BY TOM CLARK

The ElectraTherm Green Machine was designed to fit on a truck bed for simple plug-and-play upon arrival at the site.

Power From Waste Water

Mississippi, U.S.A., oilfield generates low-temperature, emissions-free geothermal energy at the wellhead

According to reports by the Massachusetts Institute of Technology and the National Renewable Energy Laboratory, there are 823 000 oil and gas wells in the United States that co-produce hot water concurrent to the oil and gas production. This equates to approximately 25 billion barrels annually of water that 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.

In the summer of 2011, ElectraTherm Inc. completed a six-month demonstration at a Mississippi, U.S.A., oil field generating renewable energy from the hot produced water that oil and gas producers consider a waste. Headquartered in Reno, Nevada, U.S.A., ElectraTherm specializes in small-scale waste heat recovery. ElectraTherm's product, the Green Machine, generates fuel-free, emissions-free power from low-temperature waste-water flows (between 88° and 116°C) using the Organic Rankine Cycle (ORC) and patented technology. This is the first small-scale (<200 kWe) application to generate fuel-free, emissions-free power at an oil well.

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 on-site 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 objective was to 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.

The greatest risk in large geothermal power projects is temperatures and flows of the wells yet to be drilled. These projects can be five to seven 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 emissions-free power.

Historically, geothermal production

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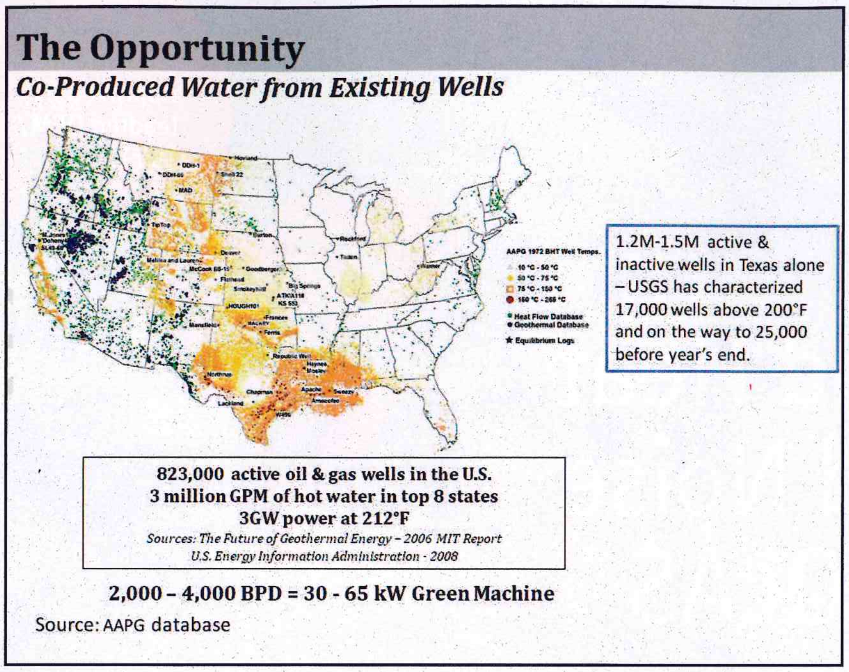

in the United States has been limited to tectonically active regions with extremely hot, naturally pressurized waters. But newly developed technology allows for the generation of electricity from moderately hot water. GCGE sought advice from Southern Methodist University's Geothermal Laboratory in finding 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, U.S.A.-based company specializes in 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.

Data provided by SMU showed that the water being produced at the wells near Laurel, Mississippi, was approximately 96°C. The well produces at 2895 m under electric submersible pumping (ESP), producing 100 barrels of oil per day and 4000 barrels of water per day, 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 avoid interfering with production. The base load electricity was utilized on-site to keep all the electricity "inside the fence." The power generated displaced US$.098/kW-hr, compared with net metering to the utility at US$.044/kW-hr, making "inside the fence" operations the best option for the site.

Green Machine Technology

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, nonhazardous, nontoxic and nonflammable 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 4300 to 4800 r/min, much slower than that of most turboexpanders. 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 and easy to maintain power plant.

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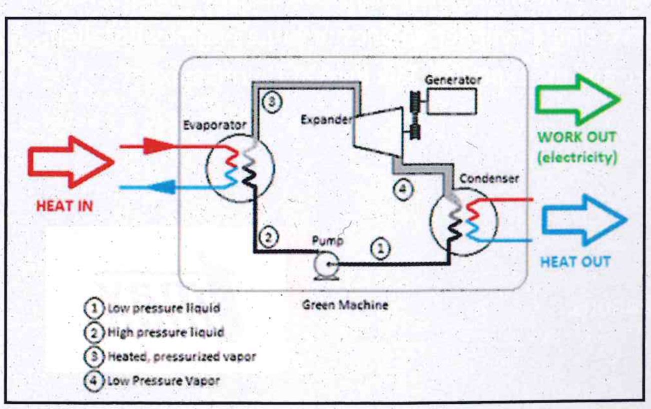

Figure 1.
Refrigerant — Honeywell R245FA — charge (lbs): 700 lbs.
Expander — 75% expansion efficiency
Electric Generator — Marathon prime line efficiency 91%
System Efficiencies — 6 to 10% (Resource temperature dependent)
Basic Cycle — Organic Rankine Cycle (ORC) twin screw

Performance Data	
Net Power Output To Grid Or Field Use	Gross Power Output: 19 to 22 kWe
Runtime Hours To Complete Demonstration	1136
Parasitic Load Breakdown	Feed Pump: 1 to 4 kWe, Fans: 0.1 to 6 kWe
Ambient Temperature (hourly)	16° to 4°C
Relative Humidity	50 to 100%
Generator Output (hourly)	8 to 30 kWe
Brine Flow Rate (daily)	454 L/min
Brine Inlet Temperature (daily)	96°C

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. 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 measures 2.2 x 2.4 x 2.1 m and is designed with no gearbox, and no oil pump or oil changes necessary. The control system is fully automated, allowing remote control, remote monitoring and off-site diagnostics and trending.

The ORC technology used in the Green Machine is demonstrated in Figure 1.

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.

Distributed Small Wells

High volumes of water flows and 120°C-plus temperatures are typically required for traditional ORC technology, but unobtainable in smaller wells with low temperatures and flows. The Green Machine requires hot water between 88° and 116°C at 454 to 757 L/min. Co-produced applications tend to scale within the lower end of both sides. For this reason, large-scale power production at these temperatures and flows is not obtainable; small-scale, distributed power generation matches the resource requirements, and ElectraTherm's Green Machine is sized well with power output between 20 and 65 kWe.

Geothermal Brine

Water corrosion and mineral build-up in the ORC's heat exchangers was a major challenge leading up to this demonstration. Brazed plate heat exchangers are not optimally suited for brine as they have clogging and stress corrosion cracking issues. The assessment of the current HX design concluded it would not be sufficient for long-term operation. However, a six-month, 1000-hour test run operating with the 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 U.S. Department of Energy grant enabled the development of an optimized gasket plate and frame heat exchanger for future sites. This new unit is currently being tested at ElectraTherm. ElectraTherm will use this heat exchanger at its Florida Canyon, Nevada, U.S.A., site to reduce the cleaning requirement and keep scaling at bay. The cleaning schedule, control of the scale build-up and/or other produced water fouling problems are site-specific problems that are dealt with at existing large-scale geothermal and similar applications today.

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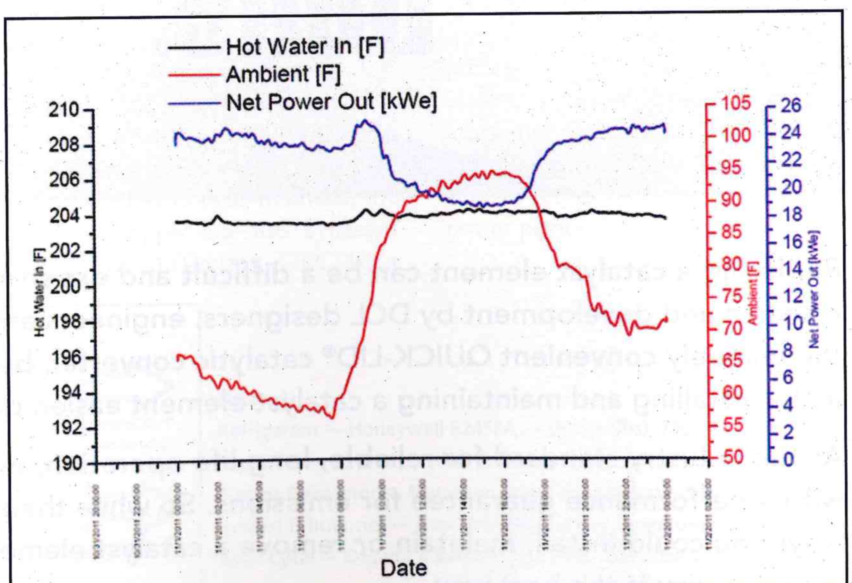

The graph represents power generation during a 24-hour period in the month of November. The hot-water flow remains steady throughout, while the net power out is directly correlated to ambient temperature during times periods above 33°C.

Cost Analysis

Total Installed System Capital Costs
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 Costs (quarterly reporting)
Total Project Costs: US$230,000

Economics

Cost of power in many U.S. markets with oil and gas wells can range as low as US$.08/kWh, and ROI can well exceed eight years. 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% of the energy required to run the down-hole pump on the oil well.

Limitations Of High Ambient Temperatures

One of the greatest challenges at the Laurel site was the high ambient temperatures during a Mississippi summer using air-cooled condensing. The high ambient temperatures mixed with lower temperature geothermal water (96°C) 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 454 L/min, 30% below Green Machine standard parameters of 644 to 719 L/min. Together, these inputs equated to a lower than name plated Green Machine output of 19 to 22 kWe 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 de-rate, a clear factor in limiting optimal output at the site. Subsequent performance modeling of the Denbury site concluded that with higher flow rates (>577 L/min) and an appropriate sized air-cooled condensing unit, the average annual output of the green machine would be 50 kWe gross/38.5 kWe net at this location. To reach maximum power output capabilities on a Green Machine (65 kWe gross), heat and flow parameters would need to reach 116°C at 606 L/min, and require an ambient air temperature of 16°C.

Installation And Operation At Remote Locations

Oil and gas wells are littered across the country, often in remote, off-the-beaten paths and with limited access to roads or services. This proves difficult and expensive for on-site 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.

The accumulation of the above challenges has greatly limited power generation research and development at oil and gas wells to this point. 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 U.S. 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.

Six-Month, 1000-Hour Demonstration

The Green Machine is designed for 30 to 65 kWe of power output, but the lower temperature (96°C) and flow (454 L/min) 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 22 kWe and an average of 19 kWe of power. This was enough to offset up to 20% of the energy required to run the down-hole pump on the oil well for which it was paired.

The demonstration at Denbury's Laurel site provides insight into future applications to reduce installation time, increase output and minimize maintenance. This kind of cogeneration 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 US$.10/kW-hr or higher. In locations where cost of power is less than US$.10/kW-hr, additional incentives or corporate objectives would be necessary to make the opportunities attractive.

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.

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