The Spectrum of Geothermal Technologies - Updated

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Summary

For the general public there has long been confusion between shallow "earth battery" geothermal systems and deep "naturally occurring, endogenous heat" extraction geothermal systems, as both are referred to as "geothermal" systems, despite having very different characteristics. This confusion has implications for regulators, consumers, investors and grant agencies. In reality, the "geoenergy" spectrum is exactly that – a spectrum of technologies. Capturing heat from the air and artificially creating a heat reservoir in the subsurface at shallow depths (<300m) using a ground source heat pump is at one end of the spectrum. This technology is suitable for single family dwellings. The other extreme are high temperature systems that convert earth's endogenous heat energy into electricity. The middle ground uses technology like Organic Rankin Cycle plants and heat exchangers to extract all usable heat out of the deep subsurface and put it to useful work. An additional complexity is heat storage technologies using industrial waste heat looking to store that heat in the shallow (or deep) subsurface. Continuing to aggregate low temperature, ground source heat pump systems and heat storage developments into the larger "geothermal" endogenous heat basket is leading to negative consequences for both shallow and deep geothermal investors, regulators, and the public.

Theory / Method / Workflow

By way of graphics (Figure 1) and a simple matrix (Table 1), this paper outlines the major differences and similarities between the various geothermal technologies. The intent is to remove uncertainty from the minds of regulators, developers, consumers and grant agencies. As well as provide a clear narrative for investors and regulators.

Ground source heat pump and shallow subsurface systems are characterized by using the ground (earth) to store heat. They artificially heat the ground by recovering heat in the summer months and putting it underground for storage, and then retrieving the stored heat when required. Heat storage (and retrieval) is through mechanical systems (ground source heat pumps for example) and requires external energy input. Long term sustainability is through balancing the heat input with the energy usage. These systems can also use naturally stored heat, such as found in unfrozen surface water and ground water. Again, sustainability is achieved by balancing inputs with outputs. In this paper these shallow systems will be referred to as "geoexchange" systems – i.e., capturing heat from the air, and storing it in the subsurface; exchanging heat seasonally

Geothermal, on the other hand uses naturally regenerating heat and residual endogenous heat to achieve energy balance. The "geo" refers to the earth and the "thermal" to this naturally occurring, non-solar, source of heat emanating from the deep earth. There is no artificial augmentation of the heat. The systems are sustainable and renewable through resource management rather than reliant on climate and artificial storage.

The fundamental differences between geoexchange and geothermal systems has many implications. Although investors are one specific group, there are specific challenges for regulators. This group is charged with the protection of the health and safety of their constituents, so they need to understand the risk of the two types of systems and what actually needs to be regulated. When a geoenergy-system development proposal lands on the desk of a government official, there needs to be a clear pathway to licensing and permitting based on the risk profile of the development and long-term implications for the environment. We believe that the job of the regulators would be easier if a consistent language was used surrounding geoenergy-system developments. In addition, those jurisdictions without geothermal regulations or groundwater legislations would be better informed by a clear understanding of the differences between the two types of geoenergy-systems.

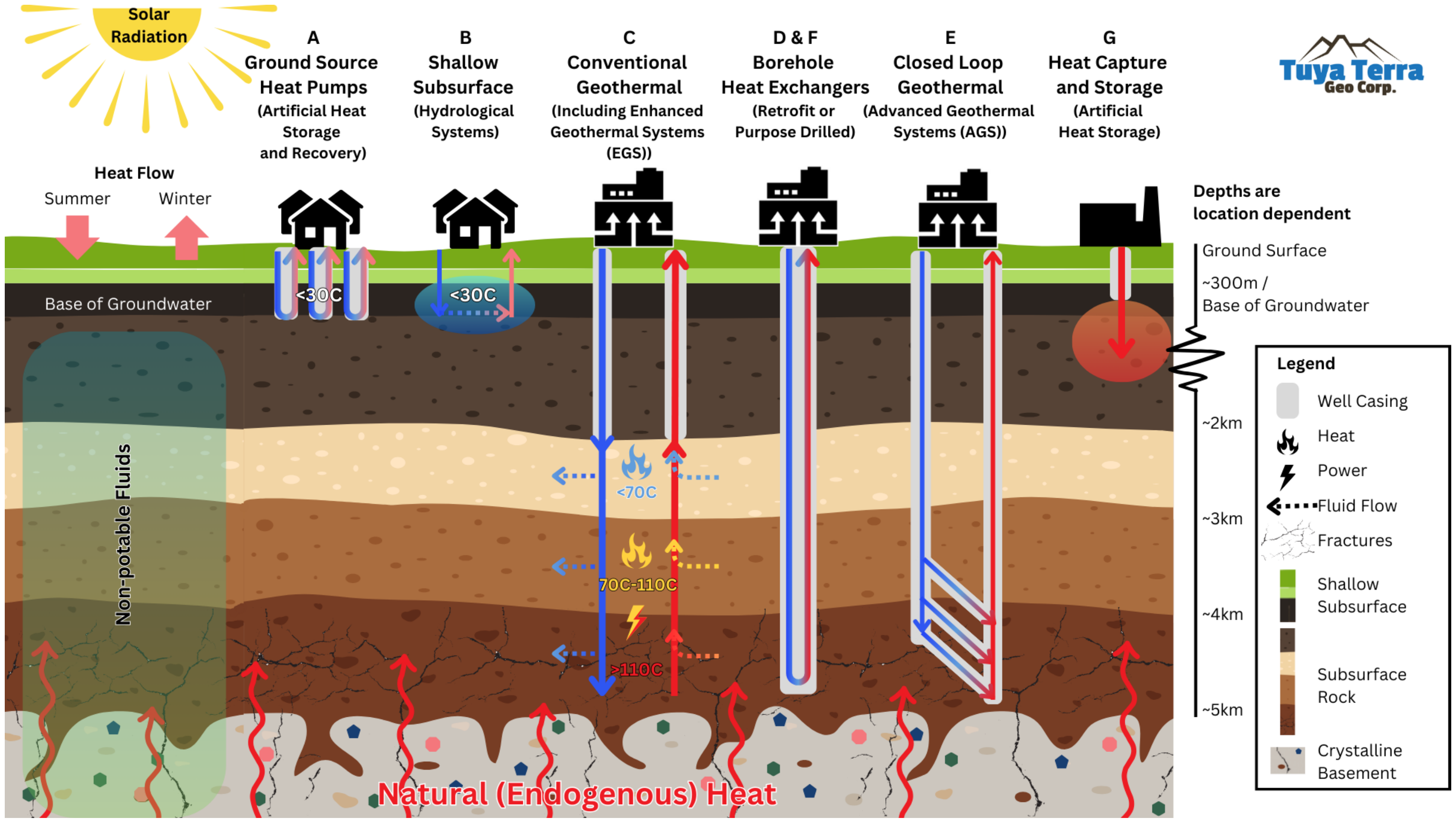

Figure 1: A graphical representation of the spectrum of geothermal technologies. Type A and B (the shallow geothermal systems) are installed above the base of groundwater and typically operate below 30°C. These systems can be closed (A) or open (B) to the subsurface, but both capture heat during the summer (for example from solar radiation) and store that heat in the subsurface. During the winter, that heat is then harvested from the subsurface and used in heating systems. The sustainability of shallow geothermal systems is dependent on a balance between heat stored and heat extracted. Type C, D, E and F (the deep geothermal systems) are installed below the base of groundwater in zones with non-potable fluids and typically operate above 70°C. These systems can be closed (D, E and F) or open (C) to the subsurface, but all use the naturally occurring endogenous heat that is produced by the earth. These systems do not require additional heat input from the earth surface but can be enhanced (stimulated) at depth to increase fluid flow and heat transfer. The final type classified here is type G, heat capture and storage. This system captures heat at the surface (typically man-made waste heat) and stores it in the subsurface (either shallow or deep depending on the location).

Table 1: Simplified Geoexchange® - Geothermal Schematic including waste heat storage using boreholes.

CLASS	GEOEXCHANGE®	GEOEXCHANGE®	GEOTHERMAL	GEOTHERMAL	GEOTHERMAL	GEOTHERMAL	GEOTHERMAL	GEOTHERMAL/GEOEXCHANGE	Waste Heat capture and storage
Type	**(A) Geoexchange® (Ground Source Heat Pumps)**	**(B) Shallow Subsurface**	**(C-1) Conventional Low T**	**(C-2) Conventional Geothermal**	**(C-3) Conventional Geothermal**	**(D) AGS Closed Loop* (e.g., Borehole Heat Exchanger^)**	**(E) AGS Conductive Heat Transfer into the borehole**	**(F) Retrofit Downhole Heat Exchanger^**	**(G) Underground Waste Heat storage (UTES)**
1. Depth (typical)	<300 m; within the Groundwater table; permafrost and subsurface soil considerations.	within the Groundwater table	600 m to ~5 km	>1.5 km to ~5 km	>1.5km to ~5 km	>300 m to ~6 km	>300 m to ~6 km	any	Depends on technology
2. Temperature	Up to 30°C	Up to 30°C	30°C to 70°C	70°C – 170°C (sed basin); higher in other geological environments	170°C and above (including super critical systems)	>30°C	>30	>30°C	Depends on technology (molten salt storage 200 – 500°C
3. Exploration Risk	subsurface soil characteristics and permafrost must be known.	not applicable in areas with ground ice; need to understand the groundwater systems	Low (dependent on existing geoscience data)	Moderate -High (dependent existing geoscience data)	Moderate -High (dependent existing geoscience data)	Moderate -High (dependent existing geoscience data)	Moderate -High (dependent existing geoscience data)	n/a	subsurface thermal characteristics required
4. Capital cost (CAPEX)	Low (relative to the other types of systems)	Low – moderate	Moderate	Moderate – high	High	Moderate – High	Moderate – High	Low (installed in pre-existing wellbores)	Low (relative to the other types of systems); but depends on technology
5. Well bore size	Tiny (<3")	Small	Moderate to Large	Large	Large	Small – Moderate	Small – Moderate	Well bore dependent	Depends on technology
6. Multiple well bores	Requires significant drilling depending on heat storage characteristics required; total drilling lengths (combined lengths) could be several km.	n/a	Requires a doublet (production well and injection well)	Requires a doublet (production well and injection well)	May not require injection; fields without injection have experienced resource decline.	Various configuration; pipe-in-pipe, U-shaped and multilaterals.	Various configuration; pipe-in-pipe, U-shaped and multilaterals.	n/a	Requires significant drilling depending on heat storage characteristics required; total drilling lengths (combined lengths) could be several km.

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7. Drilling rig capacity	Very small (capable of drilling to 300 m with light casing)	Small or not required if surface or mine source	Large	Large	Large	Moderate – Large	Moderate – Large	n/a	Dependent on depth of storage
8. Well control risk (regulations)	Artesian flow to surface	Artesian flow to surface	Yes (artesian flow; hydrocarbons; sour gas)	Yes (artesian flow; hydrocarbons; sour gas; steam/flash)	Yes(artesian flow; hydrocarbons; sour gas; steam/flash)	Yes (artesian flow; hydrocarbons; sour gas; steam/flash)	(artesian flow; hydrocarbons; sour gas; steam/flash)	n/a	Artesian flow – depending on depth
9. Engineered well design for drilling below groundwater	Should be compliant with water well regulations.	Compliant with water well regulations or not required for surface or mine source	Yes	Yes	Yes	Yes	yes	n/a	Dependent on depth
10. Power Generation	no	no	No (with current technology)	Yes; limited in 70°C – 110°C range	Yes	Project dependent	Project dependent	Project dependent	Project dependent
11. Multi commodity	No	No	Yes	Yes	Yes	No	No	No	No
12. Carbon Sequestration and/or storage	No	No	Yes	Yes	Yes	No	No	No	No
13. Open loop⁺	No	Yes - Groundwater or surface water	Yes – open to formation	Yes – open to formation	Yes – open to formation	No	No	n/a	Dependent on technology
14. Closed loop	Yes	No	Possible; convert to Type D or E	Possible; convert to Type D or E	Possible; convert to Type D or E	Yes (closed to formation)	Yes (closed to formation)	n/a	Dependent on technology
15. Heat pumps	Yes	Yes	No	No	No	No	No	No	Dependent on technology
16. Heat exchanger^	No	No	Yes	Yes (cascade off of ORC) as secondary heat recovery; heat exchanger for direct use	Yes (cascade off of Flash) ORC and heat exchanger for direct use	Yes	Yes	Yes	Dependent on technology
17. Enhanced permeability	No	No	Possible	Possible	Possible	Possible	Possible	n/a	No
18. Down hole pumps	No	No	Yes	Yes (line shaft/ESP)	No (free flow)	No (thermosyphon)	Possible	Project dependent	No

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19. Resource degradation	No; heat/cooling balanced by external inputs	No; heat/cooling balanced by external inputs	Yes; ameliorated by good reservoir management	Yes; ameliorated by good reservoir management	Yes; ameliorated by good reservoir management	Yes; resource management required	Yes; resource management required	Yes; resource management required	Balance of in/out thermal storage
20. Operating costs (OPEX)	Low	Low	Low	Mod	Low	Unknown	unknown	Low	unknown
21. Corrosion	No	No	Possible	Possible	Possible	Possible#	Possible#	Possible#	Dependent on technology
22. Scaling	No	No	Possible	Possible	Possible	Possible#	Possible#	Possible#	Dependent on technology
23. Working fluid	Propylene Glycol or Ethanol or proprietary	Formation/groundwater or Propylene Glycol or Ethanol or proprietary	Formation fluid	Formation fluid	Formation fluid/steam	Proprietary fluid	Proprietary fluid	Formation fluid and proprietary fluid	Dependent on technology
24. Longevity	20-30 years	20 years	More than 50 years	More than 50 years	More than 50 years	Unknown (TBD)	Unknown (TBD)	Unknown (TBD)	Unknown (TBD)
25. Environmental footprint	Very small	Very small	Small	Small	Small	Small	Small	n/a; dependent on well-bore used.	Very small (?)
26. Surface Spatial Requirements	Very small&	Very small	Small	Small	Small	Small	Small	n/a; dependent on well-bore used	Very small
27. Induced seismicity	No	No	Possible (due to injection and rock mass cooling)	Possible (due to injection and rock mass cooling)	Possible (due to injection and rock mass cooling)	Possible (due to rock mass cooling)	Possible (due to rock mass cooling)	Possible (due to rock mass cooling)	Possible (due to rock mass cooling) for deep storage
28. EGS (engineer/enhanced)%	No	No	Yes (deep low temperature systems in **crystalline rock** require EGS)	Yes; rock mass stimulation to increase flow if required	Yes; rock mass stimulation to increase flow if required	Yes (deep low temperature systems in crystalline rock require EGS) to increase flow around tubing	Yes to increase convective heat flow around the well bore	n/a; well bore already drilled	No
29. Permafrost considerations	If there is ice content in the subsurface melting it must be avoided or mitigated due to ground subsidence; subsurface soil	Can't be used with frozen water	Need surface casing to insulate well bore.	Need surface casing to insulate well bore.	Need surface casing to insulate well bore.	Need surface casing to insulate well bore.	Need surface casing to insulate well bore.	Need surface casing to insulate well bore.	For shallow systems, If there is ice content in the subsurface melting it must be avoided or mitigated due to ground subsidence; subsurface soil

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	conditions (granularity)								conditions (granularity); need surface casing to insulate well bore.
30. Surface ground conditions	Built in such as way as to prevent a “hot spot” or thermal anomaly (e.g. growth of invasive species)	n/a	Protection from surface degradation	Protection from surface degradation	Protection from surface degradation	Protection from surface degradation	Protection from surface degradation	n/a	Built in such as way as to prevent a “hot spot” or thermal anomaly (e.g. growth of invasive species)
31. Ground water protection	Yes; ground water contamination	Yes; ground water contamination	Yes, with casing program and drilling program	Yes, with casing program and drilling program	Yes, with casing program and drilling program	Yes, with casing program and drilling program	Yes, with casing program and drilling program	Need to demonstrate that the well bore still has adequate groundwater protection (demonstrate casing and cement integrity)	Yes, with casing program and drilling program

Reference to a specific company does not indicate endorsement of their technology; it is for reference/information only.

* Closed loop (Type D and E): Purpose drilled wellbores lined and using a high heat capacity fluid for heat recovery (e.g., Eavor~) or a downhole heat exchanger (e.g., CeraPhi and Green Fire Energy). IRENA has recently defined “AGS” as systems that use conductive heat transfer into the well bore and the well bore is isolated from the formation and uses a secondary fluid to transport heat to the surface.
€ excludes well deepening and or changes to the well bore/completion (“Change of Purpose” is still required); if deepening or changes would need to be regulated dependent on the depth and size and rights to the zone as per “C Type” developments. Downhole logging and installation of well bore plugs are assumed and would be permissible.
^ Downhole heat exchangers can be installed in wells that do not have sufficient flow to be commercial, they are recovery systems (e.g., CeraPhi~; Green Fire Energy) or are used in cases where thermal energy is being utilized at shallower depths and lower temperatures (but higher than possible with geoexchange® systems).
+ “Open loop” are systems that are open to the formation. Well completions can be “barefoot” or use perforated casing or slotted liner.
# Possible corrosion and/or scaling on the exterior of the pipe/ well bore and/or heat exchanger if applicable.
& Horizontal closed loop systems can have a large footprint
% EGS = Enhanced (or Engineered) Geothermal Systems – A Geothermal reservoir that has had permeability and porosity enhanced via completions methods (cold water infusion; fracking, Terralog “slow and easy”, acid dosing, etc.)
(12) Carbon sequestration would be dependent on regulations surrounding carbon storage and capture

Geothermal Classifications

Shallow and deep geothermal systems as outlined, have been broken down into classes based on their attributes. These attributes are outlined in Table 1. Shallow systems have been subdivided into two classes (A) Ground source heat pumps and (B) Shallow subsurface systems which still require heat pumps, but where the working fluid may be groundwater or surface water. Geothermal systems are divided into four classes (C) Conventional geothermal, (D and F) Advanced Geothermal Systems (AGS) closed loop deep borehole heat exchanger and Retrofit downhole heat exchangers, and (E) AGS closed loop conductive heat transfer. The final classification is heat capture and storage (G). These classifications are defined below:

(A) <u>GeoExchange® (Ground Source Heat Pumps)</u>

Also known as Geothermal Heating and Cooling (GHS), Shallow Borehole Heat Exchangers and Earth Coupled Heat Pumps (ECHP). Heating and cooling, with the cooling cycle being an integral part of recharging the system through heat extraction and storage (heat pump). These systems utilize shallow, purpose drilled, narrow wells with heat exchanger tubing installed, circulating a working fluid. They also require heat pumps. These systems can be used to cool and to heat; but they cannot (with current technology) generate power. Systems can operate as warm as 32C, and as cold as -1C when transferring heat to/from the ground (DeWeerd 2021).

(B) <u>Shallow Subsurface (ground water) or surface water</u>

Shallow drilled wells within groundwater (or a large body of surface water) and are open loop using formation water (typically groundwater because the systems are shallow) as the working fluid. These systems can be used to heat or cool; but do not generate power. This system works via convecting formation/groundwater water and, depending on the temperatures and the cooling and heating requirements, may require additional auxiliary equipment. Other examples of these types of systems are systems installed in flooded mine workings such as the Springhill, Nova Scotia installation (Jessop et al. 1995).

(C) <u>Conventional Geothermal</u>

Large wellbore, deep, purpose drilled wells for power generation and/or heat recovery. The systems are applicable to a wide variety of geological settings where earth's naturally occurring endogenous heat can be recovered and utilized. However, they need high permeabilities and large inter-formational fluid volumes to be commercially successful. Conventional geothermal has been further subdivided into three sub-classes based on temperature and regulatory considerations.

1. C1 Can be used to heat or cool (cooling through heat pump (refrigeration) technology). Wellbore is open to the formation and uses formation fluid as the working fluid. These systems operate above the maximum temperature of GeoExchange® systems (30 °C) to the lower limit of electrical generation (70 °C) (using currently available technology).
2. C2 Can be used to heat or cool (through heat pump (refrigeration) technology) and generate power. At temperatures between 70 °C and 110 °C heat extracted from formation fluids can be used for electrical generation, but at low efficiencies; typical usage in this temperature range is direct-use applications. In the temperature range between 110 °C

and 170 °C binary electrical generation is possible in addition to a large volume of heat that can be recovered for direct use applications. Binary electrical generation is typically using Organic Rankin Cycle (ORC) technology.

3. C3 High enthalpy systems >170C (flash systems). These systems typically utilize flash technology but are increasingly using ORC units (Eyerer et al. 2021). Significant quantities of thermal energy are available for direct-use applications.

(D) AGS Closed Loop (Deep Borehole Heat Exchanger)

Purpose drilled wells that are isolated from the formation and use proprietary fluid circulated in pipes inside the well casing. They can be used to heat or cool and generate power. The system works via conduction or convection of heat from the surrounding rock mass into the well bore (Van Horn et al. 2020)

(E) AGS Closed Loop (Conductive Heat Transfer)

Purpose drilled wells that are isolated from the formation and use proprietary fluid circulated in proprietary pipes that are isolated from the subsurface. They can be used to heat or cool and generate power. Systems work via conduction and convection of heat from the rock mass surrounding the well bore into the circulating fluid (Yuan et al. 2021).

(F) Retrofit Downhole Heat Exchanger

Existing wells (of any diameter and depth in theory) are retrofitted with a closed loop heat exchanger. This system is typically installed in high heat wells that do not have high fluid flow volumes. Can be used to heat or cool and generate power. The system works via conduction or convection of heat from the surrounding rock mass into the well bore (Van Horn et al. 2020).

(G) Underground Waste Heat Storage

Purpose drilled wells that are completed below the base of groundwater. These wells are used to store heat that has been captured at the surface (typically manmade waste heat) and store it in the subsurface. These systems are technology and location dependent and can cover a wide range of working depths and temperatures.

Conclusions

Whether a developer chooses a shallow or deep geothermal system, is ultimately dependent on a cost/benefit analysis of all the options including a thorough assessment of the resource and the heating (or cooling) load required for commercial operation. Where the subsurface is poorly known and likely made up of crystalline rocks such as granite, the most likely development would be a GeoExchange® system. For larger heating loads, especially if the site was located on a sedimentary basin, such as the Western Canada Sedimentary Basin (WCSB), investigation into the depth of sedimentary cover and subsurface conditions should be undertaken. There are large sections of the WCSB where the cover is thin (<3000m), but the connate waters of the formations are still warm to hot and suitable for direct-use applications (Class C1), although electrical generation is much more restricted (Class C2 and C3). From a regulatory standpoint, careful analysis of existing regulations for groundwater, oil and gas, and/or mineral entrained in a fluid, may find some regulatory pathways within existing regulations rather than creating new regulations that provide a development pathway for both shallow and deep geothermal systems.

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