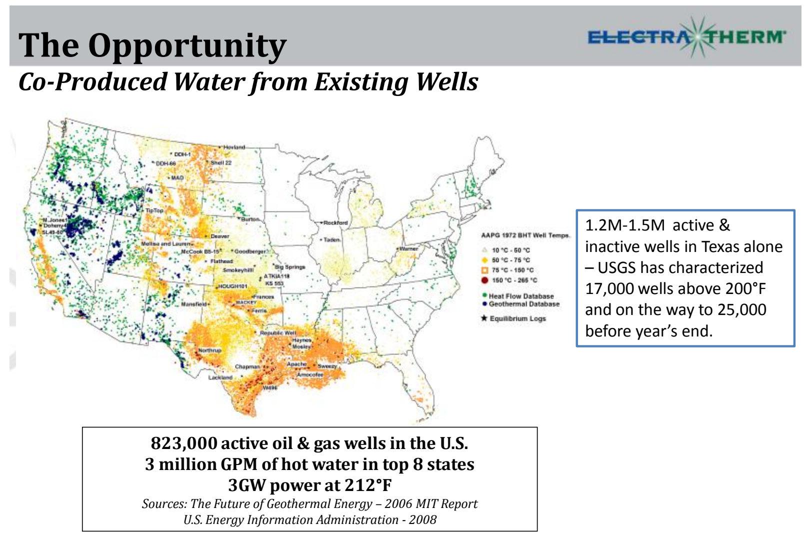
Mississippi Oilfield Generates Low-Temperature, Emission Free Geothermal Energy at the Wellhead

Summary

In the summer of 2011, the Green Machine completed a six-month demonstration at a Mississippi oil field generating renewable energy from the hot produced water that oil and gas producers consider a waste. This is the first small-scale (<200kWe) application to generate fuel-free, emission free power at an oil well. According to reports by Massachusetts Institute of Technology and the National Renewable Energy Laboratory, there are 823,000 oil and gas wells in the U.S. that co-produce hot water concurrent to the oil and gas production. This equates to approximately 25 billion barrels annually of water which could be used as fuel to produce up to 3 GW of clean power. By tapping this enormous resource to generate clean energy, the power generation potential is significant and should not be ignored. This demonstration successfully proved that the Green Machine is a viable power generator for oil and gas wells.



The demonstration developed from a grant by the Department of Energy's Research Partnership to Secure Energy for America (RPSEA). The effort funded the demonstration of a modified waste heat generator that uses produced water to create "green" electricity usable onsite for field operations or for export to the grid. The demonstration was implemented by ElectraTherm's Gulf Coast distributor, Gulf Coast Green Energy (GCGE), who submitted the grant application and performed the demonstration in partnership with ElectraTherm, Denbury Resources, Inc., and other key partners.

The greatest risk in large geothermal power projects is temperatures and flows of the wells yet to be drilled. These projects can be 5-7 years in the making and carry a significant amount of unknowns, which equates to risk. **However, in the oil and gas industry today there may be up to thousands of wells already established with known temperatures and flows that could be producing emission free power.** The purpose of this demonstration was to show that there are real solutions available today to reduce small operators' exposure to rising electric rates, offset their costs, reduce environmental impacts and create more favorable public perception. The objective was to ultimately identify and demonstrate technology that will reduce the field operating cost of electricity and minimize the environmental impact by creating green electricity using available produced water and no additional fossil fuel.

ElectraTherm's Green Machine is fueled by hot water, preferably at temperatures between 190-240^{o}F, and is based on the Organic Rankine Cycle (ORC) system.

Introduction

Historically, geothermal production in the United States has been limited to tectonically-active regions with extremely hot, naturally pressurized waters. But newly developed technology like the Green Machine allows for the generation of electricity from moderately hot water. GCGE sought advice from Southern Methodist University's Geothermal Laboratory in finding oil and gas production sites likely to have sufficient heat flows to support the Green Machine's requirements, and as a result identified Denbury Resources, Inc. The Plano, Texas-based company is a pioneer in the business of revitalizing old wells by injecting carbon dioxide into the reservoir, which increases reservoir pressure while reducing the oil's viscosity. This process allows the recovery of oil that otherwise would not be produced.

This field demonstration involved a close partnership between GCGE and Denbury, the largest oil and natural gas producer in Mississippi and the owner and operator of various wells in Laurel and Jackson, Mississippi. The partnership also included third-party verification and support from Southern Methodist University (SMU) and Texas A&M's Energy Institute.

> *"This Green Machine was designed to fit on a truck bed for a simple plug-and-play upon arrival at the site. The truck arrived at 9 a.m. on Tuesday and the machine was running in auto mode by Thursday at 11 a.m." David Mendershausen, ElectraTherm Service Engineer.*

The data that SMU provided made it clear that the water being produced at approximately 204°F by the Denbury wells near Laurel, Miss., likely had sufficient heat and flow available to operate a Green Machine. The well produces at 9,500 ft. under ESP (Electric Submersible Pumping), producing 100 BOPD and 4000 BWPD, 98% water.

Near the Laurel field wellhead, the hot water supply line was bypassed through ElectraTherm's ORC in a simple three way valve configuration to not to interfere with production. The base load electricity was utilized on site to keep all the electricity "inside the fence." The power generated displaced $.098/kWh, compared with net metering to the utility at $.044/kWh, making "inside the fence" operations the best option for the site.

How It Works

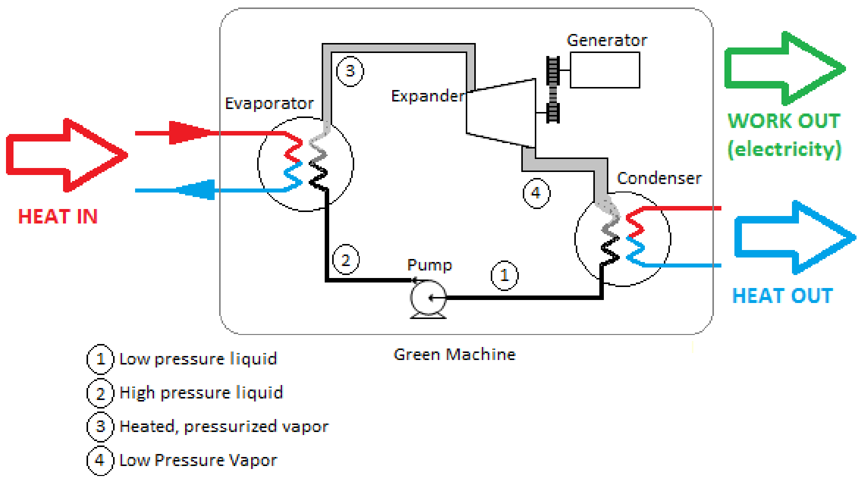
The hot water is separated from the oil that it is pumped from the well, and enters a heat exchanger. In the heat exchanger, the hot water excites (pressurizes) the working fluid, which is an EPA-approved, non-hazardous, non-toxic and non-flammable fluid, driving the twin-screw expander (the power block) to create electricity. ElectraTherm's patented twin-screw expander is unique in its configuration, lubrication and specifications, but is based on reliable, proven compressor technology that has been around for greater than 20 years.

The twin screw expander has a rotational speed of 4,300-4,800 RPM, 1/10th that of most turbo expanders. The robustness of the screw allows the admittance of wet vapor through the expander, therefore allowing access to lower temperature resources. Through a patented process and lubrication scheme, the system is simplified and eliminates lubrication reservoirs, oil coolers, pumps, lines and filters, creating a simple, robust, efficient system with fewer parasitic loads.

After the working fluid expands across the twin screw expander (spinning a generator) the low pressure vapor must be condensed to a liquid to begin the cycle again. Various methods of condensing can be utilized; a cooling tower, a direct air cooled condenser, or even ground water has been used. The condensing side of the ORC for this demonstration utilized an air cooled condenser, eliminating the extensive amount of fresh water usage and maintenance expenses associated with operating a cooling tower.

The Green Machine is a relatively small unit at 7.5x8x7 feet. This allows for easy transport to remote locations, such as the Laurel site. Additional benefits of the Green Machine include its simple design and low maintenance, with no gearbox, and no oil pump or oil changes necessary. Additionally, the Green Machine's control system is fully automated, allowing remote control, remote monitoring, and off site diagnostics and trending.

The Organic Rankine Cycle (ORC) technology used in the Green Machine is demonstrated in the visual graph below:
Refrigerant - Honeywell R245FA - Charge (lbs): 700 lbs.
Expander - 75% Expansion Efficiency
Electric Generator - Marathon Prime Line Efficiency 91%
System Efficiencies - 6% - 10% (Resource temperature dependent)
Basic Cycle - Organic Rankine Cycle (ORC) Twin Screw



Challenges with Co-Produced Fluids

There are a number of variables in co-produced fluids that have limited the technology from being adapted on such a vast resource. From the beginning of the demonstration, we were able to prepare for expected challenges, as well as adapt to unexpected challenges that arose during the process. The project was a success in that it proved educational in developing improvements and minimizing troubleshooting for future opportunities.

For this report, we will provide a simple summary of the challenges anticipated with power generation through co-produced fluids, and further in the report we will detail the challenges as experienced at the Laurel site and how ElectraTherm overcame and optimized each situation.

Distributed Small Wells

One obvious challenge is the small size and distributed nature of the wells. Typical oil production does not lend itself to high volumes of water flows or the desired 250°F+ temperatures for traditional heat recovery technology. For this reason, large scale power production at these heats and flows is not an option, and has limited the opportunities for power generation at co-produced sites.

Geothermal Brine

Corrosion and mineral build-up comes naturally from geothermal brine being pumped from the earth. These corrosive fluids can cause build-up and clogging in many heat exchangers, and require constant heat exchanger cleaning that takes extensive amounts of time, man power and down time.

Installation and Operation at Remote Locations

Oil and gas wells are littered across the country, often in remote, off-the-beaten path and with limited access to roads or services. This proves difficult and expensive for onsite construction. Most operations located on well sites require major machinery that is large, heavy and immobile. Moving equipment around and adding ancillary machinery to remote sites can be costly and not a high priority for businesses whose primary objective is producing oil and natural gas.

Operating personnel and service support are additional challenges at remote locations. Without readily accessible service technicians, troubleshooting, added downtime and travel can become costly.

Economics

Until now, the economics for power generation off waste heat at the well heads hasn't been attractive. Cost of power in many US markets with oil and gas wells can range as low as $.08/kWh, and ROI can well-exceed eight years; not attractive for most oil and gas producers. Additionally, since the primary task of oil and gas producers is oil and gas production, generating electricity off waste heat can fall behind on the list of priorities.

The accumulation of the above challenges has greatly limited power generation research and development at oil & gas wells to this point, and for good reason. Without a modular, robust, low maintenance and economical solution to present to oil and gas producers, utilizing a power generator solely for the environmental benefits will have limited acceptance. ElectraTherm's partnership with GCGE and the grant by the Department of Energy's RPSEA program enabled a low-risk demonstration project to prove that practical operations of a Green Machine at oil and gas fields are commercially-viable, and easy to install and operate.

The Green Machine Commissioning

ElectraTherm's Green Machine was manufactured and assembled at its headquarters in Reno, Nevada. ElectraTherm mounted a Green Machine to a trailer in our manufacturing facility, with the air cooled condenser, hot water bypass and electrical controls installed. The goal was to have a turnkey installation upon site arrival.

From the time of its arrival at the Laurel wellhead at 9 a.m. on Tuesday, May 26 to the time it was commissioned, 11 a.m. on Thursday, May 28, total commissioning time marked less than 50 hours. The short deployment and commissioning testified to the machine's simplicity of installation and operation.

"ElectraTherm deployed the Green Machine at Denbury to connect and generate electricity seamlessly, and we are excited with the results – 50 hours installation time is a great accomplishment for the first time," said John Fox, CEO of ElectraTherm. "The ongoing operational lessons we learned from this demonstration will benefit future installations with higher performance capabilities."

Six Month, 1,000 Hours Demonstration

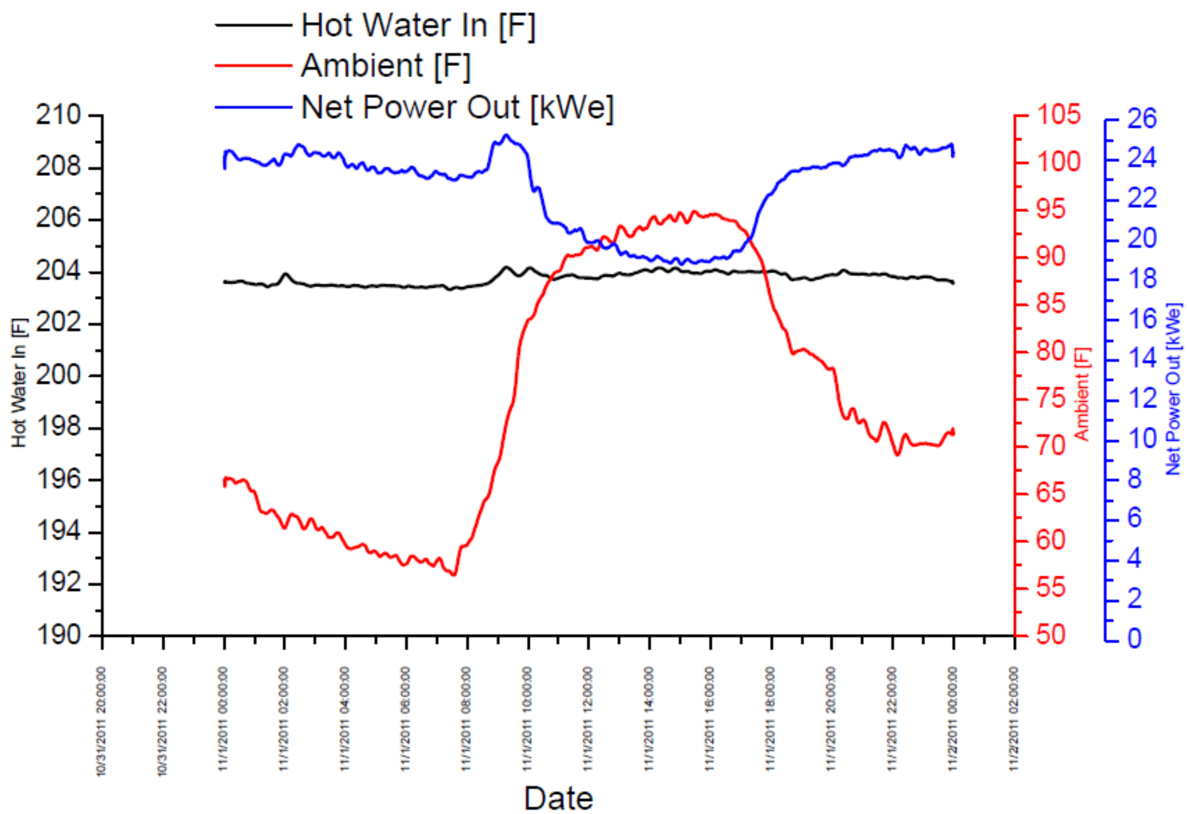
The Green Machine is designed for 30-65kWe of power output, but the lower temperature (204°F) and flow (120 GPM) at the Laurel demonstration site equated to a lower output. Also, due to the fact that this was a demonstration site the condensing solution was taken from inventory and was undersized for the high ambient Mississippi summer. The unit produced a maximum of 22kWe and average of 19kWe of power. This was enough to offset up to 20 percent of the energy required to run the down-hole pump on the oil well for which it was paired.

"We are offsetting electric consumption on the site with power generated from hot water," said Loy Sneary, CEO of Gulf Coast Energy, a Texas-based company that distributes the Green Machine for ElectraTherm, Inc. "It has been talked about for a long time, people have been researching it and there have been a lot of concepts suggested - this is the first time it's really been done with a modular solution."

Performance Data

Net power output to grid or field use	Gross Power Output: 19-22kWe
Runtime hours to complete demonstration	1,136
Parasitic load breakdown	Feed Pump: 1-4kWe, Fans: 0.1-6kWe
Ambient temperature (hourly)	60-105°F
Relative humidity	50-100%
Generator output (hourly)	8-30kWe
Brine flow rate (daily)	120 GPM
Brine inlet temperature (daily)	204°F

Runtime Graph for 24 Hours



The above graph represents power generation during a 24 hour period in the month of November. The hot water flow remains steady throughout, while the net power out is directly correlated to ambient temperature during times periods above 90°F.

Cost Analysis

Total installed system capital cost Plant and/or plant equipment capital costs (including air cooled condenser, ancillary equipment/BOP) Installation - Includes travel/trip, and SMU and A&M tech advisers Transaction costs - Engineering and other costs not directly related to construction: permitting, acquiring power sales agreement, etc. Total Operations and Maintenance cost (Quarterly reporting) **Total Project Cost: $230,000**

Lessons Learned

Our six month demonstration successfully concluded in November with 1,136 total runtime hours, and provided excellent insight for future installations. ElectraTherm overcame previous industry discouragement over generating electricity from co-produced fluids by eliminating individual hurdles. By realizing and overcoming each challenge during the six months of operation, ElectraTherm, our partners and the US Department of Energy are recognizing the ample potential for utilizing the tens of thousands of similar wells currently wasting the co-produced heat they pump for oil and gas production.

Distributed Small Wells

High volumes of water flows and 250°F+ temperatures are typically required for traditional Organic Rankine Cycle technology, but unobtainable in smaller wells with low temperatures and flows. The Green Machine requires hot water between 190-240°F at 120-200 GPM. Co-produced applications tend to scale within the lower end of both sides. For this reason, large scale power production at these heats and flows is not obtainable, but small-scale, distributed power generation matches the resource requirements, and ElectraTherm's Green Machine is sized well with power output between 20-65kWe.

Geothermal Brine

Water corrosion and mineral build up in the ORC's heat exchangers was a major challenge leading up to this demonstration. We understood going into this demo that brazed plate heat exchangers are not optimally suited for brine as they have clogging and stress corrosion cracking issues. Our assessment of our current HX design concluded it would not be sufficient for long term operation. However, a six month, 1000 hour test run operating with our current bill of material heat exchangers would have no issues. The addition of a similar plate and frame heat exchanger would allow material options, cleaning ability and would extend heat exchanger life. The use of a small metering pump to add a scale inhibitor to the produced water ahead of the Green Machine is another solution.

ElectraTherm's research and development through a recently awarded Department of Energy grant enabled the development of an optimized gasket plate and frame heat exchanger for future sites. This new unit is being tested at ElectraTherm as this paper is being published. ElectraTherm will use this heat exchanger at its Florida Canyon, Nev. site to reduce cleaning requirement and scaling at bay. The cleaning schedule, control of the scale build up and/or other produced water fowling problems are site specific problems that are dealt with at existing large scale geothermal and similar applications today.

Installation and Operation at Remote Locations

ElectraTherm's modularity proved extremely helpful in both installation and removal. The truck bed set-up enabled door to door transportation of an almost fully configured balance of plant. ElectraTherm believes that our 50 hour installation could be reduced to less than a day in the future with additional planning. The Laurel installation was stagnant for hours at a time as the team waited on engineers' scheduled arrival times. By reducing time in between processes, total install time could be cut in half.

Maintenance sometimes proved difficult with limited resources at the remote site and no trained technicians on location. Provided limited training on the Green Machine's operations, the Denbury personnel did an outstanding job of filling in as field technicians. However, ElectraTherm offers 2-3 day training courses on the commissioning, operation and service of our machines. Obviously, training of oil field operators would have gone a long way in providing simple maintenance to the equipment. It is well understood that the competencies required to operate oil and gas operations would easily cover the maintenance issues that were encountered during the trial period.

Initial installation included pilot operated bypass valves for the Green Machine to ensure ongoing site operations while the Green Machine was down due to high ambient temperatures or for routine maintenance. The valves selected on the hot water supply bypass were small pilot solenoid valves that drive a larger valve. These smaller valves were not suitable for the brine pumped through the pipes and the slurry clogged one of the pilot valves and caused a pipe malfunction. ElectraTherm learned that regular cleaning or a new selection in valves would keep this from happening again. The focus was on the Green Machine operation, proper selection of industry standard balance of plant equipment would eliminate the one issue encountered.

Economics

Review of the demonstration and cost analysis speaks to the economic benefits of the application. A post project analysis concluded that the Green Machine's power generation offset about 20 percent of the energy required to run the down-hole pump on the oil well. ElectraTherm's Green Machine can provide an attractive payback at oil and gas sites where cost of power leans on the higher side, and where producers see the environmental value in electricity from waste heat, either as a public relations benefit or acting on corporate social responsibility metrics.

Limitations of High Ambient Temperatures

One of the greatest challenges at Laurel was the high ambient temperatures during a Mississippi summer using air cooled condensing. The high ambient temperatures mixed with lower temperature geothermal water (204°F) and low flows equated to a lower system ΔT, a critical parameter for machine efficiency and power generation. The limited system ΔT reduced power output. Another sub-optimal factor of the application was a brine flow rate at 120 GPM, 25% below Green Machine standard parameters of 170-190 GPM. Together, these subprime measurements equated to a lower output of 19-22kWe gross.

Through further review of the Laurel site and its high ambient temperatures, ElectraTherm determined the air cooled condenser going in was undersized for this site. Concurrent testing at ElectraTherm's test cell showed an approximate 40% power derate, a clear factor in limiting optimal output at the site. Subsequent performance modeling of the Denbury site concluded that with higher flow rates (>150 GPM) and an appropriate sized air cooled condensing unit, the average annual output of the green machine would be 50kWe gross/38.5kWe net at this location. To reach maximum power output capabilities on a Green Machine (65kWe gross), heat and flow parameters would reach 240°F at 160 GPM, and require an ambient air temperature of 60°F.

Conclusion

The demonstration at Denbury's Laurel site provides insight into future applications to reduce installation time, increase efficiency, generate additional power and minimize maintenance. This kind of co-generation can be particularly effective to reduce the energy costs for pumping hard to reach oil, an increasing activity in the United States.

Hurdles remain in developing co-produced fluid opportunities but progress has been and continues to be made. Primarily, economics will play a critical role in the growth of this industry. Lower costs of power in the United States directly impacts demand for alternative resources. ElectraTherm sees an attractive return on investment in locations where cost of power is $.10/kWh or higher. In locations where cost of power is less than $.10/kWh, additional incentives or corporate objectives would be necessary to make the opportunities attractive.

Oil and gas companies produce oil and gas as a primary objective. Oil and gas producers will need to recognize the inherent benefits of power generation from co-produced fluids to enable cost savings at each site and establish a firm commitment to the environment and sustainability.

ElectraTherm is currently using this demonstration data for a project with the Department of Energy at a geothermal well in Nevada. The project, located at Florida Canyon mine outside Winnemucca, Nev., has similar challenges with geothermal brine and will be using a gasketed plate and frame heat exchanger. ElectraTherm will take the experience at Laurel to further progress this and future geothermal projects. That site will not be as challenged on flows and temperatures. The well flow will exceed Green Machine requirements and at 230°F we are targeting 65-75kWe gross at the site.

Scientists in SMU's Geothermal Lab see a natural partnership in co-production of geothermal energy from oil and gas wells. Large quantities of water are produced with the extraction of oil and gas, either because it was present in the reservoir before drilling, or because water was injected into the formation to force oil and gas to the surface. ElectraTherm's Green Machine can harness these wells with a modular, robust solution that is easy to install and maintain. Tapping the hot water from oil and gas wells to generate additional power from heat that would otherwise go to waste is efficient, environmentally-beneficial and economical.

ElectraTherm would like to thank the Department of Energy's RPSEA program, Denbury Resources and Gulf Coast Green Energy for their diligent efforts in making this demonstration a success.

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