DOCKETED

Docket Number:	17-GRDA-01
Project Title:	Geothermal Grant and Loan Program Workshop and Discussion
TN #:	217070
Document Title:	Jim Shnell Comments Supercritical Geothermal Cogeneration
Description:	N/A
Filer:	System
Organization:	Jim Shnell
Submitter Role:	Public
Submission Date:	4/16/2017 10:19:02 PM
Docketed Date:	4/17/2017

Comment Received From: Jim Shnell
Submitted On: 4/16/2017
Docket Number: 17-GRDA-01

Supercritical Geothermal Cogeneration

Additional submitted attachment is included below.

Workshop re: Geothermal Grant and Loan Program

Docket No.: 17-GRDA-01

Organization: Ocean Geothermal Energy Foundation

Comments re: **Supercritical Geothermal Cogeneration**

The Notice of Workshop referred to above indicates that the Agenda for the Workshop would include several issues to be addresses. The issues that are addressed by the following comments are: (a) the status of geothermal development and utilization in California; and (b) opportunities to expand and support the use of geothermal energy throughout the state. With respect to issue (a), the Ocean Geothermal Energy Foundation would concur that the current status of geothermal development in California is good, there is much need for improvement, and the comments explore a strategy and the technologies for expanding greatly the opportunities for geothermal energy in the future.

The Notice states that currently California has the potential for 4,000 megawatts of additional utility-scale power from geothermal, but recent research and development indicates that the additional capacity is over 60,000 megawatts. This greater capacity is the result not only of finding more resources than were previously recognized, but even more from finding much higher quality resources. Recent research has found that some of the resources in the Salton Sea Known Geothermal Resource Area can reach supercritical water conditions. Beyond the "critical point," which is 374C and 221 bar, certain of the properties of water change dramatically from the properties of liquid water or steam, and those changes permit much greater efficiency in both the generation of electricity (using the Brayton cycle) and in the electrolysis of water to produce hydrogen. One "byproduct" of these processes is enough "waste" heat to propel a new form of desalination of water that is being researched now. All of the foregoing processes can be combined in a new form of cogeneration. These additional, high quality resources were first found near the Salton Sea area but may also be found at existing geothermal facilities at The Geysers and the Coso Geothermal Field and are reachable in immense quantities in the ocean floor about 200 miles from the coast of California.

The Notice also states that the GRDA Program provides financial assistance to promote research into and development of California's vast geothermal energy resources. These comments call for the research, design and development of a cogeneration system that will use very high-temperature geothermal resources to balance the generation of electricity for the grid, produce hydrogen by electrolysis to eliminate the need for gasoline and use the "waste" heat from those processes to produce pure water by desalination to supply the water needed for electrolysis and for other uses (the "Project"). These innovations will enable producers to use energy from supercritical geothermal resources to balance electricity grids and increase their reliability, with an efficiency that will reduce the cost of energy, instead of increasing that cost and will, in combination with wind and solar power which can now be balanced efficiently and economically, enable California to reach a 100% renewable portfolio standard. The secondary goal is to research and develop the innovations to enable the excess energy that is not needed to balance the grid to be used to reduce California's production of greenhouse gases, in accordance with the state's statutory energy goals. The Project will develop the scientific and technical knowledge to advance electrolysis to be performed using supercritical water, to employ a number of special properties of supercritical water that will render such electrolysis much more efficient, and therefore less expensive, so that the goals described above will provide economic as well as environmental benefits. This Project is designed to research and develop the technology by which load following could, under appropriate conditions, be achieved more economically and effectively by using geothermal resources both (A) to generate electricity both for sale and for electrolysis to produce hydrogen as a non-polluting transportation fuel, and (B) to preheat the feedwater for such electrolysis. As both power generation and electrolysis of water are more efficient at high temperatures, the best environment to test this concept is at very high temperature, preferably supercritical, geothermal reservoirs. In Iceland, the Iceland Deep Drilling Project (IDDP) aims to investigate such supercritical geothermal conditions. In 2009 Phase 1 of the IDDP created the hottest geothermal well in the world (450°C) but it was too shallow to reach supercritical pressures. Phase 2, in December 2016, drilled to greater depth and reached the appropriate pressure and temperature conditions. In California, the Salton Sea and the Geysers geothermal fields both offer high temperatures at drillable depths. In fact, in some parts of the Salton Sea geothermal field temperatures exceeding the critical temperature are likely at ~3.5 km depth and in some parts of the Geysers geothermal field temperatures exceeding the critical temperature appear to occur at ~4.0 km depth. This creates the possibility of providing baseload energy efficiently and inexpensively using supercritical temperatures and producing large volumes of clean hydrogen to alleviate the serious levels of greenhouse gas and air pollution produced by combustion of fossil fuels in Southern California. Massive battery storage of electricity will not be necessary because the Project will integrate to support increased levels wind and solar power in a balanced grid.

The Project as a whole is needed because it is designed to create a cogeneration system in which the various technologies that are being developed operate in mutually supporting ways, as well as combining to resolve all of the issues and problems. For example, as parts in a cogeneration system: the electrolyzer not only produces hydrogen as a clean fuel (94% of hydrogen is currently produced by steam reformation of methane or other means that also produce greenhouse gases) to replace petroleum and curtail greenhouse gases and other pollution, it also converts into hydrogen (and thereby stores) the electricity when it is not needed to balance the grid; the geothermal turbine generates electricity not only to run the electrolyzer, but also to balance the grid when necessary; the geothermal well system produces the energy not only to generate the electricity, but also to heat the feedwater for the electrolyzer and make the electrolysis more efficient; and the desalination plant not only produces pure water for use by the electrolyzer (which is valuable water because it is turned into a replacement for gasoline) and for other local needs using "waste heat" released by the turbine and electrolyzer, it makes the turbine and the electrolyzer more efficient by absorbing the heat that the turbine and the electrolyzer need to reject (a task that generally requires a cooling tower – which will not be permissible in the Salton Sea area given the lack of water – and will otherwise generally require air cooling, which is less efficient).

The proposed SGC approach makes dual use of geothermal resources having temperatures above the critical temperature of water to power the combination of generation and electrolysis. The combination will make geothermal energy flexible enough to provide the electricity to balance the grid, and the energy to produce hydrogen to replace fossil fuels when such balancing is not needed. Electricity from geothermal power using current technologies at $50 per MWh is cost competitive with other forms of generation. *See* U.S. Energy Information Administration, Levelized Cost and Levelized Avoided Cost of New Generation Technologies in the Annual Energy Outlook 2015 (AEO2015) . SGC will use geothermal resources at supercritical temperatures and pressures, more efficient than the current technology, so the cost of electricity from the proposed approach will be lower. Supercritical geothermal fluids can provide six times as much power per liter as the geothermal fluids used in current geothermal systems; the new wells are more expensive to drill, but they will more than compensate for the higher cost by the much greater energy they produce. In addition, supercritical turbines are more efficient than steam turbines, and temperatures of 500°C will enable the use of supercritical turbines that, in a closed-loop recompression Brayton cycle, can generate electricity with a plant efficiency of 50%. These factors lower the projected cost of geothermal electricity by 20%, to $40 per MWh.

As noted above, California is a world leader in installed electrical generating capacity from geothermal resources, with The Geysers in northern California having the world's largest power production from a single field. The second largest geothermal electric power production in California is from the Salton Sea Geothermal Field (SSGF), in the Imperial valley of Southern California, which has an installed generating capacity of 392 MWe. This is produced from 11 turbines that utilize steam from production wells with temperatures of 250° to 300°C that are typically 1.5 to 3 km deep. A recent estimate of the SSGF reserves indicates that this reservoir could generate 2,950 MWe for 30 years (Kaspereit et al., 2016). A new field operator has recently announced its intention of building an additional 300 MWe, utilizing new wells in the northern part of the field.

Despite its huge heat content, development of the SSGF resource has lagged other geothermal fields, such as The Geysers, because of a unique feature, the very high salinity (up to 25 wt. % TDS) of the reservoir brines. This initially presented a problem in brine handling, which was overcome in the 1980s by the creative chemical engineering being used in the power plants operating today. Along with power generation, part of the scheme for future development involves extraction of valuable metals from the brines, such as lithium, providing an additional revenue stream that could eventually exceed the revenues from power sales. The work proposed here takes a broader, and longer term view of the development of the SSGF resources, by considering production from the deeper, hotter part of the system, and adding flexibility to its downstream utilization.

In the international geothermal community, there is a growing awareness of the exciting potential of very high enthalpy geothermal resources associated with young, or even active, volcanic systems (Elders, 2013). Although the costs of drilling of deeper, hotter, wells may be three or four times the cost of conventional geothermal wells, the power output for higher enthalpy wells should be 5 to 10 times greater, so that fewer production wells are needed, with both cost savings and smaller environmental footprints. The government of New Zealand has funded the multiyear project HADES (Hotter and Deeper Exploration Sciences) to carry out a resource assessment of geothermal systems as deep as 7 km. In Japan, the project JBBP (Japan Beyond-Brittle Project) is planning to create Enhanced Geothermal Systems in 500°C young granites. The ultra-high enthalpy project that is most advanced is the IDDP (Iceland Deep Drilling Project; www.iddp.is). In December 2016, the well IDDP-2 met success when it penetrated supercritical conditions at 4.64 km depth (bottom hole temperatures >450°C and fluid pressures of ~340 bars, with good permeability).

If the study described below yields favorable results, it would serve as the basis of study for a future project to drill and test an ultra-high temperature geothermal well at the Salton Sea. This would build upon the experience of the projects already underway in Iceland, Japan, and

New Zealand. Its initial implementation would be the drilling of a demonstration exploratory well at an optimal site in the SSGF. Such a project would advance the capitalization and development of ultra-high enthalpy, sustainable, geothermal resources.

Geothermal power generation has traditionally been reliable "baseload" power and this is both an advantage and a disadvantage. While, unlike solar and wind power, geothermal electricity can be dispatched 24 hours a day, this does not mitigate an increasingly acute problem in California of balancing supply and demand when the solar power declines before sunset. The work we are proposing will address this issue in a different way that should add value to the geothermal resources of the SSGF. We will examine the feasibility and economics of using the geothermal electricity to power electrolytic cells to form hydrogen as a fuel. The higher temperature of the water in the cells allows higher efficiency of the electrolysis process. We can use the high enthalpy of the water separated from the steam-brine mixture produced from deeper, hotter, wells to heat the water used in the electrolysis.

The Salton Sea Geothermal Field (SSGF) is currently the second most productive geothermal field in the U.S., but is believed to hold total reserves of 2950 MW (Kaspereit, 2016), potentially the largest of any geothermal field in the world. The SSGF is located in a continental rift zone where the extensional tectonics of the Gulf of California transition to the strike-slip San Andreas Fault, resulting in thin continental crust and elevated temperatures at shallow depth. The SSGF is well known for hosting fluids with temperatures exceeding 370°C and salinities greater than 25 wt.% in a continental rift environment undergoing active metamorphism to amphibolite-grade metamorphism (Elders et al., 1972; Osborn, 1989; Elders and Sass, 1990). Under hydrostatic pressure, these hypersaline fluids elevate the supercritical point to over 625°C (1150°F; Driesner and Heinrich, 2007), well above the temperatures accessible with current drilling and well completion technology.

In particular, the Project's research and development of the new tools designed to be used for very high-temperature geothermal resources will provide an extensive benefit to the local community. The Salton Sea KGRA has very extensive geothermal resources (*see* Kaspereit, above). Some of those resources are being used currently, but much more remain to be developed (*ibid*). Current circumstances prevent the economic exploitation of all of the resources, and the geothermal industry currently lacks the tools it needs to exploit the most valuable, high-energy resources. Some of the resources have already been found to be hotter than the critical temperature of water. The tools that will be developed by the Project can be used to develop all of the geothermal resources around the Salton Sea area, especially the tools that are designed to make use of the resources at temperatures higher than the critical temperature of water. The success of the Project will not only increase the importance of the geothermal resources around the Salton Sea, it will increase the importance of the other geothermal resources around California. The importance of the other renewable resources around the Salton Sea will increase because of the ability to balance the intermittent renewables.

The tangible benefits to be realized by using the research and development produced by the Project will include substantial economic and employment benefits to the Salton Sea area, which is one of the most economically disadvantaged in California. Initially, there will be considerable amounts of investment in new plant and equipment, not only for new electrolysis facilities and new desalination facilities but, as the current oversupply of geothermal electricity is absorbed, there will also be construction of new generating facilities. The wells alone will represent a significant level of investment and local job creation, giving the local economy a quick boost. The quick boost will over time convert into long-term employment, as the operation and maintenance of geothermal facilities requires more labor input than the same functions for wind or solar power. Not only the wells, but the new equipment will be "high tech" and will add to the level of local investment, which should greatly increase the level of property taxes collected by Imperial County. It will also support the local growth of general commerce and industry (largely through the improved supply of basic commodities such as electricity, fuel and water) and of agriculture. In addition to the economic and employment benefits, the Project will also provide tangible environmental benefits, not only by helping to preserve the Salton Sea, but also by curtailing pollution and saving the health of people in the area. The savings in local healthcare costs could be very significant, under the circumstances. It can also be anticipated that local tourism and other economic factors will rebound, as a result of the improvements. The benefits are achieved by investing in new systems, and the investments create higher property values and therefore higher property taxes for the benefit of the County.

It is anticipated that the Project will expand greatly the scope and effect of the geothermal industry in California by opening major markets for geothermal energy relating to the balancing of the electrical grid, and to transportation and other fluid fuels by replacing current fuels with hydrogen, locally and statewide. California and the geothermal industry will benefit from a substantial increase in the amount of Federal royalties returned to the Geothermal Resource Development Account, for use in further advancing the geothermal industry. The State, and those counties in which geothermal resources are located, will benefit from an increase in property taxes. The balancing of the grid will enable accelerated development of all renewable forms of energy, leading to lower emissions of greenhouse gas and pollution, and a unified and flexible energy industry that will be better able to support the economy and protect the environment.

Supercritical Geothermal Cogeneration (SGC) uses geothermal resources at a temperature higher than the critical temperature of water to generate electricity and create hydrogen at very high efficiencies using supercritical generation and electrolysis in a combined, flexible, and thermally integrated energy plant. SGC solves two problems: the increased need to balance the grid due to increasing use of intermittent renewable energy resources, wind and solar; and the creation of greenhouse gases by the combustion of fossil fuels. The results will add vast new geothermal resources and a flexible source of balancing that, together with rapidly increasing amounts of intermittent wind and solar power, will enable the energy industry to approach 100% use of renewables for both electric power generation and transportation.

The greatest need in California for the research and development of the advancements sought in this Project is in the Imperial Valley area. Long one of the most economically disadvantaged areas in the state, the local economy has been largely limited to agriculture. One exception in the past has been the presence of substantial renewable energy resources, including the greatest geothermal reserves in the United States, but the area has not developed sufficient transmission infrastructure and, because the recent growth in renewable energy capacity has been dominated by the intermittent resources of wind and solar, the demand for geothermal electricity has declined. Another problem for the area has arisen from recent changes in the allocation of water resources. As a result, the water level in the Salton Sea has been declining, and is expected to decline faster, leaving large areas of exposed lakebed to dry out and release vast amounts of dust and other pollution to be picked up by the strong winds that frequent the area. This will pollute the air not only in the Imperial Valley but in much of the rest of Southern California too, making even worse the current levels of pollution that have made the South Coast

Air Quality Management District one of the most polluted areas in the nation. Proposals have been made to overcome the water shortage, by investing funds raised by expanding the geothermal energy industry. Such plans have been frustrated by the decline in the market for geothermal energy. In addition to the local and regional issues, California's increasing reliance on intermittent renewable energy is making it increasingly difficult for California to continue to pursue its Renewable Portfolio Strategy and reduce the emissions of greenhouse gases, balance the electricity grid, and reduce the burning of petroleum; at this point, the response by California has been to burn more natural gas to generate electricity, and spend billions of dollars on batteries. All of these issues can be addressed by the increased geothermal energy, and changes in the energy industry, that would be brought about by the new technologies to be advanced by the Project.

Considerable research and development has already been undertaken with respect to the various tasks in the Project. OGEF team members from Geothermal Resource Group delivered a second update last October (*see* Kaspereit, D., Mann, M., Sanyal, S, Rickard W., Osborn, W., and Hulen, J., "Updated Conceptual Model and Reserve Estimate for the Salton Sea Geothermal Field, Imperial Valley, California," 40 *Transactions* 57-66, Geothermal Resources Council (2016)) to an earlier study of the Salton Sea geothermal resources. For an international survey, *see also* "Supercritical Geothermal Systems - A Review of Past Studies and Ongoing Research Activities," Dobson, P., Asanuma, H., Huenges, E., Poletto, F., Reinsch, T. and Sanjuan, B., Proceedings, 41st Workshop on Geothermal Reservoir Engineering Stanford University, February 13-15, 2017. Papers have been written and reviewed and published by members of the OGEF team on the use of geothermal brines at very high temperatures to drive the generation of electricity and the production of hydrogen by electrolysis, including Shnell, J. H., Newman, J., Raju, A., Nichols, K., Elders, W., Osborn, W., and Hiriart, G., "Combining High-Enthalpy Geothermal Generation and Hydrogen Production by Electrolysis Could both Balance the Transmission Grid and Produce Non-Polluting Fuel for Transportation," *Proceedings*, 41st Workshop on Geothermal Reservoir Engineering, Stanford University, Stanford, California (2016) and Shnell, J., G. Hiriart, K. Nichols and J. Orcutt, "Energy from Ocean Floor Geothermal Resources," *in* Proceedings of the World Geothermal Congress, April 19-24, 2015. One of the Project team members, Professor *emeritus* Wilfred Elders of U.C. Riverside, who was the initial Chief Scientist of the Salton Sea Scientific Drilling Program, has more recently been one of the Co-Chief Scientists of the Iceland Deep Drilling Program, which recently drilled a well that reached geothermal resources beyond the critical temperature and pressure of water. The Project team members doing the electrolysis research will benefit from extensive research and development on fuel cells, which operate in a very similar (although opposite) manner to electrolyzers. The team members from Lawrence Berkeley National Laboratory who are doing the desalination research and development have been working with colleagues at Idaho National Laboratory, who published a paper on desalination last October (*see* Wendt, D., Adhikari, B., Orme, C., and Wilson, A., "Produced Water Treatment Using the Switchable Polarity Solvent Forward Osmosis (SPS FO) Desalination Process: Preliminary Engineering Design Basis," 40 *Transactions* 147-159, Geothermal Resources Council (2016)). OGEF team members will seek to extend the focus of that work on its relevance to geothermal resources.