Business Finance and Development in the Future Markets for Geothermal Energy

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ABSTRACT

The Accord signed by 177 nations at COP 21 in Paris last December demonstrated the breadth of the consensus around the world that the problems of global warming and climate change must be solved. At the same time, it betrayed the lack of consensus on the best means and methods to achieve such a solution, leaving the choices of means and methods up to the discretion of the various countries. Variations in the relevant conditions and circumstances in different countries support, and even require, variations in their approaches to the solution, but a solution of the global problems will require a new foundation to replace the coal, oil and natural gas that provide the current foundation. High-enthalpy geothermal resources from around the world will enable supercritical geothermal generation and electrolysis to balance the other renewable resources and, together, will power the grids in the various countries. At the same time, such geothermal energy will provide the clean hydrogen to replace fossil fuels for transportation, industry and other uses. These steps will transform not only the geothermal industry, but the entire energy industry. To accomplish these steps will require finance and other business developments in the new, supercritical geothermal industry to enable it to work economically and achieve the efficiency and power needed to solve global warming and climate change and become the cornerstone of the new, unified energy industry.

Introduction

Many countries have signed the Accord that was reached last December in Paris to stop global warming and climate change. The intent of the Accord is to curtail the production of greenhouse gases, but the Accord has left to each country the choice of the amount of the reduction to be effected by that country, and the means and methods by which that reduction will be attained. Unfortunately, the total of the reductions that have been pledged are substantially less than the amount of reductions that will be needed in order to avert serious consequences from climate change. Moreover, although the world has developed a variety of means and methods for reducing the production of greenhouse gases, there is no general agreement on which ones are most effective to stop climate change. The energy industries are not changing quickly enough to achieve the targets that have been set, and the world has, as of this point in time, basically conceded that there is no consensus on any overall solution to the problems. In fact, some of the approaches that have been promising in the past, such as intermittent wind and solar, are creating issues, such as crating imbalance in the electrical grids to which they are connected, that are causing those approaches to lose efficacy as they become more widely adopted. Others are simply too expensive and/or ineffective to be adopted widely.

Geothermal energy is both sustainable and clean, and it is baseload and highly reliable as well, but it is not generally considered to be the solution to climate change, or even a significant part of the solution, by the world as a whole or even by many proponents of geothermal energy. This arises in part because geothermal energy is not, for practical purposes, accessible in most parts of the world using current techniques. Paradoxically, in some areas in which it is easily available, it is disfavored by some utilities and other users because its virtue as a baseload source makes it a burden when there is already more electricity available than is needed. Attempts have been made, and are being made, to establish ways to operate geothermal power facilities flexibly, but such operations makes the facilities less efficient and less durable, and the electricity is therefore more expensive, and the facilities lack the power to curtail climate change effectively.

Geothermal resources can, in fact, be the cornerstone for the new, unified and flexible energy industry that is needed to reverse climate change, but not using current techniques. We must operate facilities using very high-enthalpy geothermal resources at full throttle and efficiency, and achieve the necessary flexibility by dividing the electricity produced between balancing the grid and powering electrolysis to provide hydrogen. The resources must exceed the critical temperature of water (374°C) and preferably exceed the critical pressure of water (221 bar). There must be enough of it to have a substantial effect in solving global warming and climate change. There are very few places on land where such temperatures and pressures are practically accessible. Noteworthy exceptions are Iceland and the Salton Sea, both of which are areas where ocean rift zones exist on land. There are large areas around the world, and a huge amount of such resources, under the ocean floor in ocean rift zones and other geothermal phenomena. Although there are a large number of such places, significant questions arise about the ability to reach them and harness them efficiently and effectively enough to make them a practical solution. The answer is that we can. This paper will discuss the business, finance and market aspects of this development.

The Solutions

As mentioned above, Iceland has comparatively easy access to large, very high-enthalpy geothermal resources. A consortium of national governments and energy companies is seeking to use these exceptional resources by drilling to a depth of approximately 5,000 meters in order to tap supercritical geothermal resources. It is estimated that beneath three of the developed geothermal fields in Iceland, temperatures should exceed 550°C to 650°C, and the occurrence of frequent seismic activity below 5,000 meters indicates that the rocks are brittle and therefore likely to be permeable. (Fridleifsson, *et al.*, 2007.) The engineers working on the Iceland Deep Drilling Project have calculated that supercritical geothermal fluids can provide up to ten times as much power, per unit of volume, as the geothermal fluids used in the conventional technology. The MIT Study indicated that a liter of supercritical water at a temperature of 400°C and a pressure of 250 bars "has more than five times the power producing potential than a hydrothermal liquid water geofluid at 225°C." (Tester, *et al.*, 2006.) A few years ago, the Iceland Deep Drilling Project, in seeking to drill a deeper geothermal well, drilled into magma at a depth of approximately 2,000 meters, and a temperature of 900°C. (Elders, *et al.*, 2014.) Access to vast amounts of geothermal energy can be gained through the ocean floors, under which abundant geothermal resources can be found in a supercritical state. It is estimated that supercritical geothermal resources at the Gorda, Juan de Fuca and Explorer ocean ridge zones (200 to 300 miles off the Pacific coast of northern California, Oregon, Washington and British Columbia) are likely to exceed several hundred gigawatts. (Elders 2015a; Elders 2015b; Elders 2014) Supercritical geothermal resources will enable the generation of electricity through the use of recompression closed Brayton cycle turbines, having significantly higher conversion efficiency than Rankin cycle turbines, powered by supercritical CO2 as the working fluid, which is still in the development stage for nuclear power plants and has not previously been considered for geothermal plants. These advancements, to develop a very high-temperature and therefore very efficient form of geothermal generation, will make geothermal energy (already highly reliable, with availability factors over 90%, and very friendly to the environment, with no negative effect on the land surface or the atmosphere) more affordable, by reducing the levelized cost of geothermal power below the levels of other forms of generation. (Shnell *et al.*, 2015) For example, the Department of Energy has projected that the levelized cost of electricity in 2020 will be less than $50 per megawatt/hour for geothermal, while it will be approximately $75 per megawatt/hour for wind and for advanced combined cycle natural gas, and in a range of approximately $100 to $175 per megawatt/hour for solar photovoltaic, depending on its location. (U.S. Energy Information Agency, 2015) Such generation, being both bountiful and inexpensive, will form the foundation for a further innovation, the direct use of supercritical geothermal resources to provide heat, in addition to electricity, to produce hydrogen by supercritical electrolysis. This advance will enable the restructuring of the transportation and electrical energy industries so that the provision of inventories of transportation energy (in accordance with current industry practice) serves as a buffer for the load following demands of balancing the electricity grid. In addition, the ocean geothermal system can be operated in coordination with other energy sources such as wind and solar power or on a stand-alone basis to transform the energy generation and delivery industries. Geothermal resources are accessible in the ocean floor globally. Abundant resources are easily available near Iceland and the West Coast of North America, but such resources in fact wrap around the world.

Unfortunately, the wind and solar projects from which the utilities are purchasing much of their renewable requirements provide intermittent power rather than baseload power. As the intermittent power in the system approaches 33% of the load, the grid at certain times of day can become unstable, and it becomes necessary to adjust the supply of electricity to "balance" the demand by making expensive spot purchases, and to acquire the related "ancillary services" by which the security and quality of the electricity supply is ensured. (The Federal Energy Regulatory Commission defines ancillary services as "those services necessary to support the transmission of electric power from seller to purchaser given the obligations of control areas and transmitting utilities within those control areas to maintain reliable operations of the interconnected transmission system.") Nevertheless, the United States and many other countries are planning to increase their reliance on intermittent renewable resources, and some countries around the world are considering adopting, or have already adopted, a 100% renewable portfolio standard in their desire to fight climate change. In fact, the leaders of the "G-7" recently announced that their countries will adopt 100% renewable portfolio standards.

Another major factor creating greenhouse gases is the combustion of fossil fuels for transportation and heating. One possible replacement for fossil fuels is electricity, but there are drawbacks to the use of electricity for transportation and the sales of electric cars, for example, are far short of the level that will be needed to solve the problem. Another possible replacement for fossil transportation fuels is hydrogen, but over 90% of the hydrogen used today is provided by steam reformation of methane or other methods using fossil fuels, all of which actually produce additional greenhouse gases. This problem can be mitigated by generating electricity from renewable resources to produce hydrogen by electrolysis (which, at standard conditions, is too inefficient to be cost-competitive) if current methods of electrolysis are made more efficient and less expensive. Electrolysis of water becomes more efficient when operated at supercritical temperatures and pressures. When electricity generated using supercritical geothermal energy is not balancing the electricity grid, it can be used, along with additional heat from the geothermal resources, for supercritical electrolysis to create inventories of hydrogen for the transportation sector. When electricity is needed for balancing the grid, the amount used for electrolysis could be reduced in seconds and the power sent directly to the grid. The flexibility to respond to both the need for balancing and the need for hydrogen fuel would be accomplished by the proposed approach, combining electrical generators that use supercritical geothermal resources with electrolysis of water heated by additional such supercritical geothermal resources to produce hydrogen. (Shnell *et al*., 2016)

Hydrogen can be produced efficiently by electrolysis of geothermally heated water, using off-peak geothermal electricity that would otherwise be stored in batteries. As mentioned above, geothermal power plants operate at a constant rate, so the electrolysis can run all the time, justifying the higher capital investment needed for the most efficient cells. If the necessary associated technical problems are overcome in an economically viable manner, it should be possible to produce the least-expensive hydrogen. In contrast, current proposals for electrolysis using renewable energy would occasionally use excess power from intermittent resources that have a higher levelized cost of electricity than geothermal and, because they only run occasionally, will support only less-efficient electrolytic cells producing more-expensive hydrogen. The higher capital costs of highly efficient electrolysis, and the volume of hydrogen that will be needed to replace carbon-based transportation and heating fuels, will require baseload geothermal energy, not intermittent renewables. This use of geothermal will not only increase the contribution of geothermal to the overall portfolio of renewable resources, it will also, by providing the capacity to balance the grid, avoid the decrease in capacity and energy values of wind and solar power that arise from balancing problems, and enable those renewables to expand more rapidly as well. The hydrogen will go into the kind of inventories in which the economy has always kept transportation and heating fuels, so hydrogen is a form of storage that will not impose an additional expense or burden on the economy.

The flexibility provided by this system will be increasingly important in the future because the specifications and characteristics of the turbines and of the electrolytic cells, such as the preferred electrodes and the preferred membranes, will evolve. In the longer term, flexibility will be needed by the entire energy industry as the energy needs of countries change, the climate changes and technologies change. With such flexibility, all of the major forms of renewable energy can be built more rapidly to replace fossil fuels more quickly. The utility can sign a power purchase agreement with a wind or solar facility and not have to worry about that facility being intermittent as long as enough geothermal capacity is committed to balance it; on the other hand, the developer of a geothermal facility will not have to worry about too many wind or solar facilities being built as long as the geothermal facility can convert its energy to hydrogen. If the technology and economics of this approach are favorable, hydrogen could also be used in place of fossil fuels in existing power plants, if such plants are retrofitted for the new fuel, with no need for new electricity plants or transmission lines; most of the existing plant and infrastructure might continue to be useful in many cases, and such changes could greatly accelerate the move away from fossil fuels. The owner of a concentrating solar facility could use electrolytic cells as well, but such a facility is likely to be too intermittent to work well in support of an electrolyzer. Such a facility may, however, work efficiently in conjunction with a high-enthalpy geothermal power-and-electrolysis plant. In general, if the grid has a surplus of electricity, the excess could be transmitted to geothermal facilities, where it could be used for short periods to create overpotential in the electrolytic cells and provide even more hydrogen.

Business Development, Finance and Market Analysis

The geothermal industry will develop significant new areas of business due to the solutions described above. The flexibility to provide baseload electricity to the grid when needed for balancing and, when it is not needed for the grid, to use it to power electrolytic production of hydrogen will introduce geothermal to two new roles. Grid balancing is already a serious need in areas, such as California, where a lot of intermittent renewables are already in use and California is planning to invest billions of dollars in batteries to solve the problem. The development of geothermal resources would be a much better solution. It would actually produce electricity, and cheaply, rather than just storing it. It would, moreover, by enabling the more rapid development of even more intermittent renewables create an even greater need for geothermal. In areas where adequate electric transmission lines to transmit the geothermal power are not available, grid balancing could be provided by retrofitting existing coal- or gas-fired power plants to run on hydrogen that could be supplied by railcars or by ship.

The replacement of fossil fuels with hydrogen for transportation and heating will be a vast opportunity for geothermal energy. The markets for gasoline, diesel and other petroleum products are immense, global markets served largely by tankers and by pipelines. There is no reason that hydrogen cannot be transported by tankers and pipelines to serve the same global markets. For this new opportunity for geothermal energy, again, it will not be constrained to markets that can be reached by electric transmission lines because geothermal, and the entire energy industry, will have the flexibility of supercritical electrolysis supported by supercritical geothermal heat. The geothermal industry should in the future harness supercritical resources, first in Iceland and the Salton Sea area in California, and thereafter those which are accessible in the ocean floor (Shnell, 2009). In California, some parts of the Salton Sea geothermal field having temperatures exceeding the critical temperature are likely at ~3.5 km depth. This creates the possibility of large-scale production of hydrogen to alleviate the serious levels of greenhouse gas and air pollution produced by combustion of fossil fuels in Southern California. Progress towards this goal could get a quick start by adding electrolytic cells to existing high-enthalpy geothermal facilities that are operating at the Salton Sea today. As the new technologies are developed further, supercritical geothermal resources just a few hundred miles off the West Coast can be developed, then similar resources farther off the East Coast and in the Caribbean and ultimately around the world, providing the global cornerstone for the renewable energy solution to global warming.

Not only are the energy industries changing at an accelerating rate, so are the sources and forms of financing for their research, development and deployment. Support by national governments for research in numerous areas relating to energy has increased and many nations have promised to increase it further. The number and size of national and international agencies involved in financing the deployment of new energy facilities, at home and abroad, has grown substantially in recent years, and is expected to continue growing. In the U.S., the states are also increasing their financial support for the deployment of new facilities. California has recently initiated its cap-and-trade program, which is creating new revenues to be dedicated to uses that will support the state's climate action goals to reduce greenhouse gases. For example, one long-standing problem of the geothermal industry, reducing the initial cost and risk of drilling new wells to start a geothermal project and thereby clearing the hurdle that delays and even stops many geothermal developments, could be accomplished by loans and guarantees made from the cap-and-trade surplus, which loans could be secured by the rights to the wells drilled (so that those wells might be finished usefully at a later time if the project for some reason is not completed successfully on the first attempt). California has also recently initiated "Enhanced Infrastructure Finance Districts," which are stand-alone districts that can be created by local counties and municipalities which can finance over periods of up to 45 years the construction of local energy projects of types approved by California (which could include, for example, updating service stations to dispense hydrogen in increasing amounts). New York has recently created a fund of $5 billion to support clean energy infrastructure and related projects over the next 10 years. Such activities have led, and will continue to lead, to increasing research, development and deployment of energy projects through innovations and expansions in the use of public-private partnerships between private developers and other parties, on the one hand, and the affected local, national and international governments and their agencies, on the other hand, that are interested in the success of such projects. (Shnell and Khosharay, 2016)

The geothermal industry will open up to two vast and growing new markets, one to provide the balancing that is increasingly needed by electricity grids as more and more intermittent renewable energy replaces fossil fuels, and the other to replace fossil fuels in the global markets for transportation, industrial and other fuels. These new developments will lead to a unified energy industry in which electric power and fuels can be flexibly produced as needed because of supercritical geothermal generation and electrolysis, and geothermal energy is no longer limited to the markets it can reach with an electric transmission line, because hydrogen can be transported all around the world, and can be used to supply all the various forms of energy.

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