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

Project Title: **ENRTF ID: 165-E**

Field Testing/Demonstration of Novel Groundsource Heat Pump

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

Total Project Budget: $ 174,757

Proposed Project Time Period for the Funding Requested: 1.5 years, July 2018 to December 2019

Summary:

Project will field-test novel groundsource heat pump technology developed at the UMN. Promising research must now be followed by pre-commercial testing, paving the way for a MN heat pump renaissance.

Name: Jimmy Randolph

Sponsoring Organization: U of MN

Address: 450 McNamara Alumni Center, 200 Oak Street S.E.
Minneapolis MN 55455

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Web Address

Location

Region: Central, Metro

County Name: Hennepin, Stearns

City / Township:

Alternate Text for Visual:

Conventional groundsource heat pump, showing the differences between legacy technology and the novel Advective Heat Pump that will be field tested in this project.

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

PROJECT TITLE: Field testing and demonstration of novel ground-source heat pump technology

I. PROJECT STATEMENT

The proposed project will perform field testing of a novel ground source heat pump technology that was developed at the University of MN. With the assistance of basic research funding provided by LCCMR, the technology has been numerically modeled and physically tested in lab settings with very promising results. Now, its design must be formalized for real-world settings, and pre-commercial field testing must be completed so that by the end of this project, the tech. will have been sufficiently demonstrated to be commercially viable.

Space/water heating and cooling comprise 48% of energy use in an average US residence, and commonly, that energy is supplied by natural gas or fossil-fuel-derived electricity. Ground source or geothermal heat pumps (GHPs) can reduce energy demands for heating/cooling by 75%. GHPs can be used most anywhere in the world because they use the shallow subsurface as a thermal capacitor, removing heat during winter months to provide heating and returning heat during the summer to provide cooling. They function by boosting the temperature of heat extracted from the ground using a vapor compression cycle. Traditional GHPs require numerous wells – their main cost – and are space-intensive. This high initial cost, when compared to low-priced fossil fuels such as natural gas, is often undesirable for building owners. Thus, despite being a proven technology, GHPs have minimal market penetration in the US (1% of the HVAC market). However, in areas with higher energy costs, such as Sweden, GHPs constitute up to 75% of the HVAC market, indicating there is significant room for growth.

Conventional GHPs ignore groundwater flow and focus on conductive heat exchange with subsurface materials. However, groundwater carries heat much more effectively than rock (with air in pore spaces) and as such, our novel GHP technology takes advantage of the thermal transport properties of groundwater flow, advectively carrying the heat to/from the ground source heat exchanger. Our Advective GHP (AGHP) operates in a closed-loop fashion so that no groundwater is used and no contaminants are introduced to the subsurface. Lab tests and models show that the AGHP drastically reduces the number of boreholes needed in a heat pump installation while improving performance predictability and maintenance, as well as decreasing costs compared to traditional GHPs, thus addressing the issues that are limiting the market penetration of traditional GHPs.

The proposed project will include 1) modifying the AGHP heat exchanger design for field applications, 2) fabricating it, 3) installing a test well in the Twin Cities at the headquarters of subcontractor Braun Intertec to enable AGHP testing in the metropolitan geologic province, 4) installing a test well in central MN at a Braun client to test it in a different geologic province, 5) field testing the AGHP at both locations, and 6) post-field-test data analysis/ numerical modeling to improve performance predictions for a wide range of field conditions that cannot all be field tested immediately. This will provide the basis for commercial development and deployment.

An Intellectual Property Disclosure has been filed with the Office for Technology Commercialization at UMN. The UMN may pursue patent protection, thus some technology details are confidential, i.e., not included.

II. PROJECT ACTIVITIES AND OUTCOMES

Activity 1: AGHP Heat Exchanger Design and Fabrication **Budget: $29,257**

Here, we will modify the AGHP heat exchanger design that was developed for lab testing to ensure it is sufficiently robust for commercial applications, fabricate the unit, and develop secondary equipment to mount the exchanger in a borehole. We will also work to get the test unit permitted for field testing.

Outcome	Completion Date
1. Heat exchanger design and compliance review	08-20-2018
2. Heat exchanger fabrication and fabrication documentation	09-31-2018
3. Design and fabrication of secondary equipment for heat exchanger installation	09-31-2018
4. Permitting of heat exchanger with MN Dept. of Health and MN DNR, as needed	10-31-2018

Activity 2: Installation of Boreholes to be Used to Test the AGHP **Budget: $27,429**

We will install boreholes in two distinct geologic provinces in MN, logging the wells to determine optimal depths to install the AGHP for testing, which will provide two baseline conditions for AGHP performance.

Outcome	Completion Date
1. Drilling and installation of test bore in the Prairie Du Chien aquifer in Bloomington, MN	10/31/2018
2. Identifying location for, drilling and installation of test bore in central MN	10/31/2018
3. Flow rate logging of bores.	11/30/2018

Activity 3: AGHP Capacity Rate Testing **Budget: $36,724**

Here, we will use the unique mobile test platform developed by Braun to test the AGHP in the field under simulated heating/cooling loads. Tests will be performed for at least two weeks at each location to determine moderate-term performance. At the Bloomington site, the AGHP will be tested alongside conventional GHPs.

Outcome	Completion Date
1. Mobile test platform testing of AGHP unit installed in Prairie Du Chien aquifer	05/15/2019
2. Mobile test platform testing of AGHP unit installed in central MN overburden bore	05/15/2019

Activity 4: Numerical Model Development and Post-test Analysis **Budget: $81,347**

Numerical modeling, including modification of existing GHP subsurface and economic models to include AGHP data, and modeling to permit performance predictions over a wide range of field conditions. Additionally, field test data will be analyzed and used to inform models, then the AGHP will be compared with traditional GHPs.

Outcome	Completion Date
1. Modification of GHP hydrogeologic/economic models, development of AGHP models	06/21/2019
2. Post field test data analysis and comparison of AGHP with traditional GHPs	12/31/2019

III. PROJECT STRATEGY

Dr. Jimmy B. Randolph (PI), Prof. Dr. Martin O. Saar, Scott Alexander, UMN Twin Cities, Dept. of Earth Sciences. Randolph will manage the project, develop numerical models and assist with experimentation. Saar, as head of the Geofluids Group at UMN, can leverage their experience/equipment, Alexander contributes broad knowledge of MN geology and experiment design. The 3 conceived of and completed lab testing of the AGHP. They have over 40 yrs combined experience in geothermal energy, hydrogeology, and related environmental processes.

Braun Intertec is a MN-based consulting company and regional leader in large-scale GHP installations. Braun has the extensive expertise and in-kind resources required to thoroughly field-test the AGHP. Specifically, Braun has a state-of-the-art mobile GHP test unit that can connect to underground GHP equipment, thereby simulating building heating/cooling loads over weeks. Also, Braun designed and installed a unique GHP test facility at their headquarters in Bloomington, MN, comprising multiple ground heat exchange techniques, against which we can test the new AGHP. Braun will receive ENRTF money and contribute in-kind resources.

B. Project Impact and Long-Term Strategy

Although the technological risk of the AGHP is low in our estimation, it is none-the-less too new and unproven for commercial investment but too advanced for basic research funding. This gap in traditional funding opportunities is commonly referred to as the "valley of death." While most technologies experience this period, it is particularly challenging for technologies in the energy space, where payback periods tend to be long and initial investments, high. Thus, LCCMR is well-positioned to help demonstrate the AGHP, positioning MN to be a national leader in cost-effective, renewable energy technologies for building heating and cooling.

With successful field demonstrations of the AGHP, we will approach via the UMN Office for Technology Commercialization, a private entity to pursue licensing. Our goal is to help foster a local and, ultimately, national AGHP industry that is an economic win for installers and building owners, which could lower MN's fossil fuel requirements for heating/cooling by 50%, substantially reducing the state's greenhouse gas emissions.

Non-confidential project results will be published in peer-reviewed journals and presented at conferences.

C. Timeline Requirements

The proposed project is expected to require 1.5 years, approx. 1 year for heat exchanger construction and field testing and 6 months for extensive post processing. Most proposed activities must be completed sequentially.

2018 Detailed Project Budget

Project Title: Field testing and demonstration of novel ground-source heat pump technology

IV. TOTAL ENRTF REQUEST BUDGET *1.5* **years**

BUDGET ITEM	AMOUNT
Personnel:	$ -
Dr. Jimmy B Randolph (PI, Research Associate, 50% time per year for 1.5 years, salary 74.9% of cost, fringe benefits 25.1% of cost).	$ 55,642.00
Scott Alexander (Research Scientist, 20% time per year for 1.5 years, salary 78.6% of cost, fringe benefits 21.4% of cost).	$ 22,399.00
Undergraduate student (Research assistant, 40% time for one year, salary 100% of cost)	$ 13,240.00
Minnesota Geological Survey Staff Scientist (2% time for one year, salary 78.6% of cost, fringe benefits 21.4% of cost)	$ 2,031.00
Professional/Technical/Service Contracts:	$ -
Braun Intertec: Subcontractor. Heat exchanger design and fabrication, test bore design and installation, heat exchanger capacity rate testing	$ 75,945.00
Equipment/Tools/Supplies:	$ -
Wellbore logging and monitoring equipment.	$ 3,000
Travel: In-state travel to metro and central MN heat pump test locations.	$ 2,500
TOTAL ENVIRONMENT AND NATURAL RESOURCES TRUST FUND $ REQUEST =	**$ 174,757**

V. OTHER FUNDS

SOURCE OF FUNDS	AMOUNT	Status
Other Non-State $ To Be Applied To Project During Project Period:	N/A	
Other State $ To Be Applied To Project During Project Period:	N/A	
In-kind Services To Be Applied To Project During Project Period: Ground source heat exchanger lab, including borefield and monitoring equipment. This state-of-the art field is without comparison in the Midwest US, and it will be used as a baseline against which to compare and validate the novel GHP system in the field	$ 20,880	Secured
Discounted rental rate for TC3 mobile GHP testing rig (four weeks), to be used for field testing of novel GHP and comparison systems.	$ 11,040	Secured
Computational hardware (computer workstations) and software (EM2), for numerical modeling of the GHP system.	$ 19,700	Secured
Past and Current ENRTF Appropriation:	N/A	
Other Funding History:	N/A	

Conventional Commercial-Scale Groundsource Heat Pump

The figure shows a conventional groundsource heat pump, employing vertical subsurface heat exchange loops for a large residential or commercial building. Note that the installation has multiple vertical loops that do not intersect groundwater zones. The novel Advective GHP (AGHP) technology, which will be field-tested under the proposed project, makes use of the ability of water to move large volumes of heat to decrease the required number of wells, thereby reducing costs, eliminating much of the mess of GHP installations, and improving predictability. The AGHP is also designed to allow servicing of underground equipment without requiring excavation, improving system longevity and performance.

The basic investigation of the AGHP was previously supported by the LCCMR, and the proposed project will bring the system through the new technology "valley of death." That is, the AGHP is too advanced for basic research funding but not sufficiently proven to be commercially adopted, a stage that all technologies encounter and which is the end of many. This promising renewable energy system is expected to be a win for all parties involved, including building owners, industry, and the state of MN; with the proposed project, LCCMR can help make MN a national leader in GHP technology. Figure courtesy of Braun Intertec, 2017.

2018 Project Manager Qualifications and Organization Description
Project Title: Field testing and demonstration of novel ground-source heat pump technology

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RESEARCH AND WORK EXPERIECE:

2006-present **University of Minnesota – Twin Cities,** Department of Earth Sciences, Minneapolis, MN: **Senior Research Associate, Postdoctoral Research Associate, Research Assistant**
2014-present **TerraCOH, Inc.,** Minneapolis, MN: **Chief Technical Officer, Interim President, Director**
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.
2009 UMN Dept. of Geology and Geophysics Forrest Fellowship for academic achievement.
2008 UMN Dept. of Geology and Geophysics Gibson Fellowship for academic achievement.

QUALIFICATIONS: Dr. Randolph has extensive experience investigating coupled heat and groundwater flow using field, laboratory, and computational methods. Additionally, Dr. Randolph has extensive experience developing innovative heat pump and geothermal technologies and transitioning these technologies from the University to the commercial sector. For example, together with his former advisor, Dr. Martin Saar, and a colleague from mechanical engineering, Dr. Kuehn, 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 a startup company – TerraCOH – being spun out of the UMN to commercialize the technology.

RESPONSIBILITIES: Dr. Randolph will develop numerical models and complete numerical simulations and calculations to analyze and help validate the Advective Groundsource Heat Pump (AGHP) system. He will help supervise scientists and a student in these analyses. In addition, he will coordinate with subcontractor Braun Intertec to design and field test the AGHP.

ORGANIZATION DESCRIPTION: The University of Minnesota is dedicated to research and discovery, teaching and learning, as well as outreach and public service. Within this framework, the Department of Earth Sciences is ideally positioned to carry out the proposed project. The size and diversity of the University of Minnesota guarantees that a wide range of resources, both human expertise and equipment, can be devoted to the project. Moreover, the UMN is well-positioned to serve as a future testing ground for the proposed new technology and to ultimately commercialize this novel geothermal heat pump, for the benefit of the entire state.