Environment and Natural Resources Trust Fund
2018 Request for Proposals (RFP)

Project Title: **ENRTF ID: 169-E**

Bringing Geothermal Power to MN: CO2 Power-System Test

Category: E. Air Quality, Climate Change, and Renewable Energy

Total Project Budget: $ 315,250

Proposed Project Time Period for the Funding Requested: 2 years, July 2018 to June 2020

Summary:

Project will design, fabricate and test an innovative, closed-cycle CO2 power system, the first steps for geothermal power and grid-scale geologic energy storage to become renewable energy opportunities for MN.

Name: Jimmy Randolph

Sponsoring Organization: TerraCOH Inc.

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Excelsior MN 55331

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Location

Region: Metro

County Name: Hennepin

City / Township:

Alternate Text for Visual:

Schematics of CO2 Plume Geothermal (CPG) systems, both for the initial lab study and in field deployments.

_____ Funding Priorities	_____ Multiple Benefits	_____ Outcomes	_____ Knowledge Base
_____ Extent of Impact	_____ Innovation	_____ Scientific/Tech Basis	_____ Urgency
_____ Capacity Readiness	_____ Leverage	_____ TOTAL	_____%

PROJECT TITLE: Prototype CO_2 power system study, the first step to bring geothermal power to MN

I. PROJECT STATEMENT

The proposed project will involve the design, fabrication and in-house testing of an innovative power system that will allow geothermal power generation and grid-scale geologic energy storage to become renewable energy opportunities for MN. This project follows approximately $6 M in federal and private investment in fundamental study, patent development, and market research on CO_2 Plume Geothermal (CPG) power generation and energy storage systems, and it will be the first physical test of this transformative technology. Following anticipated successful testing, the system will be relocated to a field site for early commercial testing. TerraCOH, a start-up company spun out of the University of MN, is requesting $315,250 in funding to help de-risk CPG and enable pre-commercial study, which we will match with $470,000 in private cash investments and in-kind contributions.

Background: Baseload renewable power systems and large-scale energy storage are needed to ensure power grid stability and reliability, energy security, and to enable optimal use of grid assets such as transmission lines while reducing atmospheric CO_2 and other pollutant emissions. Increased use of wind and solar energy is causing power curtailments in parts of the US, which is challenging for inflexible baseload power plants with high capital costs, such as fossil energy facilities that could be integrated with CO_2 capture, as they require high capacity factors (fraction of time generating power) for economic viability. Most energy-storage technologies are deployed above ground, have high capital costs and limited storage capacity, requiring natural-gas-fueled back-up power.

Legacy geothermal facilities deliver 24/7 energy at the lowest levelized cost of electricity of any power technology (US Energy Information Administration, 2015), but they are severely constrained geographically. The limited number of economically viable geologic sites, high capital costs of wells, and high drilling risks have limited legacy geothermal deployment to less than 0.3% of US power demand. Similarly, confined aquifer energy storage can provide MW-scale energy storage, but it is limited geographically. CPG technology solves these challenges.

TerraCOH's technologies will be disruptive to the renewable energy and energy storage sectors. They will enable an order-of-magnitude increase in the geographic extent of economically viable geothermal power production, from less than 1% to an estimated 40% of the US, reducing greenhouse gases emissions and increasing the volume of renewable energy that can be added to the grid while simultaneously decreasing power costs. TerraCOH's approach to CPG achieves a combination of decreased drilling risk, by using existing deep wells, and, particularly in low-temperature geologic formations, increased power production efficiency. The latter is accomplished by taking advantage of the unique properties of CO_2 as a heat transfer fluid in geologic formations and power systems. The net result is a massive increase in economically viable geothermal power production.

The proposed project will provide the first demonstration of a CO_2-based bottoming power cycle fueled by simulated geothermal heat. The TerraCOH team has spent several years conducting market research, identifying a system design that has low technical risk, using off-the-shelf equipment in a new application, and is very cost effective. The project will involve modifying the design for an existing closed-cycle CO2 power system, fabricating the modified system with an appropriate manufacturer, and installing the system in a lab-based simulated geothermal environment, whereby the system can be rigorously tested under a wide range of anticipated field conditions. Following testing and after the timeframe of the proposed project, the power system will be moved to a field site for pre-commercial demonstration, paving the wave for full commercial development.

II. PROJECT ACTIVITIES AND OUTCOMES

Activity 1: Design and fabrication of prototype CPG power system. **Budget: $ 168,750**

The prototype closed-cycle CO_2 power system design is a modification of very new but demonstrated CO_2 power system that are used in other applications, such as waste heat recovery in natural gas turbines. Thus, while the technical risk is low, a new system must be built for low-temperature, geothermal applications. This activity will be undertaken in partnership with a small power system manufacturer with appropriate expertise – two such entities have been identified, and negotiations between TerraCOH and these entities is ongoing.

Outcome	Completion Date

1. Finalize power system design	Aug. 31, 2018
2. Power system contractor selection	Sept. 30, 2018
3. System fabrication.	June 30, 2019

Activity 2: Lab testing of prototype power system **Budget: $146,500**

In the prototype 50 kW power facility, CO_2 will be heated by a conventional gas burner rather than by geothermal heating. This will provide a closed-loop CO_2 power plant decoupled from a geothermal reservoir, permitting geology-independent investigations of plant design and operational aspects such as CO_2 inlet temperature and pressure, flow rate, and effects of CO_2-water mixtures. The facility will allow controlled reproductions of field site conditions, permitting modification prior to field testing. Information obtained from these tests will include performance characteristics, operational/maintenance requirements, design requirements for CPG systems at commercial scale, and a predictive model of system costs at scale.

Outcome	Completion Date
1. Power system lab installation and commissioning	Aug. 31, 2019
2. System testing	Mar. 31, 2020
3. Final analysis and reporting	June 20, 2020

III. PROJECT STRATEGY

A. Project Team/Partners: Dr. Jimmy B. Randolph's (PI) research focuses on numerical modeling of geophysical fluid/heat transfer. He is Chief Technical Officer and co-Founder of TerraCOH. His responsibilities have included technology development and commercialization, project development, and financing. He has 16 issued patents. Dr. Randolph will assist with power system design and testing, as well as numerical modeling of the system.

John P. Griffin (co-PI), CEO of TerraCOH. John holds a B.S. in Mechanical Engineering and an MBA from the UMN. He has 30+ years leading companies. As CEO and General Manager, he has led and consistently grown organizations with zero to $200+ M in revenue. His board experience includes private and public company boards.

Dr. Martin Saar (co-PI), consultant, is the Werner Siemens Prof. for Geothermal Energy and Geofluids at the Swiss Federal Institute of Technology (ETH), Zurich, Switzerland. With Dr. Randolph and Prof. Kuehn, he is inventor of CPG and PI on over $5 million in basic research funding (NSF/DOE) for CPG. He is co-Founder of TerraCOH. At ETH, he runs a 20-person research team, studying unconventional geothermal energy and geofluid technologies. Dr. Saar will contribute support in the form of power and geologic system numerical modeling.

TerraCOH will lead design and testing of the CO_2 power system. TerraCOH will receive ENRTF money and will contribute private capital and in-kind support to the project.

Power system manufacturer (one of two identified companies, currently in confidential negotiations): power system design modification and fabrication. Will receive ENRTF funds and private capital from TerraCOH.

B. Project Impact and Long-Term Strategy: If the prototype power system functions as expected, after lab testing, it will be relocated to a field site for pre-commercial testing and demonstration. Two field sites in the MN region have been identified, one for geothermal power generation and another for geologic energy storage, which uses the same power system platform. If the prototype plant requires design adjustments before field testing, such changes will be made before deployment. By studying the power system and geothermal reservoirs separately, we can correct issues with the components before developing larger-scale systems. We will pursue funding for a field pilot plant through the U.S. Dept. of Energy's ARPA-E program, the Dept. of Defense Rapid Innovation Fund, the MN Renewable Development Grant program, and private investment. The ultimate objective is for MN to become a North American center for development and implementation of geothermal and geologic energy storage technologies, leading to vast increases in the implementation of affordable renewable energy.

C. Timeline Requirements

Design, contractor selection, and fabrication will require approx. one year, followed by one year of testing, observation, system modification as needed, and modeling.

2018 Detailed Project Budget

Project Title: Prototype CO2 power system study, the first step to bring geothermal power to MN

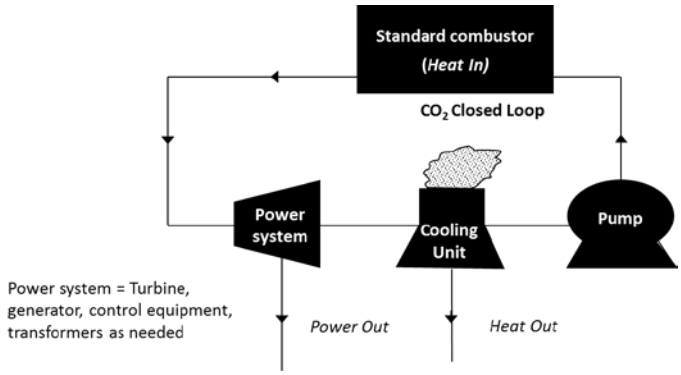
IV. TOTAL ENRTF REQUEST BUDGET: 2 years

BUDGET ITEM	AMOUNT
Personnel:	$ -
Dr. Jimmy B Randolph (PI, CTO, 25% time per year for 2 years, salary 75% of cost, fringe benefits 25% of cost).	$ 75,000.00
John Griffin (co-PI, CEO, 15% time per year for 2 years, salary 75% of cost, fringe benefits 25% of cost)	$ 45,000.00
Dr. Martin O Saar (co-PI, Scientific Advisor, 5% time per year for 2 years, salary 100% of cost)	$ 7,500.00
Steven Price (Operations, 25% time per year for 2 years, salary 75% of cost, fringe benefits 25% of cost)	$ 60,000.00
Test engineer (25% time per year for 1 year, salary 75% of cost, fringe benefits 25% of cost)	$ 26,250.00
Professional/Technical/Service Contracts:	$ -
Power system manufacturer (two have been identified, with negotiations ongoing): system design and fabrication.	$ 75,000.00
Equipment/Tools/Supplies:	$ -
Power system test equipment, including sensors and logging devices	$ 4,000
Fuel for system test	$ 2,500
Additional budget items:	
System installation in lab and commissioning.	$ 8,000
Facility rental for power system test	$ 12,000
TOTAL ENVIRONMENT AND NATURAL RESOURCES TRUST FUND $ REQUEST =	**$ 315,250**

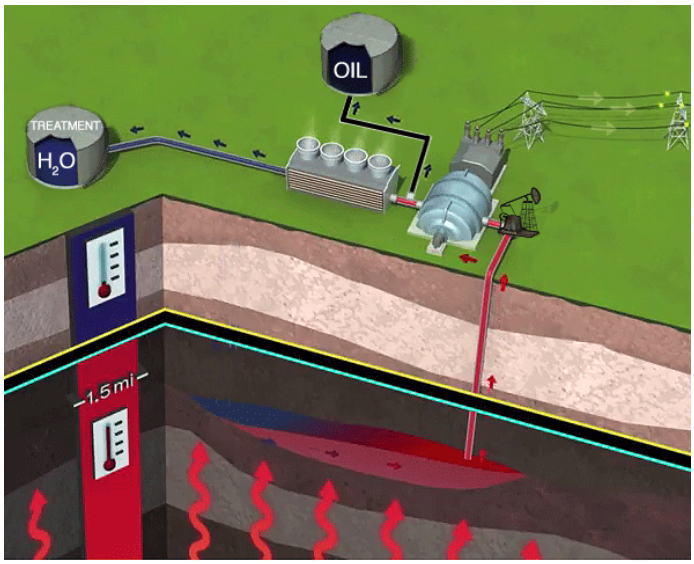
V. OTHER FUNDS

SOURCE OF FUNDS	AMOUNT	Status
Other Non-State $ To Be Applied To Project During Project Period: Private investment capital. TerraCOH has an ongoing capital raise, and the indicated amount has almost been secured.	$ 200,000	Pending
Other State $ To Be Applied To Project During Project Period:	N/A	
In-kind Services To Be Applied To Project During Project Period: 25% time (salary and fringe) for primary staff (Randolph, Griffin, Price) for two years each	$ 270,000	Secured
Past and Current ENRTF Appropriation:	N/A	
Other Funding History:	N/A	

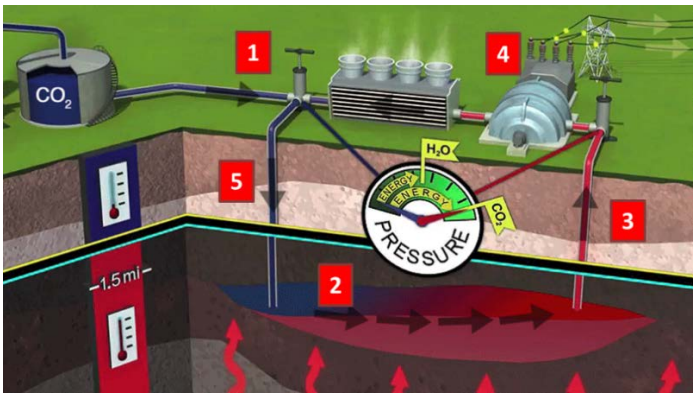
CO_2 Plume Geothermal System Schematics



Closed-cycle CO_2 power system design for the proposed project. The simulated geothermal energy source will be used to test the innovative power system over a variety of anticipated field conditions.



CPG system design for first field tests, where old oilfield infrastructure is repurposed for geothermal power generation using a closed-cycle CO_2 power system.



CPG system design when circulating CO_2 through the deep subsurface.

2018 Project Manager Qualifications and Organization Description
Project Title: Prototype CO_2 power system study, the first step to bring geothermal power to MN

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WORK EXPERIECE:

2014-present **TerraCOH, Inc.,** Minneapolis, MN: **Chief Technical Officer, Interim President, Director**
2006-present **University of Minnesota – Twin Cities,** Department of Earth Sciences, Minneapolis, MN: **Senior Research Associate, Postdoctoral Research Associate, Research Assistant**
2011-2014 **Heat Mining Company, LLC,** Rapid City, SD: **Chief Technical Officer, Senior Scientist**

EDUCATION:

2006-2011 **University of Minnesota – Twin Cities**, Department of Earth Sciences, Minneapolis, MN. Ph.D., Geophysics, emphasis in Hydrogeology and Geothermal Energy.
2002-2006 **Saint Olaf College**, Northfield, MN. B.A. in Physics and Mathematics, Summa Cum Laude.

SELECTED HONORS, AWARDS, PATENTS:

2015 Saar, M.O., **J.B. Randolph**, and T.H. Kuehn (in no particular order). Carbon dioxide-based geothermal energy generation systems and methods related thereto. U.S. Patent No. 8,991,510 issued March 31, 2015.
2012-2014 Saar, M.O., **J.B. Randolph**, and T.H. Kuehn (in no particular order). Carbon dioxide-based geothermal energy generation; Systems and methods related thereto. U.S. Patent No. 8,316,955 B2 issued 2012; Canadian, Australian, and 11 European patents issued.
2012-2013 **J.B. Randolph**. Enhanced carbon dioxide-based geothermal energy generation systems and methods. U.S. Provisional Patent Application Serial No. 61/725,270 filed November 11, 2012. U.S. and International Patent Applications filed in March, 2013.

QUALIFICATIONS: Dr. Randolph has extensive experience developing innovative geothermal and energy storage technologies and transitioning these technologies from the University to the commercial sector. Additionally, Dr. Randolph has experience investigating coupled heat and groundwater flow using field, laboratory, and computational methods. Together with his former advisor, Dr. Martin Saar, and a Dr. Kuehn from mechanical engineering, Randolph developed the concept of combined CO_2 sequestration and geothermal energy extraction while at the UMN, a technology that has been awarded several patents and resulted in the startup company – TerraCOH – being spun out of the UMN.

RESPONSIBILITIES: Dr. Randolph will collaborate with the power system manufacturer on the design of the innovative, closed-cycle CO_2 power system. Thereafter, he will lead development of numerical models to simulate system performance over a wide variety of anticipated lab and field conditions. He will work with the test engineer on lab testing and system modification as needed.

ORGANIZATION DESCRIPTION: TerraCOH Inc. is a start-up company that was spun out of the University of Minnesota in 2014, with operations commencing in 2016, that holds the worldwide exclusive license to the CO_2 Plume Geothermal (CPG) technology developed at the UMN, as well as technology developed privately. In addition, TerraCOH has an ongoing relationship with Lawrence Livermore National Laboratory and is working with them to secure a license for Earth Battery geologic energy storage technologies. TerraCOH also collaborates with the Swiss Federal Research University in Zurich, ETH, and the Ohio State University on CPG-related investigations. TerraCOH's mission is to use our proprietary CPG technology to exponentially expand sites worldwide, where renewable geothermal energy can be used, to provide emission-free, baseload (24/7) and dispatchable electricity and grid-scale energy storage (e.g. for wind and solar energy), at the lowest cost of all alternatives, while storing CO_2 permanently underground.