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Alberta's Geothermal Regulatory Framework

David Helmer[1]*, Danielle Dodd[2]
Alberta Energy Regulator[1]*, Alberta Energy Regulator[2]
email: david.helmer@aer.ca

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INTRODUCTION

Alberta's geothermal sector is attracting attention as the province navigates a complex energy diversification characterized by the need for emissions reduction, economic resilience, and the integration of stable renewable resources into existing energy systems. Geothermal energy offers several advantages relative to other renewable energy technologies. Unlike wind and solar, which are inherently intermittent and require complex implementation strategies to maintain reliability [AESO, 2025], geothermal energy provides a continuous, baseload source of heat and electricity, aligning with Alberta's historical emphasis on dispatchable energy.

Decades of oil and gas development have equipped Alberta with extensive geological knowledge, advanced drilling technology, and an expert workforce [GOA, 2016]. These capabilities position Alberta well to leverage geothermal energy as a complementary resource within its broader energy system.

The Western Canada Sedimentary Basin (WCSB) hosts geological formations with the potential to support geothermal development [Majorowicz & Grasby, 2021; Hedhli *et al.*, 2025]. While these formations do not typically reach the high temperatures observed in other global geothermal regions, they offer a moderate temperature resource well-suited for direct-use heating applications and electricity production. As well, technology advances show greater potential in improving power production from low temperature resources. As the province continually refines its regulatory frameworks, geothermal energy is increasingly recognized as a key contributor to the province's long-term low-carbon strategy [GOA, 2023]. Geothermal energy can supply renewable heat for industrial processes, institutional and commercial buildings, district energy networks, as well as electrical power generation, strengthening Alberta's energy resilience and sustainability.

Geothermal development introduces unique regulatory challenges that differ from conventional oil and gas operations. Geothermal wells require robust wellbore integrity to withstand exposure to chemically aggressive production fluids and cross contamination by wellbore or drilling fluids [Finger & Blankenship, 2010]. Maintaining integrity is essential not only for operational safety but also for environmental protection and long-term liability management.

It is expected that some wells currently licensed for oil, gas or brine-hosted mineral extraction purposes will eventually be converted to and licensed as geothermal wells [USDE, n.d.]. This introduces additional technical and regulatory considerations, including casing integrity, cement performance, gas migration, historical well construction practices, and the long-term liability of geothermal wells converted from existing depleted wells.

In response to these opportunities and challenges, the Alberta Energy Regulator (AER) has implemented a regulatory framework for the development of deep geothermal resources across throughout its development lifecycle. The framework sets minimum regulatory requirements and introduces geothermal specific expectations. Although geothermal development shares many technical similarities and challenges as with conventional oil and gas operations, it also requires tailoring to accommodate differences in geothermal specific risks including induced seismicity, thermal mobilization of elements, and surface deformation [Samuel *et al.*, 2025].

GEOTHERMAL RESOURCES IN ALBERTA

Alberta's geothermal resource base has been characterized in *the Geothermal Atlas of Alberta*, a comprehensive web-based geoscience platform developed by the Alberta Geological Survey (AGS) [Rabbani et al., 2024]. The Atlas aggregates geological, hydrogeological, and geophysical data to provide detailed insights into subsurface temperature distributions, porosity and permeability characteristics, aquifer presence, formation thicknesses, water chemistry, and geothermal resource potential. Its purpose is to serve as a decision-support tool for

industry, researchers, and government guiding geothermal exploration, feasibility assessments, and early-stage development planning.

At the core of the Atlas is a suite of formation-specific geothermal favourability maps for key geological units across the province including the Leduc Formation, the Swan Hills–Slave Point formations, and the Granite Wash. In each case, the Atlas synthesizes subsurface temperature estimates, porosity-thickness maps, aquifer indicators, and geologic structure to score these formations according to their geothermal potential. While the Atlas is not intended to replace site-specific data collection, it provides detailed provincial-scale geothermal mapping.

Additional studies have also characterized geothermal potential in Alberta [Grasby *et al.*, 2012; Majorowicz & Grasby, 2021; Brinsky *et al.*, 2022]. Public reports consistently indicate moderate-temperature resources that increase with depth, with the highest potential located in the northwestern portion of the province. These temperatures may be suitable for commercial heating and, in some cases, power generation applications.

GEOTHERMAL SYSTEMS

The two most common geothermal configurations anticipated for deep geothermal resource development in Alberta are open loop and closed loop systems. Both involve the circulation of fluids for heat extraction at the surface and subsequent injection of cooled fluids into the subsurface for reheating. However, a key regulatory distinction lies in how formation fluids are managed and the implications for environmental protection, public safety, resource conservation, and equity.

Fluids in an open-loop configuration move between the wellbore and the formation as part of the fluid circulation process. Perforations in the casing allow fluids to enter and exit the wellbore through production and injection wells. The produced water is brought to the surface necessitating greater need for careful fluid and potentially gas handling.

Open-loop systems must address challenges associated with the injection of produced-water specifically as it relates to induced seismicity and surface deformation.

These systems also present opportunities for coproduction of geothermal heat with oil and gas or minerals . In such cases, the production of hydrocarbons or minerals inherently includes geothermal heat. This poses unique regulatory considerations around resource ownership, environmental protection, and operational equity.

Closed-loop systems, by contrast, does not involve mass transfer of fluids from the formation into the wellbore. Instead, a working fluid is circulated within the wellbore (or a well doublet) to absorb the heat by conduction through the well casing. To protect non saline groundwater resources, closed loop geothermal wells require surface casing to be completed to the base of groundwater protection, ensuring an additional barrier against accidental release of working fluids into non-saline aquifers.

Enhanced Geothermal Systems (EGS) has the ability to expand geothermal development into formations with sufficient heat but inadequate natural permeability. EGS involves fracture stimulation of the formation to create or enhance permeability, establishing a circulation loop where injected fluid absorbs heat as it passes through the fracture network. From a regulatory perspective, EGS would be licensed as open loop systems as there is direct contact with the formation similar to conventional open loop well systems.

Engineered closed-loop geothermal systems represent an evolutionary aspect for deep geothermal development. These systems access deep subsurface heat without relying on hydrogeological conditions by extending sealed loops into the formations [Think GeoEnergy, n.d.; NREL, n.d.]. Their applicability lies in their broad geographic application and reduced environmental risks from produced water management compared to open-loop or EGS methods. In Alberta, these systems would be regulated as closed loop systems as there is no direct mass transfer through the well casing. However, it is assumed that minor fluid leakage into or from the wellbore may occur as part of normal operations.

BASE OF GROUNDWATER PROTECTION

The Base of Groundwater Protection (BGWP) is an important aspect in Alberta's regulatory management. The BGWP is the best estimate of the depth below ground level where groundwater is anticipated to become saline as defined in the *Water (Ministerial) Regulation* to be groundwater greater than 4000 mg/L of total dissolved solids. At this concentration, groundwater is conservatively assumed to be unsuitable for agricultural or domestic use without significant treatment. The BGWP is set to a maximum depth of 600 m [Lemay, 2008] as a

reasonable and conservative measure since non-saline water wells are rarely completed by non-industrial users at depths greater than 600 m.

The BGWP triggers several regulatory requirements:

- surface casing requirements and groundwater aquifer isolation,
- cementing requirements,
- composition of drilling fluids,
- well completion limitations, and
- Abandonment requirements.

Beyond well construction standards, the BGWP also determines the regulatory jurisdiction for geothermal development. Geothermal wells completed deeper than the BGWP are regulated by the AER under the geothermal regulatory framework, while wells that are completed at or above the BGWP are regulated as a water well by Alberta Environment and Protected Areas (AEPA) [GOA, 2018a]. This depth-based distinction separates the deep geothermal development from the geo-exchange systems which remain under AEPA oversight.

Integrating the BGWP into geothermal regulation provides a clear jurisdictional boundary and aligns geothermal projects with established groundwater protection practices mitigating risks associated with deep geothermal operations.

ALBERTA'S GEOTHERMAL REGULATORY FRAMEWORK

Alberta's geothermal regulatory framework is established through the *Geothermal Resource Development Act* (GRDA), proclaimed in 2021. The Act defines geothermal resources as the natural heat of the earth below the BGWP and grants the AER authority to regulate geothermal wells, facilities, and pipelines.

The *Geothermal Resource Development Rules* (GRDR) operationalize the GRDA by providing detailed requirements for licensing, drilling, well completion, production operations, conversions of existing wells, data reporting, and project closure. These rules are supplemented by *Directive 089: Geothermal Resource Development*, the AER's primary regulatory document outlining application, operation, and closure expectations. In addition, many of the oil and gas focused directives, such as for drilling and completing wells, liability & security management, well servicing operations, emissions and noise are leveraged for deep geothermal resource development.

Geothermal development is integrated into Alberta's existing energy-development application system principally through *Directive 056: Energy Development Applications and Schedules*, which also covers geothermal wells, facilities, and pipelines. The associated *Manual 012: Energy Development Applications* provides instructions for completing applications, submitting technical data, and meeting procedural requirements.

Geothermal development requirements overlap with the specified enactments for environment, land, and water. Approvals may be required under *Environmental Protection and Enhancement Act* (EPEA), the *Public Lands Act*, and the *Water Act*, depending on project specifics. For example, geothermal power plants may require an approval under EPEA where the power plant exceeds 1 megawatt peak power capacity or a public lands disposition if the surface infrastructure is located on crown land under administration by the province.

GEOTHERMAL POWER PLANT CONFIGURATION AND ALBERTA'S RESOURCE FIT

Power generation from geothermal heat primarily falls into one of three plant configurations: dry steam, flash steam, and binary-cycle systems. Alberta's geothermal resource profile (that is, moderate temperatures having an upward temperature ranging from 80 to 155°C) tends to favor the latter [Zarrouk & Moon, 2014]. There is higher temperature potential at greater depths (i.e., in the order of 4 to 6 km, but operations are more complex).

Dry steam plants require vapor-dominated reservoirs with temperatures exceeding 200°C. The steam is used to directly turn generator turbines. Flash steam plants require high-temperature, liquid-dominated reservoirs above approximately 170 to 180°C. The high pressure hot water is converted to steam (in a flash tank) to drive the generator turbines. The steam is condensed to water to reinject into the formation [USDE, n.d.; CEC, n.d.]. The geothermal conditions favorable for dry steam or flash steam power generation are not characteristic of the WCSB [Majorowicz & Grasby, 2021]. As a result, both dry and flash steam configurations are considered unlikely for Alberta.

By contrast, binary-cycle power plants are designed to operate with moderate-temperature geothermal fluids. These systems transfer heat from geothermal produced water to a secondary working fluid with a lower boiling point than that of the produced water temperature and flashed. The vapour from the secondary fluid turns the turbine enabling electricity generation even at relatively low resource temperatures. While binary systems exhibit lower conversion efficiencies, their applicability to moderate temperatures seen in Alberta makes binary-cycle plants a more likely option [Sanyal & Butler, (2010); Hirschmiller (2020)].

SECURITY AND LIABILITY MANAGEMENT FOR GEOTHERMAL DEVELOPMENT

A foundational principle of the liability management framework is that the licensee is responsible for all lifecycle obligations related to energy development, from the early stages of well preparation to the final stages of closure and reclamation. Directive 089 and Manual 012 provides the geothermal-specific structure around security and liability management, while *Directive 088: Licensee Life-Cycle Management*, *Directive 068: Security Deposits*, *Directive 011: Estimated Liability*, and *Directive 001: Requirements for Site-Specific Liability* provide the broader regulatory tools that determine how liability is estimated, assessed, and secured.

At the core of the liability management framework is the requirement for proponents to provide a full estimate for geothermal wells and facilities. Manual 012 specifies how applicants are to submit a detailed liability estimate using the AER's F102 form: *Liability Assessment for Brine-Hosted Mineral or Geothermal Wells*, supported by the cost methodologies in Directive 011 and, where necessary, site-specific liability assessments under Directive 001. These estimates cover suspension, abandonment, remediation, reclamation, and the cost of reasonable care and measures that may be required at any time during or after operations.

Security deposits are a key tool to ensure closure and environmental obligations are met without burdening the public. Directive 089, or more specifically the GRDR, authorizes the AER to require security at any point in the lifecycle, including at application, amendment, conversion, or licence transfer. Manual 012 sets out the interim geothermal security framework, under which the AER may require 50 to 100 percent of the total liability estimate upfront, with remaining amount up to 100 percent collected on a schedule as risk or liability changes.

Security must be posted in accordance with Directive 068, which governs acceptable forms and the conditions for holding and returning security.

Transfers trigger a reassessment of both parties' (that is, the transferor and the transferee) liabilities and may require new or increased security.

GEOTHERMAL WASTE MANAGEMENT

Waste generated by geothermal development is broadly comparable to that produced by the oil and gas sector. Common waste streams include drilling waste, flowback fluids, and produced water which may contain elevated dissolved solids, gases or naturally occurring radioactive materials (NORMs). Waste from heat transfer fluids, scaling residues, and filters or sorbents is also possible depending on the facility configuration.

Waste generated during the development of geothermal resources is managed within the established waste management framework used for oil, gas, and pipelines. Waste management requirements are encapsulated in Directive 089 setting the overarching expectations for geothermal operations, while *Directive 058: Oilfield Waste Management Requirements for the Upstream Oil and Gas Industry* provides the detailed requirements governing waste management including classification, handling, storage, treatment and disposal. The waste generated is, therefore an "oilfield waste" by definition and managed as such.

Aligning geothermal waste management with the existing oil and gas framework is a deliberate regulatory strategy. This approach leverages proven management provisions for environmental protection and operational safety, avoiding the need to create a parallel waste management regime specifically for geothermal development.

GEOTHERMAL SUBSURFACE RIGHTS

Under the GRDA, subsurface rights to the geothermal heat must be secured before the license can be issued. Administration of the subsurface rights is managed by the Government of Alberta in the department of Alberta Energy and Minerals. The *Geothermal Resource Tenure Regulation* sets out the administration for the non-exclusive right to explore for, develop and recover geothermal resources. A geothermal lease is required for all stand-alone geothermal operation to develop the natural heat of the earth occurring at depths below the BGWP.

The rights to the geothermal heat are also part of the mineral agreements granted by Alberta Energy and Minerals. An agreement granting rights to win, work, and recover a mineral is deemed to include the right to explore for, develop and recover geothermal resources. The specific mineral agreements that include geothermal are outlined in Information Letter 2022-02 issued by Alberta Energy and Minerals [GOA, 2018b].

Closed loop geothermal wells do not include a mass transfer of formation fluids and, as such, can only be considered solely for the purpose of geothermal development. These well configurations require a stand-alone geothermal subsurface right in order to apply for and obtain a well or facility licence even when the project proponent holds the appropriate mineral rights where geothermal is deemed to be included.

INDUCED SEISMICITY

Induced seismicity refers to seismic events caused by human activities such as fluid injection, wastewater disposal, hydraulic fracturing operations and geothermal energy extraction [CAPP, 2022; CAPP, 2024]. Seismic events can threaten structures, underground infrastructure, and wellbore integrity, even if the probability of serious damage remains low. Alberta Geological Survey highlights recent induced events near Fox Creek, Cardston, and Rocky Mountain House, illustrating that relatively shallow, moderate-magnitude earthquakes can be widely felt and draw public attention [AGS, n.d.]. In Alberta, most induced earthquakes have so far been linked to oil and gas disposal wells but the same physical mechanisms are directly relevant to emerging geothermal projects that will also inject and circulate fluids at depth.

Alberta's Western Canada Sedimentary Basin contains critically stressed faults, and studies note that the province has already experienced documented induced seismic events, motivating cautious design of geothermal developments [Yaghoubi *et al.*, 2024].

Under Directive 089, Licence applicants are expected to assess for the possibility for induced seismicity resulting from their project and apply the "stoplight" protocol as appropriate.

SURFACE DEFORMATION

Surface deformation in geothermal developments refers to subsidence, uplift, or lateral ground movement caused by changes in pressure and temperature within the reservoir during fluid production and reinjection. Fluid withdrawal reduces pore pressure and leads to reservoir compaction; and, if not balanced by recharge or reinjection, this can create subsidence bowls and differential settlement that damage wells, pipelines, roads, and other infrastructure. Case studies such as the Wairakei field in New Zealand document vertical displacements and associated well and pipeline damage, illustrating that uncontrolled deformation can shorten field life and increase costs [Hawuory, 2022]. Directive 089 explicitly requires applicants to assess "surface deformation (e.g., ground subsidence and heave)" as part of hazard identification. Proponents must demonstrate how design, operating strategies, and reinjection plans will mitigate deformation risks and outline monitoring programs to manage these hazards throughout the project lifecycle.

THERMAL MOBILIZATION

Thermal mobilization of elements in groundwater is a geochemical concern in geothermal resource development. When water aquifers surrounding the geothermal well are heated, the groundwater may alter in the solubility of constituents including trace elements and potentially affecting groundwater quality [GOA, 2018b].

The AER addresses these risks in its requirements for thermal in situ oil sands operations provided in the document *Assessment of Thermally-Mobilized Constituents in Groundwater for Thermal In Situ Operations*. This approach provides structure for evaluating how heating groundwater around the wellbore can mobilize substances such as arsenic, iron, and other trace metals. Although written for thermal bitumen projects, the same geochemical principles apply to geothermal developments where reservoir temperatures may increase due to circulation of high-temperature fluids or heat extraction processes. The directive emphasizes the need to characterize baseline groundwater conditions, predict thermally driven geochemical changes, and monitor potential migration pathways. This is an approach directly transferable to geothermal risk assessment.

SUMMARY

Geothermal energy represents a promising complement to Alberta's resource development landscape, offering baseload heat and potential electricity generation. Alberta's geological context is characterized by moderate temperature sedimentary formations potentially supporting a range of geothermal applications using district heating and binary-cycle power plants. The direct use of geothermal heat such as for district heating, industrial

processes, and commercial or institutional buildings may represent a significant share of the market opportunity for geothermal energy. While there is some potential for power production from known resources, advancements in technology could significantly expand this opportunity. Regardless, the province's extensive subsurface dataset, combined with the Geothermal Atlas of Alberta, provides a strong foundation for exploration and feasibility assessment.

Regulatory frameworks administered by the AER provide clear requirements for geothermal licensing, operations, liability, environmental protection and public safety. The BGWP plays a central role in defining jurisdiction and increasing groundwater protection requirements for the deep geothermal wells. While geothermal regulation borrows heavily from oil and gas systems, it also addresses unique geothermal risks and operational requirements specific to geothermal resource development.

As technologies mature, costs decline, and regulatory experience grows, Alberta is well positioned to grow its geothermal sector, supporting energy diversification, emissions reduction, and long-term sustainability.

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