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Geothermal Energy as a Heat Source for oil Sands processing in Alberta: Greenhouse Gas (GHG) Emissions Quantification

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Summary

In line with the global decarbonizing goals, Canada is committed to reducing its emissions by 40-45% by 2030 from its 2005 emissions levels and reaching a net zero carbon economy by 2050. Over 80% of the country's total GHG emissions are related to the current energy production and consumption (Government of Canada (GoA), 2022). Therefore, switching to cleaner energy sources is crucial for a low-carbon future. One such energy source is geothermal energy, thermal heat derived from the earth. It is a clean and sustainable energy source that provides baseload heat and power with considerably low GHG emissions. The research focuses on quantifying GHG emissions reduction in Alberta's oil sands operations if some of the natural gas use is offset by developing enhanced geothermal systems. Conducted literature review, data collection, analysis, and results interpretation allowed us to draw the following conclusions: over 71Mt CO2eq, or ~50% of the emissions from all 702 large GHG emitting facilities in Alberta in 2020, came from 34 oil sands extraction facilities. Considering the 2020-2031 oil sands' total bitumen production levels, we estimate 197- 682 EGS doublets would substitute natural gas use. The geothermal heat produced from these EGS doublets would help reduce GHG emissions by ~21 Mt CO2eq in 2020 and ~29 Mt CO2eq in 2031. This reduction would be equivalent to taking ~4.5M - 6.3M gasoline-powered vehicles off the road. The expected drilling cost per 5.5km EGS well will be ~66% of the total cost, operational cost ~22%, and exploration and simulation costs ~5% and ~7%, respectively. The expected cost per 5.5km EGS well will be ~25MM.

Theory / Method / Workflow

The research estimates the reduction in Greenhouse Gas (GHG) emissions in Alberta's oil sands operations if some of the natural gas use is offset through the development of enhanced geothermal systems.
Based on the Government of Canada data, Alberta is the highest GHG-emitting province in Canada (Figure 1). The province's emissions have continuously increased for the last three decades (GoC, 2022). The province has emitted 256.4 Mt CO2 eq, ~35% of the national total in 2020, which is an ~55% increase compared to the emissions in 1990 (Figure 1). The province's emissions per capita are the second highest in the country, with ~60 tons of CO2 eq, triple the national average of ~20 tons per capita (Canada Energy Regulator, 2021; UNEP, 2021). Fossil fuel production is the province's primary, over 50% contributor to GHG emissions (Figure 3). Total GHG emissions from over 700 large facilities in Alberta were 143 Mt CO2 eq, which is ~52% of the 273 Mt CO2 eq total emissions from 1704 large facilities in Canada (Asmaryan, 2022).

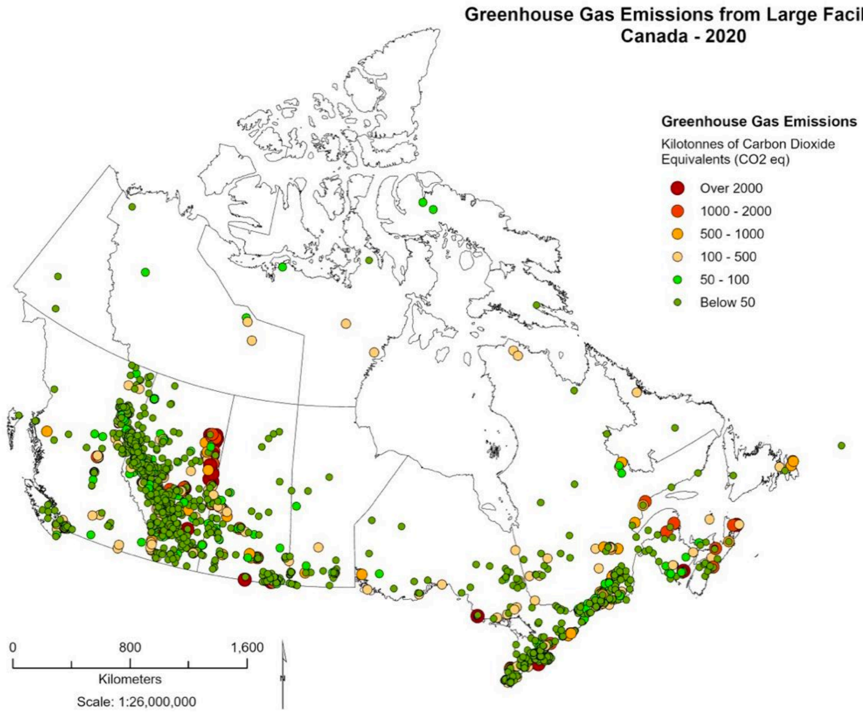

Figure 1. GHG Emissions from the Large Facilities in Canada in 2020.
Notre: From Asmaryan, 2022

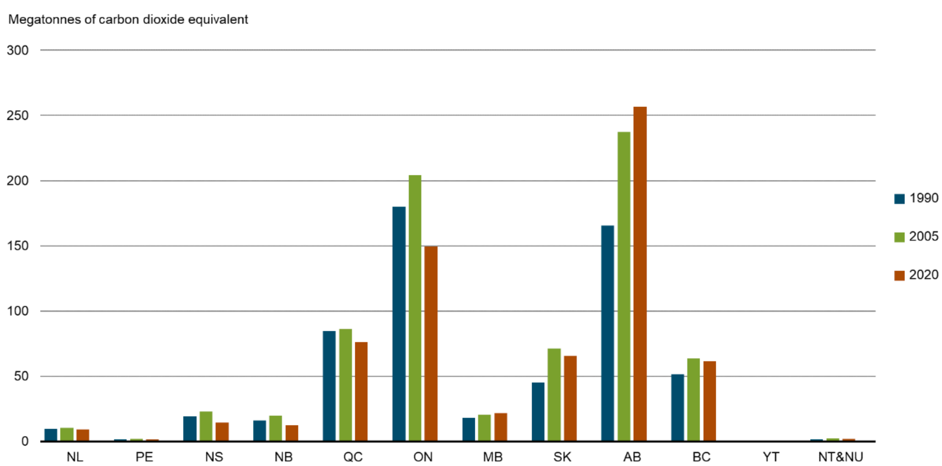

Figure 2. GHG Emissions from the provinces and territories in Canada in 1990, 2005, and 2020
Notre: From Government of Canada, 2022

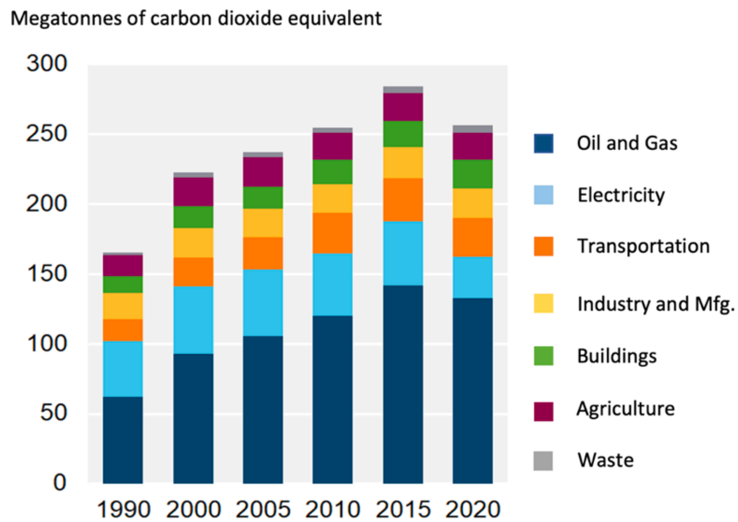

Figure 3. GHG Emissions from seven sectors in Alberta every five years from 1990 to 2020
Note: From Canada Energy Regulator, 2021

71 Mt CO2 eq, or ~50% of the emissions from the abovementioned large GHG emitting facilities in Alberta in 2020, came from 34 oil sands extraction facilities (Asmaryan, 2022). These emissions are associated with the natural gas used to heat the water (1000 – 10000 m3/h) for bitumen separation from oil sands. The natural gas used to heat the water in oil sands facilities accounts for 6% of the county's natural gas combustion annually (Canadian Oil Sands Innovation Alliance (COSIA), 2015). Therefore, the project focused on quantifying GHG emissions by utilizing geothermal energy as a heat source for oil sand separation. Replacing natural gas with geothermal heat will help reduce emissions (Hu et al., 2022).

Geothermal energy is thermal energy generated in the earth, which can be harnessed for various functions, including but not limited to geo-exchange systems and direct heat and power generation (GoA, 2018). It is a clean and sustainable energy source (Powell, 2020). Geothermal energy production can reach long-term success in Alberta due to the high potential, oil and gas industry history, similarities in processes, activities, and talent pool (Leitch, Hastings-Simon, & Haley, 2017; Powel, 2020).

In the oil sands facilities, in the process of separating bitumen from oil sands, the water is heated to 50°C and above (Canadian Oil Sands Innovation Alliance (COSIA), 2015). Based on numerous studies, Enhanced Geothermal Systems (EGS) can provide commercial-scale hot water of greater or equal to 60°C for the bitumen separation at the oil sands facilities (Majorowicz & Grasby, 2010; Majorowicz & Moore, 2014; Hoffman et al., 2014; Pathak et al., 2014; *C-FER Technologies, 2020;* Hu et al., 2022). EGS are unconventional systems used in areas where the fluid and the underlying rocks' porosity and permeability are insufficient for heat transport. Using hydraulic or thermal fracturing, EGS enhances the existing fluid pathways or creates new ones (UK Parliament POST, 2022).

The following methodology and workflow were employed to meet the research goal: Canada's Official Greenhouse Gas Inventory (COGGI) data were utilized to understand and assess the GHG emissions' past and current trends in Canada and Alberta. GHG emissions data from the COGGI for Canada's and Alberta's energy sector, including emissions from the large facilities, was downloaded, and maps illustrating the GHG emissions from the large facilities were created (Figures 1 and 4).

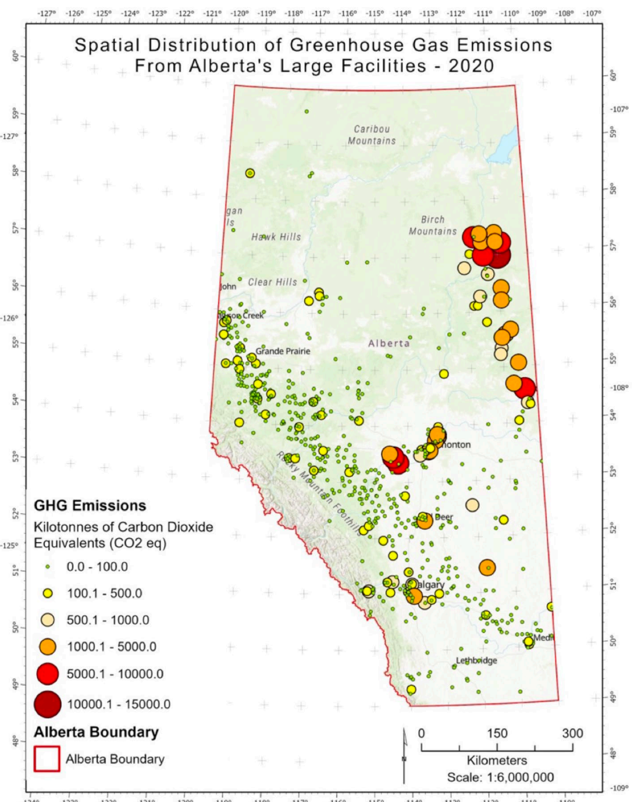

Figure 4. GHG Emissions from large facilities in Alberta in 2020.
Note: From Asmaryan, 2022

Daily bitumen production levels for 2020-2031 are derived from AER's website (AER, 2022). The literature review helped to assess geothermal energy production as a potential replacement for the current energy production, particularly in Alberta's oil sands facilities, calculate the amount of water used for the present and future bitumen production in the province, natural gas used to heat the water, GHG emissions from the natural gas use and the emissions' potential reduction in Alberta's oil sands operations if some of the natural gas use is offset through the development of EGS (Hu et al., 2022; Lambda Geeks, 2022). Using the United States Environmental Protection Agency (US EPA) GHG equivalency calculator, the reduced GHG emissions equivalency to passenger vehicles was calculated (US EPA, 2022). Basic capital and operational cost calculations were completed to understand the preliminary cost of the EGS system based on several assumptions. The latter was about the water temperature loss of ~10°C from the well to the application area, from the formation to the production wellhead.

Further assumptions were about an average of 30°C temperature decline within the project's 30 years lifetime. Based on these assumptions, the target formation temperature is ~100°C, which can be reached at ~5000m and deeper, considering the geothermal gradient of ~20°C in the oil sands area. Considering the oil sands area geology, with the sedimentary cover with a maximum thickness of ~400 m, we are looking into drilling ~4500m of the geothermal through granitic rocks with low porosity and permeability. Therefore, we run our calculations for an EGS system of 5000 m +/- 500m depth.

Results, Observations, Conclusions

The hot water use was calculated with bitumen production data from Alberta Energy Regulator (AER) for 2020 - 2031 (Figure 5).

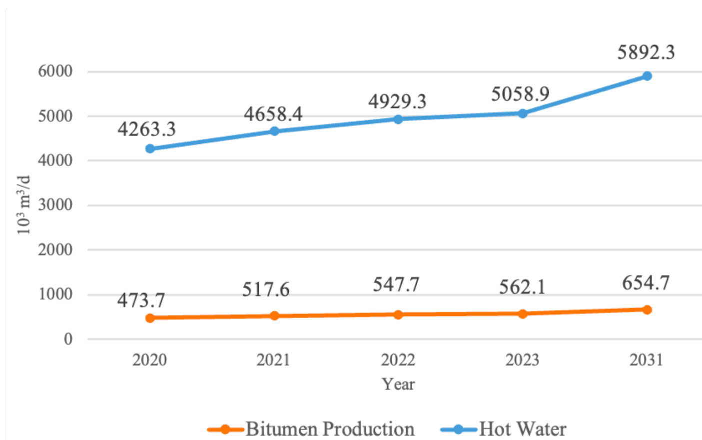

Figure 5. Hot water required for Daily Bitumen Production (10^3 m^3/d) in Alberta in 2020, 2021, 2022, 2023, and 2031
Note: From Asmaryan, 2022

The annual natural gas use (PJ) for heating the water for the bitumen separation in oil sands facilities was calculated (Figure 6).

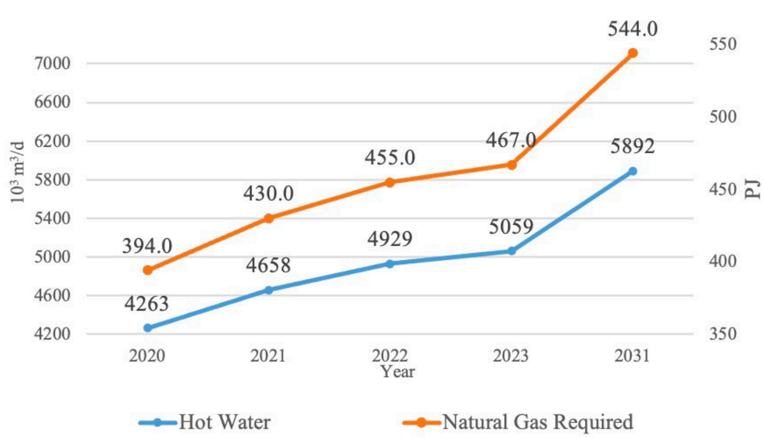

Figure 6. The annual amount of natural gas (PJ) required to heat the water (10^3 m^3/d) for the bitumen production in Alberta in 2020, 2021, 2022, 2023, and 2031
Note: From Asmaryan, 2022
Based on the calculated numbers of the annual hot water use for bitumen production, the number of EGS doublets required to substitute the natural gas use was calculated (Table 1).

	2020	2021	2022	2023	2031
Hot water for The bitumen production (10^3 m^3/d)	4263.3	4658.4	4929.3	5058.9	5892.3
EGS doublets required	197 – 493	216 – 539	228 – 570	234 - 585	274 - 682

Table 1. The number of EGS Doublets required to substitute natural gas use for bitumen production in Alberta
Note: From Asmaryan, 2022

The GHG emissions (MT CO_2 eq) were calculated based on the annual natural gas and EGS doublets use data for 2020 – 2031 (Figure 7).

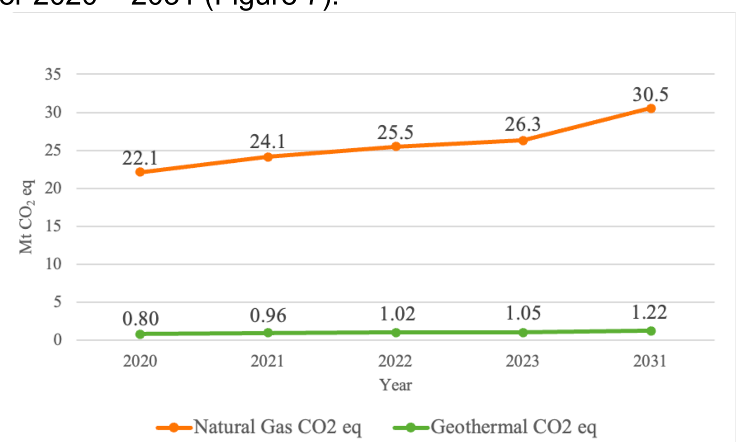

Figure 7. GHG emissions (Mt CO_2 eq) from natural gas use (PJ) and EGS for the bitumen production in Alberta in 2020, 2021, 2022, 2023, and 2031
Note: From Asmaryan, 2022

The geothermal heat produced from the numbers mentioned in table 1 for EGS doublets would help to reduce GHG emissions to only 0.8 Mt CO2 eq in 2020, 0.96 Mt CO2 eq in 2021,1.02 Mt CO2 eq in 2022, 1.05 Mt CO2 eq in 2023, and 1.22 Mt CO2 eq in 2031 (Figure 7). This reduction would be equivalent to taking ~4.6M gasoline-powered vehicles off the road in 2020, ~5M in 2021, ~5.3M in 2022, ~5.5M in 2023, and ~6.3M in 2031.
The geothermal drilling cost calculations are done for EGS with 4500m and 5500m depths.

The cost of one well with 4500m is estimated to be ~$12MM and for 5500m EGS, ~$17MM. The calculated cost will be twice more for a doublet (injector-producer pair). The pre-drilling or exploration cost that includes fieldwork, geophysical survey of the field structure and the interpretation of the results is considered constant $1MM. An additional $120 000 is added for technical and office support. The reservoir hydraulic simulation cost is calculated at $1 250 000. The EGS operational cost for 30 years lifetime is calculated to be ~4.1MM for 4500m EGS and ~5.6MM for 5500m EGS. Thus, the total cost of a 4500m EGS system with 30 years of life will be ~$18.5MM, and a 5500m EGS system is ~$25MM. Figure 8 shows the calculated EGS systems costs in percentages.

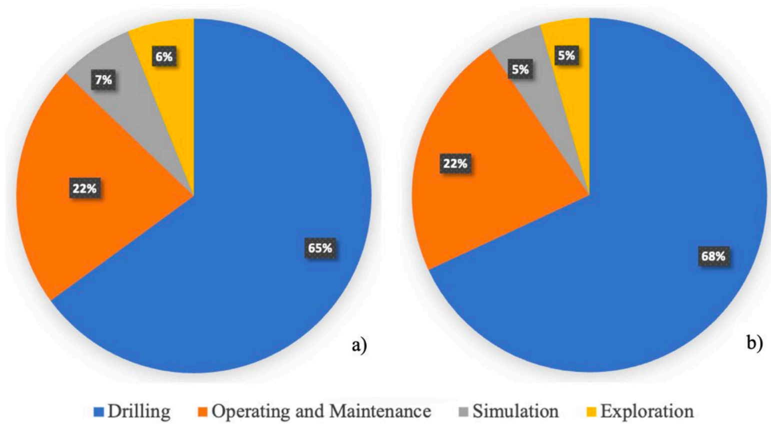

Figure 8. Calculated EGS total costs in percentages. a) costs for 4500m EGS, b) costs for a 5500m EGS well.
Note: From Asmaryan, 2022

Novel/Additive Information

The research quantifies the GHG emissions from Alberta's oil sands facilities, analyzes the emissions' spatial-temporal distribution and assesses the emissions reduction of the oil sands facilities if EGS replaces the natural gas use. The research is an essential part of the University of Calgary's Sustainable Energy Development Programs' sustained efforts in assessing cleaner energy resources' potential, focusing on socio-economically feasible and enviro-friendly energy resources as an essential step toward a low-carbon energy future.
The research assesses the GHG emissions from operations. A potential continuation of the research would be a lifecycle analysis that includes GHG emissions from the manufacturer, resource extraction, materials transportation, construction, and other associated activities for both fossil fuel production and geothermal heat and power production. Techno-economically viable geothermal system choices can be based on energy simulation data. Furthermore, various potential geothermal systems' financial viability and performance can be assessed and optimized using clean energy management software platforms such as RETScreen or System Advisor Model (SAM), ensuring a more thorough cost, product specifications, sensitivity and risk analysis.

The outcomes of this research can be used for educational purposes. They can lead to broader interdisciplinary and multidisciplinary research studies. The research outcomes can contribute to public and private energy companies' and corporations' efforts in energy resource diversification and transitioning into renewable energy production in the province. The research will also be helpful for governmental agencies and regulatory bodies in developing policies for geothermal energy production.

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References

Alberta Energy Regulator. (2022, May). Crude Bitument Production. Retrieved October 27, 2022, from Alberta Energy Regulator: https://www.aer.ca/providing-information/dataand-reports/statistical-reports/st98/crude-bitumen/production

Asmaryan, H. (2022, January 4). Greenhouse Gas (GHG) Emissions Quantification with Geothermal Energy Replacing Alberta's Fossil Fuels. Retrieved January 2023, from d2L Sustainable Energy Development University of Calgary: https://d2l.ucalgary.ca/d2l/le/content/44213/viewContent/5673268/View

Canada Energy Regulator. (2021). Provincial and Territorial Energy Profiles – Alberta. Retrieved February 5, 2022, from Canada Energy Regulator: https://www.cerrec. gc.ca/en/data-analysis/energy-markets/provincial-territorial-energyprofiles/provincial-territorial-energy-profiles-alberta.html

Canadian Oil Sands Innovation Alliance. (2015, October 1). Direct Hot Water Production for an Oil Sands Mining & Extraction Process. Retrieved October 16, 2022, from COSIA: https://cosia.ca/uploads/files/challenges/ghg/COSIA%20Challenge%20GHG%20-%20Direct%20Hot%20Water%20Production%2016-10-14.pdf

C-FER Technologies. (2020, February). Alberta Energy Regulator. (2022, May). Crude Bitument Production. Retrieved October 27, 2022, from Alberta Energy Regulator: https://www.aer.ca/providing-information/data-and-reports/statistical54reports/st98/crude-bitumen/production. Retrieved October 29, 2022, from Canada's Oil Sands Innovation Alliance (COSIA): https://cosia.ca/sites/default/files/attachments/C528%20Final%20Report_06APR2020_FINAL.pdf

Government of Alberta. (2018). A Guide to Support Indigenous Renewable Energy Development in Alberta. Retrieved February 5, 2022, from Government of Alberta: https://open.alberta.ca/dataset/aec61a62-1af7-499d-b7a0-f1ee5ec10110/resource/a32a9a56-439b-45f3-8316-4a165d930af5/download/aigedpguidebook.Pdf

Government of Canada. (2022, August 25). Greenhouse gas emissions. Retrieved September 7, 2022, from Government of Canada: https://www.canada.ca/en/environment-climatechange/ services/environmental-indicators/greenhouse-gas-emissions.html

Hofmann, H., Babadagli, T., Zimmermann, G., (2014) Hot water generation for oil sands processing from enhanced geothermal systems: Process simulation for different hydraulic fracturing scenarios, Applied Energy, Volume 113, Pages 524-547, ISSN 0306-2619, https://doi.org/10.1016/j.apenergy.2013.07.060. Retrieved from:https://www.sciencedirect.com/science/article/pii/S0306261913006272

Hu, X., Banks, J., Guo, Y., Liu, W. V., (2022) Utilizing Geothermal Energy from Enhanced Geothermal Systems as a Heat Source for Oil Sands Separation: A Numerical Evaluation, Energy, Volume 238, Part A, 121676, ISSN 0360-5442: https://doi.org/10.1016/j.energy.2021.121676.

Lambda Geeks. (2022). Find Thermal Equilibrium: 7 Important Facts You Should Know. Retrieved September 19, 2022, from Lambda Geeks: https://lambdageeks.com/findthermal-equilibrium/

Leitch, A., Hastings-Simon, S., & Haley, B. (2017, December). Heat Seeking: Alberta's geothermal industry potential and barriers. Retrieved December 11, 2021, from Pembina Institute: https://www.pembina.org/reports/heat-seeking.pdf

Majorowicz, J., Grasby, S.E. (2010, September) Heat Flow, Depth -Temperature Variations and Stored Thermal Energy for Enhanced Geothermal Systems in Canada. Journal of Geophysics and Engineering; Volume 7, Issue 3: Pages 232 – 241: https://doi.org/10.1088/1742-2132/7/3/002

Majorowicz, J., Moore, M. (2014) The Feasibility and Potential of Geothermal Heat in the Deep Alberta Foreland Basin-Canada for CO2 Savings, Renewable Energy, Volume 66, Pages 541-549, ISSN 0960-1481: https://doi.org/10.1016/j.renene.2013.12.044.

Pathak, V., Babadaghli, T., Majorowicz, J., & Unsworth, M. (2014, June). Evaluation of Engineered Geothermal Systems as a Heat Source for Oil Sands Production in Northern Alberta. Natural Resources Research, 23(2), 247- 265. DOI: 10.1007/s11053-013-9218-4

Powell, B. H. (2020). Gaining Steam: A Regulatory and Policy Framework for Geothermal Energy Development in Alberta, Module 1: Geothermal Energy and Alberta's Current Regulatory Landscape. Retrieved December 4, 2021, from https://elc.ab.ca/wpcontent/ uploads/2020/10/Geothermal-Energy-Module-1-Geothermal-Energy-and-Alberta-Current-Regulatory-Landscape.pdf

UK Parliament POST. (2022, April 26). Geothermal Energy. Retrieved November 1, 2022, from UK Parliament POST: https://researchbriefings.files.parliament.uk/documents/POST-PB-0046/POST-PB-0046.pdf

United Nations Environment Programme. (2021, October 26). Emissions Gap Report 2021. Retrieved February 3, 2022, from United Nations Environment Programme: https://www.unep.org/resources/emissions-gap-report-2021

United States Environmental Protection Agency. (2022, March). Greenhouse Gas Equivalencies Calculator. Retrieved October 15, 2022, from United States Environmental Protection Agency: https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator