Environment and Natural Resources Trust Fund
2014 Request for Proposals (RFP)

Project Title: **ENRTF ID: 116-E**

Innovative Groundwater-Enhanced Geothermal Heat Pump Study

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

Total Project Budget: $ 196,000

Proposed Project Time Period for the Funding Requested: 2 Years, July 2014 - June 2016

Summary:

We propose to analyze and validate a novel geothermal heat pump method and technology that is expected to substantially reduce heat pump cost while improving performance and predictability.

Name: Martin Saar

Sponsoring Organization: U of MN

Address: 310 Pillsbury Drive SE
Minneapolis MN 55455

Telephone Number: (952) 457 8959

Email rando035@umn.edu

Web Address

Location

Region: Statewide

County Name: Statewide

City / Township:

_____ Funding Priorities _____ Multiple Benefits _____ Outcomes _____ Knowledge Base

_____ Extent of Impact _____ Innovation _____ Scientific/Tech Basis _____ Urgency

_____ Capacity Readiness _____ Leverage _____ Employment _______ TOTAL ______%

PROJECT TITLE: Innovative Groundwater-Enhanced Geothermal Heat Pump Study

I. PROJECT STATEMENT

Space and water heating and cooling consume 48% of all energy used in an average US residence, and generally that energy is supplied by natural gas or fossil-fuel-derived electricity. Geothermal heat pumps (GHPs) can reduce energy requirements for heating/cooling by 75%. However, traditional GHPs are expensive, and their performance is difficult to predict before installation. We propose to analyze and validate a novel GHP method/ technology that is expected to substantially reduce GHP cost while improving performance and predictability.

GHPs can be used anywhere in the world because they use the shallow subsurface as a thermal capacitor, removing heat during winter months to provide space/water heating and returning heat during the summer to provide cooling. They function by boosting the temperature of heat extracted from the ground using compression. Traditional GHPs require considerable wells and/or excavation – their main cost – and are space-intensive. Thus, in the US, they have achieved minimal market penetration (3% of the heating, ventilation and air conditioning (HVAC) market). However, in areas with higher energy costs, such as Sweden and Switzerland, GHPs constitute up to 75% of the HVAC market, indicating there is significant room for growth in the US.

Conventional GHPs ignore groundwater flow and focus on heat exchange with subsurface rocks and sediments. However, groundwater carries heat much more effectively than rock and as such, our novel GHP system and technology specifically acknowledge groundwater flow. This groundwater-enhanced GHP takes advantage of the thermal transport properties of groundwater but in a closed-loop fashion so that no groundwater is used and no contaminants are introduced to the subsurface. Preliminary simulations suggest that our system is far more efficient, less space intensive and thus less costly than conventional systems.

The ultimate objective of this project is to determine the viability of groundwater-enhanced GHPs using numerical modeling and lab/field testing of a prototype. Early-stage modeling and validation of the novel technology/ approach have been completed. This project modifies existing GHP technology while incorporating established hydrogeologic practices and information; thus, we feel the new technology is well-position for success. The novel GHP would be smaller and cheaper than existing systems, permitting faster payback periods, more widespread GHP use, and helping GHPs become a significant renewable energy technology.

An Intellectual Property Disclosure has been filed with the Office for Technology Commercialization at the UMN. The UMN may pursue patent protection and as such, some information concerning this proposal is currently confidential. This proposal thus provides less detail than it would otherwise.

II. DESCRIPTION OF PROJECT ACTIVITIES

Activity 1: Detailed numerical modeling of innovative GHP system. Budget: $18,500

Here, we propose to extensively expand upon existing models in order to study the new GHP system under a variety of configurations and geologic conditions relevant to Minnesota. This modeling will further examine the efficacy of the novel method and determine optimal system design. The GHP subsurface component can be installed vertically, using wells, or horizontally. The former is less space-intensive and, thus, well-suited for urban areas while the latter may be less costly and suited for rural or industrial spaces. The new GHP is anticipated to require far less space than conventional systems under either configuration. However, numerical modeling is needed to determine space needs and overall system design for varied geologic conditions.

Outcome	Completion Date
1. Development and testing of base case GHP numerical models using Comsol simulator.	Dec 31, 2014

Activity 2: Prototype subsurface unit modeling, design and construction. Budget: $69,500

The groundwater-enhanced GHP incorporates a novel subsurface heat exchange unit, which is projected to decrease the GHP subsurface footprint, substantially reducing installation costs while making the system more serviceable than conventional GHPs. This activity will finalize the design of a prototype unit, test the unit in geologic models, and construct a small prototype.

1. Finalize design of the prototype subsurface heat exchange unit.	Mar 31, 2015
2. Incorporate the subsurface heat exchange unit into geologic numerical models.	June 31, 2015
3. Have prototype subsurface unit constructed at UMN milling facilities.	Sept 31, 2015

Activity 3: Prototype laboratory testing, numerical verification. Budget: $55,500

The prototype subsurface GHP unit will be tested in a lab setting. We will construct a tabletop-scale subsurface analogue consisting of a rectangular, open-topped Plexiglas box filled with sediment. It will be filled with water, and a pump will drive the water, simulating groundwater flow. The prototype will be installed in the subsurface analogue, and a heat transfer fluid will be circulated through the device. Heat will be added to or removed from the transfer fluid using a heat exchanger. The system will be used to determine the efficacy of heat transfer through the prototype, to ensure the analogue groundwater is isolated from the heat transfer fluid, and to quantify heating and/or cooling of the analogue space. We will also compare lab models with numerical models. Note, we have previously constructed and successfully operated similar analogues for other studies.

1. Subsurface analogue device construction.	Sept 31, 2015
2. Installation and operation of GHP prototype; comparison of lab and numerical results.	Jan 31, 2016

Activity 4: Prototype field testing. Budget: $52,500

The prototype subsurface unit will be installed in a groundwater monitoring well – selected to be similar to wells used for commercial GHP operation – on the UMN campus. It will be connected to a conventional GHP surface unit, housed in a small enclosure, to test the prototype operation over a variety of operating conditions. We will install monitoring devices to facilitate analysis of GHP performance and subsurface impacts.

1. Install subsurface prototype in a well; construct surface facility.	Mar 31, 2016
2. Operate and analyze prototype system.	June 31, 2016

III. PROJECT STRATEGY

A. Project Team/Partners: Dr. Martin O. Saar (PI), Dr. Jimmy B. Randolph (co-PI), Scott Alexander (co-PI), UMN Twin Cities, Dept. of Earth Sciences. Saar will manage the project and assist with modeling/experimentation. As head of the Geofluids group, he can leverage their experience and equipment, thus permitting this novel GHP to be tested with minimal time and financing. Randolph will conduct all numerical modeling and, with Alexander, design the prototype unit and conduct lab/field testing. Alexander contributes broad knowledge of UMN geology, access to UMN groundwater monitoring wells, and experience in experiment design. Together, the three conceived of and completed proof-of-concept analysis of the novel groundwater-enhanced GHP. They have over 40 combined yrs experience in geothermal energy, hydrogeology, and related environmental issues.

B. Timeline Requirements: The proposed project is expected to require two years, one year for numerical modeling and system design and one year for prototype equipment construction and experimentation. Most proposed activities must be completed sequentially, thus necessitating the proposed timeframe.

C. Long-Term Strategy and Future Funding Needs: A successful prototype-scale demonstration of the novel GHP system would be followed by a full-scale system design. Thereafter, we will approach the UMN facilities division to investigate installing a full system on campus to heat/cool the to-be-renovated Tate Hall or the Biomedical Discovery District. Soon, the UMN will require additional heating infrastructure, which could be supplied renewably with the new GHP technology/approach rather than with coal, which dominates the current heating system. In addition, we anticipate approaching, with the assistance of the UMN Office for Technology Commercialization, a commercial entity to pursue statewide implementation of the novel GHP technology. GHPs that are less costly, more predictable, and more serviceable – such as what we propose – could reduce Minnesota's fossil fuel requirements for heating and cooling by 50%, substantially reducing the state's greenhouse gas emissions and providing massive environmental benefits.

Non-confidential results of all studies will be published in peer-reviewed journals, such as the *Hydrogeology Journal*, and presented at conferences including the *Midwest Groundwater Conference.*

2014 Detailed Project Budget

Project Title: *[Innovative Groundwater-Enhanced Geothermal Heat Pump Study]*

IV. TOTAL ENRTF REQUEST BUDGET: 2 years

BUDGET ITEM	AMOUNT
Personnel Overall (Wages and Benefits):	$ 111,036
Dr. Martin O Saar (PI, associate professor 8.3 % time per year for two years, salary 83.4% of cost, fringe benefits 16.6% of cost).	23,166
Dr. Jimmy B Randolph (co-PI, research assistant, 25% time per year for two years, salary 74.1% of cost, fringe benefits 25.9% of cost).	30,317
Scott Alexander (co-PI, research scientist, 33.3% time per year for two years, salary 73.1% of cost, fringe benefits 26.9% of cost).	47,423
Undergraduate Research Assistant (19.2% time per year, or ten weeks, for two years, salary 93.1% of cost, fringe benefits 6.9% of cost).	10,310
Equipment/Tools/Supplies Overall:	$ 84,784
Prototype subsurface equipment, including design, machining and ancillary equipment such as tubing and insulation.	32,500
Laboratory equipment -- including monitoring equipment, heater, water pumps, tubing, and benchtop-scale simplified subsurface replica to allow for testing of prototype geothermal heat exchanger prior to installation in a real environment.	24,000
Small geothermal heat pump surface unit, related automated control equipment, and surface heat exchanger, to be used for experimentation and demonstration of prototype system.	9,500
Outdoor enclosure, electrical connections, and heat pump-to-well connections for prototype operation.	3,500
Monitoring equipment, to measure subsurface and surface conditions conditions during geothermal heat pump prototype testing.	7,500
Additional Budget Items Overall: Funds for equipment repair and maintenance.	$ 2,284.00
Geophysical surveys of the geologic formation in which the prototype unit will be tested, to allow for thorough analysis for prototype performance and determine any impact upon the subsurface.	5500.00
TOTAL ENVIRONMENT AND NATURAL RESOURCES TRUST FUND $ REQUEST =	$ 196,000

V. OTHER FUNDS

SOURCE OF FUNDS	AMOUNT	Status
In-kind Services During Project Period: Computational hardware (computer workstations, linux cluster) and software (Comsol Multiphysics and TOUGH2 software), for numerical modeling of the GHP system.	$ 40,000	Secured
Monitoring well on UMN campus, to be employed for GHP subusrface unit prototype testing.	$ 20,000	Pending

Conventional Geothermal Heat Pump

The figure shows a conventional geothermal heat pump, this one employing vertical well-based subsurface heat exchange loops. Note the use of multiple vertical loops/wells and the lack of reference to groundwater. The novel groundwater-enhanced geothermal heat pump technology, to be investigated in the proposed study, specifically acknowledges groundwater flow and is designed to decrease the required number of wells, thereby reducing costs and improving predictability. Also note that the wells in the figure are fully buried, whereas the novel technology in this proposal is designed with wells that reach the surface and subsurface equipment that can be serviced without excavation, improving long-term system performance. Figure retrieved 2013 from www.geoexchange.org .

2014 Project Manager Qualifications and Organization Description

Project Title: *Innovative Groundwater-Enhanced Geothermal Heat Pump Study*

Dr. Martin O. Saar
Department of Earth Sciences
University of Minnesota – Twin Cities
310 Pillsbury Dr. SE
Minneapolis, MN 55455, USA

E-mail: saar@umn.edu
Office: +1 612-625-7332
Lab: +1 612-625-3928
Web: www.geo.umn.edu/orgs/geofluids

CURRENT POSITIONS AT THE UNIVERSITY OF MINNESOTA (UMN):

2011-present Associate Professor of Geology and Geophysics, Dept. of Earth Sciences, UMN
2011-present Institute on the Environment Resident Fellow, UMN
2008-present Affiliated Member of the Graduate Faculty, Computer Science and Engineering, UMN
2006-present Member of the Graduate Faculty, Water Resources Sciences, UMN
2005-present Assistant Professor of Geology and Geophysics, Dept. of Geology & Geophysics, UMN
2005-present George and Orpha Gibson Chair of Hydrogeology and Geofluids, UMN

EDUCATION:

2003 Ph.D. in Earth and Planetary Sciences, University of California – Berkeley,
1998 M.S. in Geology, University of Oregon – Eugene, OR, United States
1995 Vordiplom (~B.S.) in Geology, Albert-Ludwigs University, Freiburg, Germany

SELECTED HONORS, AWARDS, PATENTS:

2012 US patent awarded to Saar, Randolph, and Kuehn (through the UMN) for a new method to generate electricity in low geothermal heat-flow regions
2009 McKnight Land-Grant Professor, 2009-2011, UMN
2005 Endowed Gibson Chair of Hydrogeology and Geofluids, UMN
2003 Turner Postdoctoral Research Associate Fellowship, University of Michigan

QUALIFICATIONS: Martin Saar and scientists in his Geofluids research group have extensive experience investigating coupled heat and groundwater flow, CO_2 flow, and multiphase-multicomponent flow employing field, laboratory, and computational methods. Moreover, Dr. Saar has considerable experience developing and commercializing geothermal technologies. Together with his former graduate student, Dr. Jimmy Randolph, and a colleague from mechanical engineering, Dr. Kuehn, Saar developed the concept of combined CO_2 sequestration and geothermal energy extraction that was submitted for patenting by the University of Minnesota and awarded a US patent in 2012. Numerous additional patents have been submitted, and a startup company – Heat Mining Company LLC, based in Rapid City, SD – was spun out of the UMN to commercialize the technology.

RESPONSIBILITIES: Dr. Saar will supervise undergraduate students and scientists on numerical simulations and calculations to help validate the groundwater-enhanced geothermal heat pump method. Furthermore, he will assist in the design, construction, and testing of an innovative prototype heat pump technology, part of the groundwater-enhanced geothermal heat pump technology.

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.