Hot Rocks, part 2

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1. Introduction

I really don't know what started my recent interest in geothermal resources, but I quickly remembered that hadn't been that long since I had done a major post on this subject, described and linked below.

Hot Rocks – The Perfect Renewable Energy: *This post will start in my deep past, over 40 years ago and travel several decades into the future. The subject of this post is Geothermal Power, a renewable energy source that was first used to generate electricity in Larderello, Italy, in 1904, and thus is one of the oldest renewable energy sources. It has been used in my home state (California) to generate a significant amount of our electric energy since the early 1960s.*

In 1985 I became heavily involved with the Geysers Geothermal Generating Field, what is now (still) is the largest in the world by several metrics.

However I have never posted a paper about Geothermal Power. I have decided to rectify this failure and write this post. As I started researching this, I found that this technology has not only been amazing in the past and present, it will be important to our efforts to overcome climate change in the future.

https://energycentral.com/c/cp/hot-rocks-%E2%80%93-perfect-renewable-energy

The original "Hot Rocks" post focused on mainstream geothermal power, that is, hydrothermal resources, which are considered conventional geothermal resources because they can be developed using existing technologies. The natural formation of a hydrothermal resource typically requires three principal elements: heat, water, and permeability.

I called these the "low hanging fruit" because a large number of these have been identified and developed, but there are still many undeveloped hydrothermal resources. Thus in the first section below, we will focus on existing firms that develop all types of resources. In the following sections we will focus on unconventional geothermal resources.

2. Major U.S. Geothermal Developers

The US produced 16.7 billion kWh of geothermal energy in 2018, becoming the world's leading producer of geothermal energy. The country holds geothermal plants in seven of its states that accounted for 0.4% of the country's total utility-scale electricity generation last year.[1]

[1] NS Energy, "Profiling the major geothermal power companies in the US," 02 Aug 2019, https://www.nsenergybusiness.com/features/us-geothermal-power-companies/

The following are major US Geothermal developers.

Calpine *is the largest producer of geothermal power in the US, operating several plants in The Geysers located north of San Francisco.*

The company's Big Geysers, with a capacity of 725MW, is one of its geothermal power plants operating at The Geysers in Northern California. Big Geysers is claimed to be the single largest geothermal power project in the world.

Located in the Mayacamas Mountains, north of San Francisco, the Big Geysers, which is powered by GE steam turbines, meets the power consumption needs of around 725,000 homes. The 15 geothermal power plants of the Big Geysers cover almost 60% of the average demand for electricity in the North Coast region, spanning from the Golden Gate Bridge to the Oregon border.

The Big Geysers, which has been in operations since 1980, is part of The Geysers geothermal field from which steam is drawn using more than 350 wells.

Calpine, which has a fleet of nearly 80 power plants, including natural gas-fired plants, was acquired by a consortium led by Energy Capital Partners for $16.6 billion in March 2018.

Nevada-based ***Ormat Technologies*** *claims to have developed more than 150 geothermal power plants across the world with a combined capacity of more than 2.1GW.*

The current generating portfolio of the company is located across the US, Guatemala, Honduras, Guadeloupe, Kenya, and Indonesia…

The company's other major geothermal power plants are… the 100% owned 138MW McGinness Hills Complex in Nevada, US.

In December 2018, the third phase of the McGinness Hills Complex, of 48MW, was commissioned to increase its capacity to 138MW…

Ormat Technologies, apart from being an independent power producer that develops and owns geothermal power plants, provides engineering design, procurement for geothermal projects of other companies. The company, also designs, manufactures and sells geothermal power generating equipment and also complete power plants, on a turnkey basis.

Berkshire Hathaway*'s geothermal operations, which comprise 10 geothermal power plants in the Imperial Valley in southern California, are carried out by its subsidiary CalEnergy Operations. The plants are owned by another Berkshire Hathaway subsidiary CE Generation.*

The geothermal power project in the Imperial Valley, which has a total capacity of around 349MW, is located in the Salton Sea Known Geothermal Resource Area.

The first of the company's geothermal facilities – Salton Sea 1 was commissioned in 1982, while the latest to begin operations are the CE Turbo and Salton Sea 5, which were both put into service in 2000.

Five of the Imperial Valley geothermal plants, that include Vulcan, Salton Sea 1, Elmore, Hoch and Salton Sea 3, provide their output to the city of Riverside, Salt River Project, Imperial Irrigation District, and the Sacramento Municipal Utility District under long-term portfolio arrangements.

The Leathers, Salton Sea 2 and Salton Sea 4 geothermal plants in the Imperial Valley provide their output to Southern California Edison. The Salton Sea 5 plant provides power to the city of Riverside, while the CE Turbo plant delivers its output to Arizona Public Service.

***The Northern California Power Agency (NCPA)**, a California Joint Action Agency, owns and operates two geothermal power plants with a combined generation capacity of 220MW.*

The firm operates the 110MW NCPA Geothermal Project located in Sonoma Country in California, US. Commissioned in 1983, the power plant features two power generating units each with 55MW capacity.

Additionally, it operates the 110MW NCPA 2 geothermal power plant located in the Mayacamas in California, US. (near Calpine's units in the Mayacamas).

Commissioned in 1985, the power plant features two generation units, each with 55MW capacity. The units were manufactured by Fuji Electric Systems.

Power generated by the NCPA 2 geothermal power plant is being sold to San Diego Gas & Electric, under a power purchase agreement signed earlier…

***Terra-Gen Power** operates three geothermal power plants in the US with a combined generation capacity of 86.7MW.*

The firm operates 67MW Dixie Valley Geothermal Power Plant located in Churchill County, Nevada. It was commissioned in 1988.

In 2010, Terra-Gen Power said it has closed a $286m financing for the Dixie Valley power plant, which provides power to Southern California Edison as part of long-term power purchase agreements through 2038.

Additionally, Terra-Gen owns and operates the 17.7MW Beowawe I geothermal power plant located in Eastern Nevada. It was commissioned in 1985.

In 2011, Beowawe II low-temperature, binary cycle geothermal power plant, with a generation capacity of approximately 2MW, was commissioned. Developed by Terra-Gen Power and TAS Energy, the binary cycle plant uses waste heat produced by the geothermal brine of an existing geothermal plant at the facility.

3. Ready-made Geothermal Wells

A few days ago as I'm writing this, the US Department of Energy just announced the awarding of $8.4 Million to bootstrap the conversion of several existing oil wells into geothermal production wells.[2]

The U.S. Department of Energy (DOE) today selected four new projects to receive up to $8.4 million to establish new geothermal energy and heat production from abandoned oil and gas wells. With this funding, DOE is partnering with existing well owners and operators to use their idle or unproductive wells to access otherwise untapped geothermal potential. Transforming oil wells into geothermal wells could expand U.S. geothermal energy capabilities, supporting the Biden-Harris Administration's goal of a carbon-free grid by 2035. This work also supports the creation of new clean energy jobs, helping transition some of the oil and gas workforce to the production of renewable energy…

The selected projects include:

Geothermix, LLC (Austin, TX): *Geothermix will harvest waste heat from existing oil and gas wells in Texas to generate commercial quantities of geothermal electricity.*

ICE Thermal Harvesting (Houston, TX): *ICE Thermal Harvesting will produce electricity from 11 existing oil and gas wells in California's San Joaquin Valley using an innovative power generation technology.*

Transitional Energy (Aurora, CO): *Transitional Energy will install state-of-the-art, American-made geothermal heat engines at Blackburn Oilfield in Nevada for electrical power production. As a result of the project, Transitional Energy will generate geothermal energy at the site and construct new rural electric vehicle charging infrastructure.*

University of Oklahoma (Norman, OK): *University of Oklahoma will produce heat from an Oklahoma oilfield for use in Tuttle Elementary and Middle Schools in Tuttle, Oklahoma. With access to four hydrocarbon wells within a mile, the schools will benefit from the 'recycling' of oil and gas infrastructure at considerable savings for the schools.*

4. Critical Materials from Geothermal Wells

Water from low to moderate temperatures geothermal wells absorbs minerals from subsurface deposits, and in some cases these minerals are critical for various domestic manufacturing. The following subsections review technologies for recovering these from geothermal brines.

4.1. Salton Sea Lithium Resources

The Salton Sea geothermal field in California potentially holds enough lithium to meet all of America's domestic battery needs, with even enough left over to export some of it. But how much of that lithium can be extracted in a sustainable and environmentally friendly way? And how long will the resource last? These are just a few of the questions that

[2] DOE, Office of Energy Efficiency & Renewable Energy Press Release, "DOE Awards $8.4 Million for Accessing Geothermal Potential from Abandoned Oil and Gas Wells", Jan 12, 2022, https://www.energy.gov/eere/articles/doe-awards-84-million-accessing-geothermal-potential-abandoned-oil-and-gas-wells#

researchers hope to answer in a new project sponsored by the U.S. Department of Energy (DOE).[3]

There are currently 11 commercial plants at the Salton Sea field producing geothermal energy, a clean, renewable form of energy in which hot fluids are pumped up from deep underground and the heat is then converted to electricity. Normally the cooled fluid would simply be reinjected underground, but the idea is to first extract the lithium from the brine before injecting it back.

With the push by California and many other states and countries to expand adoption of electric vehicles (EVs), the demand for batteries – and the lithium needed to make those batteries – will skyrocket. With nearly $1.2 million in support from DOE's Geothermal Technologies Office, scientists from Lawrence Berkeley National Laboratory (Berkeley Lab), UC Riverside, and Geologica Geothermal Group, Inc. will work together to both quantify and characterize the lithium in this hypersaline geothermal reservoir, located far beneath the surface of Earth near the Salton Sea in Imperial County.

The project is the first comprehensive scientific effort to map out California's so-called "Lithium Valley" and attempt to gain a detailed understanding of the mineral-rich underground brine at the Salton Sea geothermal system. Using an electron microscope and other advanced analytical tools, for example, they hope to learn the mineral sources of lithium and whether the rocks will "recharge" the brine with lithium after it has been extracted from the produced fluids.

The project team will also investigate potential environmental impacts – to quantify how much water and chemical usage is needed for lithium extraction, air quality during the extraction process, and potential induced seismicity from the associated geothermal energy production…

4.2. ORNL sorbent to recover lithium from geothermal brines

In the quest for domestic sources of lithium to meet growing demand for battery production, scientists at the Department of Energy's Oak Ridge National Laboratory are advancing a sorbent that can be used to more efficiently recover the material from brine wastes at geothermal power plants.[4]

Domestic production of lithium, the lightest of elemental metals, is considered a priority for the nation. It is essential for the manufacturing of lithium-ion batteries commonly used for everything from electric vehicles to cell phones and laptops. Yet it is sourced almost exclusively from other countries, either concentrated using a solar evaporation process from natural brine sources or recovered from ore. The United States imported 4,000 metric tons of lithium in 2018, according to the U.S. Geological Survey, a figure expected to grow exponentially.

In work for DOE's Critical Materials Institute, scientists at ORNL are working to refine a sorbent that can more effectively recover lithium salts from concentrated brines at geothermal plants. These plants pump hot water from geothermal deposits and use it to

[3] Julie Chao, Lawrence Berkeley National Laboratory, "Quantifying California's Lithium Valley: Can It Power Our EV Revolution?" Feb 16, 2022, https://newscenter.lbl.gov/2022/02/16/quantifying-californias-lithium-valley-can-it-power-our-ev-revolution/

[4] Parans Paranthaman, Bruce A Moyer and Yongqiang Cheng, Oak Ridge National Laboratory, Jan 21, 2020, https://www.ornl.gov/news/ornl-develops-sorbent-recover-lithium-geothermal-brines

generate electricity. Concentrated brines left over from the operation are then pumped back into the ground.

Those brines can contain as much as 250 to 300 parts-per-million lithium. By some estimates, as much as 15,000 metric tons per year of lithium carbonate could be recovered from a single geothermal power plant in the Salton Sea area of California—one of the most mineral-rich brine sources in the United States. There are currently 13 geothermal plants in the region and more are planned.

ORNL and its research partners are working to improve the capacity and selectivity of a sorbent that could extract the lithium from these brines. The lithium-aluminum-layered double hydroxide chloride (LDH) sorbent they're developing is a low-cost, reusable option for large-scale industrial plants.

The LDH sorbent is made up of layers of the materials, separated by water molecules and hydroxide ions that create space, allowing lithium chloride to enter more readily than other ions such as sodium and potassium. After the sorbent loads with lithium chloride, it is selectively washed to remove unwanted ions, and then to unload the remaining lithium chloride. In a bench-scale demonstration, the LDH sorbent recovered more than 91% of lithium from a simulated brine…

4.3. Geothermal Lithium Extraction Prize

The American-Made Geothermal Lithium Extraction Prize is designed to find solutions that de-risk and increase market viability for direct lithium extraction (DLE) from geothermal brines. Advancement of DLE technologies allow for improved methods that lower costs, lessen environmental impact, and further the mission to turn the threat of climate change into an opportunity to revitalize the U.S. energy and manufacturing sectors.[5]

Lithium is a major component of high-charge-density batteries for electric vehicles and grid-scale electricity storage. It is expected that global demand for lithium will increase by 500% by 2050 due to widespread adoption of electric vehicles and grid-scale battery storage, making lithium supplies a crucial element in the clean energy supply chain.

The current U.S. lithium stock is almost entirely imported, with only 1% of U.S. lithium supply being sourced domestically. Furthermore, traditional sources of lithium are environmentally destructive. This combination of rapidly expanding global demand and lack of a safe, domestic supply has created an urgency to develop a safe, domestic, cost-competitive source of lithium to ensure American leadership in the transition to a carbon-free economy and a robust domestic supply chain.

Prize Structure

The Geothermal Lithium Extraction Prize consists of three phases that will fast-track efforts to identify, develop, and test disruptive solutions to improve the profitability of DLE from geothermal brines. Each stage will include a contest period when participants work to rapidly advance their solutions.

[5] American Made Challenges, "Geothermal Lithium Extraction Prize," https://www.herox.com/GeothermalLithiumExtraction

This competition started in March, 2021, and the Semifinalists were announced in November 2021. The Semifinalists Teams are listed below. Note that there are links to each team/project on the page through the link below.

https://www.herox.com/GeothermalLithiumExtraction/teams

- Ellexco: The George Washington University
- Espiku: Oregon State University
- Freeman Lab: The University of Texas at Austin
- Lirix-nano Sengupta: University of Massachusetts Dartmouth
- LiSED: Rice University
- Lithium from Home: Massachusetts Institute of Technology
- Miami Solution: University of Miami
- Nanoporous Graphene Membrane: Massachusetts Institute of Technology
- Pober-Strauss: Boston University
- SelectPureLi: University of Illinois Urbana-Champaign
- Team TELEPORT: University of Virginia
- Tech Desal: Texas Tech University
- Univ of Wyoming Team Goldilocks: University of Wyoming
- University of Utah: The University of Utah

The prizes for each of the three phases is shown below.

The submission deadline for Phase 2 in April 2022. The final (Phase 3) winners will be announced in September of 2023.

The detailed rules for this competition are available through the link below:

https://americanmadechallenges.org/geothermallithiumextraction/docs/Geothermal_Lithium_Extraction_Official_Prize_Rules.pdf

5. Low-Temperature & Coproduced Resources

Low-Temperature & Coproduced Resources represent a small but growing sector of hydrothermal development in geothermal resources below 150°C (300°F). Considered non-conventional hydrothermal resources, these technologies are bringing valuable returns on investment in the near-term, using unique power production methods. The Geothermal Technologies Office (GTO) works with industry, academia, and national laboratories to develop and deploy new low-temperature and coproduction technologies that will help the geothermal community achieve widespread adoption of under-utilized low-temperature resources.[6]

The Energy Department recently announced $3 million for research and development to help grow U.S. low-to-moderate-temperature geothermal resources and support a domestic supply of critical materials.

Low-temperature geothermal energy is defined as heat obtained from the geothermal fluid in the ground at temperatures of 300°F (150°C) or less. These resources are typically used in direct-use applications, such as district heating, greenhouses, fisheries, mineral recovery, and industrial process heating. However, some low-temperature resources can be harnessed … using binary cycle electricity generating technology.

Hot geothermal fluid is a byproduct of many oil and gas wells within the United States, and 25 billion barrels of it are produced each year. Historically this hot water has been an inconvenience and a disposal issue; however, it is now being looked at as a resource to produce electricity for field use or to be sold to the grid. These and other co-produced geothermal resources have the potential to produce significant amounts of baseload electricity at low costs and with near zero emissions.

Of the 2,558 MW of geothermal power plant capacity currently operating in the US, 1,826 MW of capacity is from steam-powered plants and 731 MW of capacity is from binary-cycle powered plants. But the balance is shifting, according to the US Energy Information Administration (EIA).[7]

Utility-scale geothermal power plants in the US use either steam power or a binary cycle to generate electricity. A little more than 70% of the country's current geothermal capacity was built before the year 2000, using mostly steam-powered technology. However, of the 735 MW of capacity built since the turn of the century, nearly 90% is binary-cycle capacity.

The reason for the shift from steam to binary-cycle power may be a matter of flexibility. Geothermal plants are geographically limited to areas with hydrothermal resources that occur naturally in underground reservoirs of steam and hot water. The steam and hot

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[6] Energy.gov, Office of Energy Efficiency and Renewable Energy, Geothermal Technology Office, "Low Temperature & Coproduced Resources," https://www.energy.gov/eere/geothermal/low-temperature-coproduced-resources

[7] Journal of Petroleum Technology, "US Geothermal Power Technology Shifts From Steam to Binary Cycle," Aug 5, 2020, https://jpt.spe.org/us-geothermal-power-technology-shifts-steam-binary

water can be used for power generation by drilling a well into the reservoir and piping them to the surface. The hot water or steam powers a turbine, which generates electricity. The type of geothermal power plant technology used depends on the characteristics of the reservoir.

Steam-powered technology uses steam directly from a geothermal well to spin a turbine and generate electricity. Binary-cycle geothermal power plants use a heat exchanger to take heat from the hot water in the well to heat a secondary fluid that then spins a turbine.

Currently all of the geothermal plants in the US are located in the western part of the country, mostly in California or Nevada. California has 91% of the country's steam-powered capacity, and 65% of binary-cycle capacity is found in Nevada.

Binary-cycle plants are used for lower-temperature reservoirs (200°F to 330°F). These plants pump hot water from the reservoir through a heat exchanger, where the heat is transferred to a secondary working fluid with a lower boiling point than water. The working fluid vaporizes and passes through the turbine, generating electricity, while the water is returned to the reservoir.