Environment and Natural Resources Trust Fund
2020 Request for Proposals (RFP)

Project Title: **ENRTF ID: 193-E**

Multifunctional Materials for Building Energy and Power Generation

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

Sub-Category:

Total Project Budget: $ 395,136

Proposed Project Time Period for the Funding Requested: June 30, 2023 (3 yrs)

Summary:

Our collaborative team proposes to design and engineer novel two dimensional (2D)-material aerogels with multifunctionalities for renewable energy applications including both building superinsulation and power generation.

Name: Xiaojia Wang

Sponsoring Organization: U of MN

Job Title: Assistant Professor

Department: Department of Mechanical Engineering, College of Science and Engineering

Address: 246 Mechanical Engineering, University of Minnesota, 111 Church ST SE

Minneapolis MN 55455

Telephone Number: (612) 625-1583

Email wang4940@umn.edu

Web Address: http://www.me.umn.edu/labs/mnttl/

Location:

Region: Metro

County Name: Hennepin

City / Township: Minneapolis

Alternate Text for Visual:

The proposed 2D-material aerogels can prevent heat loss in winder and keep hot air out in summer (superinsulation), and meanwhile, use the in-door/out-door temperature difference to generate electricity (power generation).

_____ Funding Priorities _____ Multiple Benefits _____ Outcomes _____ Knowledge Base

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

_____ Capacity Readiness _____ Leverage _______ TOTAL _____%

PROJECT TITLE: Multifunctional Materials for Building Energy and Power Generation

I. PROJECT STATEMENT

Imagine a home insulation that better insulates your house in the winter and produces electricity from the temperature difference between the indoors and outdoors. Developing such a multifunctional insulation is the goal of this proposal. Aerogels, highly porous media consisting of fibers or nanometer-sized particles, can act as **superinsulation**, whose insulating power can exceed that of current fibrous insulations. We are proposing to develop such superinsulations with plasma synthesis, a technique based on ionized gases developed at the University of Minnesota. We further propose to coat the highly porous structure of the superinsulation with **thermoelectric** (TE) materials. Such materials turn temperature differences into electrical voltages (the so-called TE effect), and thus are able to produce electricity from the heat that would otherwise be lost to the environment.

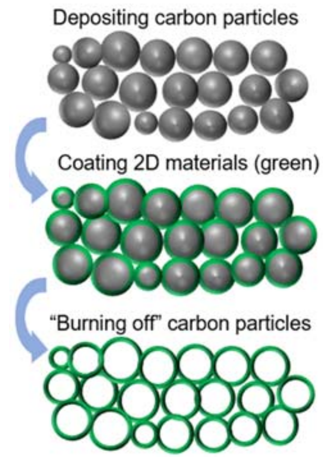

Figure 1. Schematic of the 3-step synthesis of 2D-material aerogels.

Superinsulations will be produced by depositing nanometer-sized particles into highly porous films. The nanoparticles will be produced in a plasma, in which an electric field excites free electrons in a gas to such high energies that they can easily decompose gaseous precursor molecules. This leads to the formation of well-controlled nanoparticles by adjusting parameters such as gas pressure and flow rate. We will produce amorphous carbon particles by decomposing methane or acetylene. By carefully depositing these particles at low velocities, carbon-particle films with large porosities can be produced. Particles will be bound to each other to improve mechanical stability via high-temperature sintering. Such highly porous materials have shown thermal conductivities close to or even lower than that of ambient air, about three times lower than that of current fibrous insulation materials.

To give the superinsulation thermoelectric properties, we will coat the carbon particle porous structure with an atomically thin layer of the so-called two-dimensional (2D) materials. Gas phase deposition processes are known for many 2D materials, and some of the 2D materials have attractive thermoelectric properties. Tin disulfide (SnS_2) and tungsten diselenide (WSe_2) are suitable materials that we will coat onto the superinsulation with gas phase chemical vapor deposition. In a final step, heating the material to 800-900 degree Celsius may be used to "burn off" the carbon particles. This would leave behind only the structure of 2D materials with the carbon template removed (**Fig. 1**). We hypothesize that this structure will have even better insulating properties, because the heat conduction through the network of carbon particles has been eliminated. Meanwhile, the low heat conduction of the porous 2D material is favored for producing a large temperature difference to generate electricity based on the TE effect. In addition, the electrical properties of 2D materials can be readily improved through doping (the introduction of certain atoms into a material to enhance its electrical properties). Thus, our proposed 2D-material aerogels are multifunctional offering both superinsulation and power generation in one package.

The proposed work will be carried out by a collaborative team leveraging the expertise of two research groups at the University of Minnesota, Twin Cities. Professor **Kortshagen** is a world-renowned expert on plasma synthesis techniques. He will lead the materials synthesis and device fabrication. Professor **Wang** has significant experience in ultrafast-laser-based measurement techniques and multiscale modeling to study the transport properties of materials. She will establish the structure-functionality relationships for the proposed materials, which will serve as guidance for **Kortshagen**'s group to further optimize the materials properties (and thus the performance of superinsulation and thermoelectric devices) via structural engineering.

II. PROJECT ACTIVITIES AND OUTCOMES

The materials synthesis, structure and property characterization, and device fabrication will be integrated in an iterative manner between two groups to ensure the success of the proposed work.

Activity 1: Initial synthesis and property measurements of 2D-material aerogels

Description: In activity 1, the team will synthesize and characterize 2D-material aerogels using a custom-designed template made of carbon particles from plasma synthesis. The team will start with SnS_2 and WSe_2.

ENRTF BUDGET: $129,301

Outcome	Completion Date
1. Design and Fabrication of SnS_2 & WSe_2 aerogels	*Dec. 31, 2020*
2. Material property characterization to establish the structure-property relationship	*Jun. 30, 2021*

Activity 2: Performance optimization of 2D-material aerogels

Description: In activity 2, the team will focus on optimization of the proposed 2D-material aerogels to achieve the best performance of thermal insulation and the highest efficiency of power generation.

ENRTF BUDGET: $131,688

Outcome	Completion Date
1. Optimization of the superinsulation performance of the proposed 2D-material aerogels	*Jun. 30, 2022*
2. Improvement of the power generation efficiency of aerogels via structural engineering	*Jun. 30, 2022*

Activity 3: Demonstration of multifunctional materials and prototype devices

Description: In activity 3 (upon completion), the team will demonstrate superinsulation materials with optimal thermal and electrical performance and a prototype of power generation devices based on 2D-material aerogels.

ENRTF BUDGET: $134,148

Outcome	Completion Date
1. Demonstration of superinsulation materials with optimal performance	*Jun. 30, 2023*
2. Prototype of thermoelectric devices for power generation	*Jun. 30, 2023*

III. PROJECT PARTNERS AND COLLABORATORS:

The research modalities and complementary technical backgrounds of both members are uniquely pronounced and undeniably necessary to accomplish project activities. Professor **Wang** is an expert in energy transport, especially in analyzing the transport properties of materials at the atomic and molecular levels. Professor **Kortshagen** is famous for his research accomplishment in the area of plasmas kinetic theory, nonthermal plasmas at atmospheric pressures, and plasma synthesis and functionalization of nanomaterials. In addition, our collaborative team will leverage insights from industry to ensure real-world significance and broad transformative impact. Both team members have proven records of collaborating with industrial companies. For example, **Wang** has been working on projects involving Minnesota-based companies including Seagate and 3M. **Kortshagen**'s group developed a novel plasma technique for materials synthesis in 2005, which is covered by three US patents and was licensed to companies including DuPont-Innovalight and Dow Corning.

IV. LONG-TERM IMPLEMENTATION AND FUNDING:

This proposed work has merits in both basic scientific foundation (materials engineering) and applied technology (device performance). In the long run, outcomes of this work also hold promise for large-scale commercialization due to the novelty and scalability of the technology, which can potentially create job opportunities and benefit the state economy. The team requests a three-year duration (from July 01, 2020 to June 30, 2023) to complete this proposed work (with milestones explained above). Results generated by this collaborative proposal will serve as preliminary data to seek for federal funding resources to support continued efforts on this topic. We plan to target agencies with portfolios focused on renewable and sustainable energy, materials sciences, and building energy, including National Science Foundation (Energy for sustainability, Energy, Power, Control, and Networks (EPCN), Thermal Transport Processes (TTP)), Department of Energy (Buildings Energy Efficiency Frontiers and Innovation Technologies), among others.

Attachment A: Project Budget Spreadsheet
Environment and Natural Resources Trust Fund
M.L. 2020 Budget Spreadsheet
Legal Citation:
Project Manager: Xiaojia Wang
Project Title: Multifunctional Materials for Building Energy and High-Efficiency Power Generation
Organization: University of Minnesota
Project Budget: 395.136.00
Project Length and Completion Date: 3 years, July 1, 2020, through June 30, 2023
Today's Date: April 10, 2019

ENVIRONMENT AND NATURAL RESOURCES TRUST FUND BUDGET	Budget	Amount Spent	Balance
BUDGET ITEM			
Personnel (Wages and Benefits)	$ 341,136	$ -	$ 341,136
Xiaojia Wang, Project Manager (1 week (.06FTE) + fringe 36.0% fringe) for 3 years	$ 11,867		
Uwe Kortshagen (1 week (.06FTE) + fringe 36.0% fringe) for 3 years	$ 22,601		
One-Graduate Research Assistant in ME (advised by Wang), 50% FTE (fall & spring include 16.1% fringe plus $20.50/hour tuition, summer 16.1% fringe only) for 3 years	$ 153,334		
One-Graduate Research Assistant in ME (advised by Kortshagen), 50% FTE (fall & spring include 16.1% fringe plus $20.50/hour tuition, summer 16.1% fringe only) for 3 years	$ 153,334		
Professional/Technical/Service Contracts	$ -	$ -	$ -
Equipment/Tools/Supplies	$ 54,000	$ -	$ 54,000
Purchasing reference materials, including bare silicon ($1000), silicon dioxide ($1000), sapphire ($1000) wafers for thermal and electrical characterization. Cost for purchasing precursor gases ($1000*3=$3000), sample substrates ($1000*3=$3000), and chemicals ($1000*3=$3000) for nanoparticle synthesis. Purchasing of characterization accessories, including AFM tips, TEM grids, electrical current sources, probes, objective lenses, among others ($9000). All #s are given for three years	$ 24,000		
User fees for rental and usage of facilities at the campus CharFac center for sample thermal property characterization (electrical conductivity, ellipsometry, and atomic force microscopy, $3000*3=$9000 for three years); User fees for rental and usage of facilities at the campus CharFac center for materials structural/property characterization (X-ray diffraction, secondary electron microscopy, Raman spectroscopy, tunneling electron microscopy, $4000*3=$12000)	$ 21,000		
User fees at MNC for thin-film deposition of metal transducers and electrods for electrical measurements (sputtering and thermal evaporation, $1000*3=$3000); Usage fees for the MNC Facility for housing the plasma reactor and precursor gases and processing samples ($2000*3=$6000)	$ 9,000		
Capital Expenditures Over $5,000			
	$ -	$ -	$ -
Fee Title Acquisition			
	$ -	$ -	$ -
Easement Acquisition			
	$ -	$ -	$ -
Professional Services for Acquisition			
	$ -	$ -	$ -
Printing			
	$ -	$ -	$ -
Travel expenses in Minnesota			
		$ -	$ -
Other			
	$ -	$ -	$ -
COLUMN TOTAL	$ 395,136	$ -	$ 395,136

SOURCE AND USE OF OTHER FUNDS CONTRIBUTED TO THE PROJECT	Status (secured or pending)	Budget	Spent	Balance
Non-State:		$ -	$ -	$ -
State:		$ -	$ -	$ -
In kind:		$ -	$ -	$ -

Other ENRTF APPROPRIATIONS AWARDED IN THE LAST SIX YEARS	Amount legally obligated but not yet spent	Budget	Spent	Balance
		$ -	$ -	$ -

Example application: residential building coated with multifunctional materials

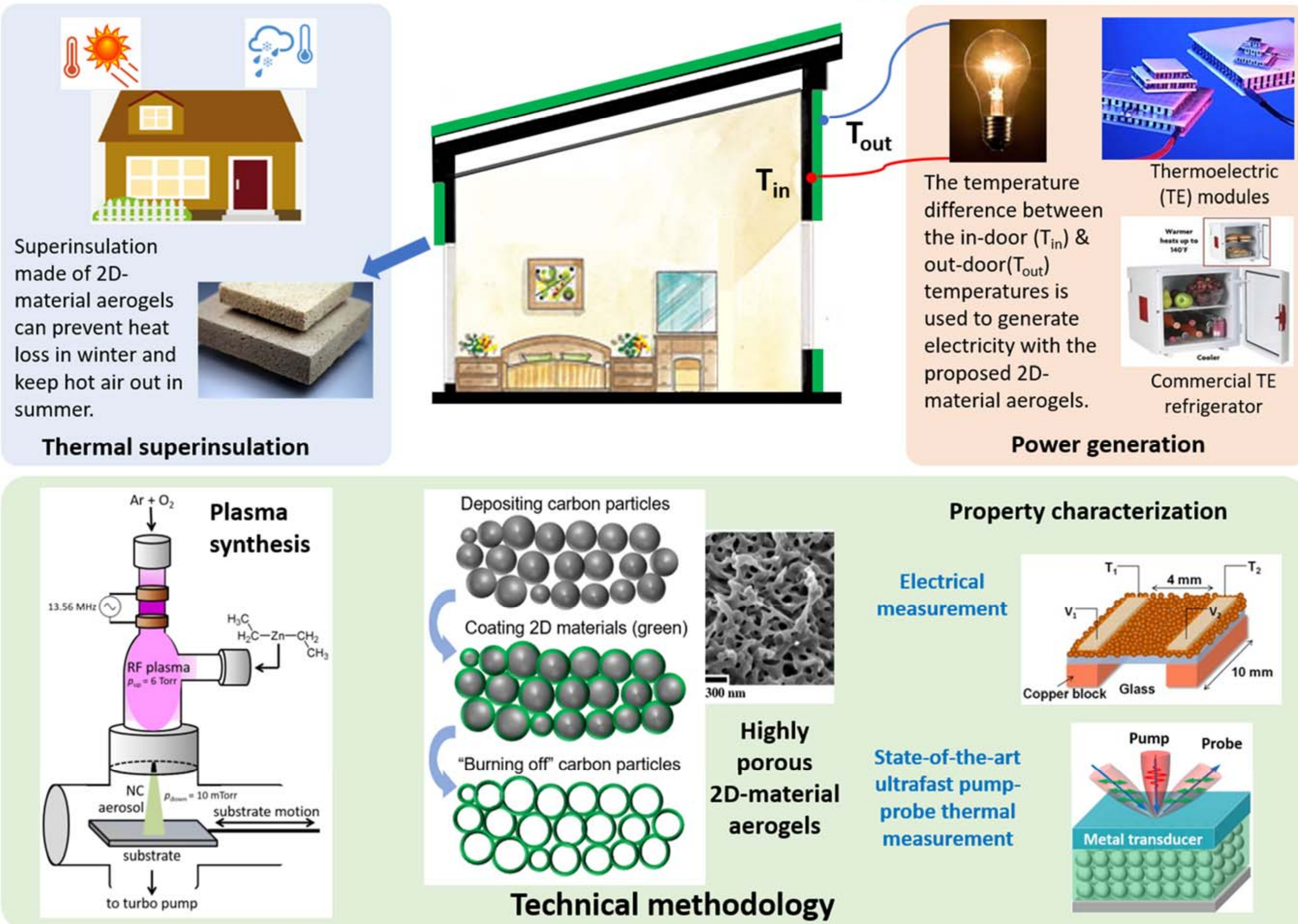

Image credits: Google Images

Project Manager Qualifications & Organization Description

A. Project Manager Qualifications

Xiaojia Wang is an assistant professor in the Department of Mechanical Engineering at the University of Minnesota (UMN) starting in the fall of 2014. She received her Ph.D. in Mechanical Engineering from the Georgia Institute of Technology in 2011, and her M.E. in 2007 and B.E. in 2004 from Xi'an Jiaotong University, China, all in Mechanical Engineering. She was a postdoctoral research associate in the Department of Materials Science & Engineering at the University of Illinois, at Urbana-Champaign from 2012 to 2014. Her research focuses on the fundamental mechanisms of thermal transport in micro/nano-engineered structures for energy conversion and harvesting, by utilizing the ultrafast pump-probe technique and other optical spectroscopic approaches. She received the 3M Non-Tenured Faculty Award (2018), Innovation Award for poster competition at ASME 2009 IMECE, and the Outstanding Reviewer Award for the *Journal of Quantitative Spectroscopy and Radiative Transfer* in 2014. Her work has been featured on the cover images of *Advanced Functional Materials, Advanced Electronic Materials*, and *Nanoscale and Microscale Thermophysical Engineering*. She is currently a member of ASME Heat Transfer Division K9 Committee on Nanoscale Thermal Transport. She also serves as the editor of *Scientific Reports* and *Instruments*.

Uwe Kortshagen is Distinguished McKnight University Professor and Head of the Department of Mechanical Engineering at the UMN, and a member of the graduate faculties of Physics, Chemical Engineering and Materials Science, and Nanoparticle Science and Engineering. He earned his Diploma degree in Physics in 1988, and his Ph.D. in Physics in 1991 from the University of Bochum, Germany, under Hans Schlüter. He came to the U.S. in 1995 with an Alexander von Humboldt Fellowship and spent a year at the University of Wisconsin-Madison. He earned the Habilitation in Experimental Physics at the University of Bochum in 1995. In 1996, he joined the Department of Mechanical Engineering at the UMN as Assistant Professor, where he was promoted to Associate Professor in 1999, and to Full Professor in 2003. He served as President of the International Plasma Chemistry Society and is a Fellow of the American Society of Mechanical Engineers, the American Physical Society, the Institute of Physics (IOP, London, UK), and the International Plasma Chemistry Society. He was awarded the 2005 Institute of Technology-George Taylor Award for Distinguished Research and was named Distinguished McKnight University Professor of the University of Minnesota in 2007. His work is in the area of kinetic theory of plasmas, nonthermal plasmas at atmospheric pressures, and in the plasma synthesis and functionalization of nanomaterials. His work has been published in more than 140 articles in peer-reviewed journals and received more than 5,000 citations with an H-index of 39.

Xiaojia Wang will lead this proposed work and she will be responsible for the overall management of this project and the status reports of project update. Her expertise lies in the heat transfer in micro- and nano-scale using novel ultrafast optical characterization techniques. She will be in charge of investigating the thermal properties of the proposed aerogel materials for superinsulation and thermoelectric power generation and correlate the material thermal performance to their structure/property characterization. **Uwe Kortshagen** has directed research on grants exceeding $25M. For this project, he will be working on the synthesis of aerogel materials with precisely controlled structures and doping concentration to tailor the materials' electrical properties for device fabrication. Two PIs will coordinate with each other to experimentally develop and characterize the proposed materials and device fabrication and to theoretically explore and validate the relation between the device design and property performance.

B. Organization Description

(1) Micro/Nanoscale Thermal Transport Laboratory, Directed by PI Wang

The materials property characterization will be will be performed at the UMN in the **Micro/Nanoscale Thermal Transport Laboratory (MNTTL)** led by Wang. The lab has 1200-ft^2 room space and is fully functional for users to conduct ultrafast and standard spectroscopic measurements. **Figure 1** depicts (a) the optical layout of the ultrafast time-domain thermoreflectance system (TDTR), (b) accessories for advanced ultrafast transient absorption measurements, (c) setup for Time-resolved Magneto-Optical Kerr Effect measurements, and (d) gimbal stage for mapping out