CASCADE INSTITUTE

Submission to Natural Resources Canada's Request for Information: Artificial Intelligence and Energy Innovation
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Overview

Geothermal energy can provide abundant, clean, and reliable baseload power by tapping into the heat generated by the Earth's core. Given the overlap with oil and gas expertise, Canada has a unique opportunity to leverage its world-class energy industry and compete in geothermal power.

Artificial intelligence (AI) can complement these strengths by addressing key barriers across the geothermal project lifecycle:

1. **Resource characterization**: by better modelling Canada's deep geothermal resource, which cannot be measured simply and directly like wind and solar resources.

2. **Site Selection**: by analyzing geophysical and geological data to site projects in optimal locations, reducing exploration risk and creating certainty for investment.

3. **Drilling**: by improving early identification of potential hazards and enhancing operators' real-time decision-making based on drilling performance and rock properties, leading to meaningful reductions in downtime and costs.

4. **Reservoir Creation**: by predicting how rocks will react to stimulation, improving flow rates—a vital element of project economics.

5. **Operations**: by optimizing plant performance, forecasting maintenance needs, and extending equipment life.

By reducing risk, lowering costs, and improving performance at each stage, AI can help unlock the potential of geothermal power as a pillar of Canada's clean energy system.

1. Resource Characterization

Challenge: High-temperature geothermal resources are located kilometers underground and cannot be directly observed. Unlike solar or wind resources, they must be inferred from indirect data such as heat flow measurements, seismic surveys, gravity measurements, well logs, and fluid geochemistry samples. Due to these challenges, Canada currently lacks a national geothermal dataset that integrates all key components.

The existing characterization of Canada's geothermal resource is extremely limited as it fails to use all available data and up-to-date methodologies. Only 40% of the country's land mass has been characterized to date, creating major challenges for assessing geothermal's potential contribution to Canada's energy systems.

AI Opportunity: Physics-based AI and machine learning can integrate sparse and heterogeneous datasets to model deep geothermal resources. Stanford University's neural network–based spatial interpolation algorithm (InterPIGNN) has already generated a national resource map for the U.S. Further, the model was able to predict key variables such as temperature, heat flow, and thermal conductivity more accurately than previous methods.

The Cascade Institute is adapting InterPIGNN for Canada. This model uses publicly available surface and subsurface measurements to aggregate temperature, heat flow, and rock conductivity data, enabling the creation of a Canadian thermal resource map akin to the Canadian Wind Atlas. This algorithm utilizes thirteen additional data sets in addition to the data used in previous models with greater coverage of the country. Even in locations with limited initial data, the model can highlight key data gaps and guide exploration. This iterative model will improve over time as more data becomes available. Utilizing this physics-based artificial intelligence algorithm would represent a step change in the characterization of Canada's geothermal resource.

The resulting dataset could enable robust modelling of Canada's cost-effective geothermal potential, as well as facilitate private investment by identifying Canada's most promising development locations.

2. Site Selection

Challenge: Once potential development locations are identified, detailed analysis is needed to pinpoint the exact site for drilling an exploration well. Siting geothermal wells is complex because critical factors such as permeability, naturally-occurring fracture networks, and subsurface fluid pathways, can vary dramatically over short distances. Exploration drilling is costly, especially for deep resources, and the combination of high exploration costs and uncertainty of the quality of the geothermal resource can deter investment.

AI Opportunity: AI can integrate existing geological, geophysical, and drilling data to identify optimal drilling locations. At least two U.S. companies are leveraging this approach now:

- Zanskar used stochastic resource modeling and AI to triple output at the Lightning Dock plant by simulating thousands of scenarios to pinpoint the most promising production pathways. Zanskar aims to repower ageing conventional geothermal wells by applying AI and advanced modelling to identify whether there are additional resources to unlock.

- New Mantle Technologies: is developing a physics-based AI tool to predict deep subsurface conditions. Whereas Zanskar is applying existing AI tools where data is available, New Mantle is developing entirely new tools to predict conditions in poorly understood environments.

In Canada, similar methods could be applied to extensive oil and gas well datasets, particularly in western provinces with mature drilling infrastructure. AI-enabled siting could reduce exploration risk, improve financing prospects, and accelerate project development.

3. Optimizing Drilling

Challenge: Drilling is one of the most significant costs for geothermal power projects, typically accounting for between 40-60% of capital expenditures. While geothermal drilling is similar to oil and gas drilling, geothermal projects require higher-powered rigs to drill geothermal wells. This is because geothermal wells typically have larger-diameter wellbores, penetrate to deeper formations, and have longer horizontal laterals to access larger volumes of rock than their oil and gas counterparts. Geothermal wells also tend to be drilled through more challenging conditions that include harder rocks and higher temperatures.

All else being equal, the more challenging conditions result in:

- Lower drilling speeds (rate of penetration – ROP) and;
- Less productive time drilling, due to more frequent equipment failure.

Together, these factors significantly increase drilling time and associated costs. In short, reducing drilling times—both through faster drilling rates and fewer failures—is vital to improving geothermal power project economics.

AI Opportunity: Drilling in the oil and gas industry has become a data-rich activity and is increasingly automated. This creates significant opportunities to improve drilling speeds through the use of AI. Key applications include:

- **Real time operating centers (RTOC):** site and geology experts can work remotely to oversee and manage drilling operations via the rich data stream of downhole instrumentation. This allows a single team of experts to constantly work on multiple drill sites, which minimizes non-productive time and reduces costs. This level of automation also benefits greatly from AI-assisted analysis of the immense real-time data collected during drilling operations which can further improve drilling performance.

- **Downtime prevention:** immense datasets from past and current drilling campaigns and well completions can be fed into AI that can judge when maintenance or equipment replacements should happen, which minimizes non-productive time and saves costs.

- **Optimization:** of key parameters such as 'weight-on-bit', which can prevent or lengthen the time between bit failures, again minimizing NPT and increasing the average rate of pentration. For example, Corva's AI was used in ADNOC's drilling with Baker Hughes to optimize drilling performance and allow for real-time adjustments, taking advantage of huge datasets gained from drilling

- **Mitigating stick-slip dysfunction**, a common issue where the drilling string rotates at erratic speeds in the well. This has been addressed by solutions such as Nabors' REVit ZT.

These applications already show potential. Akita, a Canadian drilling operator, achieved performance improvements in drilling for Kiwetinohk Energy Corp by using Nabors' SmartROS system in 2024. While Canadian drilling and energy companies are benefitting from the introduction of AI in the oil and gas industry, it is primarily Houston-based technology providers that are innovating on the high-tech aspects of development.

4. Advancing Reservoir Creation

Challenge: Enhanced geothermal systems (EGS) require artificially stimulating low-porosity, low-permeability, high-temperature rock to create fluid pathways. This process is technically challenging and requires engineered solutions that are linked to key properties of the geothermal reservoir such as pressure, in-situ stress orientation, brittleness, rock type, and anisotropy.

Modeling fracture networks and reservoir stimulation processes are data-intensive and complex, and modelling processes to date do not always lead to a predictable performance of fracture propagation and geothermal fluid flow and leave little opportunity for real-time decision-making or iterative updates to engineering based on previous performance of earlier fracture stages.

AI Opportunity: AI-enabled reservoir modeling can improve accuracy and responsiveness. Techniques like Ensemble Kalman Inversion can estimate parameters and quantify uncertainty with fewer simulations.

Hybrid deep learning models (e.g., CNN-LSTM) can serve as fast surrogates for computationally heavy simulations, enabling adaptable designs that make better use of in-situ performance. Reinforcement learning can dynamically adjust injection parameters to minimize the risk that injected fluids result in fault slippage while maintaining output.

Applying these methods to Canadian reservoirs with site-specific geologic information from Canada as well as leveraging open datasets from international projects like Utah FORGE could significantly improve stimulation success rates, optimizing performance outcomes and de-risking project economics.

5. Optimizing Operations

Challenge: Geothermal plants require precise, near-continuous operation to maintain energy output and avoid costly downtime. This is particularly critical to manage thermal characteristics of the reservoir and geochemical properties of the produced geothermal fluids. Even with skilled operators, unexpected failures and inefficiencies can occur.

AI Opportunity: Advanced monitoring platforms can apply AI to optimize plant operation, predict maintenance needs, optimize use of scaling or corrosion inhibitors, and extend equipment life. EtaPRO's software suite, for example, provides early fault detection and thermal efficiency optimization. Edmonton-based EZ Ops applies AI to manage equipment fleets and prevent failures in oilfield operations. Similar approaches in geothermal can ensure maximum uptime, improve efficiency, and reduce operating costs, further strengthening project economics.

Conclusion

Integrating AI across the geothermal project lifecycle can dramatically reduce risks and costs that have historically limited deployment, while also improving the performance of key project drivers. This includes mapping hidden resources, pinpointing optimal drilling sites, preventing costly equipment failures, fine-tuning reservoir stimulation, and running plant operations.

Leveraging Canada's oil and gas expertise, data assets, and existing drilling infrastructure, these AI tools can accelerate geothermal development, unlock new baseload capacity, and attract private investment. AI tool integration would help create a stronger, more resilient clean energy system that complements variable renewables, enhances energy security, and advances national climate goals.