Global geothermal energy

It is generally accepted that a wide range of sustainable and integrated energy sources are going to be needed to reach the greenhouse gas (GHG) targets set by the world community at COP meetings, in order to prevent global temperatures from rising to 2˚C above pre-industrial levels. To this end, the use of solar and wind power has increased dramatically over the last few years, but what happens at night time, when it is cloudy or the wind drops?

Step forward energy from within the Earth itself. Originating in the heat generated when the planet was first formed and constantly regenerating through radioactive decay, geothermal energy is always there and fully sustainable. It has been used as a local heat source for millennia, as well as more recently to generate electricity in places where there is a high heat flow close to the surface of the Earth (Figure 1).

But accessing geothermal energy need not be confined to these regions – in fact, there is potential for utilising it throughout the globe.

Heat from within the Earth

The temperature of the Earth's subsurface rises with distance from the surface. This gradual change, known as the temperature gradient, is usually approximately 25˚C for each kilometre of depth, increasing up to temperatures in excess of 900˚C where rock may be in a molten state – magma. Near plate boundaries and volcanic centres, such as the Pacific 'Ring of Fire', magma rises towards the surface where it heats underground aquifers to temperatures of 350˚C or more and pressurised water escapes in the form of geysers, hot springs, and steam vents. These surface emanations have been utilised for decades in places such as Iceland, Italy, New Zealand, and California, the US (Figure 2). Naturally occurring hydrothermal fluids such as these can be used directly to heat buildings, greenhouses, and swimming pools, or, where hot enough, they can be used to produce steam for electrical power generation.

However, rather than rising to the surface, most of the heat remains locked in the Earth, and this is where its potential as a global sustainable energy source lies. Geothermal energy is now being developed in a variety of different geological settings throughout the world; all it requires is a system by which fluids heated within the subsurface can be accessed by drilling. These hot fluids may be naturally occurring water or brine, in pores and fractures in permeable rocks. If the hot rock does not contain enough natural cracks for the fluid to flow easily, it can be artificially fractured and a fluid circulation system developed. Sometimes the rock does not contain sufficient water to give commercially useful flow rates, in which case additional water can be pumped from the surface into the hot dry, fractured rocks, where it is heated by conduction. Once the hot fluid comes to the surface, whether by pumping or under natural convection, it can be used to produce steam for power generation, and in many cases the water cooled after use is pumped back into the aquifer to create a circular system (Figure 3).

Historically, geothermal developments were located close to surface expressions of natural hydrothermal geofluid circulation systems, often in igneous or metamorphic rock areas. However, recent advances in technology give increasing

Figure 1. Pressurised water escapes in the form of a geyser, a common sight in Yellowstone National Park, USA. Image courtesy of Greg Rhodes.

Dr Ellie MacInnes, Head of Geothermal, CGG, UK, looks at how geothermal energy, with the help of geoscience, can be accessed throughout the world – and how the add-on value chain is crucial to economically exploiting the resource.

capability for finding hidden geothermal systems and for accessing geothermal energy from sedimentary basins.

Geoscience has the answers

Since this energy is based within the Earth, geoscience is the route to finding the optimum ways to access it. In order to do this, it is important to understand not just areas of high heat flow in the subsurface, but also how permeable and porous the rocks are and whether fluids will flow through them easily or if fracturing will be needed. Being able to recognise how rocks respond chemically and physically to heat and pressure, and how they change when fluids pass through them, makes it possible to assess how easy it will be to drill through them to access geothermal fluids.

Companies that have worked in the oil and gas industry for many decades have built up a valuable and detailed understanding of the Earth and its subsurface. One such company is CGG, a global geoscience technology and HPC leader that has been collecting and interpreting geoscientific data for over 90 years. Its geoscientists can draw on their knowledge, skills, and technologies to bring valuable intelligence and capabilities to help better understand and de-risk the development of geothermal energy throughout the world. Over the last 20 years, for example, CGG has undertaken more than 150 geothermal projects, mostly applying geophysical technologies such as analysis of magnetotellurics, gravity, and microseismicity in traditional areas such as the 'Ring of Fire', but latterly also helping companies explore and develop 'hidden' geothermal resources using these techniques (Figure 4).

Over the years, CGG geoscientists have collected extensive databases of the important parameters that need to be understood in oil and gas exploration, and many of these, such as temperature gradients, porosity, permeability, fluid chemistry, and flow rate, are also essential for geothermal projects. All this data has been merged with the company's extensive seismic library to develop a geoscientific understanding of the Earth which can help identify new potential areas for the development of geothermal energy projects. Using this information, CGG recently completed a global Geothermal Resource Assessment study that can be used not only to identify and assess potential promising geothermal energy sites, but also to analyse the nature of the geothermal reservoir rock and provide information on production and monitoring solutions (Figure 5).

Sedimentary basins have been a major focus for the oil and gas industry, but they are of interest to the geothermal industry, not only because over the years a great deal of geological knowledge has been gathered about them, but because, unlike volcanic areas, they are often close to population centres and therefore any geothermal resource developed in them will have a ready market. The aquifers of the Paris Basin, for example, have been providing district heating for over 700 000 people for more than 30 years. However, key properties of the producing layers, such as distribution of porosity and permeability, which will identify the rocks with high rates of fluid flow that will make future development of this resource more effective, remain poorly understood. To reduce this uncertainty, a recent study by CGG, using established oil and gas techniques such as seismic inversion and recently developed rock physics-guided deep neural networks, was able to characterise the reservoirs and guide the location and design of future geothermal wells.

In oil and gas field areas, the percentage of water co-produced from the subsurface reservoir increases as the hydrocarbons are extracted. This water, which is usually discarded or pumped back into the reservoir, can be at temperatures high enough to be used directly for heating or in some cases to generate electricity. There are some technical challenges – the higher flow rates needed for useful geothermal energy production may need a wider

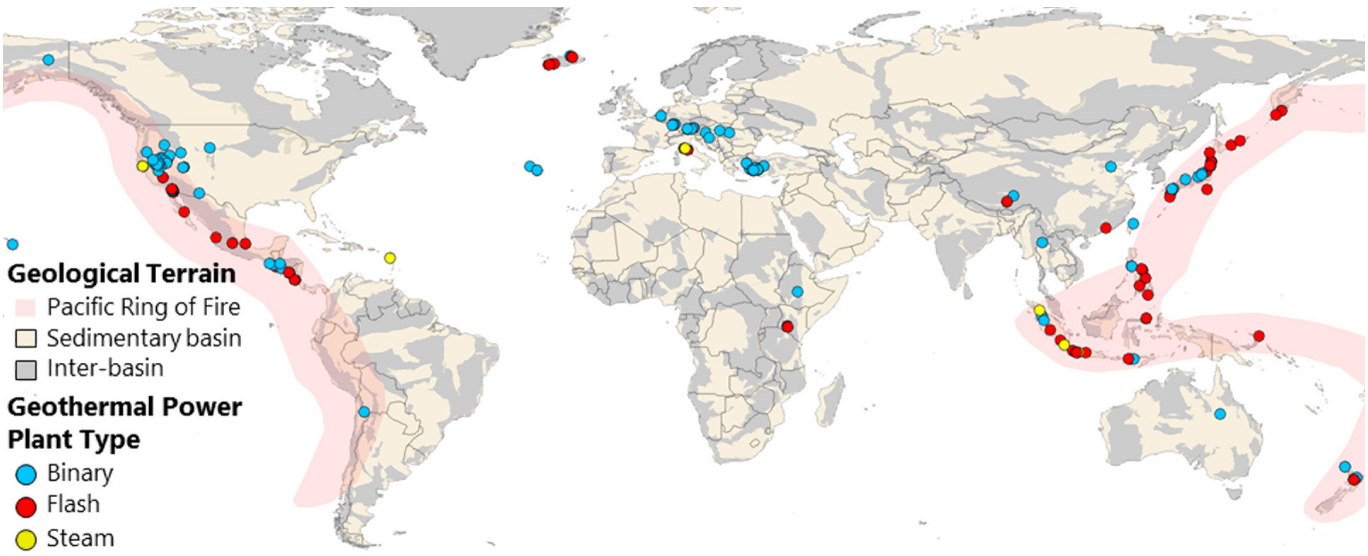

Figure 2. The map shows the location of geothermal power plants, which are mostly concentrated around the Pacific 'Ring of Fire'. Sedimentary basins are identified as areas of future geothermal energy growth.

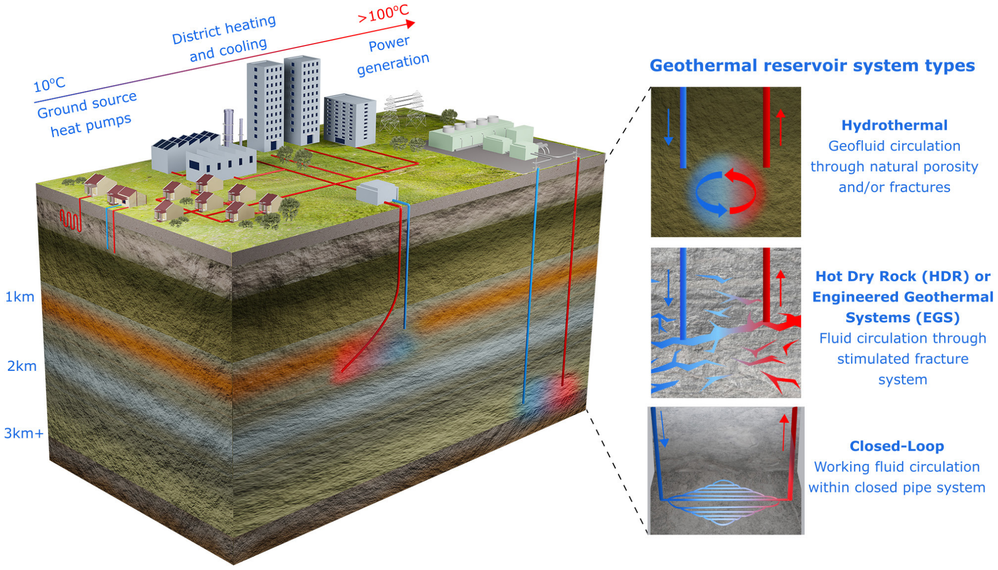

Figure 3. Multiple geothermal energy uses and technologies dependent on the depth to reservoir, heat available, and energy needs.

provide much more additional heating in the Arctic than in the Tropics.

If the geothermal resource is hotter than approximately 120˚C, it can be converted directly to electricity using flash, steam, or binary turbine systems and supplied to the grid. As the water cools, it can be recycled, with cascading uses as the temperature drops. Geothermal fluids of less than 120˚C can be used directly to heat or cool residential and industrial premises, for some manufacturing processes, and in agriculture and fish farming, all without access to a power grid or without imposing extra demand on an existing power grid. Other uses for thermal energy include drying industrial cement and aggregate and for pulp, paper, and food processing.

Since approximately 40% of carbon released into the atmosphere currently comes from domestic and industrial heating and cooling, switching as much as possible to geothermally sourced heat makes sense, through individual ground source heat pumps and on an industrial scale. China is a leader in the field of geothermal direct heat; Sinopec Green Energy has built 719 heat centres in China and drilled over 700 wells. It annually produces 15 MWe, and estimates it has saved 16 million t of CO_2 emissions since it started in 2006.[1]

After passing through flash or steam turbines, the steam is normally condensed to water for re-injection into the reservoir to maintain geothermal fluid pressures and flow rates. However, if alternative sources of injection water are available, the condensate can be used directly with minimal further treatment as potable water. In coastal arid environments, geothermal energy can be used in desalination plants, to preheat the saline water prior to final desalination using gas, for example.

As with wind, solar, and nuclear, geothermal electrical energy can be used to generate green hydrogen through hydrolysis of fresh water. The freshwater condensate from flash or steam geothermal turbines provides a self-contained hydrogen-generation system, whereas the other energy sources would need an external source of fresh water – a potential problem in water-stressed areas.

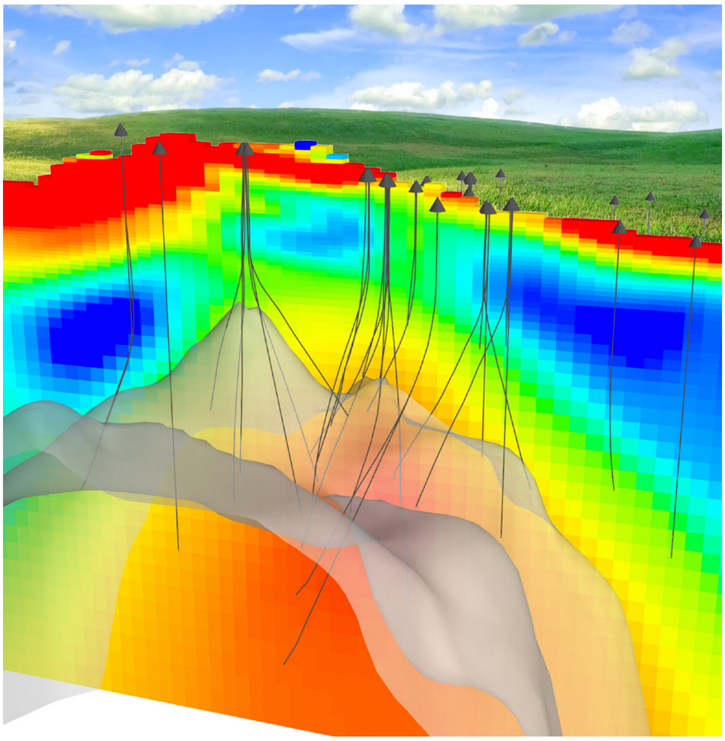

Figure 4. Geophysical 3D modelling delineates most prospective geothermal reservoir zone.

diameter borehole, for example – but it is a promising and potentially cost-effective development.

The geothermal value chain

However, accessing the natural heat of the Earth is not just about producing heat to generate electricity; there is abundant thermal energy in the fluid remaining after driving the turbines. The value of this remaining thermal energy varies with climate: 40˚C water would, for example,

A potentially very important economic benefit from geothermal projects is in critical mineral production. When brines are trapped at high pressure deep in the Earth, they often have high concentrations of minerals, including critical elements such as lithium and manganese, as well as rare earths, platinum group metals, and arsenic, all of which are in high demand for the production of batteries and electronics and the construction of wind and solar farms. If these critical minerals can be economically extracted and purified from the brines, geothermal projects would become more cost-effective at a wider range of locations.

Considerable research is being undertaken on this idea in, among other places, the Salton Sea, a shallow, saline lake in southern California, the US, that lies on the San Andreas fault and is an area of high geothermal activity, where there are already a number of producing geothermal power stations. Several of these are working on direct lithium extraction from the hot brine residuals from the power plants, and it has been estimated that the 11 existing geothermal plants along the Salton Sea alone could have the potential to produce enough lithium metal to provide approximately 10 times the current US demand.[2]

Since at the moment the value of lithium is 6 – 8 times greater than that of geothermal power, mineral extraction from brines could be the key to making geothermal projects more economic. A knowledge of the subsurface and constituents of geothermal waters may be key to unlocking this promise, and this can be provided through CGG's Lithium Brine Screening study, which evaluated more than 250 000 data points and 27 000 lithium measurements to create a comprehensive and consistent water chemistry database, supplemented by key engineering and geochemical characteristics (Figure 6).

This cascading chain of additional uses and products is an important aspect of geothermal projects, as they can deliver more than electrical energy alone.

Decades of cumulative expertise

The capabilities, technologies, skills, and understanding acquired by CGG over many years is relevant to geothermal projects because the exploitation of a geothermal project follows a similar trajectory to that of an oil or gas discovery and uses similar technologies. Initially, research may be on a global scale, aided by products such as the global Geothermal Resource Assessment study and then, akin to the exploration phase of an oil and gas project, it will move to a more regional scale, where subsurface knowledge from CGG's seismic databases will be crucial. Having identified a promising area, the project would progress to the appraisal stage, where, to understand the reservoir and predict what the resource will be, a detailed knowledge of the rock properties is key. This is followed by the development stage, in which detailed 3D structural models based on seismic, other geophysical technologies, and well data are used to ensure optimum well placement into the aquifer. Once a geothermal project is underway, reservoir modelling tools and seismic are used to monitor what is happening underground and to help to understand the flow of the fluids in the subsurface.

Therefore, to ensure geothermal projects can take full advantage of the value chain and minimise subsurface risks, it is vital that there is a good understanding of the subsurface using geoscience knowledge, including the databases, technologies, skills, and experience developed over many decades by companies, such as CGG.

References

1. 'Who We Are', *Arctic Green Energy*, https://arcticgreen.com/about/
2. CARIAGA, C., 'Entire US lithium demand can be supplied by Salton Sea geothermal plants', *ThinkGeoEnergy*, (24 March 2022).

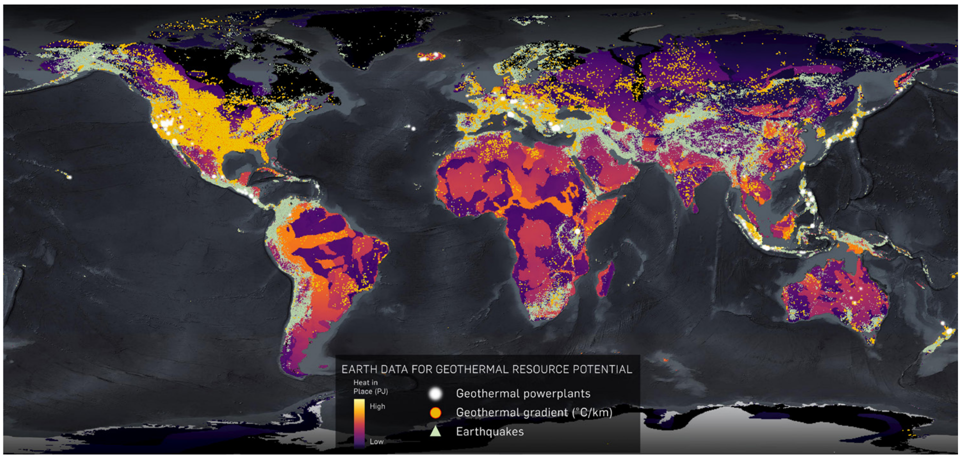

Figure 5. CGG's Geothermal Resource Assessment (GRA) study draws upon CGG's unique well, seismic, and interpretation database and experience in over 150 completed geothermal projects.

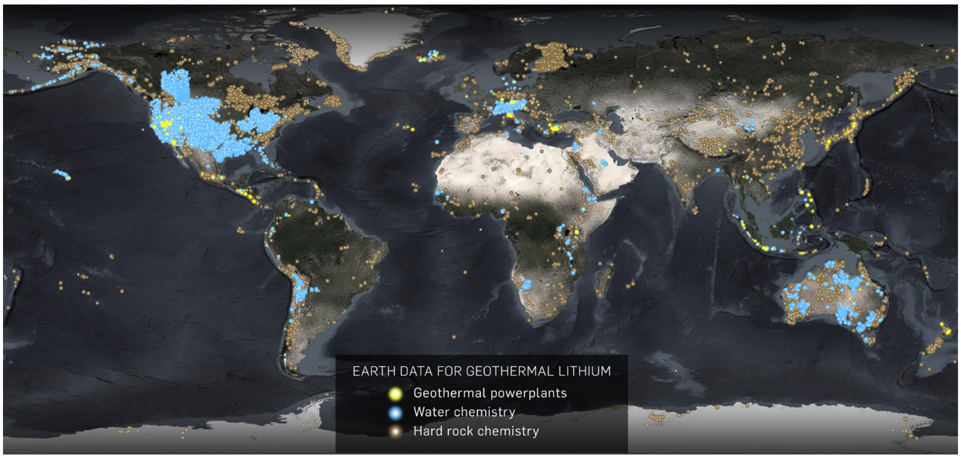

Figure 6. CGG's Lithium Brine Screening study supports client exploration for sustainable sources of lithium (and other critical elements) found within geothermal fluids. The map shows investigated screening locations for lithium brines.