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The Emerging (and Proven) Technologies that Could Finally Make Geothermal Scalable

Robert Winsloe, Alexander Richter and Jeanine Vany

Suite 2813, 150 – 9th Avenue SW, Calgary, Alberta, Canada T2P 3H9

robert.winsloe@eavor.com

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ABSTRACT

As an industry, one of the challenges we have faced in the development and acceptance of geothermal as a global energy source is that we have been largely limited to permeable aquifers (or creating artificial permeability) or tapping into volcanic hotspots.

And yet, at sufficient depth, geothermal energy is available everywhere. Fortunately, a range of proven and emerging technologies could finally make geothermal energy scalable by eliminating the need for a hot, permeable aquifer. This paper will review these technologies, associated case histories, and assess their potential impact on the global competitiveness of geothermal energy and the energy balance of the countries and regions that embrace them.

The paper will begin by looking at the global theoretical potential of geothermal energy and comparing that with current and planned capacity. The viability and impact of the technologies that could help us begin to fully exploit the earth's geothermal potential will be assessed.

Several technologies will be evaluated based on a review of the literature, case studies and ongoing projects. These include:

- Shallow, low enthalpy aquifers
- Water production from oil and gas operations
- Closed-Loop (or conduction based) geothermal

As the case studies will demonstrate the first two of these are already being exploited and are ready for expansion at scale. The third, conduction based geothermal, already has a long (and largely unsuccessful) history following a series of failed laboratory and field scale experiments. However, there are two emerging technologies which promise to finally make conduction economically viable and geothermal scalable. Neither of these was possible 3 years ago and both are benefitting from exploitation of proven technologies from the oil and gas sector.

The first is going deep and very hot in a single well closed-loop configuration. The second comes shallower in a u-shaped multilateral well configuration that effectively buries 100km of pipe at temperatures of around 120°C. This paper will present the science, economics and commercial demonstration projects that support these technologies and will conclude by assessing the potential impact of these technologies on the economics and energy balance of the countries and regions that embrace them.

1. GEOTHERMAL POTENTIAL OF PLANET EARTH

Suitable aquifers for traditional (hydrothermal) geothermal energy extraction underlay 16% of the earth's surface and are capable of delivering a similar amount of world energy that is being consumed annually (Limberger et al. 2017).

Another way of looking at the earth's geothermal potential is to look at the design and capacity of closed-loop systems such as Eavor-Loop™. The surface area of the earth is 510 MM km2. Of this, the land area is 149 MM km2. 57% is made up of uninhabitable areas (deserts and mountains) leaving an inhabitable land area of 64 MM km2.

Eavor-Loop™ multilateral closed loop systems are predicted to produce 4MWe for every 10 km2 (Toews et al. 2019). Therefore, it is reasonable to assume the geothermal capacity of the inhabitable land mass could be up to 25,600 GWe, or 224,256 TWh.

If the heat was used directly for heating or cooling the energy potential would be 6 to 10 times greater.

Total global energy consumption was 161,249 TWh in 2018 (BP Statistical Review of World Energy 2019) as illustrated in Figure 1. In other words, geothermal energy has the potential to satisfy more than 100% of the world's heating, cooling and electricity demand.

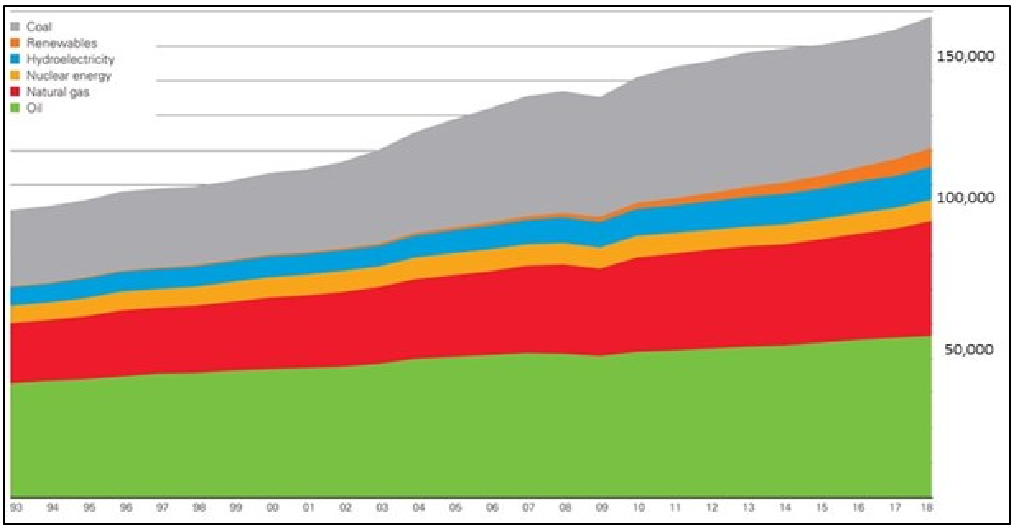

Figure 1: World Consumption -TWh (Source: BP Statistical Review of World Energy)

2. GEOTHERMAL ENERGY SUPPLY TODAY

2.1 Electricity Generation

As of July 2019, installed geothermal electricity generating capacity reached 14,900 MW (Source: ThinkGeoEnergy, 2019). See Figure 2.

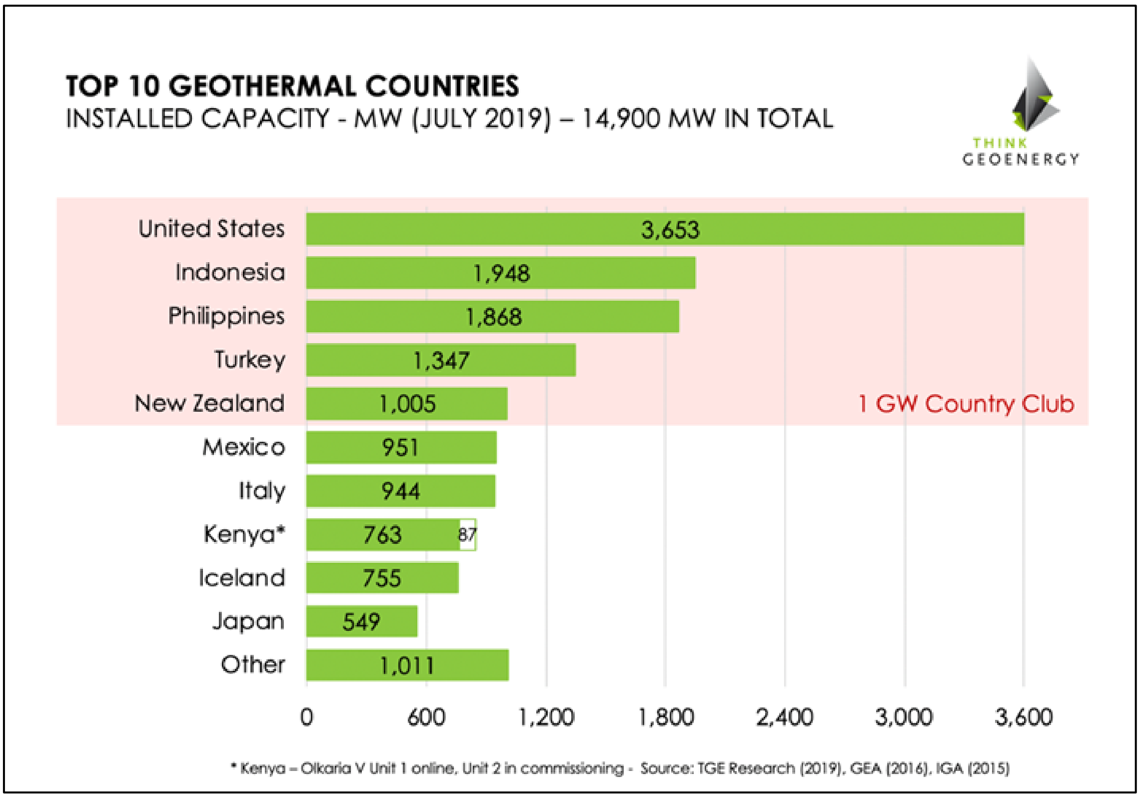

Figure 2: Global geothermal electricity generation capacity (MW) – Top 10 countries (ThinkGeoEnergy, 2019)

To deliver economically viable capital efficiencies, geothermal electricity generation projects have invariably focused on areas with permeable aquifers or faulted structures and high temperature gradients. These conditions are typically found in the ring of fire (Figure 3) which explains why the vast majority of current geothermal electricity production (14,900MW – see Figure 2) comes from Iceland, Indonesia, Italy, Japan, Kenya, Mexico, New Zealand, Philippines, Turkey and the USA.

These locations are not always near centers of demand but the ability to transport electricity across existing distribution networks to the consumer is a significant development advantage.

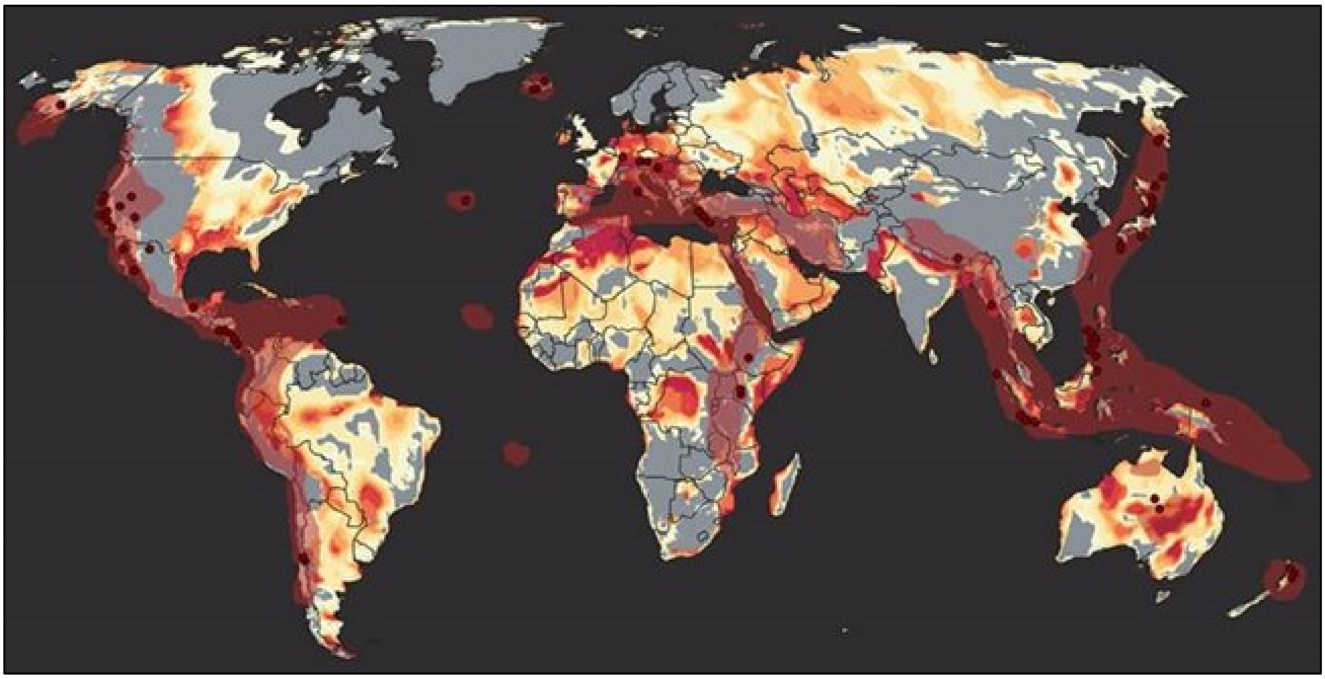

Figure 3: Worldwide sedimentary basin aquifers modified from modified from Limberger et al., 2018, volcanic ring of fire overlay sourced from google images

2.2 Direct heating and cooling

As shown in Figure 4, direct geothermal energy capacity was 70,329 MWth in 2015 with 71% of this from ground source heat pumps, and with load factors averaging 26.5%, utilisation was 163 TWh (Lund et al. 2015).

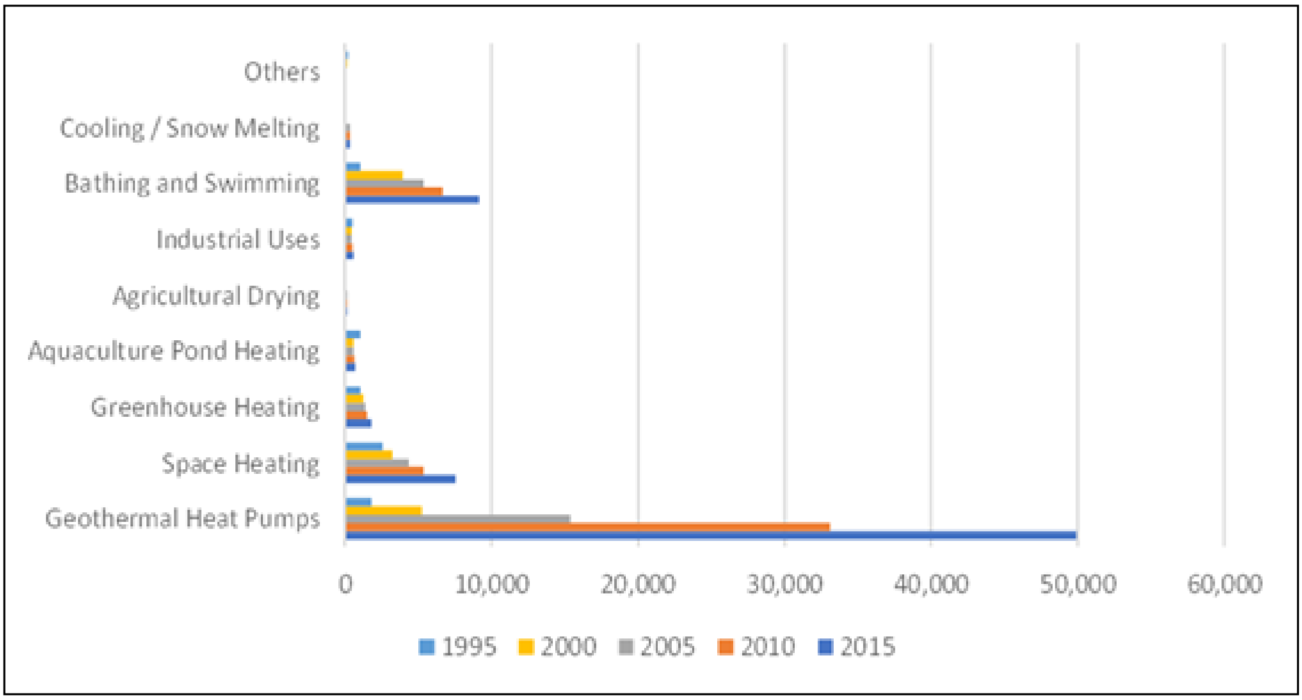

Figure 4: Capacity of Direct Geothermal Use (Lund et a1. 2015)

Heating works well at relatively low temperatures if the aquifer is highly permeable (e.g. the district heating system in Paris). The disadvantage is that large scale heating or cooling projects must be created very close to the centers of demand (cities, industry, agriculture). Geothermal district heating systems have been installed in several European countries (Figure 5).

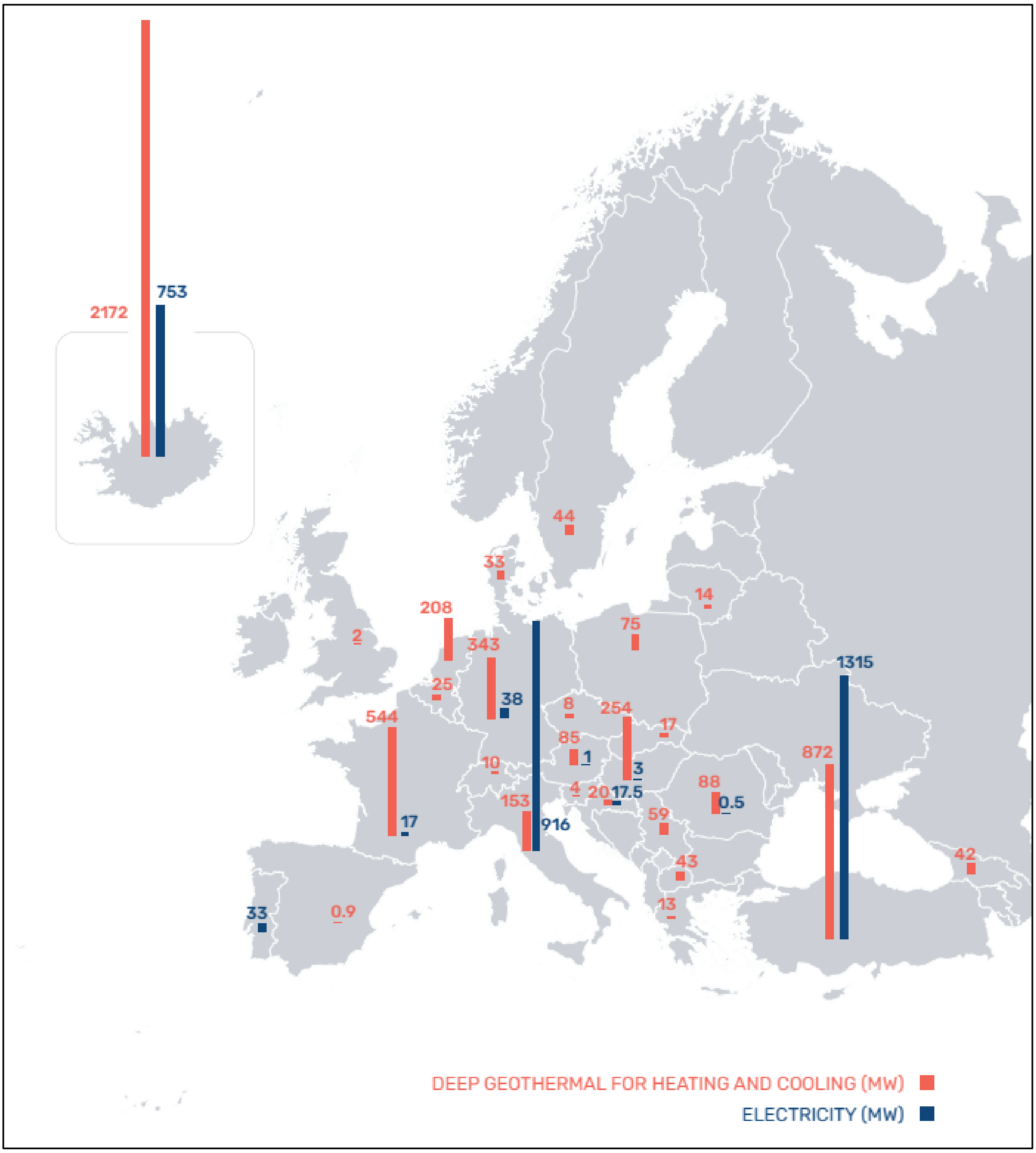

Figure 5: Number of district heating systems in Europe (Source: EGEC)

Ground source heat pumps (GSHP) are the only closed-loop technology that has gained market traction to date. Ideally suited for single dwellings, hospitals and schools, there has been spectacular growth in the installed capacity in China (Liu et al. 2015), particularly when compared with the USA. Europe also has seen significant growth in the number of GSHPs installed and this is trend is expected to continue (Figure 6).

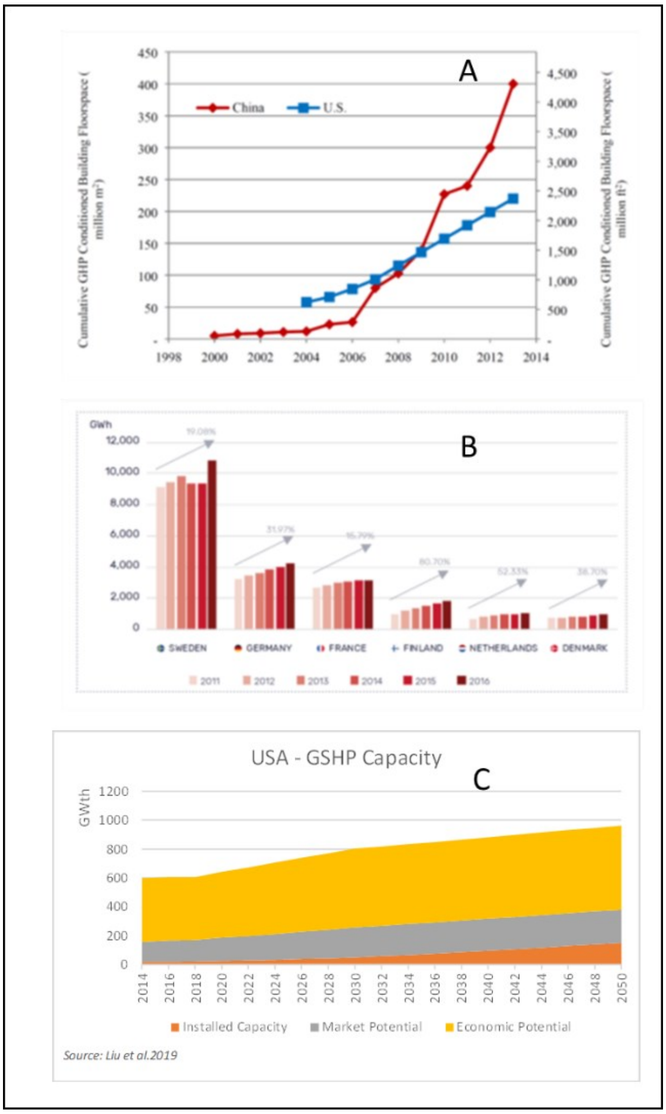

Figure 6: GSHP growth trends. A) Relative GSHP growth in China and USA. B) GSHP capacity in selected European countries "EGEC Geothermal Market Report" 2017. C) GSHP capacity in USA (2019)

2.3 Current geothermal capacity versus potential

Current geothermal capacity shows that less than 1% of the earth's geothermal energy potential is being realised today. So, what is holding us back? The perception is often that gas and/or coal have a lower overall cost but when you factor carbon capture and sequestration (CCS), the levelized cost of energy (LCOE) for geothermal energy can be extremely competitive (Figure 7).

Another consideration is that, other than ground source heat pumps, geothermal energy production has focused almost exclusively on hot permeable aquifers and, for direct heating and cooling at least, the supply is not always close to the centers of demand.

Unlocking the full geothermal potential of the earth is discussed in the next section.

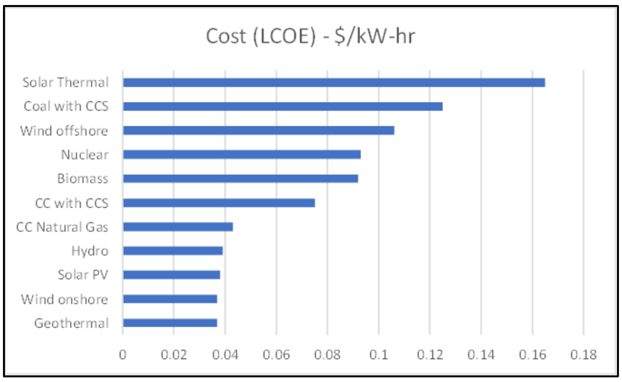

Figure 7: LCOE costs of different energy sources (source: www.renewable-energysources.com)

3. GEOTHERMAL ENERGY SUPPLY IN THE FUTURE

As illustrated in the figures above, geothermal energy supply from current sources (hydrothermal and GSHPs) is expected to grow steadily through 2050. This growth will be supplemented by four emerging concepts that have the potential to make geothermal energy available almost anywhere.

3.1 Hot water as a by-product of oil and gas production

In mature oil and gas provinces water production can make up to 90% of the production by volume. In Oklahoma for example water production averages 10 million barrels per day (Murray 2018) but little or no use is being made of this geothermal energy source today.

One notable exception is Vermilion's project (Vermilion, 2018) in France, where the co-produced hot water from their oil and gas operation is generating 8MWth to support an 8 hectare greenhouse operation for growing tomatoes (Figure 8).

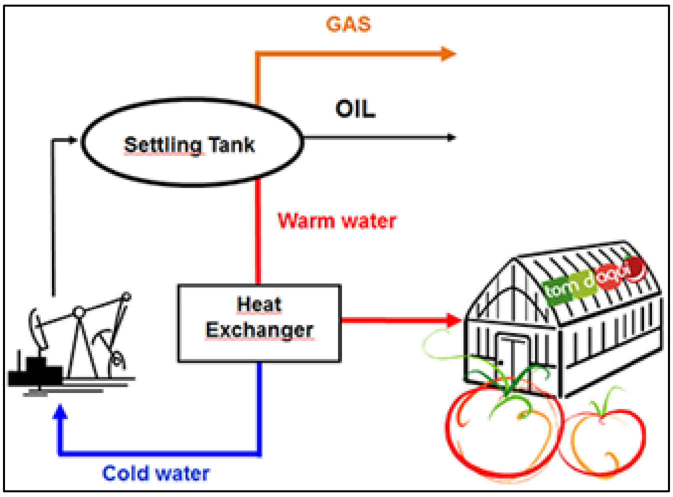

Figure 8: Geothermal heat from oil and gas water production (Source Vermilion)

3.2 Enhanced Geothermal Systems

There are numerous definitions of Enhanced Geothermal Systems (EGS). For the purposes of this paper, we will limit this to open systems in either aquifers with insufficient permeability or hot dry rock. In both cases the geothermal system is created by artificially inducing permeability (fractures) in the rock. The 2019 GeoVision report predicts that "as yet unknown technologies will emerge by 2030, increasing geothermal energy potential by a factor of 10". It is unclear at this stage exactly what these technologies will be. However, if you broaden the definition of EGS to include closed-loop technologies, it is reasonable to assume the probability of making geothermal scalable increases.

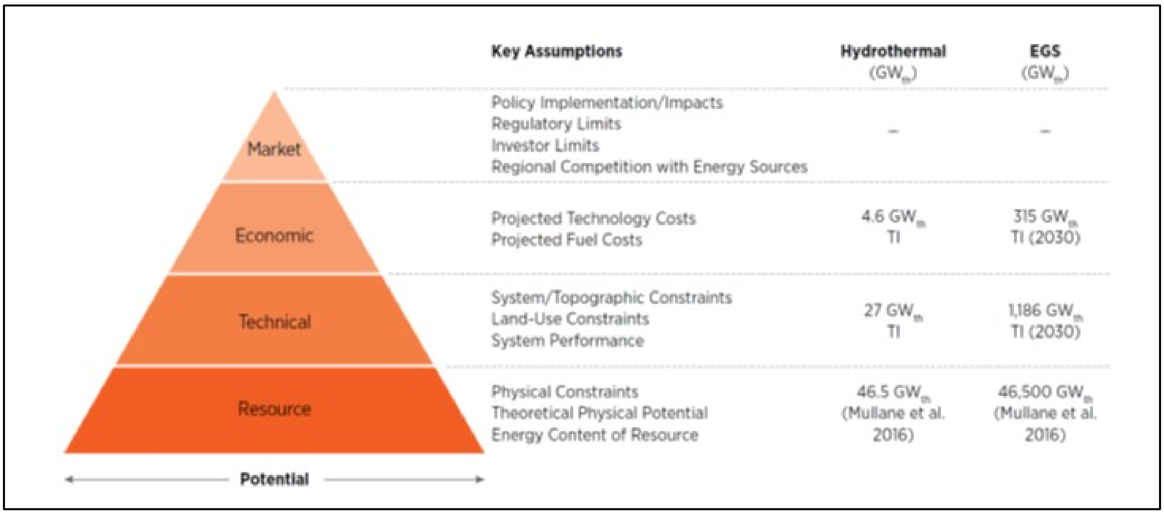

Figure 9: District heating potential from EGS (GeoVision 2019)

3.3 Pipe in pipe closed-loop systems (e.g. Greenfire Energy)

Much has been written about the potential for reusing abandoned oil and gas wells for geothermal energy production (CanGEA, 2019). Greenfire Energy are testing this concept along with their novel "pipe in pipe" closed loop geothermal system at their Coso project in California. And although Greenfire are exploring the feasibility and value of retrofitting their closed-loop system to both oil and gas wells and underperforming open system geothermal wells, the real potential of the technology is in making geothermal available anywhere.

At the time of writing Greenfire's initial project has completed construction and will demonstrate and test two approaches to closed-loop geothermal (Greenfire Energy, 2019).

- "The use of GreenFire's technology to retrofit nonperforming or underperforming hydrothermal wells to become more productive. GreenFire will allow geothermal steam and brine from the geothermal resource to be produced, while simultaneously circulating water and then supercritical CO2 (sCO2) as working fluids in a downbore heat exchanger."
- "The use of the technology in hot dry rock formations for large greenfield projects. GreenFire will circulate both water and then CO2 in the downbore heat exchanger under static resource conditions. The conceptual simplicity of closed-loop systems in such formations is inherently appealing because a sealed downhole heat exchanger obviates the need to deal with the full subsurface complexity. Drilling risk is reduced because intersecting natural fractures with flowing water is not essential and the problems associated with maintaining water circulation through rock are avoided. Further, a closed-loop system in hot dry rock reduces the problems of corrosion, non-condensable gases, chemical reactions, and particulates."

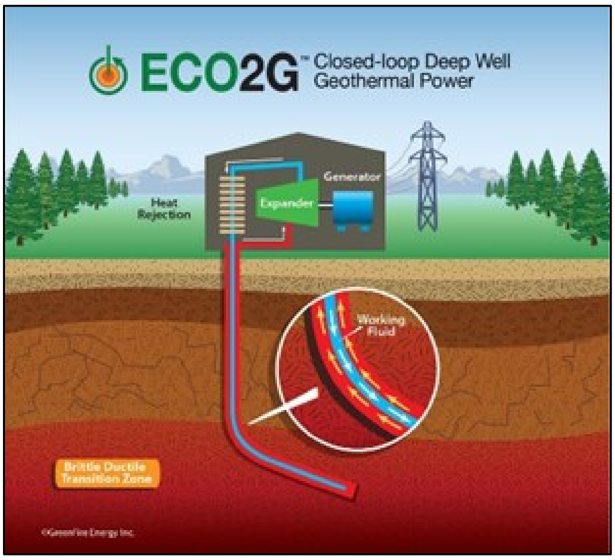

Figure 10: Greenfire's pipe in pipe closed loop solution (Source Greenfire)

3.4 Closed-loop U-shaped heat exchanger systems (e.g. Eavor Loop)

Eavor's approach is to create what is effectively a giant heat exchanger at depth. The full-scale system is built by two drilling rigs operating simultaneously nearly 6km apart, drilling down to target depths of around 3,500 metres and then drilling horizontally to meet in the middle to create a u-shaped configuration. A series of up to 10 laterals are then drilled. The operation is repeated with two further vertical wells and 10 laterals to effectively "close the loop". With 100km of pipe (20 x each 5km lateral) spread across a subsurface area of 10km2 the system is capable of generating either 2MWe or 20MWth on each side (Figure 11A).

The simplicity of this approach means that no aquifer is required and that the systems can be constructed almost anywhere making geothermal scalable. It offers a complimentary approach to open systems when an aquifer isn't available or as an alternative solution when the first half of a doublet has failed to find a permeable aquifer.

Eavor Technologies are at a similar stage of development as GreenFire with their first demonstration project under construction in Canada and a growing list of full commercial projects in the pipeline

The Eavor-Loop™ Demonstration Project or "Eavor-Lite" (Figure 11 B), is a full-scale prototype of the technology intended to de-risk the key technical components. It consists of a large U-tube shaped well with 2 multilateral legs at 2.4km depth, and a pipeline connecting two sites at surface.

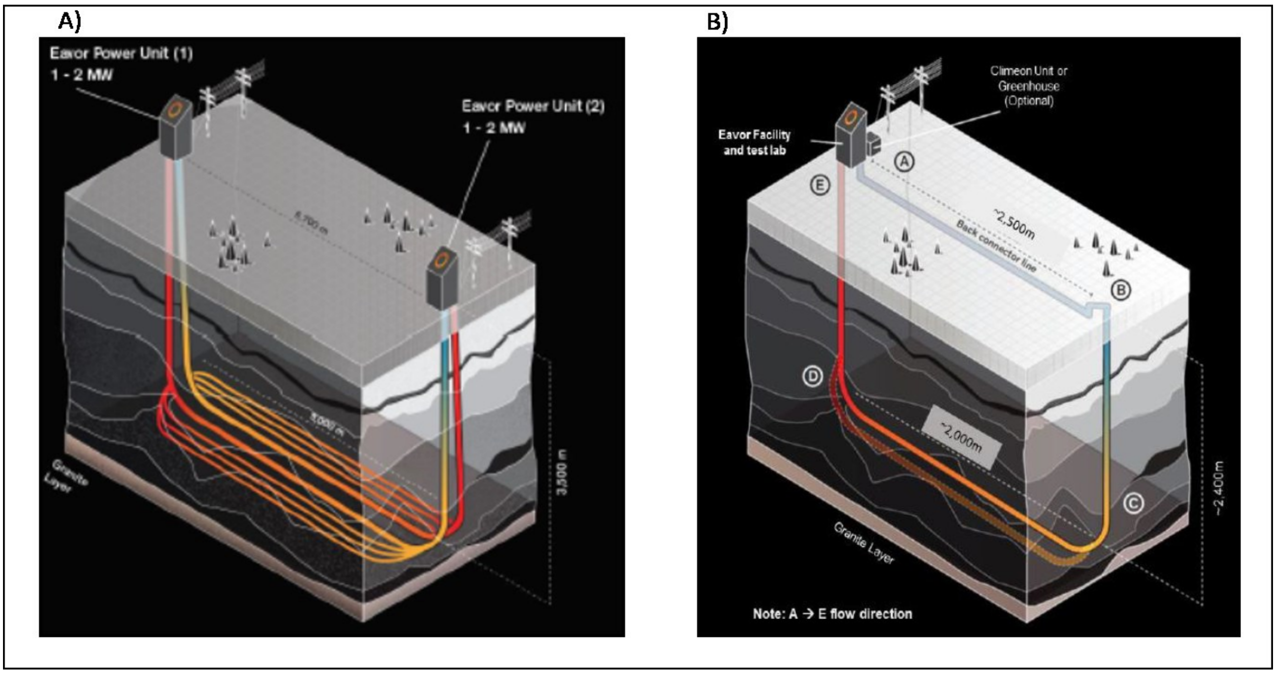

Figure 11: Eavor-Loop™ full commercial scale schematic

The project is located west of Sylvan Lake, near the town of Eckville, Alberta, Canada. The technical objectives are to:

• Drill and intersect a multilateral Eavor-Loop™ with 2 laterals

• Seal the Eavor-Loop™ while drilling

• Validate thermodynamic performance and demonstrate the thermosiphon.

The facility will consist of a water storage tank, a solids filter, centrifugal pump, aerial cooler and a small chemical injection skid. The aerial cooler will cool the water prior to entering the Inlet well, thus creating a thermosiphon. Water temperature when entering the inlet well is ~20°C and exiting the outlet well will be ~50°C – although these temperatures can be adjusted based on flow rate and ambient temperature. The heat transfer profile will be similar to planned Commercial projects: an increase of ~30°C from the inlet well to the outlet well.

Drilling 100km of horizontal sections means that this technology is particularly sensitive to drilling costs. Fortunately, the solution is perfectly placed to take advantage of the dramatic improvements in horizontal drilling technology and associated cost reductions from the oil and gas sector shale and tight sand plays in North America.

Like the oil and gas shale plays, Eavor-Loop™ should become more of a repeatable manufacturing operation that has much lower, if not insignificant, exploration risk when compared with hydrothermal.

4. SATISFYING CURRENT AND FUTURE ENERGY DEMAND

In looking at the potential to satisfy energy demand this paper assumes that the emerging technologies described above, including those that are still at the demonstration stage, will prove to be technically and economically viable.

Using this assumption, geothermal energy has the potential to fully satisfy the demand for heating and cooling and a significant percentage of electricity demand in any community or country that chooses to embrace the concept. The choice (or choices) of geothermal technology will depend on the application:

4.1 District heating and cooling networks – key factors: population density and the availability of a permeable aquifer

The economics for district heating and cooling networks obviously improves with scale. The map shown in figure 12 below provides a proxy for population density and helps to confirm that the primary markets for large scale heating and cooling systems are to be found in the eastern half of North America, Europe, India and Far East Asia. Obviously, the market extends beyond these areas to large towns all over the world.

Figure 12: Earth at night as seen from space (Source National Geographic, 2012)

Where these population centers coincide with permeable aquifers at suitable temperatures (e.g. Paris), hydrothermal technology provides a viable solution. To complement this, and in all other areas of high population density where an aquifer doesn't exist, the demand can be satisfied with either Greenfire or Eavor-Loop™ technology.

EGS (with the risk of induced seismicity) is unlikely to gain support from the community in such areas.

4.2 Heating and cooling for individual homes or for large individual buildings (schools, hospitals) – factors: low population density

Ground Source Heat Pumps are already the preferred technology and this trend will continue. In truly remote/off grid areas a source of electricity will need to be found to drive the heat pumps.

4.3 Heating and cooling for agricultural or industrial applications – factors: availability of a permeable aquifer

Where the agricultural or industrial demand coincides with a permeable aquifer at suitable temperature (e.g. Netherlands in the areas around Rotterdam), hydrothermal technology provides a viable solution. To complement this, and in all other areas where an aquifer doesn't exist, the demand can be satisfied with EGS, Greenfire or Eavor-Loop™ technology.

Small scale farming applications may also be viable using a ground source heat pump.

4.4 Electricity generation – factors: heat gradient and the availability of a permeable aquifer

Although technologies are emerging that allow electricity production at lower temperatures, the current reality is that the economics are often marginal when bottom hole temperatures are lower than 130°C.

Where a permeable aquifer can be found at appropriate temperatures and depths (to date this has almost invariably been around the ring of fire), hydrothermal solutions are likely to dominate. However, away from these relatively rare circumstances, EGS, Greenfire and Eavor-Loop™ can fill the gap.

5. CONCLUSIONS

The geothermal energy capacity of usable land mass is 25,600 GWe or 224,256 TWh. Only a tiny percentage of this potential is being used today.

By continuing to expand the use of ground source heat pumps, and by exploiting the emerging closed-loop technologies, any country or community will be able to plan its energy transition from fossil fuels to green baseload geothermal power. Government plays a huge role by incentivizing development through feed in tariffs and subsidies because technology is always more expensive in early stage developments.

These emerging technologies are beginning to make geothermal scalable, because they enable development away from conventional reservoirs, and will allow geothermal energy to take its place as an equal partner alongside wind and solar in the transition to a green economy.

The economic viability of geothermal energy development depends on five primary factors, and these are important considerations for Governments wishing to create an attractive investment environment:

- Exploration risk in finding a permeable aquifer (eliminated with closed-loop technologies)
- Conductivity of the rock (for closed-loop technologies)
- Drilling costs largely limit current focus to sedimentary basins. However, technologies are emerging which should make it economically viable to drill igneous rocks by 2030.

- Temperature gradient
- Price. Several countries (or large corporations) have already recognised the potential for geothermal energy to displace fossil fuels and have begun to encourage investment by offering subsidies, grants and feed-in tariffs. Places like France, Germany, Switzerland, Netherlands and Japan have excellent subsidies and/or feed in tariffs for heat or electricity in place.

Figure 13 below illustrates the relative applicability of each geothermal energy technology discussed in the paper based on subsurface temperature and rock permeability.

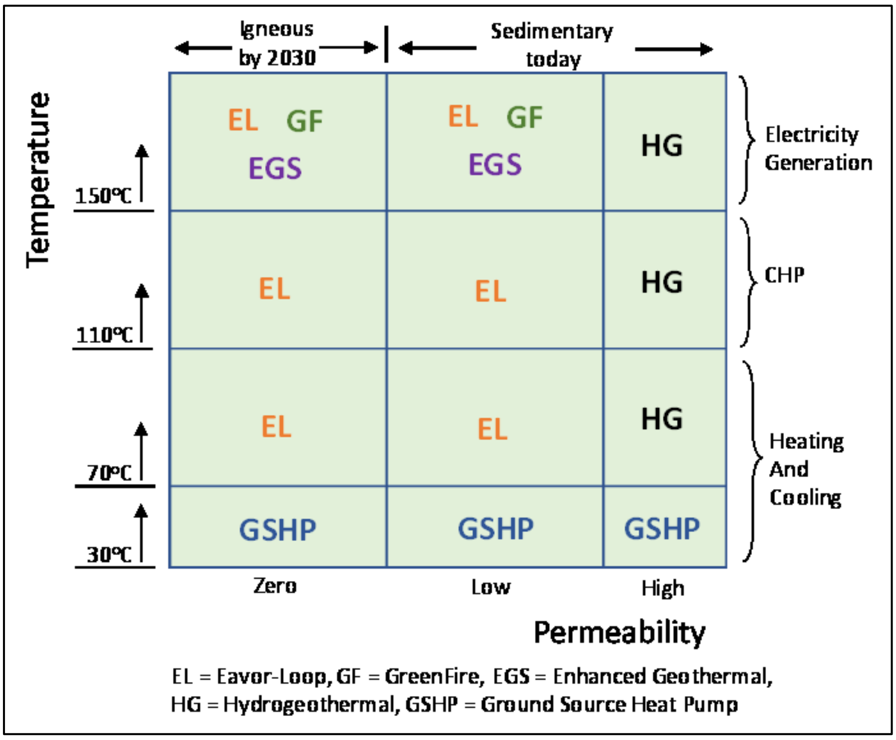

Figure 13: Relative Applicability of Geothermal Energy Technologies

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