RPSEA

Final Report

Electrical Power Generation from Produced Water: Field Demonstration for Ways to Reduce Operating Costs for Small Producers

Project: 08123-10

April 30, 2012

Loy Sneary, President

Robin Dahlheim, Sales

Gulf Coast Green Energy

1801 7th St, Ste 230

Bay City, TX 77414

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ABSTRACT

Gulf Coast Green Energy demonstrated a modified waste heat-to-power (H2P) generator that uses produced water to create fuel free and emission free electricity which can be used on site or for transmission off site for field operations. The goals of this project were to reduce the small operators' exposure to rising electric rates, increase their productivity, increase energy efficiency, reduce environmental impacts, and to create a more favorable public perception. The overall 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 produced water and no additional fossil fuel.

The electrical generation technology operates on heat from produced water, preferably at temperatures above 190oF. The technology is based on an organic Rankine cycle (ORC) system. The ORC used an Air Cooled Condenser (ACC) to condense the working fluid of the ORC to eliminate the extensive amount of fresh water usage and maintenance expenses of operating a cooling tower.

The research included two phases with the objective of developing cost-effective emission free and fuel free distributed electrical generation by using produce water from Oil and Gas production. The first phase was well selection and Phase II, was the installation, startup, and operation of the waste heat generator.

An oil field owned by Denbury Resources, Dallas, Texas, near Laurel and Jackson, Mississippi was the site of the field demonstration. Denbury has a number of wells that could have been used for this project. At the chosen location the produced water flow line was bypassed through the ORC heat exchanger in a simple 3- valve configuration to prevent any interference or disruption in production. The base load (24/7) electricity generated by the ORC created was credited to Denbury's utility bill. During the six month trial, record ambient heat was recorded thus reducing the power output of the ORC. However, 19,180 of distributed, on-site power KWh were produced. There was additional down time attributed to summer electrical storms and field operational priorities.

Principal Investigator: Mrs. Robin Dahlheim,

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Robin Dahlheim ____________________

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DATE: _April 30, 2012__

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Introduction

Gulf Coast Green Energy demonstrated a waste heat-to-power (H2P) generator that used produced water from an oil well to create emission free and fuel free “green” base load (24/7) geothermal electricity that was used on site. The goals of this project were to reduce the small operators exposure to rising electric rates, increase their productivity, increase energy efficiency, reduce environmental impacts, and to create more favorable public perception. The overall objective was to identify and demonstrate technology that will add energy efficiency by reducing the field operating cost of electricity and minimizing the environmental impact by creating electricity using produced water from an oil or gas well without consuming additional fossil fuel.

The electrical generation technology used in this demonstration used the waste heat from the oil wells produced water as the heat source for the waste heat-to-power (H2P) generator. The minimum temperature for the produced water is preferably above 190oF. The technology is based on an organic Rankine cycle (ORC) system. The ORC used an Air Cooled Condenser (ACC) to condense the working fluid of the ORC to eliminate the extensive amount of fresh water usage and maintenance expenses of operating a cooling tower.

The research included two phases with the objective of developing cost-effective emission free and fuel free distributed electrical generation by using produce water from Oil and Gas production. The first phase was well selection and Phase II, was the installation, startup, and operation of the waste heat generator.

Mrs. Robin Dahlheim was the principal investigating project manager for Gulf Coast Green Energy and Loy Sneary was the Co- PI on this 6 month demonstration project. Our industry partners are: (a) Denbury Resources, Inc., (b) ElectraTherm, Inc. (c) Dry Coolers, Inc., (d) Texas A&M University Petroleum Engineering GPRI, and (e) Southern Methodist University Geothermal Laboratory. This field demonstration required collaborative efforts by Gulf Coast Green Energy and Denbury Resources, Inc. to identify and select the optimum well. Gulf Coast Green Energy installed operated, and maintained the equipment with assistance from Denbury Resources engineering and field personnel.

An oil field owned by Denbury Resources, Dallas, Texas, near Laurel and Jackson, Mississippi was the site of the field demonstration. Final selection was based on stability and geography. After the knock out pot the flow line was bypassed through the ORC heat exchanger in a simple 3- valve manifold configuration so that there was no disruption or interference with production. The base load (24/7) electricity created on site was net metered and credited back to Denbury.

Background

There are 823,000 oil and gas wells in the U.S. that co-produce hot water concurrent to the oil and gas production1,2. This equates to approximately 25 billion barrels annually of water that could be used as fuel to produce up to 3 GW of clean power1. Not only will generating power from the produced water from these wells add much needed electrical generation, the life of many of these wells will be extended allowing for additional oil and gas (O&G) production.

Current Technologies

Organic Rankine Cycle (ORC) generators create pressure by boiling various refrigerants/chemical working fluids into a high pressure gas. The gas then expands in a one way system and turns an expander or high speed turbine, which then drives a generator that generates electricity.

Historically, ORCs incorporating turbo-expanders or turbines have not been commercially viable in sizes less than 1MW. These ORC systems are in the 250 KWh-1 MW range and require large hot water flow rates, approximately 1,000 gpm +. Typically wells with high water volumes are shut in because of the high cost of water disposal. The shut in occurs long before they reach these volumes. However, one technology uses a patented, robust, low-cost twin screw expander which requires much less water volume than the larger ORC's . The ElectraTherm Green Machine is capable of generating between 30 kWh and 65 kWh with hot water flows of 200 GPM and less. And, because most O&G wells produce less than 200 GPM of hot water, the ElectraTherm Green Machine waste H2Pgenerator was selected for this demonstration. While the technology is relatively new, a prototype suitable for O&G applications was tested and demonstrated in a boiler room application beginning in May of 2008 at Southern Methodist University. In demonstrations and testing at SMU this unit has operated at the 50 KWh rate and at times 10% above the 50 KWh rating.

Another reason the Green Machine was selected for this project is size and portability. It is skid mounted and can be moved with a small forklift, making it easy and quick to install. It has a minimal footprint of 300 square feet. This was important because of the speed and efficiency at which the O&G industry operates. The standard 4-inch flanged connections are available for connecting to the wastewater source and the cooling water source in and out of the WHG.

How The Green Machine Works

The hot water is separated from the oil that 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. The 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 robust screw allows the admittance of wet vapor through the expander, therefore allowing access to lower temperature resources. A patented process and lubrication scheme simplifies 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 7.5 x 8 x 7 feet, which allows for easy transport to remote locations, such as the Laurel Mississippi 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. 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

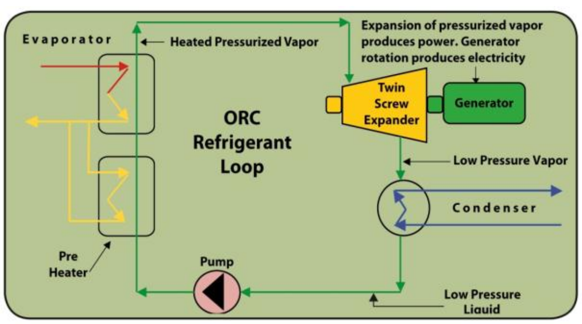

Figure 1. Schematic of ORC with Twin Screw Expander.

Project Goals and Objectives

The primary goal of the project was to prove the feasibility of interfacing the ElectraTherm Green Machine waste H2P generator (Equipment) with a producing oil or gas well.

The project had several subsidiary goals. Chief among these were:

- Demonstrate the ability of the (Equipment) to produce electricity from the waste heat in the produced water,

- Demonstrate that producing electricity from produced water does not interfere with the normal operations of an oil/gas well,
- Address the needs of small oil and gas producers to increase the profitability of producing oil and gas wells by adding additional income during production,
- Determine the economic viability of generating electricity from the heat from produced water,
- Determine if the kWh output would have practical applications,
- Determine any environmental impact from generating fuel-free, emission-free electricity from heat from the produced water.

It was important to use an actual field trial to determine the unknowns that were known to exist, but which could not be identified in lab and bench scale runs. A field trial was also needed to identify the areas for corrective action that could be incorporated in newly designed equipment and produced water projects. The overall purpose of this study was to identify and demonstrate technology that will increase energy efficiency and that will reduce the field operating cost of producing oil and gas wells by producing “on-site power” (distributed generation) to offset the cost of purchased power.

The profitability component is identified below; the cost of power is multiplied by the power produced. Each location has a different cost of power; the reported Irreducible Rate of Return (IRR) of 12% for this project is discussed in the Results section.

The objective of this project was to use produced water from small oil and gas producers (“O&G”) to demonstrate the viability of a commercially available waste heat generator to generate geothermal electricity from the hot wastewater that oil and gas producers consider a nuisance. Another goal was to offset a portion of the electric consumption on the site with power generated from hot water that comes with the oil and gas. The Denbury Resources, Inc. well selected for the demonstration project has the following thermal properties: Thermal Heat Input: 500kWt, Hot Water Input Range: 204°F, Hot Water Flow: 120 GPM and Ambient Temp Range: 60-105°F.

There is a significant challenge in changing the way small producers utilize their current waste stream of produced water. This project was designed to demonstrate that produced water is a valuable, untapped resource that can be used to make small producers more efficient, competitive and profitable. Gulf Coast Green Energy (GCGE) installed the ElectraTherm Green Machine waste heat-to-power (H2P) generator together with an air-cooled condenser on a producing Denbury Resources, Inc. oil well that is producing oil and additional hot produced water. The hot produced water provided the heat source to produce fuel free, emission free electricity. Partners on the project were GCGE, ElectraTherm, Denbury Resources, Research Partnership to Secure Energy for America (RPSEA), The Southern Methodist University (SMU) Geothermal Lab, and the Texas A&M Petroleum Engineering Department, and Dixie Electric Coop.

Project Organization and Management

Management of the project consisted of a work structure breakdown plan that addressed the overall project, a technology status assessment report, and a technology transfer plan. There were seven major project tasks, described below. These Project Tasks were:

PMP Task 1.0 Partners Planning Meeting

PMP Task 2.0 Economic Analysis

PMP Task 3.0 Field Equipment Design and Refitting:

PMP Task 4.0 Field Installation

PMP Task 5.0 Field Operations and Monitoring

PMP Task 6.0 Data Analysis and Equipment maintenance

PMP Task 7.0 Technology Transfer

Project Tasks

PMP Task 1.0 Partners Planning Meeting

A site selection and project-planning meeting was held with the Partners at the SMU Geothermal Lab in Dallas, Texas. Attending were: Denbury Resources Inc., GCGE, SMU Geothermal Lab and Texas A&M Department of Petroleum Engineering. 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. Texas A&M University Petroleum Engineering department provided consultation, access to all the partners of the Environmentally Friendly Drilling program (EFD) and assisted in the technology transfer via web links and provided introductions to industry partners at TAMU events.

Denbury Resources Inc. provided the oil well and the location for the Green Machine. The Engineering Team at Denbury and their field personnel in Mississippi were professional, willing, and able to bring this project to a successful conclusion. The Denbury field crew installed a replacement hot water by-pass while the ESP was being repaired, they would respond to any request as soon as possible after taking care of their primary responsibilities, usually within 1 hour.

The site was determined, and the method for testing produced water chemistry was agreed to. The testing period was to be for six months of operation. The site chosen was a producing oil well, Denbury Summerland #2, near Laurel, Mississippi because it was typical for wells in the region. The well chosen has a high water cut and the high water temperature and operation has been steady for the past 5 years. This well was producing at a depth of 9,500 feet and producing 100 BOPD and 4000 BWPD with an ESP (electric submersible pump). The temperature of the produced water exiting the "knockout tank" was 204°F. There was space available to set the truck mounted Green Machine equipment an appropriate distance away from the tanks and Denbury equipment. The electrical classification of the existing Green Machine for this trial is weather proof but not explosion proof. Simple piping and available real estate made this electrical classification a nonissue. Scale inhibitor equipment was to be installed between the knockout tank and the Green Machine to prevent possible scale build up in the heat exchangers, however, by mutual agreement between the Denbury and GCGE field teams, the inhibitor equipment was not installed because it was determined there was sufficient scale inhibitor injected by Denbury at the wellhead to protect our equipment and scaling would not be an issue for the six month trial period.

Connecting bypass to the Knockout Tank

Connecting Knockout Tank to Green Machine

Green Machine connected to Knockout Tank in less than 6 hours

Figure 2. Site location and installation

PMP Task 2.0 Economic Analysis

An economic analysis is provided at the conclusion of the project. See the Results section for this analysis.

PMP Task 3.0 Field Equipment Design and Refitting

The Green Machine and air-cooled condenser were tested and mounted on a drop deck flatbed trailer at the factory and trucked to the site. A hot water bypass valve was installed by GCGE and Denbury field personnel, which allowed the produced water to by-pass the Green Machine during times that the Green Machine was down.

Figure 3. The balance of plant is totally self-contained on a drop deck trailer including the Green Machine waste heat to power generator, air cooled condenser, hot water by-pass, condenser interface, and refrigerant containers.

PMP Task 4.0 Field Installation

The truck with the equipment mounted on the trailer arrived onsite and 9 hours later a test run was completed. The Denbury pipe fitter contractor laid and connected the pipe from the hot water by-pass to the trailer and the final connections to the Green Machine were made-up with high pressure hoses. There was training and cooperation between the GCGE commissioning crew and the Denbury field staff. On the second day the Denbury Electrical Engineer and Dixie Electric Coop closed the breaker. Dixie Electric Coop agreed to “net meter” the electricity generated by the Green Machine and credit the electrical production at retail rates which allowed for the generated electricity to be kept "inside the fence". There was a cellular signal problem, so a different cellular provider was chosen and the modem was replaced by the Denbury field personnel in short order. By day 3 all systems were going. The field personnel for Denbury were excellent to work with and their "can do spirit" was infectious.

Figure 4 Delivery of drop deck trailer, which contains all necessary equipment.

Figure 5. GCGE conducts operation training for Denbury personnel.

PMP Task 5.0 Field Operations and Monitoring

Several electrical storms occurred throughout the demonstration period necessitating multiple manual restarts of the equipment. Because of the relationships and cooperation experienced during installation, one phone call to Denbury and the Denbury field Team would reset MSR switch on the Green Machine whether day or night which allowed for GCGE and ElectraTherm to re-start the equipment from remote locations away from the field. Midway in the demonstration the Denbury field crew also changed out the hot water by-pass assembly, which had become clogged. Denbury's cooperation prevented the need for GCGE to have technicians drive from Texas to change the valve. In fact, Denbury's field crew was always willing to be the hands in the field for the few times they were needed. These times required less than 30 minutes for Denbury to perform the needed tasks.

PMP Task 6.0 Data Analysis and Equipment Maintenance

The high temperatures of the summer months reduced the temperature differential (ΔT) between the hot water temperature and the condensing temperature so much that the equipment was programmed to shut down when the ambient temperature was above 92° F. Future shut downs could be avoided by using larger condensing fan units. The larger size condensers could have added up to 40% more output KWh by increasing the heat transfer surface area for the refrigerant, thus allowing the temperature differential to increase. Because the hot water by-pass valve became clogged requiring a replacement valve to be installed, it was determined that the by-pass valve used for produced water applications must have a different design.

Lessons Learned

The six month demonstration successfully concluded in November 2011, with 1,136 total runtime hours, and provided excellent insight for future installations. The project 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, we have demonstrated that there is good 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

As stated previously, high volumes of water flows and 250°F+ temperatures are typically required for traditional 250 KW to 1 MW ORC technology, but such conditions are usually unobtainable in smaller wells typical of those operated by small producers. The Green Machine requires hot water between 190-240°F at 120-200 GPM. For temperatures of 212oF at 4,200 BWPD the Green Machine can generate 65 KWh. Co-produced applications tend to work best within the lower end of both parameters. For this reason, small-scale, distributed power generation matches the resource requirements, and ElectraTherm's Green Machine is sized well with power output between 20-65kWe.

It is estimated that small wells in the top eight states with high volumes of warm water can produce up to 3 million GPM of hot produced water (Fig. 6). In locations where water production from a single well might not be sufficient to warrant installation of the equipment, using produced water from wells that

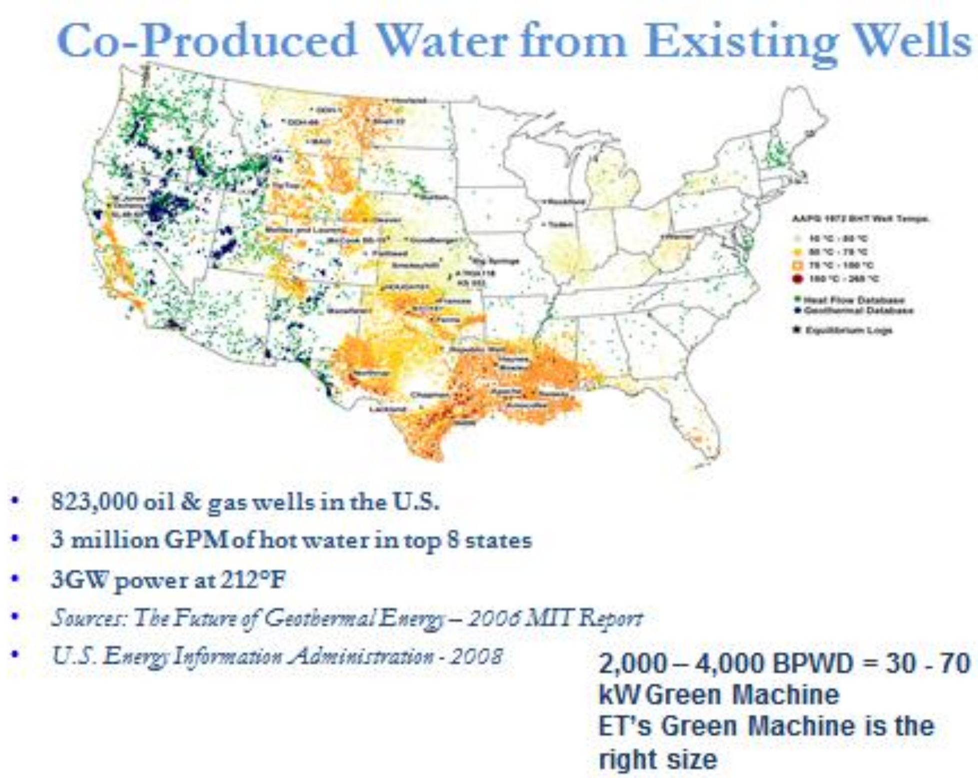

Figure 6. Map showing distribution of bottomhole temperatures in the US.

are closely spaced might offer useable resources. For example, two small wells with enough hot water to each produce 30 KWh in close proximity could be manifolded together; or in the case of this project, if two wells had been feeding into the knockout vessel, then the flow rate could have increased and proportionally the output would have increased. Figure 7 shows that increased flow rates at constant temperature could yield 60 KWh production thereby doubling the output with minimal extra piping and the same surface equipment.

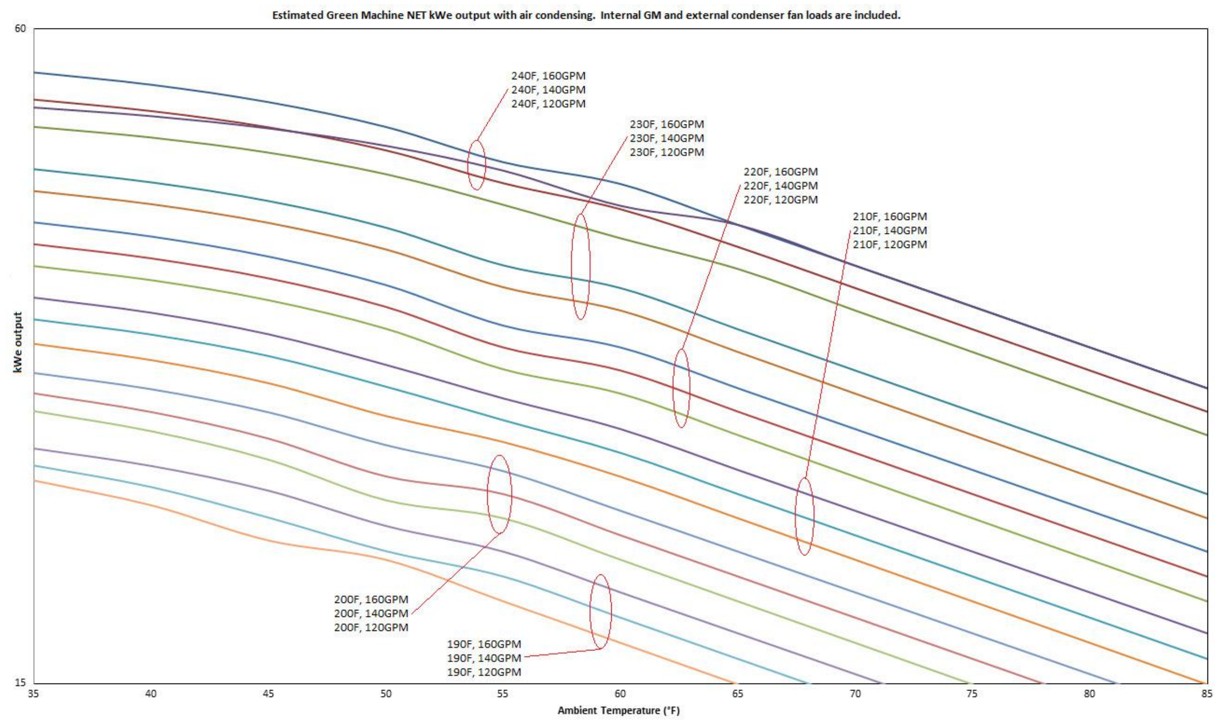

Figure 7. Graph of estimated KWh outputs vs. ambient temperature at various combinations of flow rate and produced water temperature using evaporative cooling. Clearly, higher produced water flows and temperatures and lower ambient temperatures are preferable.

Geothermal Brine Issues

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 heat exchanger design concluded it would not be sufficient for long term operation. However, a six month, 1000 hour test run operating with the installed heat exchangers had 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 potential solution.

Installation and Operation at Remote Locations

The Green Machine's modularity proved extremely helpful in both installation and removal. To reach our objective of identifying the technology that will reduce the field operating cost of electricity and create green electricity while being simple to use, the equipment was preloaded on a flatbed trailer. The truck bed set-up enabled door to door transportation of an almost fully configured balance of plant. The piping from the manifold near the knock out pot to the drop deck trailer approximately 35 feet away was completed in less than 4 hours. The final connections were made up with high pressure hoses thus allowing for "plug and play" ease of installations that can be completed in less than 24 hours for future projects. The 50 hour installation time required by the demo 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. 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 in 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. We learned that regular cleaning or a different selection of valves would keep this from happening again. The focus in this phase was on the Green Machine operation, so proper selection of the industry standard for the balance of plant equipment would eliminate the one issue encountered.

Limitations of High Ambient Temperatures

One of the greatest challenges at the Laurel site was using air cooled condensing in the high ambient temperatures during a Mississippi summer. 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, it was determined that the air cooled condenser going in was undersized for this site. Concurrent testing at the ElectraTherm 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 (>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 need to reach 240°F at 160 GPM, and require an ambient air temperature of 60°F.

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 providing an attractive payback at oil and gas sites where cost of power is over $.08/kWh, 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.

For wells with increase produced water flow and/or temperature, the IRR and Net revenue will be substantially greater. For example a single well that can produce 65 kWh using the ElectraTherm Green Machine, the IRR would be 25% with a $.028/kW 20 year cost of power and net revenue of $1,160,000 over the life of the equipment. This will provide the incentive for oil and gas producers to continue producing long after current wells are shut in due to increasing produced water. It may also be an incentive for oil and gas producers to consider bringing wells into production that until now would not have been due to unacceptable projected produced water volumes.

Figure 7 shows a graph of water temperature and various flow rates with estimated KWh outputs while using evaporative cooling. This graph is an output estimator for inputs of 190-240oF produced water and flow rates from 120 to 160 gpm. It is clear that higher temperature water and high flow rates are preferable, and that the process is more efficient at lower ambient temperatures, where evaporative cooling is more effective.

Conclusions

The demonstration at Denbury's Laurel site provides insight into feasibility of future applications from lessons learned 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. Depending on criteria, there is 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.

The Green Machine waste H2P generators' manufacturer, 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 hot water produced from 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.

As discussed previously and shown in Figure 6, states in the Gulf Coast region and midcontinent have the highest potential for this type of enhanced geothermal electrical production with excess hot produced water. Typically the data on the volume of disposal water per well is not reported to the states, so more information would need to be collected for a full economic analysis of a given field or site. One method of improving the performance where there are several smaller wells in close proximity would be to use the total water produced, either by manifolding them together or if enough heat is retained, using the water from the knockout tank.

Environmental Impact

By addressing the needs of the both the public and government to produce electricity without burning any additional fossil fuels in a cost effective manner, this project is a success. No additional water was used which is a major consideration during periods of extreme drought.

By keeping the production "inside the fence" or producing "Distributed Generation" oil and gas operators can offset their electrical use and thus become better resource stewards at a time that our nation faces increased electrical consumption and power shortages.

The total electrical production was 19,180 Kwh and this is equivalent to the offset of 172 tons of CO_2. Using what was learned regarding the air cooled condenser and with over 150 GPM produced water flow and a net output of 38 kWh, 360 tons of CO_2 can be offset according to a CO_2 emissions calculator found at the Carbonify web site (www.carbonify.com).

Figure 8. CO_2 offset calculator at carbonify web site (http://www.carbonify.com).

Applicability and Potential

Until now, the economics for power generation off waste heat at the wellhead haven't been attractive. Costs of power in many US markets with oil and gas wells range below \$.08/kWe, and the return on investment (ROI) can well-exceed eight years; not lucrative 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 RPSEA Small Producer 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.

Cost Analysis

The total cost listed in Table 1 below includes additional expenses due to the research nature of this project. Had the air-cooled condensers been larger and properly sized for the high ambient temperatures, the output could have been as much as 40% increase. There were several valve changes and lessons learned to reduce fouling of the valves. All inclusive, the total of \$230,000 has an IRR of 12%. The example of a higher flow rate well with a gross production of 65 KWh is listed in Table 1 with a 25% IRR. The returns are dependent on the input BTU values and the equipment optimization. Table 2 and Figure 9 provide more specifics about the project.

Table 1. Details of project

Total installed system capital cost
Plant and/or plant equipment capital costs (including air cooled condenser, ancillary equipment/balance of plant)
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
IRR: 12%
Net revenue over life of equipment: $450,000
NOTE: For wells with increase produced water flow and/or temperature, the IRR and Net revenue will be substantially greater. For example a well that can produce 65 kWh using the ElectraTherm Green Machine, the IRR would be 25% with a $.028/kW 20 year cost of power and net revenue of $1,160,000 over the life of the equipment

Table 2. Power production

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

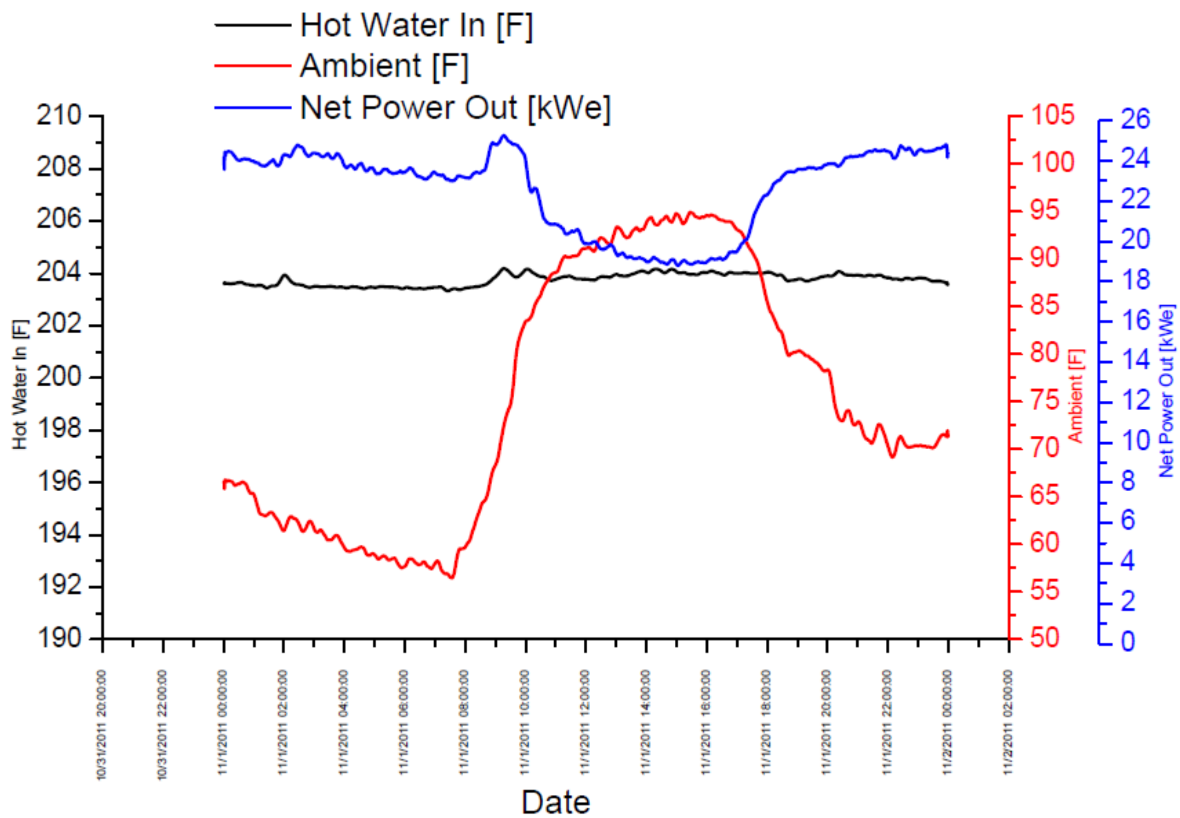

Figure 9. 24 hour runtime graph, showing temperature of air and water and net power output.

Technology Transfer

Information regarding the project was presented by GCGE at several venues in multiple states, attended by oil and gas professional, power companies, investors, geothermal power developers, students and academia. The following are those venues and the numbers in attendance:

Geothermal Energy Association Geothermal Energy Technology and International Development Forum on Wednesday, November 2010 - 500 attending

North Texas Gas Processors Annual Meeting, Dallas - September 9, 2010 – 150 attending

Invited by DOE's Geothermal Technologies Program Office of Energy Efficiency and Renewable Energy to be a participant and contributor to the Low-Temperature and Co-Produced Geothermal (LTCG) Subprogram. The purpose was to develop a Strategic Action Plan to facilitate efforts to advance geothermal technology development and deployment by the Geothermal Technologies Program Office of Energy Efficiency and Renewable Energy Department's Low-Temperature and Co-produced Geothermal (LTCG) Subprogram. July 13–14, 2010 in Golden, Colorado - 60 attending

Geothermal Energy Association: Geothermal Energy and Utilities, Co-ops and Public Power Workshop, Las Vegas, NV, July 22, 2010 – Presenter – 100 attending

CHP: Basics and Benefits - Thurs., Feb. 24, 2011- Presenter - 50 attending

Environmentally Friendly Drilling Program New Technology seminar - Speaker, San Antonio March 15,2011 – 125 attending

Geothermal Energy Technology and International Development Forum - Presenter and panel member - The event was developed by the Geothermal Energy Association in conjunction with the U.S. Department of Energy and the U.S. Department of Commerce. May 4, 2011, Washington D.C. The event showcased geothermal projects, trends, and government policies in the U.S. and around the world. – 150 attending

TXCHPI Member Luncheon, Houston - Q&A, May 27, 2011 – 80 attending

Renewable Energy World North America Conference & Expo.- Speaker, March 8-10, 2011 Tampa Convention Center, Tampa, FL – 300 attending

DOE Geothermal Program Webinar: Geothermal Technology Advancement FOA - Participant, June 23 – 10 attending

SOUTHERN METHODIST UNIVERSITY-Huffington Department of Earth Sciences - SMU Geothermal Laboratory GEOTHERMAL ENERGY UTILIZATION CONFERENCE-Dallas - Trade Booth and Conference Sponsor – 150 attending

Presented and sponsored booths at several Texas Renewable Energy Association (TREIA) conferences in Austin and San Antonio, Served for two years as Chairman, TREIA Geothermal Power Subcommittee. – 200+ attending

Texas Renewable Energy Industry Association Conference, Nov, 2011 – 80 attending

Western States Land Commissioners Conference in Jan. 11, 2012 – 120 attending.

Three presentations to the Texas Engineering Extension Services “Growing Green

Communities” conferences – 275 attending total

Total Technical Transfer Venue Participants: Approx. 2350 people

References

1. MIT Report, “Future of Geothermal Energy”, Tester et al., 2006

2. “Geothermal Energy Under our Feet” Technical report NREL/TP-840-40665, Gren and Nix 2006.

3. www.carbonify.com

List of Acronyms

AAPG	American Association of Petroleum Geologist
BOPD	Barrels of Oil Per Day
BPD	Barrels per day
BWPD	Barrels of Water Per Day
EFD	Environmentally Friendly Drilling
ESP	Electric Submersible Pump
F	Fahrenheit
GCGE	Gulf Coast Green Energy
H2P	Heat-to-Power
IRR	Internal Rate of Return (based on 20 year life of the demonstrated equipment, operating 8000 hr/year, and a $.10 cost of power with a 2%/year increase in cost of power)
ORC	Organic Rankine Cycle
SMU	Southern Methodist University
TAMU	Texas A&M University