GREENFIRE – GLOBAL COMMERCIALIZATION OF CLOSED LOOP CO₂ GEOTHERMAL

APPLICANTS & AFFILIATIONS

John R. Muir, Andrew J. Van Horn, Geothermal Resources Council Geothermal Energy Association
* Lawrence Berkeley National Laboratory
* Baker Hughes
* Geothermal Resources Council
* Geothermal Energy Association
* Electric Power Research Institute
* US Department of Energy Geothermal Technologies Office

INTELLECTUAL PROPERTY STATUS, PATENT OR TECH TRANSFER NUMBERS:
Exclusive license from Alamos National Laboratory US Patent No. 6,668,554; Applications re optimized thermosiphon and "tiered" geothermal

TIME TO MARKET - 1 - 3 Years

C2M OBJECTIVES

GreenFire Energy has spent several years designing and developing an innovative, environmentally superior renewable power technology, ECO2G. GreenFire’s next generation geothermal technology will produce no carbon emissions and, unlike other geothermal technologies, consumes no process water, because supercritical CO₂ is the working fluid. While ECO2G technology will have global applicability, particularly along the Rim of Fire, projected electricity price structures in the western United States suggest that international markets may offer the best opportunities for commercialization.

GreenFire needs an assessment of the market potential for the ECO2G technology and an evaluation of the opportunities, risks and revenues that can be obtained in domestic and international markets. This information will be an essential component of GreenFire’s strategic business plan. We believe that the information and insights provided by the C2M project will be instrumental in developing a credible market assessment.

GreenFire would welcome the opportunity to work with the C2M program, in order to:

• Develop a strategic business plan for entry into the global energy market by selecting foreign countries with the most attractive combination of geothermal resources, promising electricity markets, and potential local partners and other means of market entry.
• Determine likely market sizes for ECO2G as a function of projected electricity prices, the Levelized Costs of Energy (LCOE), geothermal resource characteristics and demand growth over the next 30 years for baseload power, competing “flexible” technologies and renewable power in these electricity markets.

• For those countries with adequate geothermal resources for ECO2G,
understand the regulatory, environmental, political, market and cultural conditions for commercialization and profitable operations.

- Identify favorable and unfavorable regulations, government and utility policies, local development hurdles, and legislation that will shape the mix of renewable energy sources in the geothermal regions of these countries, particularly in places that are actively seeking to limit emissions of greenhouse gases (GHG) and promote green power.
- Point out how projected electricity contract/power purchase agreement prices and payments for energy, capacity and ancillary services are structured and are expected to change as these markets evolve. Indicate how contract terms might best be structured to accommodate the costs and returns and operating characteristics of flexible baseload power sources like ECO2G.
- Help GreenFire understand the logistics of operating in the selected countries including international taxation, skilled labor, availability and costs of drilling rigs, electric interconnection, site acquisition, permitting and project development requirements, and other barriers to achieving profitable operations.
- Estimate future revenue streams for 1 MW, 5 MW, and 25 MW ECO2G power plants for selected values of LCOE: $50/MWh, $80/MWh, $100/MWh and $150/MWh or breakeven prices appropriate for the designated local electricity market.
- Determine which of the candidate country and regional electricity markets are the best for ECO2G. Summarize the opportunities; describe complementary technologies, competitive threats and barriers to commercialization. Identify fatal flaws, potential show-stoppers, key uncertainties and next steps.
- Define a potential exit strategy for GreenFire’s investments in each selected foreign country. Identify national or multi-national companies that might be potential partners, such as existing geothermal or international developer/driller/builder/energy company partners around the world for project development purposes, in-kind assistance, licensing, or stake-out investments in GreenFire and, ultimately, for acquisition of GreenFire Energy.
- Provide introductions to the companies currently sponsoring the C2M program, as well as other companies that might be interested in funding GreenFire’s projects.

TECHNOLOGY

ECO2G is an environmentally advanced renewable power technology designed to access the vast unexploited geothermal resources located around the world. Lack of subsurface permeability has been the greatest constraint for conventional hydrothermal projects. To circumvent the permeability problem, ECO2G circulates supercritical CO2 in a closed-loop pipe system to gather and transfer high temperature heat. In essence, we reliably create our own “permeability.”

A further advantage of ECO2G is that it eliminates the need for process water, thus removing another important constraint in geothermal development.

ECO2G reduces drilling risk, a major obstacle to project development. Conventional hydrothermal projects require the right combination of heat,
water and permeability with the result that about half of all drilled wells fail to produce. In contrast, ECO2G’s optimized closed-loop design requires only sufficient heat, minimizing drilling risk. By reducing the risks of drilling, ECO2G can transform geothermal development from a series of wildcatting ventures into an industrial process.

We are now completing the integration of engineering and technical designs along with cost and performance modeling below-ground and above-ground.

These models indicate ECO2G will create power in the range of 5 to 10 cents per kWh with 22% resource depletion in 25 years.

GreenFire technology development:
• 2010 - DOE grant to investigate CO2 geothermal in open systems,
• 2014 – 2015, LBNL modeling of geothermal production and resource depletion over 30 years with the validated TOUGH2 computer code.
• 2015 – 2016, Intensive in-house thermodynamic modeling using TOUGH2 and other models.
• 2015 – 2016, Intensive research on drilling technology using engineering resources from the Baker Hughes"

CUSTOMERS

We envision ECO2G fitting well into the developing “energy cloud” made up of utility-scale interconnected grids and microgrids, special-use customers (data centers, military), and complementary wind and solar projects, in domestic and international markets.

Market Opportunities

• Geothermal power is the greatest anomaly in the worldwide energy sector. No other baseload, clean power source has such an imbalance between its potential and its current degree of utilization.
  • World market:
    o 12,500 MW installed with a growth rate of 4.5%.
    o Estimated potential of 250,000 MW.
  • U.S. Market:
    o 3,500 MW installed with a growth rate of about 3%.
    o At least 75,000 MW potential at 95% resource probability (USGS 2009).

• Geothermal has the greatest potential for any baseload energy source to reduce worldwide GHG emissions. Recent USGS research indicates that 70% of geothermal resources are yet to be discovered.

Problems addressed by ECO2G

• Creates clean baseload and flexible power with zero GHG emissions and
without process water consumption

- Provides 95% availability, secure, baseload power, 24/7 without huge ramping requirements and operational changes to the grid.
- Learning curve to achieve material reductions in project risk, cost and time.
- Makes geothermal generation possible on a much larger scale both in the U.S. and worldwide.
- Modular design enables more precise matches with available resources and electricity demand.

SCALING

ECO2G addresses the global power market

- First priority will be to fix/augment the 70% of existing geothermal projects that are underperforming or that can be expanded
  - Rehabilitating an underperforming existing site with “failed” wells and available transmission will significantly reduce market entry cost and time
  - No interference with existing, conventional hydrothermal wells, even where co-located.
  - Successful hydrothermal projects use only about 10-15% of the available heat. ECO2G can gather heat without being limited to natural fractures, so, we estimate we can get to 50%.
- GreenFire may buy or enter into partnerships to acquire non-performing projects
  - Permitted but abandoned projects that have sufficient heat and transmission capacity
  - A Memorandum of Understanding is in place with one geothermal owner and several other existing sites are currently being examined
- GreenFire might inexpensively acquire the many known geothermal resources that cannot be developed using conventional technology
- Licensing or acquisition transactions
  - GreenFire will contemplate technology licensing or acquisition
  - GreenFire would like to learn whether licensing the technology internationally is a feasible business model
  - GreenFire would also like to learn about multinational firms that could purchase the company.

ADVANTAGES

Conventional geothermal is limited to moderate temperature zones where there is sufficient permeability for water to flow to production wells and so is limited to use only about 2% of the available geothermal resource. A competing technology “Enhanced Geothermal Systems” (EGS) has tried for decades to create artificial permeability. However, EGS is still far from commercialization because of the difficulty of creating long symmetrical racks in complex and varied terrains.

ECO2G uses oil and gas drilling technology to create closed-loop sealed wells. Further, supercritical CO2 is better than water for heat transfer in this system, and thus eliminates the water constraint. This simplified approach reduces the complexity and risk of drilling, thus transforming geothermal development from a series of wildcatting ventures into an industrial process.
This approach will also be successful because, in comparison to conventional water-based geothermal, ECO2G:

- Enables geothermal power to be developed in many more sites
- ECO2G benefits from the R&D expenditures of the oil industry to reduce drilling costs
- Can access significantly more of a given geothermal heat resource
- Uses extracted heat much more efficiently
- Can generate revenue in less than half the time with less capital
- Is less likely to engender opposition on environmental grounds than other renewables,
- Modular 1 to 5 MW power units can provide fast flexible power for grid-balancing

**BARRIERS**

Power pricing structures in some jurisdictions may not be favorable to geothermal power production, despite the inherent advantages of geothermal power as a renewable resource. For example, California’s regulatory and legislative mandates provide incentives to solar, wind and energy storage technologies, but effectively penalize new geothermal power projects by allowing curtailment of this reliable renewable baseload resource, hence, reducing its revenues and economic attractiveness, unless “flexibility” can be properly compensated. Even in such jurisdictions, however, the inherent advantages of geothermal power as a baseload power source will ultimately be valuable. For example, as the CAISO Energy Imbalance Market expands regionally and as coal-fired (or nuclear) plants retire, there will be a need for additional baseload power, which is also renewable.

- Today there is a perception that geothermal drilling and power projects are too risky and geographically limited to comprise a significant share of the market. However, ECO2G makes possible technological and cost advances that can make geothermal more economically competitive.
- Although supercritical CO2 turbines exist, they need some modifications to be optimized for the input temperatures ECO2G will produce. GreenFire has had discussions with current manufacturers that indicate that this is an engineering cost, but not a feasibility issue.

**FEEDBACK**

- LBNL: Test results indicate the CO2 geothermal systems can generate power more efficiently than water-based systems.
- Baker Hughes: Various configurations of ECO2G wells are feasible, each with its own cost and risk. Advances in directional drilling and well completion technologies will reduce risk and costs over time.
- USGS: Geothermal heat represents a vast energy source, and most geothermal resources are yet to be discovered. Unfortunately, even the best conventional systems use only about 15% of the available heat, so the process is less efficient than it might be.
• GreenFire Advisors: GreenFire’s Advisory Board members represent the disciplines necessary to develop ECO2G, most with deep experience in the conventional geothermal industry. Its members have decades of experience in the technical, business and market disciplines needed for success. Each is contributing time and effort to the future success of the ECO2G technology and to GreenFire to develop and deploy ECO2G as the best next generation technology for advancing geothermal power production

ACADEMIC/JOB TITLE(S)

John Muir - Sr. VP Business Development, Andy Van Horn - Member Advisory Board

STATUS

Company or LLC formed, Other DOE funding, Significant lab performance data, Founder(s) plus >2 full-time equivalent employees

TIME TO MARKET BACKGROUND

GreenFire intends to select a demonstration site from 5 current options by June 2016. The demonstration project will require about 7 months from October 2016 to April 2017. If the demonstration project succeeds as expected, then the project will be converted to the first phase of a commercial project at that site by November 2017. Bear in mind that we will be using an existing geothermal site with permits in place, wells drilled, and an available connection to the power grid.
Lawrence Berkeley National Laboratory modeled ECO2G geothermal production and resource depletion over 30 years with the validated TOUGH2 computer simulation. Non-confidential elements of this work were presented in a recent paper that can be found in the Proceedings of the 41st Workshop on Geothermal Reservoir Engineering, Stanford University, Stanford, California, February 22-24, 2016, SGP-TR-209:


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# GreenFire Energy Inc. Team and Relationships

**Management Team**
- **Joseph Scherer, CEO:** Attorney/MBA with 30+ years experience in project finance including renewable energy
- **Dr. Brian Higgins:** PhD in Mechanical Engineering with extensive experience in thermodynamics and power cycles
- **Joseph Osha, CFO:** MBA/CFA with extensive public and private market experience in renewable energy
- **John Muir, VP Business Development:** MBA with several successful exits in technology ventures
- **Dr. Alan Eastman, Principal Research Scientist, Co-Founder:** PhD in chemistry with 37 patents, industrial experience
- **Mark P. Muir, Senior Consulting Scientist, Co-Founder:** MBA and geologist specializing in hydrogeology

**Advisory Board**
- **Dr. Leland “Roy” Mink:** Former Director of DOE Geothermal Technologies Program; expertise in geology, hydrogeology, and geothermal resource characterization
- **Lou Capuano, Jr.:** 40 years of geothermal drilling expertise; widely recognized industry expert; current President of the Geothermal Resources Council (GRC)
- **Hailey Dickey:** 40 years of experience in power generation systems development; expert in geothermal power system design and SC02 turbines
- **Dr. Andy Van Hom:** Ph.D. with 35+ years’ experience as an economic, technical and regulatory consultant to utilities, EPRI, EPA, IPP generators, electricity, natural gas and emission market participants

**Collaborating Research Partners**
- U.S. Department of Energy
- Lawrence Berkeley National Laboratory
- Pacific Northwest National Laboratory
- University of Utah
- Electric Power Research Institute

## ECO2G™ is at Convergence of Advanced Energy Technologies

**Subsurface: drilling technology from the oil & gas industry**
- Directional/horizontal drilling in hot formations
- Precision drilling to connect wells 1-2 km apart
- Multiple lateral wells from a single vertical shaft

**Surface: SC02 turbine technology from power industry**
- Off-the-shelf 10 MW turbines available in 2017
- Improve generation efficiency up to 50% over conventional geothermal steam turbines/generators

*Costs and risks greatly reduced because ECO2G™ uses proven technologies from existing industries*
Strategy Will Initially Focus on Improving Existing Projects

- JVs to augment power at existing installations
- Acquire & fix “failed” projects
- Leases in place
- Permits obtained
- Geophysical analysis done
- Wells drilled and logged
- Power Interconnect available

ECO2G™ Offers Flexible, Reasonably Priced Power

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<tr>
<th>Cost MWH</th>
<th>ECO2G Improves on Conventional Geothermal</th>
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Source: US Energy Information Administration