geoconvention
Calgary · Canada · June 17-19 2024

Geothermal Energy for Sustainable Development: The Tu Deh-Kah Geothermal Project in British Columbia

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Summary

This study discusses geothermal energy and the Tu Deh-Kah (TDK) geothermal project near Fort Nelson, British Columbia. Geothermal energy is a sustainable and clean energy source that comes from the Earth's internal heat. This is especially noticeable in regions with geothermal abnormalities such as the Pacific Ring of Fire. Geothermal energy is utilized for heating, cooling, and electricity production in several ways, such as through dry steam, flash steam, and binary cycle power plants. This abstract highlight the use of the binary cycle approach in the TDK project, which is well-suited for reservoirs with moderate temperatures. This process utilizes a secondary fluid that is heated by geothermal fluid to create vapor and power turbines for generating electricity. Geothermal energy can replace diesel for electricity and heating in Canada’s remote areas, contributing to Canada's clean energy objectives.

The research examines the incorporation of hydrogen generation via electrolysis utilizing geothermal energy, introducing an innovative method for sustainable energy. Hydrogen, a rising mainstream energy source, offers promising growth potential, particularly when produced using geothermal energy for a clean process. The TDK project, led by the Fort Nelson First Nation, is located in the abandoned Clarke Lake gas field. Its goal is to harness the field's geothermal resources for generating electricity and heat. The idea employs a binary system to generate energy by using heat from geothermal fluid to evaporate a secondary liquid, which then drives a turbine. In this paper, hydrogen production using geothermal heat through the electrolysis method is offered. This method offers clean energy and is in line with environmental goals and the increasing need for hydrogen fuel. The paper delves into the geological features of Clarke Lake, the socio-economic effects of the TDK project on the Indigenous community, and the possible dangers and policy consequences related to geothermal energy production, including induced seismic activity and the necessity for efficient risk management procedures.

Introduction

Geothermal energy harnesses the heat within the Earth, offering a clean, reliable, and locally available source of power. When hot water or steam rises and becomes trapped in porous rocks beneath impermeable layers, geothermal reservoirs form. These reservoirs require adequate temperature, fluid, and rock permeability as a heat carrier. Duchane (1996) and Fridleifsson, (1996) showed that the Earth's crust experiences an average temperature change of about 20 to 30°C per km below the surface. Geothermal anomalies, characterized by higher-than-average temperature gradients, are typically found near tectonic plate boundaries with features like young volcanoes, seismic activity, and magma movement. The Pacific Ring of Fire, a zone encircling the Pacific Ocean coastline, is particularly noteworthy for its concentration of geothermal anomalies due to continuous volcanic activity and plate movements (Pyle, 1998).

This energy is utilized for direct-use applications, utilizing hot fluid extracted from reservoirs, typically within the range of low to medium temperatures (~50-150°C), for heating and cooling without the need for conversion into other forms of energy like electricity (Arianpoo, 2009). This hydrothermal fluid can be converted into electricity via three kinds of geothermal power plants: dry steam, flash steam, and binary cycle. Each plant depends on the field’s temperature and the geothermal fluid (steam or water). Flash steam and dry steam techniques are utilized for high-temperature reservoirs, typically exceeding ~180°C, while the binary cycle approach is employed for reservoirs with moderate temperatures, 74°C being the lowest temperature (Armstead, 1978.; Dickson & Fanelli, 2005). The binary-cycle power plant is utilized when the temperature of the geothermal fluid is below its boiling point. In this approach, a second fluid with a lower boiling point is evaporated using the heat from the geothermal fluid. This method involves passing the hot geothermal water through a heat exchanger to vaporize the secondary fluid, which flows in a separate loop in the opposite direction. Our focus lies on the binary cycle method, as it is the approach employed by the Tu Deh-Kah (TDK) geothermal project located at Clarke Lake, British Columbia.

In Canada, particularly in its remote and northern regions, geothermal energy emerges as a pivotal and non-intermittent solution, it is justified by its low carbon impact, resource-rich potential, and stability (Dincer & Ishaq, 2022). Moreover, in isolated Indigenous settlements with limited access to regional electricity infrastructure, geothermal energy addresses the prevalent use of diesel for electricity and heating, offering a cleaner and more sustainable alternative. The implementation of binary geothermal technology, capable of generating electricity efficiently even at lower temperatures, proves to be a promising solution for harnessing the substantial recoverable thermal energy within the Clarke Lake Field aquifer. This energy is around 10.1 x 1014 kJ, which is equivalent to around 165 million barrels of oil, presents a substantial and renewable resource that could significantly benefit the Fort Nelson region, aligning with Canada's clean energy goals and mitigating issues of intermittency in these northern areas as mentioned in the study done by Warren Walsh (2013).

Geothermal energy holds promise for diverse applications, with one particularly exciting prospect being its role in hydrogen production through electrolysis (Yue et al., 2021). This process harnesses the heat from geothermal wells to split water molecules, yielding clean, emission-free hydrogen fuel. As society increasingly aims for sustainability, the synergy between geothermal energy and hydrogen production offers a compelling solution for reducing greenhouse gas emissions and environmental degradation.

The current heavy reliance on coal, oil, and natural gas for various energy needs has resulted in significant environmental impacts, including the accumulation of greenhouse gases and exacerbation of climate challenges. In response, the shift toward renewable energy sources gains momentum. Hydrogen, long used in industries such as refining and chemical manufacturing, now emerges as a mainstream energy contender. As practical applications expand, the demand for hydrogen is projected to grow steadily, with a compound annual growth rate of 5.48% expected until 2025 (Shah et al., 2021). This transition toward hydrogen-based energy systems not only reduces fossil fuel consumption but also promises a more sustainable and environmentally friendly future.

TDK geothermal project

The Tu Deh-Kah geothermal project, initiated in 2019 by the Fort Nelson First Nation (FNFN), represents a pioneering venture set in the Clarke Lake gas field of Northern British Columbia (BC). located within one of the last regions of the province reliant on fossil fuels for electricity, TDK marks a pivotal shift towards sustainable energy sources. Despite the Clarke Lake gas field being depleted, it holds significant potential for geothermal energy production. TDK is a ground-breaking endeavor aimed at addressing environmental imperatives and revolutionizing energy paradigms in alignment with ambitious net-zero carbon emissions targets. Fully owned by Indigenous stakeholders, the FNFN secured $40.5 million in Federal Funds for the project by 2020 (Gilpin, 2023), with ongoing efforts to secure additional funding as the project progresses. Spearheaded by Deh Tai LP, the economic arm of the FNFN, in partnership with the Barkley Project Group, TDK seeks to harness geothermal energy for electricity production and various other applications, including providing heat for buildings, forestry, and agriculture, with a particular emphasis on enhancing food security in the Fort Nelson area by utilizing excess heat from the geothermal plant to warm agriculture greenhouses (Gilpin, 2023).

The TDK Geothermal project operates on a binary system, a method of harnessing geothermal energy. This involves extracting fluid, typically water, from beneath the Earth's surface through a production well, which extends approximately 2.6 km deep. Once brought to the surface from depths exceeding 2 km, the fluid undergoes a heat exchange process with isobutane, a secondary liquid. The intense heat causes the isobutane to vaporize into steam, which then drives a turbine, producing electricity through mechanical energy conversion. This electricity can be distributed to the grid or utilized for various purposes as needed. The condensed steam is subsequently cooled back into a liquid state, ready to be recirculated into the system, thus creating a continuous cycle of energy production. This cyclical process exemplifies the sustainability of geothermal energy, as it operates continuously without depleting finite resources, providing a reliable and renewable energy source capable of generating power all the time.

In addition to its primary aim of generating clean electricity and providing sustainable heating solutions, the TDK geothermal project is poised to add significant value by integrating hydrogen production into its operations. Establishing the abundant heat reservoirs beneath the Clarke Lake gas field, TDK has the potential to utilize geothermal energy for electrolysis, a process that splits water molecules into hydrogen and oxygen gases (Yue et al., 2021). By incorporating hydrogen production into its operations, TDK can diversify its offerings and contribute to the growing demand for clean fuel alternatives. This strategic integration not only enhances the project's economic viability but also aligns with broader environmental objectives by facilitating the adoption of hydrogen as a clean energy source in various sectors, including transportation. Furthermore, by harnessing geothermal energy to produce hydrogen, TDK can further solidify its position as a pioneering venture at the forefront of sustainable energy innovation, setting a precedent for future projects seeking to maximize the potential of renewable resources for comprehensive energy solutions.

Study area

Clarke Lake, located approximately 10 km southeast of Fort Nelson, British Columbia, is a notable geological site characterized by its unique rock formations and geothermal energy potential. The area's geological history is deeply intertwined with the processes that shaped the Western Canadian Sedimentary Basin and resulted in the formation of dolomitized carbonates within the Slave Point Formation (Figure 1). These carbonates, originally composed of limestone, underwent a transformative process known as dolomitization. Dolomitization occurred as hydrothermal fluids migrated through the sedimentary basin, altering the chemical composition of the rocks by replacing calcium carbonate with magnesium carbonate, thereby forming dolomite. This process was particularly pronounced within the Middle Devonian Presqu'ile Barrier, extending from Pine Point in the Northwest Territories to northeastern British Columbia, where a pervasive body of dolomite was created (Qing & Mountjoy, 1994). The dolomitization of the limestone rocks in the Clarke Lake area has imparted them with distinct characteristics. The once impermeable limestone has become porous and permeable, allowing for the flow of fluids such as water and gas. This transformation has significant implications for resource extraction, enabling the development of gas reservoirs within the otherwise tight limestone formations. Moreover, the elevated temperatures observed within the Clarke Lake reservoir further enhance its geological significance. The high temperatures observed within the Clarke Lake field, as depicted in Figure 2, suggest significant geothermal energy potential, prompting ongoing investigations into the feasibility of harnessing this resource for sustainable energy production (Renaud, 2020). A study conducted by Renaud in 2020 on these dolomitized rocks revealed that they have an average porosity of 6.4%, indicating significant pore space for fluid movement. Although there is variability in porosity among the dolomitized rocks, those with higher porosity are recognized as the primary flow units due to their enhanced fluid transmission capabilities.

Thus, Clarke Lake presents an enticing opportunity for geothermal energy exploration, distinguished by its elevated reservoir temperatures, water drive, and porous rocks. The Clarke Lake gas field, once a productive site, is now depleted, prompting interest in alternative utilization. Extracting over 52 x 10^9 m^3 of gas and 49 x 10^9 m^3 of water since its establishment in 1961 has led to diminishing economic value, impacting stakeholders and the local community in Fort Nelson (Gas, 2009; Weides & Majorowicz, 2014). However, the high geothermal gradients and a water drive within the permeable hydrothermal dolomite reservoir has sparked consideration for repurposing the field as a potential source of sustainable geothermal power. The formation of a porous and permeable reservoir near the platform margin through hydrothermal alteration of the host limestone into dolomite further enhances its potential for geothermal energy extraction.

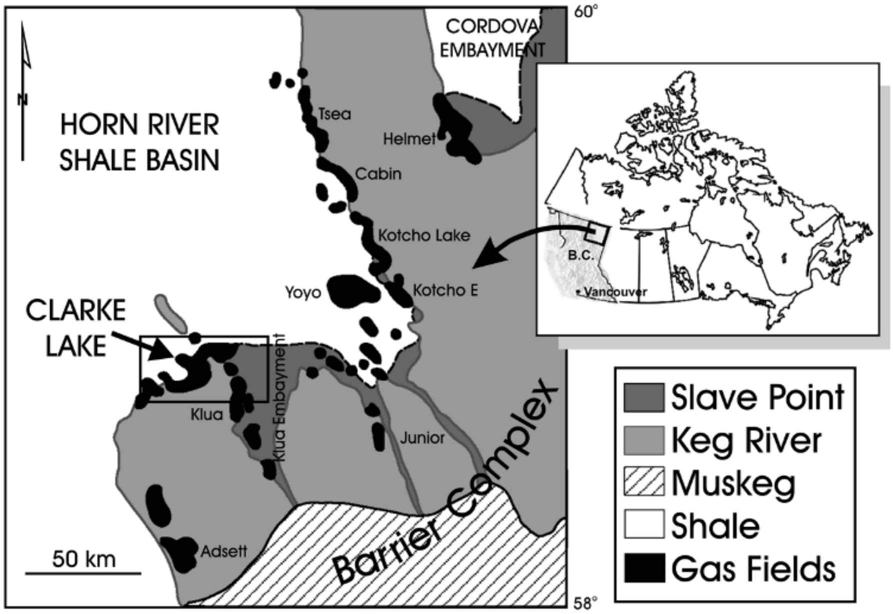

Figure 1- Geothermal Energy Potential Assessment of Clarke Lake Gas Field within Dolomitized Carbonates of the Slave Point Formation, Fort Nelson, B.C (Renaud, 2020).

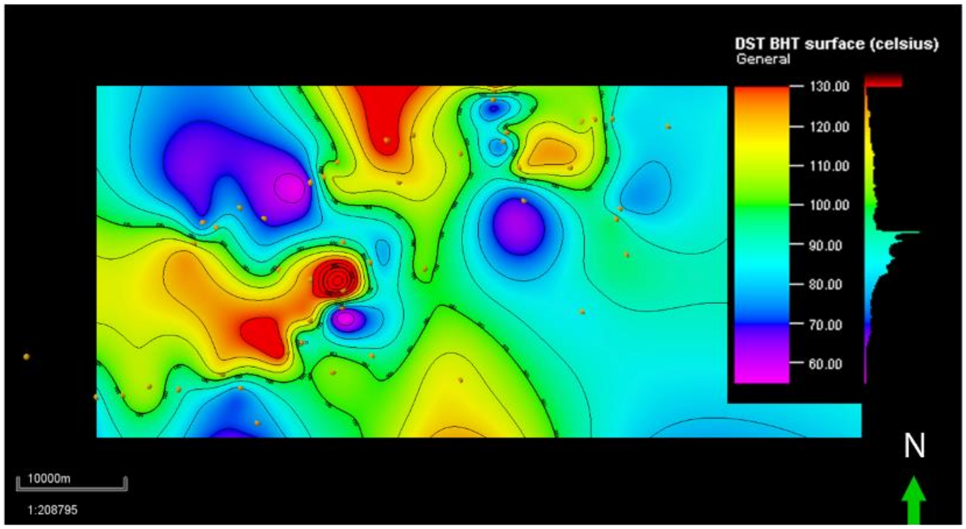

Figure 2- Temperatures of the Clarke Lake Gas Field (Renaud et al., 2018).

Framework

The proposed framework for this research seeks to seamlessly integrate hydrogen production with the Tu Deh-Kah (TDK) geothermal project and utilizes its innovative approach to increase energy production through strategically drilled wells. The method unfolds systematically and includes the following key steps.

The initial phase involves a meticulous evaluation of alternative approaches for harmonizing hydrogen production with geothermal energy. This assessment considers a spectrum of methods, including liquid reforming, natural gas reforming, high-temperature thermochemical water-splitting, electrolysis, nuclear high-temperature electrolysis, and various photo-driven processes (Balta et al., 2010; Yilmaz M.; Bolatturk A.; Gadalla M., 2012). Notably, steam methane reforming constitutes eighty percent of global hydrogen production, while the remaining twenty percent is a by-product of diverse chemical processes like Chlor-alkali manufacturing. It's important to highlight that water electrolysis contributes only a small fraction of the overall global commercial hydrogen production (Hand, 2008).

Given the inherent advantages of continuous heat supply from geothermal sources, water electrolysis emerges as a compelling method for hydrogen production. This approach harnesses geothermal energy to facilitate the required heat and electricity for water electrolysis, ensuring a sustained and efficient hydrogen generation process (Bamisile et al., 2022). The integration of hydrogen generation technologies with geothermal sources offers a promising pathway for a rapid transition to a hydrogen-based economy (Balta et al., 2010).

A critical aspect of the methodology involves a comparative analysis between geothermal-based hydrogen production and conventional methods such as steam methane reforming. This analysis accentuates the environmental and sustainability dimensions, elucidating the potential benefits of adopting geothermal energy for hydrogen production (Bamisile et al., 2022).

The research by Gholamian et al. (2018) delves into the intricacies of integrating hydrogen production systems within the geothermal power plant (GPP). The geothermal fluid extracted from production wells assumes a dual role, contributing to electricity generation within the power plant and preheating water for subsequent hydrogen production. The surplus energy is judiciously employed to enhance the overall efficiency of the system (Gholamian A.; Zare V., 2018).

Kanoglu et al. (2010) investigated three cases of geothermal energy application in H_2 liquefaction, exploring a binary GPP for electricity production and hydrogen liquefaction managed through the precooled Linde–Hampson cycle. An analytical approach was established, and performance parameters were scrutinized using energy and exergy studies (Kanoglu A.; Yilmaz C., 2010).

Siddiqui et al. (2019) proposed a project for hydrogen production from geothermal energy on Japan's Hachijo Island, guided by the outcomes of an environmental impact assessment. This initiative aims to serve as a model for other regions considering the widespread adoption of geothermal energy in hydrogen production, showcasing the potential for sustainable and environmentally conscious energy solutions (Siddiqui H.; Dincer I., 2019).

Drawing inspiration from the project proposed by Siddiqui et al. (2019) on Japan's Hachijo Island, the methodology incorporates an environmental impact assessment. This evaluative process aims to unravel the sustainability and ecological implications of coupling hydrogen production with the TDK Geothermal project, offering insights into the potential positive effects and environmental considerations for widespread adoption in diverse regions.

Socio-economic impact

The socio-economic aspect of Tu Deh-Kah geothermal projects and their impact on the indigenous people is investigated here. This project is owned by indigenous people and its goal is to make clean energy from geothermal heat (Tu Deh-Kah Geothermal, n.d.). Fossil fuels are now the main source of energy used every day there (Tu Deh-Kah Geothermal, n.d.). In such remote areas, getting energy from geothermal sources in the form of hydrogen or electricity not only saves the government money on providing fossil fuels and shipping costs but also helps the growth of these areas in many ways. Cutting back on fossil fuel use is beneficial for the economy and also helps Canada reach its goal of having zero net-zero CO_2 emissions by 2050.

The Tu Deh-Kah gas reservoir, which is now considered a geothermal plant, is located 10 km southeast of Canada's Fort Nelson (Walsh, 2013). According to initial estimates, this project can make between 12 MW and 74 MW of energy (mean 34 MW; standard deviation 10.8 MW) over a few decades (Walsh, 2013). Furthermore, the fluid extracted from this reservoir was found to include dissolved minerals like lithium, boron, helium, and other important substances (Harris, 2024). These minerals are extractable and can enhance the commercial value of reservoir projects (Harris, 2024).

The FNFN community situated 7 km south of Fort Nelson in the northeast of British Columbia, owns the project. This community, one of six nations that are part of Treaty 8, has about 811 band members who live on and off reserve and speak the Slavey/Cree language (Fort Nelson First Nation, n.d). Treaty 8 is a land agreement between First Nations and the federal government of Canada signed on June 21, 1899 (Treaty 8 Tribal Association, n.d.). It was the last and biggest land agreement in Canada in the 1800s (Treaty 8 Tribal Association, n.d.).

People who live there will benefit from the geothermal energy development. Creating job opportunities for the indigenous people as well as the economic enhancement of this community are goals that can be reached by implementing this project. However, people who work in this field need to be educated, so it's an excellent suggestion for the government to hold short-term workshops and courses as well as give out scholarships to the local students so that indigenous people can get educated and be hired for this project. Creating job opportunities for the young generations who live there motivates them to stay in such remote areas, which helps protect the indigenous people's valuable culture and traditions.

The production of clean hydrogen from geothermal heat is a good alternative fuel to be used for trucks, buses, and heavy cars in that area. Hydrogen can be produced to an extent that meets the local area’s demands then the remaining energy is converted to electricity. Canada's government has offered incentives through the Incentives for Medium- and Heavy-Duty Zero-Emission Vehicles Program (iMHZEV) since July 11, 2022, providing up to $200,000 at the point of sale for acquiring or leasing medium- and heavy-duty zero-emission vehicles (ZEVs) such as trucks, cargo vans, shuttles, and other commercial vehicles (Zero Emission Vehicles, n.d.). Providing fuel for these automobiles, together with incentives, can motivate local residents to buy vehicles that use hydrogen, helping to reach the goal of attaining net-zero CO_2 emissions by 2050.

Risks and policy

Geothermal energy production raises significant concerns about induced seismicity, particularly in regions where fluid injection is employed. An illustrative example is the Alberta No. 1 geothermal project, which, through the injection of fluids south and east of its location, triggered a seismic event measuring 4.1 Mw in the Fox Creek region on January 12, 2016 (Schultz R.; Gu Y.J.; Haug K.; Atkinson G., 2017). An event took place in the Musreau Lake region, where fluid injection practices led to a 3.94 Mw earthquake on December 25, 2019, as documented by Li et. al. (2021). These instances underscore the seismic implications associated with geothermal energy activities and highlight the importance of understanding and mitigating induced seismicity in such projects.

To effectively mitigate the risks associated with injection-induced seismicity in geothermal energy projects, it is essential to conduct a comprehensive evaluation of the probability and potential impact of seismic events. Implementing appropriate preventive measures is crucial, and one valuable tool for this purpose is the adoption of a Traffic Light Protocol (TLP). This safety measure is particularly significant for subsurface injection projects, as highlighted by various studies (Baisch et al., 2019; Mignan M.; Wiemer S.; Giardini D., 2017; Schultz G.; Ellsworth W.; Baker J., 2020).

The induced seismicity TLP serves as a practical framework for managing the risk of seismic activity in injection projects. It categorizes potential risks into different magnitude ranges, each defined by threshold values represented by green, yellow, and red lights. In the TLP system, operations can proceed as usual when conditions are deemed safe (green), make adjustments to limit seismic risk (yellow), or suspend operations altogether (red) to facilitate further analysis (Baisch et al., 2019; Mignan et al., 2017; Schultz et al., 2020).

Therefore, when implementing geothermal projects, it becomes crucial to establish a well-defined TLP to effectively manage induced seismicity and promptly address unexpected large seismic events. This proactive approach enhances the overall safety and reliability of geothermal energy production while ensuring responsible and sustainable practices in the industry (Baisch et al., 2019).

The geothermal regulations of British Columbia mandate that, during fracturing, injection, or disposal operations on a well, the well authorization holder must promptly inform the commission of any seismic event within a 3 km radius of the drilling pad. This reporting requirement is activated if the seismic event attains a magnitude of 4.0 or higher or induces ground motion felt on the surface within the specified radius (*Geothermal Operations Regulation*, 2020).

However, it is recognized that this regulation may be considered too general, as it does not account for site-specific factors such as location, geology, underground stress fields, and the existence of fault mechanisms in the region.

To enhance safety and mitigate potential hazards more effectively, it is crucial to supplement the existing regulation by incorporating a comprehensive monitoring system for seismicity rates (Sedghizadeh M.; Shcherbakov R., 2023; Sedghizadeh R., 2022). This involves actively tracking and investigating any abnormality or changes in seismic activity. Considering site-specific conditions and geological characteristics will contribute to a more nuanced and tailored approach to risk management in geothermal operations (Yaghoubi R.; Hickson C.; Wigston A.; Dusseault M. B., 2024). By adopting a proactive stance and continuously evaluating seismicity, authorities, and well authorization holders can better identify and respond to potential risks, thereby reinforcing the overall safety measures in geothermal projects.

Conclusions

This study highlights the significant potential of the Tu Deh-Kah (TDK) geothermal project in Clarke Lake, British Columbia, as a sustainable and innovative energy solution. Emphasizing geothermal energy's role in providing clean, reliable power, the study illustrates how the TDK project, employing the binary cycle method, effectively utilizes moderate-temperature geothermal reservoirs for electricity generation. This project not only promises to reduce reliance on diesel in remote Canadian areas but also aligns with national clean energy objectives. The integration of hydrogen production via electrolysis, leveraging geothermal energy, is particularly notable for its potential to contribute to a clean and sustainable energy future. This approach, alongside the TDK project's focus on indigenous community empowerment and environmental stewardship, marks a significant stride in renewable energy development. The study also acknowledges the challenges, particularly the risks of induced seismicity associated with geothermal energy production, underscoring the need for effective risk management strategies. Overall, the TDK project serves as a pioneering model for integrating renewable energy technologies, showcasing a path towards a more sustainable and environmentally conscious future.

Acknowledgments

The authors acknowledge the National Sciences and Engineering Research Council of Canada (NSERC) for funding through the CREATE REDEVELOP Grant #386133824, and all REDEVELOP members for their guidance and support Throughout this project.

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