
5. Municipal Sustainability Plan in place with emphasis to reduce GHG emissions
6. For municipally-owned systems, a large enough population to justify costs of system

### 1.3.1 Advantages of District Energy Systems

There are number of key advantages to district energy systems, many of which stem from the economies of scale associated with centralizing heat infrastructure.

**Lower Levelized Cost of Energy**: Centralized heating systems offer cost savings on equipment requirements and capital infrastructure. New customers can avoid the cost of an in-building HVAC system. Operating and maintenance costs are reduced due to equipment efficiencies and optimized operations. The larger capital spend allows for negotiation of lower financing rates, and longer capital amortization terms.

**Increased System Reliability:** In comparison to individual commercial or residential heating systems, DES are designed to be utility grade, have greater redundancy built into the system, and are managed by trained professionals.

**Reduced GHG Emissions**: The economies of scale of developing a centralized heating system dramatically increases efficiencies and the DES can be integrated into non-fossil fuel-based heating sources (i.e. renewable energy sources like geothermal heat, biomass or solar thermal).

**Long-Term Stable Pricing:** In a DES, the initial capital cost of installation is amortized over decades, and the customer/revenue stream is pooled over a multitude of customers. This creates the opportunity for long-term pricing contracts and greater energy price stability. With the integration of a renewable energy resource as the primary source of energy, versus volatile commodity-based fossil fuel pricing, the DES is able to offer long-term fixed price energy contracts to customers.

**Flexible Design:** DES design allows the system to scale in a cost-efficient way, and to accept new green sources of heat and new heat customers over time as technology and/or availability creates new opportunity.

### 1.3.2 Challenges to DES Development

**Existing Community Layout:** DES are more effective when buildings are located in close proximity to one another. Where buildings are located far apart or are not clustered, materials and installation costs can be prohibitive to project success.

**Capital Investment:** Community-based DES call for considerable up-front capital costs and may entail extensive retrofitting to existing in-building heating systems. Initial investment can be a barrier to project development. It is necessary to develop an understanding of the costs and savings of a DES as compared to the current business environment.

**Community & Consumer Buy-in:** For a successful DES, a substantial heat load from customers in a concentrated area is imperative. Therefore, it is necessary to have buy-in to the project from the heat customers from the initial planning stage of the project. Initial leadership and design for the project is essential to build the required momentum to move DES projects to construction.

**Policy and Regulatory Environment:** A jurisdiction may not have the regulatory environment to facilitate the development of a community-based energy program. A municipally owned/operated DES may involve new regulation and policy, which can be an obstacle to project development and, in particular, project timelines.

**Awareness and Education:** There is a significant lack of awareness of the advantages for these community-based systems; less than 1% of North America's heating comes from DES. This obligates communities and potential customers to be educated about the prevalence of other active and successful DES projects globally.

Please refer to Appendix A for a more in-depth review of DES.

## 1.4 Geothermal Resource Overview

Energy extracted from heat occurring naturally within the Earth, known as geothermal energy, is a clean and renewable source of both power and heat. This short overview explains in basic terms how production of energy from geothermal sources works.

Unpotable water present in underground reservoirs, known as formation water, is naturally heated to high temperatures by the Earth's abundant heat resources. Well(s) drilled into the subsurface where the heat resource exists transport the hot formation water and/or steam to the surface using natural pressure and pump systems. At the surface, formation water travels through the wellhead and into the power facility (for electricity production) or across a heat exchanger (in the case of DES) that heats the secondary fluid to be circulated through the system.

A geothermal resource requires all three of the following key variables for a successful project:

1) Heat,
2) Water/brine, which provides a fluid medium for heat transport, and

**3)** A permeable, or fractured, and porous geological environment, which allows the water to move and flow.

When all three variables are present, the subsurface heat resource can be cost-effectively transferred to the surface for heating and power applications. In cases where these variables are not present or are of insufficient quality then there may be ways to mitigate the issue(s). For example, "fracking"/stimulating the rocks within the reservoir can create permeability and thus flow of fluids, where there is otherwise insufficient permeability.

A geothermal reservoir operates like an underground heat exchanger. Therefore, understanding heat flow and temperature gradient is fundamental to assessing the potential of any geothermal resource project development. In a porous and permeable formation, water can circulate through the reservoir and is exposed to the surfaces of hot rock allowing it to gain heat. The rate of heat transfer and, consequently, the final temperature the fluid achieves is related to the mass flow rate of fluid, residence time of the fluid and the surface area of the fluid/rock contact.

Geothermal heat is produced from two sources: the heat stored in the interior of Earth (core and mantle), and radiogenic heat production in the crust (sedimentary rocks and crystalline basement). In general, heat increases with greater subsurface depth; this increase of temperature with depth is defined as a geothermal gradient, and the global average geothermal gradient is 25°C / km.

The focus of the Upstream section of the report will be to determine the viability of the geological horizons believed to be prospective for geothermal production. The Upstream section will also describe the reservoir characteristics and challenges, as well as different well-bore heat extraction scenarios.

## 1.5 Hinton Sustainability Goals

Beginning in 2011, Athabasca University and Grande Prairie Regional College investigated the current economic state of Hinton and Grand Cache with a focus on long-term sustainability. It was determined that economic stability was strong but the historic, resource-dependent economies were unsustainable in the long-term. Project objectives included identifying local priorities for sustainability and investigating innovative practices and opportunities for social and economic diversification. With oil and gas (O&G) and geothermal having very similar resource development structures, one of the objectives of this project is particularly relevant to a geothermal based DES: "capitalizing on the existing knowledge base of generations of resource extraction" [7].

The Town of Hinton's "Hinton 2040" program (the action arm of the Hinton Community Sustainability Plan) outlines the vision for a community that "balances innovative economic development and ecological, human and social resources" and defines sustainability as "living in a way that meet's today's needs without compromising the ability for future generations to meet their own needs" [3]. Under this sustainability plan, multiple action items are in line with the development of a renewable energy-based DES, which are developed upon further in Appendix B. The points were identified from multiple sections within the Sustainability Plan:

- Education & Wellness: pertain to the educational cross-over opportunities with grade school students, as well as training on DES operations and maintenance.
- Local Economy: the points identified within this section relate to the business opportunities that the DES presents by association. The consistent, reliable supply of heat is attractive to many industries with heat-intensive operations.
- Natural and Built Environments: These points relate specifically to cross-over of the DES with factors like community food security, energy conservation and renewable energy opportunities, future infrastructure planning, and implementing "green" practices.

Overall, there is significant community support for projects that are aligned with the vision of long-term sustainability and viability for the Town of Hinton. There is also extensive interest in community co-operation and engagement, which is necessary to the development of a DES in the town.

# 2 Upstream: Geology & Heat Production

## 2.1 Summary of Upstream

The Town of Hinton is located in a region with well-researched geothermal resource potential. Having been the focus of multiple in-depth studies dating back to the early 1980s, including the University of Alberta's recent "Deep Dive" study† [8] completed in 2017, the Hinton area has been earmarked as one of the highest geothermal potential regions in Alberta. Elevated deep subsurface temperatures and the suggestion of water-bearing reservoirs presented attractive conditions for considering the development of the geothermal resources near Hinton. Additionally, an array of oil and gas wells in the area that are potentially near the end of their producing life presented the possibility of obtaining and repurposing them for geothermal purposes. Repurposing existing wells has the advantage of avoiding expensive drilling costs that typically represent one of the largest hurdles to geothermal development.

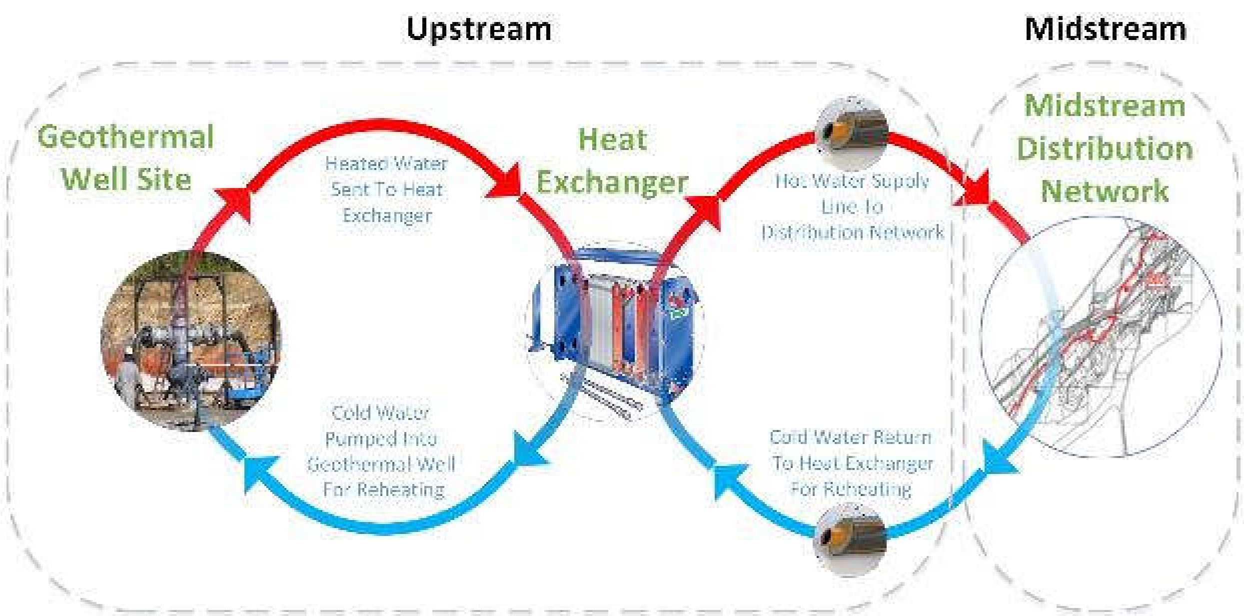



**Figure 4 - DES Upstream overview**

The Upstream section includes analysis of the geology, new well design and associated configuration modeling, and the Upstream facilities (see Figure 4). To accomplish assessing the subsurface environment near Hinton for geothermal heat production, first the technical viability of repurposing existing wells was tested. This process involved first performing a technical analysis of the geology in the area, including estimated flowrates, temperatures and predicted fluid compositions of potential geothermal zones, from which the most promising geothermal reservoir would be identified. Part of the methodology also included reviewing 98 wells, with associated drilling, completion, and production logs to create a substructure data set to review. Once the best geothermal zone was identified, technical

† *The Deep Dive study specifically researched geothermal electricity generation potential, which is geared towards a more heat intense and larger-scale project.*

review would be conducted to determine the best well candidate(s) for repurposing, and a well testing program would be designed and run to confirm the reservoir conditions.

The geological analysis identified four potential geothermal reservoir candidates for the Hinton area: Devonian age formations, Mississippian age formations, the Cretaceous Spirit River and the Cretaceous Cardium formation. Of the four proposed geothermal reservoir candidates, three of them were ruled out as potential geothermal zones due to structural issues, accessibility risk and lack of available water. The only potential zone based on required zone and fluid characteristics was the Cardium zone. However, this zone was found to have lower than desired estimated bottomhole temperature, sparse availability of reservoir data, and no identified water flow rates in any documented well tests.

Multiple well-repurposing configuration options were generated to overcome the technical geological hurdles. But as subsurface work proceeded it became obvious there were no zones present with suitable geology to support fluid flow requirements for most of the options.

In addition, through discussions with current well owner/operators it became apparent that obtaining an existing well was an unviable option. The Hinton area is a well-known gas producing area, and although many of the wells are what may be considered near "end-of-life" at current natural gas pricing, forecasting of a future price increase provides basis for reluctance to relinquish any land or well ownership in the area.

With the well repurposing option removed, the project scope was expanded to consider the feasibility of drilling a new well, which is more expensive. Multiple well configuration scenarios were proposed and explored to navigate the complex geology of the area. The more traditional two-well configuration (where one well would produce heated water and the other well would inject used, cooled water) proved to be infeasible due to reservoir flow concerns.

To circumvent these reservoir flow issues, a well configuration involving circulating fluid within a single well using a closed loop system was pursued. In this configuration, no fluid leaves the pipe and the heat would be extracted via heat exchangers. Because of significant subsurface concerns, including high-pressure zones and sour ($H_2S$ rich) formations, several different closed-loop configurations were explored (see Section 2.3.4). Theoretical heat production for each configuration scenario was modeled to assist in determining the feasibility of each scenario, including evaluating the effectiveness of mitigating heat loss measures.

It should be noted that while repurposing an existing well came with a comparatively modest price tag that yielded attractive financial outcomes for the Hinton DES, in contrast drilling a new well would cost in the range of 10-20 times more, making project economics much more challenging to satisfy.

In studying the localized geology and wells immediately surrounding Hinton for this FEED project, multiple challenges were encountered involving both the geology and well configurations. Geothermal resources are a very geologically localized phenomenon, and the geology of the Hinton area is more complex than initially indicated. While high temperatures exist deep beneath Hinton, the character of the geology is high risk as the reservoirs are structurally complex and technically challenging to access.

The heat within the subsurface is significant enough for a potential power project, but the technical complexity of developing Hinton's geothermal resource increases the capital required, which at current market conditions does not make it viable for a standalone heat project.

## 2.2 Geological Assessment

### 2.2.1 Introduction

Many subsurface gas wells are present in the Hinton area that are producing at relatively low rates and are considered to be near end-of-life. The Hinton DES was initially to be designed to recover subsurface heat from these wells to supply heat energy to mixed-use buildings in the town.

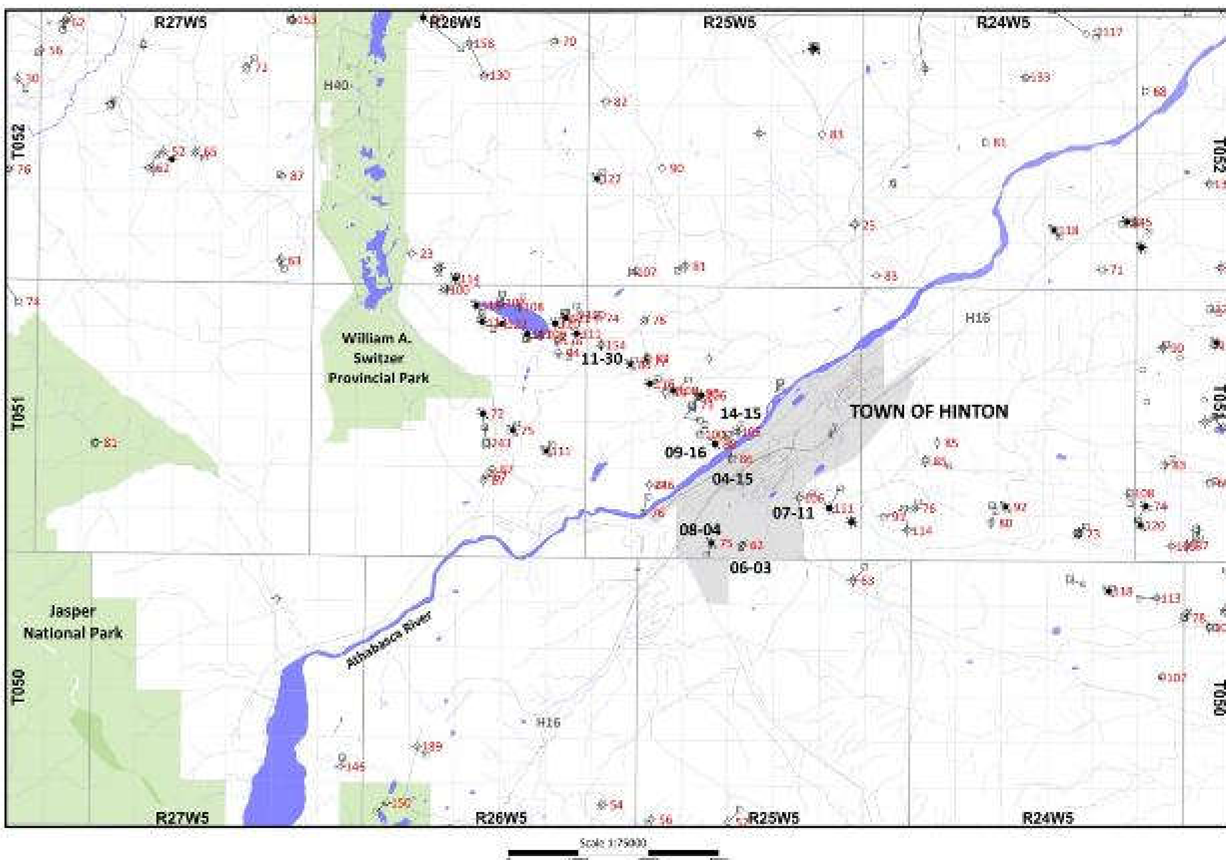



**Figure 5 - Location of the Hinton study area in west central Alberta. Six producing gas wells were identified as potential candidates for geothermal exploitation: 06-03, 08-04, 07-11, 04-15, 14-15 and 09-16-051-25W5. Reported bottomhole temperatures are indicated in red (uncorrected).**

Oil and gas exploration in the area began in the early 1940's with the drilling of the Shell Solomon Creek No. 1 well at 06-17-051-27W5 to the Cretaceous Cadomin Formation. Activity was limited in the region from the 1950's to 70's with less than 10 wells drilled to formations in the Devonian, Mississippian and Cretaceous. Of these wells, Ionic Entrance 11-30-051-25W5, which is located 5.8 km NW of the Town of Hinton, is the only well currently still producing with 109 mcf (3.1 e3m3) daily average gas flowing from the Cretaceous Dunvegan Formation.

Exploration increased from the 1980's to 2000's, with multiple wells drilled to the Devonian and Cretaceous.

The majority of the subsurface wellbores currently producing near the Town of Hinton were directionally drilled targeting natural gas from the Cretaceous Spirit River, Cardium and Dunvegan formations. These wells produce 21 – 1105* mcf (0.6 – 31* e3m3; *commingled) average daily dry gas from fractured sandstones with relatively low porosity within seismically defined anticlines and thrust fault repeats. Several of these wells with relatively low daily production and close proximity to the Town of Hinton were identified as potential candidates to be repurposed for geothermal heat gathering: 06-03, 08-04, 07-11, 04-15, 14-15 and 09-16-051-25W5 (Figure 5).

### 2.2.2 Geothermal Discussion

Hinton was identified as an area with geothermal potential from previous published studies of wellbore bottom-hole temperatures [9], [10], [11]. The overall *region* has a relatively high geothermal gradient (~36°C/km) that is most likely a result of fluid movement along fault planes from hotter zones at depth [11]. In the immediate Hinton area, however, the average geothermal gradient is approximately 29°C/km based on independently corrected bottomhole temperature measurements.

The geothermal potential of the Hinton and neighboring Obed area was investigated as part of the University of Alberta (U of A) Deep-Dive Analysis of Best Geothermal Reservoirs for Commercial Development in Alberta report [8]. The high-level study identified the Devonian Leduc, Swan Hills and Gilwood formations as potential geothermal reservoirs, with mean bottomhole temperatures of 120°C and greater at depths of up to 4500 m. The data analyzed in the study is primarily from the Obed area and does not take into consideration the composition of reservoir fluids, quality and extent of the reservoir or risks associated with drilling at depth in the structurally complex foothills region. Consequently, the recommendations made in the report only pertain to the Obed and surrounding regions to the east and north and are not applicable to the immediate Hinton area.

Geothermal analysis of potential reservoirs in the immediate Hinton area is being conducted independently by the University of Alberta. This investigation included well-bore flow analysis, thermal modeling of subsurface conditions, geochemical risk analysis of brine samples and modeling of production scenarios using numerical modeling (see Section 2.4). Geothermal analyses will not be conducted as part of the geological review to avoid duplication.

### 2.2.3 Potential Reservoirs

Potential geothermal reservoirs in the Hinton area are Devonian to Cretaceous in age (374 - 91 Ma; Figure 6 and Figure 7). The Late Devonian Leduc Formation is the lowermost hydrocarbon bearing and potential geothermal reservoir unit in the Hinton area. It is overlain by several potential zones with variable reservoir quality including the Pekisko, Shunda and Turner Valley formations of the Mississippian Rundle Group. These formations are in turn overlain by fractured reservoir sandstones of the Cretaceous Spirit River, Dunvegan and Cardium formations that are present in the majority of subsurface wells in the Hinton area.

The extent and quality of potential reservoir(s) was evaluated through geological mapping and well analysis. Geological mapping included the construction and interpretation of stratigraphic cross-sections and structure, isopach and net sand subsurface geologic maps. Structure maps, a type of map where contours represent the subsurface elevation of a formation surface, and isopach maps, where contour lines are lines of equal stratigraphic thickness, illustrate the lateral extent and overall structural complexity of the geologic formations. Net sand maps, which are a type of isopach map, are comprised of contours that represent the sum of the stratigraphic thicknesses of reservoir sand only, excluding all other types of lithologies.

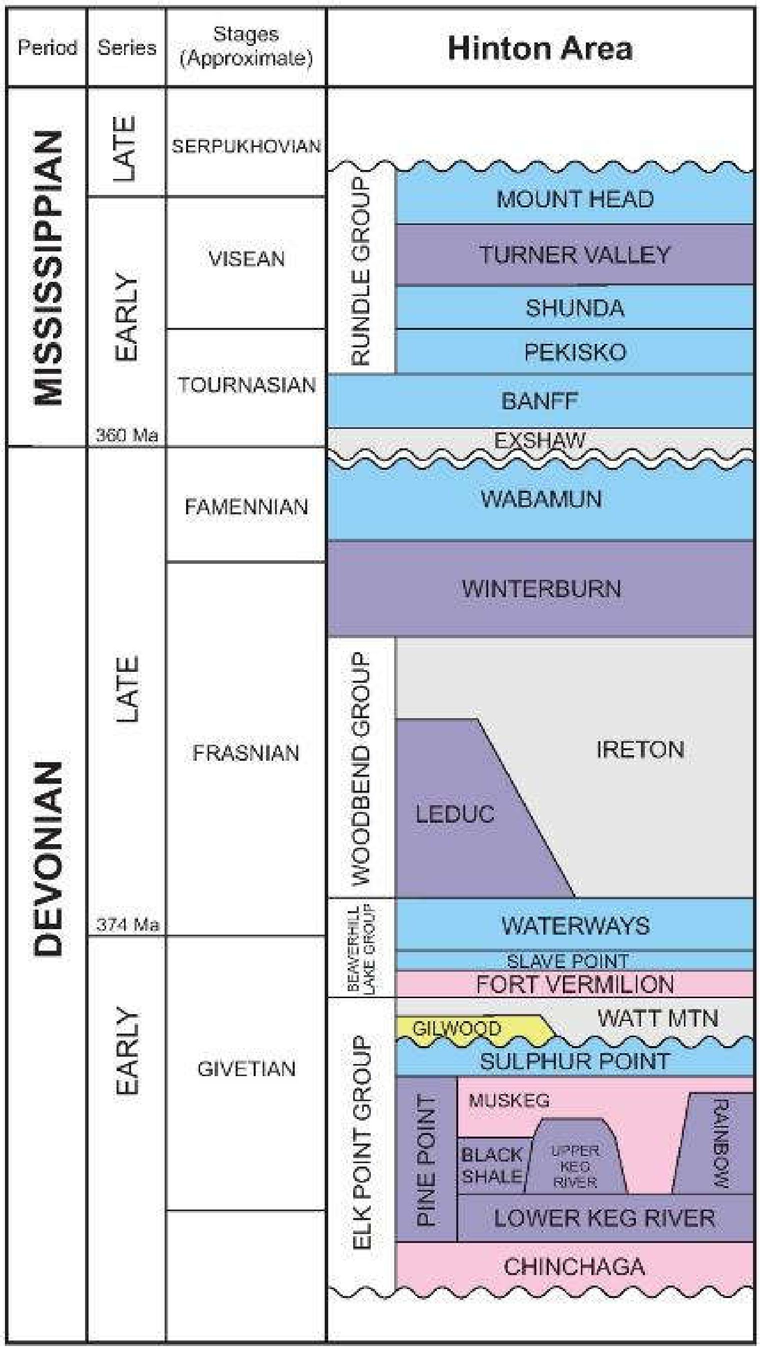



**Figure 6 - Table of Devonian and Mississippian subsurface formations in the Hinton area, west central Alberta. Modified from Core Laboratories Stratigraphic Chart (2016) [12].**

### 2.2.3.1 Devonian Formations

Porous carbonate rocks of the Middle to Late Devonian Slave Point, Leduc and Wabamun formations are the lowermost potential geothermal reservoir zones in the greater Hinton study area ( [11], [13] Figure 2). Of these zones, the Late Devonian Leduc Formation has the best geothermal reservoir potential in the Hinton region since it is laterally continuous with conventional reservoir characteristics. The Leduc Formation is 180 - 300 m thick and is comprised of reefal limestone, dolomitized limestone and dolostone with minor skeletal mudstones, packstones and wackestones that were deposited in a shallow water reef complex [14].

A limited number of wells have been drilled to the Devonian in the Hinton area. The closest well to the Town of Hinton, Ionic Entrance 11-30-051-25W5 is producing 109 mcf (3.1 e3m3) daily average gas from the Cretaceous Dunvegan Formation. The well was drilled in 1973 to the Devonian Beaverhill Lake Group to a total depth of 5624 m True Vertical Depth (TVD) or 5650 m Measured Depth (MD), with a reported bottomhole temperature of 154°C (uncorrected; Figure 5 and Figure 6). The top of the Leduc Formation occurs at a depth of 5266 m TVD and is approximately 300 m thick.

Recent analysis of gas samples from dolomitic reservoir facies in the Leduc at 5358 - 5615 m MD in 11-30-051-25W5 yield a composition of 14.6% $H_2S$ (August 24, 2007). This result is comparable to analyses from reservoir units in the Leduc at 14-33-052-26W5 (6303 - 6437 m MD: 22.9% $H_2S$, August 24, 2007) and the Beaverhill Lake at 00/06-34-052-26W5 (5575 - 6605 m MD: 20.95% $H_2S$, November 20, 2001). These values are significant and would result in the classification of a critical sour well, which is defined by the Alberta Energy Regulator (AER) as a well that could potentially release large quantities of $H_2S$, causing significant harm to nearby communities. The implications of sour formation water are discussed further in Sections 2.3.3.1 and 2.3.7.

Although the Leduc occurs at depths with ideal reported bottomhole temperatures, there are several factors that limit its potential as a geothermal reservoir. Overlying Cretaceous aged formations are extensively folded and thrust faulted, which has resulted in the requirement for cost prohibitive directional steering and management of pressure buildups and other issues during drilling operations. There is a significant risk of well abandonment as a result of drilling issues and the possibility of missing the target geologic zone due to limited data. As a result, the Devonian Leduc Formation is not a potential geothermal reservoir zone in the Hinton area due to the excessive economic costs to drill and risk associated with the depth (> 4000 m), complex overlying geology and high $H_2S$ concentrations. Following discussion with the project reservoir and drilling engineers, it was decided that the Leduc Formation would not be investigated further through geologic mapping and analysis and was ruled out as a potential geothermal zone.

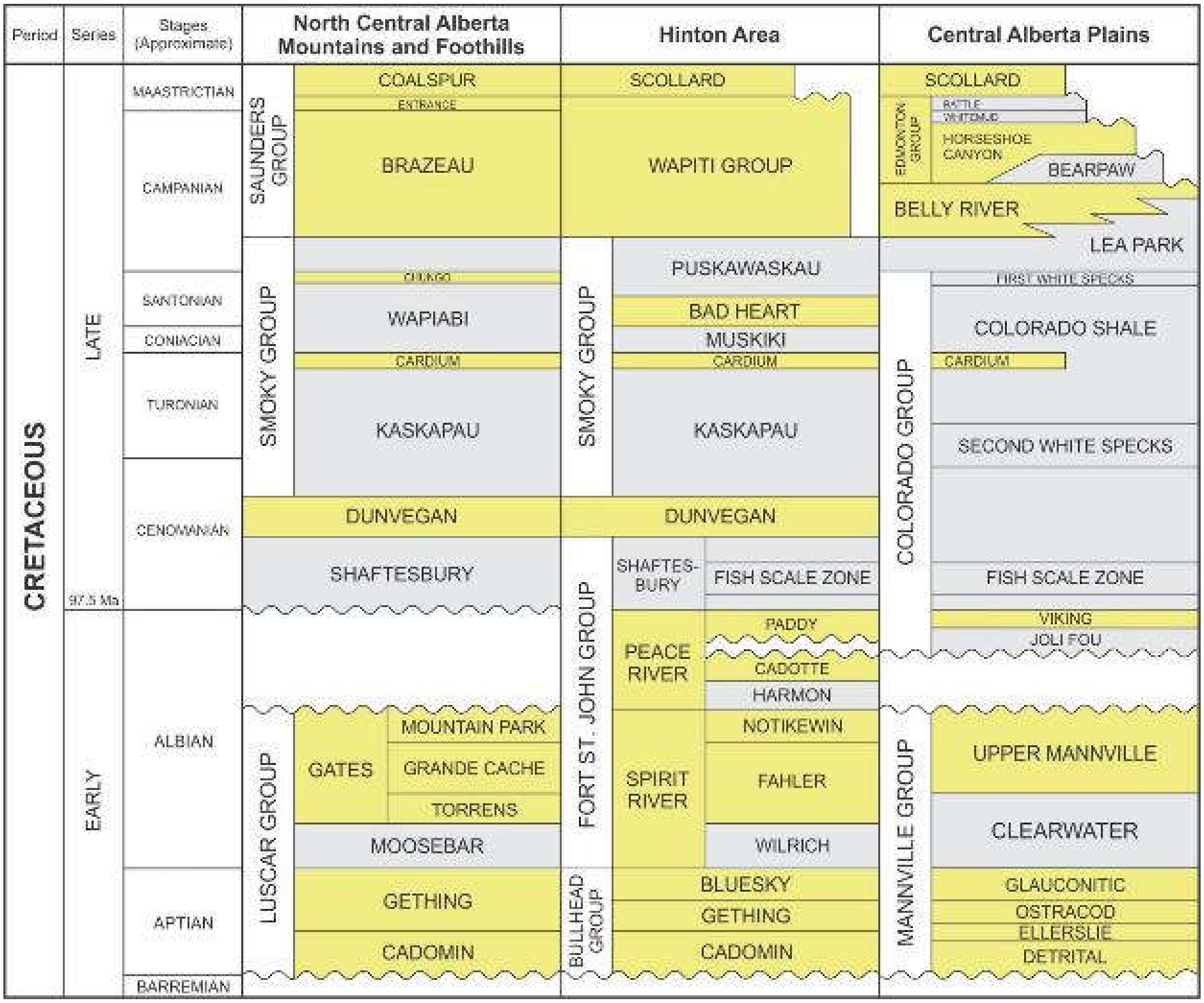



**Figure 7 - Table of Cretaceous formations in the Hinton, Central Alberta Mountain-Foothills and Central Alberta Plains regions. Modified from Core Laboratories Stratigraphic Chart (2016) [12].**

#### 2.2.3.2 Mississippian Formations

Porous carbonate rocks of the Mississippian Rundle Group (Pekisko, Shunda and Turner Valley formations) were identified as potential geothermal zones during early regional studies ( [11], Figure 6). However, reservoir development of carbonates in the Rundle Group in the immediate Hinton area is limited. Substantial critical sour gas production in the Mississippian occurs in neighboring regions to the west and southwest where the Rundle Group has been fractured and structurally repeated through extensive folding and thrust faulting. However, the Mississippian is not deformed enough in the immediate Hinton area to produce economic accumulations of gas, which is reflected in the low number of subsurface wells in the area targeting formations of this age.

The combination of poor reservoir quality and critical sour classification in neighboring areas make the Mississippian Rundle Group a poor geothermal reservoir candidate in the Hinton area. As a result, it was decided that it would not be investigated further through geologic mapping and analysis and was ruled out as a potential geothermal zone.

#### 2.2.3.3 Cretaceous Spirit River Formation

Gas production in the Hinton area is primarily from fractured reservoir sandstones of the Fahler and Notikewin members of the Early Cretaceous Spirit River Formation (Figure 7). The Fahler Member consists of a series of 5-10 m thick coarsening upwards shoreline successions (A-E) of conglomerate, fine to coarse-grained sandstone, siltstone, shale and minor coal (Figure 8; [15], [16], [17], [18]). The Fahler is unconformably overlain by coarsening upward marine to marginal marine sequences of fine to coarse-grained sandstone interbedded with shale, siltstone, coal and local conglomerate of the Notikewin Member (Figure 8; [16], [17], [19]).

The upper Notikewin Member is laterally continuous and ranges in thickness from 30 to over 100 m in the Hinton area. Variations in thickness are a result of thrust fault repeating and folding from compressional deformation during the formation of the foothills (Figure 8). These structural repeats are evident on petrophysical logs for Tourmaline Hinton 09-16-051-25W5 (Figure 8). Although log porosities are relatively low at 2 to 4%, the Notikewin produces dry gas due to the presence of extensive fractures.

The Spirit River Formation was initially evaluated as a potential geothermal reservoir zone. The Formation occurs at a depth of 3200-3500 m TVD with reported bottomhole temperatures of 65 - 105°C (uncorrected) in the wells immediately surrounding the Town of Hinton (Figure 5 and Figure 8). There is no $H_2S$ recorded in gas samples from the Spirit River in these wells, which immediately decreases the cost and risk associated with repurposing an existing wellbore or drilling a new location. However, after evaluation of all wells in the surrounding area and the construction of a stratigraphic cross-section and preliminary subsurface maps, it was determined that there is no evidence of the presence of formation water, either from reservoir sandstones, adjacent coal seams or along fault planes (Figure 8, Appendix C.1.1). As well, the Spirit River was determined to not be of sufficient reservoir quality to freely produce fluids even with extensive well stimulation in some locations (i.e. "frac" or other completion methods). As a result, the Spirit River Formation was ruled out as a potential geothermal reservoir candidate.

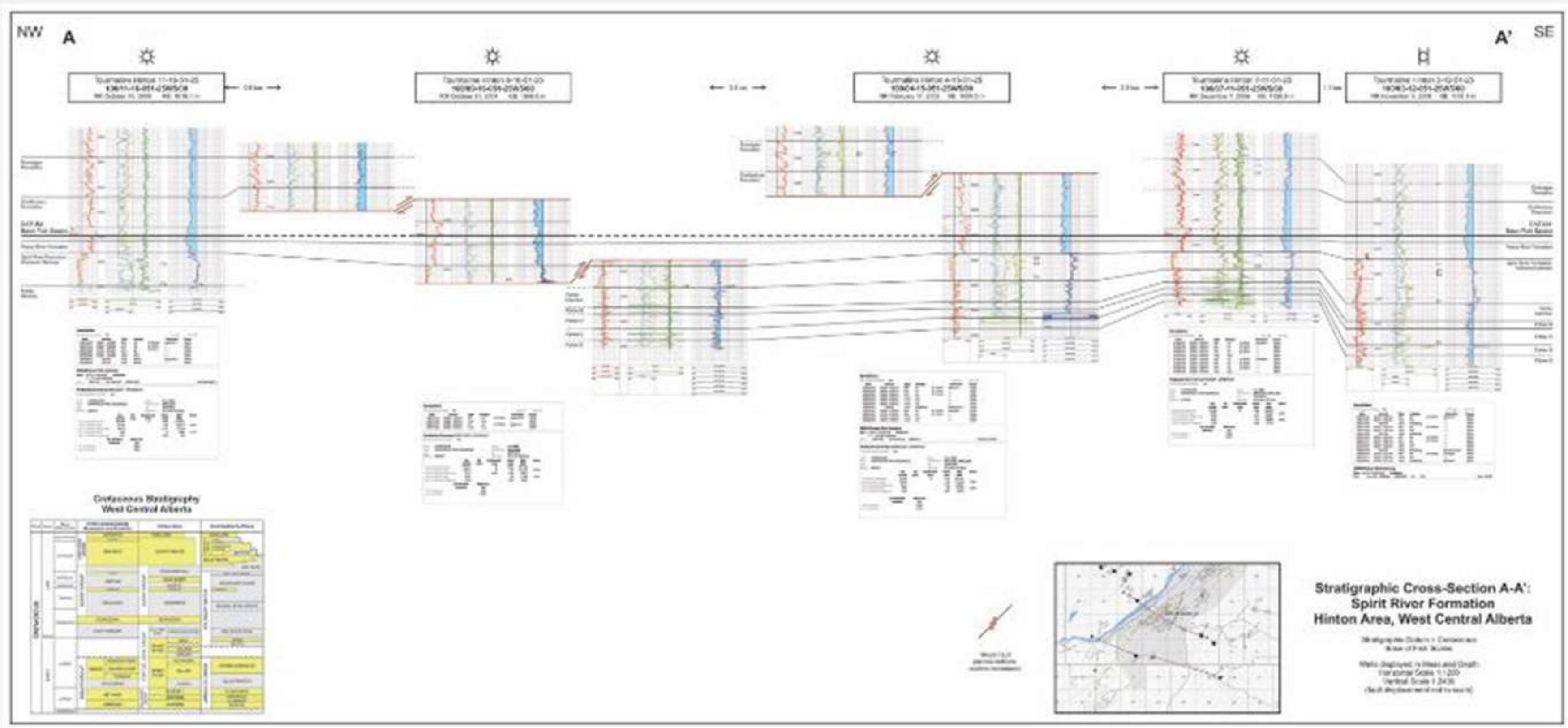



**Figure 8 - Stratigraphic Cross-Section A-A' of the Cretaceous Spirit River Formation. Refer to large-scale copy of section in Appendix C.1.1 for wireline log, testing and production details of wellbores.**

#### 2.2.3.4 Cretaceous Cardium Formation

Reservoir sandstones of the Late Cretaceous Cardium Formation are host to major hydrocarbon reserves in Alberta (Figure 7). Near the Town of Hinton, the overall Cardium Formation is 70 to 100 m thick and consists of fine-grained sandstone, siltstone and shale (Figure 11). These lithologies represent cyclical deposition in a shallow marine shelf margin to deep water setting. Turbidity and storm currents have been proposed as mechanisms of sand transport, which affect the reservoir quality and lateral distribution of sediments [20].

Gas producing reservoir sandstones of the Cardium Formation, formally referred to as the Cardium Sandstone, were evaluated as a potential geothermal reservoir zone in the area surrounding the Town of Hinton. The Cardium Sandstone occurs at a depth of 2300-2800 m TVD with reported uncorrected bottomhole temperatures of 65-105°C (Figure 5, Figure 9, Figure 10). Variations in thickness are a result of thrust fault repeating and folding from regional compressional deformation (Figure 9, Figure 10, Figure 12). The sandstone is structurally repeated up to two to three times resulting in true stratigraphic (isopach) thicknesses ranging from 20-32 m up to 41-54 m in the immediate Hinton area (Figure 9, Figure 10, Figure 12).

To evaluate the reservoir quality of the Cardium Sandstone and its suitability as a geothermal reservoir, preliminary well analysis and net sand mapping was conducted in the immediate Hinton area (Figure 13, Figure 14, and Table 1). Reservoir cut-offs were chosen based on established parameters used in the adjacent Deep Basin area of west central Alberta. Net clean sand with values of 60 API or less (gamma ray wireline log values) and density porosities of 0-3% or greater were mapped to capture the maximum extent of the Cardium Sandstone reservoir. The distribution of net clean sand is relatively consistent in the area, with thicker accumulations corresponding to areas of structural repeating (Figure 13, Figure 14). This indicates that the reservoir is laterally continuous and is likely to be present throughout the study area.

Preliminary well analysis of the Cardium Sandstone was conducted for six wells adjacent to the Town of Hinton (Figure 5, Table 1). These wells were analyzed to determine parameters for reservoir engineering analysis and modeling and were selected based on their proximity to the Town of Hinton, availability of data and borehole integrity. Resistivity parameters derived from wireline logs were applied to net sand values to obtain net pay, which is the thickness where porosity is high enough to be able to produce reservoir fluids. Based on producing Cardium gas fields in the Deep Basin region, the following relative cut-offs were applied: 0-20 $\Omega$ = potential water production, 20-80 $\Omega$ = gas to water transition, and greater than 80 $\Omega$ = gas production.

To capture the maximum reservoir potential of the selected wells, net pay cutoffs of 0 and 3% porosity and 20 $\Omega$ resistivity (producing water to gas transition zone boundary) were applied to the Cardium Sandstone interval. The resultant values summarized in Table 1 indicate that the reservoir quality is relatively consistent with maximum net sandstone thicknesses of 20-22 m and corresponding net pay thicknesses of 18-22 m in structurally repeated sections. These values align with the isopach and net sand maps, which indicate the reservoir is laterally continuous and present throughout the area (Figure 11, Figure 12, Figure 13, Figure 14).

Of the selected wells, 100/06-03-051-25W5/02 and 100/08-04-051-25W5/00 were identified as the best initial candidates for wellbore re-entry to conduct geothermal reservoir testing

(Figure 5, Figure 10). 2122.0 m of saline water (~ 30000 g/m$^3$ salinity) was recovered during a Drill Stem Test (DST) of the uppermost Cardium Sandstone thrust repeat in 06-03-051-25W5-02 (DST # 1, February 1995, 2122.0-2134.0 m MD; recorded mud temperature 67°C). Initial interpretation of the recorded DST curve(s) indicates high reservoir permeability but requires further analysis and testing to determine absolute values. The water-bearing Cardium reservoir zone in 06-03 can be correlated to the neighboring 08-04 well (1.1 km NW). However, well testing and seismic interpretation are required to determine if the sandstone is laterally continuous and water bearing.

**Table 1 - Hinton Area Cardium Sandstone Well Analysis***

| WELL | RIG RELEASE | CRDS REPEATS | NET SAND (0% ϕ) | NET SAND (3% ϕ) | NET PAY (0% ϕ, 20 Ω) | NET PAY (3% ϕ, 20 Ω) |
|---|---|---|---|---|---|---|
| 100/06-03-051-25W5/02 | 02-07-1995 | 2 | 22.1 m | 18.6 m | 20.0 | 18.1 |
| 100/08-04-051-25W5/00 | 06-04-2008 | 2 (*1 log) | 11.4* | 10.5* | 11.4* | 10.5* |
| 100/07-11-051-25W5/00 | 12-07-2009 | 1 | 9.2 | 3.3 | 9.2 | 3.3 |
| 100/04-15-051-25W5/00 | 02-17-2008 | 2 | 17.5 | No ϕ Logs | No ϕ Logs | No ϕ Logs |
| 100/14-15-051-25W5/00 | 12-09-2006 | 1 | 8.8 | 6.0 | 8.8 | 6.0 |
| 100/09-16-051-25W5/00 | 10-31-2007 | 2 | 20.5 | No ϕ Logs | No E-Logs | No E-Logs |

*Detailed wireline logs and list of formation tops and cut-offs for each well are included in the appendix.

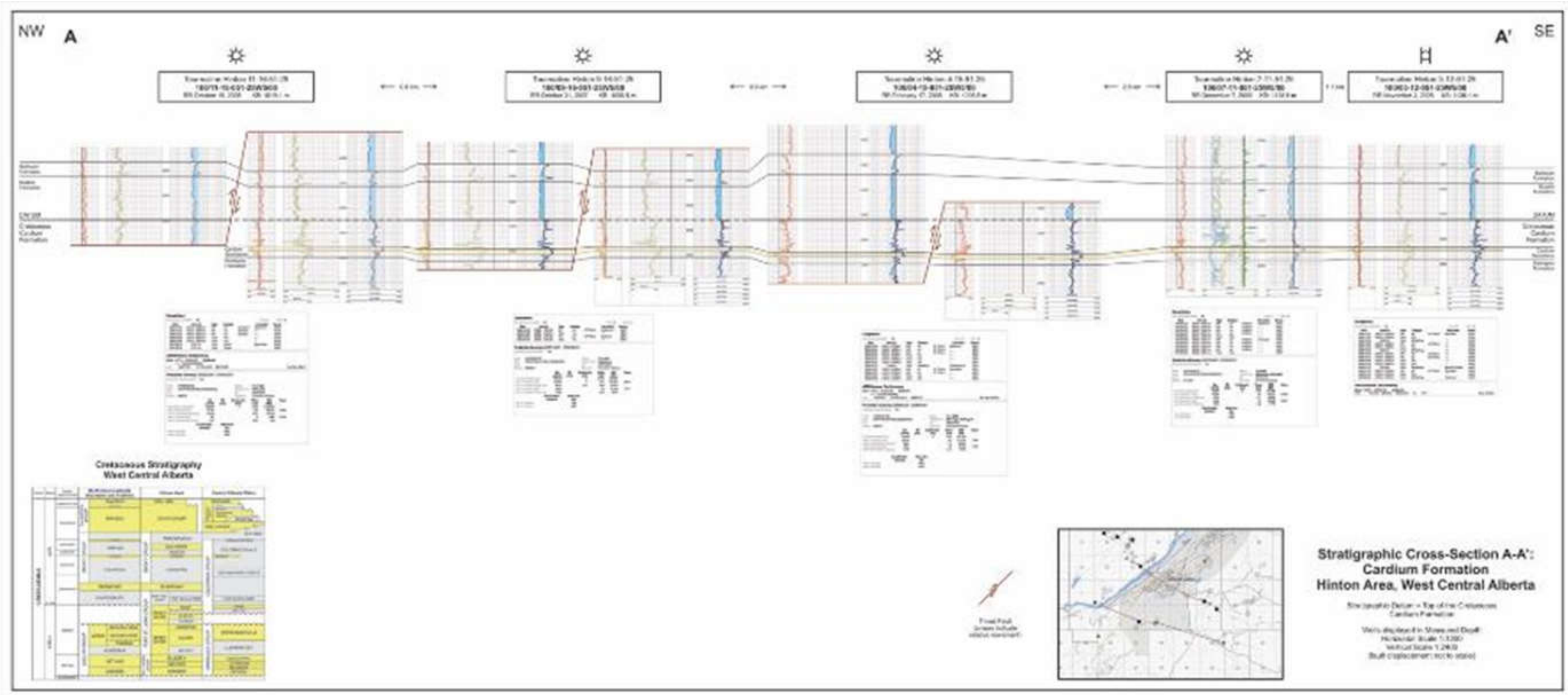



**Figure 9 - Stratigraphic Cross-Section A-A' of the Cretaceous Cardium Formation. Refer to full-scale copy of section in Appendix C.1.1 for wireline log, testing and production details of wellbores.**

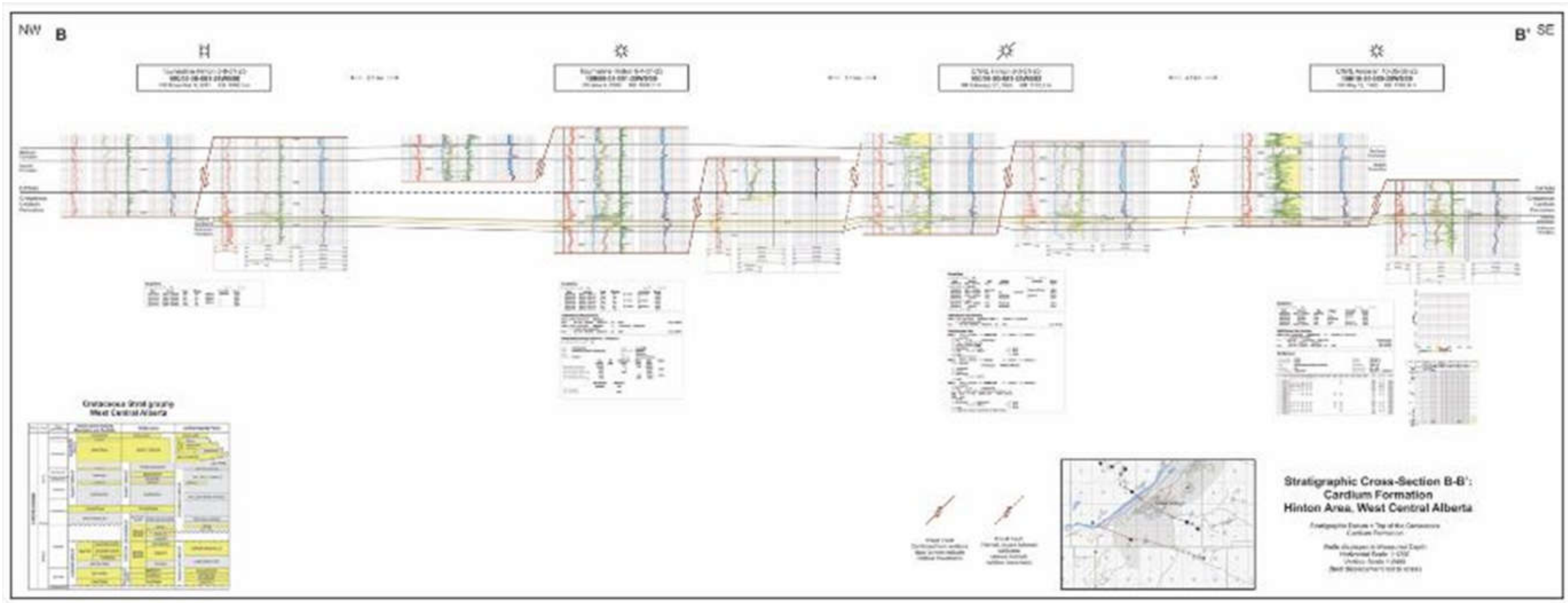



**Figure 10 - Stratigraphic Cross-Section B-B' of the Cretaceous Cardium Formation. Refer to full-scale copy of section in Appendix C.1.1 for wireline log, testing and production details of wellbores.**

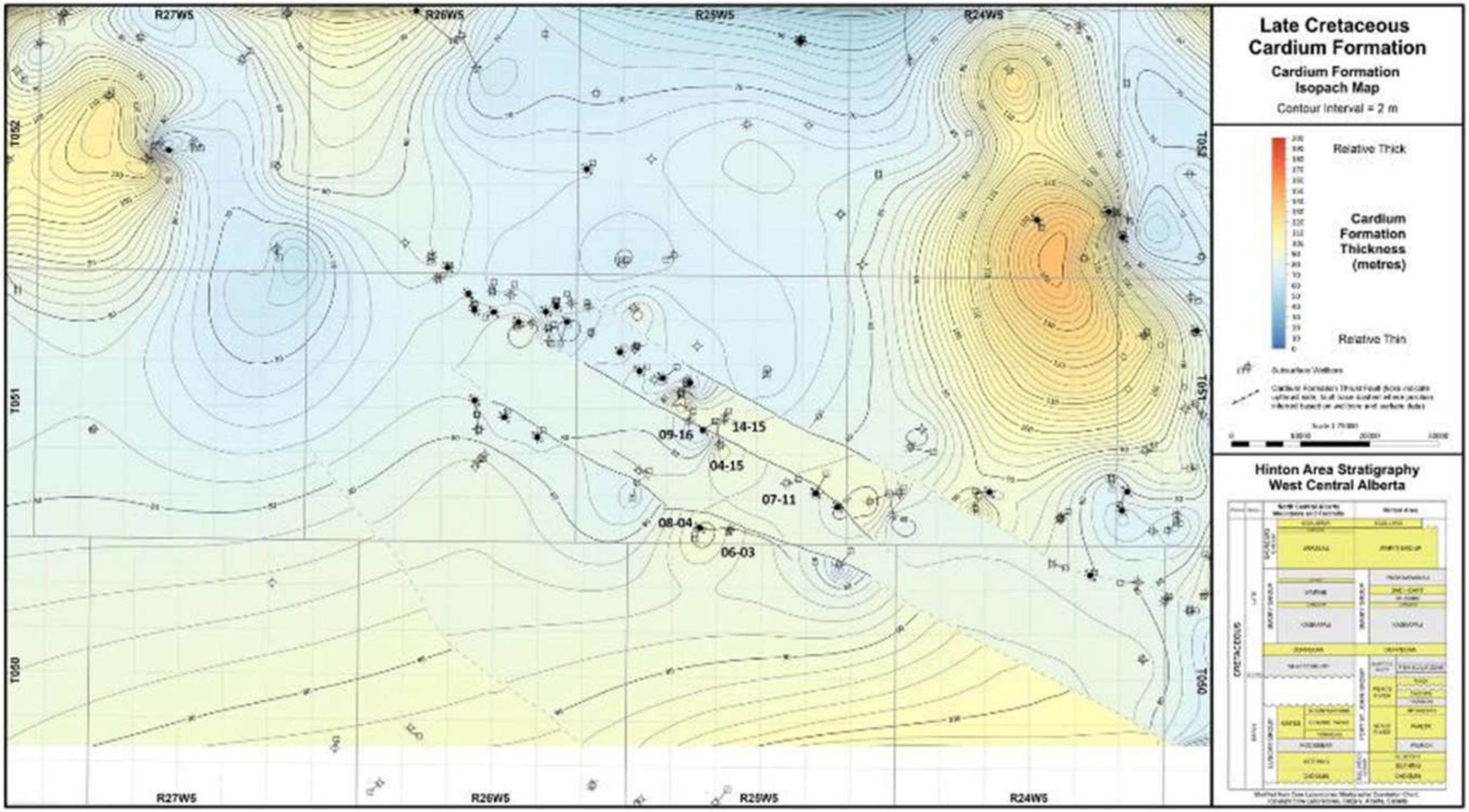



**Figure 11 - Isopach Map of the Cretaceous Cardium Formation. Refer to full-scale copy of map in Appendix C.1.2.**

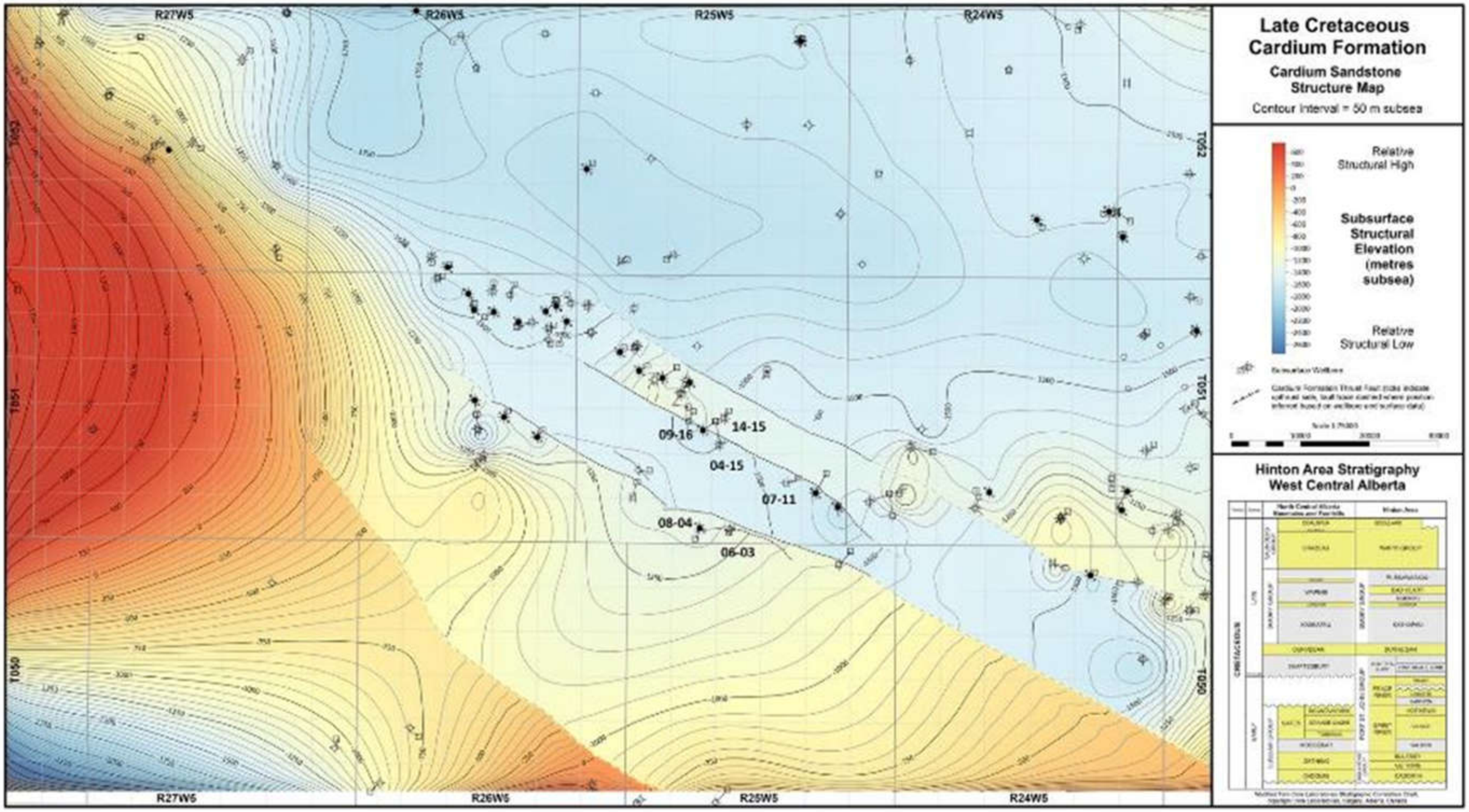



Figure 12 - Structure Map of the top of the Cardium Sandstone. Refer to full-scale copy of map in Appendix C.1.2.

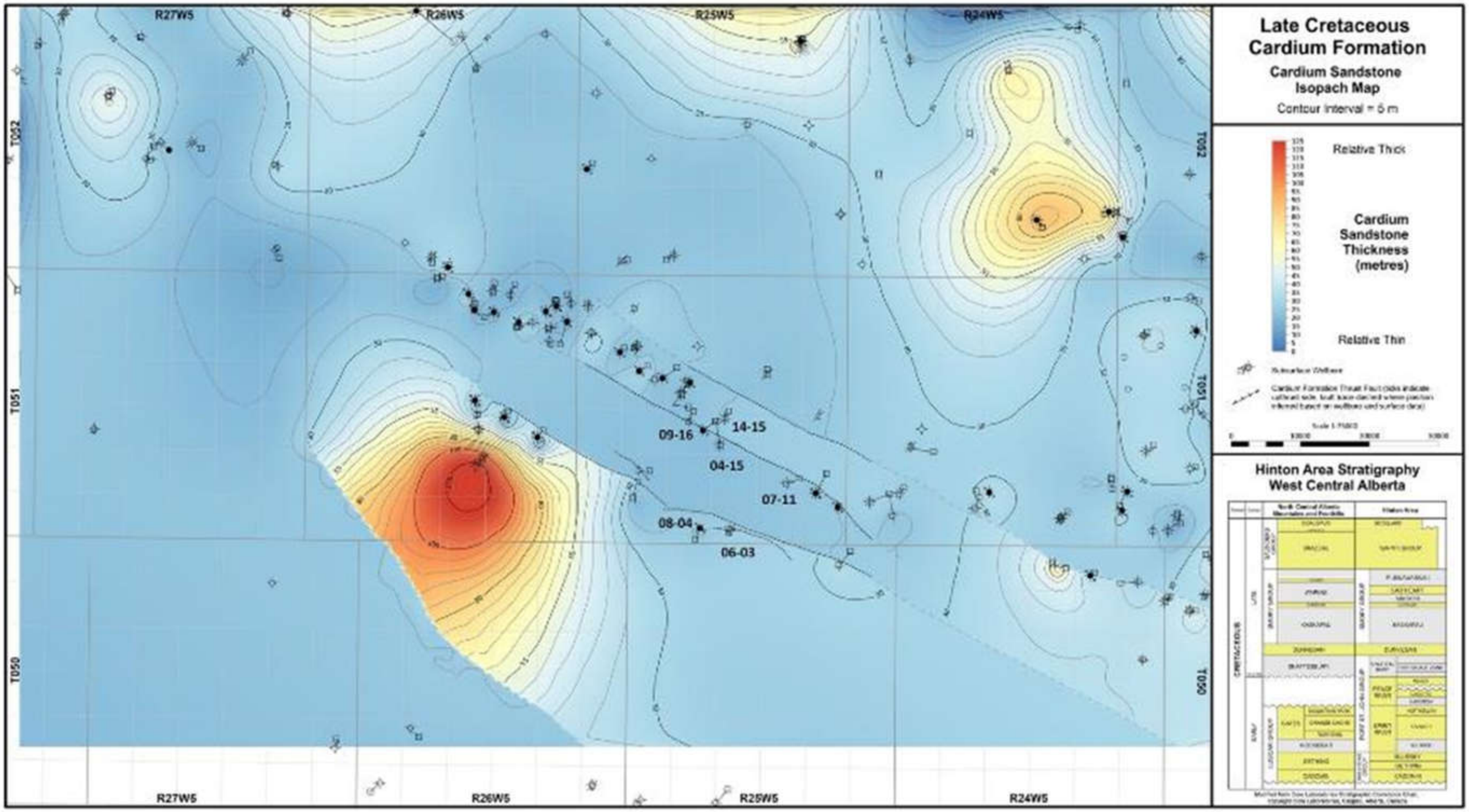



**Figure 13 - Isopach Map of the Cretaceous Cardium Sandstone. Refer to full-scale copy of map in Appendix C.1.2.**

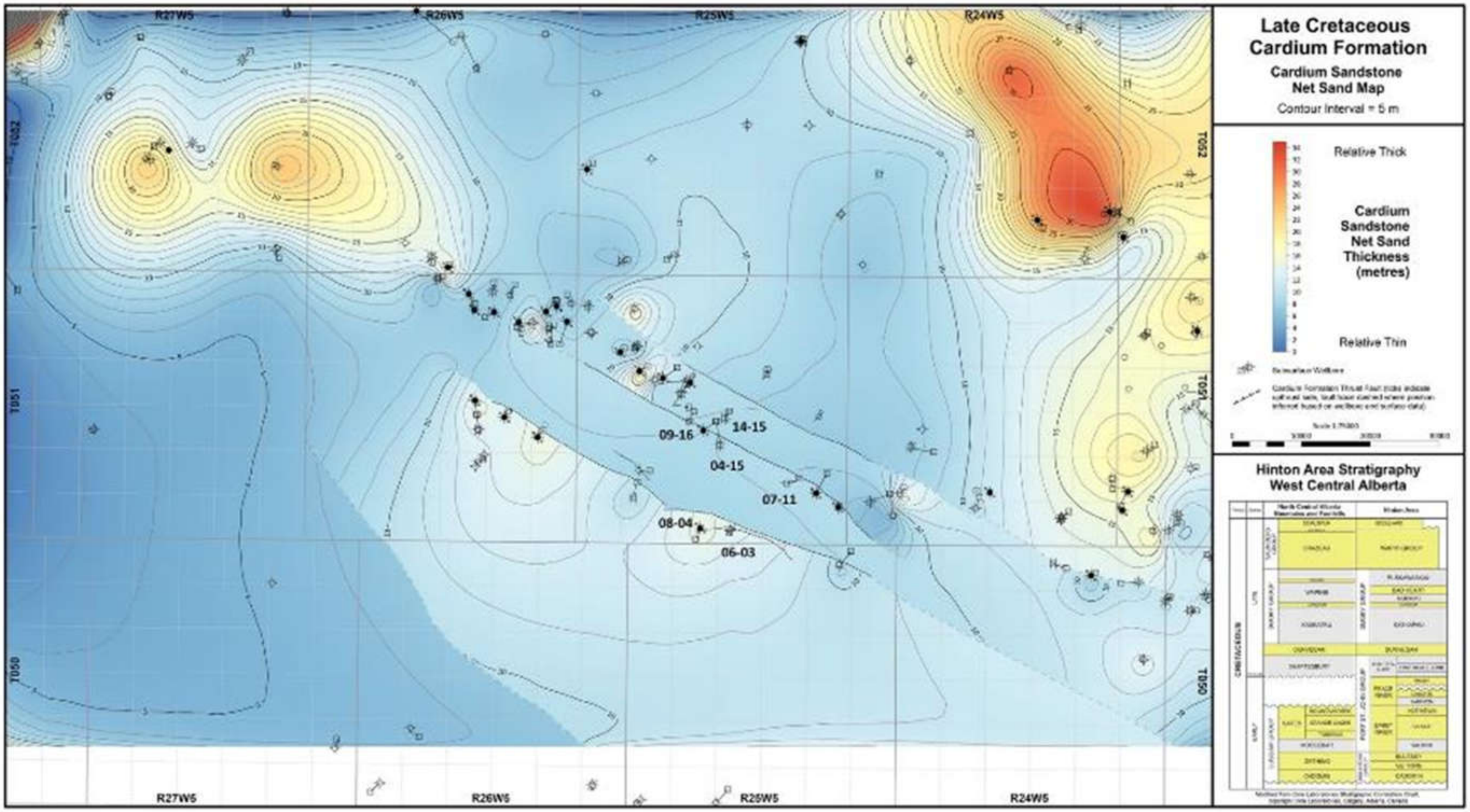



**Figure 14 - Net Sand Map of the Cretaceous Cardium Sandstone. Refer to full-scale copy of map in Appendix C.1.2.**

### 2.2.4 Structural Geology

The Hinton area is located in the structurally complex foothills region of west-central Alberta. The area is characterized by a series of large-scale folds and thrust faults and is part of the larger Rocky Mountain region [21]. Although these structures can be delineated at the surface by outcrop mapping, additional information such as structural orientation and seismic data is required to accurately map geologic units and faults in the subsurface.

In the Hinton region, a large 3-D seismic program is available for purchase through SCI Canada. This data can be used to delineate potential reservoir zones and resolve the fault and fold geometry in the subsurface. The seismic data can be tied to surficial geology and well information using synthetic seismograms and checkshot survey data. However, seismic was not available for this project due to time and cost restraints. In the absence of seismic data, surficial geology information, interpreted formation tops, structural orientation data and reservoir information was used to interpret the Cardium structure in the Hinton area.

Several thrust faults are mapped at the surface and juxtapose lithologies of different composition and age against each other in outcrop (Figure 15). These faults were formed during regional compression during the formation of the foothills and cross-cut several large-scale folds, known as anticlines and synclines. A large-scale syncline fold is evident on the surface immediately to the south of the Town of Hinton in Township 050 (Figure 15). Synclines are concave-up shaped folds where younger geologic layers are on the inner concave side and older layers are on the outer convex side. This syncline is the northern extension of the Entrance Syncline, which has been mapped and interpreted in the Coalspur region in Township 048-049, Range 21W5 (Figure 16; [22]).

Interpreted Structural Cross-Section A-A' illustrates the structural complexity of the geologic formations in the subsurface near the Town of Hinton. A "triangle zone" is clearly imaged in the cross-section and emphasizes the challenges and risks of drilling a subsurface well in the region. A structural triangle zone is a triangular area bound by thrust faults located at the outside edge of a deformed foothills region. The upper bounding thrust faults are directionally opposite to each other and share a lower thrust fault or basal detachment. The interior of the triangle zone is characterized by a series of smaller thrust fault sheets and folds, which consist of Cretaceous age and younger geologic formations in the Alberta foothills [23].

Drilling into a complex structure such as a triangle zone or large-scale fold or fault in the subsurface is challenging. Directional steering is required to maintain a vertical wellbore trajectory since the angle of the geologic formations will preferentially guide the direction of the drill bit. Even with directional steering, it can be difficult to maintain a vertical wellbore inclination resulting in a directional orientation that may not be positioned in an optimal configuration or location. Also, it is not always possible to predict the complexity and location of subsurface structures. Although the risk of missing a structure or target geologic zone is reduced with seismic and other imaging methods, additional folds, faults, geologic formations and complex fracturing may be revealed. Encountering an unexpected structure or reservoir unit during drilling can result in drilling fluid loss, pressure build-up and release, and/or release of formation gases and fluids.

The interior of the triangle zone in the Central Alberta Foothills consists of Cretaceous aged and younger geologic formations. In the Hinton area, these formations include prospective geothermal reservoir zones of the Cretaceous Spirit River and Cardium formations. These formations are thrust fault repeated up to 2-3 times resulting in increased thickness and the formation of separate blocks referred to as thrust sheets. Thrust sheets may be sealed along the bounding thrust faults causing the formation of separate reservoir compartments. Compartmentalization of geologic formations between sealed thrust faults limits the lateral extent of the reservoir and prohibits the movement of fluid across the fault surfaces. As a result, there is a substantial risk that fluid will be unable to flow between an injection and production well if they are positioned within separate thrust sheets on opposing sides of a fault.

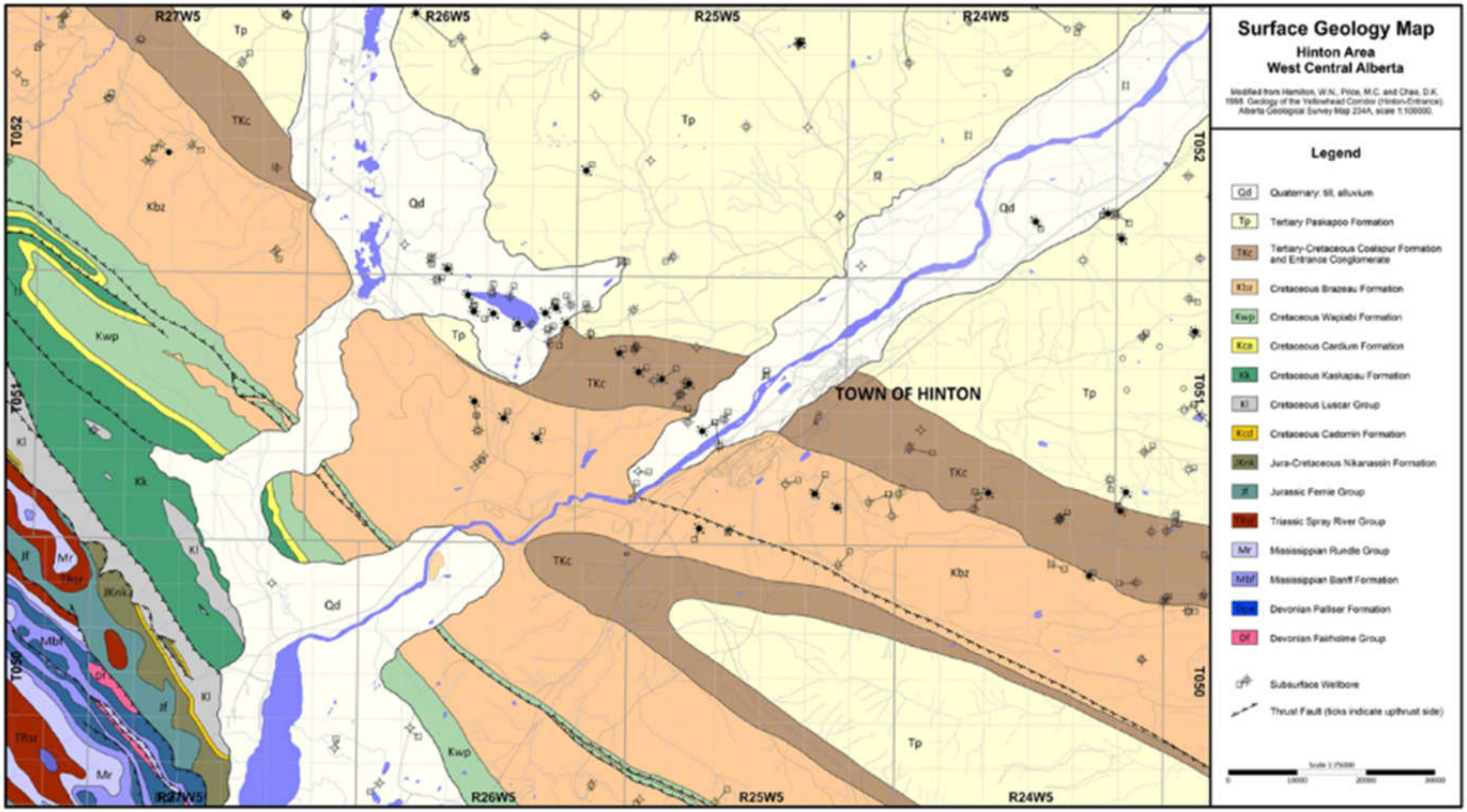



**Figure 15 - Surface geology map of the Hinton Area (modified from [24]). Refer to full-scale copy of map in Appendix C.1.2.**

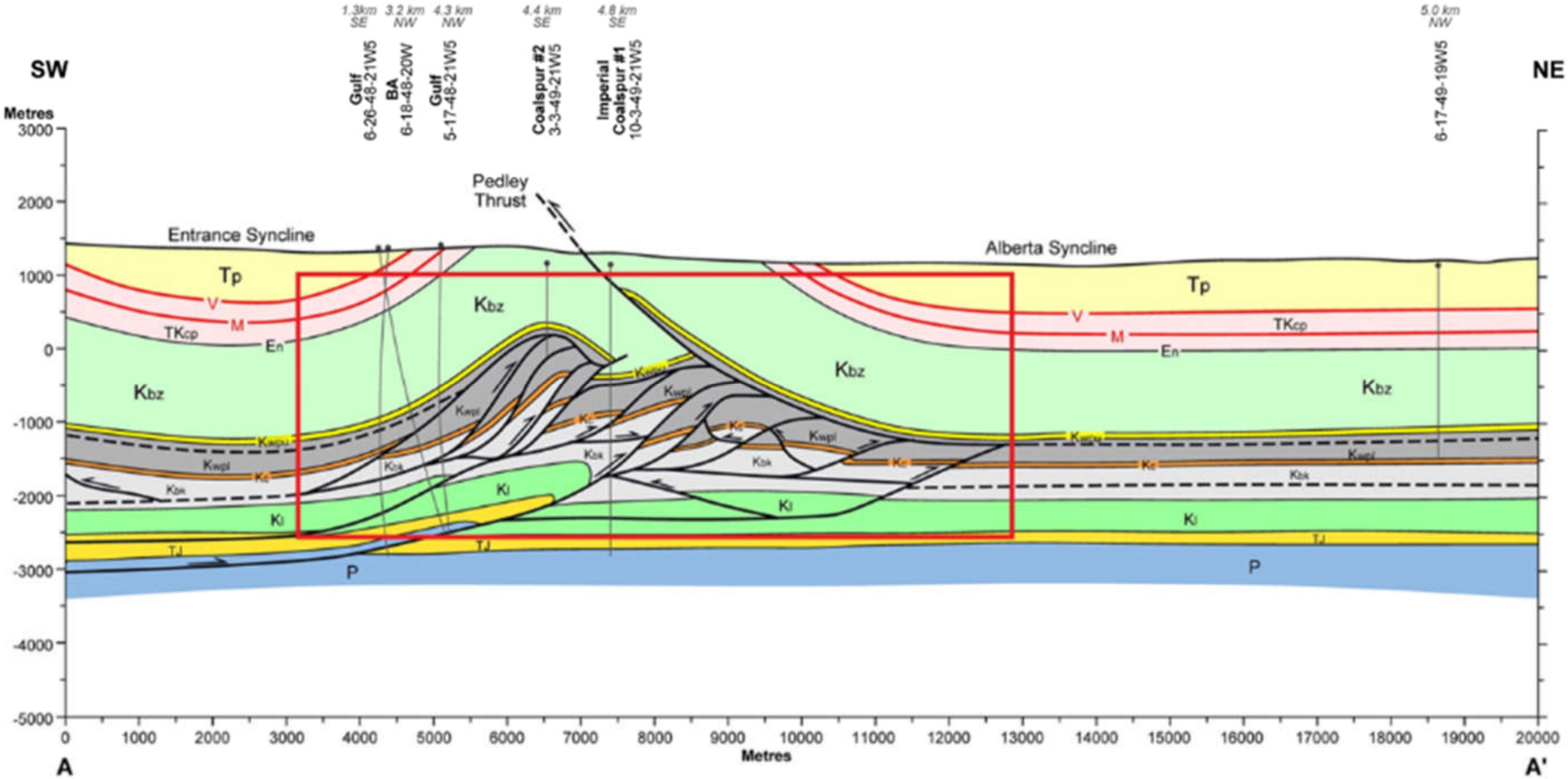



**Figure 16 - Representative foothills structural cross-section A-A' south of the Hinton area in Township 048-049, Range 21W5 [22]. Approximate location of the triangle zone outlined in red.**

### 2.2.5 Geology Summary & Recommendations

The Town of Hinton is located in a region with geothermal potential. Repurposing of subsurface gas wells as part of a proposed DES could reduce Greenhouse Gas (GHG) production and provide long term stable heat energy pricing. However, in order to repurpose existing wellbores, the owner and operator of existing wellbores needs to be willing to participate in the testing of possible zones and construction of geothermal facilities.

The operator of the majority of wells producing in the area surrounding the Town of Hinton was exceptionally generous with providing and discussing confidential wellbore, production and completion information. Although they see the value and potential in repurposing wellbores for geothermal heating, they were unwilling to relinquish access to their wells at this time as it did not align with their subsurface interpretation and future exploration plans in the area. Without access to the wellbores, it was not possible to test the Cardium Sandstone for geothermal reservoir suitability, effectively suspending the project. However, it may be possible to access wellbores at a later date if economic conditions change or if there is a change in ownership. Also, other operators in the area may be willing to participate in well testing for the purpose of geothermal evaluation. It is recommended that Epoch discuss this possibility with other energy companies in the area to pursue this option.

As an alternative to repurposing existing wellbores, drilling a new wellbore(s) for geothermal heating has been proposed. In order to avoid excessive cost and risk associated with drilling a critical sour well, it is recommended that a potential new wellbore only be drilled to the base of the Cretaceous Spirit River Formation. In order to select an appropriate location for the new well, seismic will need to be acquired and interpreted as it is not possible to accurately image the complex geology using only the available wellbore data. This interpretation will be used to calculate and complete a geologic prognosis, which is standard procedure before drilling any new well in western Canada. The prognosis is used by the drilling engineer to plan the well as well as by the AER to assess and approve the location. Also, it is recommended that a full technical and economic risk assessment be conducted to determine the chance of success (COS) of the proposed location.

## 2.3 Drilling & Well Design

Conceptual well design and budget class cost estimates for several different well configurations were performed with the objective of maximizing heat extraction per unit capital cost.

### 2.3.1 Existing Oil & Gas Well Repurposing

Initially, heat extraction was to be accomplished by the re-completion (a.k.a. repurposing) of (an) existing suspended well(s) to a water bearing reservoir such that the heated water could be flowed (or pumped) from the water reservoir through production tubing to surface for heat extraction. While considering this concept together with support from Geology and Reservoir Engineering, it became clear that a suitable water reservoir at sufficient depth does not exist in the local Hinton area.

In addition, existing wells in the immediate Hinton area are active dry gas producers and as such, Operators of these wells are fully reluctant to support a well conversion proposal based upon future expected economic gains from a forecasted natural gas price increase.

### 2.3.2 Alternative – Drilling New Well(s)

The following concepts have been considered as alternatives to the re-completion of an existing well:

1. Circulation between new well pairs:

This concept, shown visually in Figure 17, involves drilling a pair of new wells (Injector/Producer) and extracting heat by circulating fluid from the Injector to the Producer through a deep sub-surface reservoir with sufficient channel permeability to allow for direct flow of fluid between the pair of wells. This concept was not pursued as Geological and Reservoir Engineering interpretation suggests a reservoir capable of such direct flow is not present in the local area. In addition, because the local area is so highly faulted/fractured, it is likely that most of the injected fluid would simply disperse into the fracture network surrounding the Injector wellbore instead of migrating to the Producer well.

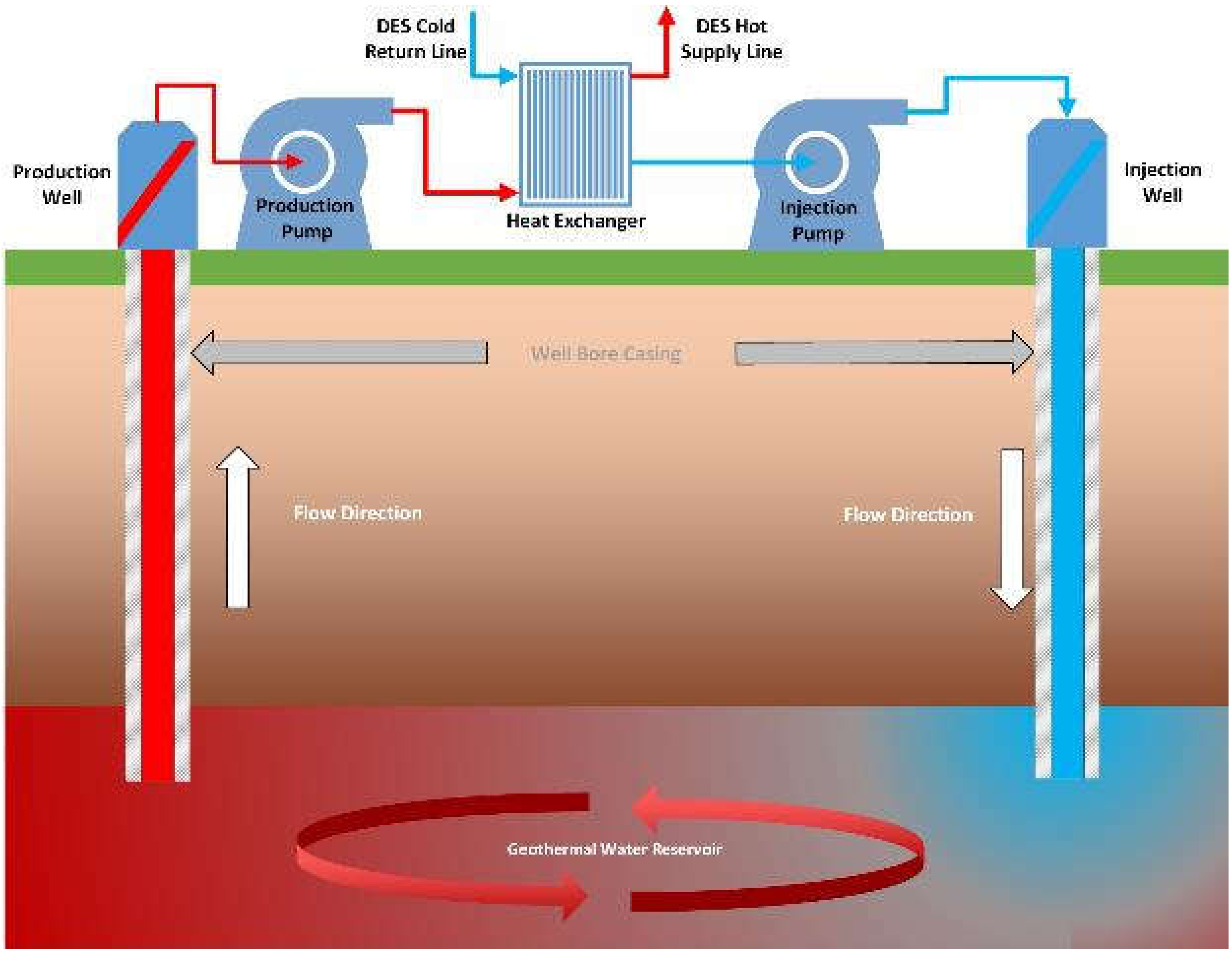



**Figure 17 - Example of a production and injection well pair**

2. New well, closed-loop circulation:

This concept, shown visually in Figure 18, involves drilling a single new well that is capable of heat extraction by circulating fluid in a closed loop system from surface to total well depth. In this case the flow path includes fluid injection downhole into production tubing with fluid returning back to the surface via the tubing/casing annulus (i.e. fluid would head down the well into the subsurface to gain heat via a narrower inner tube and would reach the end of the well where it would be pushed into the outer tube and circulate back up to surface). The flow path could also operate in the opposite direction (down the outer tubing/casing annulus and up the inner production tubing). Heat extraction is accomplished through surface heat exchangers and the cooled fluid is reinjected back down the inner tubing.

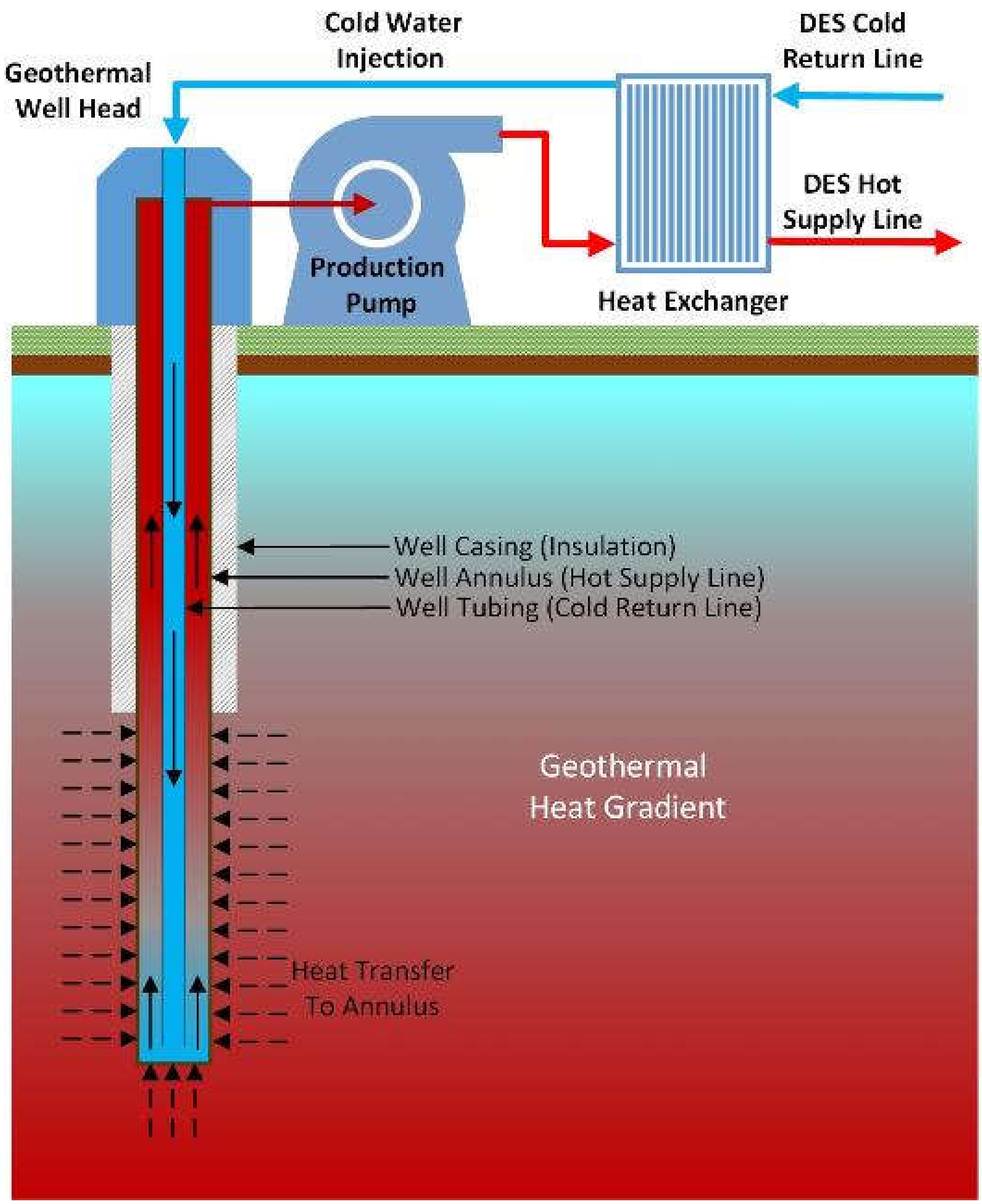



**Figure 18 - Example of a single well using closed-loop circulation**

There are global examples of single wellbore heat exchangers in operation (such as Klamath Falls, Oregon), using one well bore in a closed loop system to transfer heat to surface.

This second closed loop concept was chosen as the well design to be used within this FEED report. The details for it are included below. With the objective of optimizing heat extraction per unit capital cost, both vertical and horizontal (a 500m horizontal leg length that was included to increase the time the fluid spends in the subsurface to increase the heat gained) well configurations at varying true vertical depths (TVD) have been prepared.

## 2.3.3 New Well Closed Loop Circulation – Design Considerations

### 2.3.3.1 Sub-surface hazards

When considering the maximum TVD of a new drill well, the following hazards have been considered as these will have an impact on well cost/risk:

- Varying sub-surface formation pressure gradients
    - Several under-pressured reservoirs (reservoir pressure < 1.0 S.G.) exist in the depth range of 1,000 – 2,000m TVD. In addition, several over-pressured reservoirs (reservoir pressure >1.0 S.G.) exist in the depth range 1,500 – 3,000m TVD. The combination of these different pressure gradients in the same wellbore create the risk of well flow (well kick) and/or drilling fluid losses (lost circulation). Although controllable, the combination of these events make drilling relatively slow and costly.
- Significant over-pressure
    - The Spirit River formation is encountered at a depth of approximately 3,000m TVD, and based on the offset well review this formation may require drilling fluid density as high as 1.90 S.G. to safely control as it is indicated to be under significant pressure. As the shallower formations will not withstand this high mud density (their lower pressure would likely cause them to break down under contact with such dense drilling mud), prior to entering the Spirit River formation it is necessary to set an intermediate casing string that will effectively isolate the Spirit River from all shallower, lower pressure gradient reservoirs. Setting intermediate casing effectively mitigates the risk associated with drilling such an over-pressured zone but adds significant capital cost to wells that are drilled to the Spirit River formation and deeper depths.
- $H_2S$ (sour gas)
    - The Devonian formation is encountered at a depth of approximately 4,200m TVD, and this formation has exhibited $H_2S$ in concentrations as high as 30% in other areas of the Province. Even though the proposed well design involves closed loop circulation and thus does not intend to bring potentially $H_2S$-bearing reservoir fluids to surface, the risk from $H_2S$ still remains due to drilling into the formation. Based on this, from a regulatory perspective it must be assumed that the Devonian may create a hazard to the Public and therefore this must be considered in the well design and licencing process.

### 2.3.3.2 Regulatory Licencing

The time and ultimate ability to licence drilling a new well in close proximity to the Town of Hinton will depend on several factors, including:

- Proximity to the Town
    - The closer the wellsite is to the Town of Hinton, the more likely it is that the well may be classified by the AER as "non-routine". If a well and/or facility is classified as non-routine, this elevates the application requirements, and in some cases may result in a Public hearing which will add significant time for application and approval.
- Presence of $H_2S$

- If the well is to be drilled to Devonian or deeper depths (approximately >4,200m TVD), the well will almost certainly need to be licenced as sour, which necessitates a very thorough and extensive licencing process. A sour well within close proximity to the Town of Hinton will almost certainly require a Public hearing and the ultimate chance of approval in this case must be considered low.

### 2.3.4 Well Design – Cases

Based on the design considerations outlined above, the following different well design "Cases" have been developed. Each Case includes an outline of the basic well design, and the associated time and cost to drill/complete. These cases are then used in models to determine the optimal heat extraction per unit capital cost (see Section 2.4). Refer to the included well schematics and associated cost summary (see Appendix C.2) for each of the detailed Case specifics.

Due to the low estimated reservoir temperatures of shallower formations there is a distinct need to reduce any heat loss experienced by the fluid from full depth up to surface. As fluids are moved from depth up the wellbore towards surface there is naturally some heat loss; however, there are some mitigating actions that can performed on the well in order to prevent as much heat loss as possible. The different well cases explained below include the use of nitrified cement, which acts as an insulator, thus preventing heat loss.

Cases 3, 4 and 5, begin with a well profile that has a larger diameter casing and tubing at the initial stage, which then taper down to a smaller diameter tubing in the later stages as they get closer to the bottom of the well. This tapering acts to decrease weight as without tapering the likelihood for it to shear and break increases. After this casing is set, a 177.8mm Production liner is extended back to surface (called a tie-back string) and cemented in place with cement that has nitrogen injected into the slurry while mixing. This production liner, also known as a "tie-back" string, is a type of casing that is inserted inside of a previously set casing that has already been cemented in place. Effectively this causes the final well profile to have a consistent diameter throughout the entire well profile. The porosity (approximately 50%) created by the nitrogen in the cement creates an insulating effect that will reduce the heat loss while circulating the geothermal fluid back to surface during operation.

Cases 3a, 4a and 5a are the same well designs but do not include the tieback strings and thus retain their tapering profile. These additional cases were included so that economics can be run to analyse the cost/benefit of the tieback string to life cycle economics.

**Table 2 - Well Design Case Summary**

| Case No. | Description | Terminating Formation | Profile | Max. Depth (m) | | Days to Drill | Total Cost ($M) |
|---|---|---|---|---|---|---|---|
| | | | | Measured | Vertical | | |
| **1** | 3000m Vertical Well | Dunvegan | Vertical | 3000 | 3000 | 27.7 | 2.988 |
| **2** | 3600m (2900m TVD) Horizontal Well | Dunvegan | Horizontal | 3600 | 2900 | 33.7 | 3.495 |
| **3** | 3650m Vertical Well - includes tieback | Spirit River/Miss. | Vertical | 3650 | 3650 | 44.5 | 5.655 |
| **3a** | 3650m Vertical Well - without tieback | Spirit River/Miss. | Vertical | 3650 | 3650 | 43.6 | 5.299 |
| **4** | 4300m Horizontal Well - includes tieback | Spirit River/Miss. | Horizontal | 4300 | 3650 | 51.4 | 6.355 |
| **4a** | 4300m Horizontal Well - without tieback | Spirit River/Miss. | Horizontal | 4300 | 3650 | 49.7 | 5.972 |
| **5** | 4500m Vertical Well - without tieback | Devonian | Vertical | 4500 | 4500 | 54.4 | 6.608 |
| **5a** | 4500m Vertical Well - includes tieback | Devonian | Vertical | 4500 | 4500 | 52.8 | 6.218 |

### 2.3.5 Well Design – Major Assumptions

- Well cases 1 and 2 terminate prior to the high-pressure Spirit River formation.
- Well cases 3, 3a, 4 and 4a terminate in the high-pressure Spirit River formation, but prior to the sour Devonian formation.
- Wells 5 and 5a terminate in the sour Devonian formation.
- All wells drill surface hole with water base drilling fluid and all hole sections below surface hole with oil base drilling fluid.
- Well cases 1 and 2 do not require intermediate casing.
- Well cases 3, 3a, 4, 4a and 5, 5a include 244.5mm intermediate casing.
- All wells include 177.8mm production casing.
- All wells include 88.9mm tubing inside 177.8mm casing and 114.3mm tubing inside 244.5mm casing.

### 2.3.6 Well Schematics & Associated Cost Summary

See Appendix C.2: Upstream Drilling for detailed schematics and cost summaries.

### 2.3.7 Sour Well Drilling Considerations

To even begin to scope the challenges in drilling a formation and confirming the $H_2S$ Release Rate (described in more detail below) and Well Category requires a significant amount of preliminary work to be conducted. Before an "AFE (Authority for Expenditures) Ready" cost estimate is scoped out, this work must be completed as it may significantly impact final costs. Once a well location is chosen, detailed geological work must be completed, and then this data will be used to determine at this location the depth it is expected to be sour, and also how sour it may be.

It can't be assumed that even though a well is drilled to a certain depth that it will be classified as "sweet" (i.e. contains no $H_2S$) as a search area of approximately three townships must be considered after detailed geology is conducted. The sour zones are not always depth dependent; they are dependent on the lithology and geologic formation. The depth at which the sour zones occur is highly variable due to reservoir presence and quality, which is further complicated by folding and faulting and other geological considerations. You cannot apply an absolute depth limit to where the sour zones occur for the area, but only confirm this with detailed work.

Geologic zones below the base of the Cretaceous may be sour in the greater area of review as required by the AER (Alberta Energy Regulator) Directive [25]. While an initial review did not indicate this, this review was not over the large area that the AER may require once a full geological work-up is completed. It has been confirmed that the carbonate rocks of Mississippian and Devonian age (Turner Valley, Shunda, Pekisko, Leduc formations) are known to be sour in the area, with $H_2S$ rates in excess of 20%.

When planning to drill a new wellbore, a geologic prognosis that lists all of the geologic zones and the depth that they are expected to occur is drafted including all possible sour zones. If any geologic zones / formations are known to contain $H_2S$ anywhere in the region, they must be listed and used in the calculation of the $H_2S$ Release Rate Radius for the well. For any possible well near Hinton, zones below the base of the Cretaceous will potentially be sour.

Prior to filling in a well license application for any well to be drilled there is a significant amount of background data work-up to gather the data that would appear in a well license to determine what the level of work required to drill a sour formation would be. In the case of the Hinton Geothermal project, this also includes a geophysical data acquirement and analysis to support geological work before starting the engineering work.

Depending on the results of this detailed work, the consultation process can be very time intensive, especially if residents or other affected persons have concerns that must be addressed. This must be completed before a well license will even be issued. Without doing detailed work, a speculation as to what these challenges might be cannot be made.

#### 2.3.7.1 Background

The $H_2S$ Release Rate Assessment Process Flow is shown below, referencing the Canadian Association of Petroleum Producers (CAPP) $H_2S$ Release Rate Assessment and Audit Forms Publication [26].

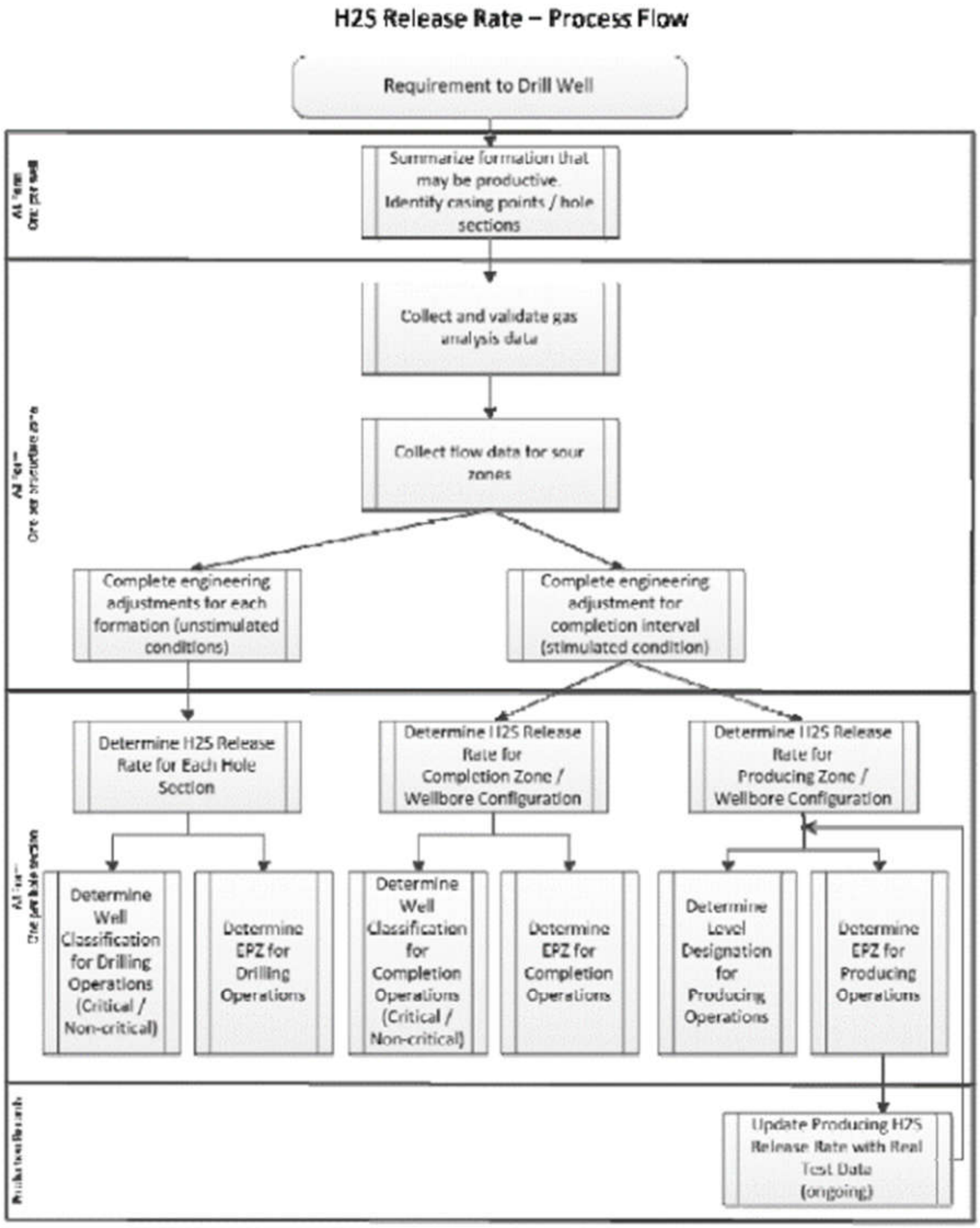



**Figure 19 - Process flow diagram for $H_2S$ Release Rate Assessment [26]**

2.3.7.2 Expected Sour Zone Depth

A very preliminary review indicates that potential zone production of gas in the Cretaceous zone in the Hinton area appears to be sweet; without an in-depth review of geology and wells within a specified radius this is only an indication.

If the 07-11 well mentioned in Section 2.2.1 is being used as an analog, 3,500 m MD is approximately the deepest that a new well can be drilled before encountering sour zone(s). This depth will most likely change depending on the geology of the location (as well, the bottomhole location should be based on the subsurface geology and not the surface location). In order to drill a new well a full geologic prognosis would need to be drafted and would require seismic to complete.

There are noted intervals within the Devonian age formations in the Hinton area that had concentrations of $H_2S$ when tested. The specific tests were as follows:

1. In the 00/14-33-52-26W5 well, over a depth interval from 6303.0 to 6437.0 mKB, showing an $H_2S$ concentration of 22.93%
2. In the 00/06-34-52-26W well, over a depth interval from 5575.0 to 6605.0 mKB, showing an $H_2S$ concentration of 20.95%

Note the variation in these zonal depths, again indicating the geological complexity in this area.

The $H_2S$ release rate is expressed in units of m3 /s and can be calculated using Equation 2.1 from the CAPP $H_2S$ Release Rate Assessment [26] as follows:

$$H_2S_{RR} = H_2S\% * 0.01 * \left(\frac{AOF}{86{,}400}\right)$$

Where;

$H_2S_{RR}$ = Surface $H_2S$ release rate ($m^3/s$)

$H_2S\%$ = Maximum $H_2S$ concentration measured as a percentage of the total gas stream

AOF = Surface absolute open flow potential ($m^3/d$)

#### 2.3.7.3 $H_2S$ Well Licencing

Before submitting a well licence application, the company must assess the $H_2S$ potential of all formations that the well will encounter. For every formation capable of resource recovery, a potential release rate must be calculated and incorporated into the well's assessed $H_2S$ release rate. The regulations for this assessment process are described in Directive 056: Energy Development Applications and Schedules [25].

$H_2S$ concentrations tend to vary, not only from well to well, but even within a single well from sample to sample. As such, it is important to reference all valid sample points that represent the maximum valid $H_2S$ concentration. A better understanding of the geological analogues allows the restriction of data to more representative samples and gains confidence in the quality of the analysis. In addition, as the number of data points in a representative sample set increase, the confidence of the data quality also increases.

Directive 56 recommends beginning with a three-by-three township study area to examine the well penetrations for the prospective zone, and to define the appropriate geological analogies from which representative $H_2S$ and AOF samples can be obtained. However, although the regulatory agencies would generally like to see the geological trends and related mapping for this area, smaller review areas may be used if sufficient data can be obtained. Conversely, the best geological analogues may be more distant and outside the perimeter of a three-by-three-township grid. Similarly, larger review areas may be needed in sparsely drilled areas. In other words, someone with experience in an area must use their best judgement and be able to explain their process.

According to AER's Directive 056 [25]: "Prior to filing a well licence application, the applicant must also do the following:

a) Prepare an adequate $H_2S$ release rate assessment that meets the outlined requirements.
b) Evaluate all formations up to and included in the 15 m overhole interval and incorporate this information into the $H_2S$ release rate assessment.
c) Upon AER request, provide documentation to demonstrate that the $H_2S$ release rate assessment was conducted prior to filing the well licence application.
d) Include related $H_2S$ details for a well that may encounter $H_2S$ gas and this forms the basis for the applicant's participant involvement program for the proposed well project.

Each $H_2S$ release rate assessment must consist of the following four components, but may include additional components as circumstances warrant.

The following four components constitute the $H_2S$ release rate documentation package:

a) Geological well prognosis, with a comprehensive geological discussion (Section 7.11.15.1),
b) Geological mapping (Section 7.11.15.2),
c) Engineering discussion (Section 7.11.15.3), and
d) Tabulated data (Section 7.11.15.4).

#### 2.3.7.4 Drilling Sour Wells Near Populated Areas

##### *2.3.7.4.1 Potential Health Impacts*

$H_2S$ (Hydrogen sulfide) is a colourless, highly flammable, highly toxic gas that smells like rotten eggs and can be dangerous at low concentrations [27]. The following table is taken directly from Work Safe Alberta and outlines the expected health effects from contact with $H_2S$.

**Table 3 - Health Effects from Short-Term Exposure to Hydrogen Sulfide [28]**

| Concentration (ppm) | Health Effect |
|---|---|
| 0.01 – 0.3 | Odour threshold |
| 1 – 20 | Offensive odour, possible nausea, tearing of the eyes or headaches with prolonged exposure |
| 20 – 50 | Nose, throat and lung irritation; digestive upset and loss of appetite; sense of smell starts to become fatigued; acute conjunctivitis may occur (pain, tearing and light sensitivity) |
| 100 – 200 | Severe nose, throat and lung irritation; ability to smell odour completely disappears. |
| 250 – 500 | Pulmonary edema (build up of fluid in the lungs) |

| | |
|---|---|
| 500 | Severe lung irritation, excitement, headache, dizziness, staggering, sudden collapse (knockdown), unconsciousness and death within a few hours, loss of memory for the period of exposure |
| 500 - 1000 | Respiratory paralysis, irregular heart beat, collapse and death without rescue |
| >1000 | Rapid collapse and death |

The values provided above are in ppm (parts per million). Using the conversion 1% = 10000 ppm (i.e. 1% of one million parts), the last row of the table above shows that exposure above 1000 ppm or 0.1% results in fatal consequences. To put the previously mentioned percentages of $H_2S$ in perspective, carbonate rocks (including the Devonian Leduc) are known to be sour in the area, with $H_2S$ rates in excess of 20%.

*2.3.7.4.2 Drilling Setback Distances*

According to the AER's Directive 056 there are specific setback distances from any human habitation, given in the table below, based on the proposed well's calculated $H_2S$ release rate:

**Table 4 - Setback Requirements for Wells Containing $H_2S$ [25]**

| Level | $H_2S$ release rate ($m^3/s$) | Minimum distance |
|---|---|---|
| 1 | $\geq$ 0.01 to < 0.3 | 0.1 km, as stated in Section 2.110 of the *OGCR* |
| 2 | $\geq$ 0.3 to <2.0 | 0.1 km to individual permanent dwellings and unrestricted country developments<br>0.5 km to urban centres or public facilities |
| 3 | $\geq$ 2.0 to <6.0 | 0.1 km to individual permanent dwellings up to 8 dwellings per quarter section<br>0.5 km to unrestricted country developments<br>1.5 km to urban centres or public facilities |
| 4 | $\geq$ 6.0 | As specified by the ERCB but not less than Level 3 |

If the proposed well is considered a "Critical Well", this impacts the drilling procedures that must be used. This also greatly increases the costs and complexity of drilling a well.

## 2.4 Upstream Well Heat Exchanger Simulation

Although there are high subsurface temperatures in the Hinton area, they are found very deep and within geological formations that have characteristics that make accessing that heat technically difficult at this study's small project scope. Independent research recently conducted by the University of Alberta suggests a promising subsurface environment for the production and injection of water (considered the best method for heat extraction); however, as mentioned in Section 2.2, preliminary geological review conducted for this FEED project suggests that water production is poor and that many sour $H_2S$-rich zones exist near the Town of Hinton.

The amount of heat able to be extracted from a feasible well in the Hinton area is estimated to be low. The largest unknown of this District Energy System (DES) is found upstream of the District Energy Center (DEC), where the largest concern is how much heat can be extracted from the well.

As production/injection methods were deemed unviable, a closed loop circulation method within a single well bore was explored. This method, first proposed in the pre-FEED, allows for the extraction of heat from the subsurface without any actual exchange or extraction of fluids, thus circumventing the issue of lack of permeability and available fluid in the subsurface. During the Pre-FEED study a method was developed (see Appendix C.3 for the methodology used) to estimate the amount of heat that could be obtained from a well using a closed loop method. This FEED report utilized the same method, which emulates the well as a large vertical shell and tube heat exchanger (see Section 3.3.2 for exchanger type descriptions). In this closed loop well configuration, cooler water flows down the well annulus in the area between the casing and the tubing gaining heat as it descends into the warmer subsurface and would then return up through the centre tubing to surface. Note that a reverse flow path with the cooler water coming down the tubing and the heated water returning up the annulus between the casing and tubing would also be possible.

This heat exchanger model was based on several assumptions, which are listed below:

- There is zero heat transfer between the annulus and the surrounding rock at depths where the temperature is below the fluid inlet temperature,
- There is zero heat transfer through the tubing wall,
- The fluid used is a 30% to 70% Glycol to Water mixture,
- The temperature gradient is linear and assumed at 28.3°C per vertical km,
- Steady state heat transfer (i.e. reservoir is not being depleted of heat),
- Convective heat transfer only.

The assumptions listed above are the main differentiators between this model and similar work performed by the University of Alberta (U of A). Following the pre-FEED modeling of the single bore heat exchanger well, U of A was approached to do a more in-depth, independent model of the scenario. Similar methodologies were used, but with different assumptions. U of A's modeling used higher inlet fluid temperatures and bottom hole temperatures, as well as a uniform tube and annulus as they were not trying to optimize hydraulics initially. The pre-FEED model assumed materials used that would perform as near perfect insulators to prevent the heat exchange between the injection tubing and production annulus. However, in U of A's model the heat transfer between these sections was included, which showed a significant amount of heat loss with the tubing cooling down the fluid in the annulus as it came back to surface. This resulted in outlet temperatures lower than the inlet temperatures, compared to pre-FEED model that had assumed using a vacuum insulated tubing to be able to negate this effect.

Although there are commercially available tubing strings that are specially designed to mitigate heat transfer between the tubing and the annulus (the vacuum insulated tubing mentioned above), and nitrogen filled cement for the casing that can be used to prevent heat loss between the casing and surrounding ground, the assumption of zero heat transfer is not practical because no material is a perfect insulator. In real-world operation it is presumed that the annulus and tubing will effectively operate as a counter flow heat exchanger, with the heated fluid losing heat to the cold fluid jacket as it rises to surface. As well, the inlet water will transfer heat to the casing at shallower depths.

Efficiency in this design is defined as the maximum amount of heat extracted from the well at the least amount pumping power. Another factor included in this design is the outlet temperature of the fluid, as the DES is designed to function at a temperature of 85°C. In most of these scenarios, peak heating will be required due to the diminishing returns of heat transfer. Heat transfer is a function of temperature differential; therefore, a target outlet temperature of 85°C from a well with a bottom hole temperature (BHT) of 85°C at 3,000m depth is much more difficult to obtain (because of inevitable heat loss) compared to, for example, a well with a BHT of 113°C at 4,500m. In the following sections, as a base case a 4,200m (bottom hole depth) well will be analyzed to give insight into the effect of depth, heat gradient, and the addition of horizontal segment.

The following sections describe three different optimizing scenarios:

1. Well profile configuration related to friction loss (Section 2.4.1)
2. Heat extraction from varying flow rates (Section 2.4.2)
3. Pumping power, balancing heat and cost of the pump (Section 2.4.3)

### 2.4.1 Well Profile Comparisons of Hydraulic Performance

The following sections present the methodology for developing the optimal well design. The first optimization compares well profiles. Due to the increase in pressure in the formation below 3,000m, the largest possible casing diameter was 7" below 3,000m and 9-5/8" above 3,000m. Due to this constraint, the only other factor to optimize was tubing diameter.

The well profiles are outlined in the table below.

**Table 5 - Well Profiles Used for Comparison**

| Well Profiles | | | | |
|---|---|---|---|---|
| Inner Diameters (m) | | | | |
| Profile # | 1 | | 2 | |
| Depth from Surface | Casing | Tubing | Casing | Tubing |
| 0-2900m | 0.217 | 0.095 | 0.217 | 0.095 |
| >2900m | 0.162 | 0.095 | 0.162 | 0.070 |
| Hydraulic Diameters (m) | | | | |
| Depth from Surface | Annulus | Tubing | Annulus | Tubing |
| 0-2900m | 0.102 | 0.095 | 0.102 | 0.095 |
| >2900m | 0.047 | 0.095 | 0.073 | 0.070 |

Table 5 above lists two well profiles using the depth/diameter constraints outlined in this section. The initial instinct was to increase the diameter of the tubing, as it was the assumed to be the bottle neck of the down hole heat exchanger. However, contrary to the initial assumption, it was determined through pressure loss modeling that the opposite occurs. Increasing the hydraulic diameter of the annulus reduces pressure drop by a larger factor compared to increasing the tubing diameter.

Pressure loss in the pipe occurs due to friction experienced by the fluid in contact with the pipe. This needs to be accounted for because any reduction in pressure needs to be compensated for by the pump acting to circulate the fluid through the pipes, so optimizing this factor is essential to achieving the most efficient flow through the well and thus reduce operating costs.

The pressure loss model is based on the Hazen-Williams equation, which utilizes hydraulic diameters of each flow channel. The tubing's hydraulic diameter is equal to its inner diameter, and the annulus hydraulic diameter is equal to the inner diameter of the casing minus the outer diameter of the tubing. The Hazen-Williams equation is as follows;

$$h = \frac{0.2083(100/C)^{1.852} * q^{1.852}}{{d_h}^{4.8655}}$$

Where;

h = friction head loss in feet of water column of water per 100 feet of pipe

c = Hazen-Williams roughness constants (conservatively assumed as 140 for both smooth concrete and tubing)

q = volumetric flow rate (gal/min)

$d_h$ = inside hydraulic diameter (in)

Note: Due to the various parties involved, imperial and metric units were both used for calculations, with answers converted to SI units for consistency.

Using this equation, the friction loss at various flow rates were tested in each well profile in intervals from 10 L/s to 50 L/s. The results can be found below:


**Figure 20 - Friction Loss vs. Flow Rate in Well Profiles**

Profile 1 shows the pressure loss of larger diameter tubing resulting in a smaller annulus, and profile 2 the pressure loss of smaller diameter tubing resulting in a larger annulus. At the lowest flow rate (10 L/s), the resulting pressure drops look comparable; however, Profile 1 has six times more friction losses compared to Profile 2. At increasing flow rates, the disparity becomes exponentially larger. Profile 2 is a more efficient well profile and should be used for further investigations into optimization. Having an annulus and tubing with similar hydraulic diameters is a key factor in minimizing pressure losses.

### 2.4.2 Well Heat Extraction Modeling

The well profile plays a key role in heat extraction. Factors that improve heat extraction include:

- higher temperature gradients
- greater depth
- larger wellbore diameters
- higher flow rates

Unfortunately, most of these factors result in negative and/or cost-intensive impacts to the project, which will render it unfeasible.

Temperature gradient is location-dependent while the other factors can be controlled.

Drilling a deeper well will lead to higher temperatures; however, drilling to a greater depth increases drilling costs and risks, as well as pumping power to circulate fluid. Drilling larger well bores have similar costs and risks associated; however, increasing bore diameter would reduce pump power requirements since it minimizes friction losses.

Finally, higher flow rates will improve heat extraction but will also increase friction losses. Higher flow rates and friction losses require increased pumping power. In addition, at higher flow rates the outlet temperature of the fluid will decrease. This relationship is important to this specific application as the Hinton DES is designed for a fluid temperature of 85°C. To obtain this outlet temperature from the optimal well profile described above, flow rates circulating the well are estimated as low as 6 L/s.

Ultimately, the objective of this analysis is to determine the optimal thermal performance of the well by varying flow rates.

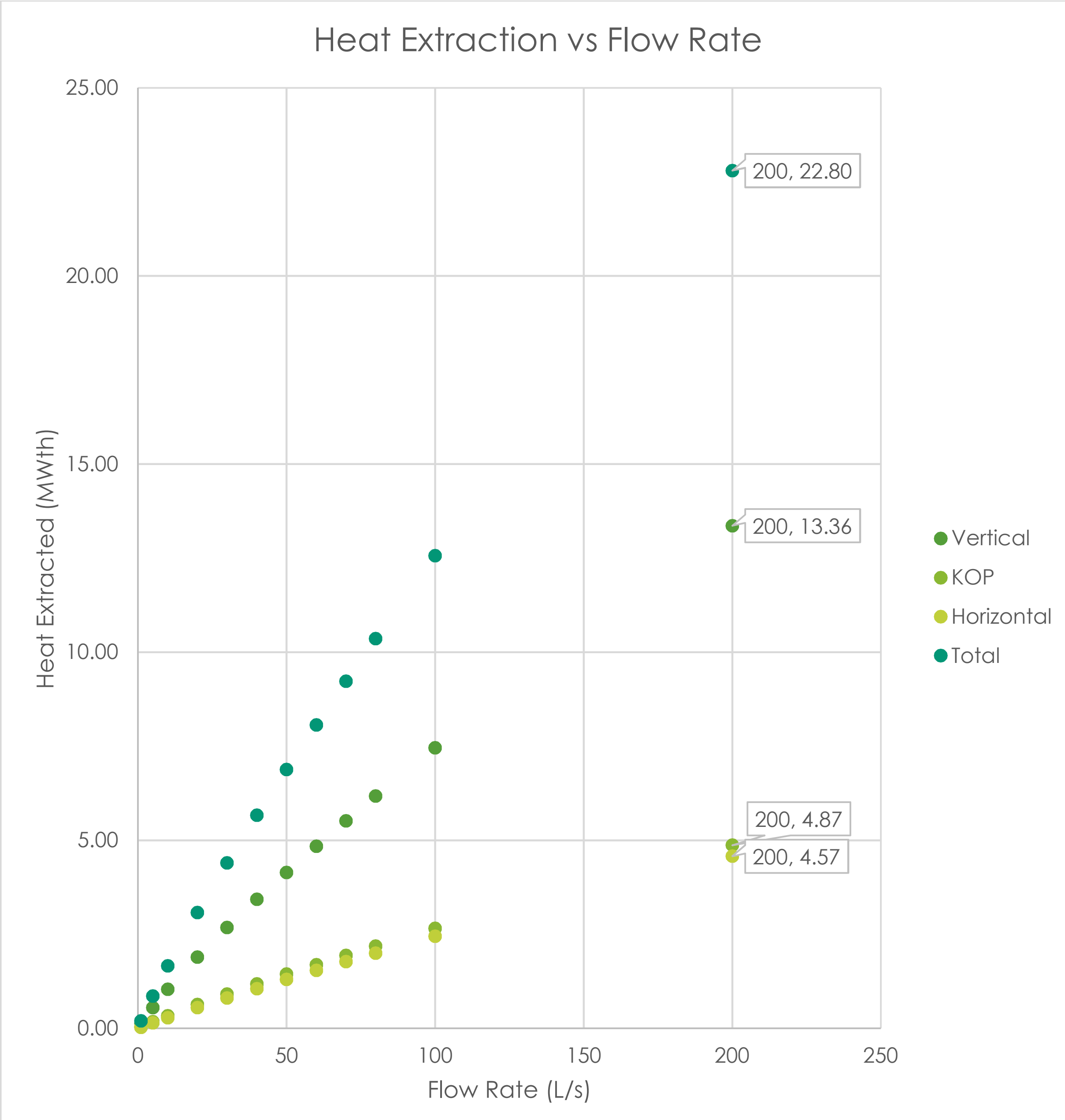



**Figure 21 - Well profile 2 heat extraction through each section vs. flow rate**

The figure above plots the heat transfer in each section of the well (Profile 2), and the total heat transfer through the entire well. The vertical portion defines the heat acquired from 0m to 3400m depth (excluding the insulated portion), the Kickoff Point (KOP) is the depth at which the vertical section transitions to the horizontal leg (approximately 400m), while the horizontal leg is another 400m length completely horizontal at a depth of approximately 3600m.

On average, the vertical portion of the well accounts for 60% of the total heat acquired, while the KOP and horizontal leg each average 20%. These two sections account for 40% of heat acquired and only 19% of the total well length. A few factors account for this, the main factor being the larger temperature differential at those depths. The results suggest that this project depends primarily on the temperature gradient of the geological formation.

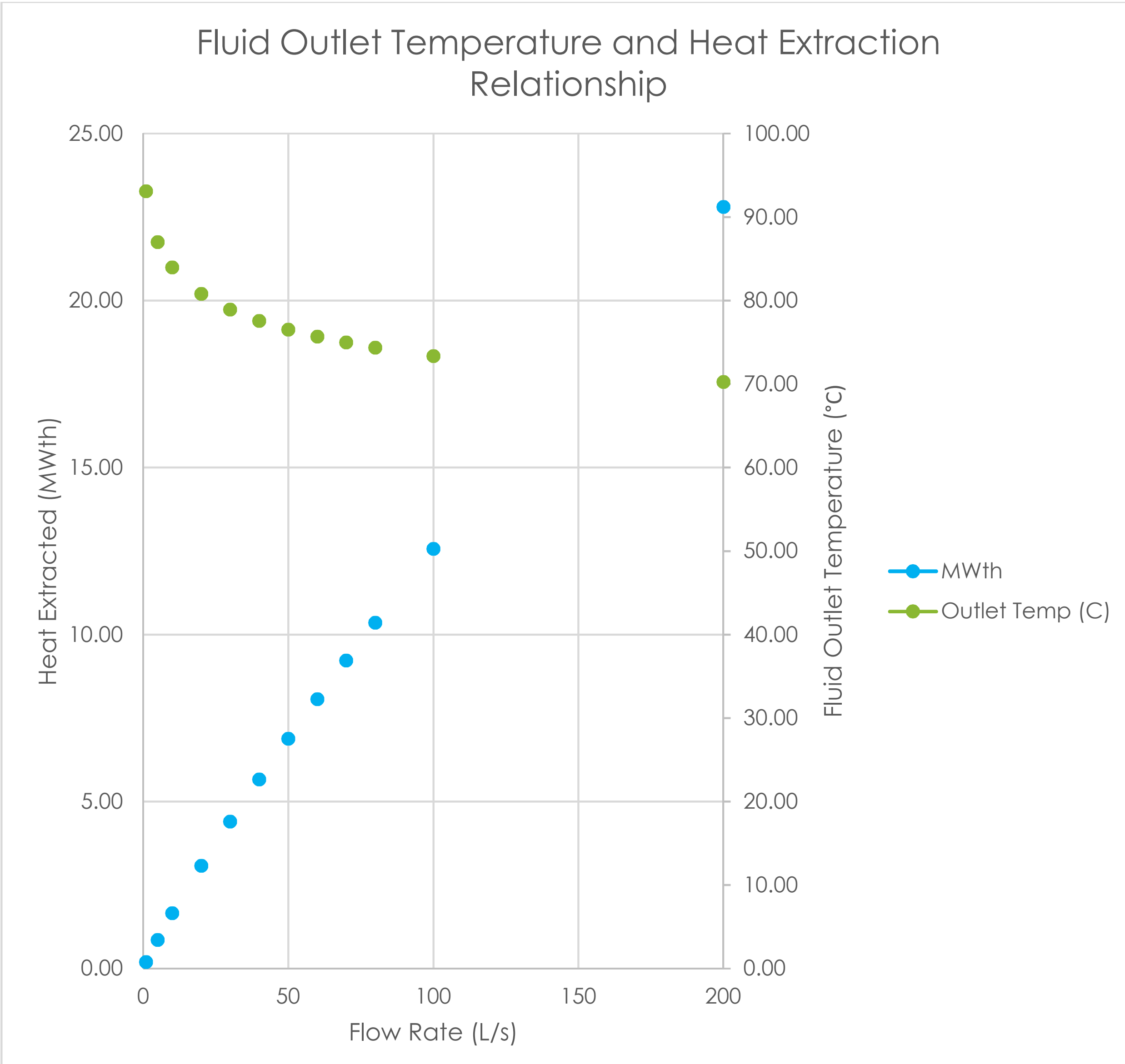



**Figure 22 - The effect of heat extraction on fluid outlet temperature**

Figure 22 plots the effect of heat extraction on the fluid outlet temperature at varying flow rates. There is clear visual indication that amount of heat extracted and fluid outlet temperature are inversely related. The amount of thermal energy extracted is fundamentally a function of mass flow rate and temperature differential. While increasing heat extraction results in a lower outlet temperature, the effect of heat extraction to fluid outlet temperature is not linearly related due to additional factors of heat transfer such as the Reynold and Nusselt numbers. These factors are impacted by volumetric flow rate, which increase with mass flow rate for this type of convective heat transfer.

For the Hinton DES and an anticipated DES fluid temperature of 85°C, there is no benefit to a high flow rate. The optimal solution for heat transfer is to match the flow rates of both the upstream circulating loop and the distribution loop of the DES. Equal flow rates result in lower heat extracted from the well, but also result in greater energy transfer into the Hinton DES. This reduces the amount of peak heating required from the DES boiler. If the DES at full load were to operate at approximately 40 liters/sec, matching that flow rate to circulate in the well would result in a heat output of 5.66 $MW_{th}$, and outlet temperature 77.6°C. Peak heating from the boiler would be required to add 5-10°C to the DES fluid temperature, depending on the heat loss through transmission and heat exchangers.

### 2.4.3 Optimizing Pumping Power

In the previous section, the well design of Well Profile 2 was optimized to minimize friction losses at a flow rate equal to that of the DES. When optimizing pumping power, it is important to understand that friction loss and flow rate directly affect pump size, which in turn affects initial capital expenditure and operating costs. The optimal pump design will extract the most thermal heat at a pump size that still makes the project economically feasible.

There is a limit to sizing the pump where the pump power requirement is so high; the ratio of heat extracted ($MW_{th}$) is equal to or less than the cost at which the electricity used to power the pump can be sold for other purposes. This limit will need to be identified through an economic sensitivity analysis, but this section will demonstrate a method to determine this value.

Pumping power was obtained using the equation for head loss, with a pump efficiency factor of 0.75 to 0.9 applied. A reciprocating pump with a conservative efficiency of 0.8 was used. The equation below was used:

$$P_s = \frac{q * p * g * h}{3.6(10)^6} * \eta$$

Where;

$P_h$ = Shaft Power (kW)

q = Flow Rate ($m^3/h$)

p = Density of Fluid ($kg/m^3$)

h = Differential Head (meter of water column)

η = Pump Efficiency (%)

Differential Head is the anticipated friction loss through the well in kPa, converted to meters of water column.

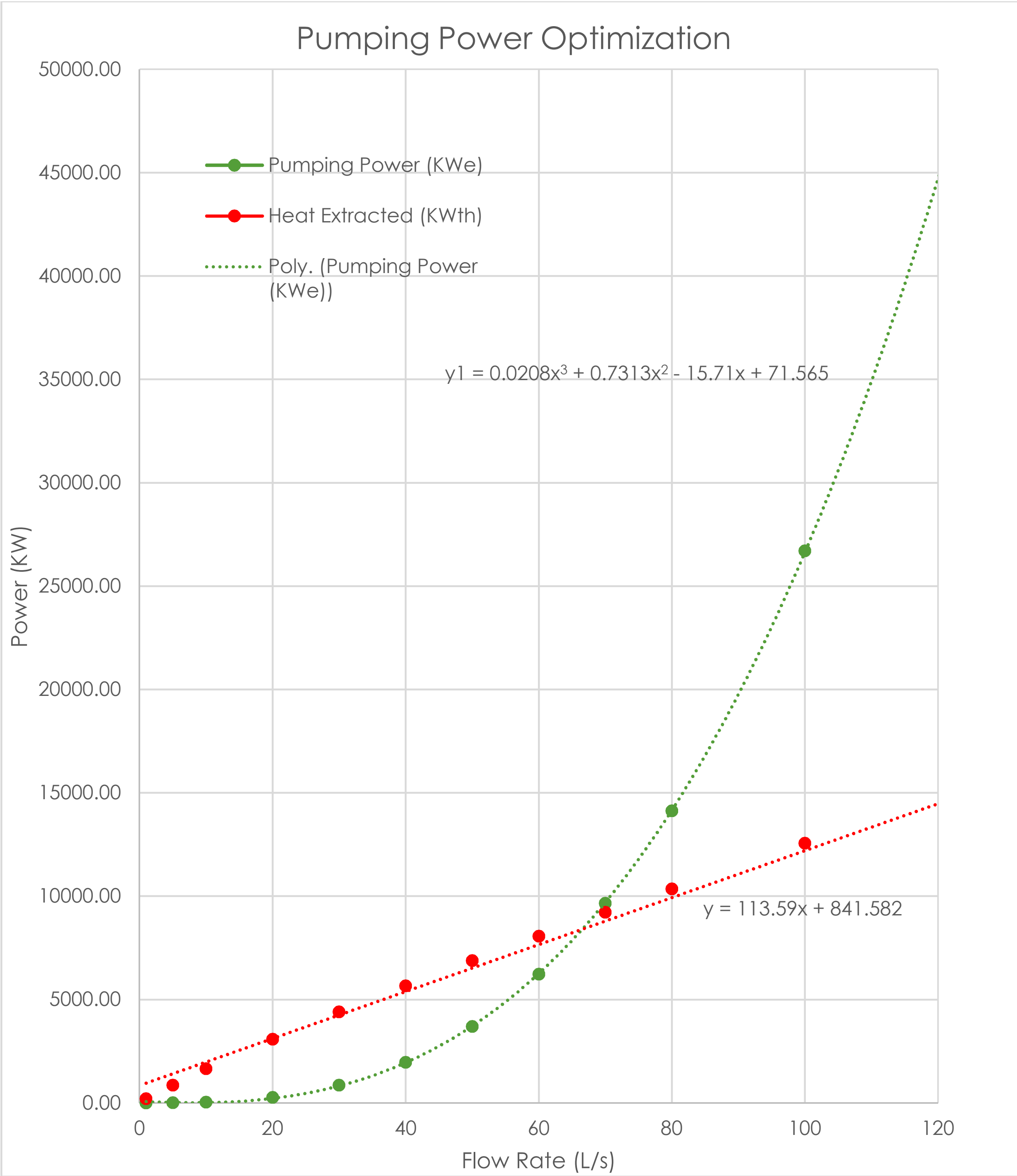



**Figure 23 - Results from simulating pumping power and heat extracted vs. flow rate**

Figure 23 is used to optimize the pump to extract the most heat while minimizing pump power requirements. The relationship of heat extracted to flow rate runs linearly at an estimated slope of 113.59 $KW_{th}$/L/s, while pumping power vs flow rate fits a polynomial curve, with the slope constantly increasing. To determine the slope of the polynomial, the polynomial is differentiated with respect to flow rate (i.e. variable 'x'):

$$\frac{d}{dx}(0.208x^3 + 0.7313x^2 - 15.71x + 71.565) = 0.0624x^2 + 1.4626x - 15.71$$

Utilizing this formula correctly requires an economic analysis to determine the correct ratio of thermal heat to pump power required. This ratio will then be applied to the differentiated polynomial.

For example, if it is determined from an economic analysis that 3 $KW_{th}$ is profitable to the DES if it only requires 1$KW_e$ pumping power to extract that heat, then the optimal slope for pumping power would be equal to a third of the slope for heat extracted:

$$113.6\frac{KW_{th}}{L/s} * \left(\frac{1\ KW_e}{3\ KW_{th}}\right) = 37.87\frac{KW_e}{L/s}$$

Solving the differentiated formula for pump power at 37.9 $KW_e$/L/s results in a flow rate of approximately 19.5 L/s. Therefore, for this scenario, it is concluded that at a flow rate below 19.5L/s, each KW of electrical power produces more than 3 KW of thermal energy from the well.

### 2.4.4 Conclusion

Each factor affecting the design of the well and pump can be optimized individually, but important considerations must be made to the economics of the project. As mentioned in Section 2.4.2, the well has potential to extract an infinite amount of thermal energy due to the steady state assumption. The temperature in the well, however, will (eventually) deplete in a transient model and the required pumping power to maintain the same level of heat extraction will increase dramatically as flow rate will need be increased accordingly, thus increasing operating costs due to friction loss. The methodology described above can be used to optimize well design and determine if the project is practically and economically feasible, but more details must be determined on the well reservoir and economics.

Cost estimates for the feasibility of this project will proceed under the assumption that a well profile with similar hydraulic diameters (Profile 2), and a fluid circulation rate of 20 L/s is used. This results in a 375HP (275 $KW_e$) pump that acquires approximately 3.1 $MW_{th}$ of energy at a fluid outlet temperature of 81°C. Using the methodology described above, eight well profiles will be examined in Section 2.5.

## 2.5 Upstream Well Design Comparison

Many variables need to be considered during the process of selecting the optimal well for the Hinton DES. Operating cost, capital cost, and risks are factors which must be explored before proceeding. Working with drilling experts and utilizing the same hydraulic and thermodynamic models as Section 2.4.2, eight well profiles were modelled. Each well profile is characterized with varying depths, orientations and tubing/casing diameters (see Table 6 below). The drilling and geochemical risks associated with each well are not assessed as part of this comparison. The well recommended will be based on a financial and performance basis while the other risks associated with each well will be covered in other sections.

To ensure consistent comparisons between each well profile, some variables were controlled. All wells would have the following characteristics:

- 40°C fluid inlet temperature
- Circulating flow rate of 20 L/s
- Vertical thermal gradient of ~28°C/km.

As required, the well profiles of each well candidate are divided into sections due to variations in:

- Orientation (Vertical, Horizontal, etc.)
- Casing Diameter
- Tubing Diameter

If a well is divided into separate sections, the outlet conditions of one section would be modelled as the inlet conditions of the following stage until the end of the well. For the KOP sections, vertical temperature gradient is determined by the true vertical depth of the section instead of the measured depth.

**Table 6 - Well profile configurations and cost estimate**

| Well Profile | Well Section | Orientation | Length | Casing Dia. | Tubing Dia. | Capital Cost |
|---|---|---|---|---|---|---|
| | | | m | mm | mm | $ |
| 1 | Stage 1 | Vertical | 3000 | 177.8 | 88.9 | $2,988,000 |
| 2 | Stage 1 | Vertical | 2700 | 177.8 | 88.9 | $3,495,000 |
| | Stage 2 | KOP | 400 | 177.8 | 88.9 | |
| | Stage 3 | Horizontal | 500 | 177.8 | 88.9 | |
| 3 | Stage 1 | Vertical | 3650 | 177.8 | 88.9 | $5,656,000 |
| 3A | Stage 1 | Vertical | 2900 | 244.5 | 114.3 | $5,299,000 |
| | Stage 2 | Vertical | 750 | 177.8 | 88.9 | |
| 4 | Stage 1 | Vertical | 3350 | 177.8 | 88.9 | $6,314,000 |
| | Stage 2 | KOP | 450 | 177.8 | 88.9 | |
| | Stage 3 | Horizontal | 500 | 177.8 | 88.9 | |
| 4A | Stage 1 | Vertical | 2900 | 244.5 | 114.3 | $5,972,000 |
| | Stage 2 | Vertical | 450 | 177.8 | 88.9 | |
| | Stage 3 | KOP | 450 | 177.8 | 88.9 | |
| | Stage 4 | Horizontal | 500 | 177.8 | 88.9 | |
| 5 | Stage 1 | Vertical | 4500 | 177.8 | 88.9 | $6,607,000 |
| 5A | Stage 1 | Vertical | 2900 | 244.5 | 114.3 | $6,218,000 |
| | Stage 2 | Vertical | 1600 | 177.8 | 88.9 | |

Table 6 outlines eight well profiles. As mentioned in Section 2.4.4, operating cost and capital cost are critical factors in selecting a well for the Hinton DES. As in Section 2.3.4, well candidates with the suffix "A" begin with a well profile that has a larger diameter casing and tubing at the initial stage, then taper down to a smaller diameter tubing in the later stages. Well candidates without the suffix have consistent diameters throughout the entire profile. The tubing diameter is modified to minimize pumping power demand by having similar hydraulic diameters for both flow channels (i.e. between the annulus and tubing, and within the tubing).

Coinciding with the hydraulic model (Section 2.4.1), the thermodynamic models determined the heat acquired ($MW_{th}$) from each well profile and the outlet temperature of the fluid at surface. The same assumptions outlined in Section 2.4 were used for these models.

The methodology summarized in Section 2.4 determines:

- Total pressure drop through the well
- Heat acquired
- Fluid outlet temperature at surface

When compared with the capital cost of constructing the well, new factors can be formulated to determine the most efficient and optimal well profile. The new factors determined are:

- Operating Efficiency - $MW_{th}$ / MPa
    - A ratio of heat acquired to operating costs, as determined by the total dP (differential pressure) required to circulate fluid through the downhole loop. A higher ratio is desirable, as the well increases in operating efficiency.
- Cost Efficiency - $MW_{th}$ / $
    - A ratio of heat acquired to initial capital expenditure. This factor is a good indication of payback period. As with the factor above, a higher ratio is desirable, as the well becomes more cost efficient.
- Pump Size is determined from the resulting pressure drop (from friction) at a flow rate of 20 L/s. This provides an outlook at additional costs associated with installing larger pumps. A conservative efficiency factor of 0.8 was applied for reciprocating pumps. The equation for determining pump size can be found in Section 2.4.3.

**Table 7 - Hydraulic and Thermodynamic Well Simulation Results**

| Well Profile | Total dP | Heat Acquired | Outlet Temp | $MW_{th}$/MPa | $MW_{th}$/$MM | Pump Size (η=0.8) | |
|---|---|---|---|---|---|---|---|
| | kPa | $MW_{th}$ | °C | | | KW | HP |
| 1 | 10262 | 1.22 | 56.16 | 0.119 | 0.41 | 269 | 361 |
| 2 | 12314 | 1.87 | 64.84 | 0.152 | 0.54 | 323 | 433 |
| 3 | 12485 | 1.66 | 62.06 | 0.133 | 0.29 | 327 | 439 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 3A | 4787 | 2.18 | 68.91 | 0.455 | 0.41 | 125 | 168 |
| 4 | 14709 | 3.02 | 80.05 | 0.205 | 0.48 | 386 | 517 |
| 4A | 7011 | 3.05 | 80.46 | 0.435 | 0.51 | 184 | 246 |
| 5 | 15393 | 3.75 | 89.80 | 0.244 | 0.57 | 403 | 541 |
| 5A | 7695 | 3.91 | 91.95 | 0.509 | 0.63 | 202 | 270 |

Each case varies significantly, with predictable patterns from earlier sensitivity studies (Section 2.4). Deeper wells result in higher outlet temperatures due to higher bottom hole temperatures and a constant vertical thermal gradient. Hydraulic performance increased in profiles 3A, 4A, and 5A where the tubing diameters were tapered to match the hydraulic diameter of the flow channel between its corresponding annulus. Finally, more heat is acquired in well profiles with longer measured depths due to increased surface area for heat exchange and higher temperatures due to thermal gradient.

The best performing well in terms of heat acquisition vs. operating costs and initial capital expenditure is Well Profile 5A. While the numbers present a favourable case for this well profile, it should be re-iterated that other significant drilling and geochemical risks have not been considered. In simply reviewing the results obtained in Table 7, the well provides relatively unsurprising results, as predicted in the previous paragraph.

For Well Profile 5A, it should be noted that the hydraulic diameters of the flow channels between the annulus and the tubing, and the tubing itself are 102mm and 95 mm respectively for Stage 1 and 73mm and 70 mm for the later stages. For Well Profile 5, the hydraulic diameters are 73mm and 70mm respectively through the entire length of the well. Between both Well Profiles at Stage 1, the hydraulic diameters of 5A are ~20% larger than 5, resulting in a significantly lower pressure drop. While both well profiles acquire the same amount of heat (within 5%), the pump required for Well Profile 5 is almost double that of 5A. This results in an operating efficiency for 5A that is more than double that of 5. In addition, the cost to drill Well Profile 5 is $389k higher, making Well Profile 5A a more cost efficient well.

If Well Profiles 5 and 5A are not feasible due to drilling and geochemical risks such as high-pressure zones and/or sour zones, then a shallower well profile must be drilled, and these wells are no longer feasible. For similar reasons mentioned above, Well Profiles 3A and 4A are recommended as the next best options.

It should be noted that further considerations should be made for Well Profile 2. This well results in a relatively high cost efficiency ratio; however, its operating efficiency is too low. Potential remedies include, but are not limited to, increasing the casing diameter of the well. This would reduce pressure drop and increase thermal performance; however, the capital costs to drill the well would increase as well. It is not yet known the degree in which each factor will affect overall efficiency.

## 2.6 Upstream Facility/Pumping Station and Circulation Loop

The geothermal circulation loop is used to transfer heat energy from the well to the District Energy Center (DEC). The upstream facility and circulation loop follow a relatively simple process flow. The facility will be built to ASME B31.1 - Power Piping (a standard that defines minimum design requirements). All equipment, vessels, fittings and pressure piping will be registered with a CRN under the Alberta Boilers Safety Association (ABSA), as required. In addition, to receive the proper permits the town heat exchanger will meet the Town of Hinton's Minimum Engineering Design Standards (2007). It should also be noted this facility may require further licensing from the AER. More information is available in Section 2.7; however, this facility is expected to meet all requirements for licensing and permitting.

## 2.6.1 Process Flow

### 2.6.1.1 Upstream Facility/Pumping Station

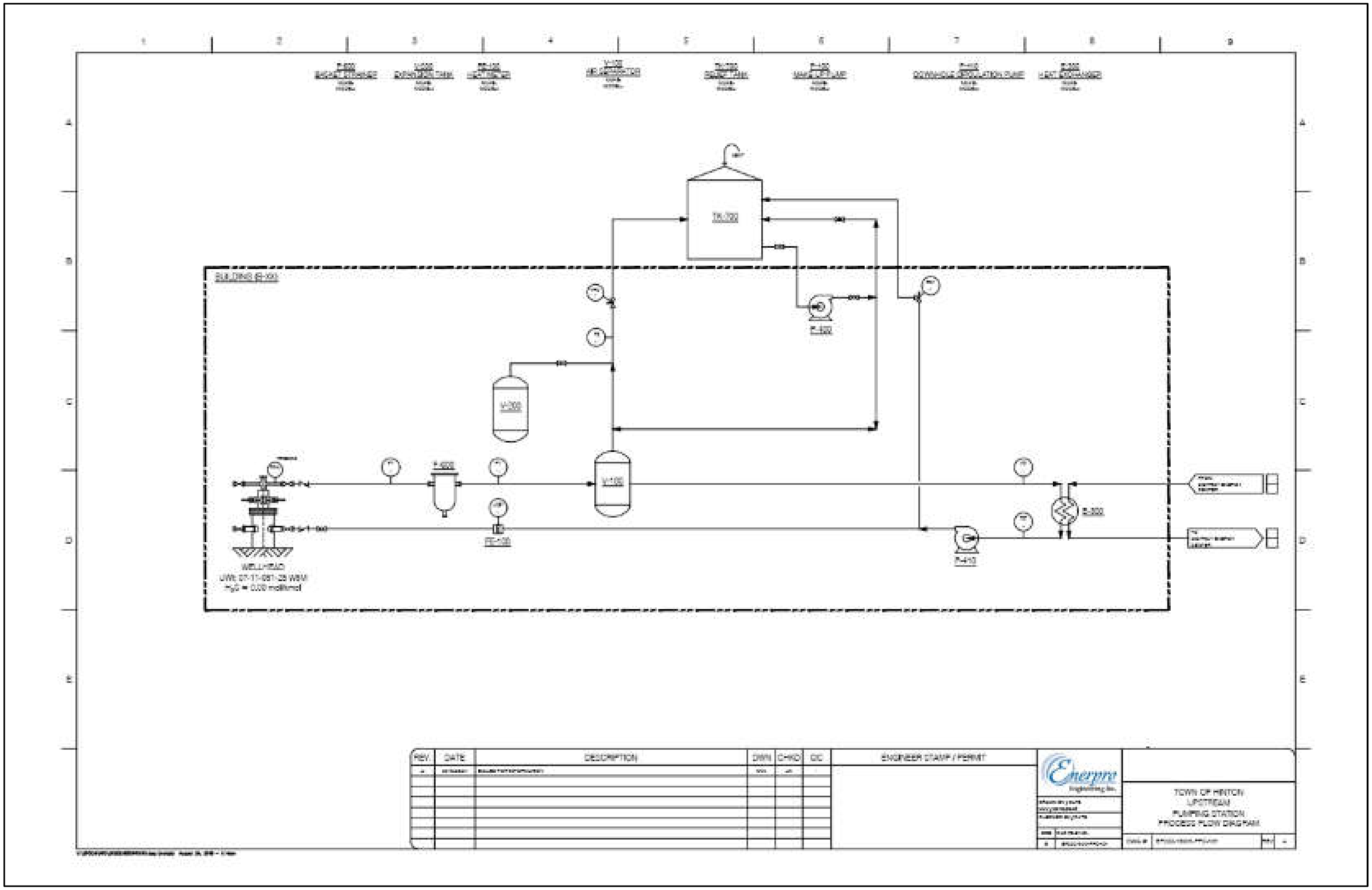



**Figure 24 - Process flow diagram of upstream facility/pumping station (Appendix D.9)**

Refer to Appendix D.9 for the Process Flow Diagram (PFD) of the upstream facility. At the upstream facility / pumping station, a reciprocating pump will circulate fluid down the well and heated fluid will flow to the surface. At the surface, the heated fluid will first enter a basket strainer to filter out any particulates from the well. It is unlikely that these particulates are significant, as this loop is a closed system. The fluid will then enter an air separator to remove any air bubbles that surface. The air separator was placed at this point because it is assumed that the pressure will be the lowest and the temperature of the fluid will be the highest at this point; these conditions create the most likely scenario for bubbles to drop out of the fluid. This air separator shall be connected to an expansion tank which will provide space for fluid expansion. After the air separator, the heated fluid will enter the heat exchanger and finally flow into the suction of the pump.

The pump is placed on the cold side of the heat exchanger for operating purposes. Lower temperatures mitigate wear and tear on pump seals and other internals. At this time, the pumping station was not designed with a backup pump. Based on preliminary calculations (Section 2.4.4), the optimal acquirable heat is approximately 3.1 $MW_{th}$. The NETSIM simulation (Section 3.2) has determined that the heat acquired meets only a third of the capacity of the DES. This doesn't account for heat losses through the well, or heat losses through the heat exchanger. Therefore, meeting only one third of the heat load is a relatively conservative estimate. For a reciprocating pump complete with a 375HP motor, initial costs for a second pump may prove economically unfeasible compared to letting the boilers meet the remaining heating demand. Further investigation and economic analysis are required to determine if adding a second pump would be feasible, which will be covered in detailed engineering, which would be the conventional next steps in project development following a FEED project.

Most of the equipment in this facility is installed on the suction side of the pump. This ensures reduced pressure requirements and ratings for most of the equipment, as pressure is expected to be lowest along the suction of the pump. Reducing the pressure rating of the equipment ultimately reduces costs for procurement and installation.

The circulating loop is equipped with isolating ball valves for the piping above ground. Apart from the heat exchanger, there is no other equipment found on the circulating loop at the upstream facility. Instead, further equipment will be found at the DEC, where there is more space available. More information regarding equipment design can be found in Section 3.3.2.

#### 2.6.1.2 Upstream Loop in the District Energy Centre (DEC)

Geothermally heated fluid will enter the heat exchanger building / town substation and will be filtered through a basket strainer. Fluid will then go through an air separator, where any entrained gases will be removed from the system prior to entering the suction of the pump.

After the fluid is discharged through the pump, it will enter a heat exchanger where heat will be transferred to the distribution side. Fluid will then be returned to the wellsite, where it will be reheated through the upstream facility heat exchanger. See Section 3.3.2 for more information on design considerations for the equipment.

The details of the electrical system at the DEC are to be finalized during detailed design. Initial load lists were estimated and the Upstream list can be found in the following table:

**Table 8 - Estimated Upstream Facility Load List**

| 480 VAC Loads | Quantity | Voltage | Phase | Expected Utilization | Expected kVA |
|---|---|---|---|---|---|
| 300 HP Circulation Pump | 1 | 460 | 3 | 100% | 279.8 |
| 2 HP Makeup Pump | 1 | 460 | 3 | 10% | 0.2 |
| 240/120 VAC Loads | | | | | |
| HVAC system | 1 | 230 | 1 | 100% | 4.0 |
| UPS (115VAC - 24VDC) | 1 | 115 | 1 | 100% | 2.9 |
| Building lighting | 3 | 115 | 1 | 75% | 3.2 |
| Yard lighting | 3 | 115 | 1 | 75% | 3.2 |
| Receptacles | 2 | 115 | 1 | 75% | 2.1 |
| 24 VDC Loads (From UPS) | | | | | |
| Instruments | 30 | 24 | 1 | | |
| PLC | 1 | 24 | 1 | | |
| RTU/SCADA | 1 | 24 | 1 | | |
| Radios | 1 | 24 | 1 | | |

### 2.6.2 Cost Estimate

The cost estimate for this Upstream section was split into two parts:

1. Upstream Facility / Pumping Station
2. Upstream Circulation Pipeline

Estimates are completed based on construction experience with similar projects. Costs shown in the tables below are rounded to the nearest thousand. Engineering costs were added to the totals, and contingency/overhead costs were excluded.

#### 2.6.2.1 Upstream Facility / Pumping Station

A finalized design of the method for extracting heat from the borehole was determined relatively late in the project. As such, costs have been estimated using quotes gathered from other sections of this project with similar equipment such as pumps, heat exchangers, buildings, etc.

**Table 9 - Estimated Cost of Upstream Facility / Pumping Station**

| | |
|---|---|
| Engineering | $210,000 (Est. 10%) |
| Materials | $950,000 |
| Construction | $405,000 |
| Total | $1,565,000 |

All costs above are represented using estimates from past projects and current quotes. It should be noted that both the design conditions of the pump and heat exchanger at the upstream facility have not been finalized and are subject to change.

Some notable costs that are subject to change:

- Downhole Circulation Pump
  - Flow rate and Pressure are subject to change, depending on which well profile is used and how much heat can be extracted without depleting the well. These factors affect pump size, which have shown to range significantly. Currently, a 375 HP pump has been sized.
- Expansion Tank

Quotes for the DES were used to size and estimate the cost of the expansion tank. Due to the heat found in the well, the fluid is not expected to expand or contract significantly, even during shut down times. The size of the expansion tank is likely to be reduced; however, numbers cannot be provided until a detailed review on the reservoir is completed.

#### 2.6.2.2 Upstream Circulation Pipeline

The cost estimate for the upstream circulation loop includes costs associated with the pipeline, construction and glycol-water mixture. The cost for construction was extracted from a cost estimate provided by Dunwald and Fleming.

**Table 10 - Estimated Cost of Upstream Circulation Pipeline**

| | |
|---|---|
| Engineering | $250,000 |
| Materials | $1,320,000 |
| Construction | $1,100,000 |
| Total | $2,670,000 |

Some notable costs that subject to change:

- Pipeline Material: Pipeline material is subject to change. Currently, the Kelit PEXR pipeline is used for this pipeline loop. This material is found to reduce installation costs and will not require thermal expansion mitigation measures. If the heat extracted from the well increases in flow rate, a larger diameter pipeline may have to be used. Kelit PEXR has a limited diameter, and therefore steel pipelines may be required. Construction and materials costs are subject to change under these circumstances.

#### 2.6.2.3 Cost Estimate Considerations

As an additional exercise for this FEED project, Epoch reviewed possible cost reduction measures. The FEED report currently describes a fully automated DES at max capacity (i.e. adding all feasible consumers into the DES). The costs associated with the construction of a full DES can be pared down to meet the minimum requirements of the DES. While some sections of the DES cannot be reduced, there are some notable cost savings that should be considered. The cost savings estimated for the Upstream section are detailed in Table 11.

**Table 11 - Estimated Cost Savings of Upstream Facility / Pumping Station**

| | Full DES | Minimized DES | Cost Difference |
|---|---|---|---|

| | | | |
|---|---|---|---|
| Engineering | $210,000 (Est. 10%) | $145,000 (Est. 10%) | $65,000 |
| Materials | $950,000 | $745,000 | $205,000 |
| Construction | $405,000 | $180,000 | $225,000 |
| Total | $1,565,000 | $1,070,000 | $495,000 |

## 2.7 Upstream Regulatory

### 2.7.1 Alberta Energy Regulator (AER) Jurisdiction

Currently, the Hinton DES is proposing to drill a geothermal well at a location in the legal subdivision of 07-11-051-25 W5M (7-11). This well will be a closed loop downhole heat exchanger, circulating a glycol-water mixture through the bore annulus, tubing and casing for heat exchange. No emulsion is to be produced from this well. The proposed geothermal well at 7-11 will be drilled through hydrocarbon-containing formations and past a depth of 150m. Due to the depth of the well and that it is drilling through hydrocarbon formations, a well license is required per Directive 056: Energy Development Applications and Schedules [25]. This application process requires the completion of the following Directive 056 Schedules:

- Schedule 4 – Well Licence Application
- Schedule 4.1 – Working Interest Participants- Wells
- Schedule 4.2 – Multiwell Pad Location
- Schedule 4.3 – Well $H_2S$ Information

Preliminary discussions with an AER representative have determined that a pipeline license is not required for the distribution network as it is proposed to be installed within Hinton's town boundaries. For the distribution network, jurisdiction lies with the Municipality.

The pipeline circulating fluid from the upstream facility to the DEC may require a pipeline license due to its location relative to the town boundary. Recent conversations with the AER mandates that CSA Z662 is to be followed for any pipeline design and construction under AER jurisdiction. The 7-11 subdivision is divided in half by the town boundary. Currently, the proposed location of the 7-11 wellsite is inside the town. Because the location of this pipeline will be constructed within the Town of Hinton, AER Jurisdiction should not apply. As the location has not yet been finalized, this has yet to be confirmed by the AER. However, should the AER possess jurisdiction on this pipeline, a license under AER Directive 056 will be required. This application process requires the completion of the following Directive 056 Schedules:

- Schedule 3 – Pipeline Licence Application
- Schedule 3.1 – Segment/Installation Identification
- Schedule 3.2 – Technical/Environmental Information

The same logic applies to the upstream facility. If the facility falls under AER jurisdiction, it is likely that a Facility License is required. Per Directive 056, the facility license application is required since a pump with greater than 75kW is going to be installed. Current estimates show that a pump of 350 HP will be used to circulate the fluid. This equates to roughly 260 kW. This application process requires the completion of the following Directive 056 Schedules:

- Schedule 2 – Facility License Application
- Schedule 2.4 – Compressors/Pumps – Facilities

More information on the Alberta regulatory environment can be found in Appendix C.4.

## 2.8 Conclusion

While Hinton has tremendous geothermal subsurface heat and geothermal resource potential, the resource characteristics present a very challenging environment for developing the resource for heat only. Complex geology, lack of appropriate water sources and flowrates, sour fluid conditions, multiple zonal pressure challenges and inability to use existing O&G wells all combine to a technologically- and cost-intensive resource.

The final conclusion made based on the technical geological analysis indicated that there was unfortunately no viable geothermal water resource in the Hinton area. It bears mentioning that this is a hyper-local phenomenon that in no way implies anything about the quality of the geothermal resource elsewhere in Alberta. Potential heated water sources (geothermal reservoirs) with fluid compositions conducive to use in a DES (and specifically required to be in close proximity to a populated area due to heat transportation cost limitations) were ruled out due to a host of factors, including lack of: porosity, permeability, areal extent, water saturation, and ultimately low flowrates.

# 3 Midstream: District Energy Infrastructure

## 3.1 Summary

A district energy system (DES) is a thermal energy distribution system for multiple buildings at a community scale. A DES consists of a heating and/or cooling center, which this report refers to as the District Energy Center (DEC), a thermal network of pipes connecting groups of buildings (Pipeline Distribution Network), and, in the case of the geothermal energy-based DES, the piping from the wellhead to the DEC.

The Midstream Section focuses specifically on the DEC and the distribution network that ties the DEC to the consumers throughout the Town of Hinton (see Figure 25 below as representation of this). The design of the distribution network and DEC are based solely on the total heating load of the consumers tied into the DES. This makes the midstream design "heat agnostic", i.e. the heat source will not affect the results of the design. Conventional DES can utilize various low-carbon energy sources such as geothermal energy, solar thermal, sewer heat, biogas, and biomass (like timber waste). The system will not change based on the heating source provided.

The figure below presents an overview of what is covered in the following Sections.

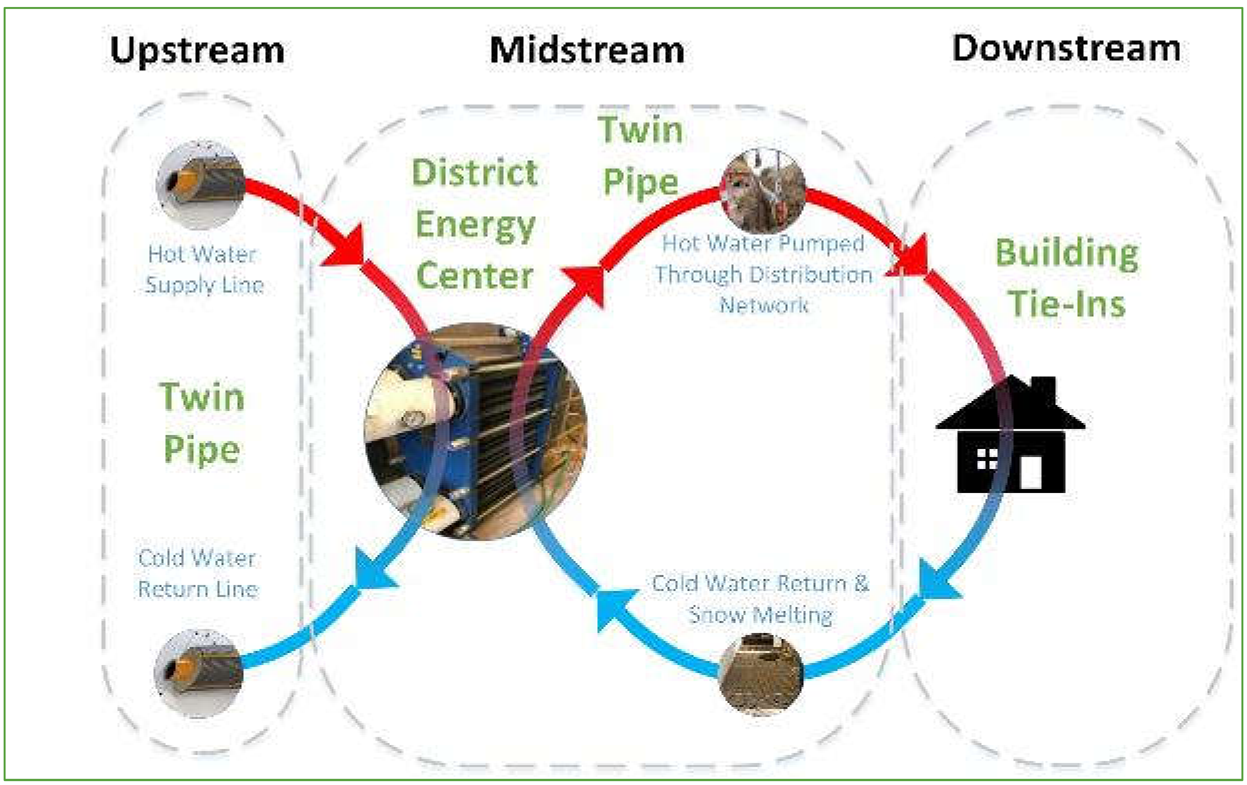



**Figure 25 - Infographic Detailing Midstream Process**

Figure 25 illustrates how the fluid will enter the District Energy Center and will be heated through the heat exchanger. Once heated, a circulation pump will discharge the fluid into the supply lines of the distribution network where it will enter the heat exchanger station of each consumer. Once the heat has been transferred, the cooled fluid will enter the return lines of the distribution system and will return to the heat exchanger in the DEC to be reheated.

The District Energy Infrastructure (composed of the Distribution Network and District Energy Center (DEC) location) ran through multiple iterations to determine the most cost-effective design. A total of ten iterations were completed using this software and a distribution network was proposed for the total projected heating load from all 53 buildings in the Town of Hinton. This design configuration featuring the total load of all considered customers was called the "Complete" system and is shown in Figure 26. A final iteration (11$^{th}$) was completed to determine the optimal system that maximizes economic feasibility and was called "Optimized" system. The Optimized system reduced the number of buildings included down to 38; the layout is shown in Figure 27. The following considerations below determined how the Hinton system evolved throughout the project:

1. DEC Location

The proposed location of the DEC is the Friendship Centre. The DEC was previously suggested to be part of the Proposed Water Treatment Plant located at the intersection of Kelley Road and W River Road. The Friendship Centre was selected for the following reasons:

- Reduction in amount of steel pipeline
- Reduction of Construction Costs associated with narrow Right of Ways (ROWs), required engineered bank stabilization (see Section 3.2.11.6 for further explanation), and CN Rail Crossings

The relocation of the DEC to the Friendship Centre resulted in an estimated 25% of material and construction cost savings (by ~$5M).

2. Number of Consumers Added to the DES

The initial objective of the FEED was to incorporate as many consumers into the DES as feasible. The addition of more consumers increases the size of the DES, which increases the system's efficiency and return on investment. Increasing the size of the DES ultimately affects the size and material of the pipelines, as well as the size of the circulation pump and any auxiliary equipment found within the process of the system.

3. Elevation Changes

The elevation changes throughout the Town of Hinton results in significant static pressure found at the DEC as it is located near the bottom of the distribution network. The high static pressure coupled with the required discharge pressure of the pump means that system pressures can approach the pressure ratings of the more commonly used pipeline materials for geothermal applications. As such, adjustments to the DES were required to ensure that the system would not overpressure.

4. Economic Feasibility

District energy systems best serve layouts where consumer loads are located within close proximity to each other. These clusters reduce the cost ($) per GJ of heat required to tie-in specific branches to the DES. In doing so, the DES minimizes the associated materials and installation costs and makes for a much more economically feasible project. Below shows the proposed Complete Hinton DES, following the first ten iterations completed.

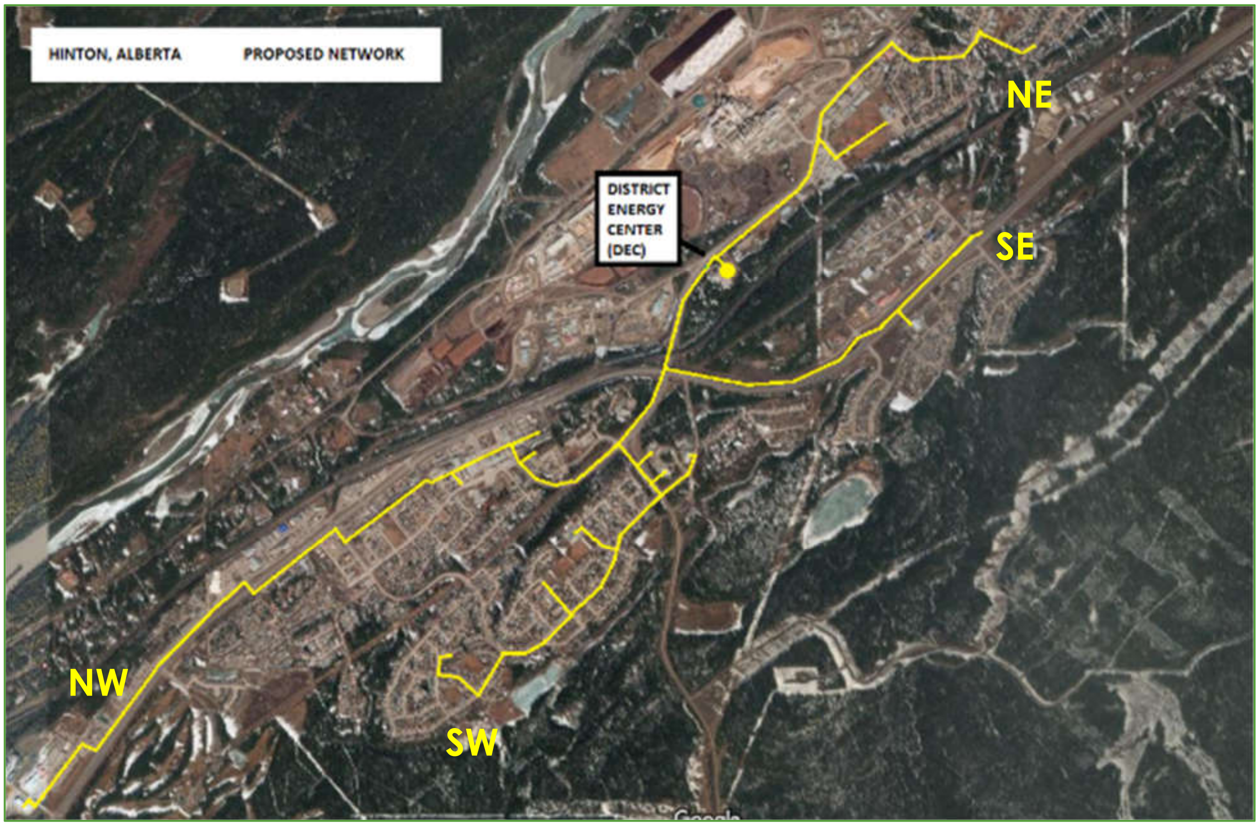



**Figure 26 – "Complete" Hinton DES, Initial Proposed Distribution Network (53 Consumers)**

Using the tenth iteration of the District Energy System developed for the town's full heating load, the system was then optimized by only including consumers into the DES that were economically feasible. This final modification removed 15 consumers from the DES load and removed the SW and SE branches from the distribution network. The reduction in heating demand and distribution further reduced costs associated with materials and construction by approximately $7.65M. The optimized design can be found in the figure below:


**Figure 27 – "Optimized" Hinton DES Distribution Network (38 Consumers)**

To increase the heating load, sidewalk heating was also proposed as a possible addition to the DES (see Section 3.2.9), and preliminary design calculations have been completed. This system will redirect some heated fluid through a series of tubes that run near the ground surface to heat and melt snow that accumulate in high traffic areas such as sidewalks, stairs, driveways, plazas, etc.

While most of the equipment found in the DEC have straightforward design guidelines and conditions, the design philosophy of the gas boiler system will require further review. The gas boiler system is used to provide supplemental heat to the DES under peak loading conditions. While the DEC is considered to be heat agnostic, the gas boilers will be altered depending on the philosophy of the entire DES as the primary heat source acquired ultimately determines whether the boiler is propane or natural gas supplied.

The midstream portion of this project terminates at each downstream connection, where a heat exchanger station specifically designed for the calculated heat load is installed. Each downstream connection will have a heat exchanger where the distribution network will transfer heat energy into the consumers existing hydronic system. Each station will be equipped with a heat meter, heat exchanger and isolation valves. Each station is site specific; however, the distribution network will have consistent tie-ins where the underground pipelines will come above ground to connect to the supply line and return line flanges found at each consumer location.

## 3.2 Pipeline Distribution Network – Design

A DES has been designed for the Town of Hinton, Alberta using Vitec's NETSIM Grid Simulation software. This software allows for the simulation of heat and mass transfer through the DES and assists in optimizing the piping network. Multiple network designs, flow regimes, and materials were tested and compared throughout the FEED project. A final design has been chosen based on the design criteria described in the section below.

### 3.2.1 Design Criteria

The DES network should satisfy the following design criteria.

1. The system design should have low construction and material costs.
2. The system should have low operating costs.
3. The system must effectively meet customer demands.
4. The system should maximize the number of customer connections to increase efficiency.
5. The system should accommodate future town expansion.

Reducing construction and material costs can be achieved by minimizing the amount of steel piping used in the network, minimizing the number of railways, highways, and water crossings, placing the DEC at a central location, and limiting the need for auxiliary buildings.

Operating costs will be composed of the power requirements to operate the DES as well as equipment maintenance, which can be reduced by maintaining a low pumping power requirement and limiting the amount of auxiliary equipment required.

Criteria 3 is met by ensuring the distribution network is correctly sized to deliver high temperature fluid to the customers.

Criteria 4 requires an analysis of potential customers within the Town of Hinton and their required building heating load.

Criteria 5 is met by ensuring that the network pipeline diameter is large enough to accommodate the increase in flow rates for future customers.

### 3.2.2 Design Principles and Constraints

The following design principles and constraints were established throughout the FEED project. Their purpose is to ensure that the design does not exceed the abilities of the materials selected and ensure that the system will meet the design criteria described in Section 3.2.1.

- System network designed to follow existing utility ROWs (right-of-ways) and secondary roads
- System diversity factor of 68.5% (See Section 3.2.7.3)
- Pressure gradient will not exceed 4 $ft_{H2O}$ / 100ft (392 Pa/meter) [29].
    - For the model, 392 Pa/m allowable pressure drop causes pressures at lower elevations to exceed the pressure rating of the pipeline distribution network. Therefore, this pressure drop limitation has been reduced to 125 Pa/meter.
- Customer pressure differential greater than 60 kPa
- Fluid velocity must not exceed 2 m/s [30]

Based on the technical specifications of the piping (See Appendix D.1), the following constraints are applied:

- PEX piping fluid pressures must not exceed 600 kPag (a safety factor of 0.9 is applied)
- PEXR piping fluid pressures must not exceed 1600 kPag (a safety factor of 0.9 is applied)
- SteelFlex piping fluid pressures must not exceed 2500 kPag [31] (a safety factor of 0.9 is applied)

### 3.2.3 Distribution Network – Proposed Hinton DES

The Hinton DES underwent ten fundamental iterations using NETSIM Grid Simulation software, before the design was finalized through an 11th iteration via economic optimization. A summary of all iterations can be found in Table 12. Factors that contributed to the number of iterations include, but were not limited to:

- Cost of materials and installation
- Effective delivery of heat to customers
- Future expansion considerations

The design iterations began with the DES network as presented in the Pre-FEED report. This network contained 12 customers, provided a peak output of 3.3 MW and was entirely constructed from PEX piping. As well, the DEC location was arbitrarily placed on the Trican Well Service property because of its central location to the proposed DES:

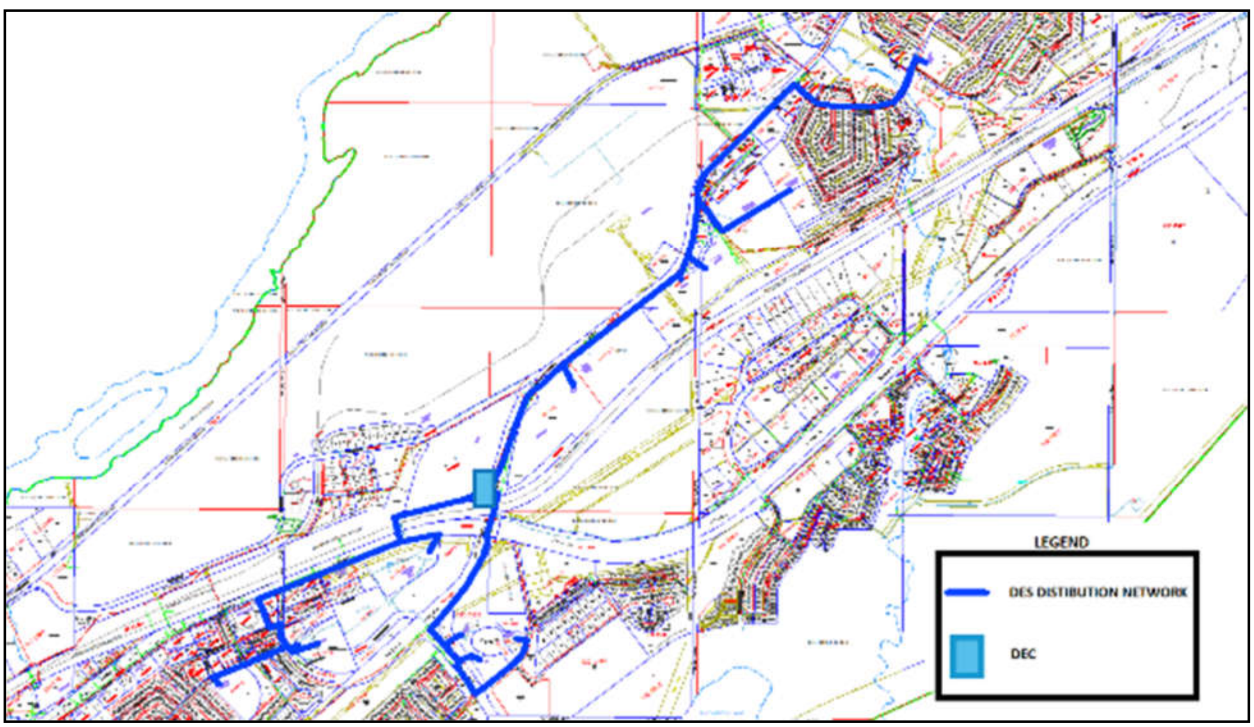



**Figure 28 - Hinton DES, Pre-FEED Proposed Distribution Network (12 Consumers)**

The first iteration of the FEED design moved the DEC location from the Trican well servicing property to the Friendship Centre and still contained the original 12 customers. As the model developed, the network was expanded to contain every feasible customer within Hinton. This included hotels, apartments, condominiums, schools, large stores, and office buildings. Loads for these buildings were entered as described in Section 3.2.7.

**Table 12 - Summary of Iterations to the NETSIM Model**

| Iteration # | PIPE MATERIALS | | | Description of Model Changes | Conclusion of the Simulation |
|---|---|---|---|---|---|
| | % Steel | % PEX | % PEXR | | |
| 0 | 0% | 100% | 0% | Pre-Feed Model with 12 customers and a building heating load subscription of 3.3 MW | - |
| 1 | 46% | 54% | 0% | DES has been expanded to 53 customers with a subscribed building heating load assumed to be 5.6 MW. The DEC is moved to the Friendship Centre. Hydraulically separate networks are used to minimize pressures found in the system so that PEX piping can be installed. | Hydraulically separate loops increase the amount of piping needed but reduce the static head found in the system. The use of a remote heat exchanger building is found to reduce the materials and equipment required while providing relief to the system from static head. |
| 2 | 26% | 74% | 0% | DEC has been relocated to share the same building with ISL's proposed water treatment plant. The DES was updated to utilize booster pumps and pressure control valves in conjunction with hydraulically separate loops to minimize and balance the system pressures, thereby increasing the amount of PEX piping installed in the system. | The use of booster pumps and pressure control valves reduce the reliance on separate loops, but this method caused problems with maintaining positive pressure in a no flow scenario. Multiple booster pumps and pressure control valve stations are found to be unfeasible. |
| 3 | 37% | 63% | 0% | DES network is split into two separate loops. Separation occurs at a heat exchanger building located at the junction of Switzer Drive and the CN Railway. The second loop services the southwest and southeast sections of town, where elevations are | The removal of booster pumps and valves allows for easier no flow pressure balancing. The heat exchanger building located at the junction of Switzer Drive and the CN Rail line allows for the south section of town to be supplied |

| Iteration # | PIPE MATERIALS | | | Description of Model Changes | Conclusion of the Simulation |
|---|---|---|---|---|---|
| | % Steel | % PEX | % PEXR | | |
| | | | | much higher than the DEC. No booster pumps or valves are used in this iteration. | without duplicating multiple lines in the same trenches. The network supplied by the heat exchanger building requires a large pump, which may be problematic in this location due to limited available space. |
| 4 | 31% | 69% | 0% | A single DES network originating from a DEC located at the water treatment plant was explored. The use of booster pumps and valves are used to control the pressure in the network. | The use of a single network increases the static head found in the system. The booster pump and valve utilized in the southwest section of the system helps prevent over-pressuring of the lower sections in the network. A pressure setting on the return side of the pump is set to maintain system pressurization under no flow scenarios. |
| 5 | 19% | 40% | 41% | Two separate DES networks originating from a single DEC at the water treatment plant are used. PEXR is used in place of steel where sizes are appropriate. No booster pumps, valves, or heat exchanger buildings are required. | The construction costs associated with PEXR piping are similar to PEX piping, but PEXR piping material costs are about 3 times more. There is still a benefit to maximizing the use of PEX piping, so two networks are still used to limit the amount of Steel and PEXR required. |
| 6 | 5% | 15% | 80% | DEC moved to the Friendship Centre. A single DES network is used with no booster pumps or valves. PEXR is used in place of steel where sizes are appropriate.<br>Updated building loads provided by Williams | The DEC located at the proposed water treatment plant requires long transmission lines to service the customers in the DES. To reduce material and construction costs, the DEC is moved back to the Friendship Centre, which is |

| Iteration # | PIPE MATERIALS | | | Description of Model Changes | Conclusion of the Simulation |
|---|---|---|---|---|---|
| | % Steel | % PEX | % PEXR | | |
| | | | | Engineering are entered in the model. Total system load is 11.3 MW. | located near the centre of the DES. |
| 7 | 9% | 24% | 67% | Two separate DES networks originating from a single DEC at the Friendship Centre are used. PEXR is used in place of steel where sizes are appropriate. No booster pumps, valves, or secondary buildings are required. | Two separate loops are used to limit pressures and increase the amount of PEX pipe used in the system. Due to flow requirements in each system, overlapping steel lines are required. Additional steel is required compared to a single network. |
| 8 | 10% | 0% | 90% | DEC moved to 07-11-051-25 W5M geothermal site. A single DES network is used with no booster pumps or valves. PEXR is used in place of steel where sizes are appropriate. | A DEC location at the geothermal well head was investigated for cost effectiveness. Because the location is near the town boundary, it requires additional steel piping for a transmission line to connect to the system. The geothermal well head is located at an elevation above the entire existing system, ruling out the use of PEX anywhere in the system. |

| Iteration # | PIPE MATERIALS | | | Description of Model Changes | Conclusion of the Simulation |
|---|---|---|---|---|---|
| | % Steel | % PEX | % PEXR | | |
| 9 | 16% | 17% | 67% | Two separate DES networks are used. The first network originates at the 7-11 geothermal well location, this network connects to a second DEC at the Friendship Centre. The 7-11 DEC feeds hot water to the southwest and southeast sections of town and supplies heat to the DEC located at the Friendship Centre. The Friendship Centre DEC provides heat to the remainder of town. PEXR is used in place of steel where sizes are appropriate. No booster pumps, valves, or heat exchanger buildings are required. | This design required a large steel transmission line from the geothermal well head to the Friendship Centre. The construction and material costs for this line are prohibitively expensive. In addition, later discussions indicated that additional heating sources such as biomass, waste heat, etc. were no longer options due to the scope of this FEED report being limited specifically to geothermal heat supply, making this iteration even less feasible as well. |

| Iteration # | PIPE MATERIALS | | | Description of Model Changes | Conclusion of the Simulation |
|---|---|---|---|---|---|
| | % Steel | % PEX | % PEXR | | |
| 10 | 5% | 0% | 95% | Iteration #6 revisited. DEC moved back to the Friendship Centre. A single DES network is used with no booster pumps or control valves. PEXR is used in place of PEX piping where sizes are appropriate, as there are no known transition pieces from PEXR to PEX.<br><br>Total system load is 11.3 MW.<br><br>This is the final iteration through Vitec's NETSIM Simulation software. | While it is possible to transition from PEXR to PEX through the use of PEXR to Steel and Steel to PEX transition pieces, the objective of the design is to minimize steel fittings for operating and maintenance purposes.<br><br>This iteration of the NETSIM modelled distribution network (prior to optimization) consists of a single hydraulic system to service the Town of Hinton. This distribution network is modelled to serve 53 customers throughout the town, with the furthest customer from the DEC being 5.5 km away. The elevation change from the DEC to the highest customer is 80m. Most of the network is made of PEXR piping, but steel piping is used on the main transmission lines to accommodate the large fluid flow. |
| 11 | 16% | 0% | 84% | The number of consumers has been reduced from 53 to 38. As a result, the SW and SE branches were removed from the distribution network.<br><br>Pipe material % distribution changed due to the removal of the SW and SE branches. | This final iteration optimized the system ($10^{th}$ iteration) based on economic feasibility.<br><br>More details can be found in Section 3.2.4. |

The optimization of the model was completed after the model was finalized in NETSIM.

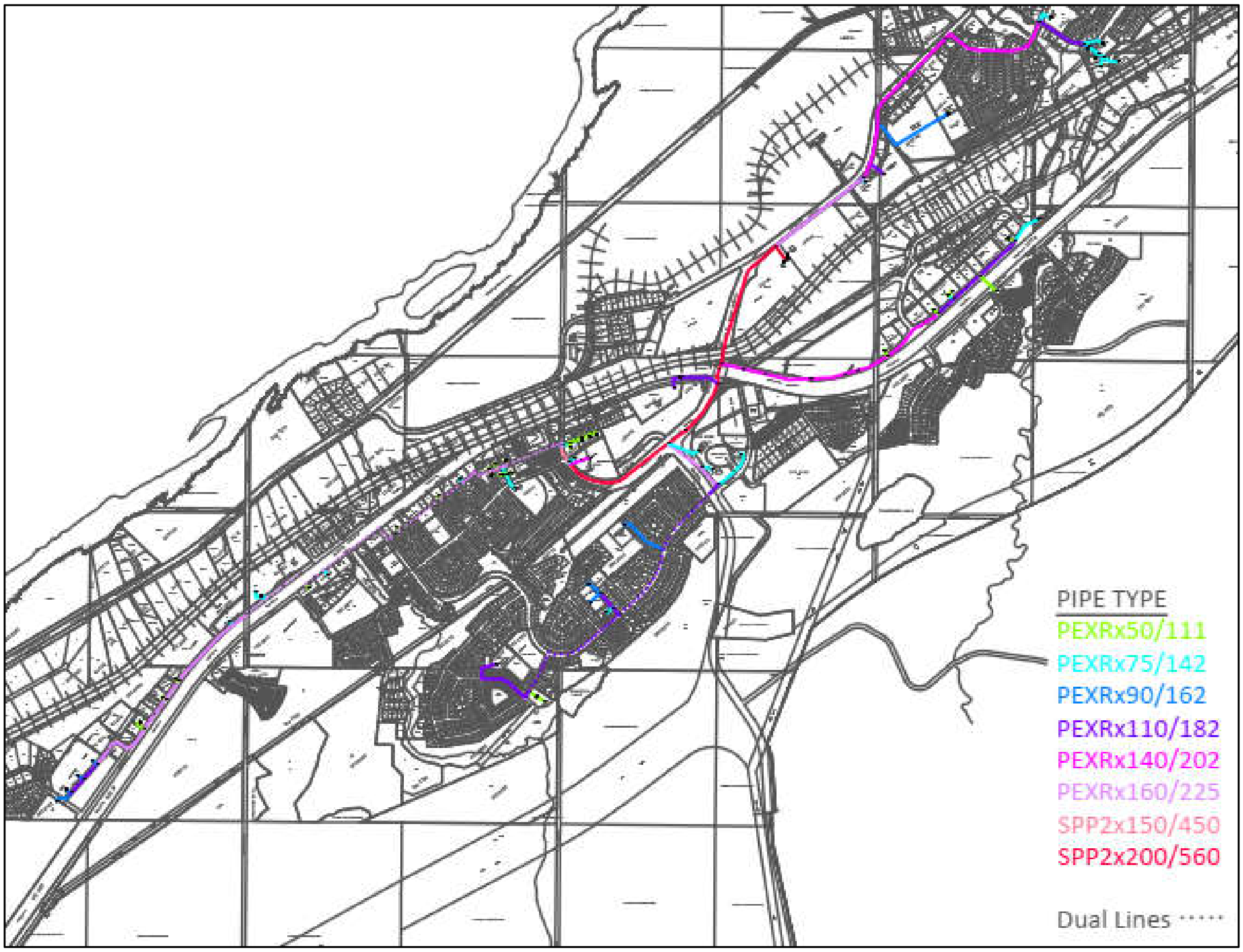



**Figure 29 - Proposed Hinton DES, NETSIM Simulation, Iteration #10 (Appendix D.2)**

### 3.2.4 Distribution Network – Optimized Hinton DES

As mentioned in the section above, the proposed Hinton DES is designed to include every feasible consumer in the Town of Hinton. This includes government, commercial and industrial buildings, which have larger loads than single residential dwellings. The complete load list can be found in Section 3.2.7. As expected, increasing the number of consumers throughout the town will increase material, installation and operating costs. These costs will need to be recovered by the revenue generated.

Details of the financial analysis which leads to the optimized design can be found in Section 5.3.6. This section reiterates the optimization of the DES for economic feasibility. This is done by creating a simplified financial model and modifying the DES to determine its effects. Modifications include removing consumers and associated pipeline branches, as well as changing parameters within the financial model such as: interest on the principal cost, revenue generated (price point for heat), and the initial capital cost of the project.

#### 3.2.4.1 Complete DES Modeling

The Proposed Hinton DES described in Section 3.2.3 includes 53 consumers, which are connected to the DEC located at the Friendship Centre. These consumers are located along four primary branches or "Zones", centered at the DEC. The Zones are simplified as the NW, NE, SE, and SW branches based on their orientation and correspond to Zones 1, 2, 3 and 4 respectively.

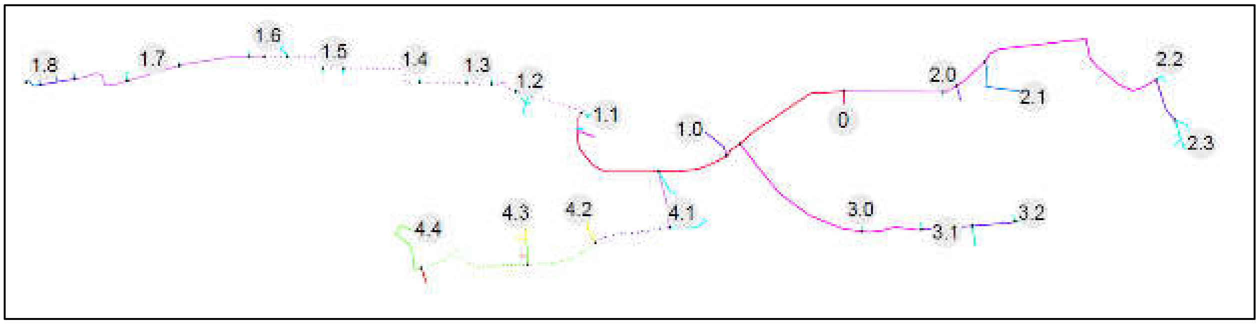



**Figure 30 - Proposed Hinton DES - Simplified Model (Zones)**

Figure 30 shows the branches with "0" allocated to the Friendship Centre (where the DEC is located), and numbers 1 through 4 for each corresponding Zone. Each node is either a single consumer or a consolidation of multiple consumers within a small vicinity. The length of each section was determined using the NETSIM model, and a price per meter for total installed cost (TIC) was developed using construction and material estimates for each section of the town. By multiplying the cost per meter obtained with the lengths of each section, the total installed cost from each node to the next was obtained. A common branch moving west from the DEC feeds multiple zones. The installed cost of this common branch was equally split between the number of zones it was feeding. Since the first pipeline segment from the DEC feeds all four zones, the cost was divided by four. The same process was used for the heat load of the DEC and the operating and maintenance cost split between zones.

**Table 13 - Financial Modeling of the Complete DES**

| Zone | Total Installed Cost | Load | | Install Cost Per GJ |
|---|---|---|---|---|
| # | ($MM) | (GJ) | (GJ/m) | ($/GJ) |
| 1 | 7.1 | 59437 | 11.2 | 120 |
| 2 | 2.9 | 29105 | 9.6 | 100 |
| 3 | 2.2 | 14121 | 6.4 | 155 |
| 4 | 3.8 | 15052 | 4.6 | 250 |
| Total | 16 | 117715 | 8.5 | 136 |

* Indicates Negative Revenue (i.e. Debt outgrows Revenue)

Table 13 shows the results of the simplified financial model of the Hinton DES. After obtaining the total installed cost and heat load for each zone, the total install cost per GJ for each zone was calculated. The higher the install cost per GJ, the less economically feasible the Zone.

Zones 1 and 2 have a substantially higher load per meter and lower install cost per GJ compared to Zones 3 and 4. Load per Meter (GJ/m) indicates how much is being consumed on average per installed meter of piping. A higher GJ/m indicates a higher density of heat consumption (i.e. more consumers or higher heat loads), which is ideal since the length of pipe directly correlates to the TIC. The economic feasibility of the project increases when the length of each section (i.e. TIC) is decreased or the consolidated loads found in the zone are increased.

The second indicator, Install Cost per Load ($/GJ), is a simple ratio of the TIC to the Load. A higher ratio indicates worse performance, as the capital cost of adding consumers is higher. The install cost per load of Zone 2 is less than half that of Zone 4. When developing any infrastructure in their respective zones, the TIC per GJ of Zone 4 makes it less economically feasible.

The "Total" row, which is for the entire Hinton DES, indicates the average performance of the system. This gives insight into optimizing the system, as investigations can begin to determine how to improve zones that are below average. Per Table 13, the best zones (in descending order) are Zones 2, 1, 3, then 4.

#### 3.2.4.2 System Optimization

Mentioned in the previous section, the Hinton DES combines all feasible consumers that are geographically convenient to tie-in into the system. Each consumer has an associated net benefit as part of the DES. To optimize the system, consumers will be examined to determine their net benefit. A consumer that is farther away from the DES or yields higher costs to tie-in must have a high heat load to generate enough revenue to recoup the installed cost within a reasonable time frame.

The initial financial model was created in segments as shown in Figure 30, and optimization was completed by process of elimination. Each zone was individually assessed, and consumers of each zone were removed one at a time to determine their effect on the simplified financial model. If removing a customer decreased the amount of years for payback, then that change was applied. If it did not, then the consumer was returned to the DES. The O&M cost was also scaled to the heat usage. For example, the $500,000 O&M cost was cut by 20% if the total load decreased by 20%.

The analysis determined that Zones 3 and 4 are not economically feasible, in any circumstance.

**Table 14 - Financial Modeling Results of Optimized System**

| Zone | Total Installed Cost | Load | | Install Cost Per GJ |
|---|---|---|---|---|
| # | ($MM) | (GJ) | (GJ/m) | ($/GJ) |
| 1 | 7.07 | 60301 | 10.29 | 117 |
| 2 | 2.68 | 29969 | 9.83 | 89 |
| 3 | | | | |
| 4 | | | | |
| Total | 9.75 | 90270 | 10.13 | 108 |

It is worth mentioning that Zone 2 can be optimized further; however, the financial benefits are minor compared to being able to supply more consumers. With the removal of Zones 3 and 4, the figures below portray the anticipated layout of each DES: the Complete, which shows the results of the ten iterations, and the Optimized, which further modifies the proposed system for economic feasibility.

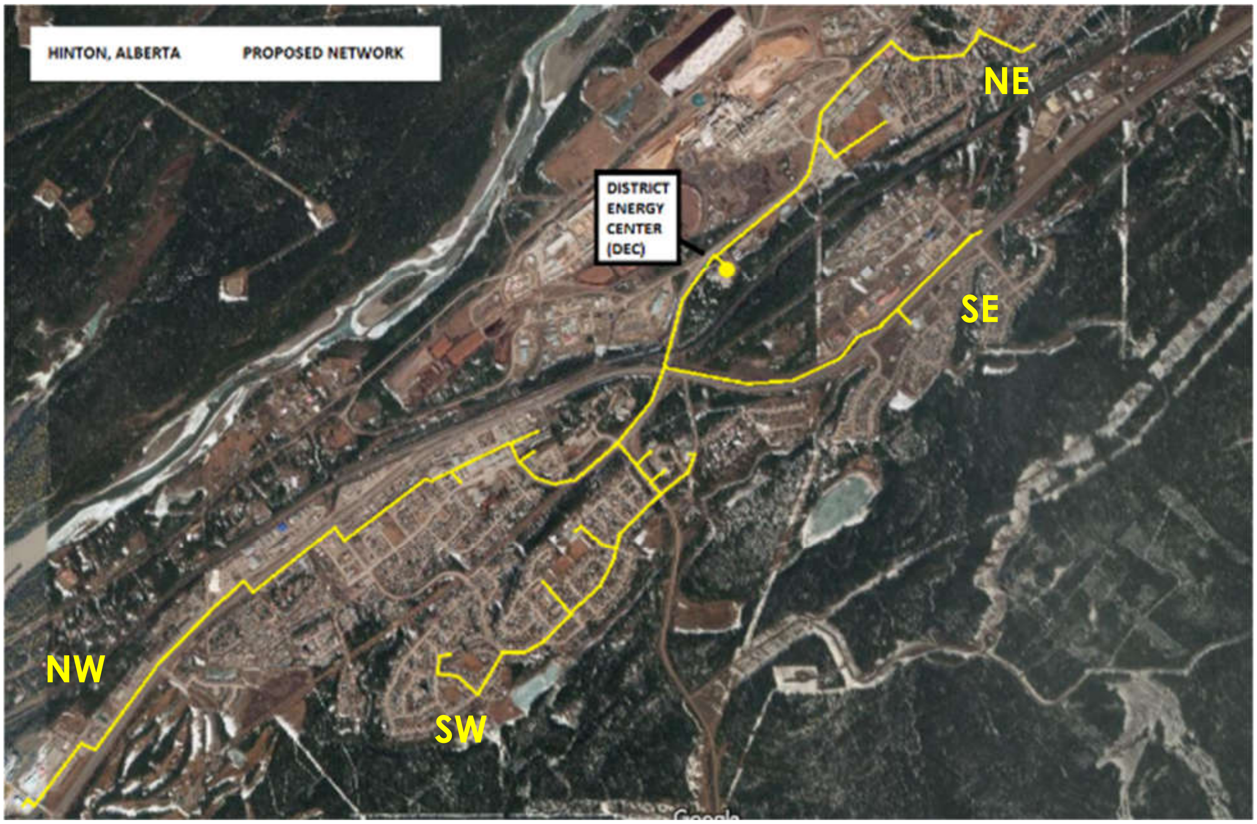



**Figure 31 - Complete Hinton DES, Proposed Distribution Network (53 Consumers, ZONES 1 to 4)**


**Figure 32 – Optimized Hinton DES, Proposed Distribution Network (38 Consumers, ZONES 1 and 2)**

### 3.2.5 Distribution Network – System Components, Results

The following sections detail the results of the design conditions for the equipment affected by the iterations and optimization of the NETSIM Simulation. These design conditions create the basis for equipment design and budgetary quotes to be used for the cost estimates detailed in later sections.

#### 3.2.5.1 Pumps

A single pump is located at the DEC and provides enough flow to service the entire network. The pumping requirements can be found in the table below.

**Table 15 - DES Distribution Network Pump Design Requirements**

| Hinton DES | Suction Pressure (kPag) | Head Pressure (kPa) | Flow Rate |
|---|---|---|---|
| Proposed | 800 | 80 – 440 | 13.4 – 55.3 kg/s |
| Optimized | 400 | 81 – 388 | 10.2 – 42.4 kg/s |

#### 3.2.5.2 Pipes

The total length of pipe types used in the DES can be found in the table below.

**Table 16 - DES Pipeline Inventory**

| Hinton DES | Pipe Type | Size | Length |
|---|---|---|---|
| Proposed | LOGSTOR PEXR | Varies | 12886 m |
| | LOGSTOR TWINPIPE SYSTEM (STEELFLEX) | Varies | 1992 m |
| Optimized | LOGSTOR PEXR | Varies | 10407 m |
| | LOGSTOR TWINPIPE SYSTEM (STEELFLEX) | Varies | 1931 m |

**Figure 33 - Logstor's TwinPipe System**

#### 3.2.5.3 Heat Exchangers

A single heat exchanger is required to transfer heat from the geothermal loop to the DES. This heat exchanger will be located inside the DEC. A heat exchanger is used instead of connecting the networks because of the separate pressure requirements of the two systems. The inlet temperature on the DES side of the heat exchanger is 45°C and is heated to 85°C at a flow rate of 55 kg/s.

#### 3.2.5.4 Network Volumes

The DES consists of a single hydraulic network to service the Town of Hinton.

**Table 17 - DES Distribution Network Volume**

| Hinton DES | Network Volume |
|---|---|
| Proposed | 415 $m^3$ |
| Optimized | 266 $m^3$ |

It should be noted that this does not include the volume associated with above ground piping and equipment.

## 3.2.6 Pipeline Distribution Network – Material Selection

A key factor in the design of the distribution network is the selection of pipeline materials that best meet the design conditions that result from the iterations and simulations of the Hinton DES. To select the type of pipe for the distribution network, six main criteria were evaluated.

### 3.2.6.1 Pressure Rating

There are two considerations in the model that affect pressure in the system. The first is the static pressures due to elevation changes. Within the Town of Hinton, the elevation change from the DEC to the highest point of the distribution system is nearly 80 meters (i.e. ~785 kPag static head). Section 3.2.8.1 describes some limitations to the distribution system due to the location of the DEC and the elevation change between the DEC and the highest consumers. The DEC is located near the bottom of the distribution network.

The second consideration for pressure is caused by friction losses (i.e. pressure drop) in the distribution network. The primary variables that affect pressure drop in the system are flow rate of the fluid and the pipeline diameter. The distribution pump is sized to overcome the system pressure drop, so balance must be established between minimizing pump power consumption and minimizing pipe diameter size for cost considerations. In addition to pressure drop, larger diameter pipelines slow fluid velocity within the pipe. High velocity flow results in pipeline erosion, which requires maintenance and operational issues. Per the model, the largest pipe diameter that mitigates both pressure drop and high velocities is 8"; therefore, the pipe selected must have sizes available up to 8".

### 3.2.6.2 Maximum Temperature Rating

The pipeline selected shall be able to withstand the operating temperature of the DES. As mentioned in previous sections, the anticipated normal operating temperature will be 85°C. The pipeline material shall meet this operating temperature at a minimum and pressure rating shall not be de-rated due to temperature.

### 3.2.6.3 Cost

The cost of the pipeline material selected shall be compared from both a per meter cost as well as the anticipated cost of installation. Additional costs to be considered include insulation, fittings, transition pieces etc. Installation costs include joining, padding, expansion joints, and minimum depth of cover.

### 3.2.6.4 Utilization

The pipeline will also be selected based on what has been operating in existing DE systems. There are several DE systems currently in operation in North America. Epoch has visited multiple operating systems in the US and Canada and researched other DE systems in operation in Europe. The most common pipeline materials shall be taken into consideration in this decision.

### 3.2.6.5 Insulation

Heat retention is vital for a District Heating System. It is imperative that the pipeline used is insulated and able to deliver the highest possible temperature to the consumer. Pre-insulated pipe has the advantage over supplementary insulation in that it is less expensive and is more efficient from a logistical point of view.

#### 3.2.6.6 Maintenance and Operation

When considering pipe material choice, a few case studies of similar DE systems were evaluated. Epoch visited and studied Geothermal District Energy Systems in Klamath Falls, Oregon and Idaho Falls, Idaho, and received feedback on design and installation.

It has been determined that these systems were constructed with steel pipelines and resulted in several problems with corrosion that required frequent maintenance and/or pipe replacement. Steel is highly susceptible to corrosion when exposed to an environment with high moisture content and with high soil conductivity. Insulation is a great way to mitigate corrosion as it acts as a barrier to moisture and the soil, however, leaking can occur due to stress, propagation, age, etc. and moisture can enter the insulation.

It is recommended that a maintenance program is established for any sections of pipe constructed using steel, or a leak detection system is installed throughout the distribution network. Leak detection is important as it identifies locations with higher probability of corrosion for steel. In addition, moisture is also known to reduce the thermal resistance of insulation, therefore, mitigating leaks would also maintain thermal efficiency of the system.

The pipeline design includes both steel and PEXR; steel is known to corrode while PEXR does not. The pipeline selected shall mitigate corrosion where needed (through material selection or mitigation measures) and provide ease of maintenance and operation.

#### 3.2.6.7 Results and Recommendations

Multiple pipeline vendors were contacted for information on their pipeline and for budgetary quote. A summary of the comparison is shown in Table 18 below. Please note that the pipelines have been rated based on their relative costs, with 1 being the lowest cost and 7 being the highest. See Appendix D.3 for more details related to pipeline material comparison.

**Table 18 - Pipe Material Comparison**

| Type | Manufacturer | Maximum Operating Pressure (psi / kPag) | Maximum Operating Temperature (°C) | Relative Price Rating (1 – Least Expensive) |
|---|---|---|---|---|
| PEX (PEXFLEX) | Logstor | 87 / 600 | 85 | 2 |
| Fibre Reinforced PEX (PEXR) | Logstor/Kelit | 217 / 1496 | 115 | 7 |
| SteelFlex | Logstor | 363 / 2500 | 130 | 1 |
| HDPE | Aquatherm | 100 / 689 | 93 | 3 |
| PEX-B | Shawcor | 1500 / 10342 | 93 | 4 |
| FRP | Fibrex | 150 / 1034 | 93 | 5 |
| PE-RT | ISCO Pipe | 800 / 5516 | 93 | 6 |

Based on the criteria described above, Epoch has elected to proceed with a combination of PEXR and Steel Logstor Pipelines for the following reasons:

- Pressure rating is determined to be the highest compared to all other pipelines.

- Max operating temperature is determined to be the highest compared to all other pipelines.

While material costs are not as attractive as the other alternatives, PEXR shall be used for most of the distribution system, which shall significantly reduce the costs associated with installation. These pipelines are supplied in spools of 130m to 300m lengths, which will reduce the installation costs related to joining compared to the other alternatives such as HDPE and PE-RT, which come in stick lengths of 50ft.

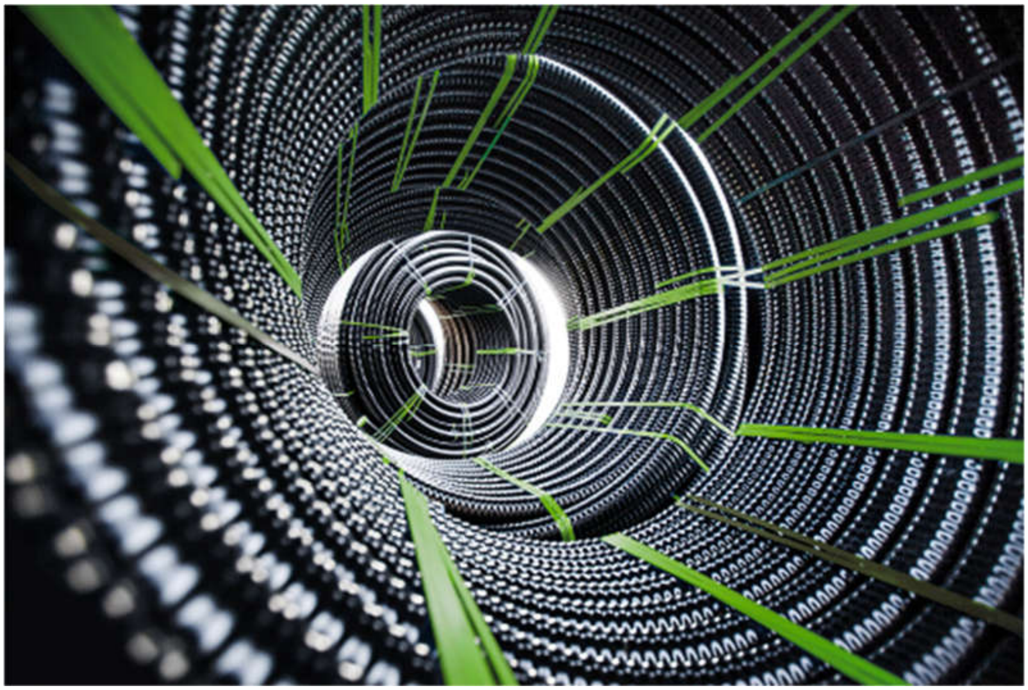


**Figure 34 - Kelit PEXR Spools [32]**

In addition, unlike their polyethylene counterparts, Logstor PEXR is suitable for installation without the need for complex thermal expansion mitigation measures (i.e. expansion joints, loops, etc.), resulting in a simplified distribution network. They also come in dual/twin lengths of pipe catering to the supply and return lines of most of the branches, which further simplify the system by requiring smaller and more shallow trenches. Following conversations with Logstor, the minimum trench depth for installation of PEXR piping is 0.2m, which would significantly reduce costs for trenching, especially in dense, urban locations.

- Logstor Pipelines are conveniently supplied pre-insulated, whereas other pipelines require purchasing and insulating at other locations or through different suppliers. Logstor pipes come pre-insulated, which guarantees a long service life span. Logstor insulates their pipelines using polyurethane foam. The heat loss from a preinsulated Logstor pipe is approximately 40% less than pipelines with traditional insulation [33].
- Logstor provides a leak detection system pre-installed in the insulation. Embedded copper wires are included within the pipeline insulation that simply requires connection into additional leak detection equipment. Given that this wiring is pre-installed, installation costs associated with leak detection can be blended in with installation costs for pipelines.

**Figure 35 - LOGSTOR Leak Detection System [34]**

- At the DEC, both the flow rate and system pressure are determined to be greatest. Unfortunately, Logstor PEXR is not available in sizes greater than 6". Logstor SteelFlex shall be used for the short section of piping that requires a greater inner diameter to accommodate the increased flow rate. Logstor steel piping is shown to have a lower cost per unit length compared to its suitable alternatives and comes in dual pipe instead of insulating separate lines for supply and return.
- Logstor is commonly found in several District Energy Systems in Canada, which brings confidence in the product with local technical support. Notable systems include, but are not limited to:
  - Calgary, Alberta – ENMAX District Energy System (East Village)
    - Both steel and PEXR pipelines have been installed.
  - Oakville, Ontario – Sheridan College District Heating System
    - Kelit PEX95R Pipe is primarily installed in this system.
  - Vancouver, British Columbia – Neighborhood Energy Utility (False Creek Community)
    - The District heating system supplied both heat and hot water to the Olympic village (2010) using untreated wastewater.

### 3.2.7 Heat Loads

The following section details how the heat loads were estimated for the NETSIM simulations. These heat loads ultimately affect the flow rate, pressures and temperatures of the fluid circulating throughout the distribution network.

#### 3.2.7.1 Natural Gas Utility Bills

Natural gas usage between 2015 and 2016 was collected from twelve buildings in the Town of Hinton. These utility bills were used to estimate the building heating loads. It was assumed that the buildings' base loads (i.e. loads from utilities other than building heating such as natural gas stoves, hot water heating etc.) would occur in the warmest summer months of July and August. The natural gas usage above the levels of these months were assumed to be used for building heating. These values can be found in Table 19.

**Table 19 - Building Heating Load Data Collected from Utility Gas Bills**

| Building | Lowest Monthly Natural Gas Usage (GJ) | Highest Monthly Natural Gas Usage (GJ) | Peak Monthly Heating Usage (GJ) | Peak Month Average Heating Loads (kW) |
|---|---|---|---|---|
| Hinton Government Building | 20.70 | 290.05 | 269.99 | 100.56 |
| Protective Services - RCMP | 7.92 | 94.07 | 86.15 | 35.61 |
| Emergency Services | 6.14 | 211.68 | 205.54 | 76.74 |
| Hinton Hospital | 583.00 | 2,213.00 | 1,630.00 | 608.57 |
| Senior Centre | 119.00 | 450.00 | 331.00 | 123.58 |
| Hinton Training Centre | 393.70 | 1,867.42 | 1,473.72 | 550.22 |
| École Mountain View School | 31.90 | 388.94 | 357.05 | 133.31 |
| Dr. Duncan Murray Rec. Centre | 390.45 | 2,478.61 | 2,088.16 | 863.16 |
| Community Hall / Friendship Centre | 5.98 | 525.89 | 519.91 | 214.91 |
| Harry Collinge High School | 66.08 | 852.47 | 786.40 | 293.61 |
| Crescent Valley Elementary | 37.71 | 585.10 | 547.40 | 204.37 |
| The Guild | 10.91 | 206.18 | 195.27 | 80.72 |

#### 3.2.7.2 Building Size

While Epoch has made a strong effort requesting this information, for most of the buildings included in the model heating, bills have not been received. An accurate building heating load is required to properly size the system, so a correlation between building floor area and heating load requirements was created from the existing data. The floor area of each proposed customer was provided by Hinton's Town Office and Building Assessment Company. Using the total area of each building, an average of 54.9W/m² floor space was used to estimate the building heating loads.

$$A_{building} \times \frac{54.9\frac{W}{m^2}}{1000} = Heat\ Load\ (kW)$$

Customers with calculated building heating loads can be found below.

**Table 20 - Calculated Building Heating Loads**

| Proposed Customer | Calculated Heating Load (kW) | Proposed Customer | Calculated Heating Load (kW) |
|---|---|---|---|
| 129 Timber Lane Condo Center | 58 | Monashee Lodge | 124 |
| 129 Timber Lane Condo East | 58 | Mountain Terrace Condominium | 220 |
| 129 Timber Lane Condo West | 58 | Mountainview Apartment Condominiums | 119 |
| Aspen Place | 115 | Parks West Mall | 137 |
| Balsam Court | 445 | Provincial Courts Building | 53 |
| BCMInns Hinton | 434 | Quality Inn & Suites | 165 |
| Big Horn Motel | 91 | Ramada Hinton | 280 |
| Carlyle Estates | 165 | Royal Canadian Legion Branch 249 | 88 |
| Crestwood Hotel | 439 | Safeway | 290 |
| Days Inn Hinton | 165 | Seabolt Apartments | 214 |
| Econo Lodge & Suites | 329 | Seabolt Apartments North | 214 |
| Freson Bro's | 195 | Southwest building | 132 |
| Gerard Redmond Community Catholic School | 258 | St. Gregory Catholic School | 181 |
| Grande Prairie Regional College | 93 | St. Regis Village | 436 |
| Hinton Lodge | 214 | Super 8 Hinton | 121 |
| Holiday Inn Express & Suites Hinton | 264 | Tara Vista Inn | 154 |
| Holiday Inn Hinton | 329 | Twin Pine Inn & Suites | 198 |
| Lakeview Inns & Suites | 220 | Villa Sundale Apartments | 142 |
| Lions Sunset Manor | 124 | Walmart | 318 |
| Maxwell Lake Apts | 214 | White Wolf Inn | 137 |
| McLeod Summit Condos | 176 | - | - |

### 3.2.7.3 Monthly Energy Usage

The building heating load represents the maximum heating power the building will require. Since the maximum heat load is required during peak times of the year and not every building in the system will require maximum heat loads simultaneously, a diversity factor is applied to the loads to prevent oversizing the system. In other words, the distribution network may be optimally sized for a load that is less than the sum of the individual customers' maximum demands. A study in Sweden was conducted on six DES where it was found that the diversity factor of these systems ranged from 0.57 to 0.79 and resulted in an average of 0.685 [36]. A diversity factor of 0.685 has been chosen for this DES.

Using ambient temperature data from Edson, AB, a factor was formulated to adjust the maximum building load to estimate heating demands at corresponding ambient temperatures. The average monthly temperatures as reported by Edson Alberta Weather Station between the years 2006 and 2017 can be found in the table below [35].

**Table 21 - Average Temperatures (°C) for Edson, AB, from 2006 to 2017**

| Month | Days | 11 Year Average Temperature (°C) |
|---|---|---|
| December | 31 | -11.9 |
| January | 31 | -8.9 |
| February | 28 | -8.0 |
| March | 31 | -3.3 |
| April | 30 | 3.5 |
| May | 31 | 9.5 |
| June | 30 | 13.5 |
| July | 31 | 16.2 |
| August | 31 | 14.3 |
| September | 30 | 9.7 |
| October | 31 | 2.7 |
| November | 30 | -5.8 |

Using the temperature data above and the utility bills provided, the factor to be applied to the building heat load is:

$$F(T) = \begin{cases} 0.685 & T < 14.5°C \\ 0.3135 \times e^{-0.058T} & T \geq 14.5\ °C \end{cases}$$

This factor can be applied to the maximum building heat loads to estimate the heating load corresponding to ambient temperature, $P_a$:

$$F(T) * Heat\ Load\ (kW) = P_a$$

Where $P_a$ = Adjusted Heat Load (kW)

To convert the heating load, $P_a$, to the energy usage of that month, the load can to be multiplied by the number of seconds in a month to determine the heating load in GJ/month.

$$P_a \times 60\ s/min \times 60\ min/hour \times 24\ hours/day \times x\ days/month = \frac{E}{month}$$

Where E = Adjusted Heat Load (GJ)

#### 3.2.7.4 Future Customers

The Town of Hinton is anticipating future industrial development which may result in additional customers for the Hinton DES. ISL Engineering has provided information on future town developments as part of their proposed water treatment plant study. The same information can be found in the Town of Hinton's Municipal Development Plan (Figure 36 and Figure 37), which can be viewed below and in Appendix D.4. Per this master plan, a large area reserved for future industrial development can be found on the south end of Hinton along Robb Road. While it is not known the extent of heating loads required for this development, the proposed DES distribution network will be designed to accommodate future loads in this area. While further information is required to determine the potential loads due to expansion, the system load of the south end of the network was doubled for an initial estimate.

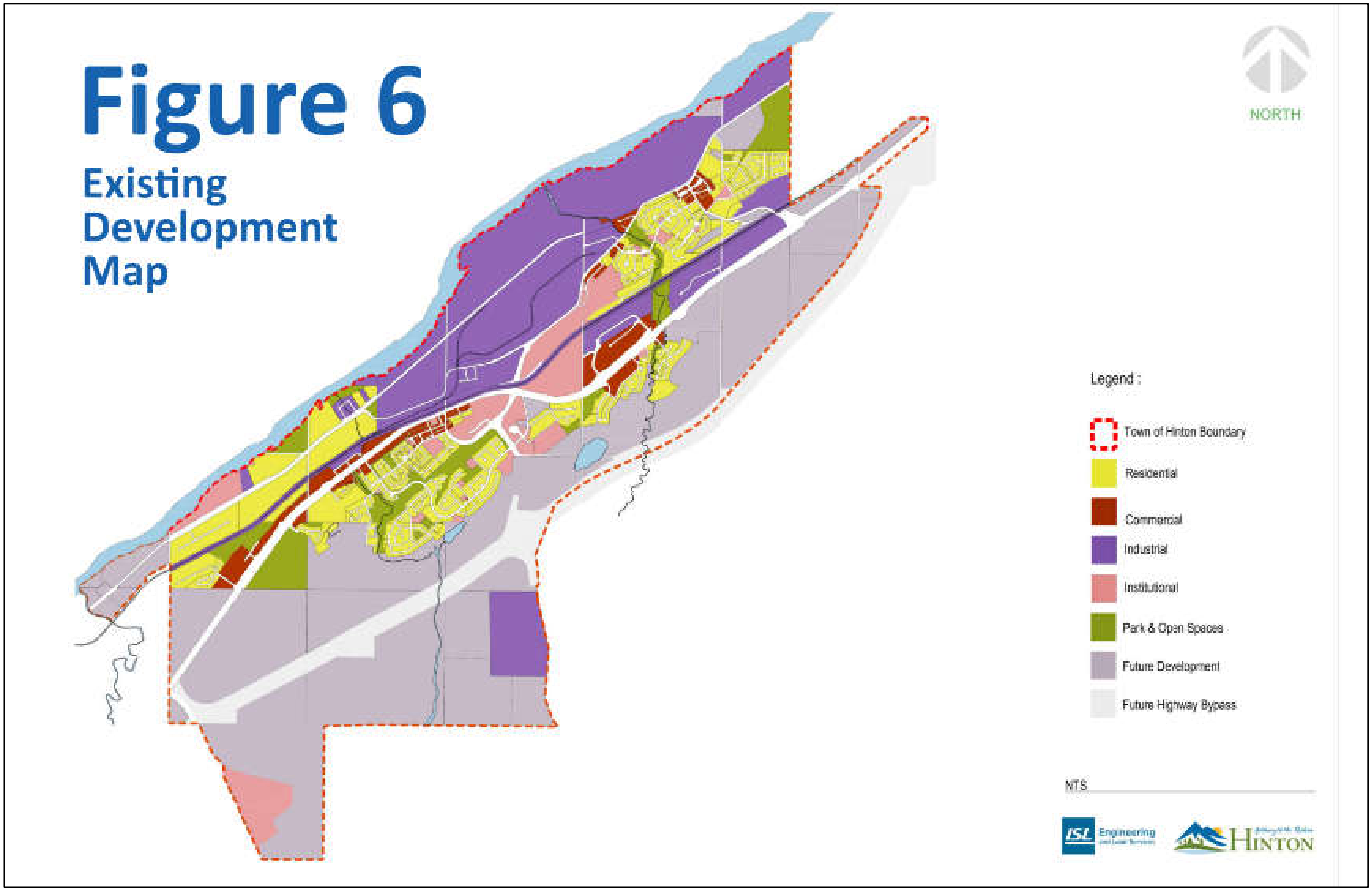



**Figure 36 - Town of Hinton's Municipal Development Plan Figure 6 [36]**

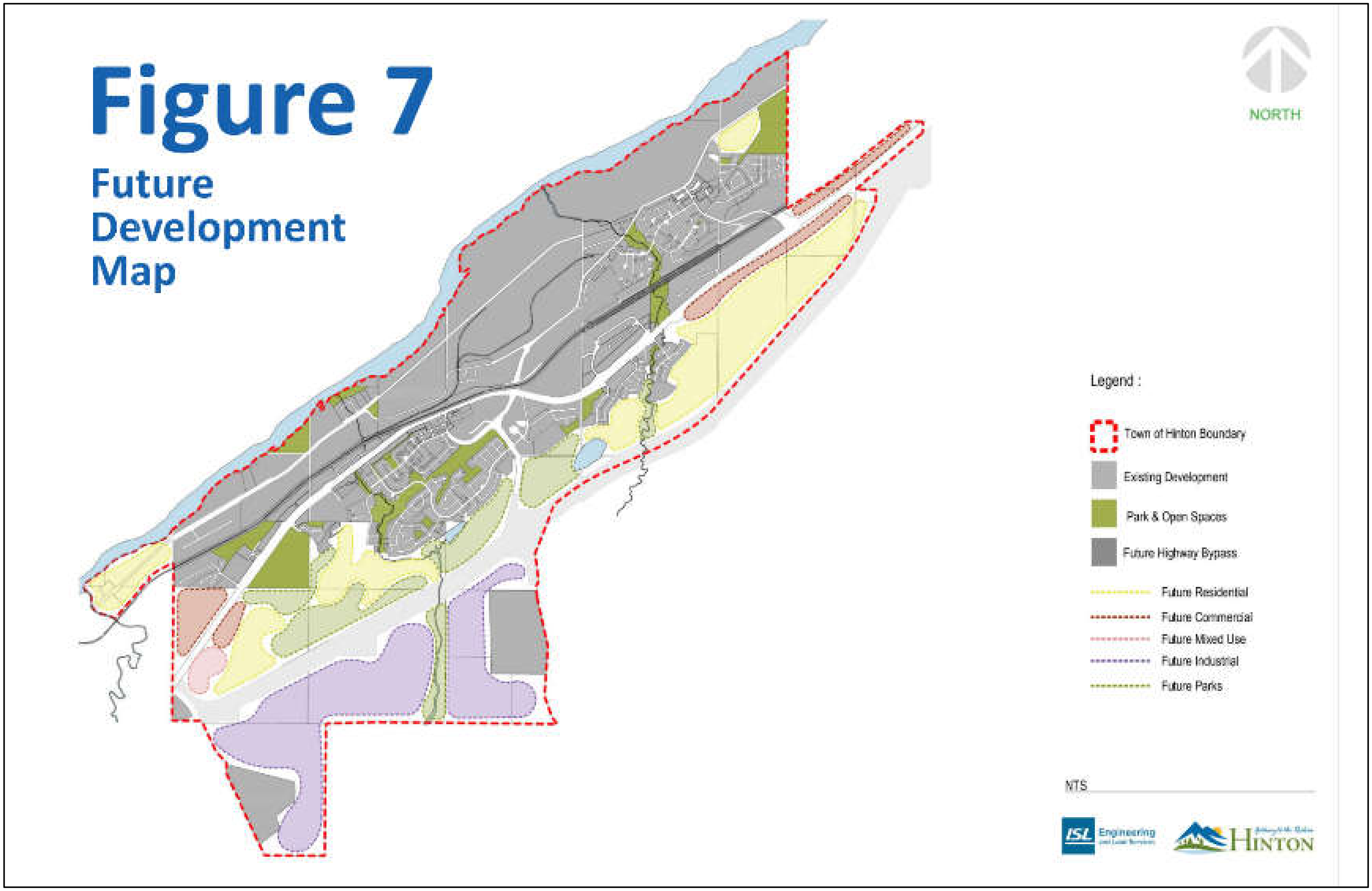



**Figure 37 - Town of Hinton's Municipal Development Plan Figure 7 [36]**

### 3.2.8 Process Requirements Considered

In addition to the design criteria listed in Section 3.2.1, to reach the tenth iteration, the following sections describe process related obstacles that the system overcame to become a balanced and efficient system.

#### 3.2.8.1 Full Flow Pressure Balance

A main objective during the model development was to maximize the utilization of PEX piping. This was based on the design criteria to limit the cost of materials and installation. The main challenge with the use of PEX piping is its low-pressure rating (600 kPag) and the large elevation changes found in Hinton, which result in significant static pressure.

When the system is at full flow, additional head pressure is needed from the distribution pumps to overcome the frictional losses throughout the DES, this results in pressures compounded with static head throughout the system. Frictional losses can be mitigated by increasing the pipe diameters, a pressure loss of 125 Pa/m is the maximum frictional loss allowed in the system to help minimize the required pumping power (see Section 3.2.2).

When the system is in a no flow situation and this additional pump pressure is not a factor, positive pressure must be maintained in the system. The importance of maintaining positive pressure throughout the network is to prevent cavitation within the system. Cavitation occurs when liquid within the system changes to vapour due to high temperature and low pressure. When cavitation bubbles collapse, they can cause large shock waves within the system that will propagate damage to pipe walls, valves, heat exchangers, pumps, and any other equipment in the system. Cavitation within the system will eventually lead to failure.

To achieve proper pressure distribution, the use of booster pumps and control valves were investigated in iterations one and two of the expanded DES. These pumps were operated to ensure positive pressure while operating below the pressure rating of the PEX piping. Pressure Control Valves (PCVs) were utilized to maintain upstream pressure on the return side of the loop. These iterations added complexity to the system and required auxiliary booster pumps and pressure control valves to maintain low enough pressures for PEX piping to be utilized.

As an alternative to the use of booster pumps and control valves, the return pressure at the DEC is set to ensure that the system remains above the vapour pressure of the fluid under zero flow conditions. This is accomplished by setting the expansion tanks to the appropriate pressure and was implemented in iteration four. The required pressure setting in the DES becomes higher than that of a system utilizing booster pumps and pressure control valves to maintain positive pressure. This limits the amount of PEX piping that can be installed, but also simplifies operations and maintenance by removing the need for booster pumps and control valves.

Four additional models were developed to determine the best option to increase the amount of PEX pipe used while accommodating the large elevation changes found in the system. These models, found in Table 12, are described as follows:

1. The outright removal of the southwest leg from the distribution system, which has the highest elevation change within the system.

2. A separate loop starting near the RCMP building that would service the southwest leg. This loop would be installed at a higher elevation, mitigating the static head of the loop.
3. Two separate loops, both starting at the Friendship Centre. One loop to serve the southwest leg, and the other to serve the remaining customers. Due to the elevation change, the loop serving the southwest leg would still require pipeline with higher pressure ratings than that of PEX pipe.
4. A separate loop used for each quadrant of the system. Due to the elevation change, the loop serving the southwest leg would still require pipelines with higher pressure ratings than that of PEX pipe.

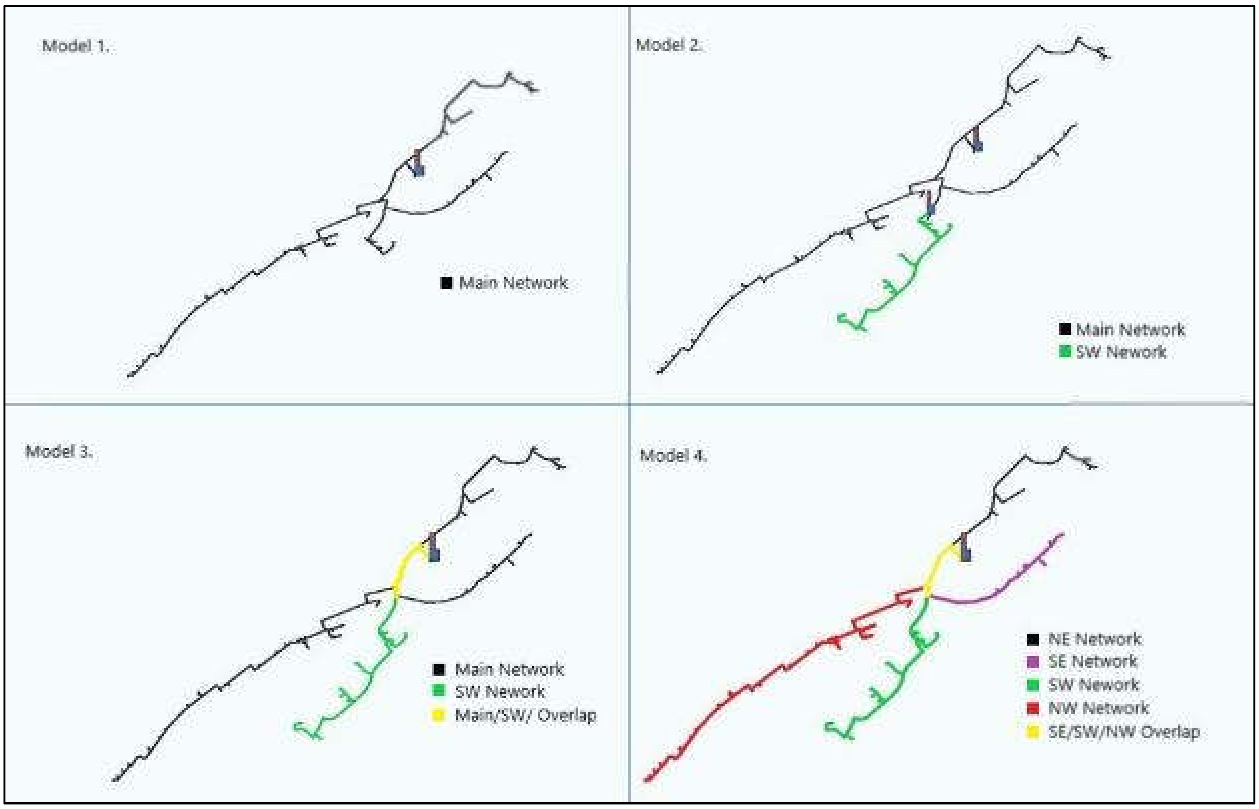



**Figure 38 - Four models compared to determine the layout that maximizes PEX pipe usage**

After discussions with the Town of Hinton, it was determined that a remote substation in Model 2 was not feasible as there was limited municipal land available at the proposed location. The most favourable option for managing the pressure caused by static head is the use of two separate loops (Model 3 above). This model limited the amount of steel pipeline installed in the main system.

3.2.8.2 DEC Location

Four separate DEC locations have been investigated throughout this study; these locations can be seen in Figure 39. The first location, which was used in the Pre-FEED study, is the Trican Well Servicing property. This location was chosen due to its central position relative to the DES but was not pursued beyond the Pre-FEED due to it being private property.

The Friendship Centre Society Building was chosen as a location to use for the DEC in this study as it is also located near the centre of the DES and land is available from the Town of Hinton.

The third location investigated is a part of ISL's proposed Water Treatment Plant (WTP) along Kelley Road. Preliminary discussions with ISL and the Town of Hinton placed the DEC inside the same building as the WTP. This location was selected because of the potential to use waste heat from the treatment plant, as well as cost savings by sharing a building.

The WTP location requires 2 crossings of the CN Rail lines, and a significant amount of steel pipe to connect it to the distribution network. In addition, due to the narrow lanes and high slopes along the proposed right-of-way, construction costs would have been excessive as seen in Section 3.6.2. Finally, it was discovered that the WTP does not utilize/produce waste heat as it is a drinking water facility, not a waste water facility. This location was abandoned, and the network reverted to using the Friendship Centre as the DEC location.

The Geothermal well site was investigated as a potential location for the DEC. This location has the benefit of combining the upstream and midstream equipment into one building. Due to the high-volume flow rate coming from the DES, the wellsite's location required large steel piping to connect to the main branches of the system. This additional steel piping proved cost prohibitive.


**Figure 39 - DEC locations explored in FEED study**

#### 3.2.8.3 Introduction of PEXR

Through continued vendor discussions on Logstor Piping, Kelit's PEXR, a flexible reinforced polyethylene pipe, was introduced as a possible alternative to PEX piping. Similar to PEX piping, PEXR piping is provided as a coiled product with similar installation processes. Due to the manufacturing methods for this piping, the pressure rating of PEXR (at up to 100°C) is 1600 kPag.

**Figure 40 - Kelit PEXR [32]**

The major benefit of PEXR piping is that it can be used in place of steel pipes in locations where higher pressures are expected, while still being installed using compression fittings. PEXR is limited to a maximum diameter of 6", and therefore steel piping is still required in certain areas because of the availability of larger diameter pipes. Large pipe diameters are required on the main distribution lines to reduce frictional pressure losses. Reducing these losses will in turn reduce the pumping power the system requires. Two models (Table 12: Iteration 6 and 7) were now compared: one using a single network and a second using two separate networks, with PEXR introduced to replace some of the steel piping. Given that PEXR has similar installation procedures to PEX but a higher-pressure rating, low pressure requirements are not as critical in developing a stable and functioning model. Based on a cost analysis, a single network is the preferred solution when PEXR is used in the network. The costs associated with installing steel lines are found to be more expensive than the materials costs of installing steel. In addition, the use of steel presents potential problems with corrosion and may require shut downs for maintenance.

### 3.2.9 Snow Melt System

Not shown in the proposed distribution network above is the proposed snow melt system. This system consists of a separate loop that will distribute heated fluid for the sole purpose of snow melting along sidewalks, roads, bridges, etc. Figure 41 and Figure 42 provide examples of what a snowmelt system entails.

**Figure 41 - Example Back End of Snow Melt System, Klamath Falls, Oregon [37]**

**Figure 42 - Example Snow Melt System - Stair Construction, Klamath Falls, Oregon [37]**

Hinton receives an average of 168cm of snowfall each year. Snow and ice are typically removed by salting, sanding, shoveling, and plowing. The use of hydronic snow melting systems in high traffic areas eliminate the need for these removal methods, allowing pedestrians to safely travel on snow-free surfaces year-round.

**Figure 43 - DES heated sidewalk in Klamath Falls, Oregon [38]**

**Figure 44 - Example installation of a hydronic snow melting system**

Based on Hinton's climate [39] and using the calculations provided in ASHRAEs Snow Melting and Freeze Protection guide, an average heating value of 60 W/m$^2$ is required to melt accumulated snow after a snowfall [40]. Assuming the system has an average temperature drop through the sidewalk of 20°C, this results in a flow rate of 7.8 mL/s per m$^2$ of sidewalk heated. See Appendix D.5 for high level calculations. Heat exchangers, circulation pumps, and pipe diameters will be sized based on the area being heated. Details will be confirmed at later stages; however, this option is feasible due to the central location of the DES and its proximity to nearby plazas and high pedestrian traffic areas.

### 3.2.10 Water Hammer

Water hammer is a large and sudden increase in pressure within a pipe when there is a sudden change in flow velocity. This sudden change in fluid velocity is often caused by a sudden valve closure, or a pump failure [41].

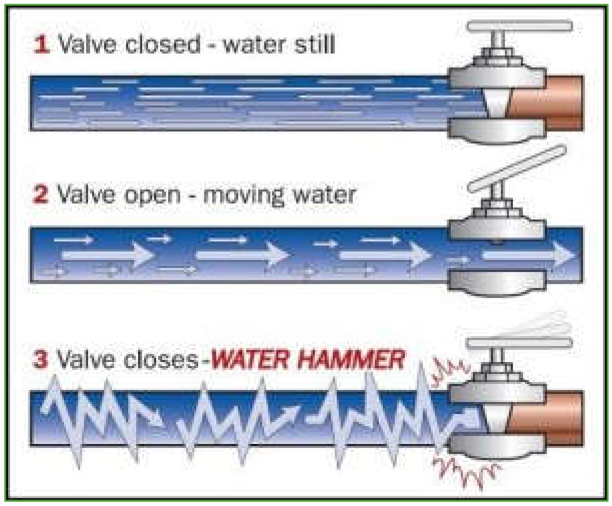



**Figure 45 - Visualization of Water Hammer [42]**

The equation below can be used to calculate the pressure rise caused by water hammer [43].

$$\Delta p_h = \rho c_s V$$

Where:

$\Delta p_h$ = pressure rise caused by water hammer (kPa)

$\rho$ = fluid density (kg/m$^3$)

$c_s$ = velocity of sound in the fluid (m/s)

$V$ = fluid flow velocity (m/s)

The maximum fluid velocity found in the DES is 1.76 m/s, which results in a water hammer of 2.7 MPag. This increase in pressure caused by water hammer has the potential to exceed the maximum pressure rating of the piping and equipment within the DES. This increase in pressure is the worst-case scenario and will only occur if there is an instantaneous flow stoppage at the point of peak flow.

The Hinton Geothermal District Energy System has been designed in a manner to prevent the occurrence of water hammer. Operational procedures that will be used in the DES specifically to prevent water hammer are mandated valve opening and closing rates and pump ramp up and ramp down rates. These procedures prevent sudden flow rate changes in the system. Additional engineering controls will be used to ensure that these operation procedures are followed, these include electrically actuated valves with pre-programed opening and closing rates as well as a fail last design. When there is a loss of power to an electrically actuated "fail last" valve, the valve will stay in its current position. Much like the electrically actuated valves, the pumps VFD's will be programmed to ensure that the flow can only be changed to meet a set differential pressure. Expansion tanks will also be utilized up stream of the pumps to help absorb any sudden pressure surges. Additionally, flow-through pumps and the use of fly wheels on pumps can alleviate sudden flow velocity changes caused by pump failure. The rotational momentum of the fly wheel will increase the time it takes the pump to stop rotating if there is a loss of power, and the flow-through pump design allows the fluid to continue flowing past the pump once it has stopped.

### 3.2.11 Construction Plan

With the pipeline materials and preliminary model established, Epoch has reached out to Dunwald and Fleming Enterprises Ltd. (Dunwald and Fleming) to initiate the development of a construction plan. This construction plan was based on the NETSIM model (Section 3.2.3), installation requirements of Logstor piping [31], the layout and existing infrastructure of the Town of Hinton (See Appendix D.6), previous geotechnical reports (See Appendix D.7) and Dunwald and Fleming's previous experience with urban utility pipeline installation. The detailed construction plan can be found in Appendix D.8.

#### 3.2.11.1 Pipeline Design and Installation

The pipeline distribution system will be primarily designed and installed under the European Standard EN 13941 – Design and Installation of Pre-insulated Bonded Pipe Systems for District Heating. This European standard "…specifies rules for design, calculation and installation for pre-insulated bonded pipe systems for buried hot water distribution networks for continuous operation with hot water at various temperatures up to 120°C and occasionally with peak temperatures up to 140°C and maximum internal pressure 25 bar (overpressure)" [44]. Additional relevant valid European Standards are EN 253 – Bonded Pipes and EN 14419 - Surveillance Systems. Additional design requirements were established through the Town of Hinton's Minimum Engineering Design Standards Document [45], which shall be followed wherever applicable.

#### 3.2.11.2 Trench Depth

The objective of proper trenching and backfilling is to obtain homogenous friction between the soil and the outer casing. The trench cross section must be wide enough to allow for safe and efficient pipeline installation and joining, and to provide access for compacting the backfill in a suitable manner.

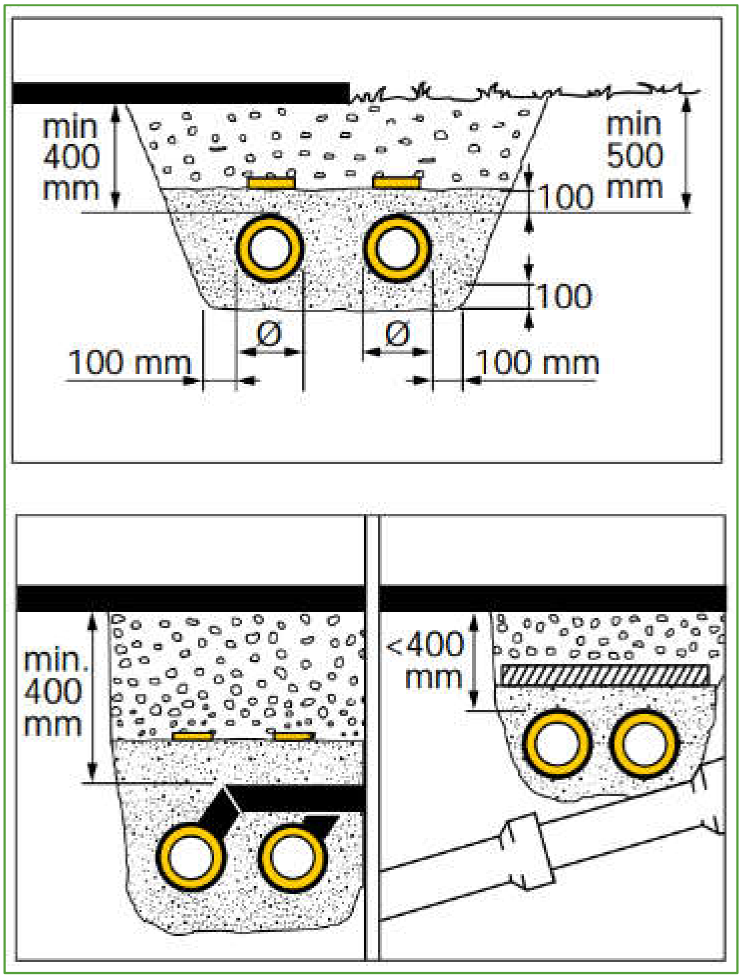



**Figure 46 - Logstor Design Manual - Minimum Soil Cover Recommendations (bottom, Branch Cover Depth) [31]**

Per Logstor, the minimum depth of cover is 500mm under the bottom of road asphalt or concrete. Depending on the diameter of the pipeline, the minimum distance between pipes ranges from 150mm to 300mm. To ensure the bond between steel service and PUR foam, the pipes have a maximum depth of cover. The following table below was taken from the Logstor Design Manual and describes the max soil cover over pipe vs. pipe diameter.

**Table 22 - Max Soil Cover vs. Steel Pipe Diameter and Insulation Series [31]**

| Steel Pipe Ø mm | Max Soil Cover Over Pipe | | |
|---|---|---|---|
| | Series 1 (m) | Series 2 (m) | Series 3 (m) |
| 26.9 | 1.50 | 1.50 | 1.50 |
| 33.7 | 1.75 | 1.50 | 1.50 |
| 42.4 | 1.75 | 1.50 | 1.50 |
| 48.3 | 2.00 | 1.75 | 1.50 |
| 60.3 | 2.25 | 2.00 | 1.75 |
| 76.1 | 2.50 | 2.25 | 1.75 |

| | | | |
|---|---|---|---|
| 88.9 | 2.50 | 2.25 | 2.00 |
| 114.3 | 2.50 | 2.25 | 2.25 |
| 139.7 | 2.75 | 2.50 | 2.25 |
| 168.3 | 3.00 | 2.50 | 2.50 |
| 219.1 | 3.25 | 2.75 | 2.50 |
| 273 | 3.25 | 2.75 | 2.50 |
| 323.9 | 3.25 | 2.75 | 2.75 |
| 355.6 | 3.25 | 3.00 | 2.75 |
| 406.4 | 3.50 | 3.25 | 2.75 |
| 457 | 3.50 | 3.25 | 2.75 |
| 508 | 3.50 | 3.25 | 2.75 |
| 610 | 3.50 | 3.25 | 3.00 |

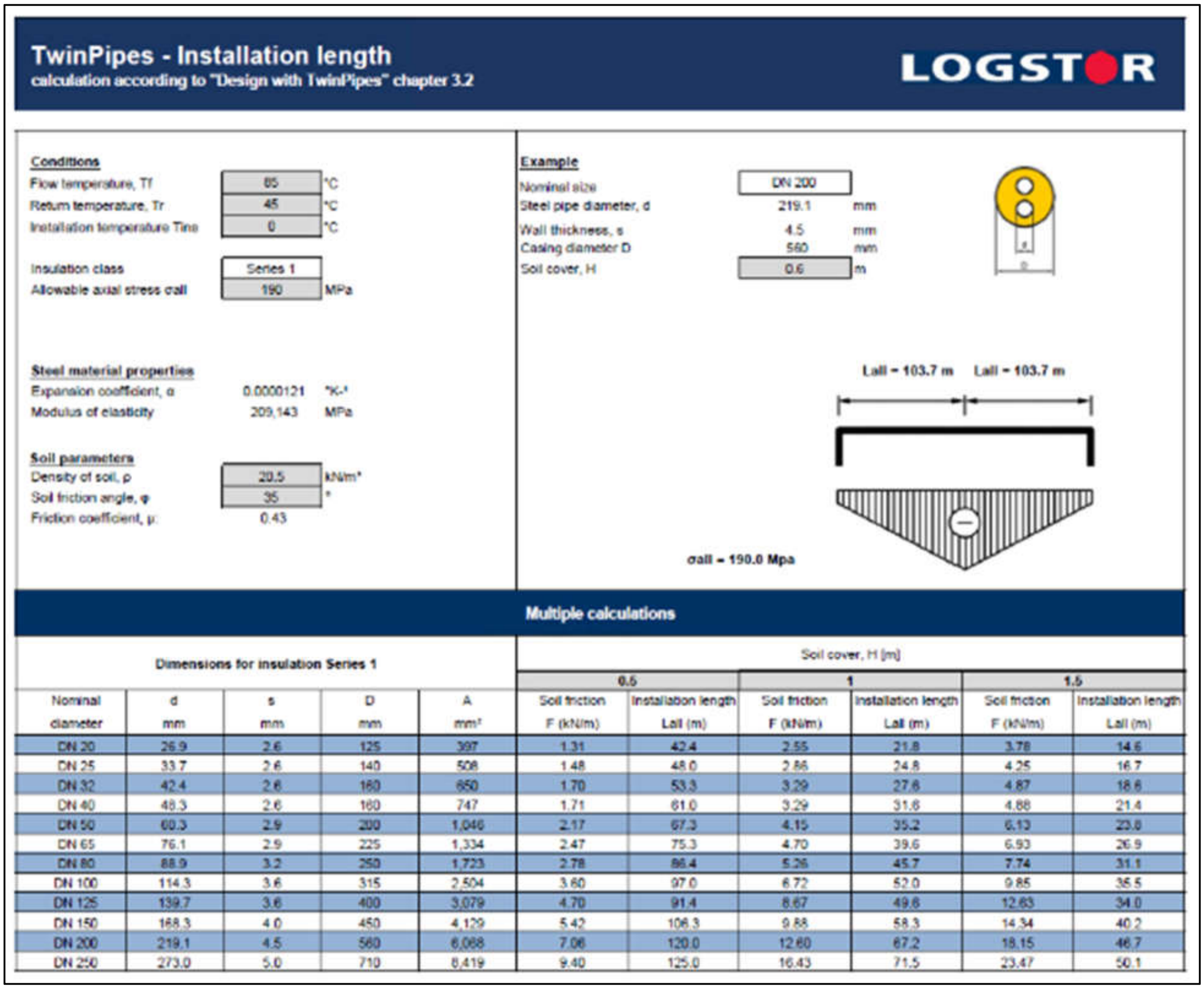
For the DES in Hinton, a depth of cover of 600mm has been set for cost estimating. This number shall be revisited in detailed engineering once a better idea of spacing between existing utilities has been established and further calculations have been completed.

#### 3.2.11.3 Straight Pipe Installation / Stress Reduction with Bends

As mentioned in Section 3.2.6.7, due to the significant temperature changes experienced by the fluid and the pipeline materials, pipeline design must include considerations to thermal expansion. Kelit PEXR pipelines benefit from their construction as not requiring mitigation measures for thermal expansion. However, one section (see Appendix D.6) will be constructed using pre-insulated steel pipelines. Steel piping expands with an increase in temperature, and therefore the change in both length and circumference must be compensated. Through straight lengths of pipe installed underground, the use of expansion loops or bends, supplemented with foam pads must be installed in line to mitigate stresses caused by thermal expansion.

Logstor provides an online calculator that allows for high level stress calculations to determine how many bends are required over a straight length of pipe that is installed. Initial calculations were completed to determine the minimum number of expansion loops or bends required across straight sections of pipe.

The results can be found below:




| Dimensions for insulation Series 1 | | | | | Soil cover, H [m] | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 0.5 | | 1 | | 1.5 | |
| Nominal diameter | d mm | s mm | D mm | A mm² | Soil friction F (kN/m) | Installation length Lall (m) | Soil friction F (kN/m) | Installation length Lall (m) | Soil friction F (kN/m) | Installation length Lall (m) |
| DN 20 | 26.9 | 2.6 | 125 | 397 | 1.31 | 42.4 | 2.55 | 21.8 | 3.78 | 14.6 |
| DN 25 | 33.7 | 2.6 | 140 | 508 | 1.48 | 48.0 | 2.86 | 24.8 | 4.25 | 16.7 |
| DN 32 | 42.4 | 2.6 | 160 | 650 | 1.70 | 53.3 | 3.29 | 27.6 | 4.87 | 18.6 |
| DN 40 | 48.3 | 2.6 | 160 | 747 | 1.71 | 61.0 | 3.29 | 31.6 | 4.88 | 21.4 |
| DN 50 | 60.3 | 2.9 | 200 | 1,046 | 2.17 | 67.3 | 4.15 | 35.2 | 6.13 | 23.8 |
| DN 65 | 76.1 | 2.9 | 225 | 1,334 | 2.47 | 75.3 | 4.70 | 39.6 | 6.93 | 26.9 |
| DN 80 | 88.9 | 3.2 | 250 | 1,723 | 2.78 | 86.4 | 5.26 | 45.7 | 7.74 | 31.1 |
| DN 100 | 114.3 | 3.6 | 315 | 2,504 | 3.60 | 97.0 | 6.72 | 52.0 | 9.85 | 35.5 |
| DN 125 | 139.7 | 3.6 | 400 | 3,079 | 4.70 | 91.4 | 8.67 | 49.6 | 12.63 | 34.0 |
| DN 150 | 168.3 | 4.0 | 450 | 4,129 | 5.42 | 106.3 | 9.88 | 58.3 | 14.34 | 40.2 |
| DN 200 | 219.1 | 4.5 | 560 | 6,068 | 7.06 | 120.0 | 12.60 | 67.2 | 18.15 | 46.7 |
| DN 250 | 273.0 | 5.0 | 710 | 8,419 | 9.40 | 125.0 | 16.43 | 71.5 | 23.47 | 50.1 |

**Figure 47 - Estimated installation length for Logstor steel piping (straight line) [31]**

As shown in the figure above, with a soil cover of 0.6m, the maximum allowable length of straight steel pipeline before a bend or expansion loop is required (installation length) is 207.4m. This installation length ensures that the stresses experienced by the steel line do not exceed 190 MPa. The installation length decreases with increased soil cover. The differential temperature between installation and flow affect installation length as well; the smaller the differential temperature, the longer the installation length. It is therefore recommended to construct the pipeline during the summer, when differential temperature will be lowest. Density of soil and soil friction angle were estimated using existing geotechnical information from the surrounding Hinton area (see Appendix D.7 for more information). A full geotechnical investigation is required, specifically along the section of pipe where steel will be installed. This will determine the installation length and provide a more accurate cost estimate for any earth work that needs to be completed.

To absorb expansion movements, Logstor recommends that foam pads are installed on one or both sides of the outer casing in accordance with the system. For major bends, it is recommended to wrap the pads in geotextile fabric to secure the pads and to prevent sand from entering between the foam pad and the outer casing. Further calculations and design review are required to ensure that the bends are properly supported, and expansion movements are absorbed. Construction and Material costs for foam pads have been included in the cost estimate.

**Figure 48 - Example Foam Pad Installation for Logstor Pipe System [46]**

#### 3.2.11.4 Existing Town Infrastructure

The Town of Hinton has provided Epoch with access to their GIS system, which provides updated information on existing infrastructure within the town boundary. This information allows Epoch to take an inventory of potential crossings or infrastructure that may interfere with construction. As such, a proposed right-of-way (ROW) for the pipeline distribution system helped identify where construction would take place, and what type of infrastructure would be found in the area.

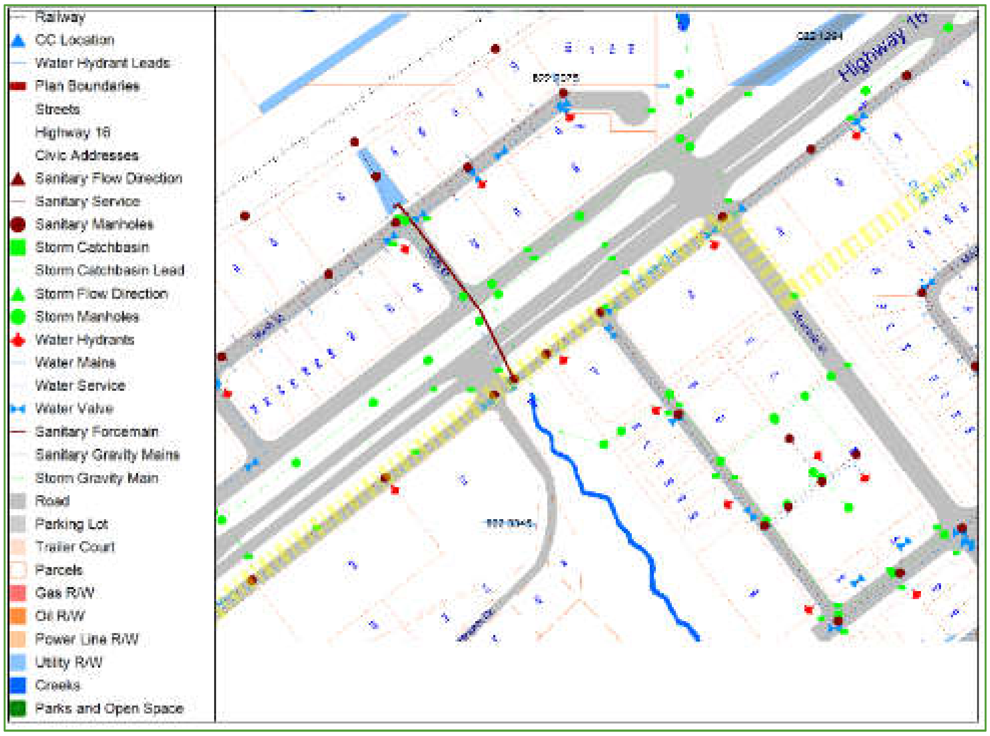



**Figure 49 - Example GIS Screenshot of Hinton Infrastructure**

The Town of Hinton's Minimum Engineering Design Standards indicate that under no circumstance is the DES pipeline to be installed within 3 meters from any water main or sewage line. In addition, Hinton also requires a minimum of 1m from any buried utility. These spacing requirements shall be taken into consideration. The proposed ROW can be found in Appendix D.6.

3.2.11.5 Geotechnical Report

As mentioned above, there are existing geotechnical reports that investigated areas throughout the Town of Hinton. It should be noted that geotechnical information is missing for some sections of the proposed ROW. The existing geotechnical reports showed that from surface to about 1.5m there are varying sections of clay fill, gravelly and soft clay, sandy gravel and muskeg throughout town. Please see a summarized map below and in Appendix D.7.

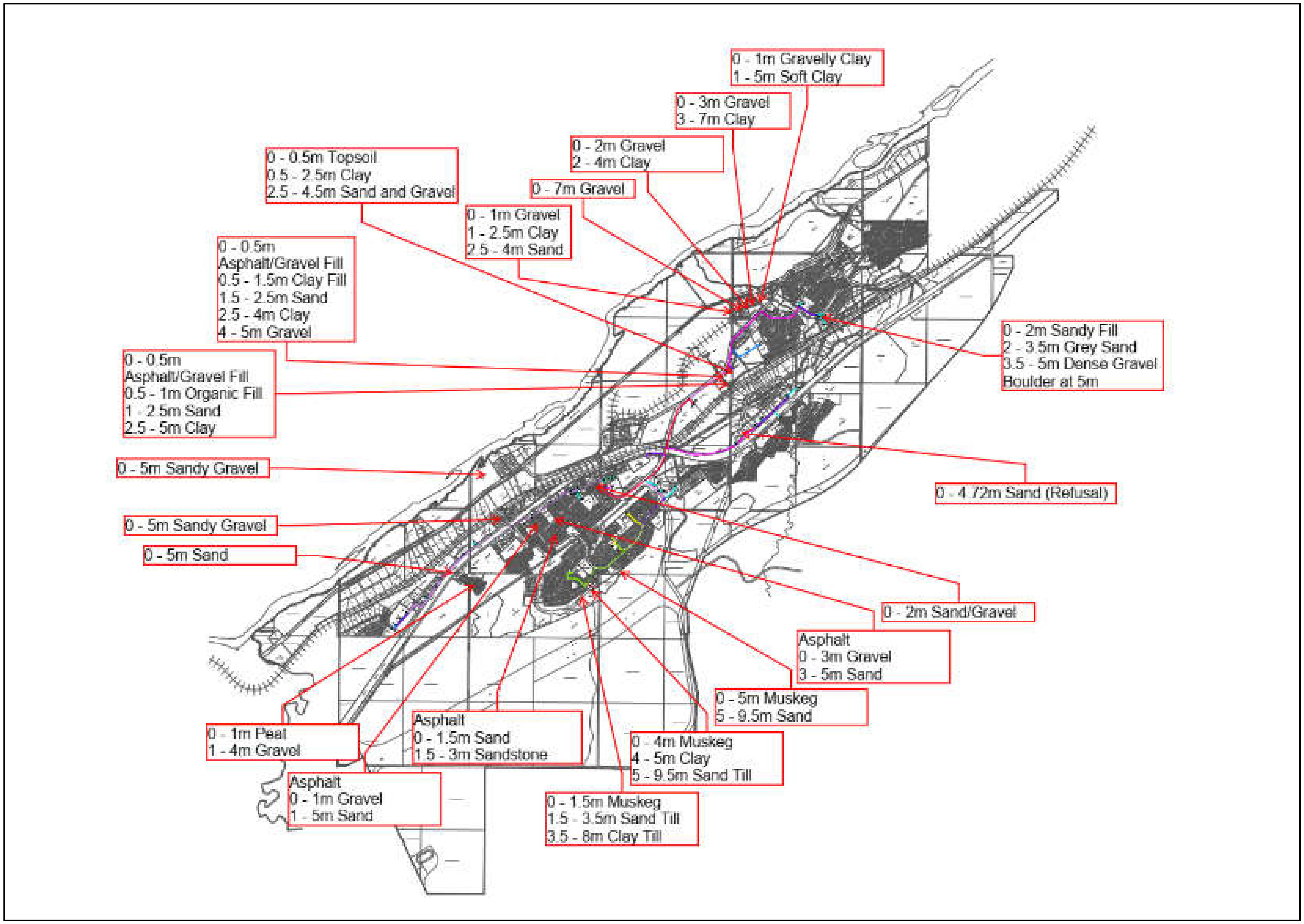



**Figure 50 - Map of Summarized Geotechnical Reports (Appendix D.7)**

Following Dunwald and Fleming's site visit and discussions with Hinton's Infrastructure Services Department, it was determined that these existing geotechnical reports are not entirely correct, and that Hinton's soil at shallow depths is comprised of rocky material, which makes boring and shallow HDD crossings difficult to complete.

It has been decided that most of the work shall be completed via open cut trenching to ensure that any cobblestone is removed. More geotechnical investigation is warranted prior to beginning construction.

3.2.11.6 Construction Plan

A summarized version of the construction plan can be found in Appendix D.8. This is the second iteration of the construction plan.

Dunwald and Fleming had reviewed and provided cost estimates for two iterations of the DES (See Table 12: Iteration 5, then 6). The first iteration had located the DEC at ISL's proposed water treatment plant. Through their visit of the town, Dunwald and Fleming determined that the steel transmission lines that run east towards Switzer Road will be very expensive to install. East of the CN Rail crossing, the transmission line will run along side a very narrow service road with a steep side slope. To install larger transmission lines along this road, Dunwald and Fleming determined that engineered bank stabilization is required, and the tight space through this roadway will significantly increase costs for installation.

**Figure 51 - Photo of Narrow Service Road with Steep Side Slopes along proposed ROW**

In addition, there are two separate CN Rail Crossings as part of this iteration. Due to the stringent requirements of CN Rail, each crossing was estimated to be relatively expensive.

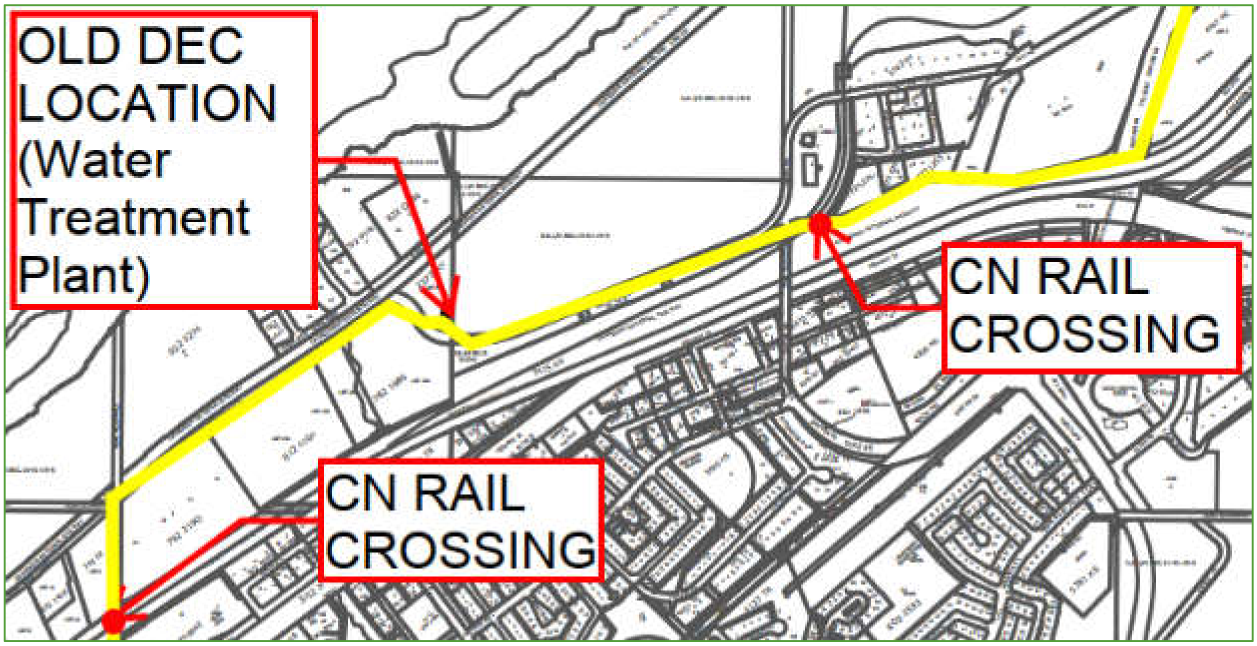



**Figure 52 - Earlier Proposed DES with CN Rail Crossings**

The second iteration moved the DEC from the ISL Water Treatment Plant to the Friendship Centre on Switzer Drive. Moving the DEC to the Friendship Centre decreases the length of transmission line required and removes the need for any rail crossings. In addition, the trenches become less complicated, reducing overall construction costs. The construction plan details the procedure for installing lines per Iteration #6.

## 3.3 District Energy Centre (DEC)

The town heat exchanger building equipment and piping will be built to ASME B31.1 – Power Piping. All equipment, vessels, fitting and pressure piping will be designed to meet the requirements to register with a CRN under the Alberta Boilers Safety Association (ABSA). In addition, to receive the proper permits, the town heat exchanger will meet the Town of Hinton's Minimum Engineering Design Standards (2007) and the requirements detailed in Section 3.7.4.2.

## 3.3.1 Process Flow

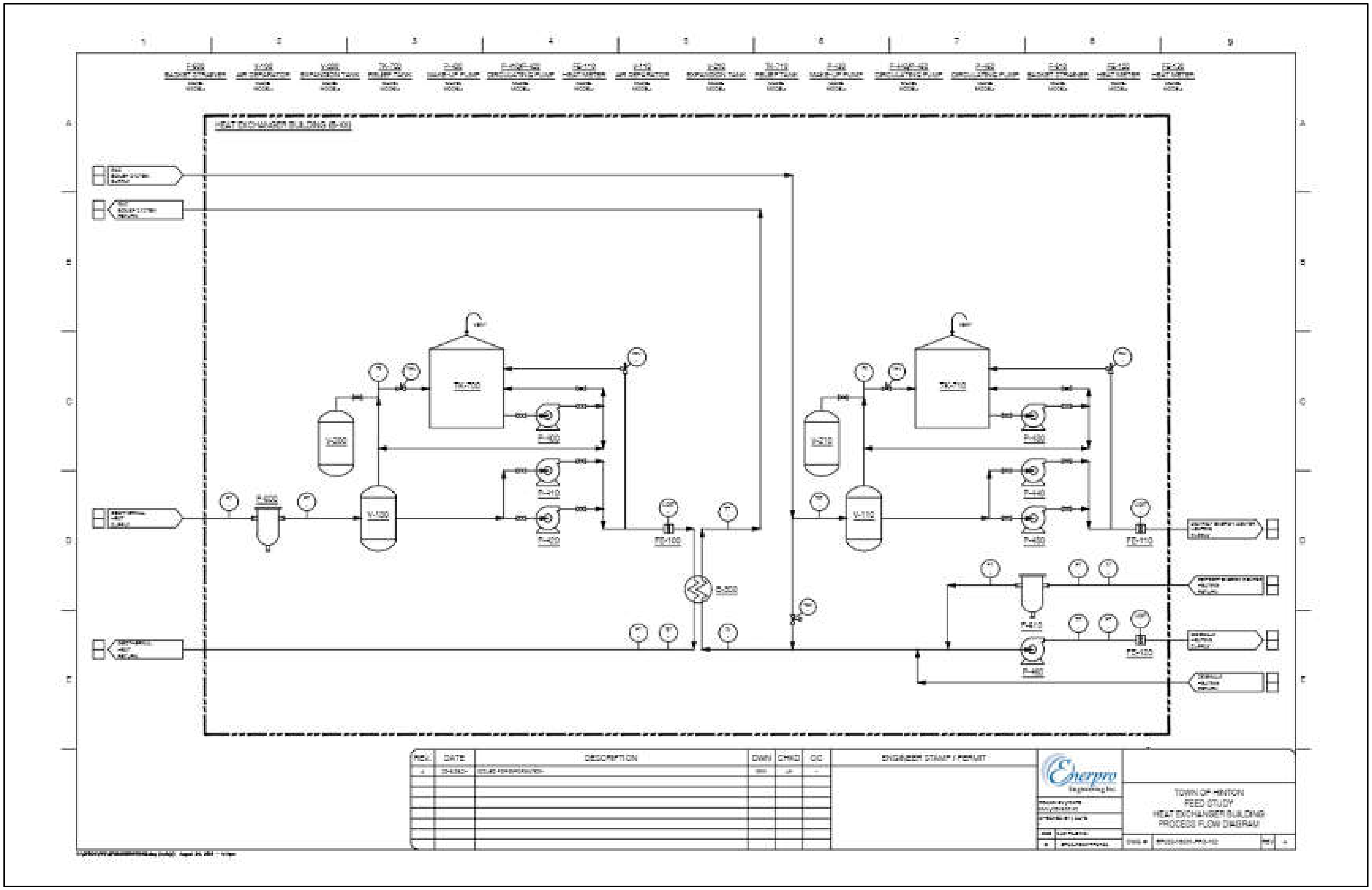



**Figure 53 - Process flow diagram of District Energy Centre (Appendix D.9)**

Please see process flow diagram (Appendix D.9, PFD-102). After fluid is run through the geothermal heat exchanger, it will enter the gas boilers (see Figure 54 as an example) to be peak heated (as required). These boilers will be temperature controlled, meaning that they will turn on or off (with varying heating power) based on outlet pressure. Once the fluid passes both heating sources, it will be sent through an air separator and expansion tank, into the suction of the downstream distribution pump, which will discharge the fluid into the distribution network. A temperature control valve is installed to recirculate fluid if the temperature of the fluid spikes above target. Once discharged, fluid will pass through a heat meter, which monitors flow rate from the discharge of the pump, while taking heat and pressure measurements from the return side of the loop. This is so the flow meter can also be used to monitor pump performance. After the fluid is distributed through town, it will converge back at the heat exchanger building, where it will enter through a basket strainer, before it is recirculated back into the geothermal heat exchanger, thus completing the distribution loop.

**Figure 54 - Example Gas Fired Boiler (Unilux)**

### 3.3.2 Equipment and Piping Design

As mentioned in the section above, all equipment, vessels and pressure piping will be registered with a Canadian Registration Number (CRN). Pressure Piping will be designed to comply with Code ASME B31.1. All fittings will be suitable for the design service conditions and will be designed to be registered with the Alberta Boilers Safety Association (ABSA). Overpressure protection shall be completed through use of pressure relieving devices, or through system design. System design overpressure protection is typically achieved through analysis of the pumps and their dead head pressure, as well, the static pressure of the system through elevation changes and superimposed pressure added by the expansion tank or make up system. If the maximum achievable pressure falls below the pressure rating of the system, further overpressure protection is no longer required. Per ASME Boiler and Pressure Vessel Code, at a minimum, dedicated relief and isolation is required for the boilers.

Further substation design considerations were taken from:

- ASHRAE 2008 HANDBOOK CHAPTER 12: HYDRONIC HEATING AND COOLING SYSTEM DESIGN
- ASHRAE DISTRICT HEATING GUIDE

Design details recommended by the above resources will be specified in each section.

Further design considerations have been made to ensure the following permits can be received from the Town of Hinton prior to construction. A description of these permits and regulatory requirements can be found in Section 3.7.

#### 3.3.2.1 Design Conditions

The entire DEC and distribution network will be designed to facilitate flow of a heated fluid throughout the Town of Hinton. Temperature, Flow and Pressure are the main design factors for equipment and pipeline selection.

**Table 23 - Design Conditions of Fluid**

| | |
|---|---|
| Fluid Type | Glycol Water Mixture, 30% Glycol with Corrosion Inhibitor |
| Temperature Range | 5°C Fill, 85°C Supply, 45°C Return |

Flow Rate was determined using load requirements in NETSIM (software that allows for the simulation of heat and mass transfer through the DES and assists in optimizing the piping network). More information can be found in Section 3.2.8.

Maximum Operating Pressures (MOP) were determined in Section 3.2.2, as pipeline materials were a key factor in determining MOP. This section provides rationale for pipeline material selection based on the assumed flow rate, temperatures and pressure of the fluid in the system.

Per the Pre-FEED, an operating temperature of 85°C was selected for circulation through the system. It should be noted that most pipeline temperature ratings were higher than 85°C.

#### 3.3.2.2 Fluid Medium Selection

To prevent freezing during off times, a glycol-water mixture is recommended as the primary circulating fluid through the DES. Based on typical design criteria, which include: Effect on System Life-cycle Cost, Corrosivity, Leakage, Health Risks, Fire Risks, Environmental Risks, and Risks with Future Use, there are no major concerns with using propylene glycol [47]. With only leakage and pumping power requirements prompting minor concerns, this fluid is best suited for the DES. Some DE systems in the US (e.g. Klamath Falls, OR and Idaho Falls, ID) use potable water due to their systems' ability to continuously circulate fluid through their system with little to no downtime. In addition, the weather in Oregon and Idaho is relatively mild compared to the harsh Canadian winters of northern Alberta. Given Hinton's low temperatures during winter months, Epoch has elected to proceed with a glycol-water mixture to prevent freezing during off times.

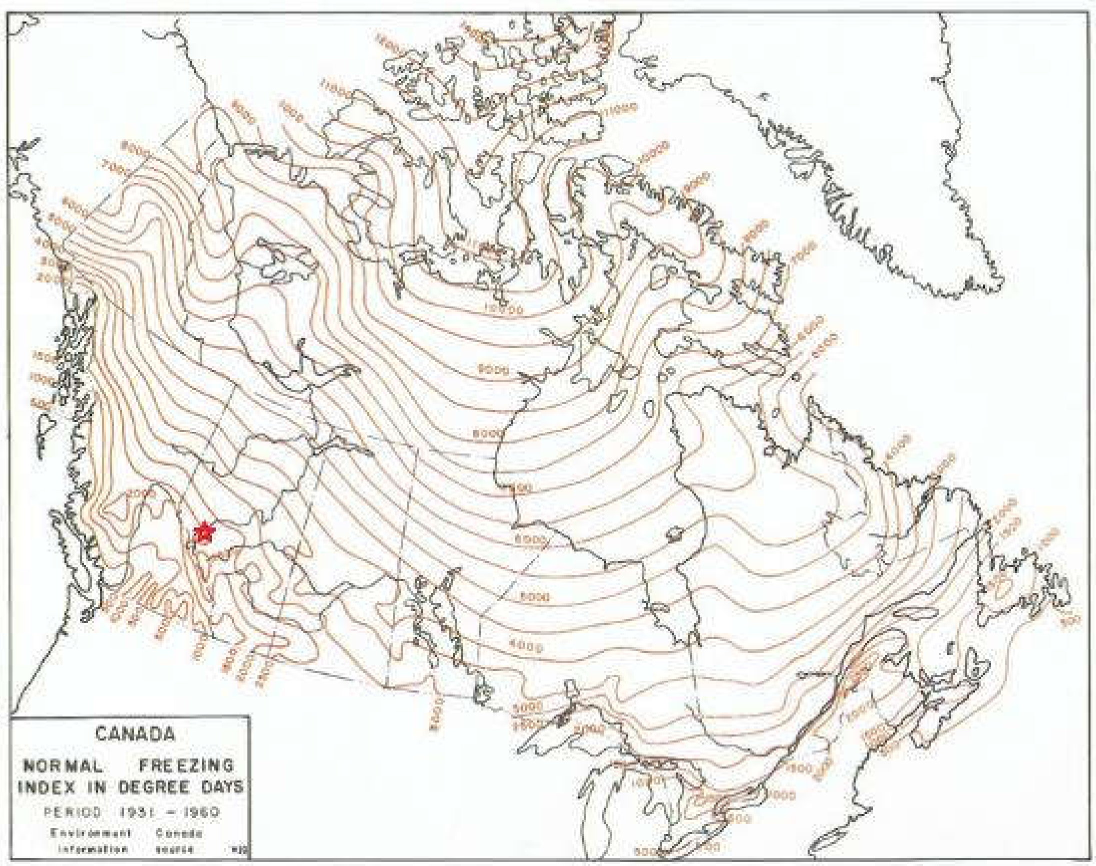



**Figure 55 - Canada, Normal Freezing Index in Degree [48]**

Using Environment Canada's Normal Freezing Index in Degree Days, it has been determined that Hinton, AB has an estimated frost depth of 1.98m. Per the Ontario Ministry of the Environment, the table below could be used to determine the approximate soil temperature at depth of cover. Using a conservative depth of cover of 1m (600mm is anticipated for the Hinton DES), the anticipated soil temperature could fall as low as -5°C.

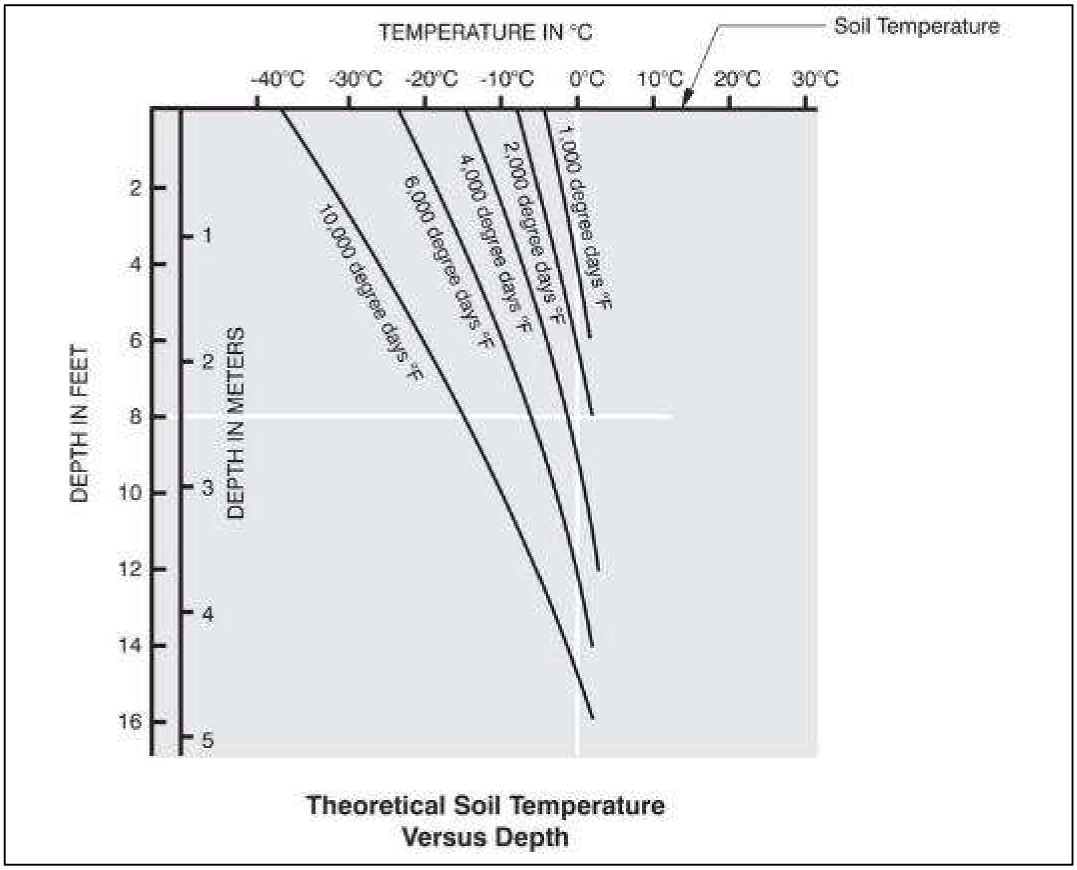



**Figure 56 - Theoretical soil temperature vs. depth (Ontario Ministry of the Environment) [48]**

Using the information above, Novamen, a glycol supplier, has provided a freezing point curve for their Novatherm Inhibited Propylene Glycol Water ratios (see Appendix D.10 for Novatherm's Safety Sheet). For this FEED study, a conservative ratio of 30/70 Glycol to Water mixture will be used. This provides a fluid that will freeze only under temperatures below -12.7°C.

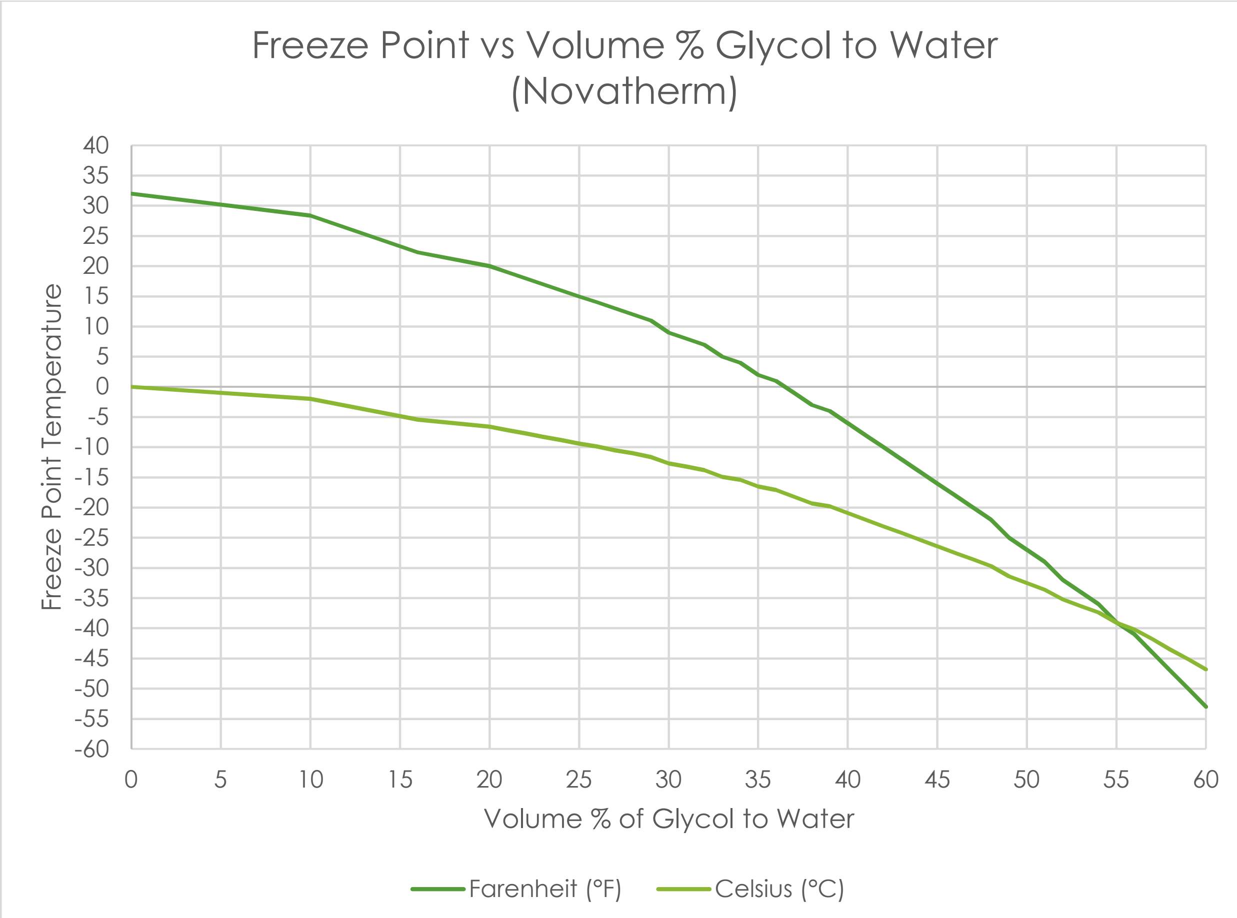



**Figure 57 - Freeze point vs. volume % glycol to water**

The DES has steel pipelines as part of their distribution system. As such, it is recommended that corrosion Inhibitor is added to the mixture to prevent corrosion and/or scaling with steel/reactive materials during operation. Corrosion inhibitors can be purchased separately as an additive or pre-mixed with the glycol-water mixture.

To avoid corrosion in the steel service pipeline, treated water must be used. Logstor's Design Manual recommends circulating fluid to comply with the following requirements:

**Table 24 - Recommended Circulating Fluid Quality Table (LOGSTOR) [31]**

| | |
|---|---|
| pH Value | 9.5-10 |
| Appearance | Clean and Mud-Free |
| Oil content | Oil-Free |
| Oxygen Content | < 0.02 mg/L |
| Salt Content | < 3000 mg/L |

3.3.2.3 Pumps

Per ASHRAE 2008 Handbook Chapter 12 and ASHRAE's District Heating Guide [49], the centrifugal pump is the most common pump type used in central hot water plants. They are known to handle high volumes of fluid flow, with pressures limited by the distribution system. Pumps are selected based on their performance curves, which are plotted by flow versus pressure. Efficiency, power and required net positive suction head ($NPSH_r$) curves often accompany these performance curves. Pumps for closed loop systems such as the Hinton DES should have flat pressure characteristics; this allows for flow rates to be adjusted with minimal effect on head pressure.


**Figure 58 - Griswold Centrifugal Pumps [50]**

The selected pumps will operate via variable frequency drive (VFD), an adjustable-speed drive used to control motor speed and torque by varying motor input frequency and voltage. The selected pumps will have operating curves that meet required flow rate and head pressures at middle operating frequencies. Selecting a pump that can speed up allows for future expansion without having to upgrade. A properly selected pump allows for some leeway to adjust to real-time pressure drops and flow rates across the system. The pump motors shall meet the required horsepower found in the performance curve of the pumps. In addition, they will be rated to meet all requirements dictated by the Canadian Electrical Code, including the classification of locations of electrical installations. However, further engineering design is required to determine fugitive emissions and hazardous area classification (HAC) of the building these motors will be installed in. Costs of the motors can be reduced if placed in a hazardous area where ignitable concentrations of flammable gases, vapours or liquids are not likely to exist under normal operating conditions.

Pumps have been selected based on min/max projected consumer loads, as well as pressure drops across each loop using NETSIM and hand calculations for pressure drop. The values can be found in the table below. More information on how these numbers were determined can be found in Section 3.2.5.1;

**Table 25 - Design Requirements for DEC Circulation Pumps**

| System | Design Conditions | | |
|---|---|---|---|
| | Suction Pressure / $NPSH_a$ (kPag) | Head (kPa) | Flow Rate |
| Distribution Loop (Complete) | 800 | 80 - 440 | 13.4 – 55.3 kg/s |
| Distribution Loop (Optimized) | 400 | 81 - 388 | 10.2 – 42.4 kg/s |
| Sidewalk Heating Loop | 400-800 | TBD | 7.8 mL/s/m$^2$ |
| Makeup System | TBD | 450-850 | TBD |

A primary circulation pump has been sized and selected for this DES. The distribution loop pump requires the ability to circulate fluids at temperatures up to 85°C. Pumps selected are VFD compatible and designed to meet requirements listed ASME B73.1. To provide redundancy in the system, a backup pump will be selected to facilitate flow for each loop.

Design requirements were determined through NETSIM Modeling Software. Details on how these numbers were determined can be found in Section 3.2.3.

Multiple vendors were contacted to determine budgetary costs and average costs. Most vendors provided similarly sized pumps with high temperature ratings well above the required 85°C. The centrifugal pumps presented had very similar pump curves and quoted prices to meet the design conditions in Table 25.

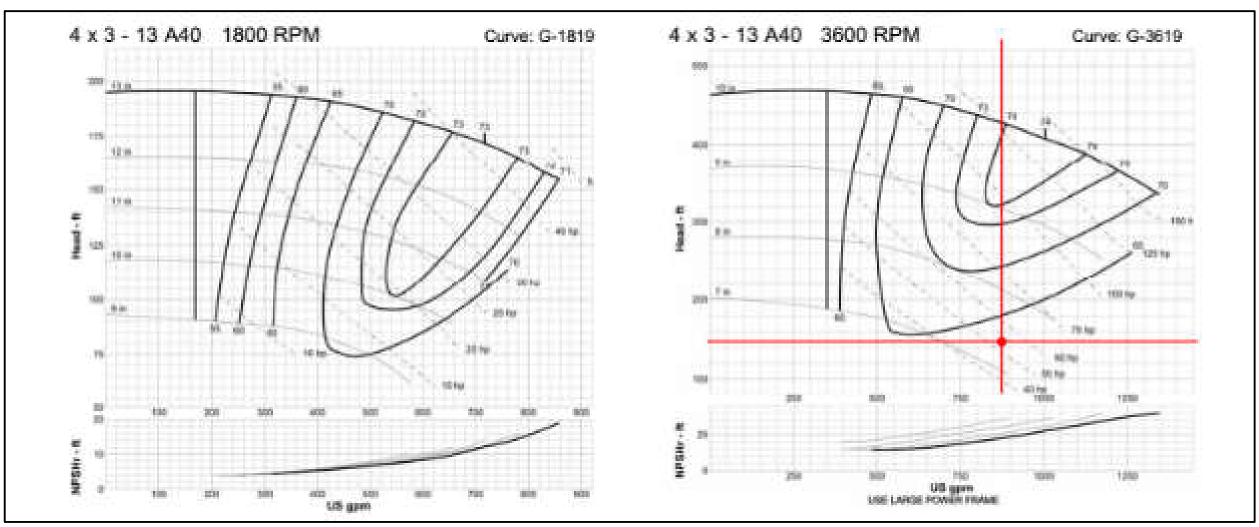



**Figure 59 - Example centrifugal pump curve [50]**

Example pump curves from Griswold can be found in Appendix D.11. To allow for potential future load expansion on pump operation, a larger motor with higher horsepower (HP) and higher speed will be selected. This gives the pump freedom to slow down or speed up, providing more flexibility in operation should the DES expand to more consumers.

The amount of Net Positive Suction Head available ($NPSH_a$) is the absolute pressure at the suction port of the pump. $NPSH_a$ is not an issue at this location for two reasons:

1. The system is a closed loop, and pressure is superimposed onto the system by the expansion tank which is installed near the suction of the pump.
2. The DEC is located at a lower elevation, so system pressure is anticipated to be relatively high.

Sidewalk Heating Loop

More details can be found in Section 3.2.9. Flow rate is dependant on the area of cover, and distance from the location/pipe diameter will affect head pressure. These numbers are to be determined. Suction pressure is the pressure at the fluid return line of the DES, which will be slightly higher than the suction pressure of the distribution loop pump.

Makeup System Pump

The makeup system pump is not as critical for operations in the DES. This pump is used to return fluid that has exited the system due to leaks or overpressure. It will be sized to overcome the pressure of the system to facilitate positive flow. Flow rate is not as important; low flow rates are acceptable, and since the pump is attached to a tank open to atmosphere, $NPSH_a$ shall vary due to tank level. This pump is currently designed to be manually operated.

##### *3.3.2.3.1 Controls*

The controls for the distribution system pump will monitor the supply and return pressure and adjust based on a desired differential pressure set point. The pump will be VFD controlled and will speed up or slow down to meet the operating set point. On failure of the main circulation pump, the backup will automatically start up.

#### 3.3.2.4 Air Separator

There may be circumstances that cause air or other gases to develop within the distribution loop. Sources of air include: Makeup water containing normal amounts of dissolved air, air trapped in the system after the initial filling, diffusion, and air ingress caused by negative pressure. If air or other gases are not eliminated, bubbles may slow flow through equipment, which may cause corrosion, noise, reduced pumping efficiency, and loss of stability through the system. Air also acts as an insulator for heat transfer [51].

**Figure 60 - Example Air Separator (Rolairtrol) [52]**

Epoch is proposing to install an air separator and air elimination valve at the point of lowest solubility (i.e. point of lowest system pressure and highest fluid temperature). For relatively flat areas, this would typically be at the suction of the pump, where pressure is lowest due to friction losses within the closed loop. In addition, directly downstream of the heating sources (i.e. where fluid temperature is highest) would also be ideal for entrained gases to develop. Given that the location of the town heat exchanger building is at a relatively low elevation, eliminating air due to low pressure solubility is an issue for design. Therefore, it has been determined that installing the air separator between the heating sources and the pumps would be ideal, as equipment protection is the main objective. Any gases entrained in the fluid will likely bubble out due to higher temperatures, and the air separator will protect the pump from taking in gas. It is recommended that a smaller, in-line air separator is installed at the highest elevation points to ensure that any gases that are trapped can be released and will not flow through any downstream heat exchangers. It is also recommended that routinely checking these air separators be a part of the maintenance schedules to be established later.

Air separators are most effective at low flow velocities. As such, it is recommended that the piping of the air separator is larger than the piping upstream. For proper separator function, velocity through the separator should not exceed 0.03m/s and should allow for water turbulence. During start-up/commissioning, it would be recommended that the pumps are run at a much lower speed, to slow flow velocity and to remove any air bubbles prior to ramping up the motors to normal operating frequency.

The air separator is sized based on the loops' maximum flow rate and pressure. Multiple quotes have been received from vendors for air separators to be installed in both loops, with information pertaining to the vessels' rated flow, and pressure drop. Some air separators offered come with strainers in their vessels, which could save pumps from circulating particles that could damage their internals. This would also prevent any need for additional basket strainers to be installed in line.

### 3.3.2.5 Expansion Tanks

The expansion tanks are used for two primary functions:

1. To impose a pressure onto the system that ensures positive pressure on the suction of the pump (typically above $NPSH_r$) and prevents any cavitation as it is circulated through the distribution and upstream circulation loops.
2. To provide a space into which the non-compressible fluid can expand or contract in volume due to changes in temperature.

**Figure 61 - Expansion Tank Configuration - Klamath Falls, OR**

There are different types of expansion tanks; however, the most common type of expansion tank to be used for this application is the diaphragm tank. This has a flexible membrane installed within the vessel to ensure there is no direct interface between the fluid and the gases in the tank. The lack of interface between gas and circulating fluid results in a typically smaller vessel, as the fluid no longer absorbs the gases until it is saturated. In modern designs, a diaphragm expansion tank is much more common than open air / steel tanks.

Expansion tanks are sized using the following factors:

- Total volume in the pipeline system
- Temperature of water when system is filled

- Maximum operating temperature of water
- Minimum and Maximum Operating Pressures
- Fluid Expansion Factor
- Acceptance Factor

The total volume of the system can be calculated by summing the volumes of all pipe, vessels and equipment.

Temperature of the water at fill can range, but previous experience has found that conservative installation temperatures are around 5°C. This is typically under winter weather conditions. The max operating temperature is set to 85°C. Minimum and Maximum operating pressures are set to what is found at the inlet of the expansion tank. This is often found at the suction of the pump, as mentioned in Section 3.3.2.4 for the air separator.

The fluid expansion factor is determined using the fluid properties and temperature differential of the fluid from install to max operating. Acceptance factor is applied to the calculations to determine the maximum volume of fluid that can fill the expansion tank before the air within the tank increases to the maximum allowable system pressure. This maximum pressure is often set to 10% below the relief valve set pressure.

Included as part of the expansion tank is the thermal relief vent, to be used for protection, should the expansion tank and system overpressure. It should be noted that safety relief should be provided to protect all equipment when the expansion tank is isolated for air charging or other service. At a minimum, the ASME Boiler and Pressure Vessel Code requires a relief valve on each boiler, and that isolation valves are installed on the supply and return connections.

#### 3.3.2.6 Relief Tank/Make Up System

Upon system overpressure, fluid that relieves from the system will be redirected into a relief tank. This tank is not pressurized and will be open to atmosphere. This same tank will hold fluid that is used to provide make up fluid to the system. To save space and re-use a fluid that is not readily available (i.e. premixed glycol and corrosion inhibitor), the same fluid that exits the system will also be reinjected into the system. As such, it is recommended that the relief tank will be sized large enough to be used as a make-up tank as well. Typically, a hydronic system has a valve connection to the makeup system that consists of a service valve, backflow preventer and pressure gage. This system will have a manually operated pump capable of redistributing the fluid from the tank back into the system. Since the expansion tank is the reference pressure point in the system, the makeup point is typically located at or near the tank.

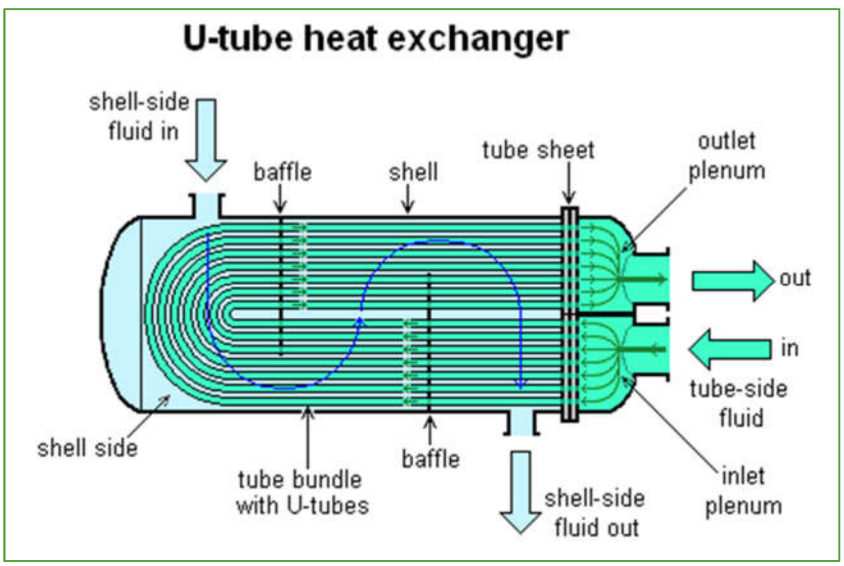
The pump has been sized to ensure that pressures can reach greater than what is specified in Table 25. This ensures that positive flow into the system happens. Flow rate is not as critical, as it is assumed that the fluids will be returned to the system in low volume intervals. Typically, fluid is lost due to pipeline leaks or any other atypical operating issues such as system overpressure or scheduled maintenance for larger equipment. Net Positive Suction Head (NPSH), or pressure found at the suction of the pump, will depend solely on tank level, as the relief tank is open to atmosphere. As such, during detailed engineering, level controls will be a factor in controlling this pump. $NPSH_a$ is expected to be relatively low, therefore should be considered during detailed engineering to avoid starving the pump.

It is recommended that the fluids in the makeup tanks are regularly monitored to avoid any scaling and oxygen corrosion in the system.

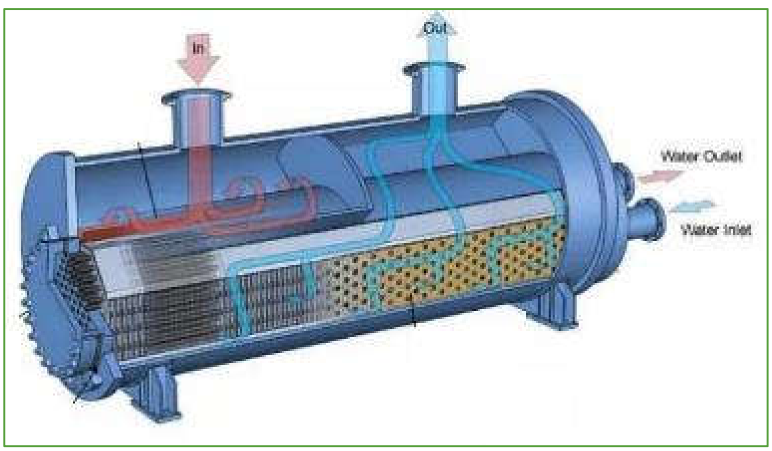
#### 3.3.2.7 Heat Exchangers

The geothermal DES relies heavily on its ability to service the consumers and to obtain heat from the well. As a utility provider that thrives on stability, this is especially important in large networks where it would be detrimental to have any shutdowns. Isolating sections of the DES also helps to distinguish clear lines of ownership and liability, separating the DES from the consumers HVAC system. Heat exchangers are vital in creating this separation in the system.

The most common heat exchanger types are shell and tube heat exchangers, plate heat exchangers and plate and shell heat exchangers. The shell and tube heat exchangers have a large shell full of fluid that houses an array of small tubes in the fluid bath. The fluid in the shell is circulated around the immersed tubes, while another fluid is circulated through the tubes to facilitate heat transfer. The plate heat exchangers stack metal plates together to create thin flow channels between each plate. The contact between both fluids occurs between the plates, similar to the tubes in the shell and tube heat exchanger. The difference between the two designs is that the plate heat exchanger alternates the flow channels between the hot and cold fluids, maximizing heat transfer. Plate and shell heat exchangers are a hybrid of the two mentioned, with metal plates replacing the tubes of the shell and tube design.

a)


b)




c)

**Figure 62 - Heat Exchanger Types: a) Shell and Tube [53], b) Plate (Klamath Falls DEC) c) Plate and Shell [54]**

In consideration for the DES design, the following factors regarding the heat exchanger were found to be critical:

- Reliability
- Maintenance
- Cost
- Size
- Customization

Although all the heat exchanger types mentioned above have comparable reliability, ultimately, the plate heat exchanger was chosen for the DES. The plate heat exchanger is commonly used in other DES' for the reasons described below.

Firstly, unlike the shell and tube heat exchanger, the foot print of a plate heat exchanger is smaller, which simplifies design and configurations for installation. This allows the heat exchanger to be placed relatively discreetly, facilitating a more compact design for the system. As well, the plate heat exchanger's capacity can be easily modified by simply adding or removing metal plates. This simplifies the design of a standard heat exchanger package, where having a slightly oversized heat exchanger will save money and time on installation. The idea of having an oversized heat exchanger allows for a larger range for heating exchange. Meaning, if a building needed 10kW while another needed 30kW, both could have the standard unit installed and just the number of plates installed in it would be different. This makes installation and design easier because the number of plates is the only factor that needs changing.

Following further conversations with multiple heat exchanger manufacturers, it was discovered that a wide range of heat exchangers from 0.1 to 30 MMBTU/hr are readily available. The cost of the plate heat exchangers does not vary significantly at lower capacities.

Finally, in using a standard heat exchanger design, maintenance and refurbishment is simplified. The standardized design minimizes downtime for maintenance as it would be relatively easy to swap out entire heat exchangers or perform minor repairs to the heat exchanger by replacing metal plates. This is doubly important since system stability is a key factor in the DES' success.

#### 3.3.2.8 Basket Strainers

Basket Strainers are used sparingly throughout the system as they are known to cause pressure drop and reduce the efficiency of the circulation pumps. However, to protect the pumps, basket strainers will be installed upstream of the suction to prevent debris from entering the pump internals and potentially damaging the pump. Per vendor pump requirements, a 1/8" perforation is typically recommended for the strainer. The basket strainer is otherwise sized for maximum flow rate and pressure, while minimizing pressure drop across the vessel.

#### 3.3.2.9 Heat Meters

Heat meters are typically installed at each consumer, and the distribution and sidewalk heating loops. A heat meter is typically installed with a multivariable transmitter capable of recording flow, temperature and fluid characteristics. Heat measurements are calculated using flow rate, differential temperature and thermal coefficient of expansion of the fluid. Each meter will be used to track flow and energy transferred throughout the system. For economic purposes, the heat meters at each building/consumer will record the total amount of heat taken from the system, while the heat meters in the DEC will record heat transfer for monitoring purposes.

Since total flow of the system is constant at the inlet and outlet of the DEC building, the flow meter will serve another purpose by being installed downstream of the circulation pumps. This flow meter will be used as an added precaution to ensure that the pumps are operating normally. Temperature transmitters will be installed on the supply and return lines to record differential temperature for heat measurement.

### 3.3.2.10 Pipe Valves and Fittings

For the DEC, major piping will facilitate flow from the geothermal heat exchanger, to the boilers and then to the pumps to be distributed. In that loop the fluid can undergo significant temperature and pressure changes. Attention to the design of an efficient and maintainable piping configuration is important. A well-designed piping configuration increases efficiency and reduces maintenance and operating costs. Due to the significant temperature change experienced by the fluid, piping design must include considerations to thermal expansion. Most of the piping used in the DEC will be pre-insulated steel. Steel piping expands with an increase in temperature. Therefore, the change in both length and circumference must be compensated. As such, throughout the piping design, the use of expansion joints or expansion loops must be implemented to mitigate stresses caused by thermal expansion.

Piping to the pumps shall be independently supported, adding no load to the pump flanges. In addition, flexible couplings can be used to further reduce the stresses that may misalign the pump.

The pressure anticipated in the DEC is below 150 ANSI rating, allowing the DEC design to follow 150 ANSI piping spec. Pipe, valves and fittings shall be designed to this pressure requirement, with additional design considerations made to corrosion prevention. Since these materials are above ground, and the fluid is treated with corrosion inhibitor, concerns for corrosion aren't as high compared to steel piping installed underground.

### 3.3.2.11 Buildings and Structural

The DEC building will use conventional structural steel for the main building. For budgetary purposes, two vendors were contacted to determine costs.

Building size has been determined by obtaining equipment sizes and placing them as part of a high-level general arrangement, seen below in Figure 63. Piping considerations shall be made to accommodate piping expansion loops, bends and expansion joints installed to mitigate thermal expansion. In general, some steps were taken for architectural treatment, as recommended by the ASHRAE District Heating Guide [55]:

- Equipment room size should provide adequate space between items. A minimum aisle space of 1.2m is recommended.
- Minimum clearance of 2.4m between boilers.
- Considerations should be made for future expansion.
- Construction should allow for equipment removal, and double doors and steel supports for chain hoists.
- Provide openings that accommodate equipment of all sizes.

Furnish the building with necessary facilities, storage area, small repair area, control room, and office space. Parking spaces to be handled later.

A general arrangement drawing was created to give an idea of spacing requirements:

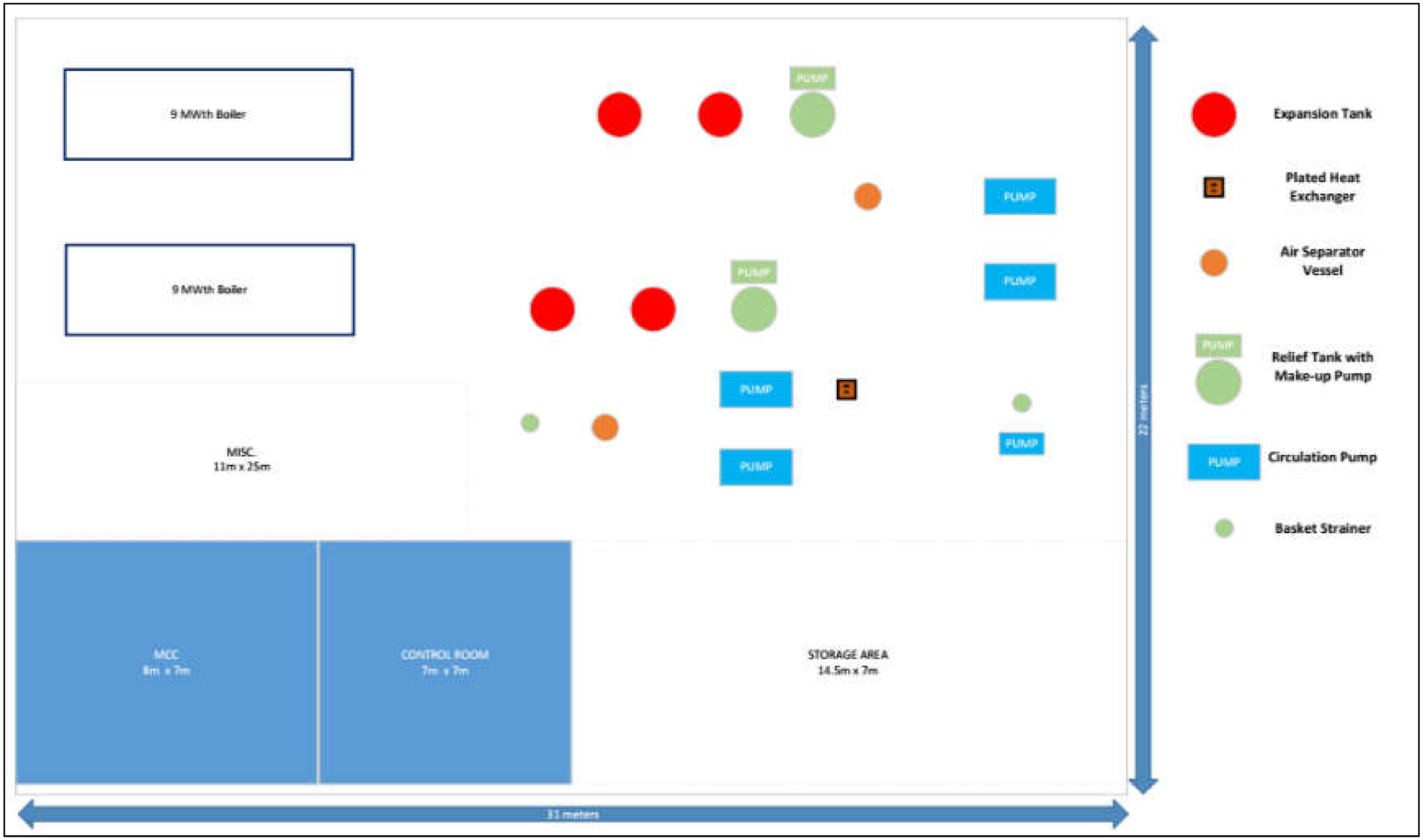



**Figure 63 - Proposed general arrangement of the District Energy Centre (Appendix D.12)**

See Appendix D.12 for the General Arrangement Drawing. This building size is subject to change; however, for budgetary purposes this drawing was used to determine initial building dimensions. Per the layout drawing, budgetary quotes for a building that is 35m x 25m was pursued.

Further design considerations must be made on structural loading (the effect of weight and movement on the building and its supports), in order to ensure that the structure is capable of holding all of the equipment without collapsing. Live (any load that can be moved) and dead (permanent loads like installed equipment) loads should be carefully reviewed, and the structural steel and floor must be engineered to fully support the loads. In addition to the live and dead loads such as basement and operating floors and office/laboratory/shop floors, other loads include (but are not limited to):

- Piping Loads
- Wind Loads
- Seismic Loads
- Equipment Loads
- Snow Loads

This engineering review will be completed in detailed engineering design, once equipment has been selected and designs have been finalized.

#### 3.3.2.12 Control Valves

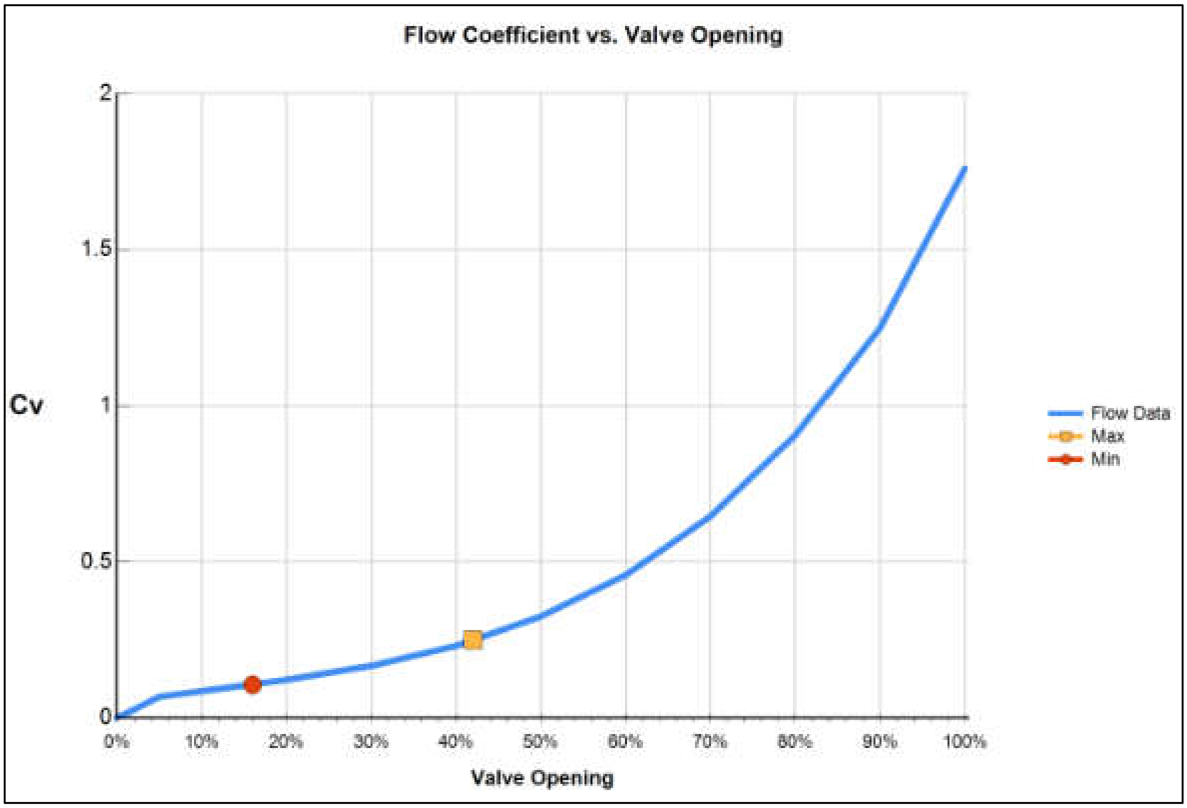
Temperature Control Valves (TCVs) will be installed downstream of the heat exchanger for each consumer. Per ASHRAE, these control valves will be sized so the pressure drop at full-open should be between 10% to 30% of the static pressure drop of the distribution system [51]. This pressure drop will give the control valve authority to control the flow of the heated distribution fluid entering the heat exchanger. In hot-water systems, the valves are normally installed on the downstream side of the heat exchanger, as the lower temperatures reduce risk of cavitation and increase valve life. Material considerations will be made to the valve plug and seat construction, packing and body. These valves are commonly equal percentage valves.

Budgetary quotes have returned a 2" valve that fits most of the design conditions provided when the earlier models were created. A spreadsheet detailing the flow rate and pressure drop requirements can be found in the Appendix D.13. These 2" valves meet the temperature, pressure and flow rate requirements listed, with flow rate and pressure drop dictating trim size. The material characteristics of the control valve are as follows:


**Figure 64 - Fisher Electrically Actuated Valve - Easy-Drive [56]**

Fisher D4E Control Valve with Easy-Drive

- 2" 150 RF LCC Steel Body
- 1" Micro-Form (Equal Percentage) 416 SST Plug & Seat
- Live Loaded PTFE Packing
- D4E easy-Drive Actuator Positioning, Fail Close On Signal Loss
- Operating Range: 12 or 24 VDC
- Maximum differential 814 psi
- Face to Face: 10.00" LCC Steel Body valve with Microform Stainless Steel Plug and Seat



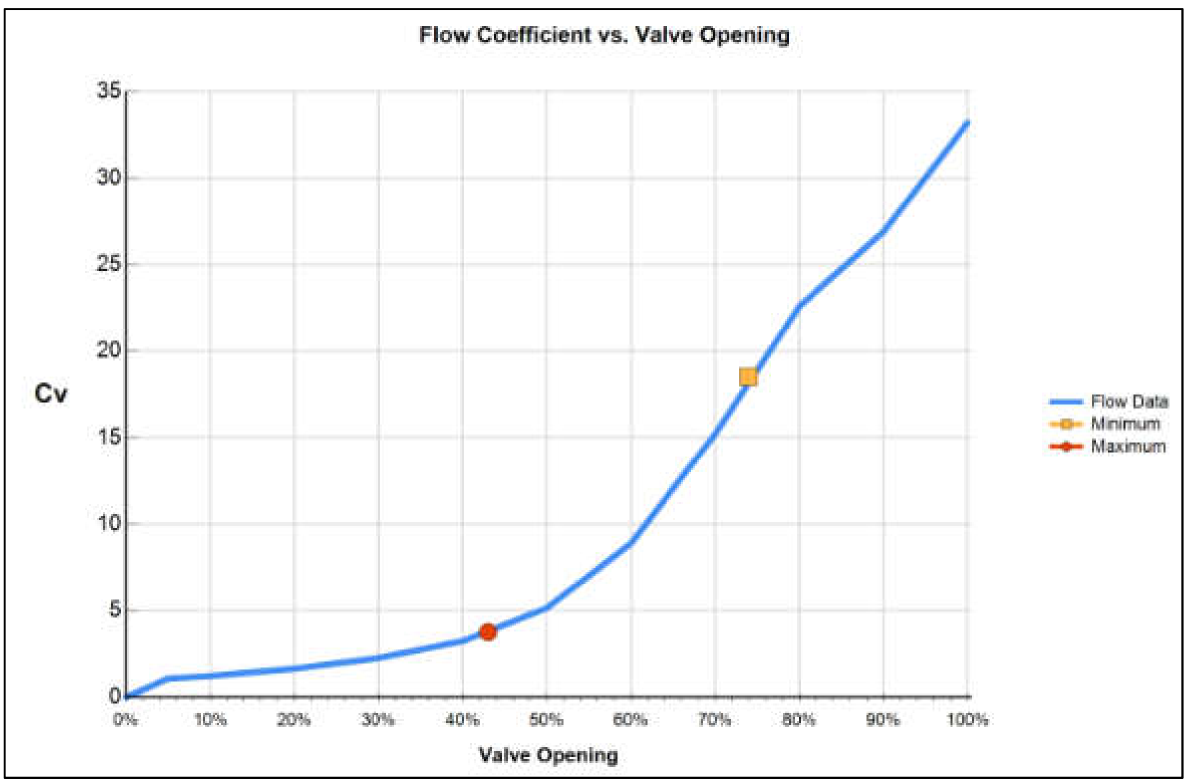




**Figure 65 - Fisher TCV Sizing Results - Minimum (top) vs. Maximum (bottom) design conditions (Appendix D.13)**

This valve is electrically actuated. Pneumatically actuated valves are found to be less expensive; however, given that there are no pressured air sources at these locations, the valves will require power to operate.

All control valve actuators should take longer than 60 seconds to close to mitigate pressure transients or water hammer. They should also be designed to close against the system pressure, so the seat of the valve cannot be forced open. Typically, only one valve is required to regulate the anticipated flow rate and pressure of the branch (at the consumer building). Industrial quality valves are typically specified for this application.

These TCV's will be controlled using either proportional with integral (PI) or proportional with integral and derivative (PID) control algorithms, as they are known to be the most common in HVAC systems [51]. If the temperature controller senses that the supply temperature of the building requires more heat, the control valve will open to facilitate more flow and vice versa. Having either integral or integral and derivative control provides a more stable system of control than the simpler proportional control system. As mentioned above under pump control, opening or closing these valves will affect the pressure drop through the system. In doing so, the pump will speed up or slow down to meet the demand of each consumer.

Another TCV will be installed as part of a bypass loop at the DEC. The valve will open when temperature increases past the set point downstream of the boiler. This allows for recirculation through the system, preventing fluid at temperatures higher than the set point from being distributed through the distribution loop. The size of this TCV is expected to be much larger, as it will be facilitating flow for the entire distribution loop. Costs have been estimated proportionally and can be found in the cost estimate. As mentioned above, an electrically actuated valve has been selected; however, future considerations will be made to include an air compressor to allow for pneumatic controls within the DEC, if economically feasible.

A TCV will be installed as part of a bypass loop at the DEC. The valve will open when temperature increases past the set point downstream of the boiler. This allows for recirculation through the system, preventing fluid at temperatures higher than the set point from being distributed through the distribution loop. The size of this TCV is expected to be relatively large, as it will be facilitating flow for the entire distribution loop. Costs have been estimated proportionally and can be found in the cost estimate. This valve is electrically actuated. Pneumatically actuated valves are found to be less expensive; however, given that there are no plans to install a pneumatic system in the DEC, the TCV will require power to operate. Future considerations will be made to include an air compressor to allow for pneumatic controls within the DEC, if economically feasible.

All control valve actuators in the DES should take longer than 60 seconds to close to mitigate pressure transients or water hammer. They should also be designed to close against the system pressure, so the seat of the valve cannot be forced open. Industrial quality valves are typically specified for this application.

The TCV will be controlled using either proportional with integral (PI) or proportional with integral and derivative (PID) control algorithms, as they are known to be the most common in HVAC systems [57]. Having either integral or integral and derivative control provides a more stable system of control than the simpler proportional control system.

3.3.2.13 Natural Gas / Propane Boiler

As mentioned in Section 3.1, the DEC and distribution network will be designed to be heat agnostic. However, the gas boiler is considered an exception, and its utility depends on the primary heating source of the DES.

If the DES requires peak heating to meet consumer demand, a gas boiler will be used as a supplemental heating source. If the primary heating source is only able to meet a fraction of the heating demand, the gas boiler will be designed to supplement the heating source by running continuously. This design condition will ultimately affect the type of fuel used to power the boilers.

For occasional peak heating, propane can be stored independently in a propane bullet. The DEC will become independent of any utility gas providers, however, additional facility equipment such as the propane bullet, associated controls, structural, etc. need to be engineered and procured. In addition, scheduling and purchasing must be done to ensure that the propane supply is uninterrupted. While natural gas is an option for fuel supply, it makes less sense to use a natural gas connection for intermittent peak heating. During the summer, the boiler may never be used, but the DES would still incur tie-in fees associated with being a gas utility customer.

If the primary heating source of the DES is consistently unable to meet consumer heating demand, then the boiler will be operating continuously to supplement the heat source. As such, it makes less economic sense to construct a propane bullet that is kept full by trucking in propane at a higher frequency. A natural gas connection maybe more economically feasible, however more calculations are required, and heating sources need to be established prior to choosing the fuel supply.

The gas boiler for the Hinton DES shall be designed to meet the full capacity of the DES and will have a turndown ratio to ensure that the heat output can be lowered to meet lower heating demands, should it be used primarily for peak heating. Two boilers total will be installed, one for redundancy/backup to ensure continuous operation. Controls will be established later to ensure that the transition between either boiler is automated to prevent any loss of service to the DES.

The boiler shall have the following design requirements, as determined by the NETSIM Model:

**Table 26 - Design Conditions for Hinton DES Water Boilers**

| | |
|---|---|
| Maximum Operating Pressure (kPag) | 1896 kPag |
| Mass Flow Rate (kg/s) | 55.3 |
| Heat Demand ($MW_{th}$) | 11.3 |
| Fluid Type | Glycol Water Mixture (30:70) |
| Emissions [58] | < 26 g/GJ / < 30 PPM<br>(For Boilers > 10.5 GJ/hr) |
| Miscellaneous | CRN - Alberta |

Boilers shall be constructed to meet the ASME Boiler and Pressure Vessel Code. The boiler to be constructed at the DEC is considered a high-pressure boiler due to the static head found at the DEC. Per the ASME Boiler and Pressure Vessel Code, a high-pressure water boiler will be designed to operate above 160 psig and/or 121°C. When installed, the boiler must be equipped at a minimum with operation and safety controls and pressure/temperature-relief devices mandated by the ASME Boiler and Pressure Vessel Code. All boilers must meet emissions requirements as established by the AEP. See Section 3.7.3 for more information.

Multiple vendors have been contacted for budgetary quote; the price range of three vendors fall between $350k and $700k CAD per unit. For the cost estimate, the median price was used. In addition to equipment costs, other economic considerations need to be made for the installation and operation of a boiler. It is relatively common that municipal codes require operating personnel on site when high-pressure boilers are in operation. In addition, introducing combustion equipment may increase property and liability insurance with the added risk of fire or accidents.

## 3.4 Instrumentation, Electrical and Controls (IEC) System

### 3.4.1 Instrumentation

The instrumentation that is expected at the District Energy Center includes the following types:

- Pressure transmitters – to measure and transmit process pressure signals to the control system; can be used to measure differential pressure (pressure drop) across filters and other similar equipment.
- Temperature transmitters – to measure and transmit process temperature signals to the control system.
- Pressure and temperature indicators (gauges) – to display pipeline pressures and temperatures, respectively.
- Heat meters – to measure and transmit heat energy signals to the control system.
- Temperature control valves – to control process flow rates to achieve a desired outlet temperature into the distribution network.

At this time, it is assumed that the temperature control valve located in the DEC is electrically actuated. Consideration should be given to pneumatic actuation to potentially save cost. Please refer to Figure 53. It is assumed that relief valves are included as part of the pipeline scope, since they do not require connection to the programmable logic controller (PLC) system.

It is assumed that pressure vessels are equipped with a level gauge/transmitter, pressure transmitter, and temperature transmitter. Tanks are assumed to be equipped with a level gauges/transmitter and temperature transmitter.

Except for gauges, the instrumentation listed above shall connect to a 24VDC PLC system and/or remote terminal units (RTUs).

The details of the instrumentation system are to be finalized during detailed design.

### 3.4.2 Electrical

Utility power will be provided by Fortis Alberta to both sites from an existing three-phase 25 kV power line (see Appendix D.14 for the list of loads provided to Fortis).

At the DEC, approximately 150 m of new 25 kV line will be installed by Fortis to a new 150-kVA pole-mounted transformer and meter to supply the site with three-phase low-voltage power. At this time, it has not been determined whether 480 VAC or 600 VAC is preferred for the site's low voltage system. Refer to the attached Fortis budgetary quotation in Appendix D.15 for details on anticipated tie-in. Note that this budgetary quote contains details pertaining to the initial DEC location, located at ISL's Water Treatment Plant. It has since moved to the Friendship Centre; however, the same process and quote are assumed.

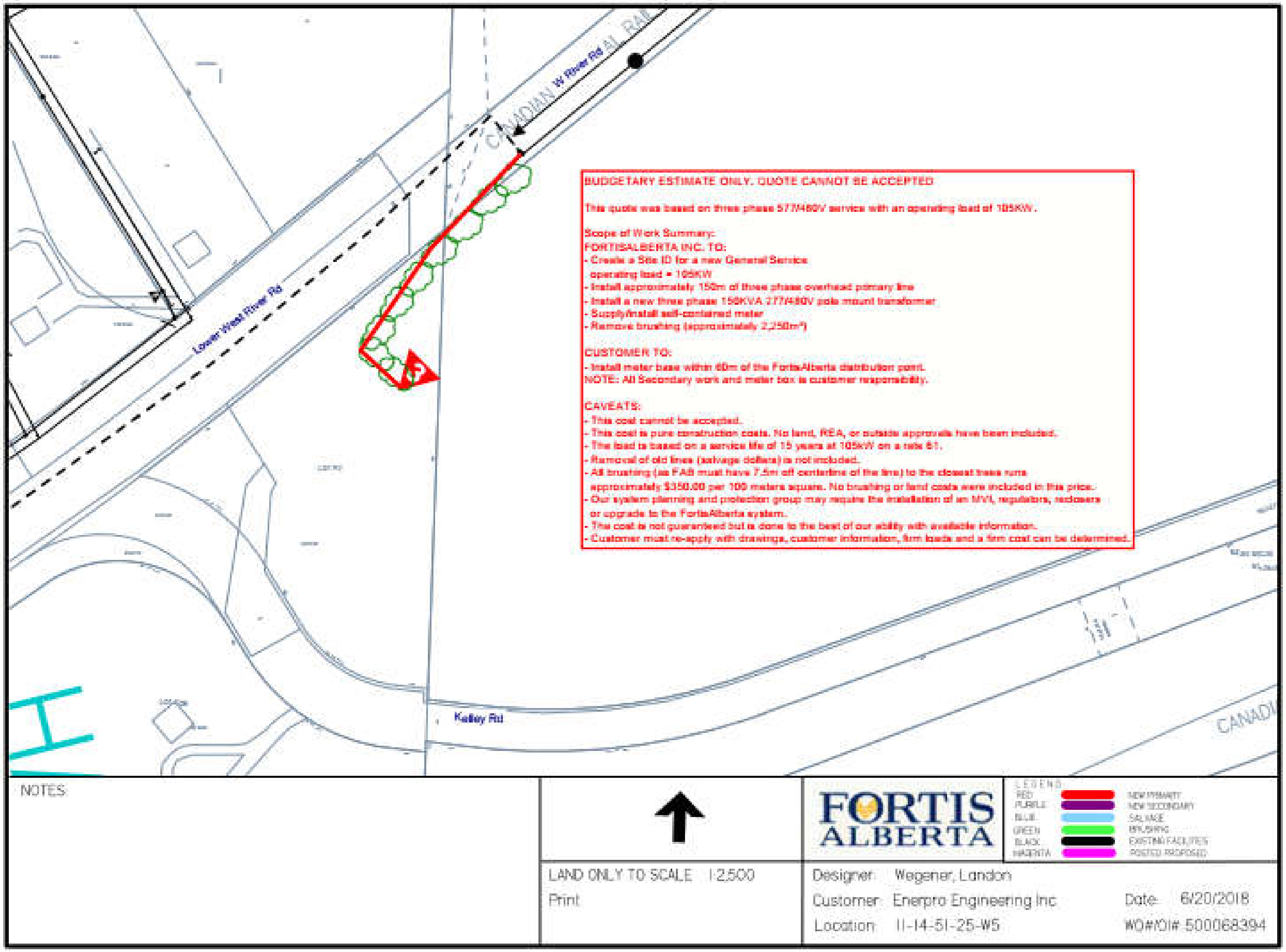



**Figure 66 - Budgetary estimate - proposed tie-in to Fortis lines at proposed ISL water treatment plant (Appendix D.15)**

Some clearing of brush will be required by Fortis.

The secondary side of the transformers will feed a separate low-voltage motor control center (MCC) at the DEC. The MCC will provide power to pump motors, blower motors, electric actuators (for control valves), and a transformer for general (240/120 VAC) lighting and power for the site. Loads that are 240/120 VAC are expected to include building HVAC, building lighting, yard lighting, and receptacles.

It is expected that pump motors and boiler blower motors will require variable frequency drives (VFDs) to allow for flexibility in operation. The drives can be integral to the MCC, or standalone. The drives will connect to the PLC control system to allow for feedback and control of motor frequency.

The 240/120 VAC system will, through a power supply located in the PLC control panel, provide 24 VDC power for instrumentation and the control system. Junction boxes for power and control may be required.

The details of the electrical system at the DEC are to be finalized during detailed design. Initial load lists were estimated and can be found in the tables below:

**Table 27 - Estimated District Energy Centre Load List**

| 480 VAC Loads | Quantity | Voltage | Phase | Expected Utilization | Expected kVA |
|---|---|---|---|---|---|
| 40 HP Upstream Circulation Pump* | 1 | 460 | 3 | 100% | 37.3 |
| 40 HP Upstream Circulation Pump* | 1 | 460 | 3 | 0% | 0.0 |
| 60 HP Downstream Circulation Pump | 1 | 460 | 3 | 100% | 56.0 |
| 60 HP Downstream Circulation Pump | 1 | 460 | 3 | 0% | 0.0 |
| 2 HP Makeup Pump | 1 | 460 | 3 | 5% | 0.1 |
| 2 HP Makeup Pump | 1 | 460 | 3 | 5% | 0.1 |
| 2 HP Sidewalk Pump | 1 | 460 | 3 | 100% | 1.9 |
| 2 HP Sidewalk Pump (backup) | 1 | 460 | 3 | 0% | 0.0 |
| 20 HP Boiler Blower | 1 | 460 | 3 | 50% | 9.3 |
| 20 HP Boiler Blower (backup) | 1 | 460 | 3 | 0% | 0.0 |
| TCV | 1 | 460 | 3 | 10% | 0.1 |
| 240/120 VAC Loads | | | | | |
| HVAC system | 1 | 230 | 1 | 100% | 4.0 |
| UPS (115VAC - 24VDC) | 1 | 115 | 1 | 100% | 2.9 |
| Building lighting | 3 | 115 | 1 | 75% | 3.2 |
| Yard lighting | 3 | 115 | 1 | 75% | 3.2 |

| | | | | | |
|---|---|---|---|---|---|
| Receptacles | 2 | 115 | 1 | 75% | 2.1 |
| 24 VDC Loads (From UPS) | | | | | |
| Instruments | 50 | 24 | 1 | | |
| PLC | 1 | 24 | 1 | | |
| Burner PLC | 1 | 24 | 1 | | |
| RTU/SCADA | 1 | 24 | 1 | | |
| Radios | 1 | 24 | 1 | | |

*Note: The Upstream Circulation Pumps for the Hinton DES are originally located inside the DEC and included as part of the initial design. For a fully heat agnostic Midstream System, the upstream circulation pump can be moved to another facility.

### 3.4.3 Control System

There will be a PLC control panel to which instruments connect. Intermediary remote terminal units (RTUs) and SCADA systems may be required, depending on the location of instruments. The PLC control may have a touchscreen keypad (human-machine interface or HMI). Data from the upstream pumping station will be communicated via SCADA to the DEC.

The PLC control panel will have as backup to utility power an uninterruptible power supply (UPS) to safeguard the control system against power outages and to allow for controlled shutdown. There is no provision for backup power generation at this time.

There may be a distributed control system (DCS) to view and control the entire district heating system on desktop computers. This may require additional SCADA (including radio communications) if the computers are to be located offsite.

The details of the control system are to be finalized during detailed design.

## 3.5 Downstream Tie-ins, Consumer Heat Exchanger Building

At each consumer, a heat exchanger will be installed to transfer energy from the DEC to the consumer's hydronic heating system. The consumer loads were estimated and can be found in Table 20. To tie-into each building, a general tie-in package was designed. Equipment sizes vary to accommodate the change in flow rate due to heat load requirements.

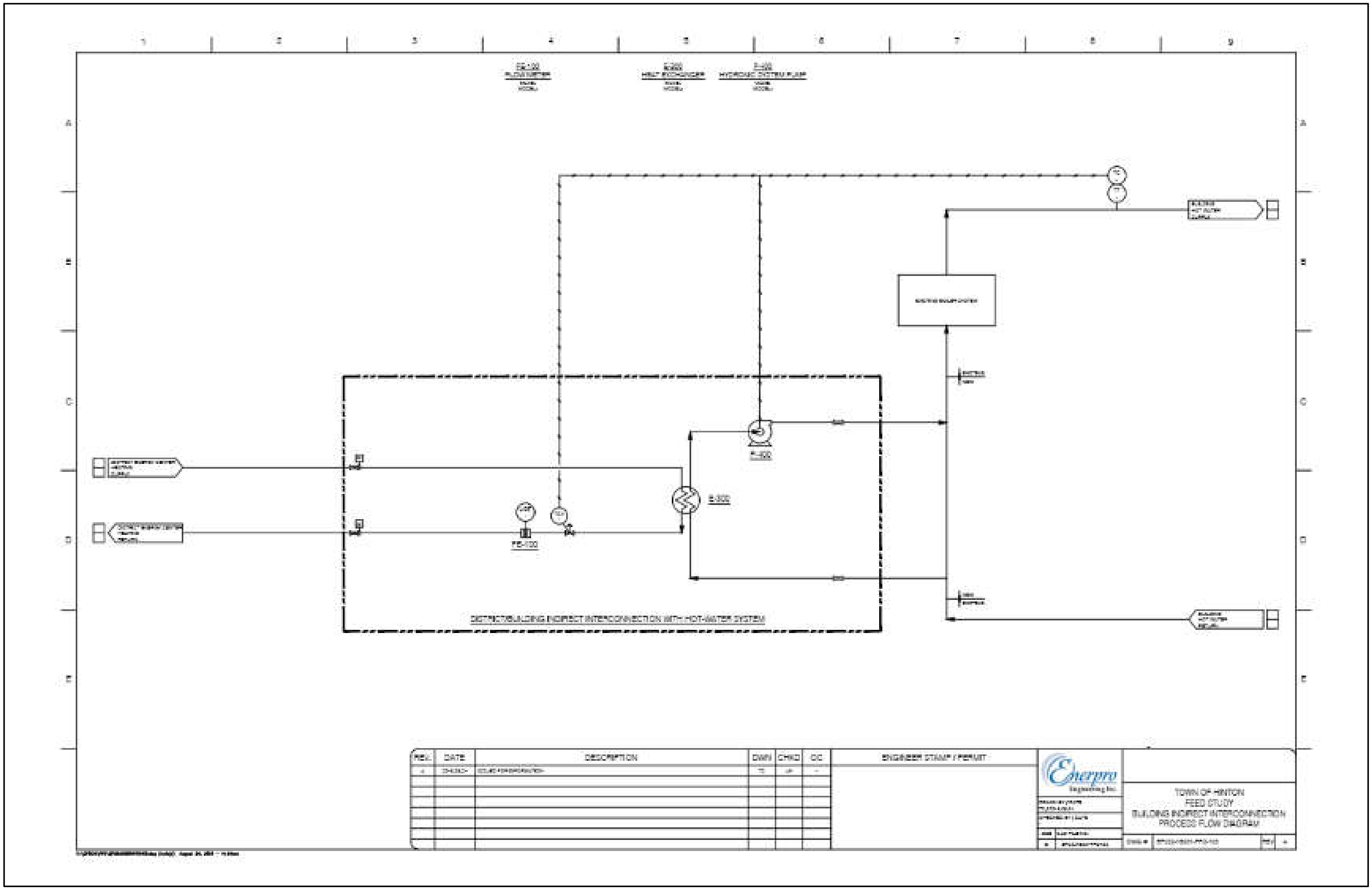



**Figure 67 - Process flow diagram - downstream interconnection (Appendix D.9)**

Please see Appendix D.9 for the PFD of the tie-in package. As shown in the diagram, the equipment to be included in this package are as follows:

- Heat Exchanger
- Building / Enclosure
- Temperature Control Valve
- Heat Meter
- Pipe, Valves and Fittings

For the tie-in, a general building tie-in method has been designed to fit for any of the buildings. For cost considerations, it was assumed that each of the 53 consumers (See Table 12; iteration 10) in the DES will be connected to the distribution network through a flat plate heat exchanger.

## 3.5.1 Equipment and Piping Design

### 3.5.1.1 Building / Enclosure

Building site visits will determine if the equipment listed above can fit inside the mechanical room of the targeted buildings. If no space is available, then a small building/enclosure will be purchased and installed exterior to the building. These aluminum, insulated enclosures must be large enough to house all equipment. A standard box was measured at 10 ft x 6 ft x 6 ft. The estimated size is subject to change, but nevertheless shall fit all equipment while maintaining a relatively small footprint near the consumer building. Materials and design emulate an enclosure used for the DES in Klamath Falls, Oregon.

**Figure 68 - Example enclosure at Klamath Falls, Oregon**

This enclosure shall fit on either a concrete pad or steel skid; at this time, the cost estimate had assumed it would rest on steel piles. Considerations to door size and location are made for the heat exchanger, as it is the largest equipment to be housed within this enclosure. Door size shall allow for the heat exchanger to be removed or maintained on site. Other equipment shall be accessible for maintenance.

#### 3.5.1.2 Heat Meter

As mentioned in Section 3.3.2.9, the flow rate, fluid type and temperature range were considered for sizing. The heat meter selected has been designed for heating and cooling applications using mixed fluids within a temperature range of -40°C to 140°C (see Appendix D.16 for heat meter data sheets). The heat meter to be installed in this enclosure operates with a pulsed flow sensor and a pair of two-wire temperature sensors. It can be fitted with a range of different communication modules. In this design, a Modbus communications system will be used. Modbus transmits signals over serial lines and is a protocol that was developed with industrial applications in mind. Costs and design considerations will require operators to visit each building to record the heat meter readings for analysis.

Temperature will be monitored at the inlet and outlet of the heat exchanger for heat calculations.

#### 3.5.1.3 Heat Exchanger

Preliminary sizing shows that the consumers have various demands for heating. These heat loads vary from 0.1 MMBTU/hr to 4.7 MMBTU/hr. For such a wide range of heat loads it will not be economical or practical to have customized heat exchangers for consumers. Factoring the low-cost differential between lower capacity units, consumers have been split into the following categories:

**Table 28 - Inventory and Cost Estimate for Consumer Heat Exchangers**

| Sizing Range (BTU/hr) | # Of Consumers | Cost Per Unit | Total Cost |
|---|---|---|---|
| < 500,000 | 10 | $3,000 | $30,000 |
| 500,000 > 1,000,000 | 18 | $3,500 | $63,000 |
| 1,000,000 > 2,000,000 | 18 | $4,000 | $72,000 |
| 2,000,000 > 2,500,000 | 4 | $4,500 | $18,000 |
| > 2,500,000 | 3 | $5,500 | $16,500 |
| CRN Certification | 53 | $1,000 | $53,000 |
| | Total Cost | | $252,500 |

The sizing intervals were established based on consumer frequency and to ensure that there are no outliers in the design that would require special attention. While it may increase the initial capital cost to install these packages, the maintenance of these units shall make up for these differences. For the cost estimate (Section 3.6.3), an average cost of $5000 per heat exchanger will be used.

#### 3.5.1.4 Pipe, Valves and Fittings

The piping within the enclosure will connect to risers where the DES network is capped off. Tie-ins will have isolation ball valves at the inlet and outlet of the enclosure. These valves shall be used to isolate the system during maintenance, operation, etc. At this time, there are no requirements for bypasses, since the equipment will not run independently. If equipment requires any maintenance or replacement, the entire package shall be isolated.

## 3.6 Cost Estimate

The cost estimate for this Midstream section was split into three parts:

1. District Energy Center
2. Pipeline Distribution Network
3. Downstream Tie-ins / Heat Exchanger Stations

Some sections have been updated with more accurate numbers than others, as quotes have been gathered and numbers were received earlier in the project. Estimates are completed based on construction experience with similar projects.

The cost estimate was updated once during the FEED phase of the project. The first iteration represented the costs associated with Iteration 5 described in Table 12. This iteration returned quotes and were re-used/adjusted to meet changes associated with the following iterations. The cost estimate was completed using the system prior to being optimized, this means the costs associated with the DEC and distribution network are for a DES that includes all 53 consumers.

Costs shown in the tables below are rounded to the nearest thousand. Engineering costs were added to the totals, and contingency / overhead costs were excluded.

### 3.6.1 District Energy Center

The cost estimate for the DEC includes costs associated with the installation of the pump and auxiliary equipment for the upstream circulation loop. Construction costs were estimated using experience from previous projects.

**Table 29 - Estimated Cost of the District Energy Center**

| | |
|---|---|
| Engineering | $450,000 (Est. 15%) |
| Materials | $1,750,000 |
| Construction | $400,000 |
| Total | $2,600,000 |

Some notable costs that are subject to change:

- Building / Skid

  - Full civil analysis is required on the building to ensure that the equipment housed on site are properly supported. Depending on the requirements that result from the analysis, a concrete pad is likely required for support.
  - The building size could be pared down; however, a larger building was selected as the facility is intended to be used as a learning facility for schools in the Hinton area. The larger size can accommodate groups of people to tour the facility without infringing on equipment and piping.
- Boilers
  - A decision is required for whether the boiler will consume natural gas or propane. If propane is to be used, then costs associated with storage (e.g. propane bullet) will need to be added to the cost estimate. Currently, it is assumed that natural gas will be used to fuel the boiler.
- Expansion Tanks
  - These tanks are currently sized to account for the full system volume. If the system is pared down and built in stages, these tanks can also be installed in stages. Currently, the tanks come in 4,000 gallon sizes, and the total volume expansion estimated for the system is 16,000 gallon (25% of total system volume). This means, tanks can be removed and added in increments for a more accurate cost estimate.

### 3.6.2 Pipeline Distribution Network

The construction cost for the distribution network was completed by Dunwald and Fleming Enterprises Ltd. Material costs were estimated using simulation numbers completed in NETSIM.

**Table 30 - Estimated Cost of the Pipeline Distribution Network**

| | |
|---|---|
| Engineering | $1,225,000 (Est. 15%) |
| Materials | $3,680,000 |
| Construction | $11,155,000 |
| Total | $16,060,000 |

Some cost considerations made for the pipeline:

- Pipeline Material
  - Kelit PEXR is used in place of all PEX piping. While PEX piping can be used at the extremities of the distribution network (where pressures are found to be <60 kPag), the transition from PEXR to PEX is difficult without first installing a PEX to steel transition fitting and a steel to PEXR transition fitting. As mentioned in the above sections, steel is to be avoided due to issues with corrosion and installation, hence the switch to PEXR to avoid the number of transitions. Further cost analysis is recommended to determine which method is the most cost-effective, since PEX piping has a cheaper per meter cost.
- Construction Costs
  - Dunwald and Fleming had reviewed two iterations of the DES (See Table 12: Iteration 5, then 6). The first iteration had located the DEC at ISL's proposed

water treatment plant. As mentioned in Section 3.2.11.6, Dunwald and Fleming determined that the transmission lines that run east towards Switzer Road and the CN rail crossings will be too costly to install.

  - The second iteration moved the DEC from the ISL Water Treatment Plant, to the Friendship Centre on Switzer Dr. Moving the DEC to the Friendship Centre decreases the amount of transmission line required and removes the need for any rail crossings. In addition, the trenches become less complicated, reducing overall construction costs.

## 3.6.3 Downstream Tie-ins

Table 31 below shows the budgetary cost estimate for the building tie-ins. Note the cost shown is the estimated cost per building and may vary depending on the size of the heat exchanger required and whether an equipment enclosure is needed. As such, an average cost was calculated by taking quotes for varying sizes and averaging them out for all 53 consumers. More information can be found in Section 3.5.1.3.

**Table 31 - Estimated Cost of a Downstream Tie-in**

| | |
|---|---|
| Engineering | $2,000 (Est. 5%) |
| Materials | |
| Aluminum Building / Enclosure | $16,800 |
| Heat Exchanger | $5,000 |
| Heat Meter | $2,880 |
| Pipe and Fittings | $200 |
| Ball Valves | $110 |
| Construction | $12,950 |
| Total | $40,000 / Tie-in |

The range of costs for building tie-ins are estimated at $18,000 to $40,500 (plus retrofit costs and electrical). Electrical costs have not been included in this estimate as they are building-dependant and are based on what kind of power is available. Some notable costs subject to change:

- Aluminum Building / Enclosure
  - The aluminum enclosure is installed on a site-to-site basis. Further review is required on the building mechanical room to determine if there is enough space to include the equipment listed in Table 31 inside the consumer building.
- Heat Exchangers
  - As mentioned above, the heat exchangers vary in size, and will therefore change on a site-to-site basis. Section 3.5.1.3 details the difference in cost.
- Building Tie-ins
  - Retro-fit costs will change significantly depending on consumer building set up. See Section 4.4.

## 3.7 Regulatory

There are a few scenarios that require regulatory approval for the Hinton District Energy Center and the Pipeline Distribution Network. Depending on the location of the DEC as well as the fluid properties within the system, certain regulatory boards will have jurisdiction of the design and construction of these components.

Preliminary review has determined that the following regulatory authorities may have jurisdiction over this project:

- Alberta Utilities Commission (AUC)
- Alberta Boiler's Safety Association (ABSA)
- Alberta Environment & Parks (AEP)
- Town of Hinton (Municipality)

The following sections present the reasoning behind their authority and how to proceed.

### 3.7.1 Alberta Utilities Commission (AUC) Jurisdiction

At this time, it has been determined that the AUC (Alberta Utilities Commission) does not play a role in licensing or permitting for this project. The AUC regulates Alberta's investor-owned electric, gas, water utilities and certain municipally-owned electric utilities. They also regulate the routes, tolls and tariffs of energy transmission through utility pipelines and electric transmission and distribution lines. Since the Hinton DES does not produce and/or distribute electricity, the AUC does not have jurisdiction.

### 3.7.2 Alberta Boiler Safety Association (ABSA) Jurisdiction

ABSA is the pressure equipment safety authority for Alberta. It administers Alberta's pressure equipment and safety programs under the Safety Codes Act and has the authority to enforce pressure equipment safety as set out in the legislation. ABSA pressure piping registration is required when a piping system will contain an expansible fluid at pressures in excess of 103 kPa and volumes greater than 0.5 $m^3$.

Per the Safety Codes Act – Pressure Equipment Safety Regulation [59], an expansible fluid is a vapour or gaseous fluid, or a liquid under pressure and at a temperature at which the liquid will change to gas or vapour when the pressure is reduced to atmospheric or the temperature increased to ambient temperature.

The Hinton Geothermal District Energy System is designed to have a maximum temperature of 90°C. The anticipated boiling point of the glycol-water mixture to be circulated through each facility is 104.4°C. At maximum design temperature, the working fluid will not change to vapour and is therefore not an expansible fluid, thus ABSA registration is not required.

However, the Hinton DES will still be designed to meet the requirements for ABSA registration should design requirements change and an expansible fluid is used in the system. ABSA Registration requires the following forms to be submitted:

- AB-31: Design Registration Application
- AB-31B: Design Registration Supplemental Sheet
- AB-96: General Engineering Requirements for Design and Construction of Pressure Piping Systems

These documents can be found for download on the ABSA website [60]. It should also be noted that ABSA registration requires the system be designed under ASME B31.1 - Power Piping. Regardless of whether the design falls under ABSA jurisdiction, the system will still meet the requirements for registration.

### 3.7.3 Alberta Environment and Parks (AEP) Jurisdiction

An Environmental Impact Assessment (EIA) is the first of four steps for a project to meet AEP regulatory requirements. Detailed information on the EIA procedure can be found in the AEP's Alberta's Environmental Assessment Process [61]. Not all projects require an EIA; there is a list of project types that either require or are exempt from completing an EIA. This list can be found in the Environmental Assessment (Mandatory and Exempted Activities) Regulation [62].

Geothermal wells and District Heating Systems are not found in the list of Mandatory and Exempted Activities outlined by the AEP [62]. Therefore, the Hinton Geothermal District Energy System is considered a "Discretionary Activity" and requires an Environmental Assessment Director to decide whether an EIA is required for this project.

A Preliminary Review document has been submitted to the AEP and Epoch is awaiting a response on whether an EIA is required for the Hinton DES, which includes the DEC and Distribution Network. If it is determined that an EIA report is required, the flow chart shown in Figure 69 is typically followed.

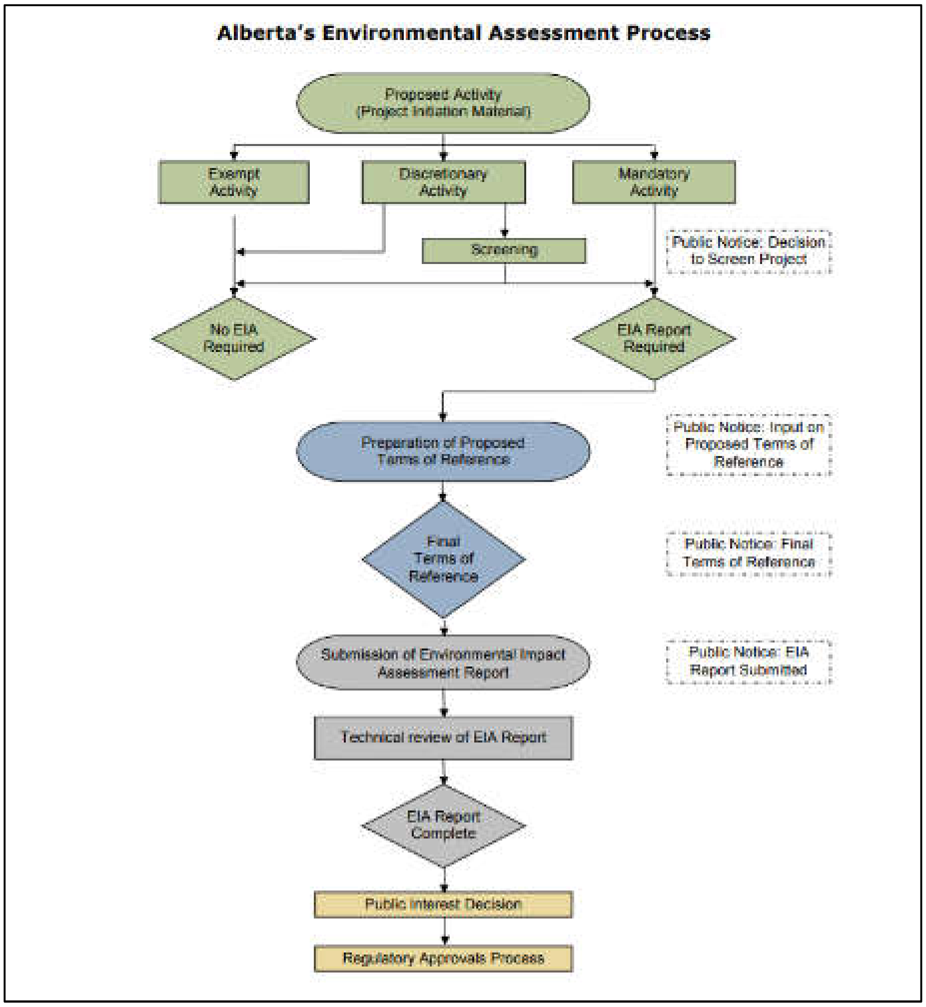



**Figure 69 - Alberta's Environmental Assessment Process Flow Diagram [61]**

When it is determined that an EIA is required, the preliminary Terms of Reference and a First Nations Consultation Plan are to be submitted. The First Nations Consultation Plan must be approved by the Consultation advisor before the Terms of Reference will be reviewed. The preliminary Terms of Reference will be reviewed by AEP as well as the public; the AEP will then issue comments and changes for the Terms of Reference which will finalize the scope for the EIA report.

Per the EIA guide, the report will contain the following sections:

1. A detailed project description.
2. A description of the location and environmental setting.
3. A baseline assessment of the environmental, social and cultural significance of the location.
4. A description of the potential positive and negative effects the project will have on the environment, health, society, the economy, and culture.
5. An emergency response plan and a plan to mitigate any adverse effects and, information on public and First Nations consultations.

Once the EIA is completed and submitted it will be reviewed for approval. The regulatory review of the EIA report is completed by either the AEP or the AER. Once the review is completed and all Terms of Reference have been satisfied, the EIA is submitted for further review by representatives of the public for approval. This is followed by formal approval of the project, as well as the assignment of specific conditions that must be met for construction and operation of the project. Finally, the compliance stage ensures the project is operating within the assigned approval conditions.

### 3.7.4 Town of Hinton – Municipality

Per preliminary discussions with the Town of Hinton, Hinton is a non-accredited municipality. This means that the town does not issue building, electrical, gas and plumbing permits. These permits will be received from accredited third parties, based outside of Hinton. For example, the Inspections Group, based out of Edmonton, Edson and Cold Lake commonly provides permits for developments within Hinton. Hinton does, however, issue development permits in accordance with Hinton's Land Use Bylaw 1088.

#### 3.7.4.1 Development Permits

Per Hinton Bylaw 1088, a development permit application shall be submitted for the DEC as it falls under Hinton's jurisdiction. As mentioned in Section 2.7, the Upstream Facility / Pump Station (if applicable) may fall within town limits and may also require a permit.

Please refer to the Bylaw document [63] for more information. There are specific regulations that are relevant to different types of development, also known as districts. According to the Land-use Bylaw Map, district boundaries have been established throughout the town. Further discussions are required on whether a development permit can be awarded to Epoch if the application of the DEC falls outside of the requirements of the proposed location's district.

As it stands, due to the proposed equipment and application of the DES, the DEC likely falls within the following districts:

- I-BUS: Business Industrial District
- I-ECO: Eco-Industrial District
- I-LHT: Light Industrial District
- I-HVY: Heavy Industrial District

The proposed DEC location at the Friendship Centre in located is the Community Services District (S-COM):

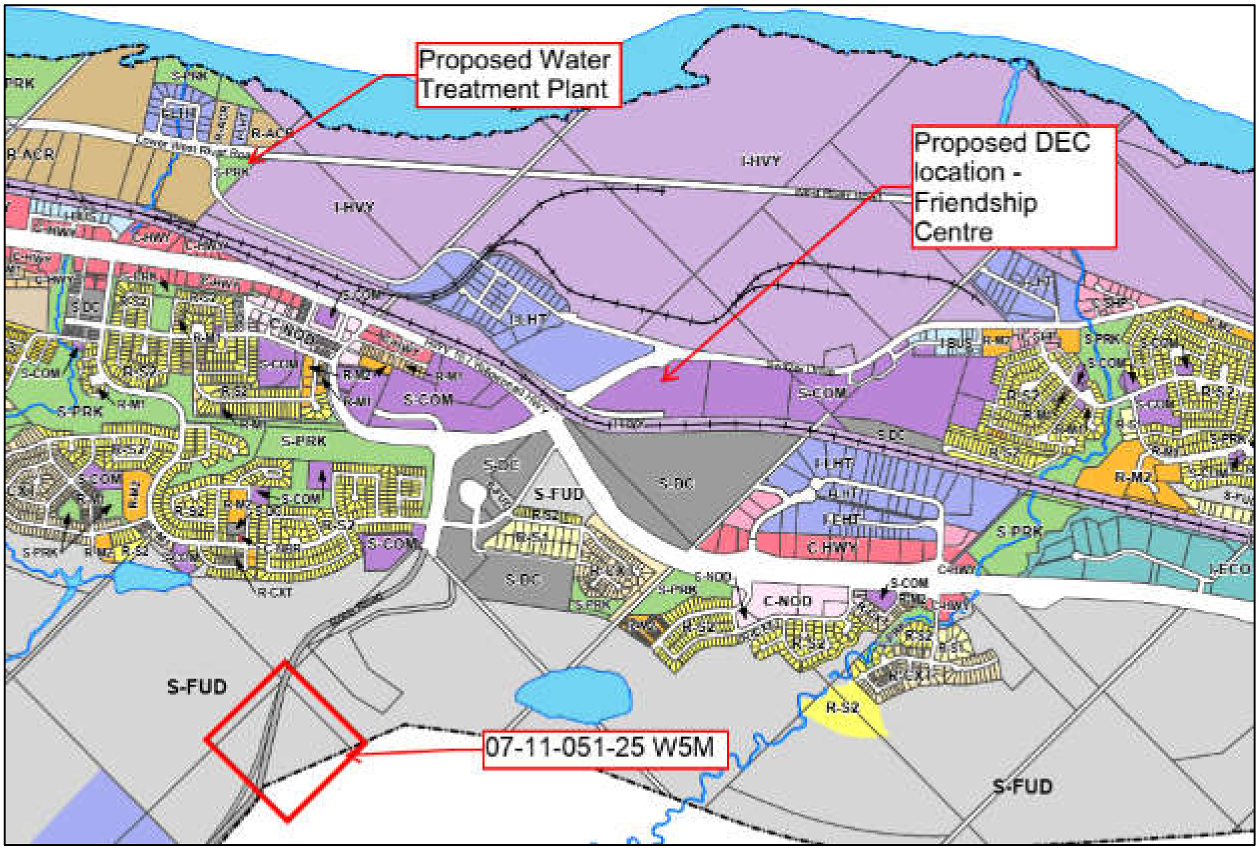



**Figure 70 - Potential Locations for the Hinton DEC - Land Use Bylaw Map [63]**

Please see Appendix D.17 for the Full Land Use district map, and a description for each district mentioned above.

The industrial, community services and future urban development districts permit the land to be developed for public utility. Per the Bylaw, the definition of public utility best matches the description of the DEC; however, it does not explicitly state it is meant for the use of distributing heated fluids:

**"PUBLIC UTILITY** – means a system or works used to provide services such as potable water, sewage disposal, public transportation operated by or on behalf of the Municipality, waste management or storm systems, as well as the Buildings that house the utility, and any offices or equipment;" [63]

It should also be noted that the industrial districts have more stringent requirements for setbacks, massing and coverings, and parcel dimensions. For example, the Heavy Industrial District has the following restrictions:

Minimum Parcel Dimensions: At the discretion of the Development Authority

Minimum Setback Requirements:

- Front Yard 6.0 m*
- Side Yard (Adjacent to Residential Use) 6.0 m
- Side Yard (Adjacent to Non-Residential Use) 0.0 m
- Side Yard (Corner Lot Adjacent to Public Roadway) 3.0 m

- Side Yard (vehicular access from the front public roadway only) 6.0 m
- Rear Yard 6.0 m

*The front yard setback shall not preclude the use of a portion of the front yard for walks, driveways or freestanding signs.

Massing & Coverage:

- Maximum Building Height 10.6 m
- Maximum Coverage 60%

It is recommended that further discussion is required between Epoch and the Town of Hinton to determine if any of the industrial restrictions would apply to the DEC being constructed in the S-COM district.

An amendment to the district borders and/or definition of Public Utility may be required.

In addition to the requirements detailed in Bylaw 1088, it has been determined that all facilities are required to meet the Hinton 2007 Minimum Engineering Design Standards.

#### 3.7.4.2 Building / Electrical / Gas / Plumbing Permits

Following discussions with a Safety Inspection Officer from the Inspections Group (Edmonton Office), receiving building, electrical, gas or plumbing permits is possible once the development permit is granted. In doing so, permit applications typically require the following:

- Stamped engineering drawings to be provided at time of application
    - Civil / Structural
        - Geotechnical Reports may be required for the building foundation
    - Architectural
        - To include Wattage / Energy Consumption and Building Insulation Calculations
    - Mechanical
    - Electrical
- Documentation demonstrating that this facility meets the National Energy Code of Canada for Buildings for energy consumption
- Calculations justifying the boiler/geothermal heat load for the DES.

Template permit applications can be found in Appendix D.18.

## 3.8 Cost Estimate Considerations – Minimum Project Requirements

As an additional exercise for this FEED project, Epoch reviewed possible cost reduction measures. The FEED report currently describes a fully automated DES at max capacity (i.e. adding all feasible consumers into the DES). The costs associated with the construction of the Complete DES can be pared down to meet the minimum requirements of the DES. While some sections of the DES cannot be reduced, there are some notable cost savings that should be considered. To proceed with the analysis, the following assumptions will be applied to the proposed system:

**Table 32 - Table of Assumptions to Determine Cost Savings of the Hinton DEC and Distribution Network**

| Assumption | Complete DES | Optimized DES |
|---|---|---|
| Number of Consumers | 53 consumers added to the DES, heat load of 11.3 $MW_{th}$. | DES has proceeded to the next iteration, where it has been optimized, effectively reducing the heating demand from 11.3 $MW_{th}$ to 7.14 $MW_{th}$ |
| Primary Heat Source Available | Gas Boiler assumed to run continuously to meet consumer heating demand. | Assumes primary heating source can meet full consumer demand. Gas boiler to be used as a back-up only. |
| District Energy Center Building | DEC to be used as a learning tool for educational tours. Space was designed for additional storage, control room and MCC. | DEC to be sized down to fit equipment and minimum spacing requirements. MCC and control room joined as a single space, no miscellaneous additional storage provided. |
| Electrical, Instrumentation, and Controls (EIC) | Full system automation, communication, and display; variable speed control for all motors; SCADA communication; remote monitoring and control of all facilities from a central DEC workstation | Minimized electrical and controls equipment; a basic and localized control system, on/off motor control; no SCADA communications between all facilities. |

Further engineering review is required to determine all effects of the assumptions above on the DEC and the distribution network (e.g. pipe diameter, fabrication/installation implications, some equipment re-sizing); however, the more obvious and direct effects applied to the midstream system are described below.

### 3.8.1 District Energy Centre

The majority of cost savings are found within the DEC.

**Table 33 - Estimated Cost Savings of Upstream Circulation Pipeline**

| | Complete DES | Optimized DES | Cost Difference |
|---|---|---|---|
| Engineering | \$785,000 (Est. 15%) | \$450,000 (Est. 15%) | \$335,000 |
| Materials | \$3,085,000 | \$1,750,000 | \$1,335,000 |
| Construction | \$795,000 | \$400,000 | \$395,000 |
| Total | \$4,665,000 | \$2,600,000 | \$2,005,000 |

With the assumption that the primary heat source can service the heating demands of the consumers, and if the system load will be reduced/optimized, the gas boilers' redundancy can be removed, and size can be reduced.

Less consumers also reduces the fluid volume in the DEC and the distribution network. This will decrease total thermal expansion, therefore reducing the size of the expansion tanks. Currently, the expansion tanks are configured as a set up of multiple tanks connected. If the volume is reduced, then reducing the expansion tank volume is a matter of removing a tank.

With an optimized system, pumps can be sized smaller, but will remain as originally designed to account for future expansion. Variable speed motor control was removed, in lieu of on/off motor control.

The DEC building can be reduced in size. The full system design currently accounts for using the centre as a learning space. This requires ample room for groups to tour the facility. Removing this design reduces the space to fit a combined MCC and Control Room, with minimum spacing requirements for equipment. All miscellaneous storage space was removed as well. An update of the building layout can be found below and in Appendix D.19.

SCADA communication was removed from the facility and associated control system was simplified to meet minimized requirements for control.

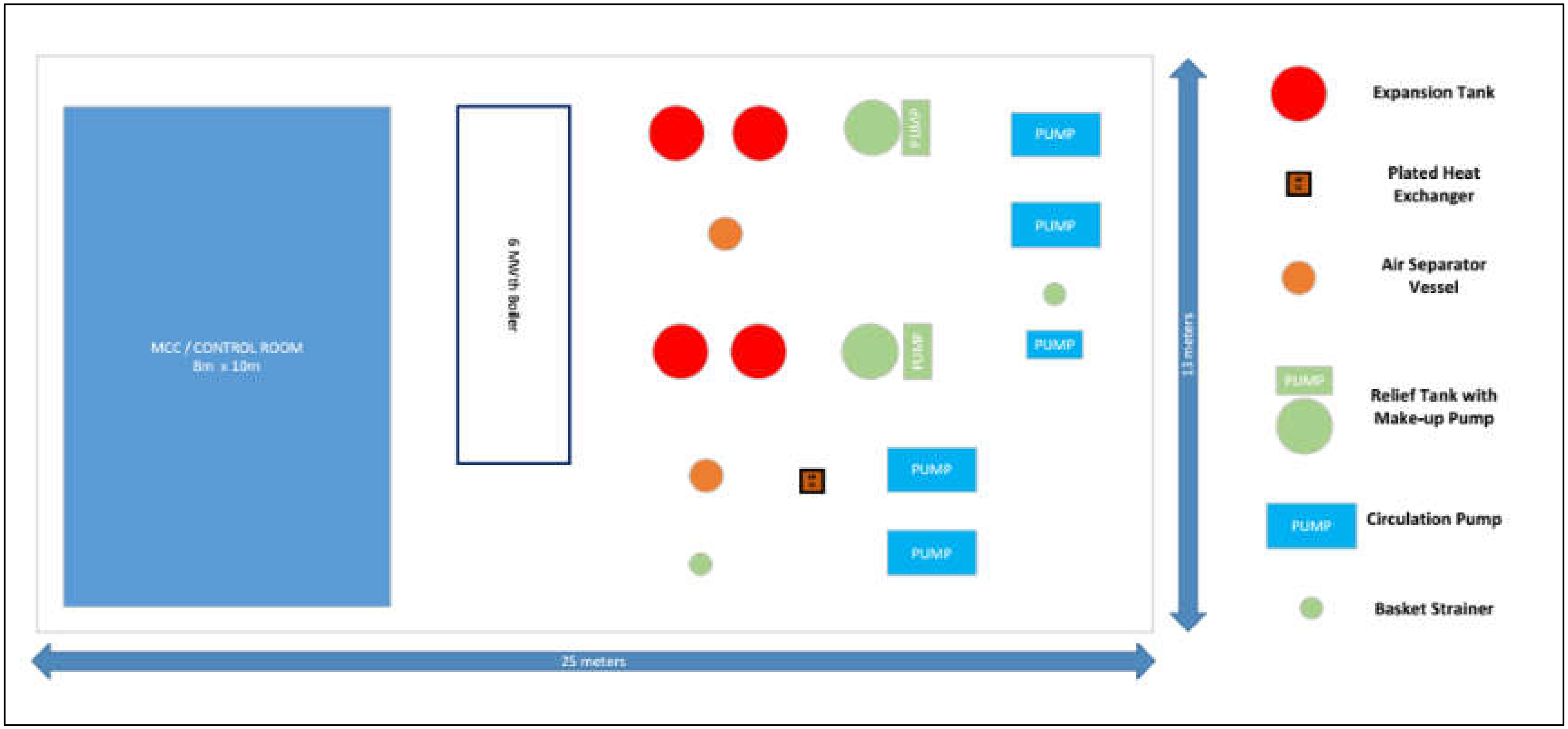



**Figure 71 - General Arrangement Drawing of The Hinton DEC (Minimized Design)**

### 3.8.2 Distribution Pipeline Network

Optimizing the system removes two zones of the distribution network. For information on which Zones were removed, refer to Section 3.2.4.2. Reducing these zones reduces the material and construction costs associated with these pipelines.

**Table 34 - Cost Estimate: Pipeline Distribution Network**

| | Complete DES | Optimized DES | Cost Difference |
|---|---|---|---|
| Engineering | $1,225,000 (Est. 15%) | $375,000 (Est. 15%) | $850,000 |
| Materials | $3,680,000 | $2,150,000 | $1,530,000 |
| Construction | $11,155,000 | $7,200,000 | $3,955,000 |
| Total | $16,060,000 | $9,725,000 | $6,335,000 |

### 3.8.3 Downstream Tie-ins

The downstream tie-ins are not affected by the assumptions listed above.

### 3.8.4 Summary

With minimizing the system to the optimal configuration, the total estimated savings can be as high as $8.3M. While this is a relatively high-level comparison, this is nevertheless a significant difference that should be considered. This analysis presents the idea that the system can be reduced in total cost while still meeting the minimum heat demand of the town. It should be noted that if the DES were to expand back to the full DES, then some material costs (e.g. pipeline, expansion tanks, etc.) will need to be added back.

The reduction in initial capital cost for the Hinton DES considers the assumptions listed above, but variable costs associated with power consumption, operations and maintenance may increase due to the simplified design. Compromise will be required to ensure that the system runs efficiently in both operation and costs.

# 4 Downstream: Building Interconnection

## 4.1 Summary

The Downstream section includes the components required to tie-in each building to the DES, including a heat exchanger, the internal piping and heat management systems. Figure 72 provides a general overview of the Downstream layout. To improve the economic viability of the DES, the scope of the FEED project was expanded to 53 buildings from the initial 12 buildings covered by the pre-FEED study. There are likely more facilities in the community that can benefit from the DES; these buildings were not included within the FEED project because of the lack of energy density at their location. Infrastructure planning that concentrated heat loads in those areas could make interconnection feasible at a later point in time. Considering this, conservative estimates suggest that the available commercial load proximal to the DES design could be around 368,000GJ per year.

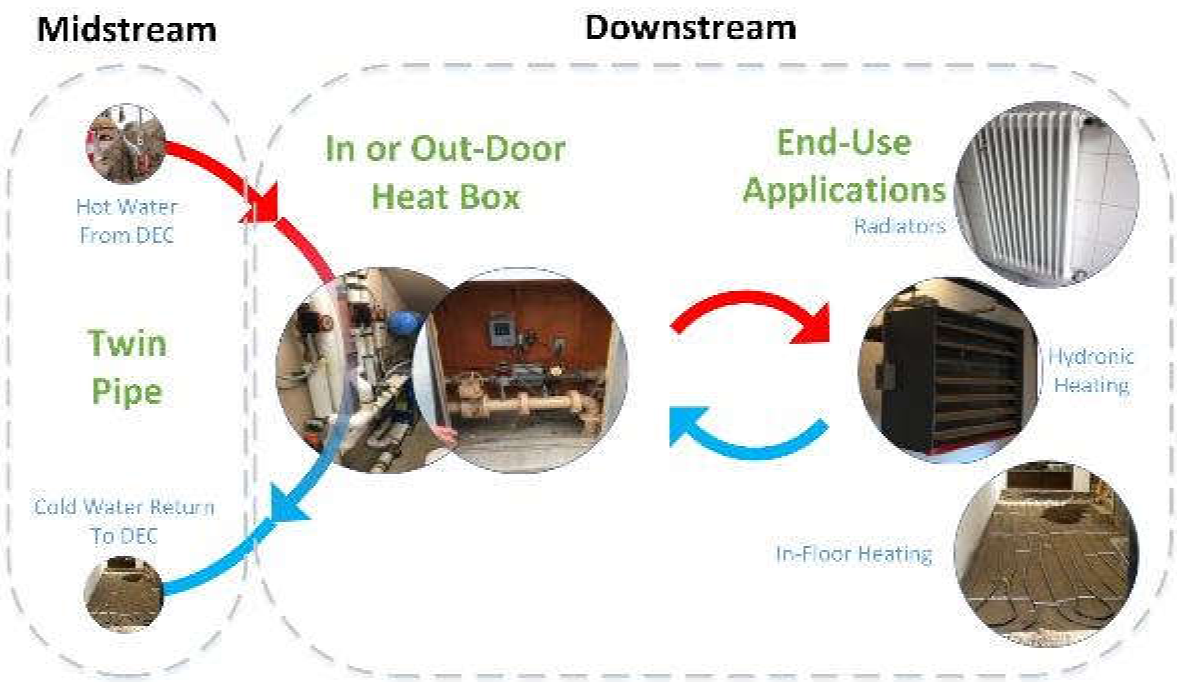



**Figure 72 - DES Downstream Overview**

There are three categories of downstream connections of the DES (from most economically feasible to least economically feasible):

1. Buildings with existing hydronic (boiler) systems.
2. Buildings without existing hydronic systems, such as electric or forced air. These systems would require heating system retrofits.
3. Other applications such as domestic hot water heating, snow melting systems, agricultural/industrial processes, etc.

In Hinton, the buildings considered as part of the DES were condos, hotels, schools, recreation centres and other municipal buildings. The project team was able to gain access to 16 of the buildings to assess the heating system, and 8 of these provided utility bills to estimate their energy consumption. For the remaining buildings that did not provide this information, an average consumption was estimated and applied using each building's area footprint to calculate the heat load. These estimates are not as accurate as having detailed utility information, so the estimated loads are within ±30% for all the buildings. The candidate building heat loads in Hinton are estimated to vary from 20 to 1,024 kW.

Most of the 16 buildings investigated, the majority have hydronic or boiler-based systems. However, as each building may have a different fluid type used in its hydronic system it is impractical to connect all of the buildings directly to the DES. Therefore, to maintain the integrity of the system, a heat exchanger was included in the design at the tie-in point to each building. The cost of the heat exchanger is included in the Midstream costs. The tie-in cost estimate includes piping with insulation, the pump, and two valves and includes 10% for design, and 10% for contingency. The cost to tie-in buildings with hydronic systems is estimated to range from about $5,000 to $37,000; this cost is heavily dependent upon the individual size of the building.

The buildings that utilize non-hydronic systems, such as electric or forced air, will require a retrofit to a hydronic heating system. For the buildings that did not provide the heating system type, to be conservative it is assumed that these buildings would require a conversion to hydronic. Many hotels have electric heating in the individual hotel suites and it would be impractical to convert each suite to hydronic heating. However, the central heating system in hotel buildings such as lobby, conference rooms or pool areas could be good candidates for a retrofit. The conversion costs was based on an entirely new hydronic system for the whole building using a cost per square foot. In many buildings, it may not make financial sense to convert the entire building to a hydronic system, so it's possible that the new hydronic system may be significantly smaller than estimated above. The cost also includes 10% for design, 15% for demolition of the existing system, and a 10% contingency. The cost to tie-in buildings with non-hydronic systems is estimated to range from about $136,000 to $1.6 million.

If building owners can provide utility bills for each building, then the load estimates will be more accurate, and tie-in costs can be more closely estimated. Confirmation of the heating system type will also have a significant impact on the conversion cost estimates if more of the buildings are found to have existing hydronic systems.

## 4.2 Understanding Building Energy Use & Potential Savings

The total annual energy consumption of a facility can be broken down into several categories. The Office of Energy Efficiency through Natural Resources Canada published a Comprehensive Energy Use Database that identifies a typical breakdown for various categories of facilities in Alberta [64]. The following charts represent typical energy-use breakdowns for similar building types in Alberta to those considered to be served by the DES.

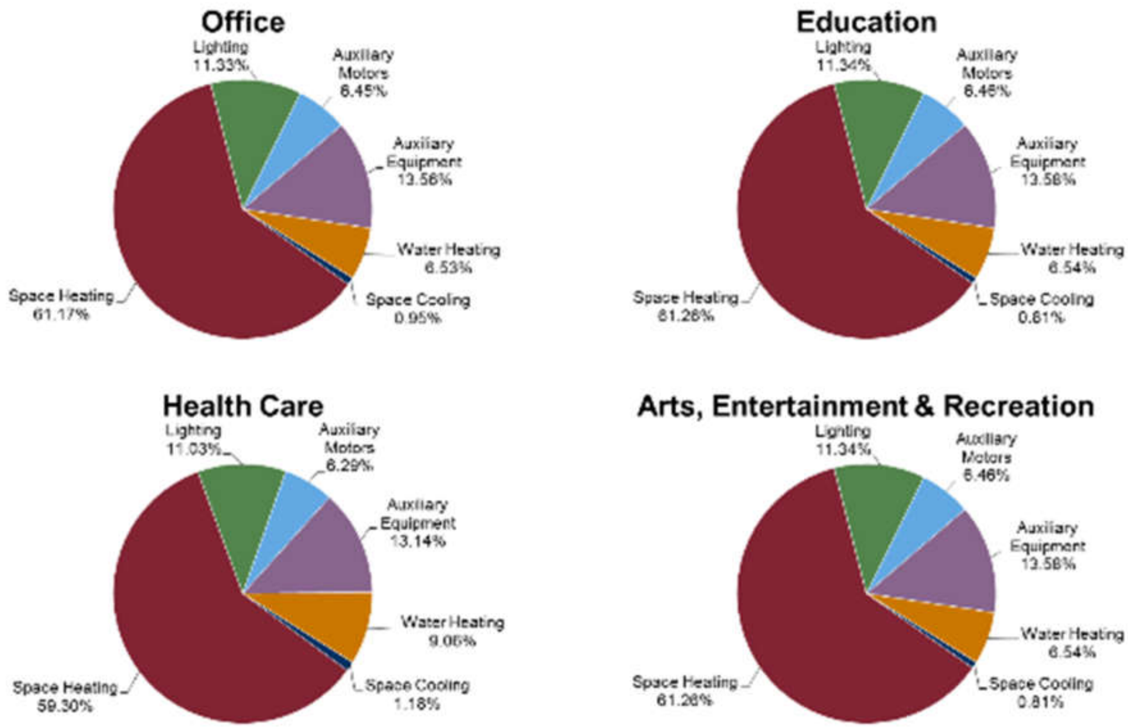



**Figure 73 - Typical energy-use breakdowns for different building types in Albert [64] a**

Building heat can be broken down into two major categories, space heating and water heating. Space heating typically represents 50-70% of utility cost, while water heating represents 5-10% which is illustrated above. The DES will be primarily supplementing the space heating portion of the energy use but can also supplement water heating in compatible systems, or buildings retrofitted to a hydronic water system.

The space heating portion can be further broken down into ventilation heating and skin loss. Ventilation heating consists of conditioning the outdoor air that is brought in through the buildings air systems to provide fresh air to the occupants. Skin loss refers to the heating required to make-up for heat loss through the building envelope. This is important to understand when evaluating the potential energy provided through the DES to a building and the modifications required of the building systems. The breakdown varies greatly depending on many factors such as occupancy and building construction. It appears to be a rule of thumb in energy audits that ventilation heating often makes up majority of the space heating load. The following section will discuss more specifically the buildings that were explored as part of this study and their potential interconnection to a DES.

## 4.3 Hinton Buildings

To maximize the operation of the DES, heating energy loads have been calculated for each building based on gas bill information (actual utilization) as opposed to using each building's total heating system capacity. The total heating system capacity represents the load on the coldest day of the year (peak heating load) when a building would require the most heat. As demonstrated using the graph below (Figure 74), which shows the heating degree days (HDD) over a 30-year period for Hinton, the peak heating loads occur during the coldest winter months. HDD is a measurement designed to quantify the demand for energy needed to heat a building; it is the number of days that the average temperature is below 18°C, which is the temperature below which buildings need to be heated.

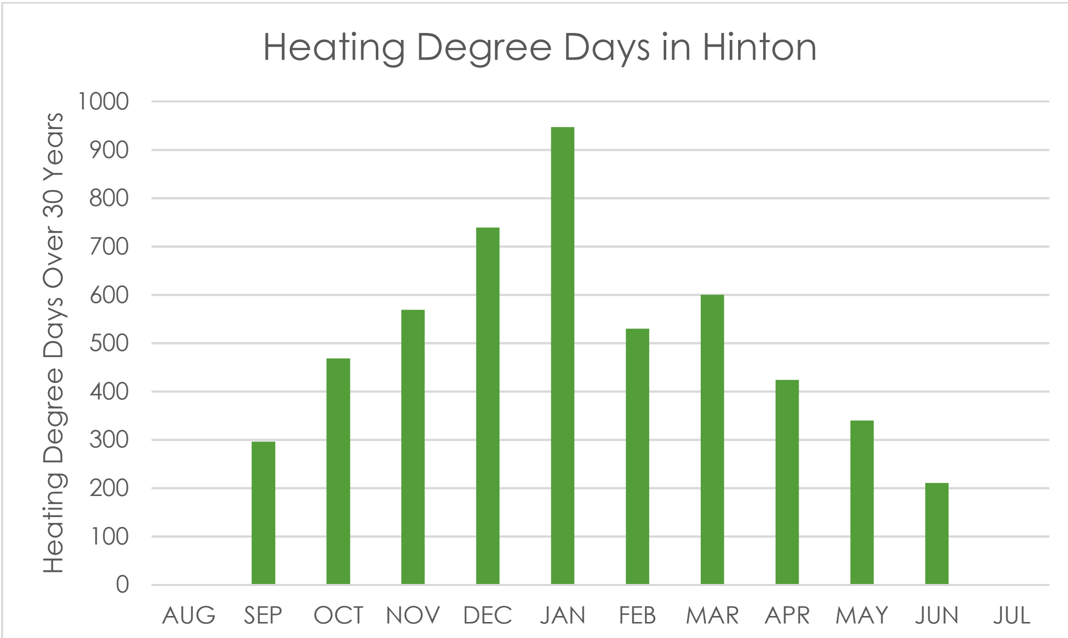



**Figure 74 - Heating Degree Days in Hinton [65]**

The graph above shows that the peak heating load doesn't occur frequently, and therefore it is preferred to undersize the DES connection slightly so that it operates at its maximum for most of the heating season. Doing so reduces capital costs for the DES connection due to the smaller heat exchanger. The existing heating system can then make up the difference during peak heating days.

For the purposes of this study, 53 buildings in the Town of Hinton are being considered. Some of these buildings have provided information on the specifics of their heating system including utility bills (used to estimate energy consumption); however, many buildings were unable to provide either heating system descriptions or utility bills. For the buildings that did not provide this information, assumptions were made to determine the building loads. Using the gas bill information provided by twelve of the buildings, it was possible to calculate an average gas consumption usage per square foot. This average consumption was then applied to the remaining buildings using each building's area to calculate a load for all the buildings; however, this is not as accurate as having detailed gas bill information for each building. Based on these assumptions the loads are within ±30% for all the buildings. The loads for each building are presented in Table 1, which includes buildings with and without hydronic systems. Most building areas are provided by the Town of Hinton, while some are estimated using Google Maps.

**Table 35 - Table of Hinton Buildings with Estimated Loads to DES**

| # | Building Name | Total Building Area (sq. m) | Load to DES (kW) |
|---|---|---|---|
| 1 | 129 Timber Lane Condo Center | 1,050 | 58 |
| 2 | 129 Timber Lane Condo East | 1,050 | 58 |
| 3 | 129 Timber Lane Condo West | 1,050 | 58 |
| 4 | Aspen Place | 2,100 | 115 |
| 5 | Balsam Court | 8,100 | 445 |
| 6 | BCMInns Hinton | 7,900 | 434 |
| 7 | Big Horn Motel | 1,650 | 91 |
| 8 | Carlyle Estates | 3,000 | 165 |
| 9 | Crescent Elementary School | 5,290 | 218 |
| 10 | Crestwood Hotel | 8,000 | 439 |
| 11 | Days Inn Hinton | 3,000 | 165 |
| 12 | Ecole Mountain View School | 5,045 | 145 |
| 13 | Econo Lodge & Suites | 6,000 | 329 |
| 14 | Fire Department | 2,230 | 79 |
| 15 | Freson Bro's | 3,550 | 195 |
| 16 | Friendship Center | 1,650 | 217 |
| 17 | Gerard Redmond Community Catholic School | 4,700 | 258 |
| 18 | Government Center | 4,260 | 108 |
| 19 | Grande Prairie Regional College | 1,700 | 93 |
| 20 | Harry Collinge High School | 13,100 | 318 |
| 21 | Hinton Lodge | 3,900 | 214 |
| 22 | Holiday Inn Express & Suites Hinton | 4,800 | 264 |
| 23 | Holiday Inn Hinton | 6,000 | 329 |
| 24 | Hospital | 10,679 | 826 |
| 25 | Lakeview Inns & Suites | 4,000 | 220 |
| 26 | Lions Sunset Manor | 2,250 | 124 |
| 27 | Maxwell Lake Apartments | 3,900 | 214 |
| 28 | McLeod Summit Condos | 3,200 | 176 |
| 29 | Monashee Lodge | 2,250 | 124 |
| 30 | Mountain Terrace Condominium | 4,000 | 220 |
| 31 | Mountainview Apartment Condominiums | 2,160 | 119 |
| 32 | Parks West Mall | 2,500 | 137 |
| 33 | Police (RCMP) | 1,350 | 39 |
| 34 | Provincial Courts Building | 960 | 53 |
| 35 | Quality Inn & Suites | 3,000 | 165 |
| 36 | Ramada Hinton | 5,100 | 280 |
| 37 | Recreation Center | 18,600 | 1,024 |

| | | | |
|---|---|---|---|
| 38 | Royal Canadian Legion Branch 249 | 1,600 | 88 |
| 39 | Safeway | 5,275 | 290 |
| 40 | Seabolt Apartments | 3,900 | 214 |
| 41 | Seabolt Apartments North | 3,900 | 214 |
| 42 | Senior Home | 362 | 20 |
| 43 | Southwest Building | 2,400 | 132 |
| 44 | St. Gregory Catholic School | 3,300 | 181 |
| 45 | St. Regis Village | 7,950 | 436 |
| 46 | Super 8 Hinton | 2,200 | 121 |
| 47 | Tara Vista Inn | 2,800 | 154 |
| 48 | The Guild | 2,820 | 85 |
| 49 | Training Center | 5,550 | 697 |
| 50 | Twin Pine Inn & Suites | 3,600 | 198 |
| 51 | Villa Sundale Apartments | 2,580 | 142 |
| 52 | Walmart | 5,800 | 318 |
| 53 | White Wolf Inn | 2,500 | 137 |
| | TOTAL | | 11,940 |

### 4.3.1 Connection to the DES

The DES will transport energy in the form of a hot fluid mixture to the buildings, and consequently must be connected to the buildings' heating systems.

As each building may have a different fluid type used in its hydronic system it is impractical to connect all of the buildings directly to the DES. The interconnection should not allow cross-contamination of the various hydronic systems, thus an indirect connection from the DES to each building is recommended. This provides a separation between the different fluid types and maintains the integrity of the DES if one building system experiences issues. This separation is achieved by adding a heat exchanger at the tie-in point to each building.

The energy consumed by each building must be metered to allow for accurate monitoring of the DES. This would be accomplished by installing a thermal meter to measure the energy used at each building.

The DES connection requires physical space either inside the building (ideally co-located with the hydronic system), or just outside the building if no space is available inside. The procedure for constructing the tie-in would involve positioning the DES components in their designated location, then completing a shutdown of the building's hydronic system so that the DES piping could be joined to the existing building piping in the appropriate location, and then restarting the building hydronic system. The final step would be commissioning the DES components including the controls to ensure that the new DES operates in conjunction with the existing system and the building's heating setpoints are still maintained.

## 4.3.2 Buildings with Existing Hydronic Systems

The DES connection for each building will consist of a heat exchanger (additional heat exchangers may be needed for buildings with higher loads or for redundancy), a heat exchanger circulation pump sized for the heat exchanger and connecting piping, a temperature control valve, a thermal meter, and a district controller. Refer to Figure 75 for a preliminary diagram of a possible DES connection to existing boiler systems. Figure 76 below shows an installation of the DES connection in a mechanical room.

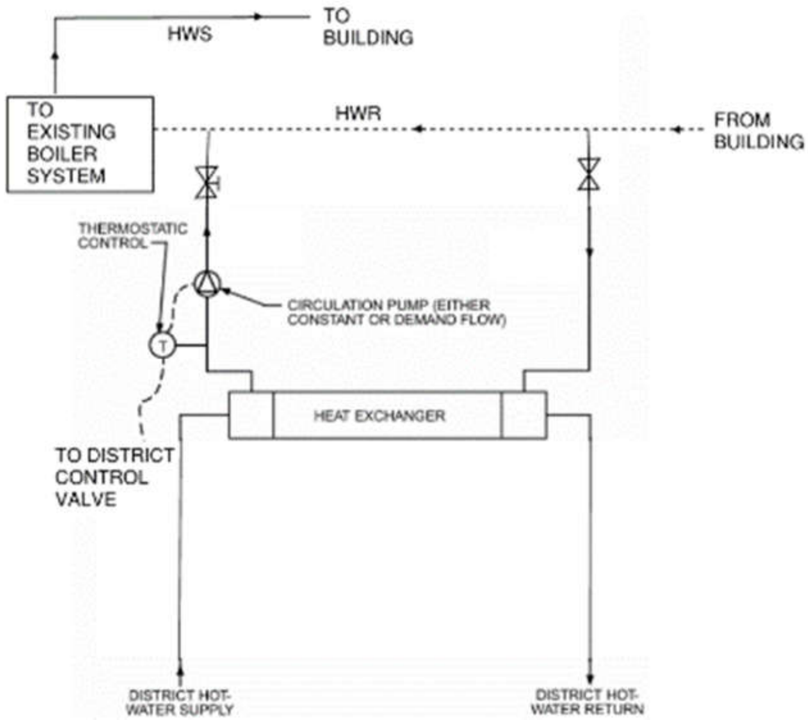



**Figure 75 - District/Building Indirect Interconnection with Hydronic System**

**Figure 76 - Photo of Installed Heat Exchanger in a Mechanical Room [66]**

The district controller will provide control of the control valve and circulation pump. Where possible, the district controller temperature setpoint should be reset by the existing building control system. For buildings with variable flow secondary heating systems, the heat exchanger circulation pump should be variable flow with the pump speed being controlled to match the heat exchanger flow to the secondary flow. For buildings with existing Building Management Systems (BMS), consideration should be given to interfacing the district controller to the existing BMS via the appropriate communications protocol.

For facilities with large flow temperature loads, consideration should be given to providing cascading heat exchangers, or modifying the existing secondary heating system to a cascaded system. Examples of large flow temperature loads are hospitals with large domestic hot water loads, swimming pools or facilities with condensing boilers. The cascading will assist with reaching the desired 45°C (113°F) return water temperature in the DES loop.

### 4.3.3 Buildings Without Existing Hydronic Systems

As well as the thermal meter and heat exchanger, each building would require a hydronic heating, ventilation, and air conditioning (HVAC) system. For those buildings that utilize gas-fired furnaces or roof top units for heating, they will require a retrofit to a hydronic heating system. The furnaces or rooftop units would need to be replaced with one or more of the following heat transfer devices:

- Fan coil unit or heat recovery ventilator
- Radiant floor heating
- Perimeter baseboard heating

In addition to the equipment noted above, the following components would be required to have a fully operational hydronic system:

- Circulating pump
- Zone and mixing valves
- Expansion tank
- Air separator
- Controls
- Piping and Insulation

Townhomes would likely each have their own furnace; it would be very cost prohibitive to convert every townhome to a hydronic system. Similarly, many hotels have electric heating in the hotel suites and it would be impractical to convert each suite to hydronic heating. The central heating system in hotel buildings such as lobby, conference rooms or pool areas could, however, be good candidates for a retrofit.

### 4.3.4 Space & Domestic Water Heating

A combination system could be employed that would provide both space heating and domestic water heating from the DES. This would require all the same equipment as stated above, with the exception that all of the piping on the building side would need to comply with the plumbing code (i.e. copper pipe), unless the space heating system is separated by a second heat exchanger. The preferred operating temperature for a combination system would be 60°C (140°F), which is generally too hot for in-floor heating. Furthermore, the existing gas-fired domestic water heater would need to be replaced with a domestic hot water storage tank.

## 4.4 Cost Estimates

Refer to Table 36 for the cost estimates associated with the downstream connections.

**Table 36 - Cost Estimates for Downstream Connections**

| # | Building Name | Hydronic System | Estimated Cost to Tie-In | Estimated Cost to Convert to Hydronic |
|---|---|---|---|---|
| 1 | 129 Timber Lane Condo Center | Unknown | $6,219 | $143,429 |
| 2 | 129 Timber Lane Condo East | Unknown | $6,219 | $143,429 |
| 3 | 129 Timber Lane Condo West | Unknown | $6,219 | $143,429 |
| 4 | Aspen Place | Unknown | $8,188 | $287,452 |
| 5 | Balsam Court | Unknown | $18,095 | $574,523 |
| 6 | BCMInns Hinton | Unknown | $8,188 | $215,967 |
| 7 | Big Horn Motel | Unknown | $8,188 | $175,357 |
| 8 | Carlyle Estates | Unknown | $15,948 | $409,797 |
| 9 | Crescent Elementary School | Yes | $18,095 | $0 |
| 10 | Crestwood Hotel | Unknown | $8,188 | $279,571 |
| 11 | Days Inn Hinton | Unknown | $8,188 | $191,880 |

| | | | | |
|---|---|---|---|---|
| 12 | Ecole Mountain View School | Yes | $15,948 | $0 |
| 13 | Econo Lodge & Suites | Unknown | $15,948 | $321,183 |
| 14 | Fire Department | Yes | $8,188 | $0 |
| 15 | Freson Bro's | Unknown | $18,095 | $484,927 |
| 16 | Friendship Center | Yes | $18,095 | $0 |
| 17 | Gerard Redmond Community Catholic School | Yes | $18,095 | $0 |
| 18 | Government Center | Yes | $8,188 | $0 |
| 19 | Grande Prairie Regional College | Unknown | $8,188 | $267,972 |
| 20 | Harry Collinge High School | Yes | $18,095 | $0 |
| 21 | Hinton Lodge | Unknown | $18,095 | $466,857 |
| 22 | Holiday Inn Express & Suites Hinton | Unknown | $18,095 | $626,745 |
| 23 | Holiday Inn Hinton | Unknown | $18,095 | $653,725 |
| 24 | Hospital | Yes | $36,745 | $0 |
| 25 | Lakeview Inns & Suites | Yes | $15,948 | $0 |
| 26 | Lions Sunset Manor | Yes | $15,948 | $0 |
| 27 | Maxwell Lake Apartments | Unknown | $18,095 | $566,655 |
| 28 | McLeod Summit Condos | Unknown | $15,948 | $437,117 |
| 29 | Monashee Lodge | Unknown | $8,188 | $206,347 |
| 30 | Mountain Terrace Condominium | Unknown | $18,095 | $546,396 |
| 31 | Mountainview Apartment Condominiums | Yes | $8,188 | $0 |
| 32 | Parks West Mall | Unknown | $24,162 | $1,612,960 |
| 33 | Police (RCMP) | Yes | $5,633 | $0 |
| 34 | Provincial Courts Building | Unknown | $6,219 | $133,275 |
| 35 | Quality Inn & Suites | Unknown | $15,948 | $458,837 |
| 36 | Ramada Hinton | Unknown | $8,188 | $244,038 |
| 37 | Recreation Center | Yes | $36,745 | $0 |
| 38 | Royal Canadian Legion Branch 249 | No | $8,188 | $226,652 |
| 39 | Safeway | Unknown | $18,095 | $720,560 |
| 40 | Seabolt Apartments | Unknown | $18,095 | $532,736 |
| 41 | Seabolt Apartments North | Unknown | $18,095 | $532,736 |
| 42 | Senior Home | Yes | $4,902 | $0 |
| 43 | Southwest Building | Unknown | $15,948 | $327,838 |
| 44 | St. Gregory Catholic School | Yes | $15,948 | $0 |
| 45 | St. Regis Village | Unknown | $18,095 | $536,604 |
| 46 | Super 8 Hinton | Unknown | $8,188 | $275,891 |
| 47 | Tara Vista Inn | Unknown | $8,188 | $183,669 |
| 48 | The Guild | No | $8,188 | $157,235 |
| 49 | Training Center | Yes | $24,162 | $0 |
| 50 | Twin Pine Inn & Suites | Unknown | $15,948 | $326,336 |
| 51 | Villa Sundale Apartments | Unknown | $18,095 | $502,987 |

| | | | | |
|---|---|---|---|---|
| 52 | Walmart | Unknown | $18,095 | $792,275 |
| 53 | White Wolf Inn | Unknown | $15,948 | $341,498 |
| | TOTAL | | $763,089 | $15,048,887 |

To estimate the costs, the Hanscomb Yardsticks for Costing 2015 [67] manual was used. This pricing includes labour but excludes GST. All the values are taken for Calgary, the closest city to Hinton, and inflation of 3% for three years has been applied to bring the pricing to 2018 values.

The tie-in cost estimate includes piping with insulation, the pump, and two valves as shown previously in Figure 75. The cost of the heat exchanger is captured in the Midstream section. The cost also includes 10% for design and a 10% contingency. Pipe size can be calculated based on the system capacity, type of fluid, and temperature difference of the fluid. For the purposes of these estimates, the fluid is assumed to be water (typical for a hydronic system) and an 11°C (20°F) temperature difference was used, which is a minimum in hydronic system design. The specific system temperatures should be obtained from each building's owners/operators; many attempts were made to do so for the FEED study, though they proved unsuccessful from lack of access and response from building owners and staff. These temperature values will have to be confirmed before a more intensive design is completed. The typical range is between 11°C and 22°C temp difference, but, as mentioned, assuming 11°C is a more conservative value for pipe sizing; this is the most conservative case for sizing the pipe as the pipe size will decrease as the temperature difference increases. If the actual system temperatures can be obtained, then the tie-in cost estimate will be more accurate.

The conversion to hydronic costs is based on an entirely new hydronic system for the whole building using a cost per square foot. In many buildings, it may not make financial sense to convert the entire building to a hydronic system, so it's possible that the new hydronic system may be significantly smaller than estimated above. The cost also includes 10% for design, 15% for demolition of the existing system, and a 10% contingency. For the buildings that did not provide the heating system type (listed as Unknown in Table 36), it is assumed that these buildings would require a conversion to hydronic as this is the most conservative scenario. It is likely, however, that some of these buildings are in fact hydronic and will not require a conversion.

If building owners can provide utility bills for each building, then the load estimates will be more accurate. Once the loads are more defined then tie-in costs can be more closely estimated. Confirmation of the heating system type will also have a significant impact on the conversion cost estimates if more of the buildings are found to have existing hydronic systems.

### 4.4.1 Post-DES Retrofit to Propane Cost Estimates

In order to eliminate any natural gas utility charges, the buildings could be converted to propane after the DES connection is installed. This ensures that the building owners are only paying for a single utility- the DES, and whichever fuel is required to run the hydronic system on peak days or if the DES is down for maintenance.

Pricing was requested from Super Save Propane. There are three sizes of tanks available; the tank delivery and the install fee is $300 regardless of the size.

The three sizes of tanks are:

- 80 gallon tank (300L)
- 500 gallon tank (1500L)
- 1,000 gallon tank (3100L)

The current cost of propane is $0.509/L plus a $12.95 delivery fee. In addition, propane conversion kits would need to be installed on the boilers.

## 4.5 Construction Schedule of Downstream Connections

This section is included in its original state from the pre-FEED report as its content remains relevant and helpful, and estimates contained therein have not changed.

The optimum time to connect to the DES is in the summer when heating demand is low to minimize disruption to the building operations. Preparation of the buildings to connect to the DES will require a standard procedure. The following outlines the steps required and the approximate timeline for preparing a simple retrofit of the downstream buildings to connect to the DES.

**Table 37 - Estimated Construction Schedule**

| Task | Timeline |
| --- | --- |
| Engineering Design of Building Connections | 8-12 Weeks |
| Construction Tender & Contracting | 2-4 Weeks |
| Construction Start-up and Shop Drawing Review | 2-4 Weeks |
| Equipment Delivery | 6-10 Weeks |
| Construction | 4-8 Weeks |
| TOTAL | 22-38 weeks |

Overall timing would likely take up to 38 Weeks, or 9.5 months, meaning the design process should start before September for summer construction.

## 4.6 Potential Future Growth

District energy systems best serve layouts where buildings that use high amounts of heating energy are located proximal to one another (i.e. are "clustered"). This reduces materials and installation costs and makes for a much more economically feasible project.

In contrast, the Town of Hinton has relatively low energy density, meaning that it is sprawling in nature; high intensity building loads are dispersed along long arms, not clustered. This has presented a challenge both to midstream pipeline design and financial modeling in order to determine which areas of town are feasible and which are not.

It is recommended that future growth within the town be managed such that new buildings with high heat loads be placed within the crown land nearest to the centre of town to cluster the heat loads. It is further recommended that any new buildings planned to be placed further out from town centre be co-located with the midstream piping design plan.

In addition to the buildings covered by the FEED study, there are many more facilities that can benefit from the DES, specifically ones with large, concentrated heat loads such as other schools, hotels or municipal buildings. Although these buildings are not included within this FEED project because of the lack of energy density at their location, infrastructure planning could lead to concentrating future heat loads in those areas and make them feasible. Ideally buildings that have an existing boiler system that provides most if not all of the building's heating requirements are the best candidates as they require the least modification to connect to the DES. The natural gas consumption offset by the DES is highly dependent on the buildings.

## 4.7 Next Steps

The recommended next steps are to create a prioritized list of buildings to be connected to the DES based on refined building loads and more detailed cost estimates. Additional information is required to progress further; every attempt was made to procure it for use in the FEED study, but, as previously mentioned, this was made very challenging due to lack of access and responsiveness. The information required includes:

1. Confirmation of HVAC system types to prioritize existing hydronic systems (most economical).
2. Utility bills for all buildings to more accurately estimate the loads.
3. Site visits to all buildings to determine the best location for the DES connection.
4. Existing building drawings to complete detailed engineering of each DES tie-in.

# 5 Financial Analysis & Projections

## 5.1 Summary

The Hinton DES has the potential to provide an alternative heating source to key customers in the Town of Hinton. The project was conceived to deliver the efficiencies of a district energy system, replacing independent building-specific systems.

The DES is heat agnostic, meaning that the District Energy Centre can receive heat from a number of sources (geothermal, biomass, waste heat, centralized boiler, geo-exchange heat pumps, etc.), and distribute the heat throughout the town to the connected buildings.

The project's capital intensity and operating expense relative to business-as-usual are important to the project financial case. In Hinton's case the business-as-usual is natural gas service. The Town of Hinton does not have the economies of scale of the incumbent natural gas system as it is city-wide. With customer growth, it is anticipated that the cost of service for Hinton DES will improve demonstrably. In addition to the cost of natural gas, there are several factors that effect the financial viability of the Hinton DES:

- **Supply provided to the DES (Upstream)**: A rise in customers coincides with a rise in demand. Additional capital and operating costs would be required in order to increase the heat production. The cost of drilling a new well to acquire the heat to provide for the DES is approximately $6.0 million with well site facilities costing $0.8 million and approximately $1.7 million to transport the heat from the well to the energy substation.

- **Number of customers (Midstream)**: Each additional customer improves the overall revenue generation stream of the DES, depending on their distance from the substation and their heat load. The number of potential customers in the optimized system is 38.
- **Energy density (Midstream)**: This is the heat load of each customer relative to the distance they are from the nearest customer. Two large heat loads are located close to each other are more efficient than if two low heat loads are located far apart. More definitive heat load information on each of the customers identified in the Optimized system is required to determine the true energy density. The total load of the 38 buildings within the Optimized system is estimated to be 84,000 GJ/yr.
- **The price of natural gas (Midstream)**: The price of natural gas is comprised of several different charges. Many of these charges are directly tied to inflation and will rise over time. The Hinton DES has relatively low operating costs and therefore does not require steep increases in price to offset these costs.
- **Carbon Levy (Midstream)**: Another one of the charges that contribute to the overall price of natural gas is the carbon levy. With the geothermal-based DES being entirely carbon neutral, the cost of service is unaffected by Provincial or Federal changes to the price levied on carbon emissions.
- **Greenhouse Gas Credits (Midstream)**: Depending on the sources of future funding, this project may be eligible for GHG reduction credits as it could reduce CO2 emissions by over 4,500 tonnes per year.
- **Capital and operating costs (Midstream)**: Capital costs with 10% contingency are close to $24.2 million. The largest contributor is the installation of the district energy system, district energy center and external building tie-ins at a cost of $14.75 million. Class 3 estimates (+30%/-20%) are based on the AACE (Association for the Advancement of Cost Engineering). The DES costs are variable based on the length of pipe in the ground, which is dependent on the size of the system. This cost is for the reduced optimized system.
- **Subsidies and grants (Midstream)**: A second benefit to being carbon neutral are potential grants and subsidies available to projects that produce renewable energy.
- **Utility ownership structure (Midstream)**: Being the owner of the utility infrastructure could have significant tax implications. Depending on if the ownership is municipally held or privately held can have impact on the ability to raise funds, as well as tax implications.
- **Individual Building Tie-Ins (Downstream)**: Buildings that were confirmed to have an existing hydronic system had a tie in cost of $5800 to $37,000. Only two buildings (The Guild and the Royal Canadian Legion Branch) were confirmed to not have a hydronic system. There would be a substantial cost to convert these to a system that could be heated through the DES (hydronic or hydronic air systems). There are many grants/subsidies from federal and provincial government programs that will assist in the conversion to a carbon reduced system. A significant portion of the buildings in the study were not available due to government privacy concerns or a lack of response from franchise corporate management within the time frame of the study.

**Table 38 - Summary of Upstream Costs**

| | |
|---|---|
| New Well | $6,000,000 |
| Facility | $825,000 |
| Pipeline | $2,570,000 |
| Total | $9,395,000 |

**Table 39 - Summary of Midstream Costs – Optimized System**

| | |
|---|---|
| District Energy Centre | $2,600,000 |
| District Energy System | $10,750,000 |
| Energy Transfer Station | $1,400,000 |
| Operation & Maintenance | $500,000/year |

**Table 40 - Summary of Downstream Costs – Optimized System**

| | |
|---|---|
| Tie-in Costs | $560,000 |
| Cost to Convert to Hydronic | $11.3 million |
| Total | $11.8 million |

The Financial Analysis looks at all three parts of the DES system separately, however, the downstream costs associated with tie-in to the DES would be the responsibility of the building owners.

Finally, in terms of a payback period for the District Energy System, if municipal bonds are used at 2%, with a price of heat of $10/GJ and a capital cost reduction of 30% due to grants and cost sharing, the payback period is 15 years.

## 5.2 Upstream Costs

The upstream costs are associated with the acquisition of heat from the well bore and transporting the heat from the well site to the District Energy Centre (DEC) in the Town of Hinton. The prospective well would be drilled approximately 2 km away from site. The components of the upstream portion of the project are the well, the wellsite facilities and the pipeline to the DEC.

### 5.2.1 Geothermal Well

Based on the heat requirement of the final design of the Hinton DES, and the wellbore heat model and the production model (both discussed in Section 2.4), the anticipated well design would be a 4300 m horizontal drill to a vertical depth of 3650 m. This is Case 4a in Section 2.3.4 at a cost of approximately $6 million.

### 5.2.2 Wellsite Facilities

The design for extracting heat from the borehole has been estimated using quotes gathered from other sections of this project with similar equipment such as pumps, heat exchangers, buildings, etc.

**Table 41 - Estimated Cost of Upstream Facility / Pumping Station**

| | |
|---|---|
| Engineering | $50,000 |
| Materials | $625,000 |
| Construction | $150,000 |
| Total | $825,000 |

The main item that will affect the price is the Downhole Circulation Pump. Flow rate and Pressure are subject to change, depending on how much heat can be extracted without depleting the well. Currently, a 375 HP pump has been sized.

### 5.2.3 Upstream Pipeline to the DEC

The cost estimate for the upstream circulation loop includes costs associated with the pipeline, construction and glycol-water mixture. The cost for construction was extracted from a cost estimate provided by Dunwald and Fleming.

**Table 42 - Estimated Cost of Upstream Circulation Pipeline**

| | |
|---|---|
| Engineering | $150,000 |
| Materials | $1,320,000 |
| Construction | $1,100,000 |
| Total | $2,570,000 |

The main item that will affect the total cost of the Upstream Pipeline is the material that the pipeline is made from. Currently, the Kelit PEXR pipeline is used for this pipeline loop. This material is found to reduce installation costs and will not require thermal expansion mitigation measures. If the heat extracted from the well increases in flow rate, a larger diameter pipeline may have to be used. Kelit PEXR has a limited diameter, and therefore steel pipelines may be required. Construction and materials costs are subject to change under these circumstances.

### 5.2.4 Upstream Costs Summary

The technical complexity of developing this particular geothermal resource increases the capital required. Based on the heat requirements of the final design of the Hinton DES, the total cost of the Upstream section is $9.4 million dollars.

**Table 43 - Summary of Upstream Costs**

| | |
|---|---|
| New Well | $6,000,000 |
| Facility | $825,000 |
| Pipeline | $2,570,000 |

| Total | $9,395,000 |
|---|---|

This estimated cost is based on a system heat load of approximately 84,000 GJ/yr with potential for expansion and additional sidewalk heating loads.

At the current market conditions, drilling a technically complex and risky geothermal well strictly for a stand-alone heat project is not viable.

## 5.3 Midstream Costs

The financial analysis and projections section is intended to provide insight into the financial outcomes of the Hinton DES project and future growth scenarios. The study examines each of the factors listed above by comparing the DES to natural gas, and providing key financial measures such as payback period, net present value, and internal rate of return.

### 5.3.1 Number of Customers

There were 12 customers included in the pre-FEED study. 53 customers were identified by the FEED project, as shown in the following table. After optimizing the DES for economic feasibility, the number of customers was reduced to 38, who are found in Zone 1 and Zone 2.

**Table 44 - DES Customers with Zones and Loads**

| ZONE | # | Building Name | Total Building Area (sq. m) | Load to DES (GJ) |
|---|---|---|---|---|
| District Energy Centre | 1 | Friendship Center | 1,650 | 536 x4 Zones |
| Zone 1 | 2 | Training Center | 5,550 | 6872 |
| | 3 | Villa Sundale Apartments | 2,580 | 1396 |
| | 4 | 129 Timber Lane Condo Center | 1,050 | 568 |
| | 5 | 129 Timber Lane Condo East | 1,050 | 568 |
| | 6 | 129 Timber Lane Condo West | 1,050 | 568 |
| | 7 | Senior Home | 362 | 196 |
| | 8 | Hospital | 10,679 | 8143 |
| | 9 | Mountain Terrace Condominium | 4,000 | 2165 |
| | 10 | Lions Sunset Manor | 2,250 | 1218 |
| | 11 | Ecole Mountain View School | 5,045 | 1431 |
| | 12 | Provincial Courts Building | 960 | 520 |
| | 13 | Mountainview Apartment | 2,160 | 1169 |
| | 14 | Royal Canadian Legion Branch 249 | 1,600 | 866 |
| | 15 | Grande Prairie Regional College | 1,700 | 920 |
| | 16 | Holiday Inn Hinton | 6,000 | 3248 |

| | | | | |
|---|---|---|---|---|
| | 17 | Tara Vista Inn | 2,800 | 1516 |
| | 18 | Big Horn Motel | 1,650 | 893 |
| | 19 | Econo Lodge & Suites | 6,000 | 3248 |
| | 20 | Twin Pine Inn & Suites | 3,600 | 1949 |
| | 21 | Freson Bro's | 3,550 | 1921 |
| | 22 | Crestwood Hotel | 8,000 | 4330 |
| | 23 | Hinton Lodge | 3,900 | 2111 |
| | 24 | Quality Inn & Suites | 3,000 | 1624 |
| | 25 | White Wolf Inn | 2,500 | 1353 |
| | 26 | Walmart | 5,800 | 3139 |
| | 27 | Parks West Mall | 2,500 | 1353 |
| | 28 | Safeway | 5,275 | 2855 |
| | 29 | Ramada Hinton | 5,100 | 2760 |
| Zone 2 | 30 | The Guild | 2,820 | 840 |
| | 31 | Recreation Center | 18,600 | 10,098 |
| | 32 | Harry Collinge High School | 13,100 | 3137 |
| | 33 | Crescent Elementary School | 5,290 | 2153 |
| | 34 | Balsam Court | 8,100 | 4384 |
| | 35 | Aspen Place | 2,100 | 1137 |
| | 36 | Monashee Lodge | 2,250 | 1218 |
| | 37 | Southwest Building | 2,400 | 1299 |
| | 38 | St. Regis Village | 7,950 | 4303 |
| Zone 3 | 39 | Super 8 Hinton | 2,200 | 1191 |
| | 40 | Days Inn Hinton | 3,000 | 1624 |
| | 41 | BCMInns Hinton | 7,900 | 4276 |
| | 42 | McLeod Summit Condos | 3,200 | 1732 |
| | 43 | Holiday Inn Express & Suites | 4,800 | 2598 |
| | 44 | Lakeview Inns & Suites | 4,000 | 2165 |
| Zone 4 | 45 | Government Center | 4,260 | 1067 |
| | 46 | Police (RCMP) | 1,350 | 383 |
| | 47 | Fire Department | 2,230 | 779 |
| | 48 | Gerard Redmond Catholic School | 4,700 | 2544 |
| | 49 | Carlyle Estates | 3,000 | 1624 |
| | 50 | Seabolt Apartments | 3,900 | 2111 |
| | 51 | Seabolt Apartments North | 3,900 | 2111 |
| | 52 | St. Gregory Catholic School | 3,300 | 1786 |

| | | | | |
|---|---|---|---|---|
| | 53 | Maxwell Lake Apartments | 3,900 | 2111 |
| TOTAL | | | | 117,715 |

It is important to note that Epoch was not able to access the buildings nor obtain the actual heating loads for a significant number of the buildings. This was due to permissions required from higher levels of management or government that were not received in the time available for this study. Access was obtained to 16 buildings and monthly heating loads was received for 8 buildings, which were mainly municipally owned.

The buildings identified in the optimized DES would require a site visit to assess the heating/cooling mechanism (forced air, hydronic, or electric) and the available space in the mechanical room for an Energy Transfer Station.

### 5.3.2 Energy Density

The total load of all 53 buildings is 117,715 GJ, and with the optimized system the load of the 38 buildings is estimated to be 84,000 GJ/yr. In Zones 3 and 4, the distance between buildings coupled with the heat load of each building resulted in a substantially lower heat density than Zone 1 and Zone 2.

### 5.3.3 Determining Projected Gas Rates

The gas bills from 8 buildings for the last 2 years were reviewed. The annualized cost of natural gas delivered to the customers was \$6.58/GJ. This does not include the addition of the carbon levy.

Determining the impact of carbon levy to the cost of natural gas is determined by the following calculation:

$$Carbon\ Levy\ on\ Natural\ Gas = CO2\ Emission\ Factor \times Usage \times Carbon\ Levy$$

Using the 2018 value of \$30/tonne CO2 on a per GJ basis

$$Carbon\ Levy\ on\ Natural\ Gas = 50.66\ \frac{kg\ CO2}{GJ} \times \frac{1\ tonne}{1000\ kg} \times \frac{\$30}{tonne\ CO2}$$

$$Carbon\ Levy\ on\ Natural\ Gas\ (2018) = \frac{\$1.517}{GJ}$$

This number reflects the provincial Carbon Levy applied to natural gas in 2018 [68]. The 2021 and 2022 numbers follow this same method of calculation.

The rate of inflation is based on the Alberta forecast by the Conference Board of Canada and ranges from 2.1% to 3%. Using the midpoint of 2.55% and applying the Provincial and Federal Carbon Levy results in the following projected cost of natural gas. It is important to note that the Carbon Levy past 2019 is based on the Federal Carbon Levy with a \$10 increase each year until it becomes \$50/tonne CO2.

**Table 45 - Projected Cost of Natural Gas**

| | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 |
|---|---|---|---|---|---|---|---|

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Carbon Levy ($/tonne CO2) | $ - | $20.00 | $30.00 | $30.00 | *$30.00 | *$40.00 | *$50.00 |
| NG Carbon Levy ($/GJ) | $ - | $1.01 | $1.52 | $1.52 | $1.52 | $2.03 | $2.53 |
| Average Gas Rates | $6.58 | $6.75 | $6.91 | $7.09 | $7.27 | $7.46 | $7.65 |
| Total Gas Rate (Est) | $6.58 | $7.76 | $8.43 | $8.61 | $8.79 | $9.49 | $10.18 |

*Denotes Federal Minimum Carbon Levy

A rate of $10/GJ was used in the model to determine payback period and sensitivities of costs.

### 5.3.4 Capital and Operating Costs of the District Energy System

The capital and operating costs were determined through the financial modeling of the DES. This section explores methods in optimizing the DES for economic feasibility. This is done by creating a simplified financial model and modifying the DES to determine its effects. Modifications include removing consumers and associated pipeline branches, as well as changing parameters within the financial model such as: interest on the principal cost, revenue generated (price point for heat) and the initial capital cost of the project.

This section determines the financial viability of the DES regardless of heat input (geothermal, biomass, waste heat recovery) or individual interconnection cost.

As mentioned in Section 3.2, the proposed DES is designed to include every feasible consumer in the Town of Hinton. This includes government, commercial and industrial buildings which have larger loads than single residential dwellings. As expected, increasing the number of consumers throughout the town will increase material, installation and operating costs. These costs will need to be recovered by the revenue generated.

General assumptions for this simplified financial model are:

- Heat loads and construction costs of pipelines that are commonly shared will be equally split between zones
- Each consumer will have an independent retrofit and interconnection cost to the system (approx. 20m in distance from the mainline)
- Operating and Maintenance (O&M) costs of $500,000/year for the entire DES
- Equipment replacement/refurbishment cost of 10% of initial capital cost every 10 years
- DEC is considered a sunk cost and not included in any zone's cost
- 4% Interest on Capital Loan
- An asterisk or no value indicates that a payback period is never achieved

### 5.3.5 Complete DES Modeling

The Complete DES includes 53 consumers connected to the DEC at the Friendship Centre. These consumers are located along four primary branches or "Zones", centered at the DEC (indicated as "0" in the figure below). The Zones are simplified as the NW, NE, SE, and SW branched based on their orientation and corresponding to Zones 1, 2, 3 and 4 respectively.

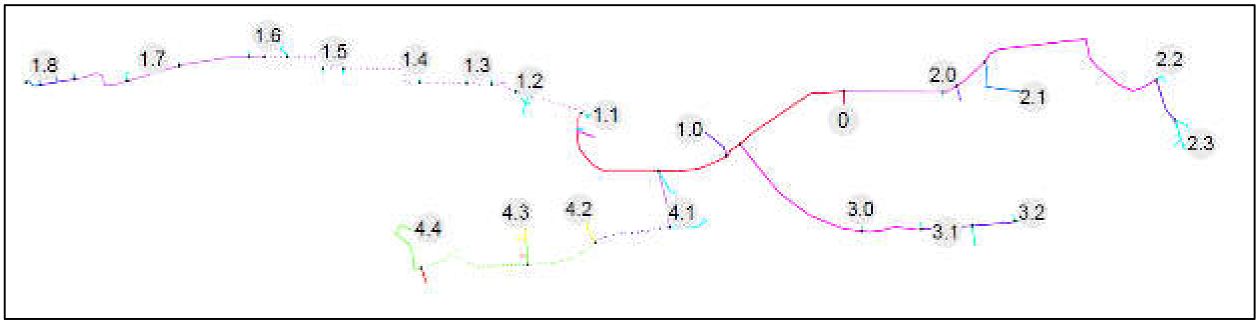



**Figure 77 - Proposed Hinton DES - Simplified Financial Model**

Figure 77 shows the branch with "0" allocated to the Friendship Centre (where the DEC is located), and numbers 1 through 4 for each corresponding Zone. Each node is either a single consumer or a consolidation of multiple consumers within a small vicinity. The length of each section was determined using the NETSIM model described in Section 3.2, and a price per meter for total installed cost (TIC) was developed using construction and material estimates for each section of the town. By multiplying the cost per meter obtained with the lengths of each section, the total installed cost from each node to the next was obtained. A common branch moving west from the DEC feeds multiple zones. The installed cost of this common branch was equally split between the number of zones it was feeding. Since the first pipeline segment from the DEC feeds all four zones, the cost was divided by four. The same process was used for the heat load of the DEC and the operating and maintenance cost split between zones.

**Table 46 - Financial Modeling of the Complete DES**

| Zone | TIC | Load | | Install Cost Per GJ | Payback Cost ($/GJ) | | | | Payback Years (Yrs) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| # | (MM$) | (GJ) | (GJ/m) | ($/GJ) | 15 yrs | 20 yrs | 25 yrs | 30 yrs | $10/GJ | 12$/GJ | $14/GJ |
| 1 | 7.1 | 59437 | 11.2 | 120 | 15.12 | 13.41 | 12.14 | 11.52 | 55 | 26 | 18 |
| 2 | 2.9 | 29105 | 9.6 | 100 | 12.52 | 11.11 | 10.05 | 9.54 | 26 | 17 | 13 |
| 3 | 2.2 | 14121 | 6.4 | 155 | 19.48 | 17.28 | 15.64 | 14.84 | * | * | 36 |
| 4 | 3.8 | 15052 | 4.6 | 250 | 31.50 | 27.95 | 25.29 | 24.00 | * | * | * |
| Total | 16 | 117715 | 8.5 | 136 | 17.10 | 15.17 | 13.72 | 13.02 | * | 41 | 24 |

**Indicates negative revenue (i.e. debt outgrows revenue)*

Table 46 shows the results of the financial model of the Complete DES. After obtaining the total installed cost and heat load for each zone, the financial model was then modified to determine the results of the following scenarios:

1. Payback Cost per GJ to obtain a payback period of:
    a. 15 years
    b. 20 years
    c. 25 years
    d. 30 years
2. Payback period (in years) with a fixed heat cost of:
    a. $10/GJ
    b. $12/GJ
    c. $14/GJ

Zones 1 and 2 have a substantially higher load per meter and lower install cost per GJ compared to Zones 3 and 4. Load per Meter (GJ/m) indicates how much is being consumed on average per installed meter of piping. A higher GJ/m indicates a higher density of heat consumption (i.e. more consumers or higher heat loads), which is ideal since the length of pipe directly correlates to the TIC. The economic feasibility of the project increases when the length of each section (i.e. TIC) is decreased or the consolidated loads found in the zone is increased.

The second indicator, Install Cost per Load ($/GJ), is a simple ratio of the TIC to the Load. A higher ratio indicates worse performance, as the capital cost of adding consumers is higher. The install cost per load of Zone 2 is less than half that of Zone 4. When developing any infrastructure in their respective zones, the TIC per GJ of Zone 4 makes it less economically feasible.

The final two columns in Table 46 are Payback Cost and Payback Period. Payback cost explores the price per GJ that would need to be charged to the consumer to obtain a net present value (NPV) of zero, while payback period is the number of years required to obtain an NPV of zero at a fixed price per GJ. As expected, a longer payback period requires fewer dollars of revenue, and an increased Price per GJ decreases the Payback period.

The asterisks found in the Payback Period column denote Zones that yield an "infinite" Payback Period due to the debt outgrowing the revenue. For some zones, having a specific fixed price will increase debt over time, resulting in a negative return on investment.

The "Total" row, which is for the Complete DES, indicates the average performance of the system. This gives insight into optimizing the system, as investigations can begin to determine how to improve zones that are below average. Per Table 46, the best zones (in descending order) Zones 2, 1, 3, then 4.

### 5.3.6 System Model Optimization

Mentioned in the previous section, the Complete DES combines all feasible consumers that are geographically convenient to tie-in into the system. Each consumer has an associated net benefit as part of the DES. To optimize the system, consumers will be examined to determine their net benefit. A consumer that is farther away from the DES or yields higher costs to tie-in must have a high heat load to generate enough revenue to recoup the installed cost within a reasonable time frame.

The initial financial model was created in segments as shown in Figure 77, and optimization was completed by process of elimination. Each zone was individually assessed, and consumers of each zone were removed one at a time to determine their effect on the financial model. If removing a customer decreased the amount of years for payback, then that change was applied. If it did not, then the consumer was returned to the DES. The O&M cost was also scaled to the heat usage. For example, the $500,000 O&M cost was cut by 20% if the total load decreased by 20%.

The analysis determined that Zones 3 and 4 are not economically feasible at this time.

**Table 47 - Financial Modeling Results of Optimized System**

| Zone | TIC | Load | | Install Cost Per GJ | Payback Cost ($/GJ) | | | | Payback Years (Yrs) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| # | ($MM) | (GJ) | (GJ/m) | ($/GJ) | 15 yrs | 20 yrs | 25 yrs | 30 yrs | $10/GJ | 12$/GJ | $14/GJ |
| 1 | 7.07 | 60301 | 10.29 | 117 | 14.92 | 13.25 | 12.01 | 11.40 | 53 | 26 | 17 |
| 2 | 2.68 | 29969 | 9.83 | 89 | 11.35 | 10.08 | 9.14 | 8.68 | 21 | 14 | 11 |
| 3 | | | | | | | | | | | |
| 4 | | | | | | | | | | | |
| Total | 9.75 | 90270 | 10.13 | 108 | 13.73 | 12.20 | 11.05 | 10.50 | 35 | 21 | 15 |

Table 47 shows the results of the financial model under the same assumptions detailed in Section 5.3.4, except, Zones 3 and 4 were removed. It is worth mentioning that Zone 2 can be optimized further; however, the financial benefits are minor compared to being able to supply more consumers. The shared costs in the previous section were also altered, now with Zone 3 and 4, common sections of pipe were no longer split, and the costs dedicated to each portion, and the GJ load per zone slightly increased due to the load of the Friendship Centre now being only halved instead of quartered.

This optimized system presents promising results, especially at lower heating prices ($/GJ). At $10/GJ, the entire system is now feasible, unlike the Complete DES at $10/GJ, detailed in Section 5.3.5. However, the 14$/GJ cost decreases the payback period from 28 years to 15 years. This decrease in payback period demonstrates promising potential in the Hinton DES.

### 5.3.7 Sensitivity Analysis of Both Systems

This section details the effects of modifying variables used in the financial models of both the entire system and the optimized system. The variables to be modified include:

- Interest rate
- Revenue Gained / Price of Heat ($/GJ)
- Initial Capital Cost

#### 5.3.7.1 Interest Rate

The interest rate is varied from 0% to 4%. Higher interest rates yielded unfeasible payback periods which were not worth investigating further. The results of this sensitivity analysis can be found in Figure 78.

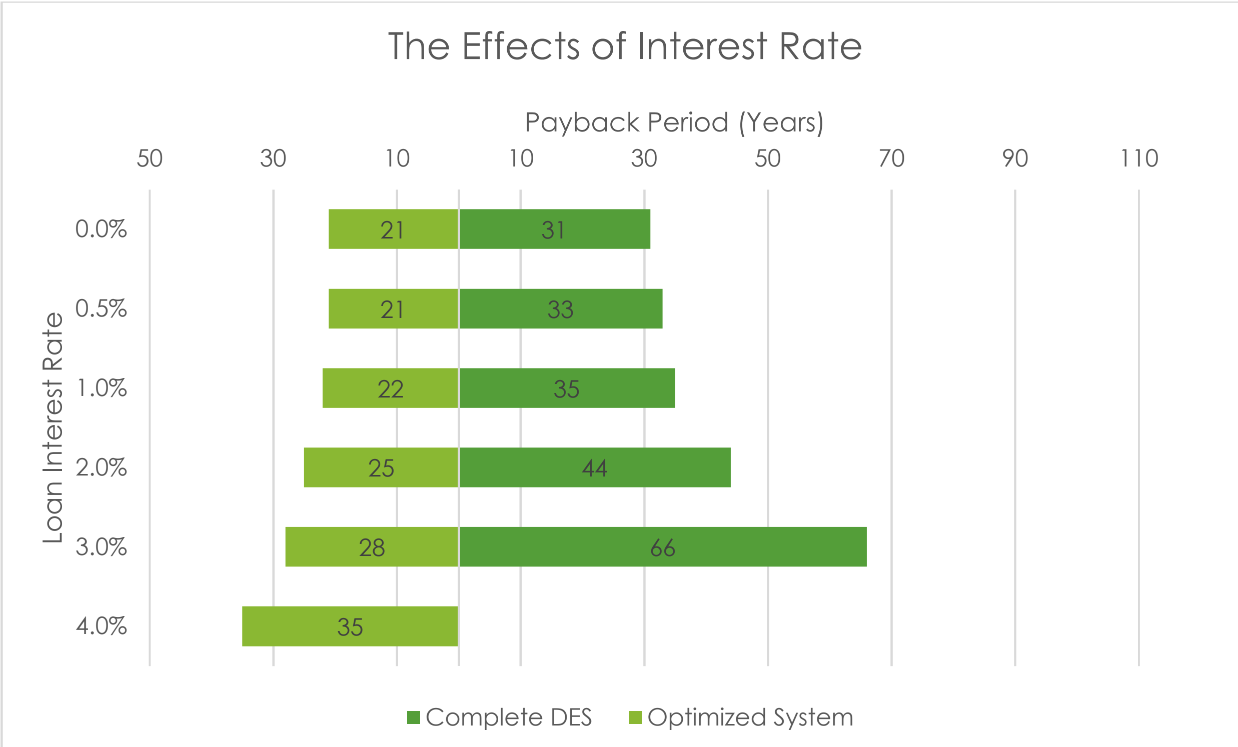



**Figure 78 - The Effect of Interest Rate on Payback Period**

The results of this analysis present dramatic differences between the optimized system and the entire system. With a fixed cost of 10$/GJ, as the loan interest rate increases, the disparity in payback periods between the two systems also increases. This increase, however, maintains a difference of roughly 40% and increases with the interest rate between both systems. This information is important; if the project is looking at a certain payback period (e.g. 20 or 40 years), the timeline can be met by either obtaining lower interest rates or through system optimization as demonstrated.

#### 5.3.7.2 Revenue Gained / Price of Heat ($/GJ)

Another method to decrease payback period is by increasing the cost per GJ. As shown in Table 46 and Table 47, increasing the charge per GJ decreases the payback period. For the entire DES, at $10/GJ, the revenue is roughly $1.2 million/year. With an increase in price of 50% to $12/GJ, the revenue increases proportionally to $1.65 million/year.

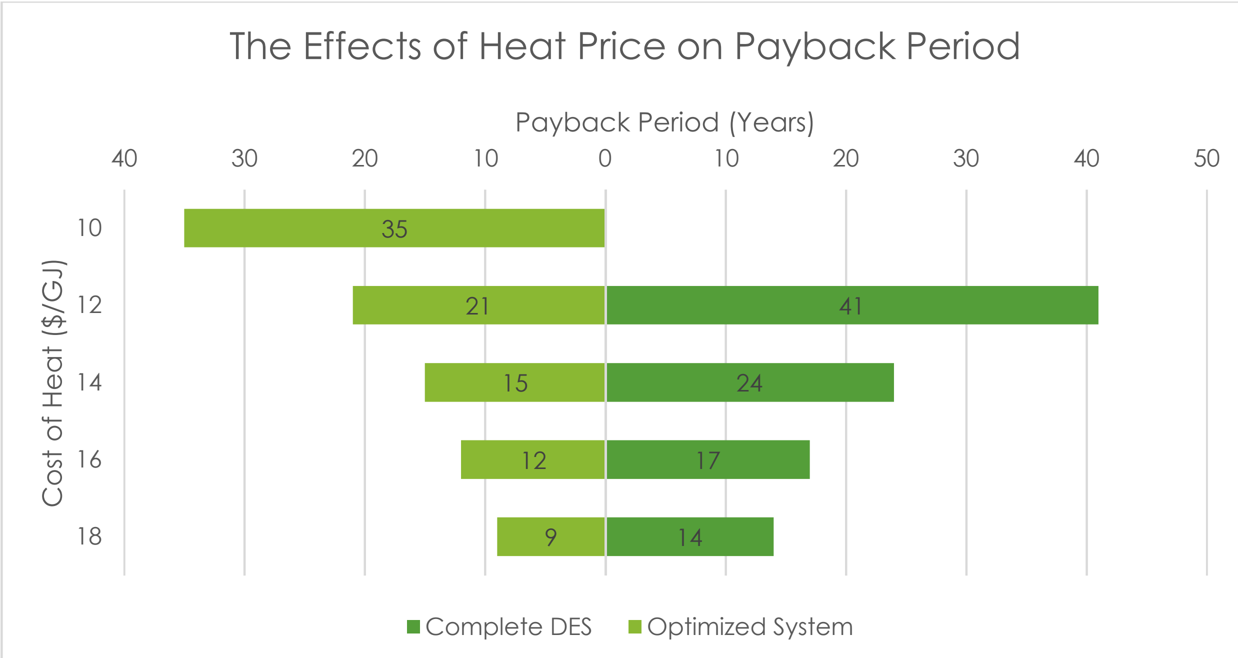



**Figure 79 - The Effect of Heat Price on Payback Period**

Although not as dramatic as changing the interest rate, at a fixed interest rate of 4%, the payback period decreases as revenue increases. A 20% increase of revenue (to $12/GJ) decreases the payback period by 40% in the optimized system. Comparing the performance of the optimized and complete system between 12 and 14 $/GJ heat price, the revenue increases by 16.7% (2$/GJ) but the payback period in the optimized system is reduced by 29% (6 years), and in the complete DES it is reduced by 41% (17 years). Increasing revenue by 60% total (to $16/GJ) further decreases in payback period by 66% (23 years) in the optimized system. This analysis presents diminishing returns by increasing the price of heat, with the optimal price for both owner and consumer near $12/GJ.

#### 5.3.7.3 Initial Capital Cost

The last variable modified was the initial capital cost. This can be done through either grants, subsidies and/or cost savings with other utilities, and tax allowances (refer to Appendix F for potential CRA opportunities). This variable provides a similar effect to modifying interest rates, as decreasing the initial capital cost also decreases the annual interest payments.

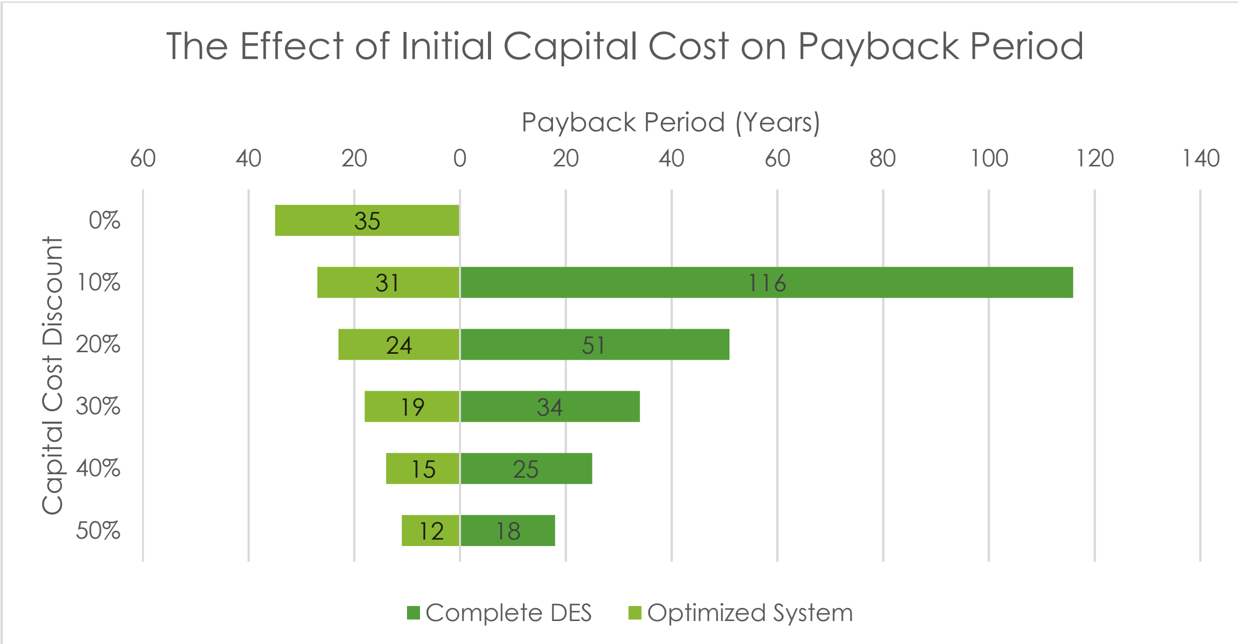



**Figure 80 - The Effect of Initial Capital Cost on Payback Period**

The discount rate shown in Figure 80 is applied directly to the initial capital cost, with the interest rate fixed at 4% and heat price fixed at $10/GJ.

As expected, decreasing the initial capital cost decreases the payback period. This trend is almost proportional in both systems as every incremental drop of 10% in capital cost decreases the payback period by roughly 25%. The Complete DES is not economically feasible until the initial capital cost is decreased by 10%. When the initial capital cost decreases further to 50%, the payback period decreases by 66% (23 years) for the optimized system, and from 00% to 50% discount for the complete DES it drops by 84% (98 years). Similar to the pattern in the effect of revenue, discount rate also has diminishing returns, with the most benefits to payback period occurring at the first 10%.

### 5.3.8 Midstream Cost Summary

The town's geographical footprint and elevation changes are substantial compared to the energy requirement of the Town of Hinton. The energy density in the core of Hinton is low, but with infrastructure planning utilizing open and available land for future heat intense industries (i.e. greenhouse, brewery, etc.) this energy density can be increased in the core of Hinton.

The total cost of the optimized system; including the District Energy Centre, District Energy System and the external building tie-ins (hotbox) is:

**Table 48 - Midstream Cost Summary**

| | |
|---|---|
| District Energy Centre | $2,600,000 |
| District Energy System | $10,750,000 |
| Energy Transfer Station | $1,400,000 |
| | $14,750,000 |

There could be cost savings with partnering with other infrastructure projects occurring at the same time. There could also be savings if there is room in each building to put the energy transfer station as opposed to having to house it in an external building that contains of all the equipment.

In summary, decreasing the interest rate and capital cost both have positive effects on the project. Increasing revenue (i.e. Price per GJ) will decrease the payback period; however, increased pricing will be perceived negatively by potential consumers, as they will no longer have any financial incentive to enroll in this project.

At this stage, based on the numbers provided, constructing the DES to the final design, eliminating the uneconomic Zones 3 and 4 and any other nodes/buildings that are deemed infeasible (if not enough customers sign up along a zone).

Other variables to review are:

- Securing funding at a lower interest rate,
- Constructing the more profitable zones, then use the revenue gained to fund the remaining Zones, and/or
- Decreasing the initial capital cost, which may be done by: utilizing innovative technology, completing further detailed engineering for the estimates, or a joint venture between other utilities to construct a shared utility corridor with upgrade services to the communities. Potential partnerships may exist with the new water treatment plant being built by ISL, as the construction right of way (ROW) proposed for the Hinton DES follow along the same ROW as the water lines.

## 5.4 Downstream Costs

This section included the cost of tying in the buildings to the DES as well as the cost of providing an Energy Audit of the building system to further increase the energy efficiency of the building.

The cost of tying in an existing hydronic system (discussed in Section 4.3.2) ranges from $5800 (Fire Station and Police Station) to $37,000 (Hospital and Hinton Recreation Complex). If there was no room in the mechanical rooms, the costs would be approximately $40,000 and would be encompassed in the Midstream Energy Transfer Station costs.

Epoch and Williams Engineering were not able to access a substantial amount of buildings in the study to review the mechanical rooms or existing heating and cooling systems due to government privacy concerns or a negative response (or lack of response) from other buildings. As such, a very conservative estimate to convert each building was applied. This can be seen in Section 4.4.

The total Downstream costs for the Complete 53 building system and the Optimized 38 building system are compared in the table below.

**Table 49 - Downstream Cost Summary, Complete vs. Optimized Systems**

| | Complete (53 buildings) | Optimized (38 buildings) |
|---|---|---|
| Tie-in Costs | $760,000 | $560,000 |
| Cost to Convert to Hydronic | $15.05 million | $11.3 million |

| | | |
|---|---|---|
| Total | $15.8 million | $11.8 million |

## 5.5 Financial Summary

The payback period of the District Energy System was calculated based on:

- $10/GJ delivered price, which, based in current inflation and scheduled carbon levy, will be the average price between 2021 and 2022
- An interest rate of 4%
- No qualifications for any provincial or government subsidies or grants
- No cost savings with partnering with other utilities

The main parameters for developing a District Energy System for the Town of Hinton that is economically viable are:

1. Interest rate of debt: Decreasing the interest rate from 4% to 2% by utilizing municipal bonds will reduce the payback period from 35 years to 25 years,
2. Price of Energy: Increasing the price of delivered energy from $10/GJ to $12/GJ will reduce the payback period from 35 years to 21 years. This may only be feasible if the future gas price increases substantially as part of the province's coal plant retirement, or by an increase in carbon levy beyond $50/tonne $CO_2$ after 2022,
3. Reduction in capital costs: The capital cost of the project can be reduced by many existing methods. Green energy grants by provincial and federal governments, working with planned infrastructure to reduce installation costs, or sharing the cost of trenching with data companies so fibre optics and DES piping are installed in the same trench.

Based on the financial analysis, if municipal bonds are used at an interest rate of 2%, with a price of heat of $10/GJ and a capital cost reduction of 30% due to grants and cost sharing then the payback period is 15 years.

# 6 Conclusions & Recommendations

## 6.1 Conclusions

Significant historical and ongoing research has shown the Town of Hinton to be located in an area of high geothermal potential. While the regional geology has shown to be favourable, the localized geology within a radius of approximately 34 km of the Town of Hinton has proven to be more complex than anticipated. The lack of water bearing reservoirs with appropriate characteristics, extensive folding, well documented pressure issues and the presence of hydrogen sulphide (H2S) all combine to present a challenging environment to extract heat, both technically and economically. Four geological zones were assessed for their viability as geothermal targets: Devonian, Mississippian, the Cretaceous Spirit River and the Cretaceous Cardium. Though shallow and potentially not hot enough, the Cardium was identified as having favourable reservoir characteristics, and having the least amount of risk where drilling is concerned.

Repurposing wells for geothermal heat extraction was found to be unviable both geologically and due to procurement issues as local well owners were reluctant to release wells. While not originally intended to be included within the scope of the project, the option of drilling new wells was explored. The previously-stated subsurface challenges made designing a well difficult. The well design settled upon was a 4,300m long single well scenario that utilized closed-loop circulation and had a 500m horizontal section (3,965m vertical depth). This well was estimated to cost around $6 million.

The required District Energy infrastructure is outlined and described in this project. The Town of Hinton exhibits some characteristics unfavourable to District Energy System design: the heating loads are spread out over a large area and there is an elevation change that complicates network design. The 53 buildings were separated into 4 branches, centered at the Friendship Centre where the District Energy Centre would be located. The design of the District Energy System was determined over 10 successive iterations. The Complete District Energy System, which consisted of four branches going NW, NE, SE and SW from the District Energy Centre, was then optimized to eliminate areas that were unprofitable. This Optimized District Energy System configuration involved only branches going NW and NE, as the branches going SE and SW were deemed unprofitable.

The design of the Midstream portion is heat agnostic and can be fundamentally applied to any town or city that have potential for District Heating. A District Energy System that is heated by other sources (biomass, natural gas, waste heat recovery) was shown to be technically and economically feasible.

The District Energy Centre was estimated to cost $4.7 million for the Complete system with 53 buildings, and $2.6 million for the Optimized system of 38 buildings. Piping material options were identified; a combination of both Steel and PexR piping was suggested with an estimated cost of $16 million for the pipeline distribution network for the Complete system and $11 million for the Optimized system.

The individual building infrastructure of existing heating systems and design were analyzed and their feasibility for incorporating into the DES is outlined. Not all buildings were able to be accessed; the true tie-in cost for those buildings remains unknown. On average the downstream cost was estimated to be $40,000/tie-in.

The financial analysis determined that the main parameters for developing a District Energy System for the Town of Hinton that is economically viable are the interest rate of debt, the price of energy and the reduction of capital costs. If municipal bonds are used at 2%, with a price of heat of $10/GJ and a cost reduction of 30% due to grants and cost sharing, the payback period reduces to 15 years.

## 6.2 Recommendations

The energy density in the core of Hinton is low, but with infrastructure planning utilizing open and available land for future heat intense industries (i.e. greenhouse, brewery, etc.) this energy density can be increased in the core of Hinton.

If the Town is solely interested in providing low-carbon, sustainable heating, an alternative viable heat source to supply the designed District Energy System will need to be determined.

Further studies and detailed engineering will require confirmed building specifics to satisfy design needs. More engagement will be needed with end-users in order to increase project buy-in.

If the Town is interested in generating low-carbon heat and power, due to the forecasted combined energy and transmission power prices to nearly double to $130/MWhr by 2022, a project to review a combined geothermal heat and power plant to justify the capital required to develop the technically complex but significant heat resource in Hinton is recommended.

# References


[1] Alberta Energy Regulator (AER), "About AER," [Online]. Available: https://www.aer.ca/about-aer. [Accessed 7 March 2017].

[2] PetroPedia, "Well Casing," [Online]. Available: https://www.petropedia.com/definition/7108/well-casing. [Accessed 7 March 2017].

[3] Hinton 2040, "Purpose of the Community Sustainability Plan," [Online]. Available: http://www.hinton2040.ca/163/Purpose-of-the-Community-Sustainability-. [Accessed 7 March 2017].

[4] J. e. a. Donev, "Energy Education - Levelized cost of energy," 2018. [Online]. Available: https://energyeducation.ca/encyclopedia/Levelized_cost_of_energy. [Accessed 19 09 2018].

[5] Hinton Town Council, "Hinton 2040- Who Are We," [Online]. Available: https://www.hinton2040.ca/166/Who-Are-We. [Accessed 30 July 2018].

[6] Hinton 2040, "A Bold & Vibrant Future," [Online]. Available: http://www.hinton2040.ca/159/A-Bold-Vibrant-Future . [Accessed 7 March 2017].

[7] Athabasca University, "Hinton & Grande Cache Sustainability Project - The Project," 2011. [Online]. Available: http://arbri.athabascau.ca/hinton-gc/about.php?page=project. [Accessed 7 March 2017].

[8] D. J. Banks, "Deep-Dive Analysis of the Best Geothermal Reservoirs for Commerical Development in Alberta: Final Report," University of Alberta, Edmonton, 2017.

[9] H. J. F. L. C. Lam, "Geothermal gradients in the Hinton area of west-central Alberta," *Canadian Journal of Earth Sciences,* vol. 19, pp. 755-766, 1982.

[10] H. a. J. F. Lam, "A statistical analysis of bottom-hole temperature data in the Hinton area of West-Central Alberta," *Tectonophysics,* vol. 103, pp. 273-281, 1984.

[11] H. Lam and F. Jones, "Geothermal energy potential in the Hinton-Edson area of west-central Alberta," *Canadian Journal of Earth Sciences,* vol. 22, pp. 369-383, 1985.

[12] Core Laboratories, *Stratigraphic Correlation Chart,* Calgary, Alberta: Core Laboratories, 2016.

[13] S. M. I. M. J. P. D. a. G. M. Weides, "Geothermal Exploration of Paleozoic formation in Central Alberta," *Canadian Journal of Earth Sciences,* vol. 50, pp. 519-534, 2013.

[14] J. Andrichuk, "Stratigraphy and fades analysis of Upper Devonian reefs in Leduc, Stettler, and Redwater areas, Alberta," *AAPG Bulletin, American Association of Petroleum Geologists,* vol. 42, pp. 1-93, 1958.

[15] D. Cant, "Spirit River Formation: A stratigraphic-diagenetic gas trap in the Deep Basin of Alberta," *The American Association of Petroleum Geologists Bulletin,* vol. 67, no. 4, pp. 577-587, 1983.

[16] D. Cant, "Development of shoreline-shelf sand bodies in a Cretaceous epeiric sea deposit," *Journal of Sedimentary Petrology,* vol. 54, no. 2, pp. 541-556, 1984.

[17] D. Cant, "Sequence stratigraphic analysis of individual depositional successions: Effects of marine-nonmarine sediment partitioning, and longitudinal sediment transport, Mannville Group, Alberta foreland basin, Canada," *American Association of Petroleum Geologists Bulletin,* vol. 79, pp. 749-762, 1995.

[18] B. H. B. Nodwell, "Deeply-rooted paleobathymetric control on the deposition of the Falher F conglomerate trend, Wapiti Field, Deep Basin, Alberta," *Bulletin of Canadian Petroleum Geology,* vol. 54, no. 1, pp. 1-21, 2006.

[19] G. a. P. S. Schmidt, "Stratigraphy and paleogeography of a conglomeratic shoreline: the Notikewin Member of the Spirit River Formation in the Wapiti area of west-central Alberta," *Bulletin of Canadian Petroleum Geology,* vol. 52, no. 1, pp. 57-76, 2004.

[20] J. a. P. A. Shank, "Allostratigraphy of the Upper Cretaceous Cardium Formation in subsurface and outcrop in southern Alberta, and correlation to equivalent strata in northwestern Montana," *Bulletin of Canadian Petroleum Geology,* vol. 61, no. 1, pp. 1-40, 2013.

[21] D. a. E. R. Pana, *Geology of the Alberta Rocky Mountains and Foothills. Alberta Geological Survey Map 560, scale 1:500000,* Alberta Geological Survey, 2013.

[22] C. a. L. J. Langenberg, *Geological Map: Coal Valley, NTS Mapsheet 83F/2. Alberta Geological Survey Map 237, Scale 1:50,000.,* Alberta Geological Survey, 2000.

[23] G. L. D. M. M. a. M. P. Stockmal, "Structural style and evolution of the triangle zone and external Foothills, southwestern Alberta: Implications for thin-skinned thrust-and-fold belt mechanics," *Bulletin of Canadian Peroleum Geology,* vol. 49, no. 04, pp. 472-496, 2001.

[24] W. P. N. a. C. D. Hamilton, *Geology and mineral deposits of the Yellowhead Corridor (Hinton-Entrance and Cadomin Sheets). Alberta Geological Survey Map 234A, scale 1:100000,* Alberta Geological Survey, 1998.

[25] Alberta Energy Regulator, "Directive 056: Energy Development Applications and Schedules," 01 09 2011. [Online]. Available: https://www.aer.ca/documents/directives/Directive056.pdf. [Accessed 01 08 2018].

[26] Canadian Association of Petroleum Producers, "H2S Release Rate Assessment and Audit Forms July 2012," 08 2012. [Online]. Available: https://www.capp.ca/publications-and-statistics/publications/211237. [Accessed 08 2018].

[27] Agency for Toxic substances & Disease Registry, "Toxic Substances Portal - Hydrogen Sulfide Carbonyl Sulfide," [Online]. Available: https://www.atsdr.cdc.gov/MHMI/mmg114.pdf. [Accessed 05 09 2018].

[28] Work Safe Alberta, "Workplace Health and Safety Bulletin - Hydrogen Sulphide at the Work site," 08 2010. [Online]. Available: https://work.alberta.ca/documents/WHS-PUB-CH029.pdf. [Accessed 05 09 2018].

[29] American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., "Chapter 22 - PIPE SIZING," in *ASHRAE Handbook - Fundamentals*, Atlanta, GA, ASHRAE, 2009.

[30] Urecon Ltd., "PREINSULATED FLEXIBLE SYSTEMS PRODUCT: PEX-FLEX PRODUCT GUIDE AND TECHNICAL MANUAL," URECON LTD., 2015.

[31] LOGSTOR, "Design Manual," 12 2015. [Online]. Available: httpd://www.logstor.com/media/5342/design-201512a.pdf. [Accessed 01 01 2018].

[32] Radius - Kelit Infrastructure, "FiberFlex Product Catalogue," [Online]. Available: http://www.radius-kelit.com/en/wp-content/uploads/sites/2/2015/09/FibreFlex_ProductCatalogue_201705_WEB.pdf. [Accessed 15 09 2018].

[33] LOGSTOR, "Pre-Insulated Pipes for Industrial Applications," [Online]. Available: https://www.logstor.com/media/1413/industry-general_en_p_in.pdf. [Accessed 01 03 2018].

[34] JGD District Heating, "LOGSTOR Detect Surveillance System," JGD District Heating, [Online]. Available: https://jgd-districtheating.com/logstor-surveillance-system-logstor-detect.php. [Accessed 15 09 2018].

[35] Government of Alberta, "Current and Historical Alberta Weather Station Data Viewer," 2018. [Online]. Available: https://agriculture.alberta.ca/acis/alberta-weather-data-viewer.jsp. [Accessed 01 04 2018].

[36] Town of Hinton, "Municipal Development Plan," 05 09 2017. [Online]. Available: https://www.hinton.ca/DocumentCenter/View/6480/Municipal-Development-Plan-No-1084---Consolidation-March-2018. [Accessed 28 01 2018].

[37] GEODH, "GEODH Home," [Online]. Available: http://geodh.eu/. [Accessed 7 March 2017].

[38] J. Barnard, *Oregon Town Warmed by Geothermal Energy,* Klamath Falls, Oregon: CBS News, 2010.

[39] Government of Canada, "Canadian Climate Normals," 2018. [Online]. Available: http://climate.weather.gc.ca/climate_normals/. [Accessed 24 03 2018].

[40] American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., "Chapter 51 - Snow Melting and Freeze Protection," in *ASHRAE Handbook - HVAC Applications*, Atlanta, GA, ASHRAE, 2015.

[41] ASHRAE, "S12 District Heating and Cooling," in *ASHRAE Handbook - HVAC Systems and Equipment*, 2016, p. 12.13.

[42] Y. B. R. Bengali, "Tech Talk: Water Hammer & Pulsation," Ryan Herco Flow Solutions, [Online]. Available: https://www.rhfs.com/pulse/water-hammer-pulsation/. [Accessed 14 09 2018].

[43] ASHRAE, "Pipe Sizing," in *ASHRAE Handbook - Fundamentals*, 2009, p. 22.6.

[44] European Committee for Standardization, "Scope," in *EN 13941 Prefabricated district heating pipe systems*, European Committee for Standardization, 2003, p. 9.

[45] Town of Hinton, "Minimum Engineering Design Standards," 09 2007. [Online]. Available: https://www.hinton.ca/DocumentCenter/View/484/Hinton-2007-Minimum-Engineering-Design-Standards?bidId=. [Accessed 02 03 2018].

[46] PPSL District Heating Ltd., "PPSL District Heating Ltd.," Facebook, [Online]. Available: https://www.facebook.com/PPSL-District-Heating-Ltd-936936373022092/. [Accessed 14 09 2018].

[47] American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., "Chatper 34 - Geothermal Energy," in *ASHRAE Handbook - HVAC Applications*, Atlanta, GA, American Society of Heating, Refrigerating and Air-Conditioning Engineers, 2011.

[48] Urecon Ltd., "Ambient Temperatures - Below Ground," Urecon Ltd., 2009-2018. [Online]. Available: http://www.urecon.com/applications/municipal_ambient_below.html. [Accessed 01 02 2018].

[49] ASHRAE, "CENTRAL PLANT DESIGN FOR LOW-TEMPERATURE WATER," in *District Heating Guide*, Atlanta, GA, W. Stephen Cornstock, 2013.

[50] Griswold Pump Company, "Griswold 811 Performance Curves," Griswold Pump Company, Grand Terrace, CA, 2012.

[51] American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., "CHAPTER 12 - DISTRICT HEATING AND COOLING," in *2016 ASHRAE Handbook - HVAC Systems and Equipment (SI)*, Atlanta, GA, ASHRAE, 2016.

[52] Bell & Gossett, "Tangential Air Separators - Rolairtrol Air Separator Hot & Chilled Water," Bell & Gossett, [Online]. Available: http://bellgossett.com/air-sediment-control-expansion/tangential-air-separators/rolairtrol-air-separator-for-hot-and-chilled-water-systems/. [Accessed 15 09 2018].

[53] Wikipedia, "Shell and tube heat exchanger," [Online]. Available: https://en.wikipedia.org/wiki/Shell_and_tube_heat_exchanger. [Accessed 15 09 2018].

[54] Engineering Solutions, "Plate-and-shell-heat-exchangers," [Online]. Available: https://www.mechlectures.com/heat-exchanger-types/plate-and-shell-heat-exchangers/. [Accessed 15 09 2018].

[55] ASHRAE, "Central Plant Design for Steam and Hot Water," in *District Heating Guide*, Atlanta, GA, W. Stephen Cornstock, 2013.

[56] Emerson Electric Co., "Fisher easy-Drive Electric Actuator," Emerson Electric Co., [Online]. Available: https://www.emerson.com/en-us/catalog/fisher-easy-drive. [Accessed 15 09 2018].

[57] American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., "Capacity Control of Load System," in *Chapter 12 - HYDRONIC HEATING AND COOLING SYSTEM DESIGN*, Atlanta, GA, ASHRAE, 2008.

[58] Alberta Environment, "Emissions Guidelines for Oxides of Nitrogen (NOx) for New Boilers, Heaters, and Turbines Using Gaseous Fuels Based on a Review of Best Available Technology Economically Achievable (BATEA)," 14 12 2007. [Online]. Available: http://aep.alberta.ca/air/legislation-and-policy/documents/EmissionGuidelinesOxidesNitrogen-2007.pdf. [Accessed 12 06 2018].

[59] Province of Alberta, "SAFETY CODES ACT," 01 12 2017. [Online]. Available: http://www.qp.alberta.ca/documents/Acts/S01.pdf. [Accessed 01 08 2018].

[60] Alberta Boilers Safety Association, "Submission Requirements for Registration of Pressure Piping Designs in Alberta," ABSA, 13 09 2016. [Online]. Available: http://www.absa.ca/design-registration/pressure-piping-design/guidelines-for-registration/. [Accessed 01 08 2018].

[61] AEP, "Alberta's Environmental Assessment Process," Government of Alberta, Edmonton, 2015.

[62] Province of Alberta, "Environmental Assessment (Mandatory and Exempted Activites) Regulation," Alberta Queen's Printer, Edmonton, 2017.

[63] Town of Hinton, "LAND USE BYLAW," 06 09 2016. [Online]. Available: https://www.hinton.ca/DocumentCenter/View/4967/Land-Use-Bylaw-1088. [Accessed 01 08 2018].

[64] Office of Energy Efficiency - Natural Resources Canada, "Comprehensive Energy Use Database," Natural Resources Canada - Government of Canada, [Online]. Available: http://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/menus/trends/comprehensive/trends_com_ab.cfm. [Accessed 8 March 2017].

[65] The Weather Network, "Degree Days Summary for Jasper-Hinton," [Online]. Available: https://www.theweathernetwork.com/api/sitewrapper/index?b=%2Fstatistics%2F&p=%2Fforecasts%2Fstatistics%2Findex&url=%2Fstatistics%2Fdegreedays%2Fcl3063526%2F%2F%2F%3F. [Accessed 15 August 2018].

[66] Wikipedia, "District Heating Substation," [Online]. Available: https://en.wikipedia.org/wiki/District_heating_substation. [Accessed 15 August 2018].

[67] Hanscomb, *Hanscomb Yardsticks for Costing - Cost Data for the Canadian Construction Industry, RS Means,* 2015.

[68] Government of Alberta, "Carbon Levy and Rebates," [Online]. Available: https://www.alberta.ca/climate-carbon-pricing.aspx. [Accessed 15 09 2018].

[69] UNEP, "DES at COP21 Summary," 2015. [Online]. Available: http://districtenergyinitiative.org/report/DES_at_COP21_Summary.pdf . [Accessed 7 March 2017].

[70] A. Richter, "Could geothermal district heating literally be the answer right beneath our feet?," ThinkGeoEnergy, 19 April 2016. [Online]. Available: http://www.thinkgeoenergy.com/could-geothermal-district-heating-literally-be-the-answer-right-beneath-our-feet/. [Accessed 7 March 2017].

[71] A. Shabbar, "University of Toronto: One hundred years of district energy," 2012. [Online]. Available: http://www.fs.utoronto.ca/wp-content/uploads/2015/12/centennialarticle_university_of_toronto_districtenergysystem.pdf. [Accessed 7 March 2017].

[72] P. Bohan, "District Energy and Combined Heat and Power," 9 December 2015. [Online]. Available: http://www.districtenergy.org/assets/pdfs/2015-Canada-EvolvingEnergy/1A.3Bohan.pdf. [Accessed 7 March 2017].

[73] EGEC - European Geothermal Energy Council, "Geothermal District Heating," 2011. [Online]. Available: http://egec.info/wp-content/uploads/2011/03/Brochure-DISTRICT-HEATING1.pdf. [Accessed 7 March 2017].

[74] GEODH, "What is Geothermal District Heating?," [Online]. Available: http://geodh.eu/about-geothermal-district-heating/. [Accessed 7 March 2017].

[75] Neighbourhood Energy Utility, "Vancouver Renewable Energy Neighbourhood Utility Factsheet," Vancouver Green Capital, Vancouver, BC.

[76] Town of Hinton Citizen Advisory Group, "The Hinton Community Sustainability Plan," 17 May 2011. [Online]. Available: https://www.hinton.ca/DocumentCenter/View/5192/The-Hinton-Community-Sustainability-Plan---Adopted-by-Council-May-17-2011?bidId=. [Accessed 15 August 2018].

[77] R. Price, "The southeastern Canadian Cordillera: thrust faulting," *Journal of Structural Geology,* vol. 8, pp. 239-254, 1986.

[78] D. E. Boerner, R. D. Kurtz, J. A. Craven, G. M. Ross and F. W. Jones, "A synthesis of electromagnetic studies in the Lithoprobe Alberta Basement Transect: constraints on Paleoproterozoic indentation tectonics," *Canadian Journal of Earth Sciences,* vol. 37, p. 1509, 2000.

[79] D. Kent, "Paleogeographic evolution of the crationic platform - Cambrian to Triassic," in *Geological Atlas of the Western Canadian Sedimentary Basin*, Canadian Society of Petroleum Geologists & Alberta Research Council, 1994, pp. 69-84.

[80] D. Smith, "Paleogeographic evolution of the western Canada foreland basin," in *Geological Atlas of the Western Canadian Sedimentary Basin*, Canadian Society of Petroleum Geologists & Alberta Research Council, 1994, pp. 277-296.

[81] G. Foo, S. Friley, T. Wasik and M. Douglas, "Co-Produced Fluid Geothermal Electricity Generation in the Western Canada Sedimentary Basin - A study of feasibility in conjunction with CanGEA and Nexen Inc.," 2008.

[82] A. Jessop, "Thermal Geophysics," *Elsevier,* p. 316, 1990.

[83] A. Jessop, "Thermal input from the basement of the Western Canadian Sedimentary Basin," *Bulletin of Canadian Petroleum Geologists,* vol. 40, pp. 198-206, 1992.

[84] R. Burwash and R. Burwash, "A radioactive heat generation map for the subsurface Precambrian of Alberta," *Geological Survey of Canada Paper,* vol. 89, pp. 363-368, 1989.

[85] S. Bachu and R. Burwash, "Regional-scale analysis of the geothermal regime in the Western Canada Sedimentary Basin," *Geothermics,* vol. 20, pp. 387-407, 1991.

[86] CanGEA, "Canadian National Geothermal Database and Provincial Resource Estimate Maps - Alberta Geothermal Favourability Maps," 2013. [Online]. Available: http://www.cangea.ca/alberta-geothermal-favourability-maps.html . [Accessed 7 March 2017].

[87] G. Nieuwenhuis, T. Lengyel, J. Majorowicz, M. Grobe, B. Rostron, M. Unsworth and S. Weides, "Regional-Scale Geothermal Exploration Using Heterogeneous Industrial Temperature Data; A Case Study from the Western Canadian Sedimentary Basin," in *Proceedings World Geothermal Congress*, Melbourne, Australia, 2015.

[88] Alberta Agriculture and Forestry, "Hinton Training Centre," [Online]. Available: https://extranet.gov.ab.ca/env/htc/. [Accessed 7 March 2017].

[89] Hinton & District Chamber of Commerce, "GROW - Hinton's Future Plans," [Online]. Available: http://www.hintonchamber.com/grow/future-plans . [Accessed 7 March 2017].

[90] S. Lawrynuik, "Geothermal energy research in Alberta making strides with new technology," 6 June 2016. [Online]. Available: http://www.cbc.ca/news/canada/calgary/geothermal-research-alberta-1.3616014. [Accessed 7 March 2017].

[91] K. Schaefer, "Can This Idea Save the Orphaned Wells," 19 December 2016. [Online]. Available: https://oilandgas-investments.com/2016/energy-services/can-this-idea-save-the-orphaned-wells/ . [Accessed 7 March 2017].

[92] A. Jessop, "Terrestrial Heat Flow in Canada," in *Neotectonics of North America: Geological Society of America Decade Map Vol. 1*, Boulder, 1990.

[93] International Energy Agency, "Key World Energy Statistics," 2016. [Online]. Available: http://www.iea.org/publications/freepublications/publication/key-world-energy-statistics.html . [Accessed 7 March 2017].

[94] Hot Rock Ltd., "The Koroit Geothermal Project - Presentation to Hawkesdale P12 College," Brisbane, 2010.

[95] T. Lewis, "Geothermal energy from Penticton Tertiary Outlier, British Columbia," *Canadian Journal of Earth Sciences,* vol. 21, pp. 181-188, 1984.

[96] J. Majorowicz, "Heat flow–heat production relationship not found: what drives heat flow variability of the Western Canadian foreland basin?," *International Journal of Earth Sciences,* 2016.

[97] E. Barbier, "Geothermal energy technology and current status: an overview," *Renewable and Sustainable Energy Reviews,* vol. 6, pp. 3-65, 2002.

[98] Alberta Energy Regulator (AER), "Inactive Well Compliance Program - Year One Final Report," AER, 2016.

[99] Enwave, "Enwave: Deep Lake Water Cooling - Keeping Toronto cool Case Study," Canadian District Energy Association (CDEA), Toronto, 2007.

[100] Logstor, "District Heating - Himmelev, Denmark Case Study," [Online]. Available: https://www.logstor.com/district-heating/cases/himmelev-denmark. [Accessed 8 March 2017].

[101] Logstor, "Design with TwinPipes Manual," 2016. [Online]. Available: https://www.logstor.com/media/5355/design-with-twinpipes-201608.pdf. [Accessed 8 March 2017].

[102] Northern Outdoor, "Underground Piping Options," [Online]. Available: http://www.northernoutdoor.ca/supplies-parts/underground-piping-electrical. [Accessed 8 March 2017].

[103] LOGSTOR, "LOGSTOR pre-insulated pipe technology," [Online]. Available: https://www.logstor.com/media/1837/logstor-pipes_en_p_dh.pdf. [Accessed 8 March 2017].

[104] Danfoss, "Product: District Heating Transfer Substation," [Online]. Available: http://products.danfoss.com/productrange/visuals/heatingsolutions/substations-heat-transfer-solutions/substations-indirect-heating-dhw/dsp-1-maxi/#/. [Accessed 8 March 2017].

[105] Evinox Energy, "Heat Meters - Commercial & Industrial Range RC50-600," [Online]. Available:

http://www.evinoxenergy.co.uk/Sites/Evinox/library/files/Commercial%20Meters%20Data%20Sheet%20429C-1.pdf. [Accessed 8 March 2017].

[106] R. Thériault and G. Ross, "Nd isotopic evidence for crustal recycling in the ca. 2.0 Ga sub surface of Western Canada," *Canadian Journal of Earth Sciences,* vol. 28, pp. 1140-1147, 1991.

[107] J. Mareschal, C. Jaupart, L. Gariepy and e. al., "Heat flow and deep thermal structure near the southeastern edge of the Canadian Shield," *Canadian Journal of Earth Sciences,* vol. 37, pp. 399-414, 2000.

[108] A. Jessop and T. Lewis, "Heat flow and heat generation in the Superior Province of the Canadian Shield," *Tectonophysics,* vol. 50, pp. 55-77, 1978.

[109] J. Majorowicz and S. Grasby, "Heat flow, depth--temperature variations and stored thermal energy for enhanced geothermal systems in Canada," *Journal of Geophysics and Engineering,* vol. 7, pp. 232-241, 2010.

[110] J. Tester, B. Anderson, A. Batchelor, D. Blackwell, R. DiPippo, E. Drake and e. al., "The Future of Geothermal Energy - Impact of Enhanced Geothemal Systems (EGS) on the United States in the 21st Century," MIT - Massachusetts Institute of Technology, Cambridge, MA, 2006.

[111] C. Williams, M. Reed and R. Mariner, "A review of methods applied by the U.S. Geological Survey in the assessment of identified geothermal resources - USGS Survey Open File Report 2008--1296," U.S. Geological Survey (USGS), 2008.

[112] G. Van Hal, "Legal Obstacles to the Development of Geothermal Energy in Alberta," *Canadian Institute of Resources Law,* vol. CIRL Occasional Paper #42, p. 43, 2013.

[113] F. W. Jones, C. Kushigbor, H. L. Lam, J. A. Majorowicz and M. Rahman, "Estimates of terrestrial thermal gradients and heat flow variations with depth in the Hinton-Edson area of the Alberta basin derived from petroleum bottom-hole temperature data," *Geophysical Prospecting,* pp. 1111-1130, 1984.

[114] S. Bachu and R. Burwash, "Geothermal regime in the Western Canadian Sedimentary Basin," in *Geological Atlas of the Western Canadian Sedimentary Basin*, Canadian Society of Petroleum Geologists & Alberta Research Council, 1994, pp. 447-454.

[115] G. Reinson, W. Warters, J. Cox and P. Price, "Chapter 21 - Cretaceous Viking Formation of the Western Canadian Sedimentary Basin," in *Geological Atlas of the WCSB*, Canadian Society of Petroleum Geologists & Alberta Research Council, 1994, pp. 353-363.

[116] S. Weides and J. Majorowicz, "Implications of Spatial Variability in Heat Flow for Geothermal Resource Evaluation in Large Foreland Basins: The Case of the Western Canada Sedimentary Basin," *Energies,* vol. 7, pp. 2573-2594, 2014.

[117] B. Hayes, J. Christopher, L. Rosenthal, G. Los, B. McKercher, B. Minken, Y. Tremblay and J. Fennell, "Cretaceous Mannville Group of the Western Canada Sedimentary Basin," in *Geological Atlas of the Western Canada Sedimentary Basin; Special Report*, Edmonton, Canadian Society of Petroleum Geologists & Alberta Research Council, 1994, pp. 317-334.

[118] Urecon, "Pre-insulated Flexible Systems Product: Pex-Flex Product Guide & Technical Manual," Urecon Ltd., 2016.

[119] Urecon, "Pex-Flex and EN253 Pipe Price List 2017," 2017.

[120] Alberta Geological Survey; Alberta Energy Regulator, "Alberta Table of Formations," 2015. [Online]. Available: http://ags.aer.ca/document/Table-of-Formations.pdf. [Accessed 7 March 2017].

[121] K. Bastedo, "Sedimentology and allostratigraphy of the Upper Albian Paddy Member of the Peace River Formation, north-central Alberta," London, Canada, 2006.

[122] H. Halbertsma, "Devonian Wabamun Group of the Western Canadian Sedimentary Basin," in *Geological Atlas of the Western Canadian Sedimentary Basin*, Canadian Society of Petroleum Geologists and Alberta Geological Society, 1994, pp. 203-220.

[123] C. Eisinger and J. Jensen, "Data Integration, Petrophysics, and Geomodelling, Wabamun Area CO2 Sequestration Project, WASP Static Earth Model: Final Report," 2009.

[124] A. DesRoches, "Integrated Ichnology, sedimentology and stratigraphy of the Lower Falher member, Spirit River formation, northeastern British Columbia and central Alberta," Burnaby, Canada, 2008.

[125] D. Leckie, "The Lower Cretaceous Notikewin Member (Fort. St. John Group), Northeastern British Columbia: A Progradational Barrier Island System," *Bulletin of Canadian Petroleum Geology,* vol. 33, no. 1, pp. 39-51, 1985.

[126] B. Boyce, "Four Devonian Pinnacles in the Windfall Reef Complex, Central Alberta, Facies Analysis, Paleoecology and Reef Development," Winnipeg, Canada, 1974.

[127] S. Switzer, W. Holland, D. Christie, G. Graf, A. Hedinger, R. McAuley, R. Wierzbicki and J. Packard, "Devonian Woodbend-Winterburn Strata of the Western Canadian Sedimentary Basin," in *Geological Atlas of the Western Canada Sedimentary Basin*, Canadian Society of Petroleum Geologists and Alberta Geological Survey, 1994, pp. 164-202.

[128] B. Buschkuehle, "Petroleum Geology of the Devonian Southesk-Cairn Carbonate Complex, Alberta," N.A..

[129] The Conference Board of Canada, "Provincial Long-Term Economic Forecast for Alberta: 2016," 2016.

[130] CME Group, "Henry Hub Natural Gas Futures Settlements," 2017.

[131] ATCO Gas and Pipelines Ltd., "ATCO Gas North Rate Schedules - March 1, 2017," 2017.

[132] Alberta Utilities Commission, "Utility Sector - Rates & Tariffs".

[133] Government of Canada, "Budget 2017: Budget Plan. Tax Measures: Supplementary Information," 2017.

[134] BDO Canada LLP, "Revelstoke Community Energy Corporation Financial Statements for the year ended April 30, 2014," 2014.

[135] Sauder School of Business, "Quest Business Case: Southeast False Creek Neighbourhood Energy Utility," 2011.

[136] American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., "Chapter 34 - Geothermal Energy," in *ASHRAE Handbook - HVAC Applications*, Atlanta, GA, American Society of Heating, Refrigerating and Air-Conditioning Engineers, 2011.

[137] American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., "Capacity Control of Load System," in *CHAPTER 12 - HYDRONIC HEATING AND COOLING SYSTEM DESIGN*, Atlanta, GA, ASHRAE, 2008.

[138] LOGSTOR, "Pre-Insulated Pipes for Industrial Applications," [Online]. Available: https://www.logstor.com/media/1413/industry-general_en_p_in.pdf. [Accessed 01 03 2018].

[139] LOGSTOR, "Design Manual," 12 2015. [Online]. Available: https://www.logstor.com/media/5342/design-201512a.pdf. [Accessed 01 01 2018].

[140] American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., "Capacity Control of Load System," in *CHAPTER 12 - HYDRONIC HEATING AND COOLING SYSTEM DESIGN*, Atlanta, GA, ASHRAE, 2008.

# Appendix A Review of DES

## Appendix A.1 DES: A Growing Opportunity

At COP21 (the 2015 UN Climate Change Conference in Paris), the UNEP (United Nations Environmental Program) recently recognized that District Energy was a key climate solution and emphasized its importance in mitigating $C0_2$, reducing air-pollution, and paving the way for fossil-fuel free cities and countries [69].

On a global scale, the development of DE Systems is growing fast. There are currently >6,000 DE systems in North America; however, this only accounts for <1% of the total heating load and represents a significant opportunity for further development. There are already >10,000 DE systems in operation in Europe* today, and in many European countries this supplies over 40% of their heating load. The growth of the Chinese geothermal district heating and cooling sector has also grown exponentially in the past ten years [70].

* Note that the Europeans use the term GeoDH instead, which stands for "Geothermal District Heating". The term is analogous to DES but is used instead by Europeans. Further discussion and examples provided later in this report will be highlighting Europe's extensive present and historical use of these systems.

A number of major Canadian cities have also developed DE systems, including Toronto, Calgary, and Vancouver. The University of Toronto's DES began in 1912 and serves most of the campus. The company Enwave operates a DES for the City of Toronto that uses Lake Ontario as a source of cooling for local buildings, including the Air Canada Center and City Hall [71]. Enmax's DEC in downtown Calgary was brought online in 2010, and currently supplies 55MWth of energy over 5.5 kilometers of installed thermal pipeline to a number of City of Calgary buildings including City Hall [72].

### Appendix A.1.1 Geothermal Energy in DE Systems

Geothermal energy (or "earth heat") resources are a renewable source of both heat and electrical energy. Geothermal energy is a vastly untapped resource in Canada and can be a significant alternative to heating and power needs supplied by fossil fuels like natural gas, fuel, oil, and propane. The concept of using geothermal as part of a DES is nothing new, and in fact dates back thousands of years to Roman times and was used for bath houses and agriculture applications. Today, geothermal DE Systems have been developed all over the world. These systems are increasing in popularity as a viable solution for renewable energy.

European cities like Paris and Munich have already been operating DE Systems based on geothermal for decades; there are >240 GeoDH systems in Europe already [37]. Iceland provided 96% of its heating needs from their geothermal resource, and Baltic states, with similar annual temperatures to Canadian cities, provides 50-60% of its heating from geothermal DE Systems [73]. With future growth in the industry, it is estimated that by 2020 nearly all states in Europe will have DES using a geothermal energy resource [74].

A full list/map of European GeoDH projects is available at: https://map.mfgi.hu/geo_DH/

Some of the best examples of the long-term nature of geothermal DE Systems are in France. In Chaudes Aigues in Central France, the city pioneered a DES in 1330 fed by the Par hot spring at 82°C. Incredibly, it is still operating today. In those times, heated homes were charged a tax by the local landlord in exchange for maintenance duties. The Paris Basin Geothermal District Heating System is based on a dependable sedimentary resource environment (similar to the geological environment in Hinton) and has been in operation since the 1980s. The system is based on a doublet concept of heat extraction: hot waters at an average temperature of 70°C are hosted in permeable sedimentary rocks at depths of 1500 to 1800 m, and the fluids are reinjected into the reservoir to avoid premature cooling of the production well [73].

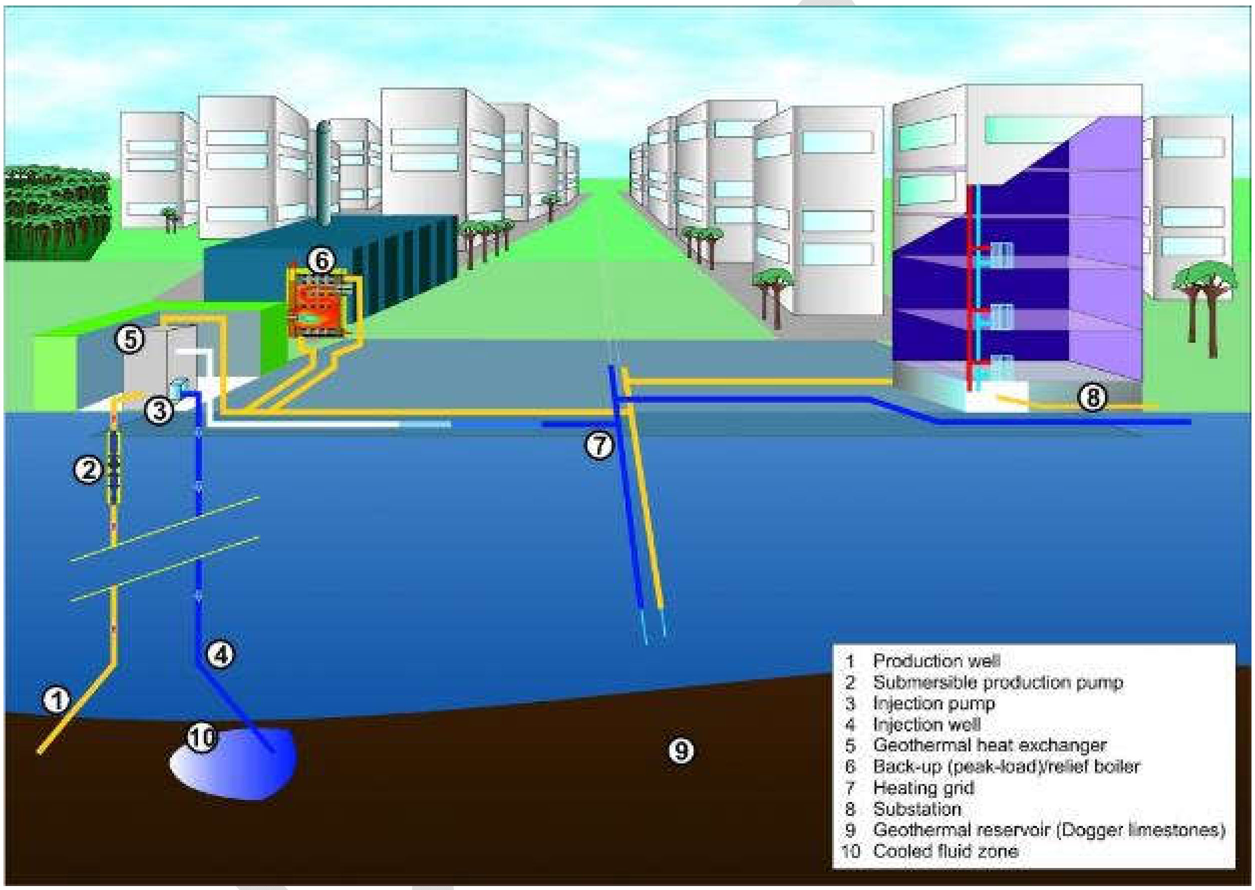



**Figure 81 - Generalized diagram of a DES showing the main components and features. [74]**

The geothermal aquifers in the Hinton area (further described in the Upstream section) are analogous to the geological environments in other countries that have already developed 'direct heat' projects using geothermal energy and DE systems (including Paris, France and Landau, Germany).

## Appendix A.1.2 Global Examples of DES Heat Sources & Implementation

### Appendix A.1.2.1 Geothermal Wells

Paris, France

The oil crisis of the 1970's created a need for affordable heating in Paris, sparking a boom of geothermal energy development within the city. Between 1970 and 1985 over 100 geothermal wells were drilled in the Paris region, and as of 2010 34 of those wells are still operating among more recent geothermal endeavours. The geothermal wells used in Paris utilize a doublet (or binary well pair) system, where each system consists of an injection and production well. The benefit of a doublet system is that formation fluids are reinjected into the aquifer, both safely disposing of the fluid and recharging the aquifer simultaneously. Geothermal district heating in Paris is powered by more than 29 production plants utilizing between one and three wells for heat.

Reykjavik, Iceland

The company Reykjavik Energy operates the largest geothermal DES in the world, providing an installed power of 750MW. The system first began operation in 1930 at a small scale, and in 1933 3% of Reykjavik's population was using the DES. Today almost every house in the city is connected to the system. The DES is split into two separate systems: the first is supplied with geothermal water from three different low temperature geothermal fields between 85°C and 130°C, and the second system is supplied with cold ground water which is heated through a heat exchanger with geothermal fluids before being distributed.

### Appendix A.1.2.2 Heat Waste – Forestry

Revelstoke, British Columbia

The Revelstoke Community Energy Corporation (RCEC) is a city owned energy company that owns a biomass heating plant and DES in Revelstoke. The biomass plant is a 1.5 MW thermal biomass boiler powered with wood waste provided by the Downie Cedar Mill. The biomass boiler provides heat through an oil-water heat exchanger into the DES.

The biomass heating plant and DES has provided Revelstoke with improved air quality, reduced GHG emissions, and reduced the need for trucked in propane. The project has provided the city with a new source of revenue and has added value to a local product.

### Appendix A.1.2.3 Heat Waste – Sewage

False Creek Vancouver, British Columbia

The community of False Creek within the City of Vancouver is home to the city's first renewable DES. The district heating system provided by the Neighborhood Energy Utility (NEU) is powered by North America's first waste heat recovery system utilizing heat from raw sewage. The system is credited with reducing over 60% of the GHGs involved in heating buildings. The NEU is a self-funded utility providing a return on investment to the City and affordable rates for its customers.

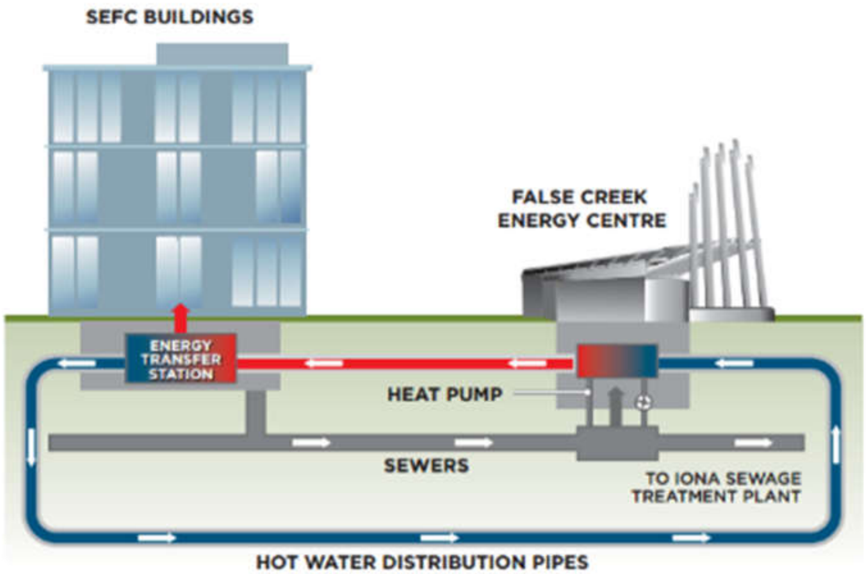



**Figure 82 - False Creek Energy Centre DES diagram [75]**

The system works by integrating a heat pump within a sewage pumping station. The heat pump collects and concentrates heat from the sewage and transfers the heat to the distribution system. The heat pump is backed up with a high efficiency natural gas boiler to maintain a reliable heat source even at peak demands.

# Appendix B Hinton Sustainability Goals

**EDUCATION AND WELLNESS**

**2.4.2: "Create partnerships with education providers who coordinate programming, identify potential enhancements and champion the establishment of a post-secondary institution."** [76]

With examples such as the Iceland School of Energy of Reykjavik University, Hinton can establish itself as a hub for sustainable energy education, with clear cut examples located within town limits. Although the geothermal resource in Hinton is not conducive to the limited scope of this DES project, there are two things to keep in mind:

- The high geothermal potential in the Hinton area and throughout the province of Alberta abound and present many locations and opportunities for it to be utilized. Alberta is currently a leader in petroleum-based education and training programs; with such close conceptual and practical alignment with geothermal resource extraction it is no big leap for it to be a leader in the geothermal education space as well. This is a chance to further expand on sustainable energy, providing students more opportunity to learn about the industry closer to home.
- A renewable energy supplied DES can operate on heat inputs other than geothermal. A DES is a complex network of many specialized and integrated components that require maintenance and operation, and potential expansion. The upkeep of such a system, and the expansion of it to incorporate any new industries looking to start in or move to Hinton to take advantage of being part of a DES, will require very well-trained individuals. Home to the Hinton Training Centre- a facility respected for education, training and research in the Forestry industry- Hinton is well positioned as an educational hub to lead in Canadian DES training.

**2.6.1: "Through partnerships, develop innovative, quality, creative and inclusive learning opportunities for K-12 students. ("Quality" is defined by parent and stakeholder input.)"** [76]

By creating a control room or heat exchanger building that kids can visit for field trips, a DES can be used as a learning tool to teach others about sustainable energy.

**LOCAL ECONOMY**

**4.13.1: "Pursue development with the natural resource industry and identify complementary businesses that diversify the local economy."** [76]

**4.13.2: "Foster entrepreneurship and encourage small business development and growth within the community."** [76]

Both 4.13.1 and 4.13.2 fit well within the spheres of DES and geothermal.

- A DES supplied by renewable heat provides a low-cost supply of heat attractive to many industries, regardless of the source being specifically geothermal in origin or something else. There are examples around the world of unique and inspired businesses that would not exist without access to inexpensive and consistent DES heat. Nearby in Klamath Falls, Oregon there are a plethora of businesses taking advantage of their DES heat: brewery, greenhouse, aquaculture, buildings for space heating, sidewalk heating for snow and ice. Opportunities for businesses tapping into this consistent, inexpensive heat are limited only by the imagination.

- The geothermal resource in Hinton is estimated to have high enough temperatures that, if accessed, could provide consistent, baseload, reliable and long-term electricity. Beyond the advantages and attractiveness of this power supply itself, the vast "waste" heat leftover from power generation could supply heat to a DES, which as mentioned above has its own business-creating advantages.

**4.13.4: "Foster industrial tourism as an opportunity to expand tourism and to showcase resource industries."** [76]

Although used globally, given that geothermal is not yet utilized and is barely known about in Canada, it would present as a fairly novel concept that would attract attention around the province, country and world. If accessed, the use of geothermal and its cascading business opportunities could be a showcase industry drawing people to Hinton to visit, and even to live.

**4.13.6: "Promote and endorse commerce and trade that support people's efforts to expand local food production operations."** [76]

Promoting other businesses to come to Hinton to capitalize on the benefits of the DES will help diversify the local economy. The use of local food production can be expanded on by using greenhouses, which, when temperature-controlled through the DES, can be used to develop new crops that are atypical in the region. Additional industries that use heat in their processes can benefit, which coincides with Hinton's strategy to develop as a regional trading hub of the West Yellowhead.

> *"Located at the intersection of Highways 16 and 40 there are two increasingly important transportation routes where Hinton serves as a gateway to the Northern Rockies, to the west coast corridor and to global markets through Vancouver and Prince Rupert.*
>
> *The community is also connected by air, with the Jasper/Hinton Airport offering chartered flights through Edmonton and other major urban centres to the rest of the world. CN Rail, VIA Rail and Greyhound stop here." [76]*

Inviting other industries to develop in Hinton can make it an attractive place to live and visit.

**4.13.8: "Source investment capital from within or outside the community to build the local economy."** [76]

**4.13.9: "Work with businesses and employers to attract and retain a balanced workforce that supports a diversified economy, employer of choice and location of choice."** [76]

Both 4.13.8 and 4.13.9 harken to the attractiveness of DES and geothermal as novel and reliable factors that attract investment and talent alike.

**4.14.6: "Creatively promote Hinton as a regional hub provincially and/or nationally through identified local niche business opportunities and healthy communal living."** [76]

As previously mentioned, DES and geothermal are poised as unique and niche providing many offshoot business opportunities. As people lean more toward a desire for lifestyles that incorporate renewable and sustainable factors, communities that imbue those ideals into their fabric will become more and more attractive, drawing both businesses and people to those places.

**NATURAL AND BUILT ENVIRONMENTS**

**5.18.1: "Develop local community gardens" and "plan for food sovereignty, in part by commercializing urban food production."** [76]

The DES is attractive because of the large optionality of connecting varied businesses and activities, which could easily include gardens and greenhouses that help strengthen community food security (uninterrupted access to safe and nutritious food, in this case grown locally).

**"Strategy 19: Practise and promote energy conversation and alternate green energy development and use within all infrastructure systems to minimize our ecological footprint.**

**5.19.1: Identify large-scale alternative renewable energy opportunities and develop where practical…"** [76]

**5.19.2: "Foster site-specific applications for renewable or alternative energy, while also fitting into the neighbouring street/land scape."** [76]

**5.19.3: "Establish Hinton as a leader in best "green" practices…"** [76]

**5.20.1: "While encouraging resource development, ensure that current "green" and scenic values are not lost."** [76]

DES and geothermal development align with this ideal as they both promote and encourage resource development and are "green" in nature.

**5.20.2: "Establish well-defined business and industrial clusters and transportation corridors."** [76]

**5.20.3: "Develop a Growth Management Plan…"** [76]

**5.20.5: "Plan and use land judicially and according to its capabilities and assets, striving for the best use of the land."** [76]

The very nature of a DES promotes this ideal. DES by design are most efficient when strong and comprehensive planning is used and- most importantly- when the buildings and businesses connected to the system are in as close proximity to each other as possible. The more clustered the users are, the more cost-effective the system becomes. Installing a DES in Hinton would drive businesses and industrial applications to cluster together.

**5.20.7: "Encourage all new developments to implement environmental best practices with the intent to regulate (e.g., green buildings, development sites and subdivisions)."** [76]

To elaborate further on the prior point, should a community install a DES, any future growth (new businesses, residential subdivisions, etc.) could be required to tie into the DES and greatly reduce their ecological impact. There is also potential economic benefit due to the increase of the desirability of land from the availability of access to a DES.

**5.21.1: "Design and implement standards that incorporate pedestrian and cyclist routes (e.g., bicycle lanes and bicycle friendly corridors) into trails, parks and roadways."** [76]

**5.21.4: "Design and implement integrated transportation strategies and systems for residents and visitors that encourage and promote walking, cycling and public transit use."** [76]

A unique benefit of a DES is that the same heat being delivered to buildings throughout town can also be used to heat sidewalks and bike lanes to keep them snow and ice free year-round. It is further advantageous that the locations of the pipes circulating the heat is usually doing so through main corridors with high foot/bike traffic, so they align well physically.

# Appendix C Upstream

## Appendix C.1 Geology

### Appendix C.1.1 Full-Scale Stratigraphic Cross-Sections

# Appendix C.1.2 Full-Scale Maps

## Appendix C.1.3 Well Analysis: Wireline Logs & Formation Tops

## Appendix C.1.4 Regional Geology

The Western Canadian Sedimentary Basin (WCSB) is a massive sedimentary basin extending from the Rocky Mountains in the West to the Canadian Shield in the east. The formation of the WCSB follows a rather simple geological model: a large depression, known as a basin, formed via tectonic activity. This basin was filled in slowly over time with sediments from various sources, including those that eroded from the surrounding features on the side of the basin that were positioned at higher altitudes, as well as from material that settled out of the water that rose because of global sea level change, forming inland seas and shorelines.

The geology of the Canadian foothills region, east of the Rocky Mountains (i.e. the Hinton area), has been shaped by both intense tectonic activity (including plate movement, compression and extension) and by the associated erosion and deposition of sediment from the upraised mountain material into foreland basins on the eastward side of the Rocky Mountains. Compressional tectonism, caused by the westward drift of the North American continent and the collision with large oceanic terranes, resulted in the accretion of this oceanic terrane onto the western margin of the North American craton. From the impact, mountain building occurred and the Canadian Cordillera was created. The weight of this material sitting on top of the North American craton caused regional north-south trending subsidence to the east of and directly adjacent to the mountain belt, forming what is known as a foreland basin, and the consequential uplift of material east of this depression, known as a fore bulge. The uplift and erosion of Cordilleran material is the source of the sediment observed to have accumulated in the foreland basin area, where present day Hinton is now situated.

With time, this material was deposited within the basin forming layer upon layer of differing types of sediments that produced the layered geological regime (stratigraphy) that is observed today. Hinton is geologically situated directly at the boundary of the western edge of the Cordilleran orogen deformation, and the Eastern limit of the undeformed deposits of the WCSB. Stratigraphically, Hinton is situated over approximately 6000m of Phanerozoic sedimentary assemblage. Marine facies Paleozoic deposits of the Cordilleran miogeocline (North American Plate passive margin) and marine to terrigenous facies Mesozoic and Cenozoic deposits are represented in the stratigraphy.

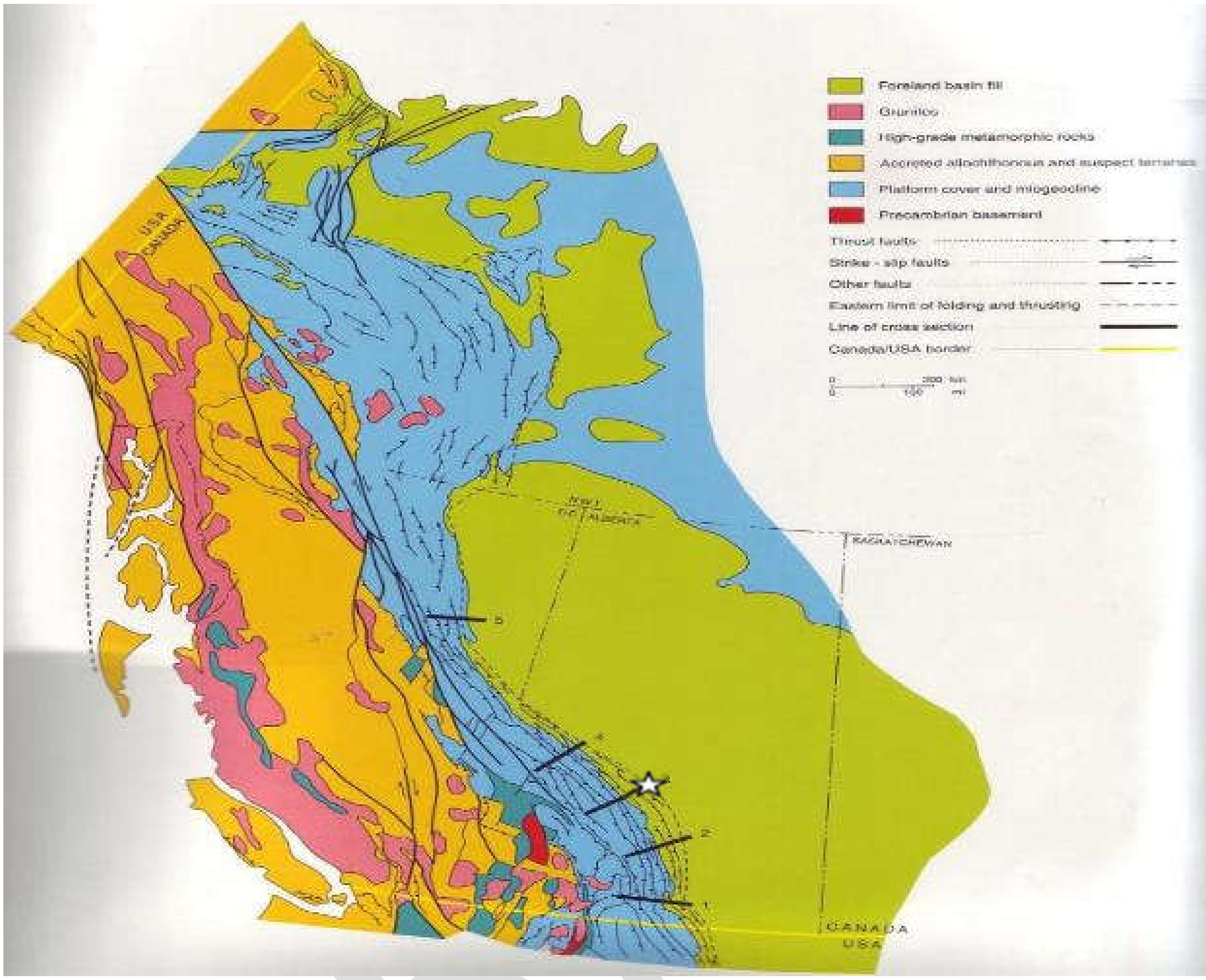



**Figure 83: Regional tectonic map of the Canadian Cordillera. Hinton, AB indicated by the white star. [77]**

Proterozoic to Triassic

The base of the sedimentary succession is located on top of Lower Proterozoic (2.0 to 2.4 Ga) North American Craton [78]. The paleogeograpic position of the basement rock underneath Hinton during the Late Proterozoic and Early Paleozoic lay at the passive margin of the continental rift of western Laurentia from 730Ma and 555 Ma [79]. This rifting produced accommodation space for marine sediment accumulation and reef growth, resulting in a succession grading upwards from deep marine shale facies Cambrian deposits to shallow water carbonates and marginal marine, mixed clastic-carbonate deposits during the Carboniferous and Triassic. The dominance of carbonate deposits over this period supports that Hinton was located on a shallowing carbonate ramp for an extensive length of time.

Jurassic to Tertiary

The deposition of Jurassic to Tertiary deposits underlying Hinton coincides with the main orogenic episodes of the Western Canadian Cordillera. These sediments, which are predominantly terrigenous clastic facies, are juxtaposed unconformably against subadjacent marine sediments from the previously mentioned passive margin, the Cordilleran miogeocline.

The post-Jurassic assemblage is characteristic of peripheral foreland basin deposits. When the weight of stacked wedges of thrusted rock depressed the continental crust during the Laramide orogeny, a basin emerged at the toe of this depression. The uplifted thrust slices provided a source rock for clastic sedimentation during basin infill. The foreland basin deposits below Hinton contain mostly shallow marine to terrigenous facies deposits. By virtue of its proximal paleogeographical location to an orogenic sediment source, the post-Jurassic assemblage of deposits contains an appreciable amount of sand which are concentrated most noticeably in the fluvial to deltaic facies Manville Group, the shallow shelf facies Viking Formation, and the fluvial to shoreline facies Belly River Group [80] [81].

The WCSB has been extensively explored for petroleum resources for decades. Based on hundreds of thousands of well logs across Alberta and British Columbia, our understanding of the WCSB is quite detailed. A summary of the stratigraphy of the different sedimentary formations in the Hinton area from surface to Precambrian basement is provided in the table below.

## Appendix C.1.5 Resource Research to Date

There has been significant research into the vast geothermal resource in the Western Canadian Sedimentary Basin (WCSB). The porous and permeable rocks that underlie much of Alberta are a massive source of low-moderate grade geothermal energy in the form of hot water. This is especially true near the Rocky Mountain foothills, which is an area of high relief, high hydraulic head and regional water recharge. The Hinton area is situated in this deep part of the WCSB and there is a substantial increase in terrestrial heat flow with depth in the area.

The Hinton area is a well-known and extensively drilled and explored oilfield. As a reference, there are >4,000 wells drilled below 2,500m within a 70km radius of the Town of Hinton, which is suggested to be one of the best geothermal resource opportunities in Alberta. Many of these wells contain bottom hole temperatures higher than 100$^0$C - temperatures more than viable for efficient direct heat applications. With known bottom hole temperatures greater than 150$^0$C, the Hinton-Edson area has been an area that generates extensive research into the geothermal resource potential there.

Beyond the extensive dataset provided by oil and gas activities, research specifically relating to the geothermal potential in the Hinton area dates back to 1985 and continues to present day. In the last 30 years, there have been a multitude of collaborations with key researchers like Jacek Majorowicz, Simon Weides, Alan Jessop, Brian Hitchon, J.W. Jones, Stephen Grasby, and most recently Dr. Jonathan Banks and the University of Alberta, that continues to authenticate the geothermal resource mapping and reservoir identification in the western Alberta and Hinton area.

One of the very first studies on the geothermal potential of deep aquifers in the WCSB, and specifically the Hinton area, was published by Lam and Jones in 1985. In their paper the authors examined aquifer porosity, thickness, water chemistry and water recovery in the

Hinton-Edson area of western Alberta. This research concluded that the Mississippian and Upper Devonian carbonate rocks specifically had significant geothermal potential. [11]

Key researchers over the years include Dr. Alan Jessop with the Geological Survey of Canada who did extensive research on the geothermal potential throughout Canada. He specifically analyzed the thermal reservoir in the WCSB, highlighting heat flow in the Hinton -Edson area and heat contribution from the underlying basement rocks. [82] [83]

Research completed by Dr. Stefan Bachu (Alberta Geologic Survey, currently with Alberta Innovates as Principal Scientist) and collaboration with Dr. Ron Burwash (University of Alberta) in the late 1980s and early 1990s on the geothermal regime in the WCSB are some of the most frequently referenced documents on this field of study. Their initial mapping of the reservoir highlighted that the Hinton-Edson area has temperature resources >120$^0$C at the top of the Precambrian basement rock. [84] [85]

In 2008, a Queen's University group in collaboration with CanGEA (Canadian Geothermal Energy Association) completed a study of the technical challenges and feasibility of a small scale (1MWe) geothermal based power facility in the Hinton area. They were able to isolate specific wells and geologic formations viable for power generation.

CanGEA continued research on Alberta's geothermal resource and in 2014 completed the "Alberta Geothermal Favourability Maps" [86]. This series of maps further highlights the resource potential within the Hinton area and throughout the Alberta Foothills.

More recently in 2015 Greg Nieuwenhuis and other University of Alberta researchers, with support from Alberta Geological survey and Helmholtz Center Potsdam in Germany, identified Hinton as a target for geothermal energy development in a "regional-scale geothermal exploration study using heterogeneous industrial temperature data." [87]

Most recently, Dr. Jonathan Banks, (University of Alberta, Department of Earth & Atmospheric Sciences), with support from Alberta Innovates, conducted research to determine the volume of geothermal energy available in reservoirs around Hinton and other communities in the Alberta Foothills. In May 2017 the report titled "Deep-Dive Analysis of the Best Geothermal Reservoirs for Commercial Development in Alberta: Final Report" was released. The study found that the Hinton area has sufficient temperature and depth as either electrical or thermal energy generating projects.

# Appendix C.2 Drilling Well Schematics & Associated Cost Summary

## Case 1: 3000m Vertical Well

| CASE 1: 3000m Vertical well | | |
|---|---|---|
| | **Total Days:** | **27.7** |
| | **Totals Estimated Cost:** | **$2.988 M** |

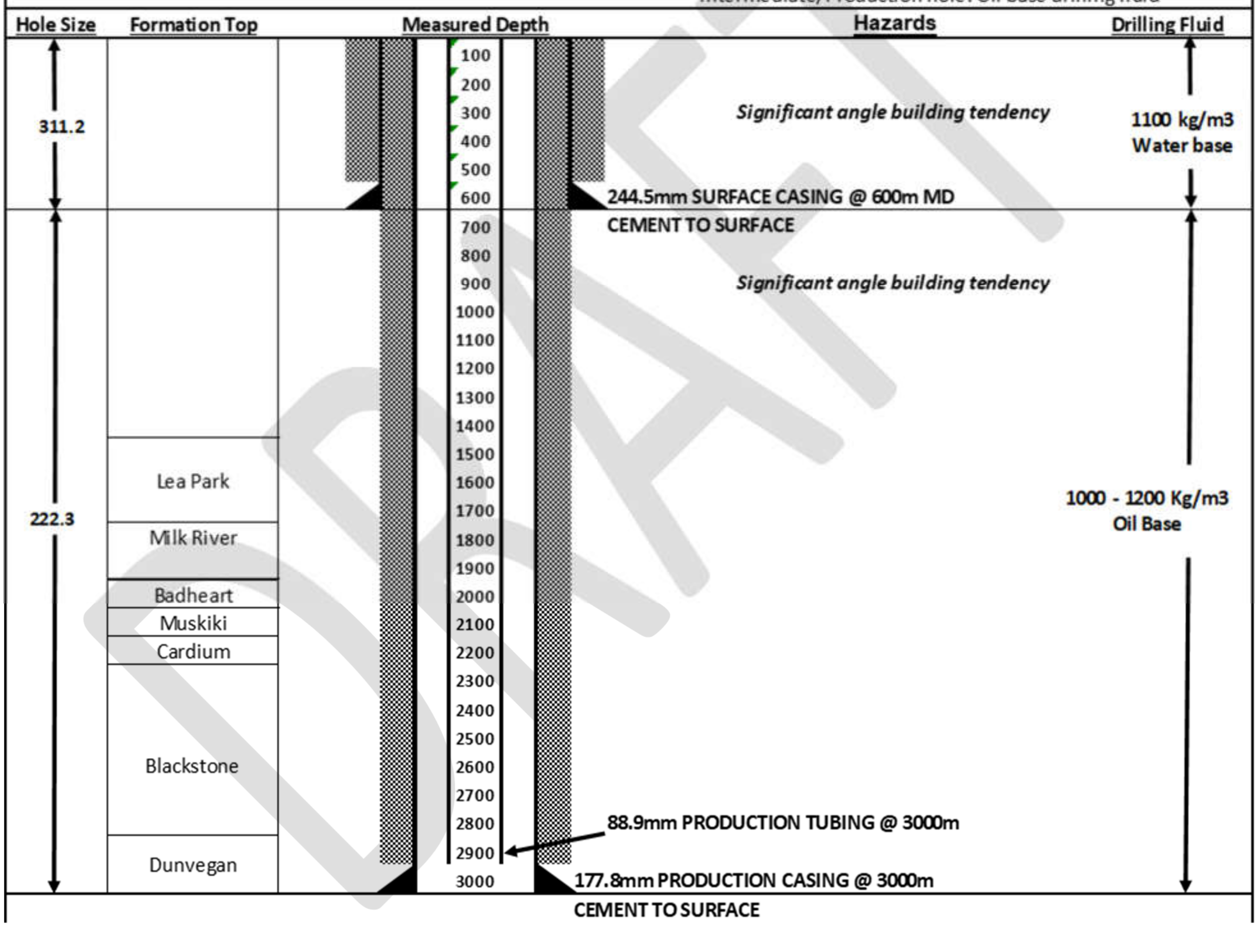
**LIST OF ASSUMPTIONS**

**Well profile:**
- Vertical well
- Total Measured/True Vertical Depth = 3000m MD/TVD
- Well terminates in Dunvegan Fm.

**Pressure Profile:**
- 1.0 S.G. normally pressured from surface to base Dunvegan Formation

**Hardware Design:**
- 244.5mm 79.6 Kg/m J-55 STC Surface Casing
- 177.8mm 43.2 Kg/m L-80 LTC Production casing
- 88.9mm 19.25 Kg/m L80 PH6 tubing

**Drilling Fluid:**
- Surface hole: Water base drilling fluid
- Intermediate/Production hole: Oil base drilling fluid



| DRILLING BUDGET CLASS COST ESTIMATE | | | |
|---|---|---|---|
| CASE: | CASE 1: 3000M Vertical well | Total Days | 27.65 |
| LOCATION: | Hinton Geothermal TWP 51 - RG 25 W5M | Total MD (m) | 3000 |
| TARGET ZONE: | Base Dunvegan | TVD (m) | 3000 |
| SPUD DATE: | Fall 2018 | Well Profile | VERTICAL |
| | | | |
| Account Code | Description | | Estimate |
| 9300 100 | SURVEYS | | 15,000 |
| 9300 101 | ROAD AND LEASE COSTS | | 100,000 |
| 9300 103 | ROAD AND LEASE CLEANUP | | 10,000 |
| 9300 105 | ROAD USE FEES | | 10,000 |
| 9300 110 | FIRST NATIONS CONSULTATION | | 0 |
| 9300 112 | WELL LICENSE | | 5,000 |
| 9300 115 | ABANDONMENT/PLUG BACK | | 0 |
| 9300 200 | DRILLING RIG | | 672,927 |
| 9300 201 | DRILLING RIG MOVE IN MOVE OUT | | 125,000 |
| 9300 202 | RIG FUEL | | 152,090 |
| 9300 205 | CONDUCTOR AND RATHOLE | | 5,000 |
| 9300 206 | DRILLING MUD AND CHEMICALS | | 330,444 |
| 9300 207 | DIRECTIONAL DRILLING | | 212,222 |
| 9300 250 | CAMP (NON SUBSISTENCE) | | 85,958 |
| 9300 450 | COMMUNICATION | | 49,892 |
| 9300 370 | EQUIP RENTAL - SURFACE | | 104,010 |
| 9300 500 | TRUCKING | | 52,000 |
| 9300 316 | DRILL PIPE INSPECTION | | 2,500 |
| 9300 310 | WELDING SERVICES | | 2,500 |
| 9300 311 | PRESSURE TESTING | | 3,500 |
| 9300 314 | LOG/PERF/ANALYSIS | | 0 |
| 9300 401 | CONSTRUCTION/WELL SITE SUPERVISION | | 81,632 |
| 9300 370 | MAT RENTALS | | 0 |
| 9300 480 | SAFETY SERVICES | | 0 |
| 9300 309 | CASING BOWL AND ATTACHMENTS | | 17,000 |
| 9300 304 | SURFACE CASING AND ACCESSORIES | | 82,000 |
| 9300 300 | SURFACE CASING - CEMENT | | 21,000 |
| 9300 306 | POWER TONGS SURFACE | | 3,000 |
| 9300 305 | INTERMEDIATE CASING & ACCESSORIES | | 0 |
| 9300 302 | INTERMEDIATE CASING-CEMENTING | | 0 |
| 9300 307 | POWER TONGS INTERMEDIATE | | 0 |
| 9300 303 | PRODUCTION CASING & ACCESSORIES | | 280,000 |
| 9300 301 | PRODUCTION CASING CEMENT | | 60,000 |
| 9300 308 | POWER TONGS PRODUCTION | | 10,000 |
| 9300 303 | PRODUCTION TUBING & ACCESSORIES | | 150,000 |
| 9300 308 | POWER TONGS PRODUCTION TUBING | | 10,000 |
| 9300 400 | ENGINEERING AND WELL PLANNING | | 34,383 |
| 9300 315 | FISHING SERVICES | | 0 |
| 9300 312 | CORING AND ANALYSIS | | 0 |
| 9300 313 | MISCELLENEOUS TESTS AND ANALYSIS | | 0 |
| 9300 502 | FLUID DISPOSAL TRUCKING | | 20,000 |
| 9300 510 | FLUID DISPOSAL COSTS | | 20,000 |
| 9300 503 | SOLID WASTE DISPOSAL TRUCKING | | 17,310 |
| 9300 511 | SOLID WASTE DISPOSAL COSTS | | 16,257 |
| 9300 371 | DOWN HOLE EQUIP RENTAL | | 39,854 |
| 9300 208 | DRILL BITS | | 107,500 |
| 9300 800 | CONTINGENCY COSTS | | 0 |
| 9300 850 | INSURANCE | | 0 |
| 9300 610 | ENVIRONMENTAL SERVICES | | 3,500 |
| 9300 501 | WATER TRUCK | | 14,326 |
| 9300 402 | WELL SITE GEOLOGIST | | 19,486 |
| 9300 700 | POTABLE WATER | | 0 |
| 9300 996 | OVERHEAD | | 0 |
| 9300 504 | VACUUM TRUCK | | 42,979 |
| | Estimated Total | | 2,988,272 |

# Case 2: 3600m (2900m TVD) Horizontal Well

| CASE 2: 3600m (2900m TVD) Horizontal well | Total Days: | 33.7 |
|---|---|---|
| | Totals Estimated Cost: | $3.495 M |

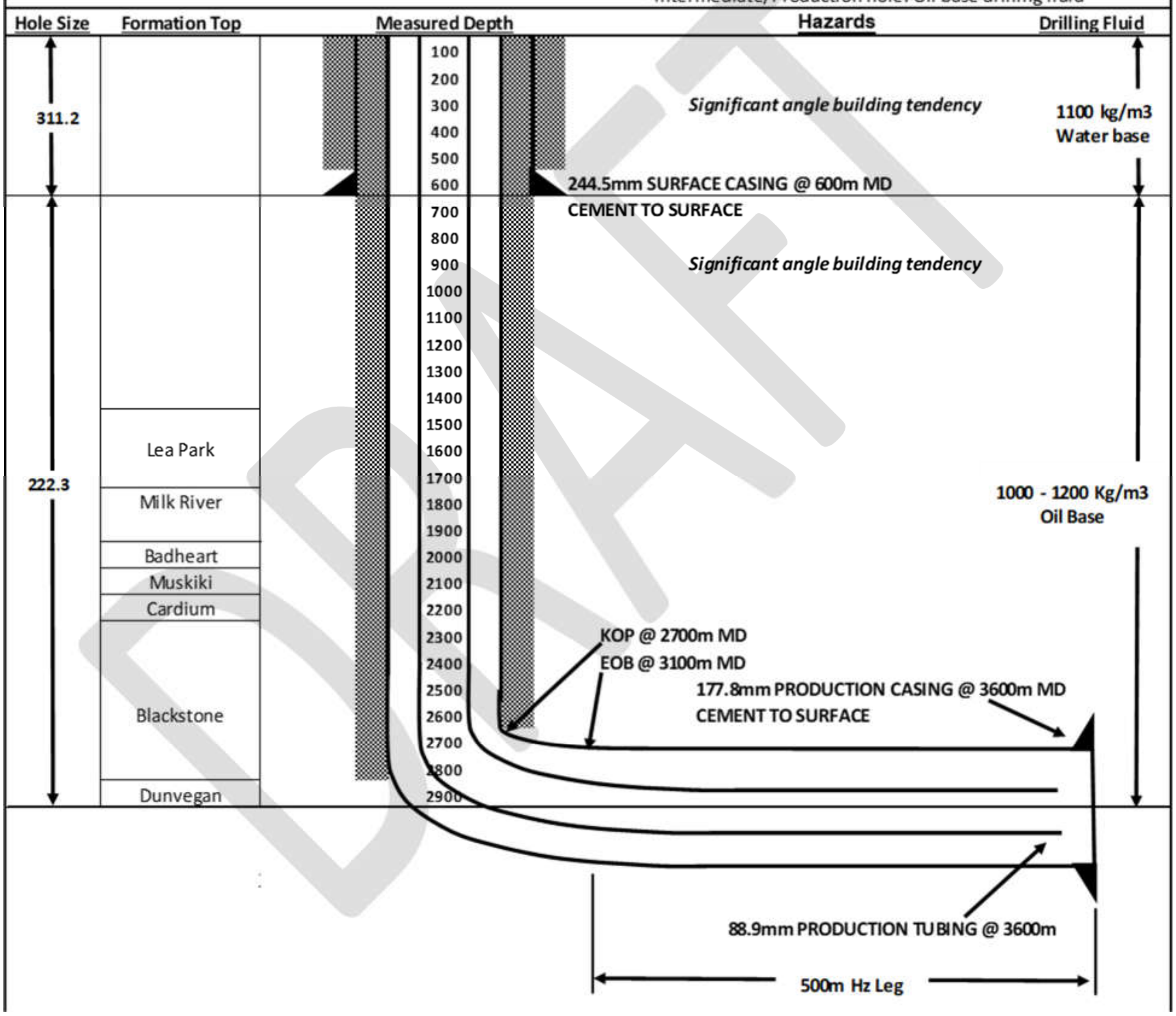
**LIST OF ASSUMPTIONS**

**Well profile:**
- Horizontal well
- Total Measured/True Vertical Depth = 3600m/2900m MD/TVD
- Well terminates in Dunvegan Fm.

**Pressure Profile:**
- 1.0 S.G. normally pressured from surface to base Dunvegan Formation

**Hardware Design:**
- 244.5mm 79.6 Kg/m J-55 STC surface Casing
- 177.8mm 43.2 Kg/m L-80 LTC Production casing
- 88.9mm 19.25 Kg/m L80 PH6 tubing

**Drilling Fluid:**
- Surface hole: Water base drilling fluid
- Intermediate/Production hole: Oil base drilling fluid



| DRILLING COST ESTIMATE | | | |
|---|---|---|---|
| CASE: | CASE 2: 3600m (2900m TVD) Horizontal well | Total Days | 33.67 |
| LOCATION: | Hinton TWP 51 - RG 25 W5M | Total MD (m) | 3600 |
| TARGET ZONE: | Base Dunvegan | TVD (m) | 2900 |
| SPUD DATE: | Fall 2018 | Well Profile | HORIZONTAL |
| | | | |
| Account Code | Description | | Estimate |
| 9300 100 | SURVEYS | | 15,000 |
| 9300 101 | ROAD AND LEASE COSTS | | 100,000 |
| 9300 103 | ROAD AND LEASE CLEANUP | | 10,000 |
| 9300 105 | ROAD USE FEES | | 10,000 |
| 9300 110 | FIRST NATIONS CONSULTATION | | 0 |
| 9300 112 | WELL LICENSE | | 5,000 |
| 9300 115 | ABANDONMENT/PLUG BACK | | 0 |
| 9300 200 | DRILLING RIG | | 812,858 |
| 9300 201 | DRILLING RIG MOVE IN MOVE OUT | | 125,000 |
| 9300 202 | RIG FUEL | | 185,192 |
| 9300 205 | CONDUCTOR AND RATHOLE | | 5,000 |
| 9300 206 | DRILLING MUD AND CHEMICALS | | 411,463 |
| 9300 207 | DIRECTIONAL DRILLING | | 260,370 |
| 9300 250 | CAMP (NON SUBSISTENCE) | | 104,014 |
| 9300 450 | COMMUNICATION | | 60,425 |
| 9300 370 | EQUIP RENTAL - SURFACE | | 125,857 |
| 9300 500 | TRUCKING | | 54,000 |
| 9300 316 | DRILL PIPE INSPECTION | | 2,500 |
| 9300 310 | WELDING SERVICES | | 2,500 |
| 9300 311 | PRESSURE TESTING | | 3,500 |
| 9300 314 | LOG/PERF/ANALYSIS | | 0 |
| 9300 401 | CONSTRUCTION/WELL SITE SUPERVISION | | 96,678 |
| 9300 370 | MAT RENTALS | | 0 |
| 9300 480 | SAFETY SERVICES | | 0 |
| 9300 309 | CASING BOWL AND ATTACHMENTS | | 17,000 |
| 9300 304 | SURFACE CASING AND ACCESSORIES | | 82,000 |
| 9300 300 | SURFACE CASING - CEMENT | | 21,000 |
| 9300 306 | POWER TONGS SURFACE | | 3,000 |
| 9300 305 | INTERMEDIATE CASING & ACCESSORIES | | 0 |
| 9300 302 | INTERMEDIATE CASING-CEMENTING | | 0 |
| 9300 307 | POWER TONGS INTERMEDIATE | | 0 |
| 9300 303 | PRODUCTION CASING & ACCESSORIES | | 334,000 |
| 9300 301 | PRODUCTION CASING CEMENT | | 60,000 |
| 9300 308 | POWER TONGS PRODUCTION | | 10,000 |
| 9300 303 | PRODUCTION TUBING & ACCESSORIES | | 180,000 |
| 9300 308 | POWER TONGS PRODUCTION TUBING | | 10,000 |
| 9300 400 | ENGINEERING AND WELL PLANNING | | 41,606 |
| 9300 315 | FISHING SERVICES | | 0 |
| 9300 312 | CORING AND ANALYSIS | | 0 |
| 9300 313 | MISCELLENEOUS TESTS AND ANALYSIS | | 0 |
| 9300 502 | FLUID DISPOSAL TRUCKING | | 20,000 |
| 9300 510 | FLUID DISPOSAL COSTS | | 20,000 |
| 9300 503 | SOLID WASTE DISPOSAL TRUCKING | | 20,213 |
| 9300 511 | SOLID WASTE DISPOSAL COSTS | | 20,321 |
| 9300 371 | DOWN HOLE EQUIP RENTAL | | 48,882 |
| 9300 208 | DRILL BITS | | 132,500 |
| 9300 800 | CONTINGENCY COSTS | | 0 |
| 9300 850 | INSURANCE | | 0 |
| 9300 610 | ENVIRONMENTAL SERVICES | | 3,500 |
| 9300 501 | WATER TRUCK | | 17,336 |
| 9300 402 | WELL SITE GEOLOGIST | | 12,639 |
| 9300 700 | POTABLE WATER | | 0 |
| 9300 996 | OVERHEAD | | 0 |
| 9300 504 | VACUUM TRUCK | | 52,007 |
| | Estimated Total | | 3,495,360 |

## Case 3: 3650m Vertical Well – includes Tieback

| CASE 3: 3650m Vertical Well - includes tieback | Total Days: | 44.5 |
|---|---|---|
| | Totals Estimated Cost: | $5.655 |

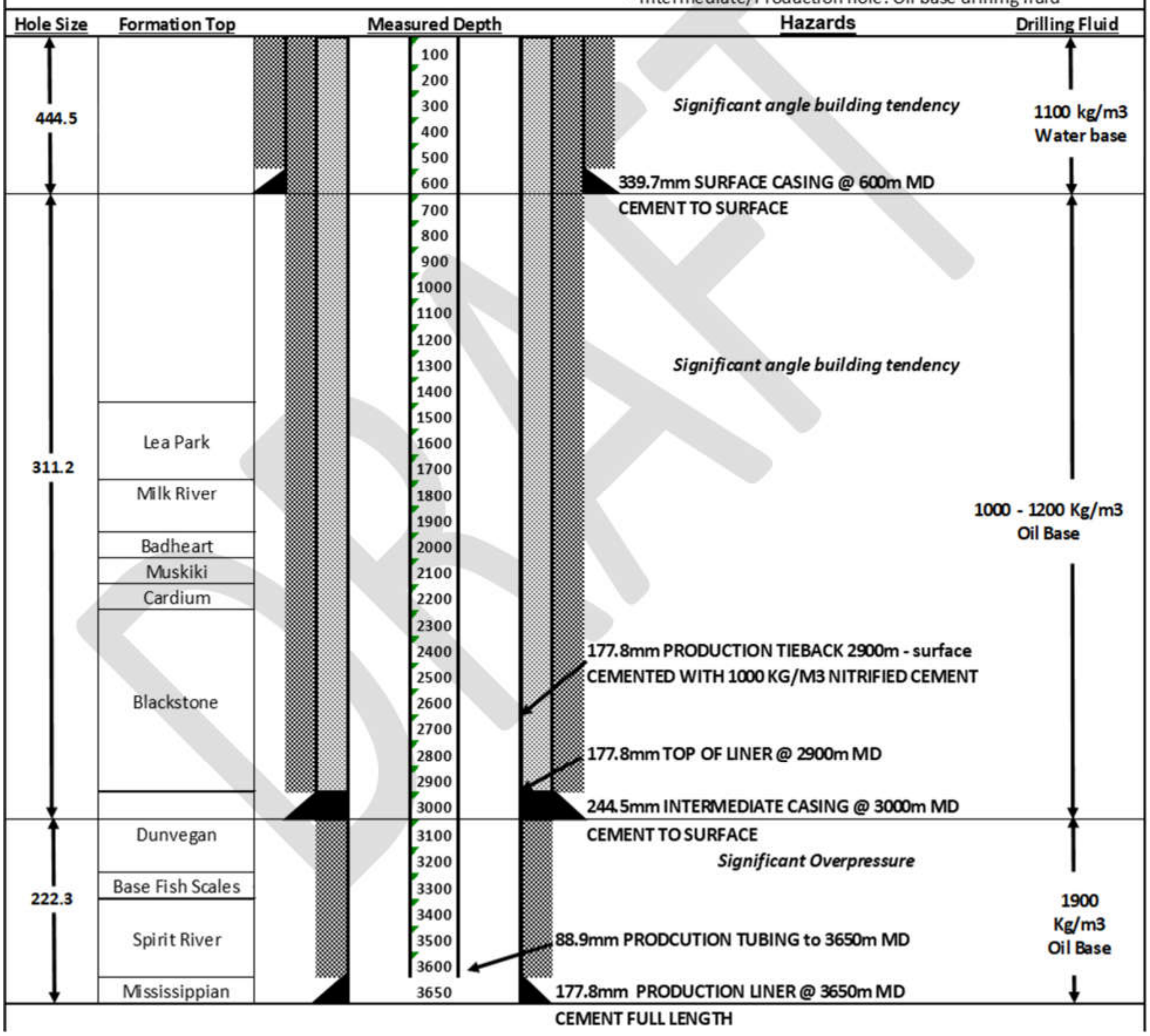
**LIST OF ASSUMPTIONS**

**Well profile:**
- Vertical well
- Total Measured/True Vertical Depth = 3650m MD/TVD
- Well terminates in Mississippian Fm.

**Pressure Profile:**
- 1.0 S.G. normally pressured from surface to base Dunvegan Formation
- 1.90 S.G. maximum over-pressure from Spirit River and deeper

**Hardware Design:**
- 339.7mm 81.1 Kg/m J-55 STC Surface Casing
- 244.5mm 79.6 Kg/m L-80 LTC Intermediate Casing
- 177.8mm 43.2 Kg/m L-80 LTC Production liner/tieback
- Nitrified cement behind 177.8mm tieback
- 88.9mm 19.25 Kg/m L80 PH6 tubing

**Drilling Fluid:**
- Surface hole: Water base drilling fluid
- Intermediate/Production hole: Oil base drilling fluid



| DRILLING COST ESTIMATE | | | |
|---|---|---|---|
| CASE: | CASE 3: 3650m Vertical Well - includes tieback | Total Days | 44.48 |
| LOCATION: | Hinton TWP 51 - RG 25 W5M | Total MD (m) | 3650 |
| TARGET ZONE: | Base Spirit River/Mississippian | TVD (m) | 3650 |
| SPUD DATE: | Fall 2018 | Well Profile | Vertical |

| Account Code | Description | | Estimate |
|---|---|---|---|
| 9300 100 | SURVEYS | | 15,000 |
| 9300 101 | ROAD AND LEASE COSTS | | 100,000 |
| 9300 103 | ROAD AND LEASE CLEANUP | | 10,000 |
| 9300 105 | ROAD USE FEES | | 10,000 |
| 9300 110 | FIRST NATIONS CONSULTATION | | 0 |
| 9300 112 | WELL LICENSE | | 5,000 |
| 9300 115 | ABANDONMENT/PLUG BACK | | 0 |
| 9300 200 | DRILLING RIG | | 1,303,343 |
| 9300 201 | DRILLING RIG MOVE IN MOVE OUT | | 125,000 |
| 9300 202 | RIG FUEL | | 260,887 |
| 9300 205 | CONDUCTOR AND RATHOLE | | 10,000 |
| 9300 206 | DRILLING MUD AND CHEMICALS | | 544,064 |
| 9300 207 | DIRECTIONAL DRILLING | | 338,183 |
| 9300 250 | CAMP (NON SUBSISTENCE) | | 133,443 |
| 9300 450 | COMMUNICATION | | 77,842 |
| 9300 370 | EQUIP RENTAL - SURFACE | | 161,467 |
| 9300 500 | TRUCKING | | 134,000 |
| 9300 316 | DRILL PIPE INSPECTION | | 2,500 |
| 9300 310 | WELDING SERVICES | | 2,500 |
| 9300 311 | PRESSURE TESTING | | 7,000 |
| 9300 314 | LOG/PERF/ANALYSIS | | 85,000 |
| 9300 401 | CONSTRUCTION/WELL SITE SUPERVISION | | 121,203 |
| 9300 370 | MAT RENTALS | | 0 |
| 9300 480 | SAFETY SERVICES | | 0 |
| 9300 309 | CASING BOWL AND ATTACHMENTS | | 35,000 |
| 9300 304 | SURFACE CASING AND ACCESSORIES | | 103,600 |
| 9300 300 | SURFACE CASING - CEMENT | | 25,000 |
| 9300 306 | POWER TONGS SURFACE | | 5,000 |
| 9300 305 | INTERMEDIATE CASING & ACCESSORIES | | 567,000 |
| 9300 302 | INTERMEDIATE CASING-CEMENTING | | 100,000 |
| 9300 307 | POWER TONGS INTERMEDIATE | | 15,000 |
| 9300 303 | PRODUCTION CASING & ACCESSORIES | | 442,300 |
| 9300 301 | PRODUCTION CASING CEMENT | | 100,000 |
| 9300 308 | POWER TONGS PRODUCTION | | 15,000 |
| 9300 303 | PRODUCTION TUBING & ACCESSORIES | | 182,500 |
| 9300 308 | POWER TONGS PRODUCTION TUBING | | 20,000 |
| 9300 400 | ENGINEERING AND WELL PLANNING | | 53,377 |
| 9300 315 | FISHING SERVICES | | 0 |
| 9300 312 | CORING AND ANALYSIS | | 0 |
| 9300 313 | MISCELLENEOUS TESTS AND ANALYSIS | | 0 |
| 9300 502 | FLUID DISPOSAL TRUCKING | | 40,000 |
| 9300 510 | FLUID DISPOSAL COSTS | | 40,000 |
| 9300 503 | SOLID WASTE DISPOSAL TRUCKING | | 48,590 |
| 9300 511 | SOLID WASTE DISPOSAL COSTS | | 36,349 |
| 9300 371 | DOWN HOLE EQUIP RENTAL | | 56,534 |
| 9300 208 | DRILL BITS | | 185,000 |
| 9300 800 | CONTINGENCY COSTS | | 0 |
| 9300 850 | INSURANCE | | 0 |
| 9300 610 | ENVIRONMENTAL SERVICES | | 7,000 |
| 9300 501 | WATER TRUCK | | 33,361 |
| 9300 402 | WELL SITE GEOLOGIST | | 27,356 |
| 9300 700 | POTABLE WATER | | 4,448 |
| 9300 996 | OVERHEAD | | 0 |
| 9300 504 | VACUUM TRUCK | | 66,722 |
| | Estimated Total | | 5,655,569 |

## Case 3a: 3650m Vertical Well – No Tieback

| CASE 3a: 3650m Vertical Well - no tieback | Total Days: | 43.6 |
|---|---|---|
| | Totals Estimated Cost: | $5.299 |

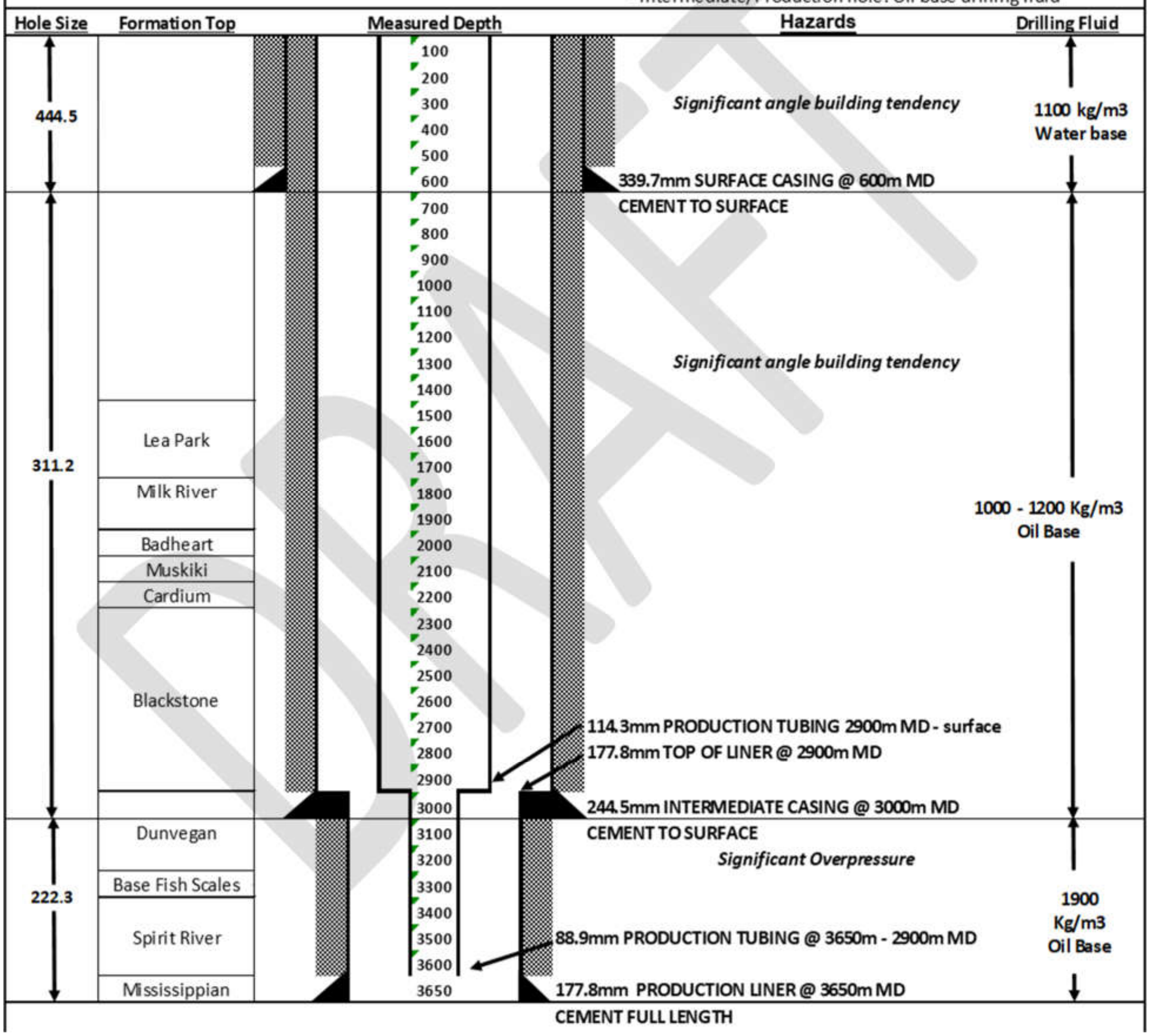
**LIST OF ASSUMPTIONS**

**Well profile:**
- Vertical well
- Total Measured/True Vertical Depth = 3650m MD/TVD
- Well terminates in Mississippian Fm.

**Pressure Profile:**
- 1.0 S.G. normally pressured from surface to base Dunvegan Formation
- 1.90 S.G. maximum over-pressure from Spirit River and deeper

**Hardware Design:**
- 339.7mm 81.1 Kg/m J-55 STC Surface Casing
- 244.5mm 79.6 Kg/m L-80 LTC Intermediate Casing
- 177.8mm 43.2 Kg/m L-80 LTC Production liner
- 114.3mm 23.0 Kg/m L80 PH6 tubing (2900m - surface)
- 88.9mm 19.25 Kg/m L80 PH6 tubing (3650 - 2900m)

**Drilling Fluid:**
- Surface hole: Water base drilling fluid
- Intermediate/Production hole: Oil base drilling fluid



| DRILLING COST ESTIMATE | | | |
|---|---|---|---|
| CASE: | CASE 3a: 3650M Vertical well - no tieback | Total Days | 43.61 |
| LOCATION: | Hinton TWP 51 - RG 25 W5M | Total MD (m) | 3650 |
| TARGET ZONE: | Base Spirit River/Mississippian | TVD (m) | 3650 |
| SPUD DATE: | Fall 2018 | Well Profile | Vertical |
| | | | |
| Account Code | Description | | Estimate |
| 9300 100 | SURVEYS | | 15,000 |
| 9300 101 | ROAD AND LEASE COSTS | | 100,000 |
| 9300 103 | ROAD AND LEASE CLEANUP | | 10,000 |
| 9300 105 | ROAD USE FEES | | 10,000 |
| 9300 110 | FIRST NATIONS CONSULTATION | | 0 |
| 9300 112 | WELL LICENSE | | 5,000 |
| 9300 115 | ABANDONMENT/PLUG BACK | | 0 |
| 9300 200 | DRILLING RIG | | 1,278,624 |
| 9300 201 | DRILLING RIG MOVE IN MOVE OUT | | 125,000 |
| 9300 202 | RIG FUEL | | 255,637 |
| 9300 205 | CONDUCTOR AND RATHOLE | | 10,000 |
| 9300 206 | DRILLING MUD AND CHEMICALS | | 543,189 |
| 9300 207 | DIRECTIONAL DRILLING | | 338,183 |
| 9300 250 | CAMP (NON SUBSISTENCE) | | 130,818 |
| 9300 450 | COMMUNICATION | | 76,311 |
| 9300 370 | EQUIP RENTAL - SURFACE | | 158,290 |
| 9300 500 | TRUCKING | | 134,000 |
| 9300 316 | DRILL PIPE INSPECTION | | 2,500 |
| 9300 310 | WELDING SERVICES | | 2,500 |
| 9300 311 | PRESSURE TESTING | | 7,000 |
| 9300 314 | LOG/PERF/ANALYSIS | | 85,000 |
| 9300 401 | CONSTRUCTION/WELL SITE SUPERVISION | | 119,015 |
| 9300 370 | MAT RENTALS | | 0 |
| 9300 480 | SAFETY SERVICES | | 0 |
| 9300 309 | CASING BOWL AND ATTACHMENTS | | 30,000 |
| 9300 304 | SURFACE CASING AND ACCESSORIES | | 103,600 |
| 9300 300 | SURFACE CASING - CEMENT | | 25,000 |
| 9300 306 | POWER TONGS SURFACE | | 5,000 |
| 9300 305 | INTERMEDIATE CASING & ACCESSORIES | | 567,000 |
| 9300 302 | INTERMEDIATE CASING-CEMENTING | | 100,000 |
| 9300 307 | POWER TONGS INTERMEDIATE | | 15,000 |
| 9300 303 | PRODUCTION CASING & ACCESSORIES | | 126,500 |
| 9300 301 | PRODUCTION CASING CEMENT | | 50,000 |
| 9300 308 | POWER TONGS PRODUCTION | | 5,000 |
| 9300 303 | PRODUCTION TUBING & ACCESSORIES - 88.9mm | | 37,500 |
| 9300 303 | PRODUCTION TUBING & ACCESSORIES - 114.3mm | | 217,500 |
| 9300 308 | POWER TONGS PRODUCTION TUBING | | 15,000 |
| 9300 400 | ENGINEERING AND WELL PLANNING | | 52,327 |
| 9300 315 | FISHING SERVICES | | 0 |
| 9300 312 | CORING AND ANALYSIS | | 0 |
| 9300 313 | MISCELLENEOUS TESTS AND ANALYSIS | | 0 |
| 9300 502 | FLUID DISPOSAL TRUCKING | | 40,000 |
| 9300 510 | FLUID DISPOSAL COSTS | | 40,000 |
| 9300 503 | SOLID WASTE DISPOSAL TRUCKING | | 48,590 |
| 9300 511 | SOLID WASTE DISPOSAL COSTS | | 36,349 |
| 9300 371 | DOWN HOLE EQUIP RENTAL | | 56,534 |
| 9300 208 | DRILL BITS | | 185,000 |
| 9300 800 | CONTINGENCY COSTS | | 0 |
| 9300 850 | INSURANCE | | 0 |
| 9300 610 | ENVIRONMENTAL SERVICES | | 7,000 |
| 9300 501 | WATER TRUCK | | 32,705 |
| 9300 402 | WELL SITE GEOLOGIST | | 27,356 |
| 9300 700 | POTABLE WATER | | 4,361 |
| 9300 996 | OVERHEAD | | 0 |
| 9300 504 | VACUUM TRUCK | | 65,409 |
| | Estimated Total | | 5,298,799 |

# Case 4: 4300m Horizontal Well – Includes Tieback

| CASE 4: 4300m Horizontal Well - includes tieback | Total Days: | 51.4 |
|---|---|---|
| | Totals Estimated Cost: | $6.355 M |

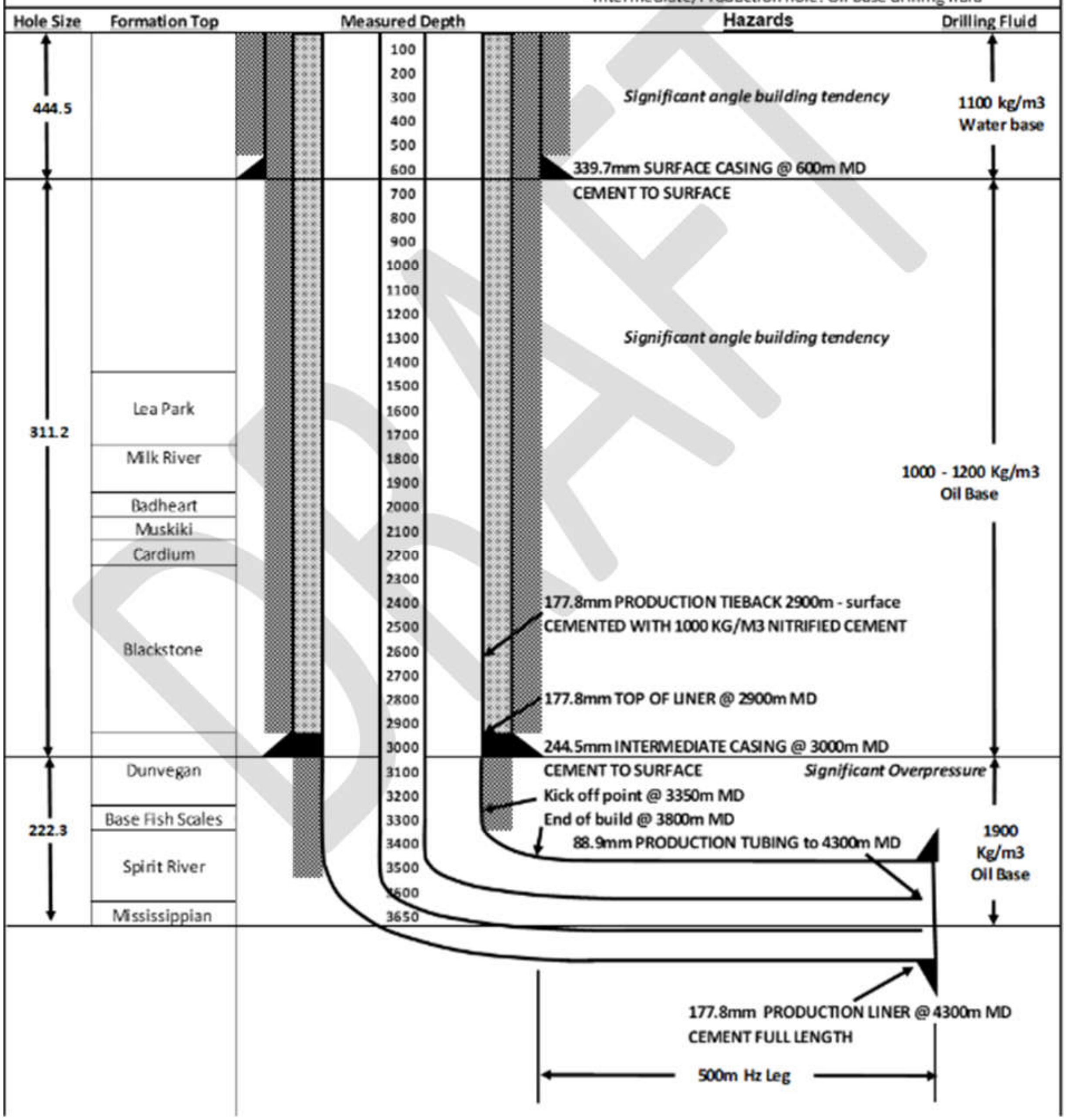
**LIST OF ASSUMPTIONS**

**Well profile:**
- Horizontal well
- Total Measured/True Vertical Depth = 4300m/3650m MD/TVD
- Well terminates in Mississippian Fm.

**Pressure Profile:**
- 1.0 S.G. normally pressured from surface to base Dunvegan Formation
- 1.90 S.G. maximum over-pressure from Spirit River and deeper

**Hardware Design:**
- 339.7mm 81.1 Kg/m J-55 STC Surface Casing
- 244.5mm 79.6 Kg/m L-80 LTC Intermediate Casing
- 177.8mm 43.2 Kg/m L-80 LTC Production liner/tieback
- Nitrified cement behind 177.8mm tieback
- 88.9mm 19.25 Kg/m L80 PH6 tubing

**Drilling Fluid:**
- Surface hole: Water base drilling fluid
- Intermediate/Production hole: Oil base drilling fluid



| DRILLING COST ESTIMATE | | | |
|---|---|---|---|
| CASE: | CASE 4: 4300m Horizontal Well - includes tieback | Total Days | 51.41 |
| LOCATION: | Hinton TWP 51 - RG 25 W5M | Total MD (m) | 4300 |
| TARGET ZONE: | Base Spirit River/Mississippian | TVD (m) | 3650 |
| SPUD DATE: | Fall 2018 | Well Profile | HORIZONTAL |
| | | | |
| Account Code | Description | | Estimate |
| 9300 100 | SURVEYS | | 15,000 |
| 9300 101 | ROAD AND LEASE COSTS | | 100,000 |
| 9300 103 | ROAD AND LEASE CLEANUP | | 10,000 |
| 9300 105 | ROAD USE FEES | | 10,000 |
| 9300 110 | FIRST NATIONS CONSULTATION | | 0 |
| 9300 112 | WELL LICENSE | | 5,000 |
| 9300 115 | ABANDONMENT/PLUG BACK | | 0 |
| 9300 200 | DRILLING RIG | | 1,499,131 |
| 9300 201 | DRILLING RIG MOVE IN MOVE OUT | | 125,000 |
| 9300 202 | RIG FUEL | | 302,470 |
| 9300 205 | CONDUCTOR AND RATHOLE | | 10,000 |
| 9300 206 | DRILLING MUD AND CHEMICALS | | 681,828 |
| 9300 207 | DIRECTIONAL DRILLING | | 390,627 |
| 9300 250 | CAMP (NON SUBSISTENCE) | | 154,235 |
| 9300 450 | COMMUNICATION | | 89,970 |
| 9300 370 | EQUIP RENTAL - SURFACE | | 186,624 |
| 9300 500 | TRUCKING | | 136,000 |
| 9300 316 | DRILL PIPE INSPECTION | | 2,500 |
| 9300 310 | WELDING SERVICES | | 2,500 |
| 9300 311 | PRESSURE TESTING | | 7,000 |
| 9300 314 | LOG/PERF/ANALYSIS | | 85,000 |
| 9300 401 | CONSTRUCTION/WELL SITE SUPERVISION | | 138,529 |
| 9300 370 | MAT RENTALS | | 0 |
| 9300 480 | SAFETY SERVICES | | 0 |
| 9300 309 | CASING BOWL AND ATTACHMENTS | | 35,000 |
| 9300 304 | SURFACE CASING AND ACCESSORIES | | 103,600 |
| 9300 300 | SURFACE CASING - CEMENT | | 25,000 |
| 9300 306 | POWER TONGS SURFACE | | 5,000 |
| 9300 305 | INTERMEDIATE CASING & ACCESSORIES | | 567,000 |
| 9300 302 | INTERMEDIATE CASING-CEMENTING | | 100,000 |
| 9300 307 | POWER TONGS INTERMEDIATE | | 15,000 |
| 9300 303 | PRODUCTION CASING & ACCESSORIES | | 508,600 |
| 9300 301 | PRODUCTION CASING CEMENT | | 100,000 |
| 9300 308 | POWER TONGS PRODUCTION | | 15,000 |
| 9300 303 | PRODUCTION TUBING & ACCESSORIES - 88.9mm | | 215,000 |
| 9300 303 | PRODUCTION TUBING & ACCESSORIES - 114.3mm | | 0 |
| 9300 308 | POWER TONGS TUBING | | 15,000 |
| 9300 400 | ENGINEERING AND WELL PLANNING | | 61,694 |
| 9300 315 | FISHING SERVICES | | 0 |
| 9300 312 | CORING AND ANALYSIS | | 0 |
| 9300 313 | MISCELLENEOUS TESTS AND ANALYSIS | | 0 |
| 9300 502 | FLUID DISPOSAL TRUCKING | | 40,000 |
| 9300 510 | FLUID DISPOSAL COSTS | | 40,000 |
| 9300 503 | SOLID WASTE DISPOSAL TRUCKING | | 53,622 |
| 9300 511 | SOLID WASTE DISPOSAL COSTS | | 40,752 |
| 9300 371 | DOWN HOLE EQUIP RENTAL | | 66,368 |
| 9300 208 | DRILL BITS | | 235,000 |
| 9300 800 | CONTINGENCY COSTS | | 0 |
| 9300 850 | INSURANCE | | 0 |
| 9300 610 | ENVIRONMENTAL SERVICES | | 7,000 |
| 9300 501 | WATER TRUCK | | 38,559 |
| 9300 402 | WELL SITE GEOLOGIST | | 33,995 |
| 9300 700 | POTABLE WATER | | 5,141 |
| 9300 996 | OVERHEAD | | 0 |
| 9300 504 | VACUUM TRUCK | | 77,118 |
| | Estimated Total | | 6,354,864 |

## Case 4a: 4300m Horizontal Well – No Tieback

| CASE 4a: 4300m Horizontal Well - no tieback | Total Days: | 49.7 |
|---|---|---|
| | Totals Estimated Cost: | $5.972 M |

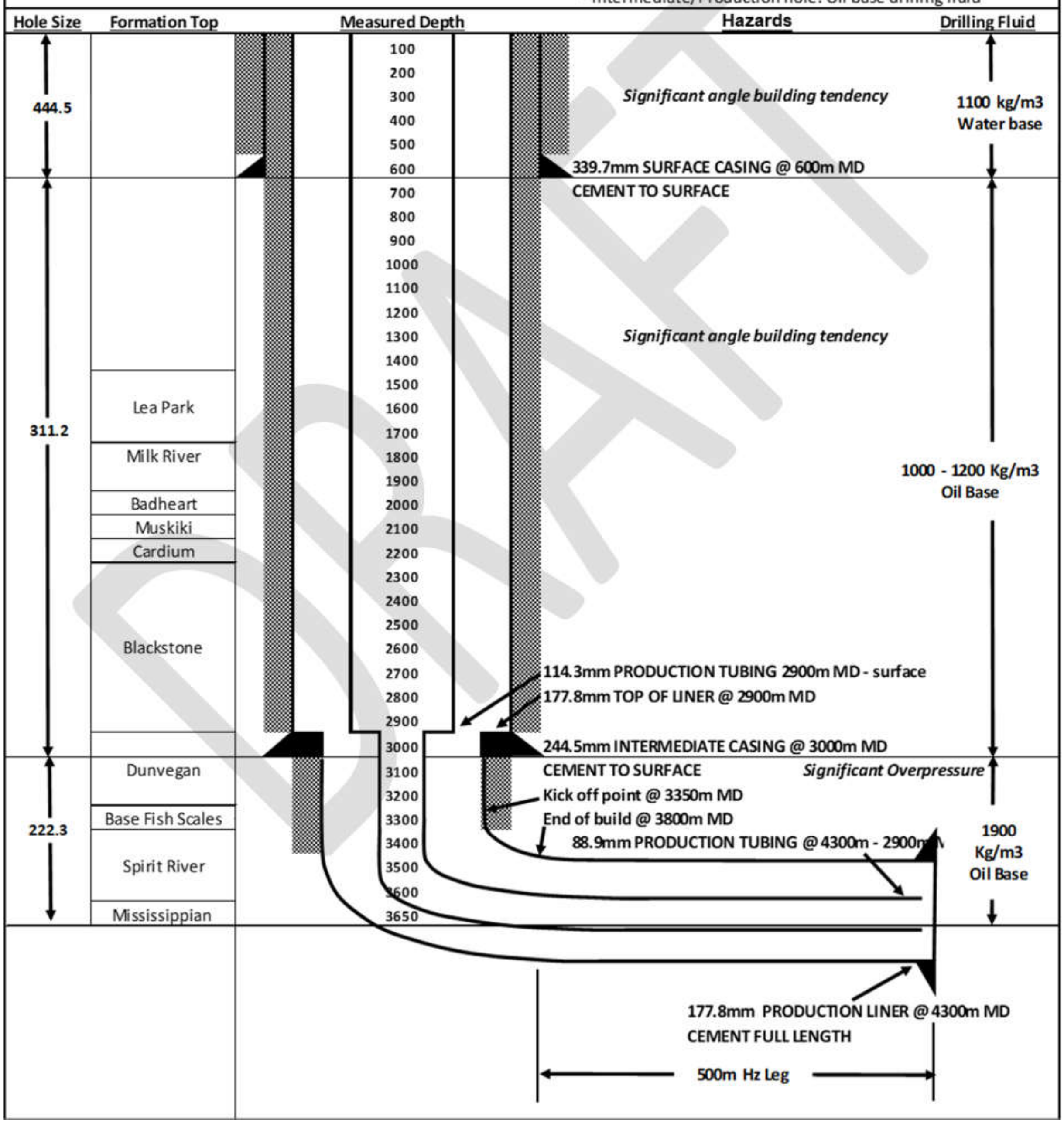
**LIST OF ASSUMPTIONS**

**Well profile:**
- Horizontal well
- Total Measured/True Vertical Depth = 4300m/3650m MD/TVD
- Well terminates in Mississippian Fm.

**Pressure Profile:**
- 1.0 S.G. normally pressured from surface to base Dunvegan Formation
- 1.90 S.G. maximum over-pressure from Spirit River and deeper

**Hardware Design:**
- 339.7mm 81.1 Kg/m J-55 STC Surface Casing
- 244.5mm 79.6 Kg/m L-80 LTC Intermediate Casing
- 177.8mm 43.2 Kg/m L-80 LTC Production liner
- 114.3mm 23.0 Kg/m L80 PH6 tubing (2900m - surface)
- 88.9mm 19.25 Kg/m L80 PH6 tubing (4300 - 2900m)

**Drilling Fluid:**
- Surface hole: Water base drilling fluid
- Intermediate/Production hole: Oil base drilling fluid



| DRILLING COST ESTIMATE | | | |
|---|---|---|---|
| CASE: | CASE 4a: 4300m Horizontal Well - no tieback | Total Days | 49.66 |
| LOCATION: | Hinton TWP 51 - RG 25 W5M | Total MD (m) | 4300 |
| TARGET ZONE: | Base Spirit River/Mississippian | TVD (m) | 3650 |
| SPUD DATE: | Fall 2018 | Well Profile | HORIZONTAL |
| | | | |
| Account Code | Description | | Estimate |
| 9300 100 | SURVEYS | | 15,000 |
| 9300 101 | ROAD AND LEASE COSTS | | 100,000 |
| 9300 103 | ROAD AND LEASE CLEANUP | | 10,000 |
| 9300 105 | ROAD USE FEES | | 10,000 |
| 9300 110 | FIRST NATIONS CONSULTATION | | 0 |
| 9300 112 | WELL LICENSE | | 5,000 |
| 9300 115 | ABANDONMENT/PLUG BACK | | 0 |
| 9300 200 | DRILLING RIG | | 1,449,693 |
| 9300 201 | DRILLING RIG MOVE IN MOVE OUT | | 125,000 |
| 9300 202 | RIG FUEL | | 291,970 |
| 9300 205 | CONDUCTOR AND RATHOLE | | 10,000 |
| 9300 206 | DRILLING MUD AND CHEMICALS | | 680,203 |
| 9300 207 | DIRECTIONAL DRILLING | | 390,627 |
| 9300 250 | CAMP (NON SUBSISTENCE) | | 148,985 |
| 9300 450 | COMMUNICATION | | 86,908 |
| 9300 370 | EQUIP RENTAL - SURFACE | | 180,272 |
| 9300 500 | TRUCKING | | 136,000 |
| 9300 316 | DRILL PIPE INSPECTION | | 2,500 |
| 9300 310 | WELDING SERVICES | | 2,500 |
| 9300 311 | PRESSURE TESTING | | 7,000 |
| 9300 314 | LOG/PERF/ANALYSIS | | 85,000 |
| 9300 401 | CONSTRUCTION/WELL SITE SUPERVISION | | 134,154 |
| 9300 370 | MAT RENTALS | | 0 |
| 9300 480 | SAFETY SERVICES | | 0 |
| 9300 309 | CASING BOWL AND ATTACHMENTS | | 30,000 |
| 9300 304 | SURFACE CASING AND ACCESSORIES | | 103,600 |
| 9300 300 | SURFACE CASING - CEMENT | | 25,000 |
| 9300 306 | POWER TONGS SURFACE | | 5,000 |
| 9300 305 | INTERMEDIATE CASING & ACCESSORIES | | 567,000 |
| 9300 302 | INTERMEDIATE CASING-CEMENTING | | 100,000 |
| 9300 307 | POWER TONGS INTERMEDIATE | | 15,000 |
| 9300 303 | PRODUCTION CASING & ACCESSORIES | | 192,800 |
| 9300 301 | PRODUCTION CASING CEMENT | | 50,000 |
| 9300 308 | POWER TONGS PRODUCTION | | 5,000 |
| 9300 303 | PRODUCTION TUBING & ACCESSORIES - 88.9mm | | 82,500 |
| 9300 303 | PRODUCTION TUBING & ACCESSORIES - 114.3mm | | 217,500 |
| 9300 308 | POWER TONGS TUBING | | 15,000 |
| 9300 400 | ENGINEERING AND WELL PLANNING | | 59,594 |
| 9300 315 | FISHING SERVICES | | 0 |
| 9300 312 | CORING AND ANALYSIS | | 0 |
| 9300 313 | MISCELLENEOUS TESTS AND ANALYSIS | | 0 |
| 9300 502 | FLUID DISPOSAL TRUCKING | | 40,000 |
| 9300 510 | FLUID DISPOSAL COSTS | | 40,000 |
| 9300 503 | SOLID WASTE DISPOSAL TRUCKING | | 53,622 |
| 9300 511 | SOLID WASTE DISPOSAL COSTS | | 40,752 |
| 9300 371 | DOWN HOLE EQUIP RENTAL | | 66,368 |
| 9300 208 | DRILL BITS | | 235,000 |
| 9300 800 | CONTINGENCY COSTS | | 0 |
| 9300 850 | INSURANCE | | 0 |
| 9300 610 | ENVIRONMENTAL SERVICES | | 7,000 |
| 9300 501 | WATER TRUCK | | 37,246 |
| 9300 402 | WELL SITE GEOLOGIST | | 33,995 |
| 9300 700 | POTABLE WATER | | 4,966 |
| 9300 996 | OVERHEAD | | 0 |
| 9300 504 | VACUUM TRUCK | | 74,493 |
| | Estimated Total | | 5,972,249 |

# Case 5: 4500m Vertical Well – Includes Tieback

| CASE 5: 4500m Vertical Well - includes tieback | Total Days: | 54.4 |
|---|---|---|
| | Totals Estimated Cost: | $6.608 M |

**LIST OF ASSUMPTIONS**

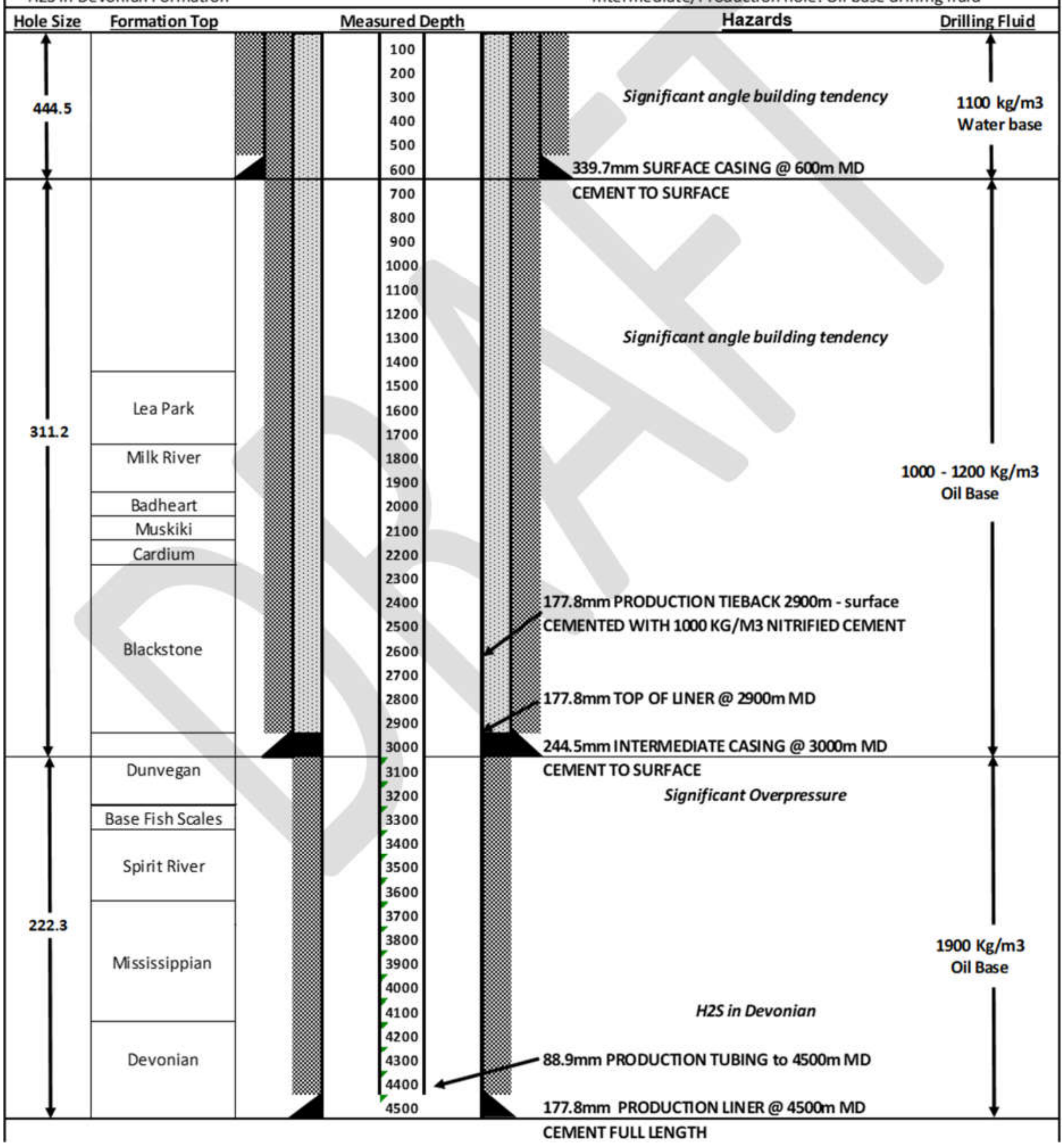
**Well profile:**
- Vertical well
- Total Measured/True Vertical Depth = 4500m MD/TVD
- Well terminates in Devonian Fm.

**Pressure Profile:**
- 1.0 S.G. normally pressured from surface to base Dunvegan Formation
- 1.90 S.G. maximum over-pressure from Spirit River and deeper

**H2S:**
- H2S in Devonian Formation

**Hardware Design:**
- 339.7mm 81.1 Kg/m J-55 STC Surface Casing
- 244.5mm 79.6 Kg/m L-80 LTC Intermediate Casing
- 177.8mm 43.2 Kg/m L-80 LTC Production liner/tieback
- Nitrified cement behind 177.8mm tieback
- 88.9mm 19.25 Kg/m L80 PH6 tubing

**Drilling Fluid:**
- Surface hole: Water base drilling fluid
- Intermediate/Production hole: Oil base drilling fluid



| DRILLING COST ESTIMATE | | | |
|---|---|---|---|
| **CASE:** | **CASE 5: 4500m Vertical Well - includes tieback** | **Total Days** | **54.40** |
| **LOCATION:** | Hinton TWP 51 - RG 25 W5M | **Total MD (m)** | **4500** |
| **TARGET ZONE:** | Devonian | **TVD (m)** | **4500** |
| **SPUD DATE:** | Fall 2018 | **Well Profile** | **Vertical** |
| | | | |
| **Account Code** | **Description** | | **Estimate** |
| 9300 100 | SURVEYS | | 15,000 |
| 9300 101 | ROAD AND LEASE COSTS | | 100,000 |
| 9300 103 | ROAD AND LEASE CLEANUP | | 10,000 |
| 9300 105 | ROAD USE FEES | | 10,000 |
| 9300 110 | FIRST NATIONS CONSULTATION | | 0 |
| 9300 112 | WELL LICENSE | | 5,000 |
| 9300 115 | ABANDONMENT/PLUG BACK | | 0 |
| 9300 200 | DRILLING RIG | | 1,583,488 |
| 9300 201 | DRILLING RIG MOVE IN MOVE OUT | | 125,000 |
| 9300 202 | RIG FUEL | | 320,387 |
| 9300 205 | CONDUCTOR AND RATHOLE | | 10,000 |
| 9300 206 | DRILLING MUD AND CHEMICALS | | 724,814 |
| 9300 207 | DIRECTIONAL DRILLING | | 414,516 |
| 9300 250 | CAMP (NON SUBSISTENCE) | | 163,193 |
| 9300 450 | COMMUNICATION | | 95,196 |
| 9300 370 | EQUIP RENTAL - SURFACE | | 197,464 |
| 9300 500 | TRUCKING | | 136,000 |
| 9300 316 | DRILL PIPE INSPECTION | | 2,500 |
| 9300 310 | WELDING SERVICES | | 2,500 |
| 9300 311 | PRESSURE TESTING | | 7,000 |
| 9300 314 | LOG/PERF/ANALYSIS | | 85,000 |
| 9300 401 | CONSTRUCTION/WELL SITE SUPERVISION | | 145,995 |
| 9300 370 | MAT RENTALS | | 0 |
| 9300 480 | SAFETY SERVICES | | 0 |
| 9300 309 | CASING BOWL AND ATTACHMENTS | | 35,000 |
| 9300 304 | SURFACE CASING AND ACCESSORIES | | 103,600 |
| 9300 300 | SURFACE CASING - CEMENT | | 25,000 |
| 9300 306 | POWER TONGS SURFACE | | 5,000 |
| 9300 305 | INTERMEDIATE CASING & ACCESSORIES | | 567,000 |
| 9300 302 | INTERMEDIATE CASING-CEMENTING | | 100,000 |
| 9300 307 | POWER TONGS INTERMEDIATE | | 15,000 |
| 9300 303 | PRODUCTION CASING & ACCESSORIES | | 529,000 |
| 9300 301 | PRODUCTION CASING CEMENT | | 100,000 |
| 9300 308 | POWER TONGS PRODUCTION | | 15,000 |
| 9300 303 | PRODUCTION TUBING & ACCESSORIES - 88.9mm | | 225,000 |
| 9300 303 | PRODUCTION TUBING & ACCESSORIES - 114.3mm | | 0 |
| 9300 308 | POWER TONGS TUBING | | 15,000 |
| 9300 400 | ENGINEERING AND WELL PLANNING | | 65,277 |
| 9300 315 | FISHING SERVICES | | 0 |
| 9300 312 | CORING AND ANALYSIS | | 0 |
| 9300 313 | MISCELLENEOUS TESTS AND ANALYSIS | | 0 |
| 9300 502 | FLUID DISPOSAL TRUCKING | | 40,000 |
| 9300 510 | FLUID DISPOSAL COSTS | | 40,000 |
| 9300 503 | SOLID WASTE DISPOSAL TRUCKING | | 55,171 |
| 9300 511 | SOLID WASTE DISPOSAL COSTS | | 42,107 |
| 9300 371 | DOWN HOLE EQUIP RENTAL | | 70,847 |
| 9300 208 | DRILL BITS | | 235,000 |
| 9300 800 | CONTINGENCY COSTS | | 0 |
| 9300 850 | INSURANCE | | 0 |
| 9300 610 | ENVIRONMENTAL SERVICES | | 7,000 |
| 9300 501 | WATER TRUCK | | 40,798 |
| 9300 402 | WELL SITE GEOLOGIST | | 36,981 |
| 9300 700 | POTABLE WATER | | 5,440 |
| 9300 996 | OVERHEAD | | 0 |
| 9300 504 | VACUUM TRUCK | | 81,597 |
| | **Estimated Total** | | **6,607,872** |

## Case 5a: 4500m Vertical Well – No Tieback

| CASE 5a: 4500m Vertical Well - no tieback | Total Days: | 52.8 |
|---|---|---|
| | Totals Estimated Cost: | $6.218 M |

**LIST OF ASSUMPTIONS**

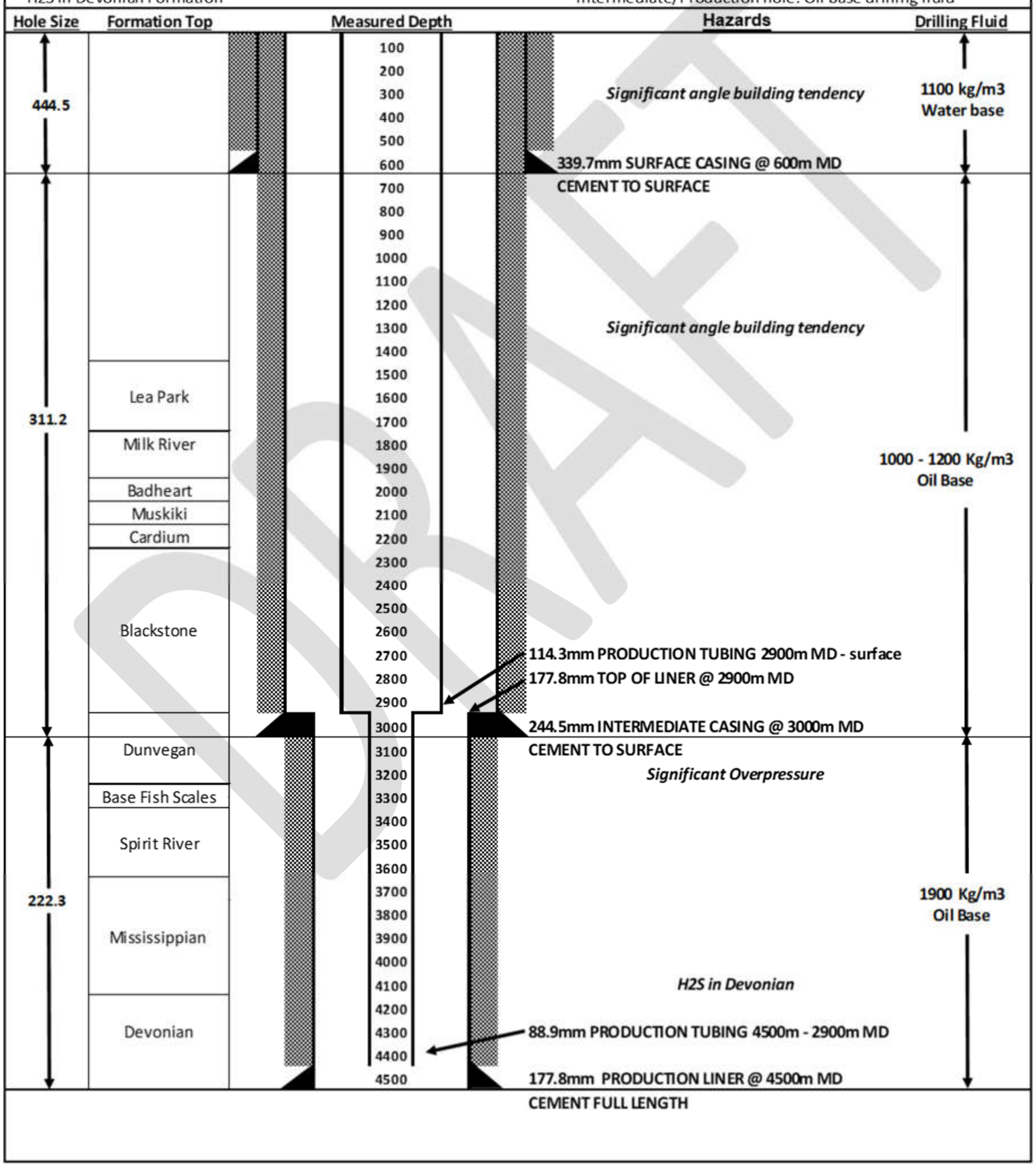
**Well profile:**
- Vertical well
- Total Measured/True Vertical Depth = 4500m MD/TVD
- Well terminates in Devonian Fm.

**Pressure Profile:**
- 1.0 S.G. normally pressured from surface to base Dunvegan Formation
- 1.90 S.G. maximum over-pressure from Spirit River and deeper

**H2S:**
- H2S in Devonian Formation

**Hardware Design:**
- 339.7mm 81.1 Kg/m J-55 STC Surface Casing
- 244.5mm 79.6 Kg/m L-80 LTC Intermediate Casing
- 177.8mm 43.2 Kg/m L-80 LTC Production liner
- 114.3mm 23.0 Kg/m L80 PH6 tubing (2900m - surface)
- 88.9mm 19.25 Kg/m L80 PH6 tubing (4500 - 2900m)

**Drilling Fluid:**
- Surface hole: Water base drilling fluid
- Intermediate/Production hole: Oil base drilling fluid



| DRILLING COST ESTIMATE | | | |
|---|---|---|---|
| CASE: | CASE 5a: 4500m Vertical Well - no tieback | Total Days | 52.77 |
| LOCATION: | Hinton TWP 51 - RG 25 W5M | Total MD (m) | 4500 |
| TARGET ZONE: | Devonian | TVD (m) | 3650 |
| SPUD DATE: | Fall 2018 | Well Profile | Vertical |
| | | | |
| Account Code | Description | | Estimate |
| 9300 100 | SURVEYS | | 15,000 |
| 9300 101 | ROAD AND LEASE COSTS | | 100,000 |
| 9300 103 | ROAD AND LEASE CLEANUP | | 10,000 |
| 9300 105 | ROAD USE FEES | | 10,000 |
| 9300 110 | FIRST NATIONS CONSULTATION | | 0 |
| 9300 112 | WELL LICENSE | | 5,000 |
| 9300 115 | ABANDONMENT/PLUG BACK | | 0 |
| 9300 200 | DRILLING RIG | | 1,537,582 |
| 9300 201 | DRILLING RIG MOVE IN MOVE OUT | | 125,000 |
| 9300 202 | RIG FUEL | | 310,637 |
| 9300 205 | CONDUCTOR AND RATHOLE | | 10,000 |
| 9300 206 | DRILLING MUD AND CHEMICALS | | 723,189 |
| 9300 207 | DIRECTIONAL DRILLING | | 414,516 |
| 9300 250 | CAMP (NON SUBSISTENCE) | | 158,318 |
| 9300 450 | COMMUNICATION | | 92,352 |
| 9300 370 | EQUIP RENTAL - SURFACE | | 191,565 |
| 9300 500 | TRUCKING | | 136,000 |
| 9300 316 | DRILL PIPE INSPECTION | | 2,500 |
| 9300 310 | WELDING SERVICES | | 2,500 |
| 9300 311 | PRESSURE TESTING | | 7,000 |
| 9300 314 | LOG/PERF/ANALYSIS | | 85,000 |
| 9300 401 | CONSTRUCTION/WELL SITE SUPERVISION | | 141,932 |
| 9300 370 | MAT RENTALS | | 0 |
| 9300 480 | SAFETY SERVICES | | 0 |
| 9300 309 | CASING BOWL AND ATTACHMENTS | | 30,000 |
| 9300 304 | SURFACE CASING AND ACCESSORIES | | 103,600 |
| 9300 300 | SURFACE CASING - CEMENT | | 25,000 |
| 9300 306 | POWER TONGS SURFACE | | 5,000 |
| 9300 305 | INTERMEDIATE CASING & ACCESSORIES | | 567,000 |
| 9300 302 | INTERMEDIATE CASING-CEMENTING | | 100,000 |
| 9300 307 | POWER TONGS INTERMEDIATE | | 15,000 |
| 9300 303 | PRODUCTION CASING & ACCESSORIES | | 213,200 |
| 9300 301 | PRODUCTION CASING CEMENT | | 50,000 |
| 9300 308 | POWER TONGS PRODUCTION | | 5,000 |
| 9300 303 | PRODUCTION TUBING & ACCESSORIES - 88.9mm | | 80,000 |
| 9300 303 | PRODUCTION TUBING & ACCESSORIES - 114.3mm | | 217,500 |
| 9300 308 | POWER TONGS TUBING | | 15,000 |
| 9300 400 | ENGINEERING AND WELL PLANNING | | 63,327 |
| 9300 315 | FISHING SERVICES | | 0 |
| 9300 312 | CORING AND ANALYSIS | | 0 |
| 9300 313 | MISCELLENEOUS TESTS AND ANALYSIS | | 0 |
| 9300 502 | FLUID DISPOSAL TRUCKING | | 40,000 |
| 9300 510 | FLUID DISPOSAL COSTS | | 40,000 |
| 9300 503 | SOLID WASTE DISPOSAL TRUCKING | | 55,171 |
| 9300 511 | SOLID WASTE DISPOSAL COSTS | | 42,107 |
| 9300 371 | DOWN HOLE EQUIP RENTAL | | 70,847 |
| 9300 208 | DRILL BITS | | 235,000 |
| 9300 800 | CONTINGENCY COSTS | | 0 |
| 9300 850 | INSURANCE | | 0 |
| 9300 610 | ENVIRONMENTAL SERVICES | | 7,000 |
| 9300 501 | WATER TRUCK | | 39,580 |
| 9300 402 | WELL SITE GEOLOGIST | | 36,981 |
| 9300 700 | POTABLE WATER | | 5,277 |
| 9300 996 | OVERHEAD | | 0 |
| 9300 504 | VACUUM TRUCK | | 79,159 |
| | Estimated Total | | 6,218,842 |

## Appendix C.3 Well Heat Transfer Methodology & Sensitivities

### Appendix C.3.1 Candidate Well Modeling

The geothermal well and the reservoir from which it operates is what makes geothermal projects viable. The ability to select and/or create wells that work at their highest efficiency helps give a good understanding of the initial capital cost and the long-term economics. Maximising the amount of energy you can pull, while keeping your construction costs for the well and operating costs such as the pump low without compromising the system.

Currently at a preliminary level of design, the ability to approximate geothermal well productivity was crucial but unable to be accurate for each specific well. To keep the comparisons on fair grounds between each candidate, assumptions were made. These assumptions include; water as the working fluid, water being kept as a saturated liquid, and negligible thermal resistance from steel pipe. These assumptions were made on the basis of properties that would be beneficial when proceeding to detailed design.

Beginning the heat transfer simulation, required a simple model of the system, this was done with a 2D model, as shown in Figure 84, that is integrated in sections over the depth of the well, since the cross sections are identical, being round.

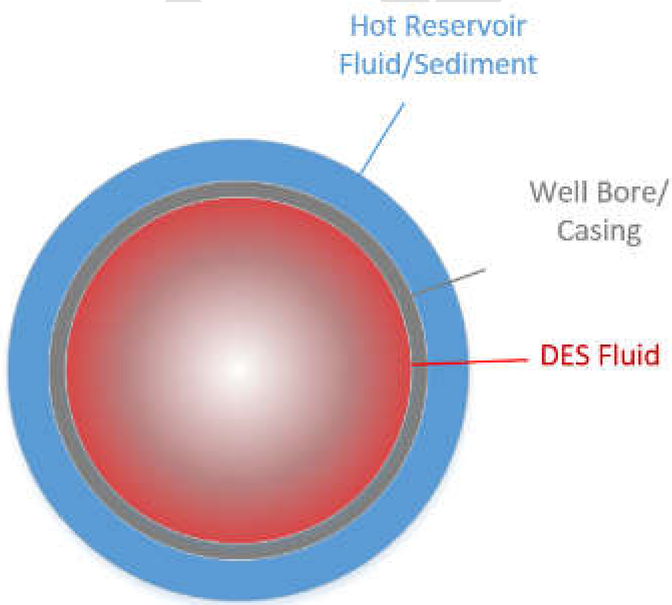



**Figure 84 - 2D Cross Section view of candidate well modeling**

Viewing Figure 84, the main difference is that there is no smaller core on the inside from which fluid is being brought to the service. This is excluded from the model because as mentioned, the pipe between the 2 fluids would give negligible thermal resistance, so any heat being transferred from the fluid travelling up is being transferred to the fluid being pumped down the well, making the DES fluid a closed system.

Since we are dealing with potential depths up to 6000m, segments lengths were tested, and the answers all converged at lengths of 100m, using smaller segments lengths that exponentially increase the amount of calculations, changed the answers by less than 1%, for this reason the 100m lengths were chosen. To calculate the amount of heat transfer for each 100m section, the following equation was used:

$$Q_T = \sum h * A_{s*}(T_{S,a} - T_m)$$

Where;

| | | |
|---|---|---|
| $Q_T$ | = | The total amount of heat transfer of the well, kW |
| h | = | Convection heat transfer coefficient, W/(m$^2$*°C) |
| $A_S$ | = | The surface area of the inside of the bore, m$^2$ |
| $T_s$ | = | Temperature of inner bore surface, °C |
| $T_m$ | = | Temperature of working fluid, °C |

Q is the final step of the calculation; it is the amount of heat being transferred from the well to the fluid. Obtaining Q requires four variables, the most difficult to calculate being h. Calculating h requires Prandt number (Pr), Reynold's number (Re), and Nusselt number (Nu), be determined for the fluid in every 100m length, after these values are calculated and extrapolated from existing charts, h is obtained using;

$$h = \frac{k * Nu}{D_h}$$

It is important to note, that for a circular cross section, the hydraulic diameter, $D_h$, is equal to the actual diameter. Calculating $A_s$ with simple geometry of a cylinder yielded;

$$A_s = 2\pi D_h L$$

Where L is equal to the length of each segment in meters.

Then the temperature of the inner bore surface was taken from the temperature gradient from the top of the well to the bottom, then the average of each segment used, with the equation;

$$T_{s,a} = \frac{\left(\frac{T_b - T_t}{L_T} * L_{b,s} + T_t\right) - \left(\frac{T_b - T_t}{L_T} * L_{t,s} + T_t\right)}{2}$$

Where;

| | | |
|---|---|---|
| $T_{s,a}$ | = | Average temperature of the segment, °C |
| $T_b$ | = | Temperature at the bottom of the well, °C |
| $T_t$ | = | Temperature at the top of the well, °C |
| $L_T$ | = | Total length/depth of the well, m |
| $L_{b,s}$ | = | Depth at the bottom of the well segment, m |
| $L_{t,s}$ | = | Depth at the top of the well segment, m |

Finally, the temperature of the fluid is taken as the exit temperature from the last segment (i.e. the initial temperature for the first segment), plus the heat gained to obtain the inlet temperature of the next segment using;

$$T_m = T_{o,s} + \frac{Q_{p,s}}{\dot{m} * C_p}$$

Where;

$T_m$ = Temperature of the fluid, °C

$T_{o,s}$ = Fluid outlet temperature of previous segment, °C

$Q_{p,s}$ = Heat transfer from previous section, kW

$\dot{m}$ = Mass flow rate of fluid, kg/s

$C_p$ = Specific heat of the fluid, kJ/kg*k

These variables are then entered and performed for each 100m segment, the summation giving $Q_T$, the total heat transfer of the well to the fluid.

The next step involved optimizing the well design for choosing candidate wells. This involved running sensitivities, the sensitivities chosen for this study were; bore/casing diameter, flow rate, bottom hole temp, and well depth. Running the sensitivity, all inputs were locked except for the sensitivity being tested, and the heat output and water outlet temperature recorded for each test. The base case can be seen in Table 50.

**Table 50 - Base Case Model Inputs Used for Sensitivity Study**

| Well Properties | | |
|---|---|---|
| Top of Well | 20 | °C |
| Bot of well | 160 | °C |
| Fluid Temp | 40 | °C |
| Segment Lengths | 100 | m |
| Well Depth | 5500 | m |
| Diameter | 12 | in |
| Flow rate | 5 | kg/s |
| Density | 1000 | kg/m^3 |

The first sensitivity study was performed on the bore diameter. The bore diameter is important, because it affects how much fluid we can flow into the well and the velocity of said fluid. The velocity is an important factor, as you don't want the working fluid to approach the bottom hole temp, or else the amount of heat transfer decays. You also do not want the fluid moving too fast, as it reduces the residence time, and the water comes out only slightly warmer, which would mean much larger heat exchangers for the clients.

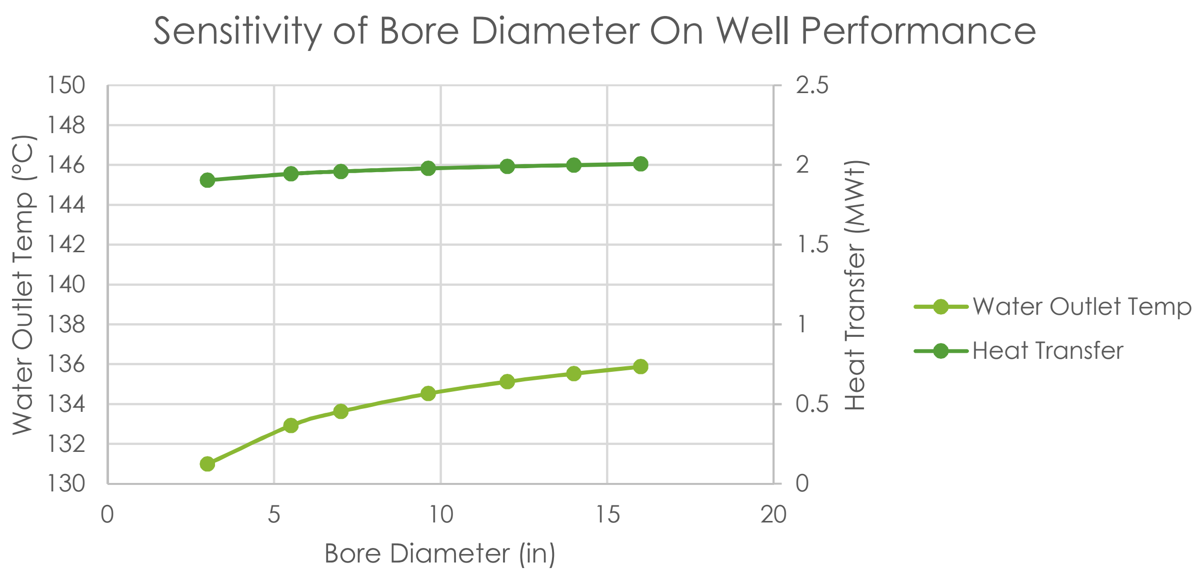



**Figure 85 - Bore sensitivity results**

Figure 85 shows the results of the first sensitivity, these results show that the bore hole size has very little impact on the performance, however, the changes are minor and due to the curved shape, these improvements have diminishing returns. The main benefit of the bore diameter comes into lay when selecting a pump. The larger bore diameters will create less friction, thus reducing the load on the pump, reducing operation costs, or allowing for more flow rate. Although there is no detriment to having a larger bore hole size in this range, when comparing wells, an 8 inch option can and may have other merits to be selected over a 12 inch candidate well.

The next sensitivity analysed was flow rate. Flow rate is very similar to the bore diameter, but inversed, as increasing the flow rate increases the velocity of the fluid and decreasing the flow rate decreases the velocity. However, with varying flow rates, increasing the flow rate means there is more fluid to carry heat from the well, which comes at the cost of that lower residence time and lower outlet temperature. This sensitivity was performed between reasonable flow rates of 1 to 50 kg/s.

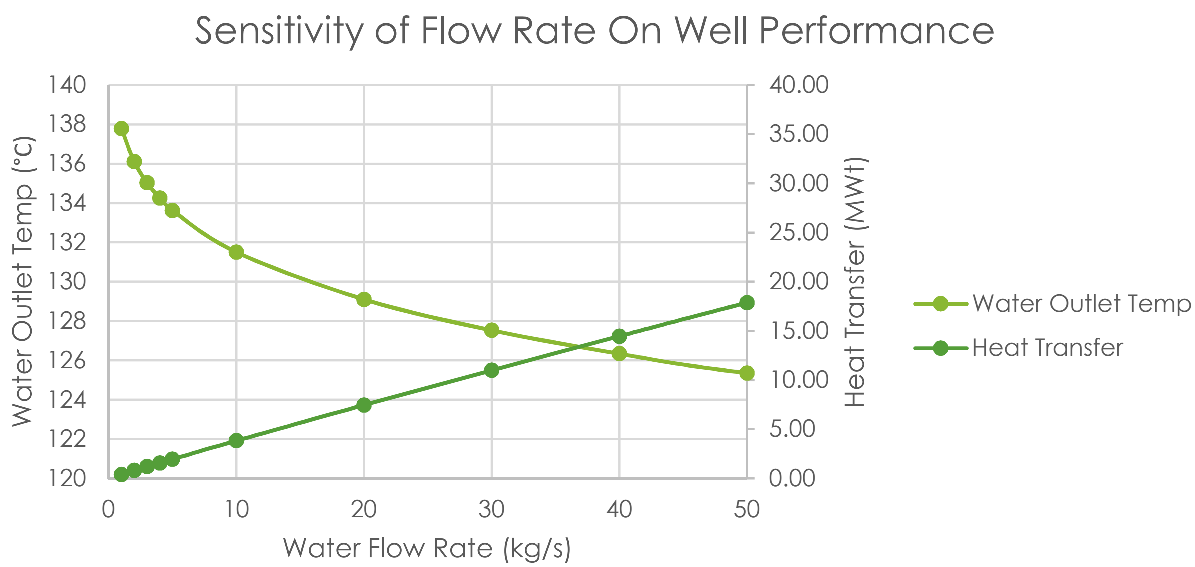



**Figure 86 - Flow rate sensitivity results**

Figure 86 is a great example of a sensitivity study for optimizing a well. It is a variable that the designer has control over, and greatly impacts the output of the well. Immediately when reviewing the graph, it becomes apparent that the heat transfer is linear. Doubling the flow rate will double the heat output, at the cost of a lower outlet temperature. This information could be used by setting a base flow rate or a base outlet temperature for the project and finding how much heat can be transferred. Especially important for industrial uses where the client may require high temperatures, and that cannot be compromised. Although this may seem like a well can produce an endless amount of heat, one of the assumptions does state the well walls remain a constant temperature, increasing flow rate in actuality does have the potential consequences of cooling the well and very large friction loads for the pump to overcome at these depths.

The final two sensitivities are directly related to the attributes of the well. Depth and bottom hole temperature both play a large role in selecting a well, due to their direct correlation to well performance.

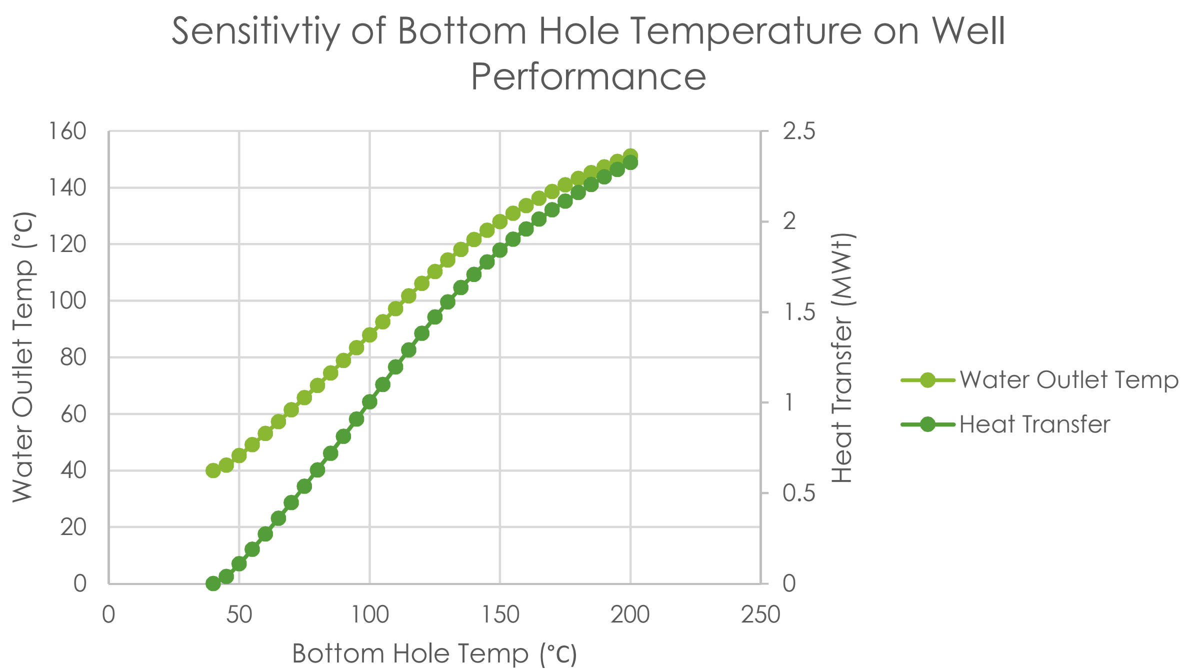



**Figure 87 - Bottom hole temperature sensitivity results**

The bottom hole temperature sensitivity was performed from 40°C to 200°C. All scenarios have a top of well temperature of 20°C, so the depths remaining the same, an increase in bottom hole temperature increases the gradient of heat along the well depth. A starting temperature was chosen equivalent to the fluid temperature, because that is the starting point where heat transfer will occur, if the temperature of the well were below that of working fluid, the fluid would be transferring heat to the well, while 200°C was chosen as it will encompass any well we expect to find in the area.

Most would view this sensitivity and assume a higher temperature will always result in more heat output, viewing Figure 87, that is the case. The performance of the well increases almost linearly. The temperature and heat transfer curves seem to converge, because as you increase the temperature gradient, there is more rapid heat transfer, which allows the working fluid to come to approach the bottom hole temperature more rapidly. As you approach the bottom hole temperature, heat transfer begins to diminish. As learned from the sensitivity on flow rate, the trade off between heat transfer and outlet temperature, an increased flow rate is the best way to take advantage of a higher resource temperature of a candidate well. A 150°C and 200°C well will only be able to transfer a limited amount of energy to water at 5kg/s as it will approach those temperatures.

The final sensitivity was the depth of the well, although our model has a heat gradient, depth will affect this gradient in the simulation. A deeper well having more sections for heat transfer to occur at lower average section temperatures, while a shallow well will only have a few sections of hotter average section temperatures. The advantage to well depth, is that the average temperature of well will always be the same, meaning depth is simply creating more surface area for heat transfer to occur.

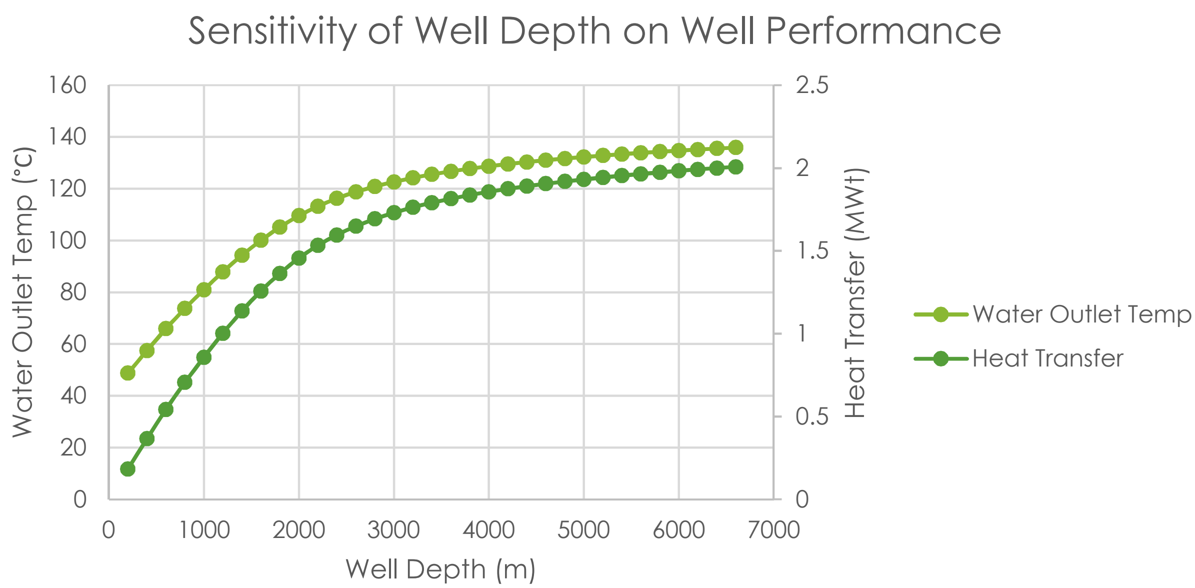



**Figure 88 - Well depth sensitivity results**

Viewing Figure 88, the amount of heat transfer seems to reach a maximum at 2MWt, with the outlet temperature following a similar trend and reaching a maximum of 140°C. The shape of the graph shows that well depth has the great benefits, but quickly displays diminishing returns. Although the hardest to explain, the heat transfer and water outlet temperature curves matching is an indicator that the flow rate is the bottle neck for well depth. Increasing the well depth at a fixed flow rate is consistently increasing the amount of time for heat transfer to occur while maintaining the same velocity in the well. The fluid having more time to come to temperature, decreases the temperature differential between the working fluid and the well, making the deeper segments, although the hottest, transfer very little heat to the fluid as it has also been heated to a relatively high temperature.

In this particular model, the important not only comes for well selection, but pumping once again. Although a candidate well may be discovered with a depth of 5 or 6km depth, the benefit to the extra pumping may not be viable. Once again referring to Figure 88, the benefits after 3000m are minimal, and even doubling the depths of this well only increases the heat transfer by ~10%.

With a constant bottom hole temperature, the gradient for all the wells in Figure 88 decreases as the depth increases. This prompted a look at comparing well depth, with a fixed gradient. To obtain a gradient, existing well data with depths and bottom hole temperatures as was used. Using 12 data points within the area, after visually inspecting and removing outliers, the following graph, Figure 89 is produced.

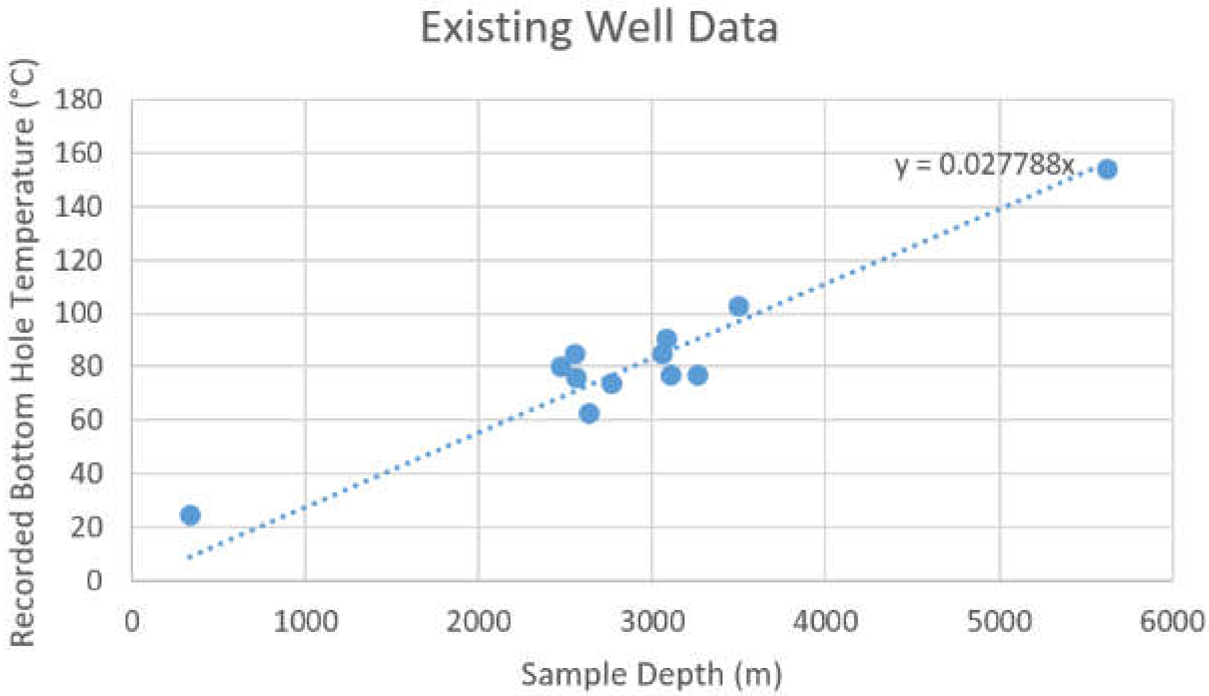



**Figure 89 - Existing well data**

Using a linear trend line with an intercept at zero, the average gradient is revealed to be 0.027788°C/m or 27.78°C/km. This gradient was then used for a depth range of 2000 to 7000m, producing Figure 90.

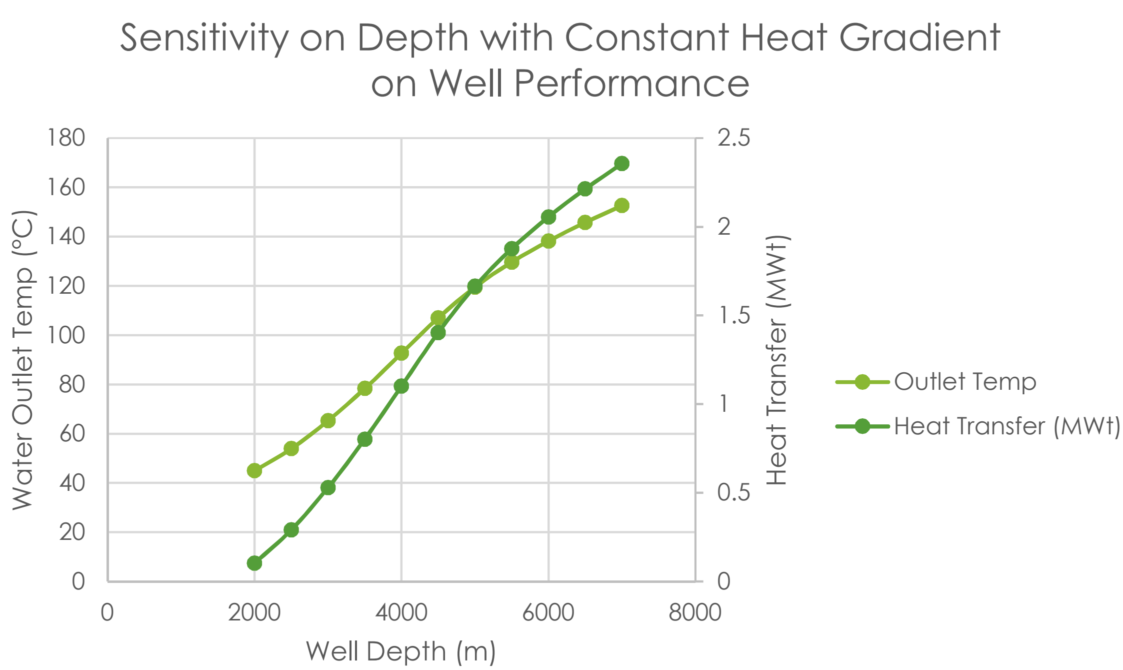



**Figure 90 - Gradient and depth sensitivity results**

The results in Figure 90 are expected, showing improved performance at deeper depths, for reasons being both a higher bottom hole temperature and more area for heat transfer. The relationship is almost linear, showing no disadvantage in well depth at a constant gradient. This is to say, a deeper well at a constant gradient will always perform better and produce a higher outlet temperature of the working fluid. The main constraint here again being the frictional load of the fluid for pumping from greater depths.

# Appendix C.4 Regulatory Environment

## Appendix C.4.1 Introduction to the Regulatory Environment

Accessing an existing oilfield wellbore for the development of a geothermal energy resource is a new concept in the province of Alberta. There is currently no regulatory framework in Alberta specific to high-temperature geothermal energy development, and any deep-geothermal project would need to operate and abide by the current regulatory requirements for oil and gas field environments.

As an abundance of oilfield wells involve production of water in conjunction with fossil fuel exploitation, there is an opportunity to align geothermal project operations with the current oil field regulatory environment. There has been precedence set by the 'Living Energy project', which uses a former oil well in Leduc (Leduc #1) to heat the Energy Discovery Centre with geothermal energy.

To help facilitate the navigation of the appropriate regulatory environment, Epoch Energy has already begun dialogue with the Alberta Energy Regulator ('AER'). "The Alberta Energy Regulator is a regulatory body with a mandate to provide for the efficient, safe, orderly, and environmentally responsible development of Alberta's energy resources. The AER is responsible for regulating the life cycle of oil, oil sands, natural gas, and coal projects in Alberta from application and construction to production, abandonment, and reclamation." [1]

There is an extensive set of regulatory processes for the access and operation of oilfield wells, which includes the requirements for 'produced water' and the liability for well owners and operators. This study completed an initial review of the regulatory directives (i.e. Directive 001) that are likely applicable for this 'well repurposing', and key requirements and rules that are specific to the project activities. This is not intended to be a complete analysis of the regulatory process as there is considerable regulatory uncertainty for deep geothermal energy development in the province of Alberta, but an overview of the relevant AER directives. A basic description of these key directives are provided below; the complete set of points for each directive is provided in the following section (Appendix C.4.2).

**Directive 001 - Requirements for Site-Specific Liability Assessments in Support of the AER's Liability Management Programs:** Directive 001 addresses one of the primary attributes in the suspension and abandonment of existing oilfield wells: the issue of estimating the cost of environmental cleanup and liability. This directive focuses on the identification and the costs associated with remediation and reclamation of oilfield wells and scoping of the environmental liability. Quantifying the 'cost of cleanup' is crucial to determining the overall liability that an owner/operator is responsible for on a well. This issue of liability is discussed further in Directive 006 below.

**Directive 006 - Licencee Liability Rating Program (LLR) And Licence Transfer Process:** Directive 006 addresses the concern that oilfield producers are required to maintain the necessary assets to offset their ongoing environmental liabilities associated with their oilfield operations.

*"The purpose of the Alberta Energy Regulator (AER) LLR Program and licence transfer process as set out in this directive is to:*

- *Prevent the costs to suspend, abandon, remediate, and reclaim a well, facility, or pipeline in the LLR Program from being borne by the public of Alberta should a licencee become defunct, and*
- *Minimize the risk to the Orphan Fund posed by the unfunded liability of licences in the program.*" [1]

Of note: This regulatory environment recently changed in June of 2016 from an asset to liability ratio (LMR: Liability Management Ratio) of 1:1 to 2:1 ratio, thus requiring oilfield operators/producers to have twice the necessary assets to ensure that they have the necessary financial fortitude to be able to cover reclamation and remediation costs. The transfer or purchase of AER-licenced wells requires approval from the AER to ensure that licencee's eligible deemed assets have a LMR ratio of at least 2.0.

**Directive 011- LLR Program: Updated Industry Parameters and Liability Costs:** Directive 011 determines the calculation of the LLR rating based on industry netback and estimated well abandonment costs. The industry netback is a calculation of earnings minus the direct operating and general expenses (i.e. midstream revenue less cost of goods sold). The estimated well abandonment cost incorporates a number of variables including location (regional cost map), depth and downhole completion scenario.

**Directive 013 - Suspension Requirements for Wells:** Directive 013 addresses the change of status from 'active' to 'suspended wells'. Wells that have not reported any 'volumetric activity for 12 consecutive months' are termed 'inactive' and require that the AER status be updated to 'suspended'. This directive also deals with the reactivation of suspended wells, which may be relevant for the repurposing of wells for geothermal applications.

**Directive 020 – Well Abandonment:** Directive 020 documents the process and AER requirements for moving well status for complete well abandonment. The documentation shows that extensive work is needed to finalize a well abandonment, including well testing, cementing, ground water protection, and cut & cap process. As discussed earlier, this creates a more complex regulatory environment to re-enter an abandoned well (addressed by Directive 056, the content of which can be found at https://www.aer.ca/rules-and-regulations/directives/directive-056 ). It should be stated that it is not the intention of this project to re-enter an abandoned well and as such this possibility is not covered. This directive also clarifies that if the licence for an abandoned well is transferred, the new licencee assumes all responsibility for the control or further abandonment of the well and the cost of doing that work, which relates back to the previous LMR discussion in Directive 006 & Directive 011.

## Appendix C.4.2 Applicable AER Regulatory Directives

### Directive 001 – Requirements for Site-Specific Liability Assessments in Support of the AER's Liability Management Programs

2.2.1 – Identifying a Potential Problem Site

3 – Scope of Liability Assessment

4.1 - Assessment of Suspension or Abandonment costs

- Guide 20 – Well abandonment guide

4.2 – Reclamation Assessment

- Phase 1 environmental assessment – meet or exceed standards in ESRD T/573: Phase 1 Environmental Site Assessment Guideline for Upstream Oil & Gas
- Phase 2 environmental assessment – environmental issues ID'd in phase 1 – meet or exceed CSA Z769-00: Phase 2 Environmental Site Assessment

5 – Cost estimate

- Address currently outstanding suspension, abandonment or reclamation obligations must be site-specific

5.1 – Suspension costs

- 3 years of care, custody, security

5.2 – Abandonment costs

- Provide for downhole and surface abandonment of a well, decommission and dismantling of a facility, or abandonment of a pipeline

5.3 – Reclamation costs

- Remediation and surface reclamation of all land directly affected by the development

5.3.1 – Remediation Costs

- Remediation cost estimate must be based on plan that:
  - Excavates
  - Treats or disposes of oilfield waste
  - Treats affected water, groundwater, bedrock and inaccessible soil contamination

5.3.2 – Surface Reclamation Costs

- Costs based on approach that returns ability of land to support land uses similar to that which existed before development

6 – Other reporting requirements

7 – Previously conducted liability assessment must be less than 3 years old

8 – Current licencee or approval hold is responsible for ensuring liability assessment provided to AER is updated according to the schedule specified by AER

9 – AER may require more frequent updates of site-specific liability assessment costs estimates

- At time of licence transfer request
- Upon audit of a licence
- If site conditions warrant update
- If AER requirement specifies an earlier submission deadline
- AER determines circumstance warrant an update

Appendix 1 – Tasks for Estimating Site-Specific Costs

- A1.3 – Well Suspension Costs
- A1.6.2 – Well Abandonment
- A1.7.1 – Remediation
- A1.7.2 – Surface Reclamation

## Directive 006: Licensee Liability Rating Program (LLR) And Licence Transfer Process

Appendix 1 – Licence Types Included in the LLR Program and Protected by Orphan Fund

- Wells – oil, gas Bitumen; injection; disposal; gas storage; oilfield source water wells; observation wells; brine well; LPG wells

Appendix 2 – Licence Transfer Process and LMR Assessments

- Agreements for the purchase and sale of AER-licenced wells do not affect a transfer of associated licences unless and until the AER approves the related transfer application
- Licence transfer application submitted electronically through Licence Transfer System (LTS) accessed through DDS
- Licence transfer application submitted by one party must be accepted by the other party with 90 days
- **6 – Transfer of Abandoned wells and Facilities**
    - AER permits licence for abandoned wells and facilities and discontinued pipelines to be transferred only in the following cases:
        - Licence for a well that has been abandoned in compliance with AER Requirements and is shown in AER records as surface abandoned (cute, capped, prospered reported) and that require but is not in receipt of a reclamation certificate or its equivalent
    - AER does **NOT** permit licences transfers for abandoned Well to be transferred in the following cases:
        - Licence for a well or facility that is abandoned and in receipt of reclamation certificate or equivalent
        - Abandoned and classified as "reclamation exempt"
        - Abandoned and in receipt of overlapping reclamation certificate exemption for its surface location
    - **AER approval of a transfer of an abandoned well does NOT permit the new licencee to re-enter the well. An application must be submitted in accordance with D056 to re-enter or reactivate.**
- **8 – LMR assessments – Security Deposit Requirements**
    - If both transferor and transferee have post-transfer LMR >= 1.0, security deposit not required
    - If LMR, 1.0, AER requires security deposit in amount representing the difference between its deemed liabilities and deemed assets plus any existing liability management security deposits.

Appendix 4 – LMR and LLR Assessment formulas

Appendix 5 – Deemed Assets

- Deemed assets of a producer licencee is the cash flow derived from oil and gas production reported to Petrinex from wells for which it is the licencee.
- Calculated by multiplying a licencee's reported production of O&G from the preceding 12 calendar months in cubic meters oil equivalent by the 3-year average industry netback by 3 years.
- Current shrinkage factor, m3 OE conversion factor, and industry netback factors are in Directive 011
- Deemed asset of an eligible producer licencee is the sum of its cash flow derived from O&G production reported to Petrinex from wells (calculated in accordance with section 1) and the cash flow derived from midstream activity from wells or facilities for which is I the licencee (calculated in accordance with section 3)

Appendix 6 – Deemed Liabilities

- Deemed liability is the sum of the costs to suspend, abandon, remediate, reclaim all wells for which it is the licencee, adjust for status (active, inactive, abandoned, problem site designation)
- 1 – Definitions
- 2 – Calculation of Deemed Liability
    - Deemed liability of a well
        - Sum of abandonment and reclamation liability. Liability for abandoned but uncertified or unreclaimed is solely its reclamation cost

Appendix 7 – Variation of LLR Formula Parameters

- 1 – Licencee-initiated Request for Variation of an LLR Parameter
    - LLR program is based on the use of provincial and regional averages, and their use may not accurately reflect the deemed assets or deemed liabilities of a particular licencee
- 1.1 – Licencee Netback
- 1.2 Well Abandonment Liability
- 1.3 Well Reclamation Liability

## Directive 011: LLR Program: Updated Industry Parameters and Liability Costs

Industry parameters and regional abandonment costs used in LLR Calculations as required

- Industry netback
- Shrinkage factor
- $m^3$ OE conversion factor
- regional well abandonment costs used in LLR are based on information provided to the AER through an annual well abandonment cost review conducted by 3rd party
- abandonment liability for a well considers its geographic location based on the Regional Abandonment Cost Map, depth, downhole completion scenario, and where applicable, the number of events requiring abandonment, the costs to address groundwater protection, surface casing vent flows, and gas migration
- 6 – Regional Well Abandonment Cost Tables

### Directive 013: Suspension Requirements for Wells

- Suspension deadline is 12 months from the date the well becomes inactive
  - Inactive status date listed in this Directive calculated based on definition of the inactive well. If no volumetric activity is reported in Petrinex, a final drill date is used as a last volumetric activity date
- For a well to attain active status and be reactivated on DDS, it must report volumetric activity for at least 1hr/month for 3 consecutive months
- Pressure testing casing or tubing for reactivation is NOT required if initial well suspension was completed <12 months prior to reactivations
- DEFINITION: Inactive well – Critical sour wells (perforated or not) that have not reported any type of volumetric activity (production, injection, disposal) for 6 consecutive months; all other wells that have not reported any type of volumetric activity for 12 consecutive months
- For wells to remain in compliance with this Directive, licencee must complete the ongoing well inspection requirements and report to AER by the end of each calendar year in which the inspection date is calculated.

2.3 – Surface and Wellhead Requirements

2.3.3 – associated infrastructure

2.4 – Repair Requirements

2.5 – Reporting requirements

- Well Status update in Petrinix
  - *Directve 007: Volumetric Infrastructure Requirements*; *Directive 059: Well Drilling and Completion Data Filing Requirements* – submitting amendments to the well status in Petrinix
- Well licence status updated in AER DDS
  - Following must be reported to AER

| | | | |
|---|---|---|---|
| Suspension Date | H2S Content (%) | Inspection Reason | Casing Failure detected |
| Suspension Class (risk) | CO2 content (%) | Packer/Plug Failure detected | Wellhead Failure detected |
| Well Operational Data | Inhibitor Program | Gas migration detected | Inspection outcome |
| Downhole Operation | Inspection Date | Vent Flow Detected | Remedial work completed |

3 – Risk-Based Suspension Requirements

- All inactive wells are divided into 3 categories – low, medium, high
- Table 1 – Suspension requirements for all inactive wells

- 3.1 – Low Risk Well requirements – downhole, wellbore fluid, initial suspension, wellhead; 3.1.2 ongoing inspection requirements
- 3.2 – Medium Risk Well requirements – Cavern Wells; downhole, wellbore fluid, initial suspension, well head; 3.2.2 ongoing inspection requirements
- 3.3 – High Risk Well requirements – downhole, wellbore fluid, initial suspensions, wellhead; 3.3.2 ongoing inspection requirements

4 – Reactivating suspended wells

- All Wells:
  - Inspect, service, pressure test wellhead
  - Inspect, service, control systems and lease facilities
  - Report reactivations of well on DDS within 30 days after attained active status and retain records
- Medium – and High-Risk wells
  - Pressure test casing to 7MPa for 10 minutes
  - If tubing is present, pressure test tubing to 7MPa for 10 minutes
- Pressure test results valid for 12 months

5 – Long-Term Suspension Requirements

  - All low-risk wells must meet suspension requirements for medium-risk wells after being inactive for 10 consecutive years after the first year of inactivity

Appendix 1 – Classifying Suspended Gas Wells

### Directive 020: Well Abandonment

Routine vs. non routine

  - Routine – planned abandonment that meets all the requirements that apply to the well based on:
    - Type of well being abandoned
    - Well's geographic location
    - Impact of the well on any oil sands zones
    - Absence of a wellbore problem
  - Routine abandonment operations do NOT require AER approval before work is started
  - Nonroutine abandonment operations DO require AER approval before work
    - 1.4 – Overview for examples of nonroutine

2 – Requirements for Nonroutine Abandonment Requests and for Notification Reporting

  - 2.1 – obtaining approval
  - 2.2 – AER notification
  - 2.3 – AER Reporting requirements
    - Well abandonment submission cannot be made if there is a casing failure or surface casing/vent flow report that is open and/or outstanding for the well licence

3 – Previously Abandoned Wells/Zones

- 3.1 – Previously Abandoned Wells (cut and capped
    - Wells abandoned to the standards in place PRIOR to this edition of D-20 are not required to be re-abandoned to current standards. Exceptions – leaking wells and wells being reentered
- 3.2 – Zonal Abandonments
- 3.3 – Leaking Wells/Lowering Casing Stubs
    - Current Licencee of well must submit nonroutine abandonment request to the Well Operations Group for approval
    - Licencee must also notify mineral rights owners and have an active surface agreement – approval from Alberta Energy is required if the mineral rights have reverted back to the Crown
    - Follow Directive 056 when reentering an abandoned well for the purpose of production or if it is not the current licencee
- 3.4 – Reentry Wells

4 – Open-Hole Abandonment Requirements

- Set cement plugs of sufficient length and number
- 4.1 – Open-Hole abandonment of non-oil sands wells
    - Figure 1 – Oil Sands boundaries
    - For well's not in the oil sands area, fillers and/or additives in the cement used for plugs is acceptable for open-hole abandonments
- 4.2 – 4.4 – Wells in Oil Sands area's

5 – Cased-Hole Abandonment Requirements

- Each completed pool must be abandoned separately and cover all nonsaline groundwater with cement
- 5.1 – cement evaluation
- 5.2 – Use of Inhibitor
    - Casing must be filled with nonsaline water from uppermost abandoned zone to surface
- 5.3 – Wells not Penetrating Oil Sands Zones
- 5.4 – Wells penetration oil sands zones
- 5.5 – Groundwater Protection
    - All nonsaline groundwater must be covered by cement
    - Groundwater protection must include the identification and isolation of the BGWP from hydrocarbon formations below, as well as ID and isolation of all protected intervals that are above BGWP
        - To determine BGWP depth refer to the query tool available on AER DDS – elevations are subsea and must be converted to Kelly bushing (KB)
    - Protected intervals are above BGWP and defined as any lithology with >3% porosity or any coal seam
        - Protected intervals may be grouped tether (i.e. not isolated), provided that the lithologies with >3% porosity are not separated from each other by more than 10m and the coal seams are not separated by >30m of non-coal-bearing strata, or a sandstone with >3% porosity.

- 5.5.2 Requesting a Groundwater Protection Waiver
  - AER requires all protected intervals be covered by cement
  - In specific situations, AER may consider industry requests to waive the requirement to cover protected intervals
  - Abandonment operations for which a groundwater waiver is requests are nonroutine

7 – Testing and Inspection Requirements

- Gas Migration Testing
- Surface Casing Vent Flow testing

8 – Surface Abandonment

- Cutting off of casing string(s) and the capping of a well
- Required testing must be performed (section 7)
- 8.1 – Cutting and capping

9 – Compliance Assurance

- AER's enforcement process is specified in *Manual 013: AER Compliance Assurance – Enforcement*
- Keep all test results and abandonment details
- **If the licence for an abandoned well is transferred, the new licencee assumes all responsibility for the control or further abandonment of the well and the cost of doing that work**

## Appendix C.4.3 Regulatory Opportunities & Challenges

The recent AER changes to the Liability Management Ratio and the increase in inactive wells in Alberta creates both an opportunity and a challenge for the repurposing of oilfield wells into geothermal applications for operators.

The opportunity for repurposing oilfield wells results from offsetting 'deemed liabilities', which is also 'adjusted for status'. A well that is currently operating with a revenue steam (i.e. 'active') continues to qualify as an asset to the well owner. However, many wells that were cost effective at higher oil or gas prices may now by sub-economic with the price change, and the prevention of a well moving to 'inactive' (i.e. not currently producing, suspended or abandoned) can present an opportunity for oilfield operators with the goal of extending the life of a well in conjunction with geothermal applications.

The challenge for repurposing oilfield wells is that the acquisition of wells (licensing, permits) requires any new owner/developer (geothermal or oilfield) to operate in the current regulatory environment and have the necessary assets to offset the environmental liability for the required LMR rating. The 'deemed assets', however, are calculated based on oil and gas production and a 3-year average of 'calculated netback'. It is uncertain that any geothermal energy-based revenue stream would qualify as assets in the LMR calculation, which would therefore prevent a positive LMR rating for active geothermal wells and require a significant security deposit to the AER to compensate for the environmental liability. The number of wells that have moved to 'inactive' has also steadily climbed in the last 20 years, furthering the environmental risk profile from defunct oilfield operators (discussed further in the Orphan Well section below).

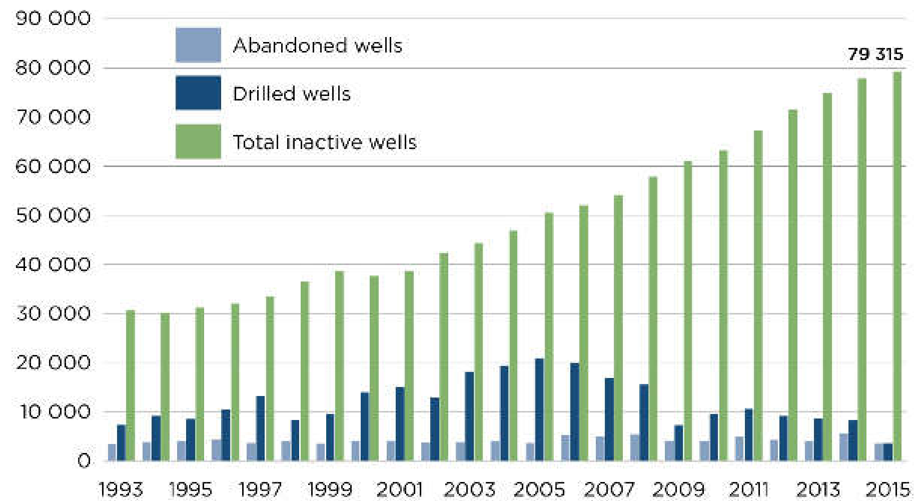



**Figure 91 - Inactive wells in Alberta [66]**

The topic of well liability is very relevant to geothermal repurposing projects as oilfield operators are highly incented to pass the liability of inactive wells onto the next developer (oilfield or geothermal). Under the current regulatory environment, a geothermal energy producer would be treated as a standard oilfield operator and would thus be expected to incur that liability, even though they may not be producing oil/gas at the well. The topic of environmental liability and its legal implications is further analyzed by Grant Van Hal in his 2013 paper titled "Legal Obstacle to the development of Geothermal Energy in Alberta" [67].

## Appendix C.4.4 Orphan Wells

There is a potential opportunity for the AER to assist with the repurposing of oilfield wells. The AER currently manages the 'Orphan Program and Fund' with the LLR regulations:

*The Orphan Fund will pay the costs to suspend, abandon, remediate, and reclaim a well, facility, or pipeline included in the LLR Program if a licencee or working interest participant (WIP) becomes defunct.*

During the recent downturn in oil pricing and the increase in LMR, there have been a significant increase in the number of wells that are now part of the orphan program.

Orphan Well exclusion has no reference to deep geothermal wells, but does reference 'municipal water wells', 'test holes' and 'industrial waste disposal wells'.

**Any alternative to acquiring future environmental liability associated with a specific well would require quantification of the costs for remediation and reclamation, agreements with current oilfield owner & operator, and agreement with AER to comply with Directives.**

# Appendix D Midstream

## Appendix D.1 Logstor Pipe Data Sheets & Technical Documentation

## Appendix D.2 Proposed Hinton Distribution Network

# Appendix D.3 Pipeline Comparison Table

## Appendix D.4 Town of Hinton – Municipal Development Plan

# Appendix D.5 Snow Melting Calculations

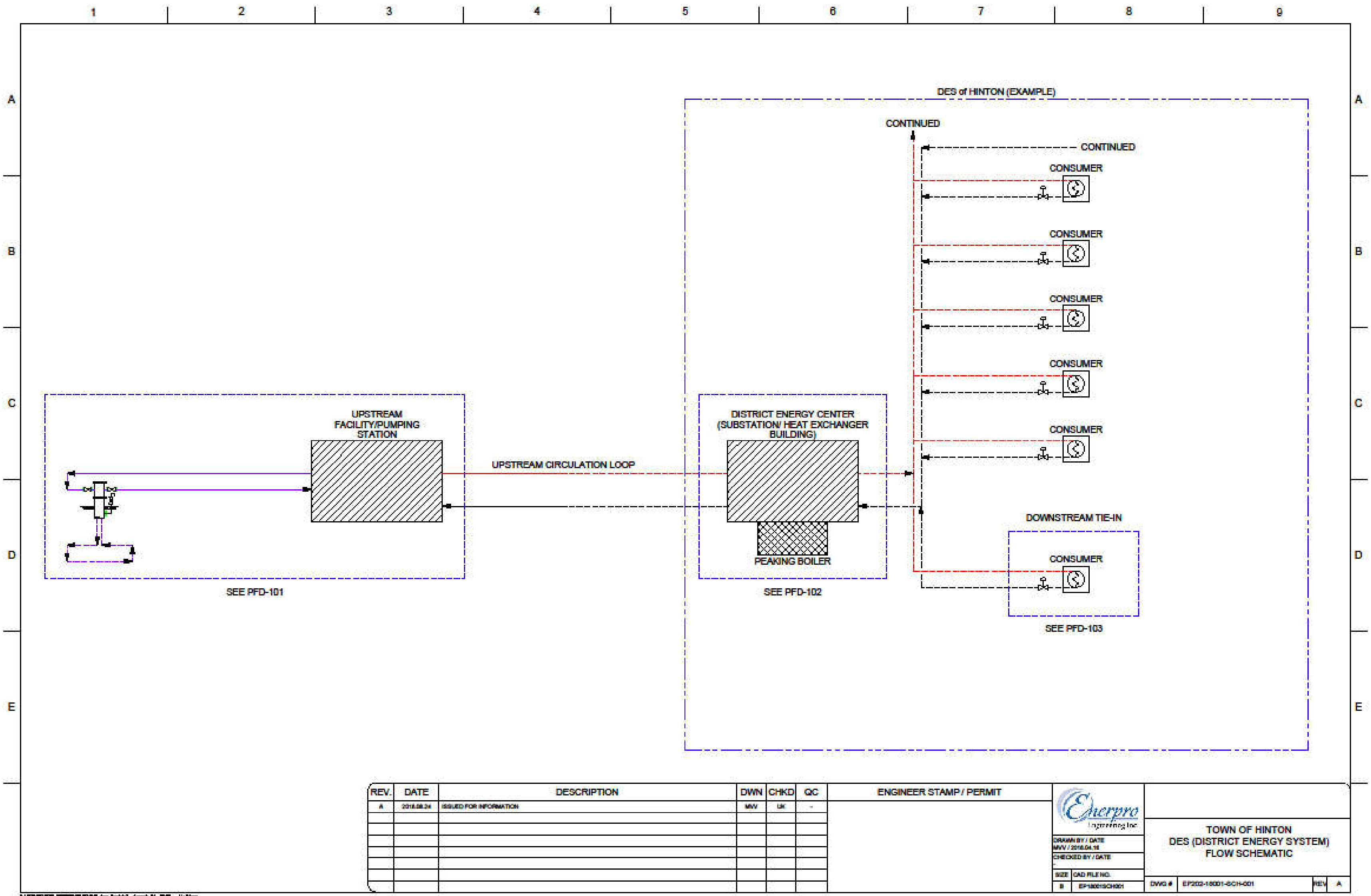
# Appendix D.6 Distribution Network Construction Proposal

# Appendix D.7 Geotechnical Summary Using Previous Reports

# Appendix D.8 Summarized Construction Execution Plan

# Appendix D.9 Process Flow Diagrams

## Appendix D.9.1 Hinton District Energy Centre Schematic (SCH-001)



Appendix D.9.2 Upstream Facility (PFD-101)

Appendix D.9.3 District Energy Centre (PFD-102)

Appendix D.9.4 Downstream Tie-in Example (PDF-103)

# Appendix D.10 Novatherm Safety Sheet

# Appendix D.11 Griswold Example Pump Curves

# Appendix D.12 DEC General Arrangement Layout Drawing

# Appendix D.13 TCV Fisher Sizing Document

## Appendix D.14 Load List sent to Fortis

## Appendix D.15 Fortis Budgetary Quote

## Appendix D.16 Heat Meter Data Sheets

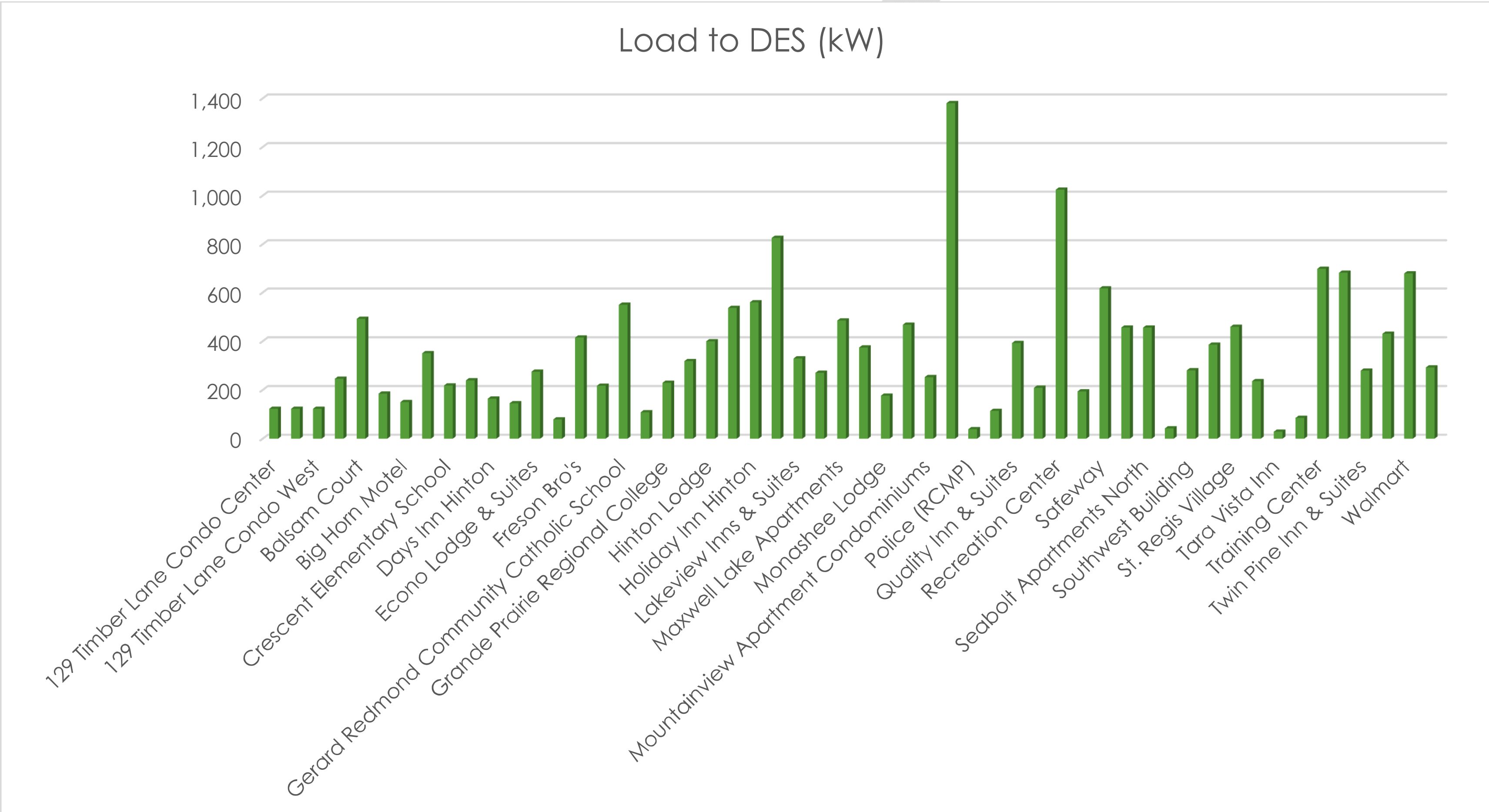
Appendix D.17 Town of Hinton Land Use Bylaw Map

# Appendix D.18 Template Permit Applications

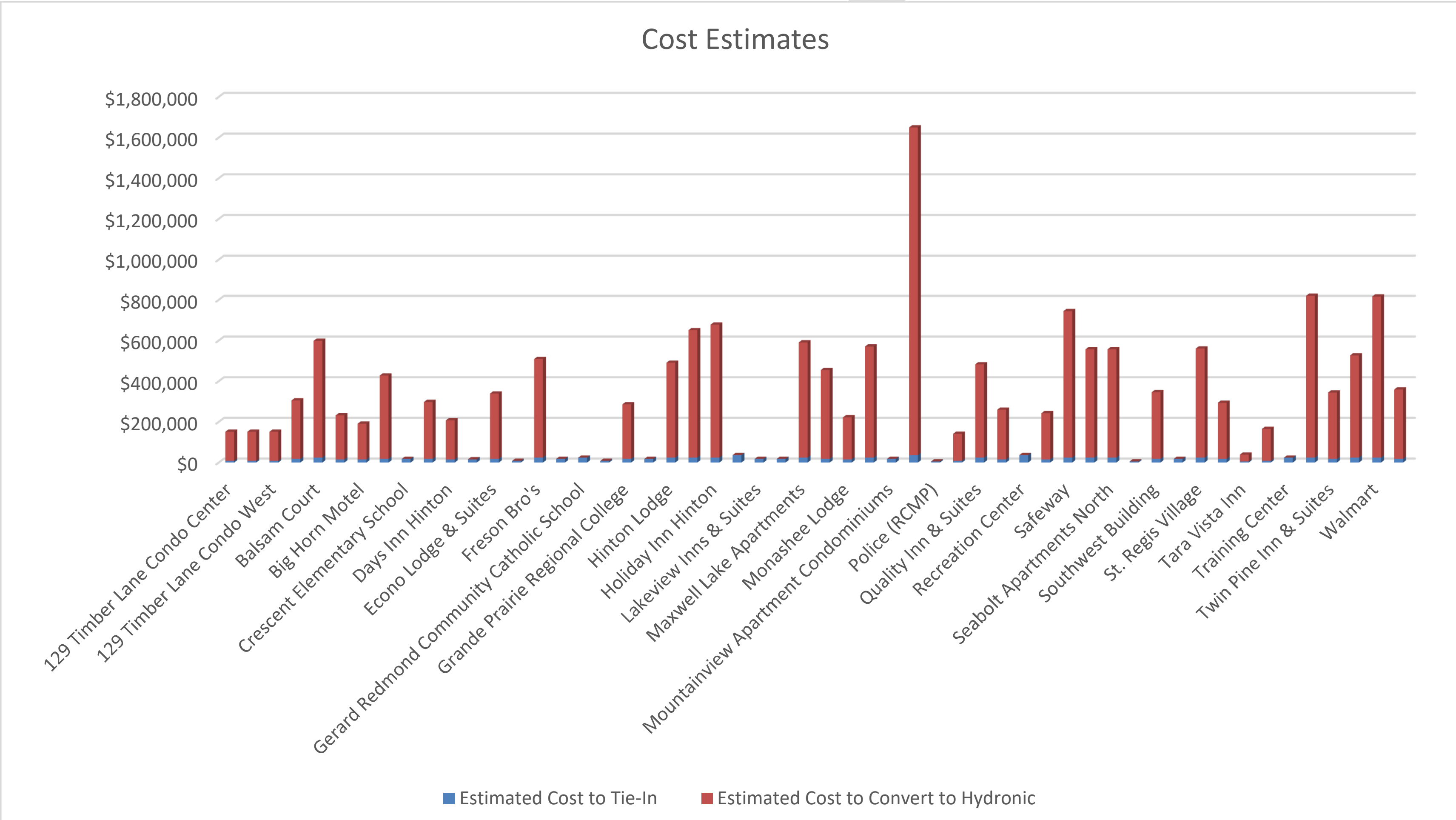
# Appendix D.19 DEC General Layout Drawing – Minimized Design

# Appendix E Downstream

## Appendix E.1 Load to DES (kW)



# Appendix E.2 Cost Estimates



# Appendix F Potential CRA Opportunities

Below is an excerpt from the Tax Measures: Supplementary Information of the Government of Canada's Budget 2017 Budget Plan. The section quoted is from "Clean Energy Generation Equipment: Geothermal Energy".

"Under the capital cost allowance (CCA) regime, Classes 43.1 and 43.2 of Schedule II to the *Income Tax Regulations* provide accelerated CCA rates (30 per cent and 50 per cent, respectively, on a declining-balance basis) for investment in specified clean energy generation and conservation equipment. Both classes include eligible equipment that generates or conserves energy by:

- using a renewable energy source (e.g., wind, solar or small hydro);
- using a fuel from waste (e.g., landfill gas, wood waste or manure); or
- making efficient use of fossil fuels (e.g., high efficiency cogeneration systems, which simultaneously produce electricity and useful heat).

Providing accelerated CCA is an exception to the general practice of setting CCA rates based on the useful life of assets. Accelerated CCA provides a financial benefit by deferring taxation. Class 43.2 is available in respect of property acquired before 2020.

In addition, if the majority of the tangible property in a project is eligible for inclusion in Class 43.1 or 43.2, certain intangible project start-up expenses (for example, engineering and design work and feasibility studies) are treated as Canadian renewable and conservation expenses. These expenses may be deducted in full in the year incurred, carried forward indefinitely for use in future years or transferred to investors using flow-through shares.

Geothermal heating is the extraction and direct use of thermal energy generated in the earth's interior. Equipment that uses geothermal energy is currently eligible for inclusion in Class 43.2 (50-per-cent rate) if it is primarily used for the purpose of generating electricity, while equipment used primarily for heating purposes is generally included in Class 1 (4-per-cent rate).

The costs of drilling and completing exploratory wells are fully deductible in the year they are incurred as Canadian renewable and conservation expenses when it is reasonable to expect that at least 50 per cent of the capital cost of the depreciable property will be used in an electricity generation project included in Class 43.1 or 43.2. The costs of drilling and completing geothermal production wells for an electricity generation project that qualifies for Class 43.2 are included in Class 43.2. In contrast, the costs of drilling and completing geothermal wells for projects that do not meet this electricity generation threshold (e.g., projects focussed on supplying heat) could be included in Class 1 (4-per-cent rate), Class 17 (8-per-cent rate), Class 14.1 (5-per-cent rate) or treated as a current expense, depending on the circumstances.

District energy systems transfer thermal energy between a central generation plant and one or more buildings by circulating (through a system of pipes) an energy transfer medium that is heated or cooled using thermal energy. Thermal energy distributed by a district energy system can be used for heating, cooling or in an industrial process. Certain equipment that is part of a district energy system is currently included in Class 43.1 or 43.2. Geothermal heat is not currently eligible as a thermal energy source for use in a district energy system.

Budget 2017 proposes three changes in this area. First, it proposes that eligible geothermal energy equipment under Classes 43.1 and 43.2 be expanded to include geothermal equipment that is used primarily for the purpose of generating heat or a combination of heat and electricity. Eligible costs will include the cost of completing a geothermal well (e.g., installing the wellhead and production string) and, for systems that produce electricity, the cost of related electricity transmission equipment. As with active solar heating and ground source heat pump systems, equipment used for the purpose of heating a swimming pool will not be eligible. Secondly, geothermal heating will be made an eligible thermal energy source for use in a district energy system. Lastly, expenses incurred for the purpose of determining the extent and quality of a geothermal resource and the cost of all geothermal drilling (e.g., including geothermal production wells), for both electricity and heating projects, will qualify as a Canadian renewable and conservation expense.

These measures will encourage investment in technologies that can contribute to a reduction in emissions of greenhouse gases and air pollutants, in support of targets set out in the Federal Sustainable Development Strategy. Accelerated CCA will be available in respect of eligible property only if, at the time the property first becomes available for use, the requirements of all environmental laws, by-laws and regulations applicable in respect of the property have been met. Similarly, Canadian renewable and conservation expense treatment will be available for expenses in geothermal projects only if, in the year incurred, such expenses meet the requirements of all applicable environmental laws, by-laws and regulations.

The measures will apply in respect of property acquired for use on or after Budget Day that has not been used or acquired for use before Budget Day." [88]