Study Context

The **Offshore Energy Research Association (OERA)** and the Nova Scotia Departments of Natural Resources & Renewables, Agriculture, and Fisheries & Aquaculture are exploring the **potential for the direct use of deep geothermal heat in the province.**

Two geothermal studies were conducted in Nova Scotia. Phase 1, completed in 2020, provided insights on the geological character of geothermal resources and unknowns. Phase 2 focused on the economic competitiveness of mid-depth heat given the unknowns highlighted in Phase 1. This report presents the results and analysis conducted for the Phase 2 study.

Deep geothermal systems **extract hot water from aquifers deep underground,** providing high quality heat that can be directly used in heating applications.

In this Phase 2 study, **direct use of geothermal heat** is assessed in the context of **three “typical” industry** opportunities within Nova Scotia

This Phase 2 study seeks to determine if deep geothermal systems can be an alternative to **heating oil, propane, biomass, or natural gas** heating systems.

The ultimate goal of the *Direct Use of Geothermal Heat in Nova Scotia* study was to **evaluate the business case for deep geothermal systems in Nova Scotia** by assessing its potential cost effectiveness as a low-carbon heat source.

Study Objectives & Methodology

The study assessed the **technical and financial suitability** of deep geothermal systems for specific heating applications in **three geological regions of Nova Scotia**:
1) Cumberland Sub-Basin, 2) Stellarton Sub-Basin, and 3) Windsor-Kennetcook Sub-Basin.
The analysis followed three main steps, as outlined below.

1. Develop Facility Archetypes

Establish key parameters and hourly energy use profiles for three "typical" facilities where deep geothermal has potential:

- **Greenhouses**
- **Aquaculture**
- **District Heating**

2. Update Geological Profiles

Characterize three applicable geological regions based on results from the Phase 1 geological study to develop the necessary modeling inputs.

3. Modeling & Sensitivity Analysis

Conduct scenario modeling and sensitivity analysis to assess economic viability of deep geothermal relative to alternatives.

Executive Summary

Facility Archetypes & Energy Use Profiles

Greenhouse

Facility	8 acres glass greenhouse
Crop	Year-long tomato production
Main Fuel	Residual biomass (wood chip)
Biomass Heating Load	49 420 GJ
Biomass System Size	3,500 kW + 10,000 kW propane auxiliary
Load factor	0.16
Current OPEX	$ 606,800

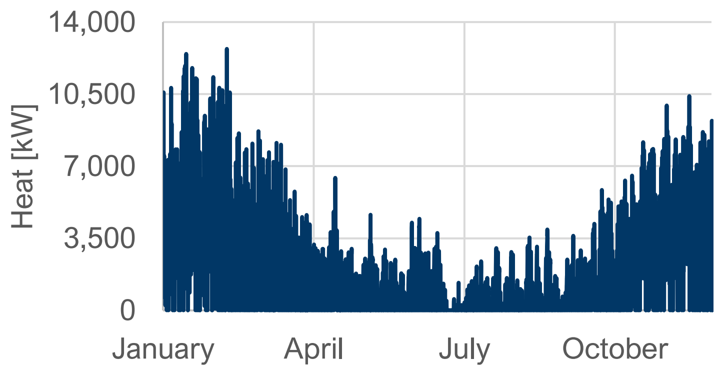
Aquaculture Facility

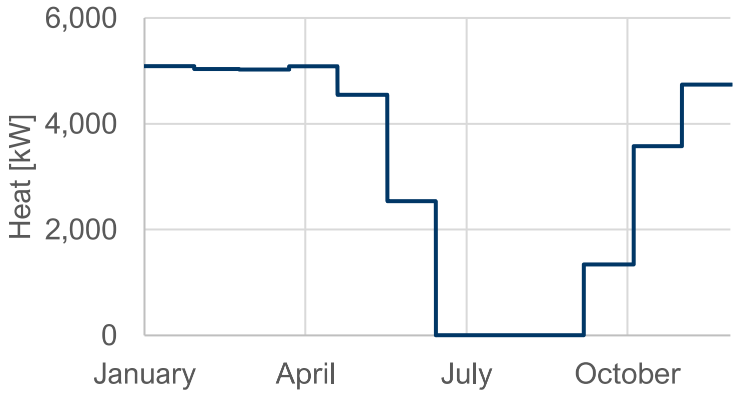
Facility	Land based, mid-sized indoor salmon hatchery
Product	Salmon Fry
Fuel	Oil boiler
Heating Load	107 750 GJ
Oil System Size	5,000 kW
Load factor	0.60
Current OPEX	$ 3,219,200

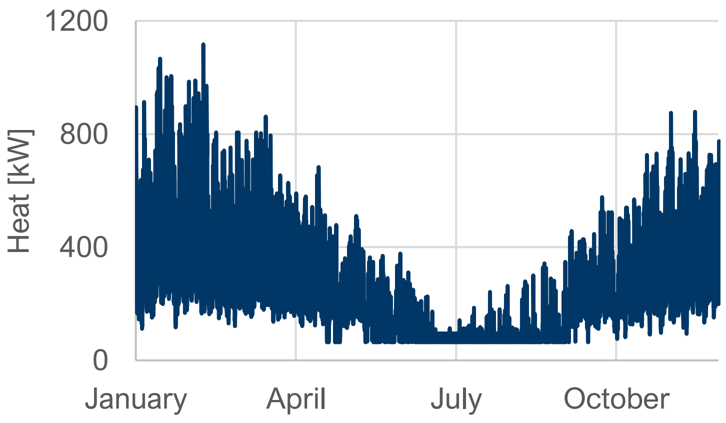
District Heating System

System	40 homes, 10 small businesses, and a community center
Services	Space and water heating
Fuel	Oil boiler
Heating Load	8 200 GJ
Oil System Size	1,117 kW
Load factor	0.23
Current OPEX	$ 260,675

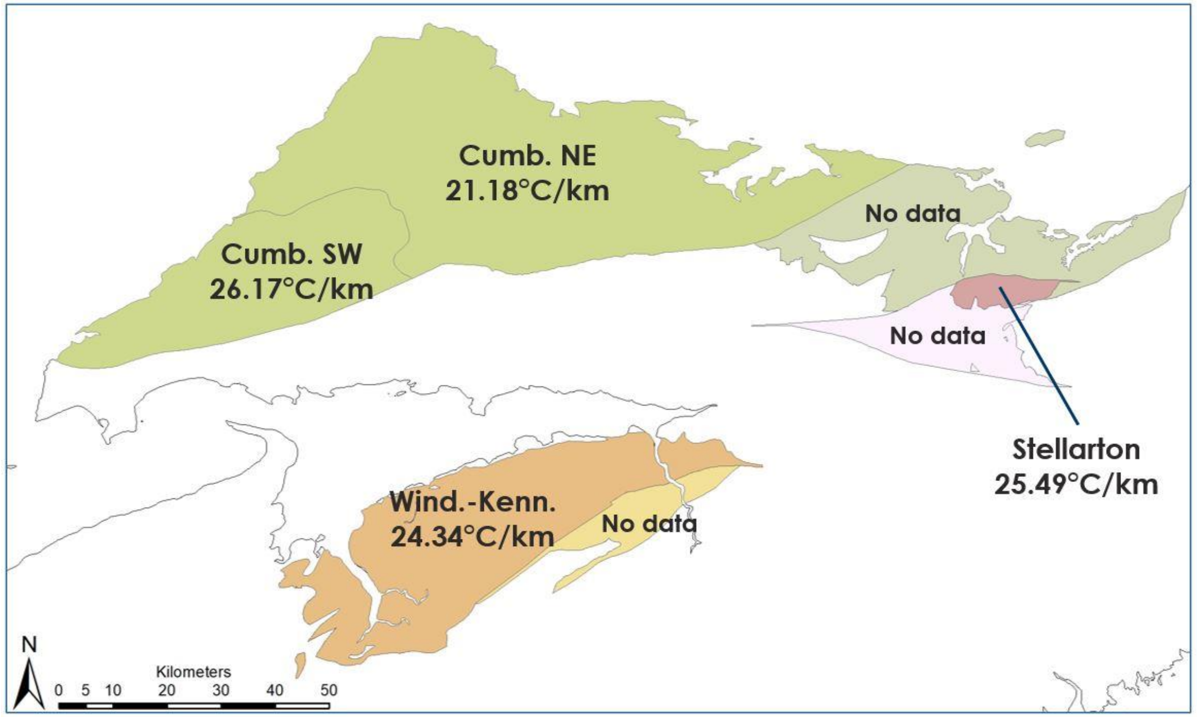
Heating Load Curves







Geological Regions Modeled



Study assumptions:

The study focused on three geological regions where sufficient data exists to assess the geothermal energy output:

- Cumberland Sub-Basin
- Stellarton Sub-Basin
- Windsor-Kennetcook Sub-Basin

These sub-basins were identified as promising regions from the Phase 1 study.

The study assessed the drilling and equipment costs and performance of deep geothermal resources, accounting for varying aquifer depth, porosity and heat quality. Each site was optimized to balance the impact of the number of wells vs pumping power needed to deliver heating required by the archetypal facilities.

Overview of Results - Financials

For the deep geothermal systems, **none of the archetypes were cost-effective under base case scenarios.**

Sensitivity analysis was conducted to determine if the deep geothermal systems could prove cost-effective under varied conditions.

When key variables were simultaneously adjusted for a “best case” sensitivity scenario, the aquaculture and district heating archetypes could become cost-effective. However, the "best case" scenario* presents a very optimistic scenario, that may be challenging to attain in reality (e.g., a 25% reduction in CAPEX, subsidies of up to 50% of CAPEX, 15% lower electricity costs, low-interest long-term financing, etc.)

		Deep Geothermal Base Case	Deep Geothermal Best Case*	GSHP Base Case
Greenhouse	NPV	- $29,467,000	-$15,627,000	- $4,832,000
	Payback	N/A	N/A	N/A
Aquaculture	NPV	- $5,019,000	$19,521,000	$50,784,500
	Payback	N/A	**2.75 years**	**< 1 year**
District Heating	NPV	- $57,538,000	$12,392,000	$5,154,000
	Payback	N/A	**6.2 years**	**4 years**

*The specific best-case conditions applied to each archetype can be found on pages 41, 45 and 49 of the report

Overview of Results – Possible Supporting Factors

	Favourable for Deep Geothermal	Findings from Nova Scotia Examples
Geology / Subsurface Conditions	• **High temperature basins:** offers more heating capacity from each well • **Shallow depth basins:** lowers drilling and well costs • Hot, shallow aquifers tend to be more desirable than deep porous aquifers	• Deep aquifers were either very deep, or not sufficiently porous • Shallow aquifers identified did not reach sufficient temperatures • The highest potential aquifers are found at depths that are only appropriate for large-scale projects
Facility Characteristics	• Stable **year-round heating demand** • **Larger facilities:** greater heating loads help justify CAPEX • Replaces **high-cost heating fuel** such as heating oil (i.e. not on gas network or fed with waste biomass)	• Greenhouse heating loads are too seasonal • Aquaculture has year-round heating needs that may be well suited to the right deep geothermal resource • District heating needs an anchor load to increase the year-round heating demand

Conditions Needed for Deep Geothermal

The study finds that if there is to be a case for deep geothermal in Nova Scotia, certain conditions would need to be met. With the knowledge we have now, the following **key factors need to align**:

- **Location, Location, Location**. Finding an appropriate aquifer is critical to establishing the business case for deep geothermal heating. Aquifer permeability, depth and temperature play a key role in the resource potential and heavily influence the project cost. Shallow, permeable aquifers tend to have lower costs by reducing well depth and pumping requirements. Where facility heating demands are relatively low, however (e.g. district heating system) permeability is less of a driver than the overall depth and temperature of the aquifer. High-temperature, shallow aquifers were identified in the study, (e.g., see Geology Appendix – Miscellaneous Information) but further geological investigation is required before they can be fully evaluated as deep geothermal resource.
- **Larger facilities with stable heating requirements are key**. Due to high fixed CAPEX costs, deep geothermal systems are only suitable in large facilities with a relatively constant heat load (i.e. load factors exceeding 0.5), which is the case for the aquaculture archetype. They may also be suitable in situations where the heat loads of various facilities can be aggregated – ideally with one or more larger "anchor loads" to raise the annual load factor.
- **Replacing high-cost fuels is also important:** The business case is stronger for deep geothermal when it replaces heating oil or other high-cost fuels. In the greenhouse example, the low cost of biomass (about five times lower than heating oil) eroded the business base for geothermal when compared to the current heating costs. However, even in cases where heating oil is the current fuel, GSHPs may still out compete deep geothermal as an alternative.
- **Financial tools can help**. Incentives and low-interest financing – in particular, those that reduce lender risk – could help to improve the business case where deep geothermal may be marginally financially viable.

The Bottom Line: For deep geothermal to be viable in Nova Scotia, a shallow high-temperature aquifer would need to be found, and then the appropriate energy end-uses would need to be identified in close proximity (e.g. large steady industrial load)

Possible Geological Niches for Deep Geothermal

Deep geothermal may be promising if locations with high temperatures at shallow depths can be found in Nova Scotia. These are highly localized in nature, and are typically found above three types of geological formations:

1) Faults that act as upward conduits for deep, hot hydrothermal waters
2) Salt domes with high thermal conductivity compared to the surrounding sedimentary rocks
3) Young, radioactive granitic bodies located near the base of the sedimentary cover that produce radiogenic heat.

These three features are present in the areas of interest, but a specific shallow high-temperature aquifer was not identified. Further studies would be needed to explore these features and determine their impact on the local geothermal gradient.

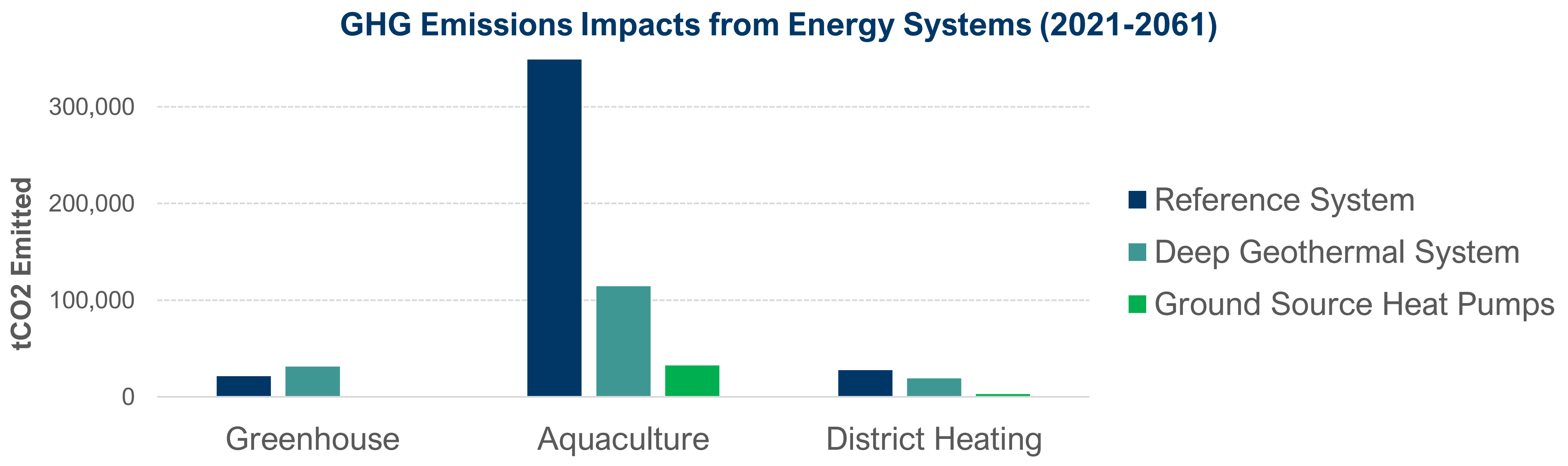
Ultimately, lower CAPEX and operating costs are required for deep geothermal to become a financially viable alternative. Specific opportunities, if identified through further study, could include:

- For projects with low heating requirements, such as the reference district heating systems of 50 houses, hot shallow aquifers are more desirable than deeper more porous aquifers. However, the shallow aquifers identified in this study were not sufficiently hot. At lower depths, the aquifers were too cold to be used in direct heating. At greater depths, the CAPEX required to reach the aquifers was not worthwhile considering the small scales of the projects.
- Projects with high heating requirements sustained throughout the year, such as aquaculture projects in porous aquifers, can support the use of deeper aquifers. A smaller number of boreholes can be pumped at high flow rates in order to supply affordable energy. However, the most interesting aquifer, the Lime Kiln Brook aquifer, is so deep that only large scale projects should be considered in order to make full use of the boreholes able to reach it.

Competition with GSHP

Ground source heat pumps (GSHPs) appear to present a more favorable option than deep geothermal for all archetypes assessed. In all cases, GSHPs outperform deep geothermal systems on an financial and GHG basis, even when the GSHP base case is compared to the best-case scenario for the deep geothermal system. GSHPs tend to have lower CAPEX costs but higher OPEX costs (due to increased electricity consumption) than deep geothermal, so it may be possible that deep geothermal could outcompete GSHPs for facilities with very high and stable heating loads, located near a viable aquifer.

Further Benefits of GSHPs. GSHPs offer further benefits over deep geothermal, including their ability to provide cooling, posing less risk of well failure, and being a more established technology in the market. While this study focused on heating only applications, the addition of cooling load would help to increase the financial performance of GSHP, mitigate the risk of wells freezing, and increasing the GHGs reductions.



Recommendations

- **Recommendation #1 - Find high potential aquifers:** The assessed archetypes and aquifers did not yield a viable business case for deep geothermal in Nova Scotia, except for under extremely optimistic “best case” conditions. As a next step it is recommended to identify aquifers that could offer a higher potential resource, particularly shallower and/or higher-temperature aquifers than those examined in this study. Given that little is currently known about Nova Scotia’s subsurface geology and the conservative regional geothermal gradients considered in the evaluation, it is possible that such a resource could be identified through further investigation.

  Dedicated geological modeling, as outlined in Section 8 of the Phase 1 report, will be needed to document the geothermal properties in selected areas for specific potential projects, especially above 1) basement-rooted faults, 2) young radioactive granitic bodies at the base of the sedimentary cover or 3) salt domes, as these geological environments are particularly suitable for enhanced heat flow. Moreover, if potentially viable aquifers are identified, but they are found to be of low permeability, Enhanced Geothermal Systems (EGS) could be considered. Two recommendations to de-risk EGS practices are detailed in the Geology Appendix, citing how the available subsurface data can provide valuable information to assess the use of EGS.

Recommendations

- **Recommendation #2 - Identify appropriate heating loads that are in close proximity:** Once an appropriate aquifer (or aquifers) is found, OERA and the government should aim to identify larger projects, such as industrial facilities with stable year-round loads that are, or could be, situated in close proximity. Engaging with these facilities at the earliest stages of the development process will further increase the chances of finding a fit for deep geothermal, particularly if it can be included in the initial construction or end-of-life heating system replacement process.

- **Recommendation #3 – Where a shallow high-temperature aquifer exists, aim to develop a pilot project:** Direct use of heat deep geothermal projects have not been constructed in Nova Scotia, and in fact, there are few examples in Canada. We recommend looking for an opportunity that aligns with the key factors that will make deep geothermal a winning solution and develop a pilot project. That will provide valuable learnings, including who can provide the needed services; further understanding on the subsurface geology; on-the-ground performance metrics; and other insights that will help refine the business case for deep geothermal.

- **Recommendation #4 – Consider further assessment of GSHP:** While direct use of heat from deep geothermal was the focus of this assessment, due to the favorable economic and GHG results for GSHP we recommend a deeper dive into the opportunity for this technology in various use cases across the province (such as for district heating/cooling and aquaculture facilities). As part of a comprehensive feasibility assessment, further study is needed to understand how deep geothermal compares to other low-carbon solutions such as air-to-water heat pumps, renewable natural gas, and hydrogen especially for replacing more costly energy sources such as heating oil.