A GeoExchange® to Deep Conventional Geothermal Energy Extraction Technology Spectrum Comparison - Simplified

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Summary

For the general public there has long been confusion between shallow “earth battery” geothermal systems and deep “naturally occurring 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 granting agencies. In reality, the “geoenergy” spectrum is exactly that – a spectrum of technologies that extends from low CAPEX heat pumps and heat exchangers using the shallow subsurface (<300m) as a battery to store ‘excess’ heat (GeoExchange®), to high CAPEX projects tapping the deeper natural occurring earth heat (geothermal). 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, GeoExchange® and heat storage developments into the larger “geothermal” basket is leading to negative consequences for both geothermal and GeoExchange® investors, regulators, and the public.

Theory / Method / Workflow

By way of graphics and a simple matrix, this paper seeks to outline the major differences and similarities between these two geoenergy-systems. One being shallow GeoExchange® “earth battery” and the other, deep conventional closed and “open” loop systems. In doing so, our intent is to remove uncertainty from the minds of consumers and granting agencies. As well as provide a clear narrative for investors and regulators.

A major driver of this review was a project supporting the government of the Northwest Territories in their efforts to understand the regulatory landscape of geothermal energy that two of the authors were involved in (CJH and ES). In this work, we reviewed regulations of several jurisdictions and interviewed both government officials and developers. What came out of this work is a need, from a regulatory standpoint, to clearly distinguish between the two geoenergy-systems. The summary provided in Table 1 is an attempt to identify the various characteristics of geo-systems and how they differ. Also identified are key characteristics that likely need regulatory oversight.

GeoExchange® systems are characterized by using the ground (earth) to store heat – the “geo” in GeoExchange®. The “exchange” is putting heat into the ground for storage, and then retrieving the stored heat when required. Heat storage (and retrieval) is through mechanical systems (heat pumps for example) and requires external energy input. Long term sustainability is through balancing the heat input with the energy usage. GeoExchange® 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.

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

The fundamental differences between “GeoExchange®” and “geothermal” have 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.

Classification of geo-systems

GeoExchange® and geothermal systems as outlined, have been broken down into classes based on their attributes. These attributes are outlined in Table 1. GeoExchange® systems have been subdivided into two classes (A) GeoExchange® (borehole heat exchanger), (B) Shallow subsurface, and geothermal into three classes (C) Conventional geothermal, (D) Closed loop (Deep borehole heat exchanger) and (E) Retrofit downhole heat exchangers as defined below:

(A) GeoExchange® (Borehole Heat Exchanger)
Also known as Geothermal Heating and Cooling (GHS), Ground Source Heat Pumps (GSHP) and Earth Coupled Heat Pumps (ECHP). Heating and cooling with the cooling cycle 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 (Figure 3) tubing installed, circulating a working fluid. They also require heat pumps (Figure 3a). These systems can be used to cool and to heat; but they cannot (with current technology) generate power. Systems can operate as warm as 32°C, and as cold as -1°C when transferring heat to/from the ground (DeWeerd 2021) (Figure 1).

(B) Shallow Subsurface (ground water) or surface water
Shallow drilled wells within groundwater (or a large body of surface water) and can be closed loop (Figure 1) or open loop (Figure 2), using formation water (typically groundwater because the systems are shallow) as the working fluid (Figure 2) (Ireland 2022). These systems can be used to heat or cool; but do not generate power. These 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) (Figure 2).

(C) Conventional Geothermal
Large wellbore, deep, purpose drilled wells for power generation and/or heat recovery (Figure 4). The systems are applicable to a wide variety of geological settings where earth’s naturally occurring 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 (Table 1).

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 (Figure 5).

3. C3 High enthalpy systems >170°C (flash systems). Fluid temperatures in the 70 °C – 110 °C can be used for electrical generation. These systems typically utilize flash technology (Figure 5) but are increasingly using ORC units (Eyerer et al. 2021)). Significant quantities of thermal energy are available for direct-use applications.

(D) Closed Loop (Deep Borehole Heat Exchanger)
Purpose drilled wells that are isolated from the formation and use proprietary fluid circulated in proprietary pipes. Can be used to heat or cool and potentially generate power. Systems work via conduction and convection of heat from the rock mass surrounding the well bore into the priority circulating fluid (Yuan et al. 2021). Technology is in the pilot phase. (Figure 6)

(E) 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). (Figure 7)

Attributes and Observations
As regulatory implications were a major driver of this review, we advocate using the word “GeoExchange®” for shallow installations (<300m), or those systems that are installed within the groundwater table (Figure 2) or recovering and disposing of heat within a large body of water, these are types A and B as defined above. We recommend reserving the word “geothermal” for deeper systems that are below the level of groundwater. Table 1 provides a simplified schematic that classifies the technologies based on a number of attributes. The first two, being temperature and well depth. These two attributes are major delimiters between the two types of systems. From these, cascade a wide range of other differences and similarities (Table 1). But fundamentally, these two factors determine exploration risk (attribute #3), govern the CAPEX of a project (attribute #4).

Projects in the (A) and (B) categories have CAPEX's that are likely to be under $1M and maybe significantly less than this depending on the volume to be heated or cooled. GeoExchange® systems are suitable for residential as well as multi-dwelling complexes and industrial facilities (Figure 1, 2 and 8). When properly designed, GeoExchange® systems are thermally balanced on an annual basis. When building heating and cooling loads are imbalanced, multiple strategies can be deployed to provide this balance. Some of these strategies included domestic hot water production, snow melting, sanitary water heat capture, and boilers (natural gas or electric). GeoExchange® systems can also contribute to much larger community energy systems (i.e., district energy) where their “earth battery” characteristics can be leveraged to enhance the overall performance of the larger system. Their limitation is they can't operate above 30 °C and long-term heating (or cooling) of the subsurface can lead to environmental complications with the creation of “heated” or “cooled” ground that differs from subsurface temperatures equilibrated since post-glacial time (DeWeerd 2021). This is especially important in arctic conditions where permafrost may be present.

Projects in the (C) and (D) classes have CAPEX values in the millions of dollars due to the significant drilling costs as well as large (relative to GeoExchange®) surface installations required. A review of the exploration and development process for conventional geothermal is outlined in (Hickson et al. 2014). The conventional geothermal projects (C) range from low enthalpy to high enthalpy systems and can have capacities of a few megawatts to hundreds of megawatts (Butler et al. 2010). Thermal capacity is commensurate with the MWe capacity. The Low enthalpy resources typically use Organic Rankin Cycle (ORC) power plants to generate electricity (Figure 5). The higher the enthalpy of the system, typically >170 °C, the more likely there is for the installation of a “flash” power plant (Figure 5) (Energy 2022). Unlike ORC units (which use a secondary fluid), flash power plants, use the steam fraction from the reservoir to drive the turbine. Typically, the condensed steam and brine fraction are reinjected back into the reservoir to maintain pressure support.

There may be sufficient heat content after exiting from the power plant to run the fluids through an ORC to generate additional power and finally through heat exchangers to provide direct-use thermal energy (IRENA 2017). Flash plants have lower operating costs (OPEX) than ORC facilities. An example of a low temperature development where 73 °C fluid is pumped from 300 m depth is Chena Hot springs in Alaska (Erkan et al. 2007). The pumped fluids are used to produce electricity, for direct use heating of buildings and greenhouses,
maintenance of an Ice Museum, and also supports a spa (Erkan et al. 2007). A handbook for low temperature, direct use development was published by Geoscience BC in 2016 (Hickson et al. 2016).

Many new high enthalpy installations are using ORC units as there are benefits to using a secondary working fluid to run the turbines rather than steam. The steam running through a turbine must be “clean” and “dry”, otherwise erosion, corrosion and scaling of the turbine blades is possible and can lead to costly repairs and down time (Figure 9) (Richardson et al. 2014).

Closed Loop systems (D) (Figure 6) use a secondary fluid that is run through the deep subsurface pipes by thermosyphon. Wells are drilled and then the well bore is coated to prevent exchange of formation fluids with the proprietary fluids used to circulate and carry the heat. It is not clear what the longevity of these systems will be, particularly in rocks where there is little or no convection. In convecting reservoirs, it is likely that heat will be more effectively transferred to the working fluid over a longer period of time, sustaining the system. It is presumed that the working fluid will be circulated through a heat exchanger for direct use applications (Yuan et al. 2021).

Projects in the (E) (Figure 7) category are typically recovery projects or well re-purposing projects. The use of downhole heat exchangers is often a “Plan B” for a well that fails to be commercially viable for electrical generation. Commercial viability is the balance between the mass flow of the well and pumping costs. For wells that don’t flow at commercially viable rates, the installation of heat exchangers may turn the well into an asset rather than a sunk cost (Van Horn et al. 2020).

Corrosion (#20) and scaling (#21) are directly attributable to the longevity of the system. Understanding fluid chemistry and the interplay between those fluids and casing, tubing and pumps is critical for designing a well (#8) that will have a long production life (Hörbrand et al. 2018). The longevity of the system is impacted by corrosion and scaling but also the operating temperatures of the system, the cement bond downhole, and types of steel chosen for casings, tubing, and pumps. This is in addition to the type of surface equipment. GeoExchange® systems are not subject to corrosion as steel pipe is rarely used. Subsurface piping is typically HDP, which has a very long lifespan – thought to be more than 40 years (DeWeerd 2021). Because these systems use a working fluid, they are also not subject to scaling. The same is true of Closed loop systems (D). The working fluid does not interact with formation fluids. Little is known about the propriety fluids that are being used in these systems, so their longevity and stability are not known. There is a possibility that the liner or coating used on the inside of the well bore may be impacted by exterior scaling in the formation, but as these systems are still in development, it is not clear what the likelihood of this happening is. It is thought that the longevity of Closed loop systems may be more limited by thermal “farming” of the heat. Conductive heat transport may not be sufficiently rapid to maintain the system for extended periods of time (Yuan et al. 2021). This may not be an issue if the piping is installed into a convecting reservoir. If conductive heat transport is too slow, additional make-up wells will be required to maintain the capacity of the system.

The environmental footprint (#24) of GeoExchange® and geothermal projects is very small. GeoExchange® systems, due to their compact size and long-life span have a very low environmental impact. Geothermal systems, by virtue of their larger sizes, have a larger footprint – but still very small compared with other renewables such as wind and solar (Sayed et al. 2021). Additionally, the spatial requirements (#25) of GeoExchange® systems are very small. Project wells can often be retrofitted onto existing building footprints by using adjoining lawns or laneways. There are also some proprietary technologies that allow angled drilling giving access to the earth below existing buildings without having to access parking areas to drill. The surface equipment is minimal, even for multi-unit complexes. The urban GeoExchange® system, currently being installed at the historic St. George campus, at the University of Toronto, is an excellent example of this (Cameron 2022). Direct use geothermal systems (Class C1) can also be relatively small. Surface facilities may include only two wells (injector and producer) with heat exchange equipment occupying a small garage sized space. Systems
with multiple wells and at higher temperatures (Class C2 and C3) are commensurately larger and electrical plants combined with heat exchangers may require up to 3 hectares. These larger facilities may be capable of generating up to 100 MWe if the system is a high enthalpy, C3 system (IRENA 2017).

Conventional geothermal systems (Class C) have an added potential to create revenue through extraction of multiple commodities as well as the injection of CO2 for sequestration (Figure 10; attributes #10 and #11). Co-production of gas and geothermal energy has been successfully shown by Futera Energy at their Swan Hills facility (Figure 11) (Power 2022). In geologically suitable locations the formation fluids may have commercial quantities of commodities such as Lithium. Li could be extracted using direct extraction technology being developed by a number of companies (Stringfellow et al. 2021). The cooled brines would then be injected. Injection wells might also be used for CO2 sequestration. The wells could be completed with multiple completions to inject CO2 into formations above the geothermal reservoir or potentially into the operating reservoir. This latter possibility is being researched by a team from the University of Alberta led by Dr. Rick Chalaturnyk in partnership with Alberta No. 1 and CANMet Energy labs scientists led by Dr. Andrew Wigston. A third possibility for CO2 sequestration is as a “Plan C” for a well that fails to be commercial for geothermal purposes (Shokri et al. 2022).

Class C geothermal systems operate on the principle of sustainability through reservoir management. Reservoir management is attained by mass balance of the production fluid with reinjection of the produced fluids. Reservoir management is key to long term sustainability that might lead to rapid resource degradation (#18). Class C1 systems, are often related to spas and thermal facilities. Here, use of the naturally occurring brines is often considered to be a health benefit, so direct use of the brines is advocated. Additionally, the cost of reinjection can be a development deterrent. Each development must be considered on an individual basis taking into account the local environmental laws as application based on water chemistry, human health, danger to the environment for surface disposal and natural recharge of the reservoir.

For C2 and C3 systems, early practices, did not fully reinject, leading to short term degradation of the reservoir (#18). More modern practices have emphasized the importance of injection for long term reservoir management. With injection, comes the possibility of induced seismicity (#26), (He et al. 2020). The large volumes of injectate are best injected into the producing reservoir in order to maintain reservoir pressure (mass balance). Typically, injection is under formation pressure and does not lead to induced seismicity. There may be some very low-level seismicity related to the contraction of the reservoir rocks from the cold injectate. Breakthrough of cold fluid into the production wells must be closely monitored (Lepillier et al. 2019). Monitoring is done through temperature and tracer testing as well as pressure testing. In GeoExchange® systems there is never the possibility of induced seismicity because there is never injection of fluids into the subsurface. Closed Loop systems (D) are cited as not producing induced seismicity, because no fluid leaves the well bore.

The last attribute considered is “Enhanced Permeability” (attribute #27) (Figure 12) and refers to creating additional permeability in the reservoir by stimulation. Enhancing the permeability is sometimes required in order to create a commercial well (Energy 2016). Permeability may be impaired by use of incorrect drilling muds (for example bentonite clays in high temperature systems), down hole problems such as a twisted well bore, caving, or scaling. Sometimes acid washes can remedy the problems, other times, high pressure acid injection is required. Deflagration can also be used to increase permeability over short sections of the wells. Cold water injection is routinely used in high temperature wells to increase permeability (Dusseault 2022). Downhole pumping of cold surface or shallow groundwater over periods of weeks to months can bring about significant improvements in the well permeability (Lepillier et al. 2019).

It is not yet known if closed loops, Class D systems might enhance the permeability near well bore in order to create a convection zone close to the well bore, or by contraction shrinkage due to cooling by operating the system.
Conclusions

Whether a developer chooses a GeoExchange® or a 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) (Figure 13) 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 GeoExchange® and geothermal systems.

Acknowledgements

Steve Grasby, Maurice Dusseault, and Jasmine Raymond reviewed the matrix and provided substantive comments; the results are the authors’ own interpretation of this complex space. Alberta No. 1 is partially funded by the Emerging Renewable Power Program administered by Natural Resources Canada. Some of comments on regulations represents thinking done on behalf of the Government of the NWT through a contract with the University of Calgary School of Public Policy, Extractive Resources Governance Program.
Table 1: Simplified GeoExchange® - Geothermal Schematic. Entries highlighted in red, indicate specific aspects requiring regulatory consideration.

<table>
<thead>
<tr>
<th>Type</th>
<th>GEOEXCHANGE®</th>
<th>GEOEXCHANGE®</th>
<th>GEOTHERMAL</th>
<th>GEOTHERMAL</th>
<th>GEOTHERMAL</th>
<th>GEOTHERMAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>CLASS</td>
<td>(A) GeoExchange® (Borehole Heat Exchanger)</td>
<td>(B) Shallow Subsurface</td>
<td>(C-1) Conventional Low T Geothermal</td>
<td>(C-2) Conventional Geothermal</td>
<td>(C-3) Conventional Geothermal</td>
<td>(D) Closed Loop* (Deep Borehole Heat Exchanger)</td>
</tr>
<tr>
<td>ATTRIBUTES</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Depth</td>
<td>&lt;300 m</td>
<td>within the Groundwater table-</td>
<td>600 m to ~5 km</td>
<td>&gt;1.5km to ~5 km</td>
<td>&gt;1.5km to ~5 km</td>
<td>&gt;1.5km to any</td>
</tr>
<tr>
<td>2. Temperature</td>
<td>Up to 30°C</td>
<td>Up to 30°C</td>
<td>30°C to 70°C</td>
<td>70°C – 170°C (sed basin); higher in other geological environments</td>
<td>170°C and above (including super critical systems)</td>
<td>Average 120°C to unspecified</td>
</tr>
<tr>
<td>3. Exploration Risk</td>
<td>Nil</td>
<td>Nil</td>
<td>Low (dependent on existing geoscience data)</td>
<td>Moderate -High (dependent existing geoscience data)</td>
<td>Moderate -High (dependent existing geoscience data)</td>
<td>Moderate -High (dependent existing geoscience data)</td>
</tr>
<tr>
<td>4. Capital cost (CAPEX)</td>
<td>Low</td>
<td>Low -moderate</td>
<td>Moderate</td>
<td>Moderate – high</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>5. Well bore size</td>
<td>Tiny</td>
<td>Small</td>
<td>Moderate to Large</td>
<td>Large</td>
<td>Large</td>
<td>Moderate</td>
</tr>
<tr>
<td>6. Drilling rig capacity</td>
<td>Very small</td>
<td>Small or not required if surface or mine source</td>
<td>Large</td>
<td>Large</td>
<td>Large</td>
<td>Large</td>
</tr>
<tr>
<td>7. Well control</td>
<td>Artesian flow</td>
<td>Artesian flow</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>8. Engineered well design for deep drilling</td>
<td>Compliant with water well regulations.</td>
<td>Compliant with water well regulations or not required for surface or mine source</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>9. Power Generation</td>
<td>no</td>
<td>no</td>
<td>No (with current technology)</td>
<td>Yes; limited in 70°C – 110°C range</td>
<td>Yes</td>
<td>Yes (not yet proven commercially)</td>
</tr>
<tr>
<td>10. Multi commodity</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>11. Carbon Sequestration</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>12. Open loop*</td>
<td>No</td>
<td>Yes - Groundwater or surface water</td>
<td>Yes – open to formation</td>
<td>Yes – open to formation</td>
<td>Yes – open to formation</td>
<td>No</td>
</tr>
<tr>
<td>13. Closed loop</td>
<td>Yes</td>
<td>Yes</td>
<td>Possible; convert to Type D or E</td>
<td>Possible; convert to Type D or E</td>
<td>Possible; convert to Type D or E</td>
<td>Yes (closed to formation)</td>
</tr>
<tr>
<td>14. Heat pumps/exchangers</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes – heat exchanger</td>
<td>Yes (cascade off of ORC) as secondary heat recovery; heat exchanger for direct use</td>
<td>Yes (cascade off of Flash) ORC and heat exchanger for direct use</td>
<td>Yes</td>
</tr>
<tr>
<td>---------------------------</td>
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<td>-----</td>
<td>----------------------</td>
<td>------------------------------------------------------------------------</td>
<td>-----------------------------------------------------------------</td>
<td>-----</td>
</tr>
<tr>
<td>15. Enhanced permeability</td>
<td>No</td>
<td>No</td>
<td>Possible</td>
<td>Possible</td>
<td>Possible</td>
<td>Possible</td>
</tr>
<tr>
<td>16. Downhole pumps</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes (line shaft/ESP)</td>
<td>No (free flow)</td>
<td>No (thermosyphon)</td>
</tr>
<tr>
<td>17. Resource degradation</td>
<td>No; heat/cooling balanced by external inputs</td>
<td>No; heat/cooling balanced by external inputs</td>
<td>Yes; ameliorated by good reservoir management</td>
<td>Yes; ameliorated by good reservoir management</td>
<td>Yes; ameliorated by good reservoir management</td>
<td>Yes; ameliorated by makeup wells</td>
</tr>
<tr>
<td>18. Operating costs (OPEX)</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Mod</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>19. Corrosion</td>
<td>No</td>
<td>No</td>
<td>Possible</td>
<td>Possible</td>
<td>Possible</td>
<td>Possible#</td>
</tr>
<tr>
<td>20. Scaling</td>
<td>No</td>
<td>No</td>
<td>Possible</td>
<td>Possible</td>
<td>Possible</td>
<td>Possible</td>
</tr>
<tr>
<td>21. Working fluid</td>
<td>Propylene Glycol or Ethanol or proprietary</td>
<td>Formation/groundwater or Propylene Glycol or Ethanol or proprietary</td>
<td>Formation fluid</td>
<td>Formation fluid</td>
<td>Formation fluid/steam</td>
<td>Proprietary fluid</td>
</tr>
<tr>
<td>22. Longevity</td>
<td>20-30 years</td>
<td>20 years</td>
<td>More than 40 years</td>
<td>More than 40 years</td>
<td>More than 40 years</td>
<td>Unknown</td>
</tr>
<tr>
<td>23. Environmental footprint</td>
<td>Very small</td>
<td>Very small</td>
<td>Small</td>
<td>Small</td>
<td>Small</td>
<td>Small</td>
</tr>
<tr>
<td>24. Surface Spatial Requirements</td>
<td>Very small</td>
<td>Very small</td>
<td>Small</td>
<td>Small</td>
<td>Small</td>
<td>Small</td>
</tr>
<tr>
<td>25. Induced seismicity</td>
<td>No</td>
<td>No</td>
<td>Possible (due to injection and rock mass cooling)</td>
<td>Possible (due to injection and rock mass cooling)</td>
<td>Possible (due to injection and rock mass cooling)</td>
<td>Possible (due to rock mass cooling)</td>
</tr>
<tr>
<td>26. EGS (engineer/enhanced) %</td>
<td>No</td>
<td>No</td>
<td>Yes (deep low temperature systems in crystalline rock require EGS)</td>
<td>Yes</td>
<td>Yes</td>
<td>possible</td>
</tr>
</tbody>
</table>

* Closed loop: Purpose drilled wellbores lined and using a high heat capacity fluid for heat recovery (e.g., Eavor)

^ Downhole heat exchangers are usually installed in wells that do not have sufficient flow to be commercial, they are recovery systems (e.g., CeraPhi; Green fire)

+ “Open loop” are systems that are open to the formation.

# Possible corrosion and/or scaling on the exterior of the pipe/ well bore.

& Horizontal closed loop can have a large footprint

% EGS = Enhanced (or Engineered) Geothermal Systems – A Geothermal reservoir that has had permeability and porosity enhanced via completions methods (fracking, acid, etc.)
Figure 1: Schematic representation of Class A and B (Table 1) geoexchange systems.

Geoexchange systems use the shallow earth as a storage system for heat energy captured from the sun. Heat exchangers (or heat pumps) extract atmospheric heat during summer months, storing it for extraction during the winter. Similarly, systems based on groundwater or surface water use the heat capacity of those systems to do useful work.

Figure 2: Shallow subsurface Class B Open Loop (Table 1) geoexchange system. Figure taken from (Geological Survey Ireland, 2022)


(Ireland 2022)
Figure 3: Geoexchange systems (a) use heat pumps to extract the warm air in a building using mechanical energy (electricity). The extracted warm air is then stored underground to be used as a source of energy during the winter. This process provides cooling in the summer and heating in the winter. (b) Geothermal systems, using naturally heated formation waters, sometimes require pumping to bring the fluid to the surface, but once on the surface the heat is passed from the working fluid (a natural brine or a proprietary working fluid) to a secondary fluid. For space heating this is likely to be water, but it could be other fluids if the heat is being used to power an ORC. In these cases fluids such as pentane or ammonia can be used.

Figure 4: Conventional deep geothermal system (Type C, Table 1), where brines are used to extract earth’s naturally occurring heat bring it to the surface where useful work is done by extracting the heat, then the fluid is returned to the deep subsurface, to be reheated and reused. Geothermal systems (Class C1 and C2, Table 1) preserve mass balance by fulling reinjecting the produced brine. Appendix D discusses injection in more detail.

(Project 2022)
Figure 5: (a) Organic Rankin Cycle unit typically used for Class C2 systems (Table 1); (b) flash system used at higher temperature Class C3 systems. Note flash systems do not use a secondary (working fluid) but generate power directly from produced steam.

Figure 6: Closed loop deep geothermal systems (Class D, Table 1), where a secondary “carrier” or working fluid is used to extract earth’s naturally occurring heat bringing it to the surface where useful work is done by extracting the heat, then the working fluid is returned to the deep subsurface, to be reheated and reused. https://www.eavor.com/

(Eavor 2021)
Figure 7: Class E systems (Table 1) are typically retrofit downhole heat exchanger showing geothermal co-production. Figure taken from (GreenFire Energy, 2022).

https://www.greenfireenergy.com/how-does-geothermal-energy-work/

(Energy 2022)

Figure 8: How geoxchange systems are used to heat and cool a residence. Figure taken from (Ontario Geothermal Association, 2022).

https://ontariogeothermal.ca/geothermal-101/

(Association 2022)
Figure 9: Silica deposits on a geothermal steam turbine – deposition on rotating blades (left) and on the diaphragm blades (right). (Richardson, et al., 2014)

(Richardson et al. 2014)

Figure 10: Holistic vision of geothermal extraction to maximize commercial viability of projects (Hickson et al. 2021)

(Hickson et al. 2021)
Figure 11: Schematic of Futera Power’s co-production of gas and geothermal at their Swan Hills facility. Figure taken from (Futera Power, 2022).

https://www.futerapower.com/

Figure 12: Schematic representation of an engineered (or enhanced) geothermal systems (EGS. Fracture networks are created artificially in the rock mass.


(Thiel 2017)
Figure 13: J. Majorowicz, S.E. Grasby, Deep Geothermal Heating Potential for the Communities of the Western Canadian Sedimentary Basin, Energies, 14, 706, 2021.

(Majorowicz 2021)

References


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1 Geoexchange® is a registered trademark of the Geothermal Heat Pump Consortium https://geothermalheatpumpconsortium.org/