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Co-Developing Geological CO_2 Sequestration with Critical Element Extraction and Geothermal Energy: A Circular Economy Approach in Alberta?

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Summary

Due to excessive greenhouse gas (GHG) emissions, Canada and Alberta have committed to a net-zero economy by 2050 [1]. Technologies such as GHG capture and sequestration, geothermal energy, and critical elements extraction will need to advance significantly to convert natural resources to marketable supplies while reducing the environmental impact. This case-study explored the feasibility of co-developing geological CO_2 sequestration (GCS), lithium (Li) extraction, and geothermal energy within deep (> 3 km) Devonian saline aquifers in Alberta, focusing in on the Leduc Formation [2]. This research expanded on the foundations laid by two pioneering pilot projects in Germany [3,4] and France [5,6] that were designed and implemented to co-develop geothermal energy with GCS and Li extraction. It evaluates the feasibility of implementing an integrated 'GCS+' strategy within the Devonian Leduc formation in Alberta. GCS+ is defined as an integrative approach that combines CO_2 sequestration with the extraction of geothermal energy and critical elements, such as Li, from deep geological formations. This research was conducted to explore the adoption of circular economy principles of maximizing resource value while reducing waste and mitigating the associated environmental footprints (e.g., water, land, noise), on these carbon sequestration and Li / geothermal energy extraction projects.

GCS is positioned as a significant option to achieve carbon neutrality in Alberta [1], especially considering the province's extensive history of oil and gas development and existing infrastructure. However, GCS is a cost-intensive technology that could be further incentivized by extracting Li and geothermal energy from produced brines. While the implementation of GCS+ demands significant financial outlays for infrastructure, technology, and the continuous management and monitoring of CO_2 storage, these costs are offset by substantial environmental and economic benefits. These include the reduction of atmospheric CO_2 levels aiding in climate change mitigation, and the extraction of valuable Li for battery production and geothermal energy as a clean energy source. This comprehensive approach diminishes the region's reliance on fossil fuels and encourages economic diversification, fostering the development of new industries in Alberta.

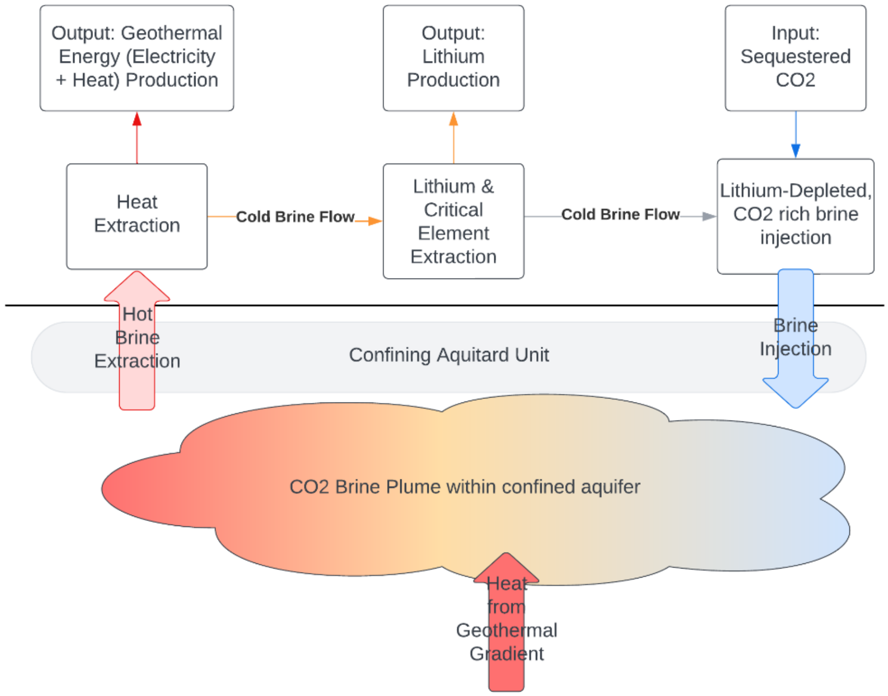

Fig. 1. A conceptual schematic of the CO_2 injection and combined extraction of geothermal energy and Li process from deep geothermal brines (the GCS+ process).

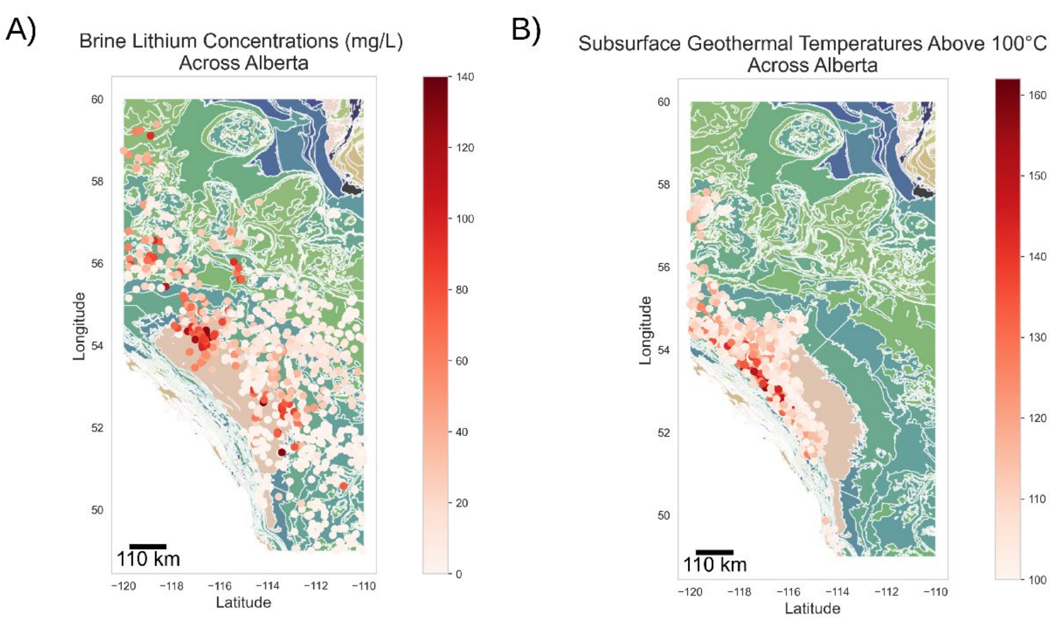

Fig. 2. Examples of geospatially varying data used to identify potential locations for GCS+ development **A)** Map of aqueous Li concentrations in subsurface brine across Alberta [7] **B)** map of geothermal temperatures above 100 degrees C across Alberta [8].

Methodology

Geospatial data, including temperature and Li concentration profile were obtained from the Government of Alberta datasets as described below. Secondary sources including academia, industry, and government publications were referenced to analyze GCS, geothermal and Li extraction technologies along with Alberta policy framework. First, a multi-criteria assessment tool for our novel GCS+ concept was developed by integrating publicly available data about subsurface temperatures [8], brine Li concentrations [7], presence of saline aquifers identified as having carbon storage potential [9], proximity to seismic activity [10], geological conditions [11], and indigenous rightsholders [12,13], exploring this spatially variable data using Python to determine appropriate project location. Fit-to-purpose modeling was then utilized including the Natural Renewable Energy Laboratory's (NREL) System Advisor Model (SAM) for techno-economic analysis and Pembina's Energy Policy simulator for Alberta policy evaluation [14]. These tools were leveraged to explore the feasibility of a GCS+ model, integrating geothermal energy extraction and critical element recovery with traditional GCS operations.

Key Findings and Suggestions

Technical Advancements Required for Evaluating Co-Development Opportunities

Multiple GCS+ configurations were explored in this study, per Figure 3, to evaluate the feasibility of optimizing GCS+ operation and its profitability and sustainability. The key technical challenges associated with the proposed GCS+ scheme include [5,6]:

- Induced seismicity and changes in pore pressure from injection versus the pressure reductions resulting from brine extraction [15,16].
- Impact of CO_2 content increase in the extracted water over time and any environmental leakage potential [17].

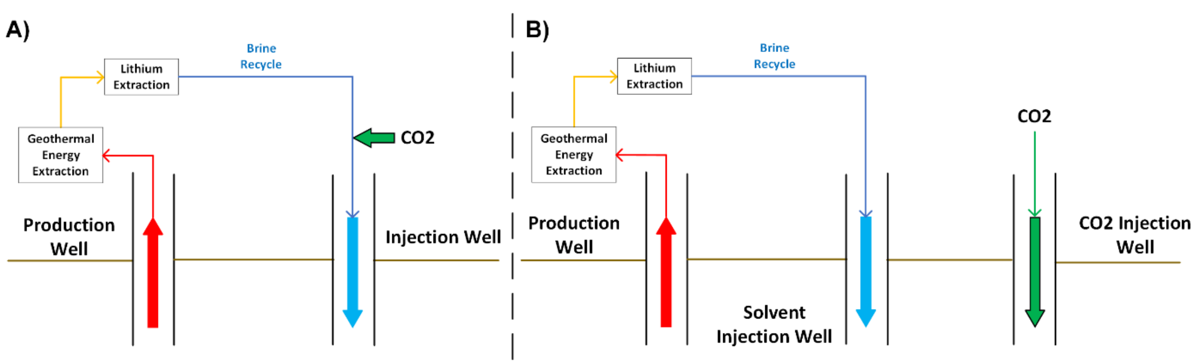

Fig. 3. Possible GCS+ co-development schemes based on previously implemented industrial pilots and designs [3,18] **A)** This scheme describes the use of dedicated production and injection wells for co-injecting CO_2 with brine **B)** This scheme describes the use of a dedicated CO_2 injection well for CO_2 sequestration within a shared pore space.

Indigenous Engagement and Policy Implications

This study examines the effectiveness of implementation of GCS+ within Alberta's policy framework as specified by the Alberta Energy Regulator's (AER) directives. These directives include Directive 051: Injection and Disposal Wells; Directive 065: Resources Applications for Oil and Gas Reservoirs; Directive 089: Geothermal Resource Development; and Directive 090: Brine-Hosted Mineral Resource Development [19]. A further critical component was the interface with Indigenous rights-holder and examination of opportunities for Indigenous-led companies in terms of ownership, jobs, and training. Ownership was explored as a policy matter, while jobs and training were recognized as being primarily related to funding and support from various government entities.

Since the discovery of oil in the Devonian reservoirs in 1947 initiated extensive conventional and unconventional hydrocarbon exploitation in the Leduc Formation, this development has resulted in over 2,900 orphaned oil and gas wells as of February 01, 2024 [20–22]. This study explored potential policy mechanisms to encourage the adoption of previously orphaned wells for GCS+ operations, considering the role of the Alberta Orphan Well Association (OWA) in facilitating these adoptions within a framework aimed at promoting a circular economy.

The significance of Indigenous rights-holders in this process is paramount, especially given the proximity of the proposed project sites to Indigenous lands, including Alexander 134A and Whitecourt #232 Alexis, which are First Nations reserves of the Alexander First Nation and the Alexis Nakota Sioux Nation, respectively [13]. The reserves are within a 50 km radius of the proposed project location as shown in Figure 4. The identified site, situated near the town of Whitecourt and the Fox Creek area, showcases high Li concentration and geothermal heat, and falls within the territories covered by Treaty 6 and Treaty 8.

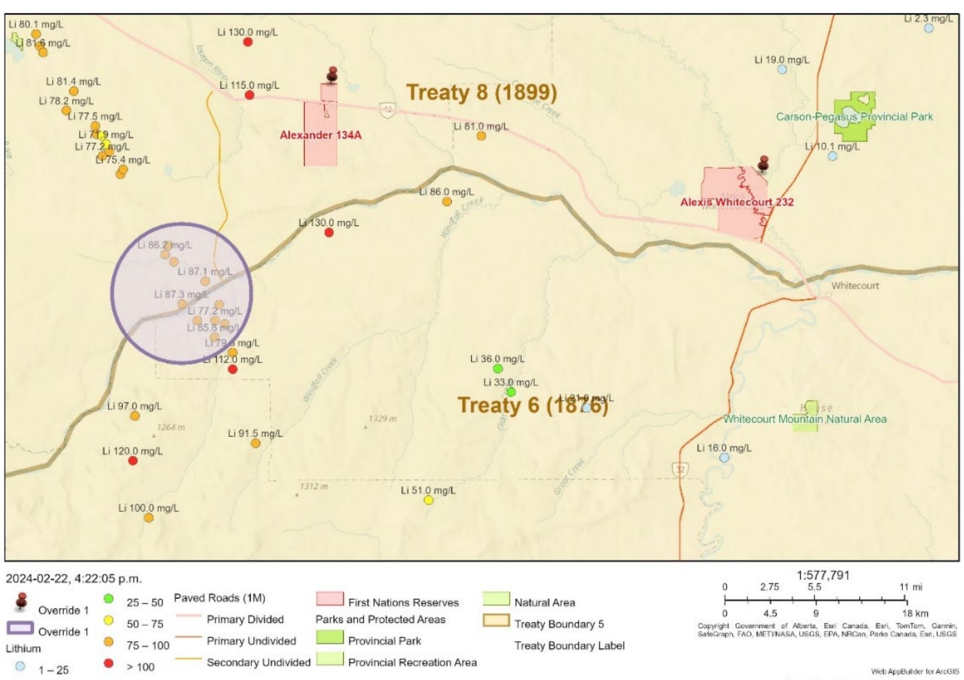

Fig. 4. Proximity of selected location (shown in purple) for the proposed GCS+ scheme to First Nation reserves (pinned in red) and signed treaties adapted from AER/AGS Interactive Minerals Map [23].

Economic Viability and Carbon Credits

Given the variability in Li concentration and geothermal heat in the Leduc Formation, the model accounted for the geospatial distribution across the select locality to recommend the most economically and environmentally viable project location. Notably, the province's deregulated volatile energy market with its occasional low electricity price ($52.19/MWh in 2020; $162.46/MWh in 2022) presents a hurdle for the economic viability of geothermal projects as standalone power generators [24,25]. One of the benefits of the proposed GCS+ concept is generating value through carbon credits in Alberta's emissions trading market [26,27].

Novel/Additive Information

This work offers new insights into the first of its kind GCS+ scheme for a sustainable circular economy in Alberta. It provides scientific-based guidance to improve and stabilize the economic benefits of traditional GCS operations within Alberta's policy framework while reducing the environmental risks associated with individual plant operation.

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