

**Environment and Natural Resources Trust Fund  
2019 Request for Proposals (RFP)**

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**Project Title:**

**ENRTF ID: 178-E**

Grid-Scale Geologic Energy Storage in MN: Earth Battery

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

**Sub-Category:**

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**Total Project Budget: \$** 315,250

**Proposed Project Time Period for the Funding Requested:** June 30, 2021 (2 yrs)

**Summary:**

The project will test an innovative power system and model a site in southern Minnesota, the initial steps to bring grid-scale, cost-effective geologic energy storage to Minnesota.

**Name:** Jimmy Randolph

**Sponsoring Organization:** TerraCOH, Inc

**Title:** \_\_\_\_\_

**Department:** \_\_\_\_\_

**Address:** 6125 Blue Circle Drive

Minnetonka MN 55343

**Telephone Number:** (952) 457-8959

**Email** j.randolph@terracoh-age.com

**Web Address**

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**Location**

**Region:** Metro, Southeast

**County Name:** Faribault, Hennepin

**City / Township:**

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**Alternate Text for Visual:**

Schematics of the power system and Earth Battery energy storage system, and map of southern MN.

<input type="checkbox"/>	Funding Priorities	<input type="checkbox"/>	Multiple Benefits	<input type="checkbox"/>	Outcomes	<input type="checkbox"/>	Knowledge Base	
<input type="checkbox"/>	Extent of Impact	<input type="checkbox"/>	Innovation	<input type="checkbox"/>	Scientific/Tech Basis	<input type="checkbox"/>	Urgency	
<input type="checkbox"/>	Capacity Readiness	<input type="checkbox"/>	Leverage	<input type="checkbox"/>		TOTAL	<input type="checkbox"/>	%
<input type="checkbox"/> If under \$200,000, waive presentation?								



**PROJECT TITLE: Grid-scale geologic energy storage in MN: The Earth Battery**

**I. PROJECT STATEMENT**

The proposed project will involve the design and testing of an innovative power system that will allow grid-scale geologic energy storage to become a renewable energy opportunity for MN, together with initial investigation of a site in south central MN for use as a demonstration site for this Earth Battery technology. This project follows approx. \$6.5M in federal and private investment in fundamental study, patent development, and market research, and it will be the first physical test of parts of this transformative technology. Following anticipated successful testing, the power 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 for pre-commercial study, which we will match with \$770,000 in private cash investments and in-kind contributions.

*Background:* MN currently has a strong renewable energy standard, and with bipartisan legislation pending to increase the standard to 50% by 2030, MN could become a national leader in renewable energy development. To meet this goal, new renewable energy technologies, accompanied by complementary public policies, will need to be implemented. Power grid experts generally recognize that supplying more than 40% of regional power via intermittent renewables – i.e., wind and solar – is difficult if not impossible without grid-scale energy storage, and even smaller fractions can be difficult to manage depending on the quality of the grid. Grid-scale energy storage, together with baseload renewable power, can allow full replacement of conventional power plants while also increasing the fraction of intermittent renewable sources that can be supported. Geologic energy storage could be a boon for MN increasing renewable energy use, improving energy security, lowering pollutant emissions, decreasing energy costs, and generating job development as new technologies are demonstrated and used.

*Earth Battery Geologic Energy Storage Summary:* Technologies developed at the UMN and collaborators make use of non-water working fluids for geologic energy storage and transfer, and they are collectively referred to as the Earth Battery. These technologies use mixtures of water and gases such as air, nitrogen (N<sub>2</sub>), and carbon dioxide (CO<sub>2</sub>) to store energy in a non-toxic, environmentally safe manner. *The Earth Battery can store low value, off peak energy in deep subsurface formations as pressure or heat, making use of carefully located/ operated wells to store energy for hours or months, and in amounts up to GWhr’s, at lower costs than most any alternative.*

*Site of Interest* – A site in Faribault county, southern MN, known as the “Wells-Bricelyn” site, has been selected for this study. The structure appeared to have appropriate qualities for natural gas storage, and was extensively drilled in the 1960’s, but was too far from the Twin Cities area to be used at the time.

The proposed project will provide the first demonstration of a CO<sub>2</sub>-based bottoming power cycle for use with an energy storage system. 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 of an existing closed-cycle CO<sub>2</sub> power system, fabricating the modified system with an appropriate manufacturer, and installing the system in a lab-based simulated geologic energy storage 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 testing, paving the wave for full commercial development.

**II. PROJECT ACTIVITIES AND OUTCOMES**

**Activity 1: Design and fabrication of prototype CPG power system.**

**ENRTF Budget: \$ 118,750**

The prototype closed-cycle CO<sub>2</sub> power system design is a modification of very new but demonstrated CO<sub>2</sub> power system that is 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 energy storage 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
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**Environment and Natural Resources Trust Fund (ENRTF)  
2019 Main Proposal**

1. Finalize power system design	Aug. 31, 2019
2. Power system contractor selection	Sept. 30, 2019
3. System fabrication.	June 30, 2020

**Activity 2: Lab testing of prototype power system**

**ENRTF Budget: \$116,500**

In the prototype power facility, CO<sub>2</sub> will be heated by a conventional gas burner rather than by energy from storage sources. This will provide a closed-loop CO<sub>2</sub> power plant decoupled from a geologic reservoir, permitting geology-independent investigations of plant design and operational aspects. 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 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, 2020
2. System testing	Mar. 31, 2021
3. Final analysis and reporting	June 20, 2021

**Activity 3: Southern MN Site Analysis**

**ENRTF Budget: \$80,000**

Considerable data for the site of interest is held by the MN Geological Survey, which is happy to share that data. We will construct a 3D reservoir model based on geologic and geophysical data. Then, we will develop numerical models to simulate geologic energy storage in the selected reservoir, choose the optimal working fluid for energy storage at this site, and inform locations to bore into the reservoir in future investigations.

Outcome	Completion Date
1. Collection of existing site data (from MN Geological Survey)	Aug. 31, 2020
2. Numerical model development	Mar. 31, 2021
3. Numerical modeling of site for Earth Battery operations	June 20, 2021

**III. PROJECT PARTNERS:**

**A. Partners receiving ENRTF funding**

Name	Title	Affiliation	Role
Dr. Jimmy B. Randolph	Chief Technical Officer	TerraCOH Inc	System design/modeling
John P Griffin	Chief Executive Officer	TerraCOH Inc	Management, power sys. testing.
Steven Price	Project Manager	TerraCOH Inc	Project management/oversight
Thomas Buscheck	Scientific adviser	TerraCOH Inc	Numerical modeling
Power system manufacturer	n.a.	(2 companies identified)	Power system design, construction, testing

**IV. LONG-TERM- IMPLEMENTATION AND FUNDING:**

If the prototype power system functions as expected, after lab testing, it will be relocated to a field site for pre-commercial demonstration. If the prototype plant requires design adjustments before field testing, such changes will be made before deployment. By studying the power system and geologic 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, and private investment. The ultimate objective is for MN to become a North American center for development of geologic energy storage technologies, leading to vast increases in the implementation of affordable renewable energy.

**V. TIME LINE REQUIREMENTS:**

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

## 2019 Project Budget Spreadsheet

**Project Title:** Grid-scale geologic energy storage in MN: The Earth Battery

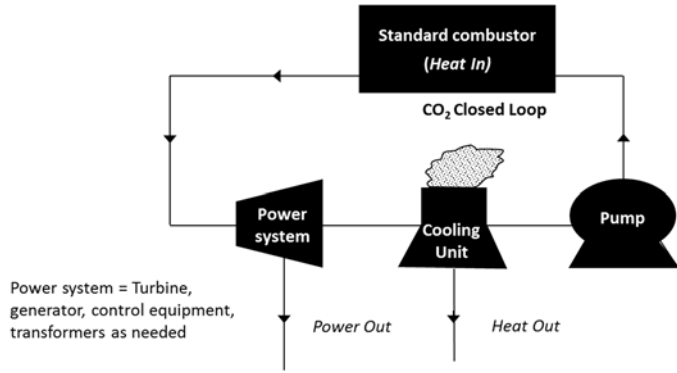
### IV. TOTAL ENRTF REQUEST BUDGET: 2 years

<b>BUDGET ITEM</b>	<b>AMOUNT</b>
<b>Personnel:</b>	\$ -
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. Thomas Buscheck (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
<b>Professional/Technical/Service Contracts:</b>	\$ -
Power system manufacturer (two have been identified, with negotiations ongoing): system design and fabrication.	\$ 75,000.00
<b>Equipment/Tools/Supplies:</b>	\$ -
Power system test equipment, including sensors and logging devices	\$ 4,000
Fuel for system test	\$ 2,500
<b>Additional budget items:</b>	
System installation in lab and commissioning.	\$ 8,000
Facility rental for power system test	\$ 12,000
<b>TOTAL ENVIRONMENT AND NATURAL RESOURCES TRUST FUND \$ REQUEST =</b>	<b>\$ 315,250</b>

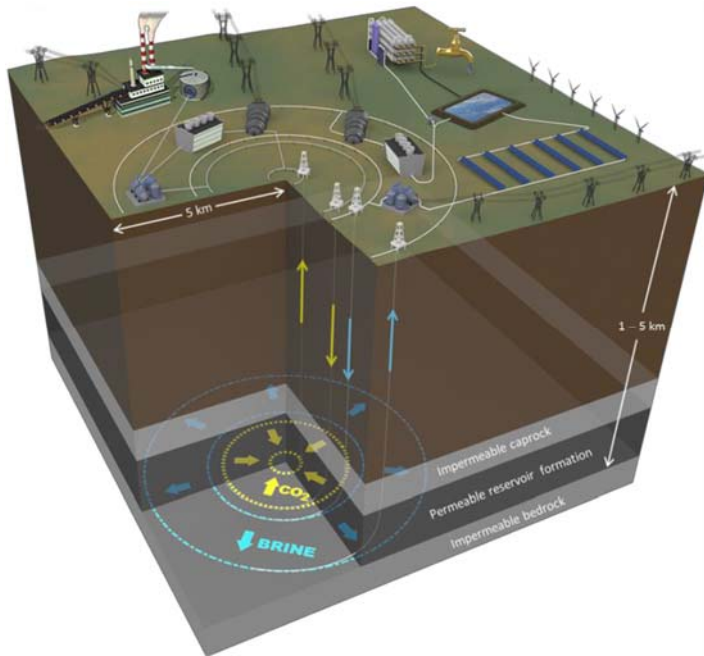
### V. OTHER FUNDS

<b>SOURCE OF FUNDS</b>	<b>AMOUNT</b>	<b>Status</b>
<b>Other Non-State \$ To Be Applied To Project During Project Period:</b> Private investment capital. TerraCOH has an ongoing capital raise, and the indicated amount has almost been secured.	\$ 500,000	Pending
<b>Other State \$ To Be Applied To Project During Project Period:</b>	N/A	
<b>In-kind Services To Be Applied To Project During Project Period:</b> 25% time (salary and fringe) for primary staff (Randolph, Griffin, Price) for two years each	\$ 270,000	Secured
<b>Past and Current ENRTF Appropriation:</b>	N/A	
<b>Other Funding History:</b>	N/A	

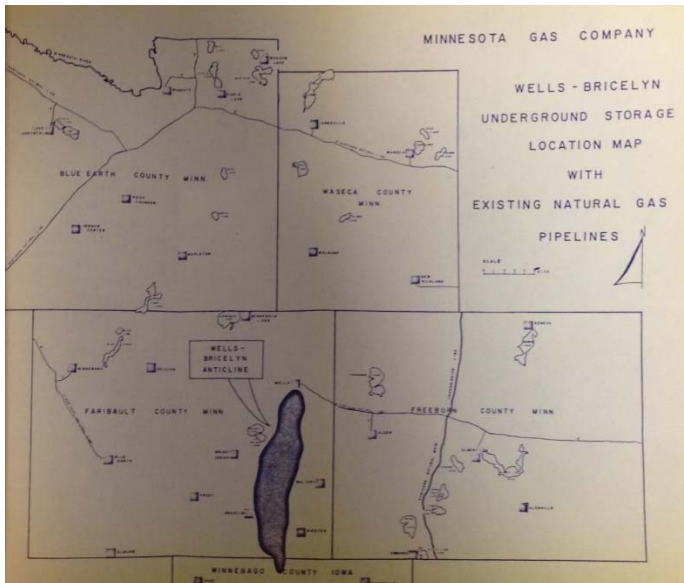
# Earth Battery System Schematics



Closed-cycle CO<sub>2</sub> 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.



The Earth Battery (Buscheck et. al, 2014). To note, CO<sub>2</sub> can be replaced with air or nitrogen, and brine with water. Additionally, while the original Earth Battery design uses concentric rings of wells, our team has since developed designs that can use fewer and simpler well configurations, particularly in dome-shaped storage formations.



1960's era map of the Wells-Bricelyn dome (Minnesota Geological Survey), located in South-central MN, which is the site of interest for testing of the Earth Battery in MN.

## 2019 Project Manager Qualifications and Organization Description

### Project Title: Grid-scale geologic energy storage in MN: The Earth Battery

Dr. Jimmy B. Randolph  
TerraCOH, Inc.  
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Minnetonka, MN 55343, USA

E-mail: [j.randolph@terracoh-age.com](mailto:j.randolph@terracoh-age.com)  
Cell: 952-457-8959

#### WORK EXPERIENCE:

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<sub>2</sub> 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<sub>2</sub> 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 also lead collection of data for the proposed test site and development of site numerical models.

**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<sub>2</sub> 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 has an option with them 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 Earth Battery-related investigations. TerraCOH's mission is to use our proprietary technologies 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 ultimately storing CO<sub>2</sub> permanently underground.