Techno-Economic Feasibility Study for a Deep Geothermal System at YYC Calgary International Airport

YYC CALGARY INTERNATIONAL AIRPORT

Authored by Leanne Komaromi, Supervised by Dr. Roman Shor[1] and Harris Switzman[2]

[1]Texas A&M University, [2]Calgary Airport Authority

Introduction

The Government of Canada has set ambitious net-zero targets for 2050, which have influenced similar targets across the country by provincial governments and industries. As part of an ambitious net-zero strategy, the Calgary Airport Authority (CAA) is exploring behind-the-fence renewable energy generation to integrate with or replace current energy systems at YYC Calgary International Airport (YYC).

This work is aligned with United Nation's Sustainable Development Goals #7: Affordable and Clean Energy and #13: Climate Action.

Figure: Sustainable Development Goals #7 and #13 (United Nations, 2015).

Purpose and Objectives

To develop a better understanding of the environmental and economic performance of deep geothermal systems in low-enthalpy geothermal zones by evaluating the techno-economic performance of a closed-loop geothermal system (CLGS) configuration under reservoir properties estimated for YYC to meet forecasted energy demand and support the CAA's net-zero carbon targets.

The main objectives are:

1. Analyze current energy demand of YYC
2. Forecast a business-as-usual (BAU) scenario from 2024-2060
3. Analyze subsurface geologic conditions
4. Simulate a deep geothermal system based on subsurface conditions
5. Quantify and compare the energy, emissions, and economic results of the BAU case, the CLGS, and an externally assessed solar PV system to assess techno-economic feasibility
6. Make recommendations for next steps and future research

Geothermal Potential

In the thickest parts of the Western Canada Sedimentary Basin, along the eastern front of the Rocky Mountain deformation belt, temperatures are highest and range from around 110 to 120^{o}C.

The study area at Calgary has temperatures from approximately 70 to 100^{o}C depending on the target formation, corresponding to a geothermal gradient of 25 to 30 ^{o}C/km (Majorowicz and Grasby, 2020).

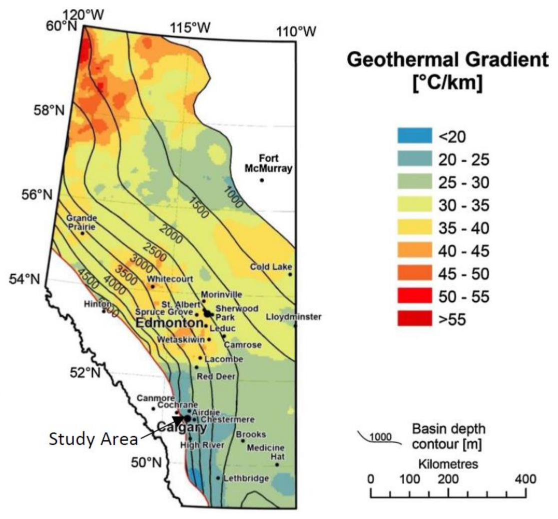


Figure (right): Geothermal gradient from surface to the base of the Western Canada Sedimentary Basin in Alberta with study area identified (modified from Majorowicz and Grasby, 2020).

Geothermal Systems & Application

There are three geothermal systems used to develop geothermal resources for heat or electrical energy: conventional, enhanced, and advanced (closed-loop). This study simulated a closed-loop geothermal system (CLGS) in u-loop configuration. Beyond uses for heating, cooling, and power; geothermal is also an energy storage resource and a mineral resource. The focus of this study was on energy generation via heat or electricity.

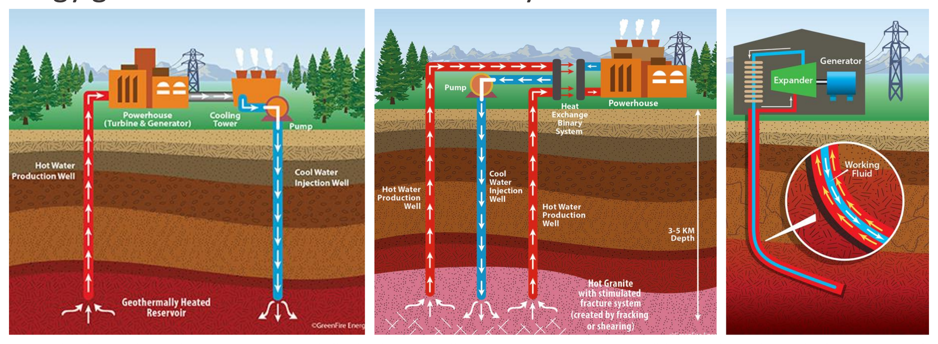
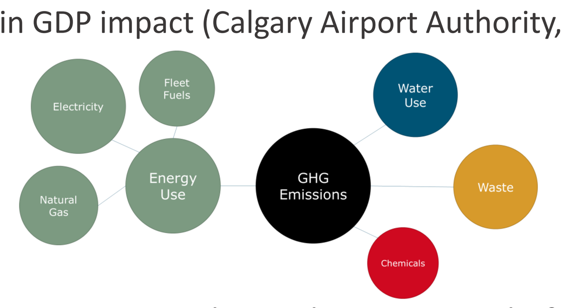


Figure (top): Geothermal system designs with fluid colour in wells representing temperature (blue = cold; red = hot). a) Conventional geothermal system in permeable geothermal reservoir with a surface electricity plant and reinjection pump; b) Enhanced geothermal system with a single injection, double production well configuration in a stimulated fracture system reservoir with surface plant and injection pump; c) a horizontal coaxial configuration closed-loop geothermal system with surface plant. (Think GeoEnergy, 2019)

YYC Calgary International Airport

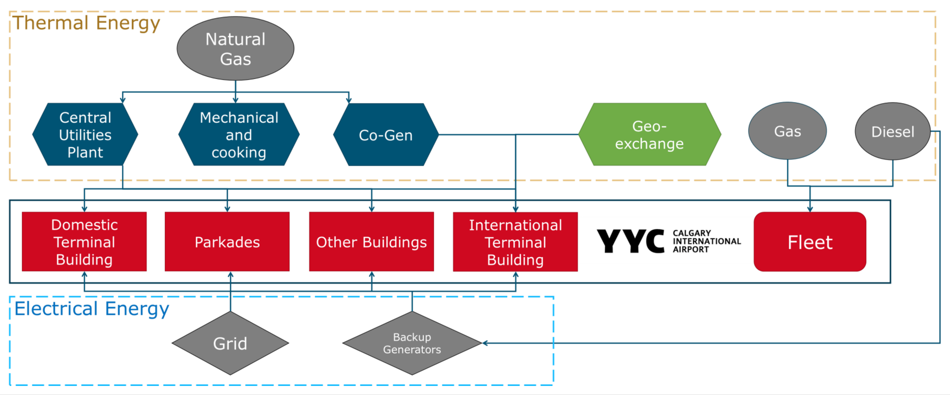
The Calgary International Airport (YYC) is the fourth largest airport in Canada. In 2023, they served 18.5 million passengers and 200,000 flights. They are also a major supporter of the local economy, supporting 50,000 jobs in the Calgary region and contributing $8 billion dollars in GDP impact (Calgary Airport Authority, 2024).



The CAA's net-zero strategy has a short-term goal of reducing GHG emissions by 30% over 2018 values by 2026, equivalent to 65,393 tCO2e emissions. In the long-term, the CAA strives for net-zero by 2050 in alignment with international, federal, and municipal climate action strategies.

2050 Goal	2026 Goal
Achieve net-zero scope 1 & 2 emissions	Reduce GHG emissions by 30% of 2018

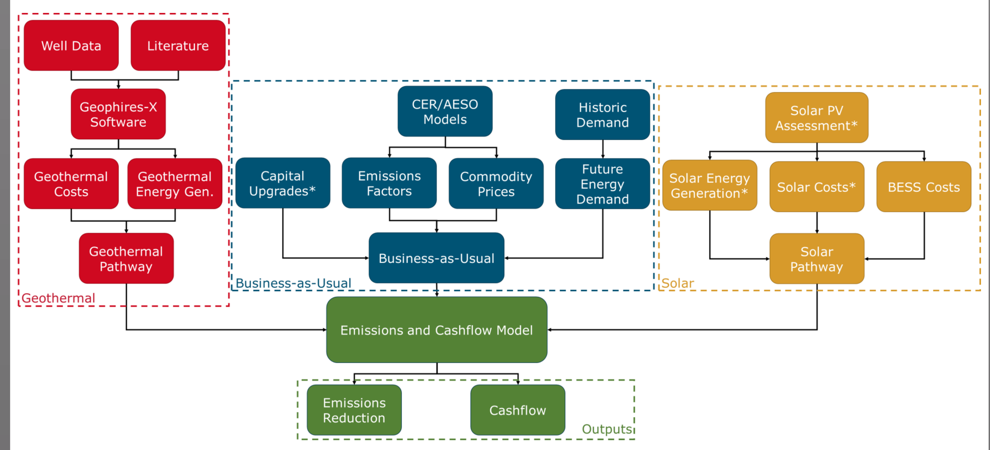
YYC has two main terminal buildings, the International Terminal Building (ITB) and the Domestic Terminal Building (DTB). There is a combined 30 MW of thermal energy provided by this plant (Siemens, 2024). Electricity is supplied by the Alberta grid and backup diesel generators.



Methodology

1. Baseline energy demand was established using historic energy bills going back to 2018
2. A business-as-usual scenario was modelled to forecast energy consumption and resulting emissions and cost
3. An analysis of subsurface geology beneath YYC was conducted
4. The National Renewable Energy Lab's GEOPHIRES-X software was used to simulate geothermal system performance based on estimated subsurface conditions
5. These results were then compared against externally derived solar PV system performance to help guide net-zero pathway decision-making at the Calgary Airport Authority.

Data sources include publicly available well data; energy bills going back six years; internal documents and reports; and the literature.

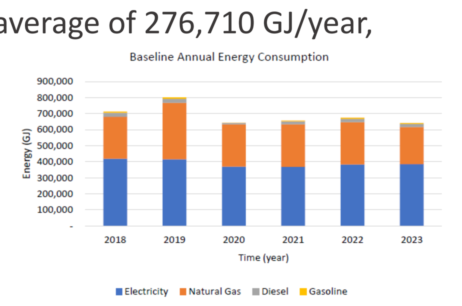


Business-as-Usual

The business-as-usual case in this study is a projection of how the business will evolve between now and 2060, without any net-zero energy investments, but while meeting operational needs of the business as it exists now.

Baseline Energy Demand

Analysis of ENMAX bills dating back to 2018 found that the average electricity consumption was 111,454,868 kWh/year. The highest consumption was attributed to the terminal buildings which had an average of 100,655,850 kWh/year in the same period, or 90% of the total electricity consumption. Natural gas consumption is the next largest contributor to overall energy demand at YYC with an average of 276,710 GJ/year,



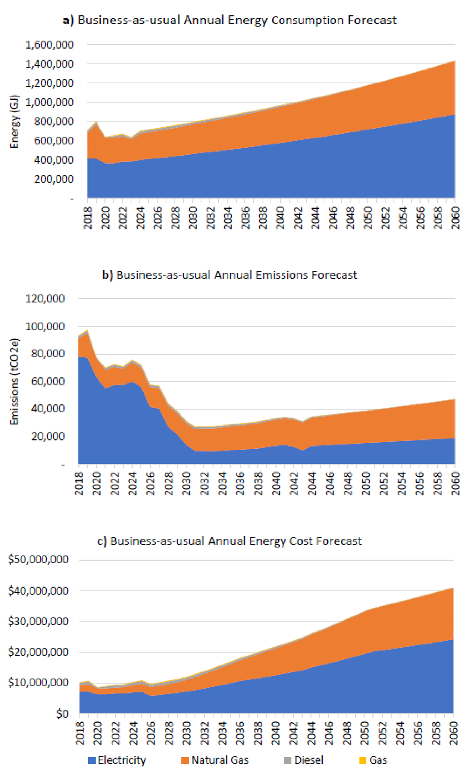
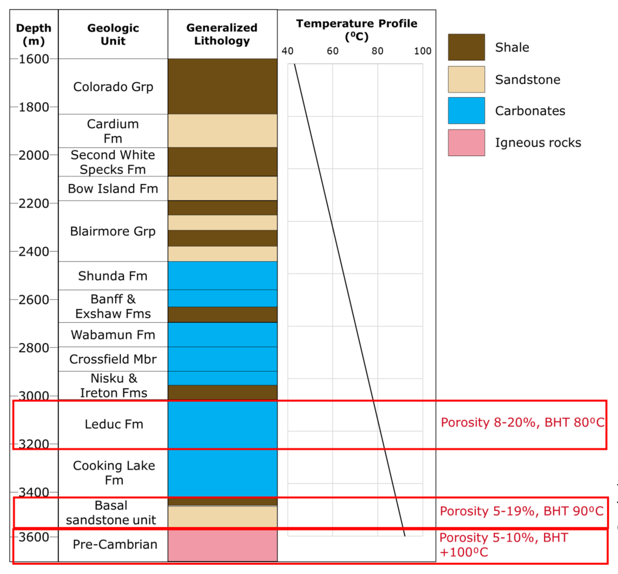


Figure (left): Baseline annual energy consumption with commodity breakdown at the Calgary International Airport from 2018 to 2023 (Komaromi, 2024).

Figure (above): Business-as-usual modelling results with source allocation breakdown for the Calgary Airport Authority: a) Annual energy consumption forecast; b) Annual emissions forecast; and c) Annual energy cost forecast (Komaromi, 2024).

Subsurface Analysis

Based on the well log analysis of formation tops in the study area, the thickness of the Leduc formation is estimated to be approximately 200 m at YYC. Based on the total vertical depth to formation tops from gamma ray logs, the estimated depths are 3000 m and 3200 m to the Leduc Formation and basal Cambrian sandstone (BCS), respectively. All the wells in the study area had recorded bottom-hole temperatures (BHT) that were used to estimate temperatures in the subsurface. Average BHTs were 84.6 and 74.3 for the Leduc Formation and BCS, respectively.



Only one well in the study area had recorded gas analysis data. Analysis was done higher up in the succession in the Wabamun Formation at an interval from 2500 m to 2520 m and shows 0.1227 ppm of hydrogen sulphide gas.

Figure (left): Schematic stratigraphic column (Well ID 100/04-22-027 01W5) showing Formation tops, thicknesses, and generalized lithology. Target intervals (Leduc Formation, basal Cambrian sandstone, and pre-Cambrian basement granite) are highlighted with estimated porosity and bottom-hole temperatures noted (Komaromi, 2024).

Geothermal System

A multilateral closed-loop geothermal system (CLGS) was simulated in GEOPHIRES-X based on subsurface parameters and rock properties as determined in the geologic assessment. The system was designed to meet or exceed YYC's natural gas for heating consumption. Electricity production with an ORC surface plant was simulated to enable comparison to solar PV and better aid decision making.

The resulting average heat production is 7.83 MW(th) and average electricity production is 140 kWh(e), based on an average production temperature of 71^{o}C. The resulting capital cost of the CLGS is $55,730,000 for direct-use heat and $51,590,000 for electricity generation in an ORC surface plant. The operating expense is $1,350,000/year for the DUH end-use and $860,000/year in the electricity generation case. Levelized cost of heat was calculated at $0.114/kWh(th) while levelized cost of electricity was $7.046/kWh(e).

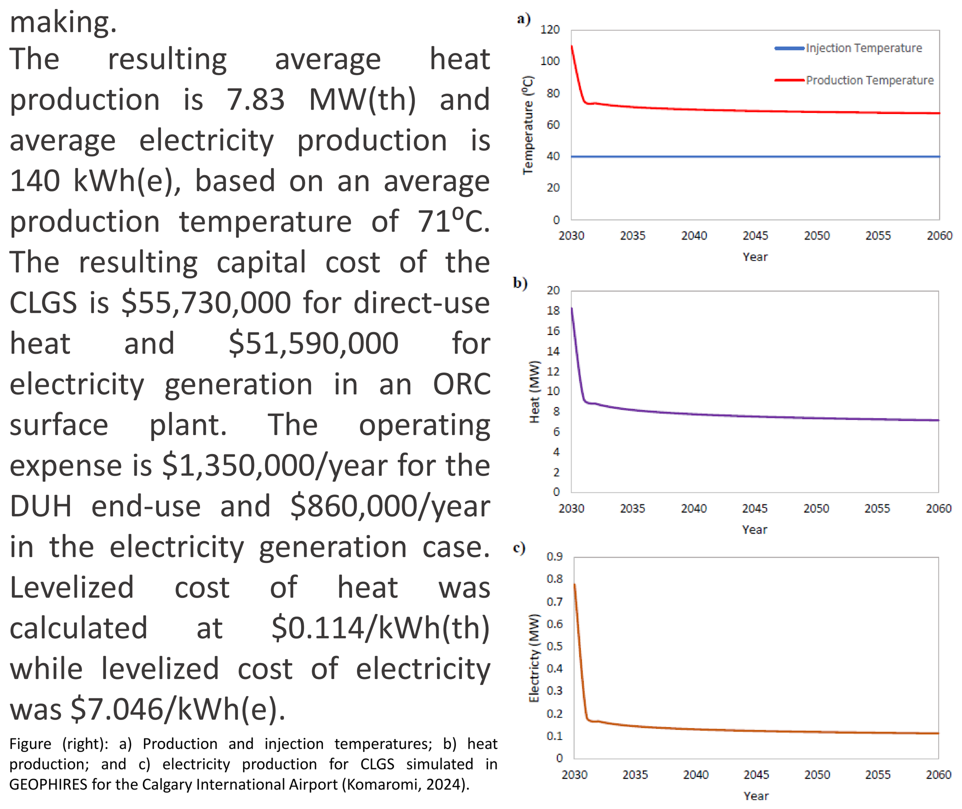
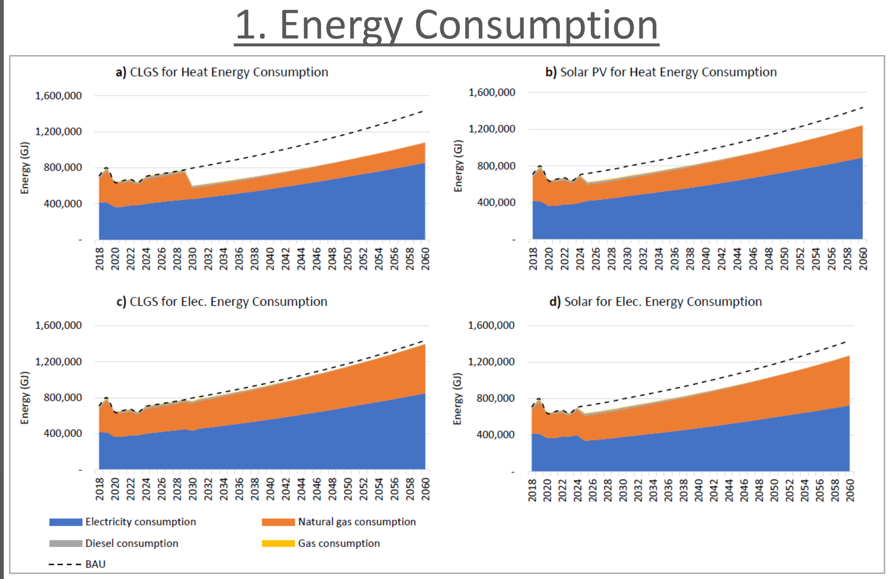


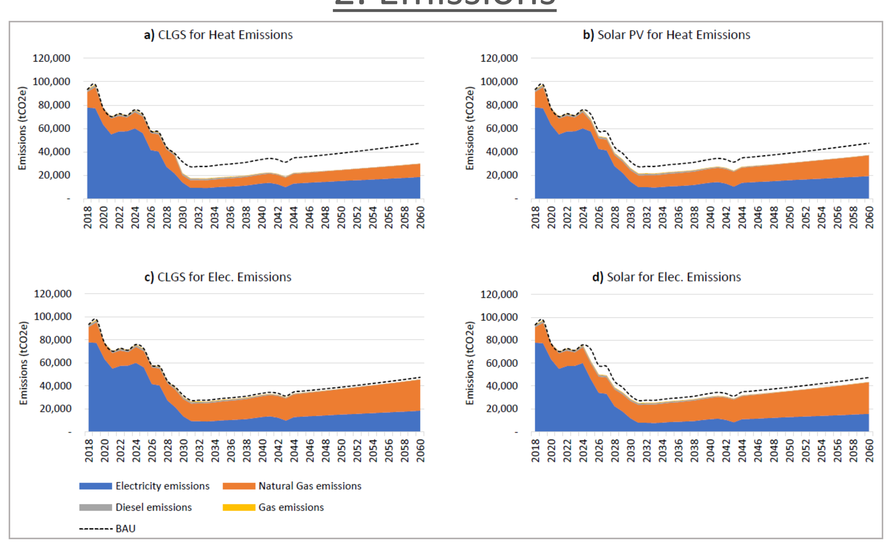
Figure (right): a) Production and injection temperatures; b) heat production; and c) electricity production for CLGS simulated in GEOPHIRES for the Calgary International Airport (Komaromi, 2024).

Energy and Emissions Performance

1. Energy Consumption



2. Emissions



3. Energy Cost

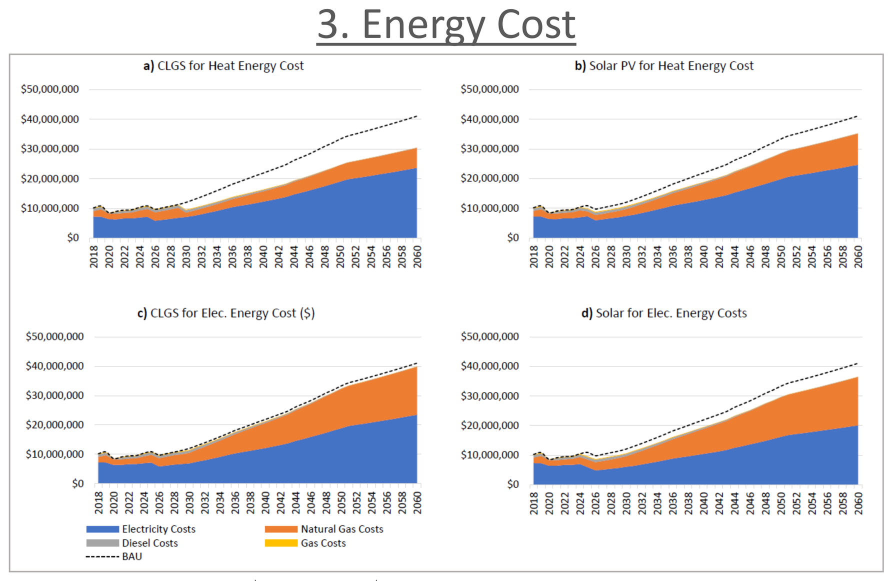


Figure (left): **1.** Annual energy consumption results for each of the four renewable pathways assessed with business-as-usual indicated by dotted line. **2.** Annual emissions results for each of the four renewable pathways assessed with business-as-usual indicated by dotted line. **3.** Annual energy cost results for each of the four renewable pathways assessed with business-as-usual indicated by dotted line. a) Closed-loop geothermal system for direct-use heating; b) Solar PV with battery energy storage system for heating; c) Closed-loop geothermal system for electricity generation; and d) Solar PV with battery energy storage system for electricity generation (Komaromi, 2024).

The CLGS for direct-use heat (DUH) scenario has a total energy consumption of 33,948,696 GJ from 2018 to 2060. This equates to a 20% reduction from BAU. In this case, natural gas consumption decreases 48% overall. The CLGS for DUH scenario shows 1,540,643 tCO2e emissions over the study period compared to 1,947,431 tCO2e in the BAU case, equivalent to a 21% reduction overall. When designed for electricity production, the total energy consumption of the CLGS scenario is 41,279,674 GJ. This is equivalent to a 2% reduction in energy compared to the BAU case (42,226,209 GJ).

When configured for heating (using electric boilers), the solar PV system has a total energy consumption of 37,239,928 GJ. The results of a solar PV with battery storage for electricity generation scenario show a 10% reduction in energy consumption. Emissions associated with electricity use reduce from 1,070,384 tCO2e in the BAU case to 961,548 tCO2e in the solar for the electricity scenario, a 10% reduction over the study period. The total emissions reduce from 1,947,431 tCO2e in the BAU to 1,820,240 tCO2e in the solar for heating case. The CLGS has the highest energy savings of all scenarios assessed.

Overall, the CLGS for DUH has the performs best in three out of four assessed criteria: energy consumption, energy costs, and project economics. Solar PV for electricity has the highest emissions reduction off BAU compared to other assessed scenarios.

Performance Criteria	Business-as-Usual	Change from BAU: CLGS Heat	Change from BAU: Solar Heat	Change from BAU: CLGS Elec	Change from BAU: Solar Elec
Total Energy Consumption (GJ)	42,226,209	(8,277,512)	(4,986,280)	(946,534)	(4,239,981)
Electricity Consumption (GJ)	25,163,004	(462,956)	425,058	(640,843)	(3,899,021)
NG Consumption (GJ)	16,383,198	(7,806,318)	(5,400,015)	(297,453)	(329,637)
Total Emissions (tCO_2e)	1,947,431	(406,788)	(262,216)	(43,468)	(127,191)
Electricity Emissions (tCO_2e)	1,070,384	(9,915)	12,184	(14,328)	(108,836)
NG Emissions (tCO_2e)	830,137	(395,546)	(273,619)	(27,716)	(16,703)
Total Energy Costs ($)	963,105,432	(212,880,874)	(121,535,065)	(23,639,642)	(99,506,236)
Electricity Cost ($)	572,950,113	(11,255,062)	9,872,421	(15,562,577)	(91,076,571)
NG Cost ($)	365,396,334	(201,321,887)	(130,986,389)	(7,749,406)	(8,008,568)
NPV ($)		6,607,726	(2,938,927)	(2,212,704)	(4,787,030)
LCOH ($/kWh$_{th}$)		(0.07)	(0.93)		
LCOE ($/kWh$_{e}$)				(2.52)	(1.17)

Table (left): Summary of results with business-as-usual (BAU) annual consumption, emissions, and cost totals and breakdown for electricity and natural gas with change in values from BAU in each assessed renewable technology scenario (CLGS for heating or electricity, and solar PV for heating or electricity) (Komaromi, 2024).

Conclusion and Recommendations

In comparison of a closed-loop geothermal system to solar PV with battery energy storage system, neither renewable technology performs favourably in both heating and electricity end-use categories, with the CLGS performing better with heating end-use and the solar PV system performing better for electricity end-use. The recommended approach is a combination of the two technologies in a pathway where CLGS provides renewable heat energy while solar PV provides renewable electricity. Based on the results presented here, it is recommended that work to refine the decarbonization roadmap and net-zero pathway continue, with a deep geothermal system regarded as a viable option with comparable or better performance to other, more widely familiar technologies. A deep geothermal system at YYC could serve as a catalyst for the geothermal industry in Alberta with wide-spread societal benefits.

References

Calgary Airport Authority. (2024). *Sustainability Strategy 2022-2026*. YYC Sustainability Strategy. https://www.yycsustainability.com/climate-action/#1.1

Komaromi, L. (2024). *Techno-economic feasibility study for a deep geothermal system at the Calgary International Airport*.

Majorowicz, J. A., & Grasby, S. E. (2020). Heat transition for major communities supported by geothermal energy development of the Alberta Basin, Canada. *Geothermics, 88*, 101883. https://doi.org/10.1016/j.geothermics.2020.101883

Think GeoEnergy. (2019, February 27). *GreenFire Energy to showcase its geothermal technology at NREL Emerging Markets Day | ThinkGeoEnergy - Geothermal Energy News*. ThinkGeo Energy. https://www.thinkgeoenergy.com/greenfire-energy-to-showcase-its-geothermal-technology-at-nrel-emerging-markets-day/

United Nations. (2015). *The 17 Sustainable Development Goals*. United Nations. https://sdgs.un.org/goals