geoconvention
Calgary • Canada • May 12-14 2025

Geothermal systems and thermal energy extraction: A framework to differentiate geothermal plays and reservoirs from open- and closed-loop heat exchangers.

Graham J. Banks [1, 2] and Philip J. Ball[1].

[1]Geothermal Energy Advisors LLC, [2]Route To Reserves Consulting Inc.

Summary

The set of geological components that naturally create a thermal energy anomaly in the Earth's crust is different to a borehole-based heat exchanger to extract thermal energy from rocks. Yet both are termed, "geothermal system" and often assumed to be the same entity. This creates confusion and misinterpretation when discussing a project. Adding to this issue, many geothermal documents and technical reports contain inconsistent and unclear geothermal terms, i.e. vocabulary specific to organizations and chosen for personal preference. To remedy this and bring a consistent approach to evaluating geothermal projects, this document's authors will present a systematic classification scheme and accurate vocabulary (e.g. Figures 1 and 2), so the geothermal sector can:

(a) Consistently evaluate geothermal systems in sedimentary, metamorphic and igneous rock, and their constituent plays and resources, within an objective framework.

(b) Classify and name thermal energy extraction techniques more clearly than the currently ambiguous and contradicting parlance.

These will be shown in the accompanying presentation using three Canada geothermal projects.

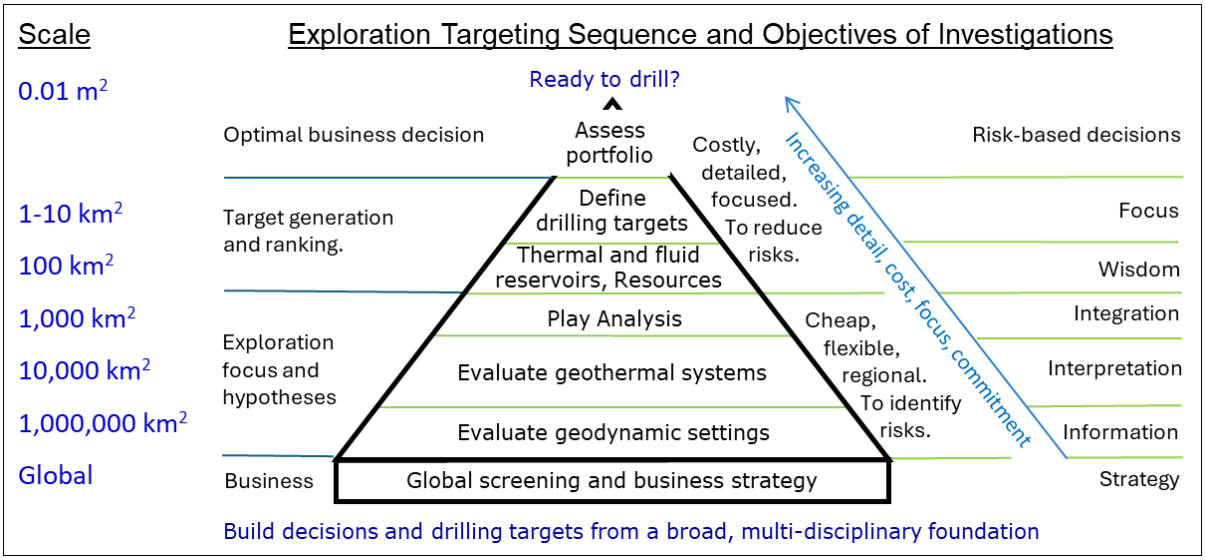

Figure 1. A summary of the geothermal Play-Based Exploration Process. It displays the progress, purposes and goals of each geothermal exploration project stage before geothermal reservoir testing and extraction technique design (Modified after Ball et al., 2025).

Analysis stage	Project name, location. Organization.	The DEEP Project, Saskatchewan DEEP Earth Energy Production Corp.	Eavor-Lite™ Demonstration Project, Alberta Eavor Technologies Inc.	Petroleum sector project stage (analogue)
	Commodity.	Thermal energy in water and rock.		Thermal energy in petroleum in rock or sediment.
	Natural entities that occur independently of human activity			
1st	Geodynamic setting.	Inactive, intracratonic, sedimentary basin.	Inactive, palaeo-foreland basin.	Petroleum province and basin.
2nd	Geothermal system.	Deep, medium enthalpy, hydrothermal system ("120˚C brine from 3.5 km deep permeable sandstone").	Deep, low enthalpy, hydrothermal system ("75˚C formation temperature, 2.4 km deep, sandstone").	Petroleum system.
3rd	Geothermal play and its 'regional' reservoir.	Sedimentary rock hydrothermal play. Heat transfer by conduction.	Sedimentary rock hydrothermal play. Heat transfer by conduction.	Petroleum play and its 'regional reservoir', fields, discoveries, prospects and exploration concepts.
4th	Thermal energy prospect, thermal energy reservoir and fluid reservoir.	Hot, sedimentary aquifer.	Hot, sedimentary aquifer.	Petroleum prospect and its 'local' reservoir.
	Engineering and economic entities.			
5th	Stage of project exploration / development.	Pilot project. Wells flowed water. Artificially enhanced the reservoir.	Full-scale prototype of a multilateral closed-loop heat exchanger. >4 years in operation. No power generation.	Stage of project exploration / development.
5th	Category of thermal energy Resource/Reserves.	"Geothermal resource able to sustain thermal energy production".	None reported.	Category of petroleum Resource/ Reserves.
5th	Thermal energy extraction technique.	Engineered, open-loop, heat exchanger (hydraulic fracturing).	Engineered, closed-loop, heat exchanger (U-shaped well, uncased completion).	Petroleum extraction technique.

Figure 2. Two of Canada's geothermal projects with their constituent parts categorized in our geological and engineering project management process. It displays the optimal sequence of geothermal project analyses. It clearly differentiates geothermal systems–and their constituent plays, prospects, reservoirs and Resources–from energy extraction techniques (Modified after Ball et al., 2025). Information about the geothermal projects is from public domain documents (EAVOR Technologies Inc., online; DEEP Earth Energy Production Corp., online).

Observations

Geothermal energy is gaining much attention and investment from organizations interested in low-carbon energy sources. Unfortunately, geothermal scientists, books, peer-reviewed publications and organizations display considerable variety and personal preferences of geothermal vocabulary. Geothermal entities are often named and described with insufficient scientific accuracy or consistency. Real examples include:

- Some scientists deem a closed loop wellbore to be a geothermal system, whilst others deem it a heat exchanger to extract thermal energy out of a geothermal system.
- One company classifies a closed loop wellbore as an, "Advanced Geothermal System". Another states, "Advanced Geothermal System" for a project with a contemporary turbine atop a hydrothermal production well.

- In some documents, “Advanced Geothermal System” is an alternative to “Engineered Geothermal System”; In others it is a category of “Engineered Geothermal System”.
- Some geologists regard a “Hot sedimentary Aquifer” to be a geothermal system’; To others it is only the aquifer component of a geothermal system.
- One geologist defines a geothermal energy source as “a volume of underground rocks, sediments and pore fluids containing thermal energy”, whilst others deem that to be the definition of a geothermal reservoir (i.e. aquifer).
- Some organizations regard Superhot Rock geothermal as a technology, even though it is a type of geothermal play.

This variety of applications for vague terms reduces the ability to compare, risk and explain geothermal exploration and production techniques between organizations. In contrast, the petroleum sector–that also extracts energy-dense fluid from deep rocks–has clearly defined vocabulary and systematic project management workflows to categorize: projects, geology, Resources, Reserves and engineering techniques e.g. the standard practice of petroleum ‘Play-Based Exploration’ and the Petroleum Resource Management System (Society for Petroleum Engineers, 2018) The benefits returned to petroleum explorers, auditors, investors and petroleum users are evident.

Results and Workflow

To counter the issues stated in the Observations section, this document’s authors created a consistent approach to evaluate geothermal projects. They have adapted petroleum ‘Play-Based Exploration’ and parts of the Petroleum Resource Management System (Society for Petroleum Engineers, 2018) for geothermal evaluations, and improved the Geothermal Energy Glossary (Banks and Ball, 2023) to:

(a) Replace this variety of often contradicting geothermal terms and entities with a systematic framework that organizes geothermal systems and their constituent parts.
(b) Differentiate geological systems from engineered heat exchange techniques.
(c) Have a workflow to progress a geothermal project through its scale-based and risk-based sequence of analyses and decisions (Figures 1 and 2).

They define each geothermal system as a naturally occurring rock volume that may be several cubic kilometres in scale. Its geological components are: thermal energy source, fluid source, thermal energy flux, thermal energy reservoir, fluid reservoir, thermal insulating cap, and fluid topseal. These components may span igneous, metamorphic, sedimentary and fault rock types. Subdivisions of the all-encompassing “geothermal” term include petrothermal system if it naturally has minimal geofluid, and hydrothermal system if it naturally has notable volumes of geofluid. There may be several geothermal systems in a geological province/basin, and they may overlap or stack geospatially, as petroleum systems do. The economic constituents of each geothermal system are its plays, leads, prospects, discoveries, Resources, Reserves and fields (Figure 2).
Conversely, “Engineered/Enhanced Geothermal System” and “Advanced Geothermal System” are subjective labels for fluid-containing heat exchangers that are constructed to enhance or create the fluid reservoir component of a geothermal system. This well field is typically ≥ 1 orders of magnitude smaller than the host geothermal system. More accurate terms are engineered, closed loop, heat exchanger and engineered, open loop heat exchanger: to differentiate them from geothermal systems and natural, open loop, hydrothermal circuit.
The thermal energy reservoir volume engineered into a heat exchanger is more accurately termed Engineered Hydrothermal Reservoir (if it already had geological fluids but insufficient natural

fracture network) or Engineered Petrothermal Reservoir (if it had insufficient geological fluid +/- fracture network naturally). The noun in both phrases should be reservoir rather than system because the engineering solutions do not try to modify the thermal energy source, insulating cap or fluid topseal. In a related manner, the geothermal adjectives, ”Conventional” and “Unconventional”–that are used differently by different companies–are best replaced to qualify geothermal reservoirs as either hydrothermal (hot water) or petrothermal (hot rock) reservoirs/aquifers. “Advanced geothermal” and “next generation geothermal” phrases are not recommended because they have a temporal connotation and may need replacing when those techniques become commonplace.

Conclusions

The onus is on geothermal practitioners to accurately distinguish and explain geological systems and energy extraction techniques in a systematic and objective way: to economists, investors, petroleum scientists working on geothermal projects, policymakers, journalists and the public. This will improve the ability for everyone to compare, risk and valuate geothermal projects.
This document’s authors bring a framework to consistently define, classify and evaluate geothermal projects, geothermal systems and reservoir heat exchangers. This framework is a geothermal adaptation of the petroleum ‘Play-Based Exploration’, some parts of the Petroleum Resource Management System, and an advancement of the Geothermal Energy Glossary.
The understanding of geothermal exploration and geological risks may improve when geothermal projects and energy extraction techniques are described and assessed with a consistent and systematic workflow across organisations and geological provinces.

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