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Advancing Alberta's Devonian Lithium Brine Potential: Accelerated Exploration and Sustainable Extraction

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Summary

As the transition to a low-carbon economy accelerates, sedimentary-basin (SB) lithium brines have emerged as vital critical mineral targets. However, securing a low-carbon supply chain requires more than just resource discovery; it demands that sustainable mining strategies be integrated at the earliest stages of project planning. This work bridges this gap by presenting a dual-pillar framework that combines predictive deep learning for resource delineation with comprehensive techno-economic-environmental assessments (TEEA) of Alberta's Devonian lithium resources. The results provide specific guidance for optimizing brine sample collection and, more importantly, showcase a new strategic perspective for unlocking and prioritizing SB lithium brine resources in a sustainable manner.

Theory / Method / Workflow

The research framework establishes two activities to address fundamental development questions: (1) resource location and (2) sustainable mining pathways.

The first pillar utilizes a 3-layer deep learning architecture to predict lithium occurrence levels ([Li]) at three strategic cutoffs (35, 50, and 75 mg/L). The model was trained using commonly available geospatial data (coordinates, stratigraphic position) and five environment-insensitive geochemical features TDS, Na^+, K^+, Mg^{2+}, Ca^{2+}) from hundreds of historical measurements to grade [Li] for 897 locations with legacy geochemistry data.

The second pillar employs an integrated system-level modeling approach to evaluate the performance of standalone Direct Lithium Extraction (DLE) against integrated strategies. Using Monte Carlo simulations with emission and environmental models, it quantifies the impact of integrating Geothermal Heat Recovery (GHR), Geothermal Power Generation (GPG), and CO_2 Capture (CC) with DLE practices under varying resource, engineering, and economic conditions.

Results, Observations, Conclusions

The first pillar demonstrated high reliability for regional resource delineation, with the predictive model achieving validation accuracies exceeding 84% across all concentration cutoffs. By leveraging legacy geochemistry data, the study extended known distributions to 897 new locations, of which 449 passed the 35 mg/L cutoff, 271 passed the 50 mg/L cutoff, and 73 reached the high-grade 75 mg/L threshold (Peng et al., 2025).

In the second pillar, the analysis revealed that the carbon intensity (CI) of simulated standalone DLE practices spans a wide range of 7.48–78.97 kg CO_{2e}/kg LCE, with about 37.4% of cases falling below the 15 kg CO_{2e}/kg LCE hard-rock benchmark (Peng et al., 2026). These findings demonstrate that DLE is not an inherent low-carbon guarantee for mining sedimentary-basin (SB) brines without system-scale intervention.

Conversely, the results show that sustainable production does not necessitate economic compromise. Among the evaluated solutions, integration with GHR emerged as the most robust strategy, enabling net-negative carbon intensities while recovering 0.85–10.90 PJ/year of otherwise wasted heat for secondary industrial use. While CO_2 capture serves as a viable secondary pathway for cooler brines, its commercial feasibility is often constrained by high operational costs and emission caps.

Novel/Additive Information

In short, this work accelerates lithium exploration by transforming legacy geochemistry data into a predictive asset and identifies geothermal synergy as a critical requirement for decarbonizing production. It introduces a strategic Lithium-Temperature decision matrix for the WCSB, providing a transferable roadmap for broad stakeholders to prioritize low-carbon mineral supplies from similar SB lithium brine resources.

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