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

Project Title: **ENRTF ID: 180-E**

Practical, Inexpensive, and Non-Toxic Solar Cells

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

Sub-Category:

Total Project Budget: $ 479,409

Proposed Project Time Period for the Funding Requested: June 30, 2022 (3 yrs)

Summary:

Unique partnership with Natural Resources Research Institute (UMN-Duluth) to integrate life-cycle assessment and toxicology analyses into the early-stage design of non-toxic materials for construction of inexpensive and efficient solar cells.

Name: Russell Holmes

Sponsoring Organization: U of MN

Title: Professor

Department:

Address: 421 Washington Ave. S.E.

Minneapolis MN 55455

Telephone Number: (612) 624-9058

Email rholmes@umn.edu

Web Address https://holmes.cems.umn.edu/

Location

Region: Statewide

County Name: Statewide

City / Township:

Alternate Text for Visual:

Schematic detailing the multiple factors to be included in the design of new solar cell materials

_____ Funding Priorities	_____ Multiple Benefits	_____ Outcomes	_____ Knowledge Base
_____ Extent of Impact	_____ Innovation	_____ Scientific/Tech Basis	_____ Urgency
_____ Capacity Readiness	_____ Leverage	_____ TOTAL	_____%
____ If under $200,000, waive presentation?			

PROJECT TITLE: Practical, Inexpensive, and Non-Toxic Solar Cells

I. PROJECT STATEMENT

Through a transformative partnership between UMN Twin Cities and the Natural Resources Research Institute (NRRI) at UMN-Duluth, we propose to develop high efficiency, low-cost solar cells that are constructed using non-toxic materials. The realization of inexpensive, efficient, and environmentally benign solar cells will permit integration into building materials like roofing shingles, paneling, and siding, transforming building surfaces for electricity generation. The adoption of building-integrated renewable solar energy will relax the demands on current power plant infrastructure, while reducing the emission of greenhouse gases and other toxic pollutants.

This project will focus on a new type of solar material, the metal-halide perovskites. Perovskites look ideal as an energy technology as efficient cells can be fabricated using low-cost methods. Unfortunately, the most efficient perovskite solar cells use lead, which is toxic. We will develop non-toxic, lead-free perovskites that are efficient and suitable for use in flexible solar cells. Importantly, we will also carry out life-cycle assessments (LCA) and toxicology assessments of candidate perovskites to determine their potential impacts on humans and the environment throughout solar cell manufacture, use, and disposal. Our multi-faceted proposal will lead to new non-toxic materials that will have high performance and can be fabricated cheaply.

To address fabrication cost, we will develop thin film solar materials and fabrication methods that are inherently compatible with mechanically flexible substrates (e.g. solar cells on plastic or metal foil). Flexibility reduces cost and increases adoption by enabling high-throughput, large-area, roll-to-roll fabrication that is analogous to the printing industry. This unique feature will permit wide application in building materials, as well as in portable electronic devices for charging applications.

We will integrate LCA and toxicology studies early in the materials discovery process, which makes our approach unique. Materials development typically occurs without awareness of potential environmental impacts, creating bottlenecks for eventual social acceptance and commercialization. By integrating these analyses into the engineering effort, we will streamline discovery and realize practical and environmentally friendly solutions. This approach is unusual and is it not currently supported by federal funding agencies. State support will catalyze this new and effective path for materials discovery that incorporates environmental assessment at all steps. Our work will become a model for future collaborations, while making Minnesota a center for integrated approaches to solving complex engineering and environmental challenges.

II. PROJECT ACTIVITIES AND OUTCOMES

Activity 1: *Synthesize non-toxic, lead-free perovskite materials* ***(ENRTF Budget: $166,094)***

We will synthesize a series of lead-free perovskites using solution-based green chemical synthesis methods. Our focus is on the use of alternate metals including tin, copper, antimony, and germanium. The resulting perovskite powders will be characterized for their composition, purity, and structure using a battery of analytical techniques including various electron microscopies and X-ray diffraction. Materials with promising light absorbing characteristics will be fed into Activity 2 in order to determine the best candidates for consideration in thin films and working solar cells (Activity 3). The central outcome of this activity will be the realization of entirely new perovskite materials. New materials will be aggressively patented, with the ENRTF sharing in any eventual licensing revenue.

Outcome	Completion Date
1. Synthesis of lead-free perovskites via systematic variations in precursor materials with emphasis on the use of non-toxic metals	*09/01/2021*
2. Characterization of the structure, composition, and properties of new materials.	*03/01/2022*
3. Air and water exposure tests of new materials to mimic environmental exposure	*06/30/2022*

Activity 2: *Life-cycle and toxicology assessments of target perovskite materials* ***(ENRTF Budget: $61,095)***
In order to assess what materials should be examined in thin films and devices (Activity 3), the most promising subset of the materials discovered in Activity 1 will be screened for toxicity and their overall life-cycle environmental impacts. The outcome of this activity will be a short-list of champion materials to be considered in Activity 3, as well as technical reports on the LCA of perovskites.

Outcomes	Completion Date
1. Thorough review of published toxicology and LCA studies on perovskite materials.	*01/31/2020*
2. Baseline assessment of the environmental impacts of known perovskites based on lead.	*06/30/2021*
3. Continuous cradle-to-grave assessment of the environmental impacts of new, candidate perovskites for materials screening purposes.	*06/30/2022*

Activity 3: *Develop high-throughput vapor-processing for solar cell fabrication* ***(ENRTF Budget: $252,220)***
We will develop clean, well-controlled vapor (gas) phase fabrication methods that avoid the toxic solvents that are currently employed to construct solar cells. We will construct a new apparatus to form perovskite thin films from the materials that pass of Activity 1 and 2. The most promising films will be integrated into solar cells and characterized for efficiency. Key outcomes are the development of thin film fabrication methods (with a new apparatus) and the integration of materials from Activity 1 and 2 into thin films and prototype solar cells. We have a history of aggressively pursuing patent protection for solar cell architectures, and will continue to file patents based on the results of this activity. As noted previously, ENRTF would share in any licensing revenue.

Outcome	Completion Date
1. Construct vapor-phase perovskite thin film fabrication system	*03/01/2020*
2. Ongoing qualification of promising perovskite materials from Activity 1 in thin films	*06/30/2022*
3. Characterize most promising thin film perovskites in prototype solar cells	*06/30/2022*

III. PROJECT PARTNERS:
Partners receiving ENRTF funding

Name	Title	Affiliation	Role
Dr. Patrick Schoff	Researcher	Natural Resources Research Institute, Duluth	Investigator
Mr. Matthew Aro	Researcher	Natural Resources Research Institute, Duluth	Investigator

IV. LONG-TERM- IMPLEMENTATION AND FUNDING:
Lead-free perovskites are ideal solar materials. We will develop economical methods for producing non-toxic, thin film solar cell materials while also analyzing the environmental and toxicological impacts of promising candidates. Our efforts will impact multiple goals of the State including the 2030 goal of realizing 10% electricity generation from solar, and the Department of Commerce's MN Solar Pathways program with the U.S. Department of Energy. Upon completion of the project, we will actively pursue federal funding to support a regional center focused on using early-stage environmental considerations as a screening metric in materials and device design.

V. TIME LINE REQUIREMENTS:
The project will take 36 months to complete. Progress on all activities will begin as soon as the project starts.

2019 Proposal Budget Spreadsheet

Project Title: Enabling Inexpensive Non-Toxic Solar Cells

IV. TOTAL ENRTF REQUEST BUDGET *3* **years**

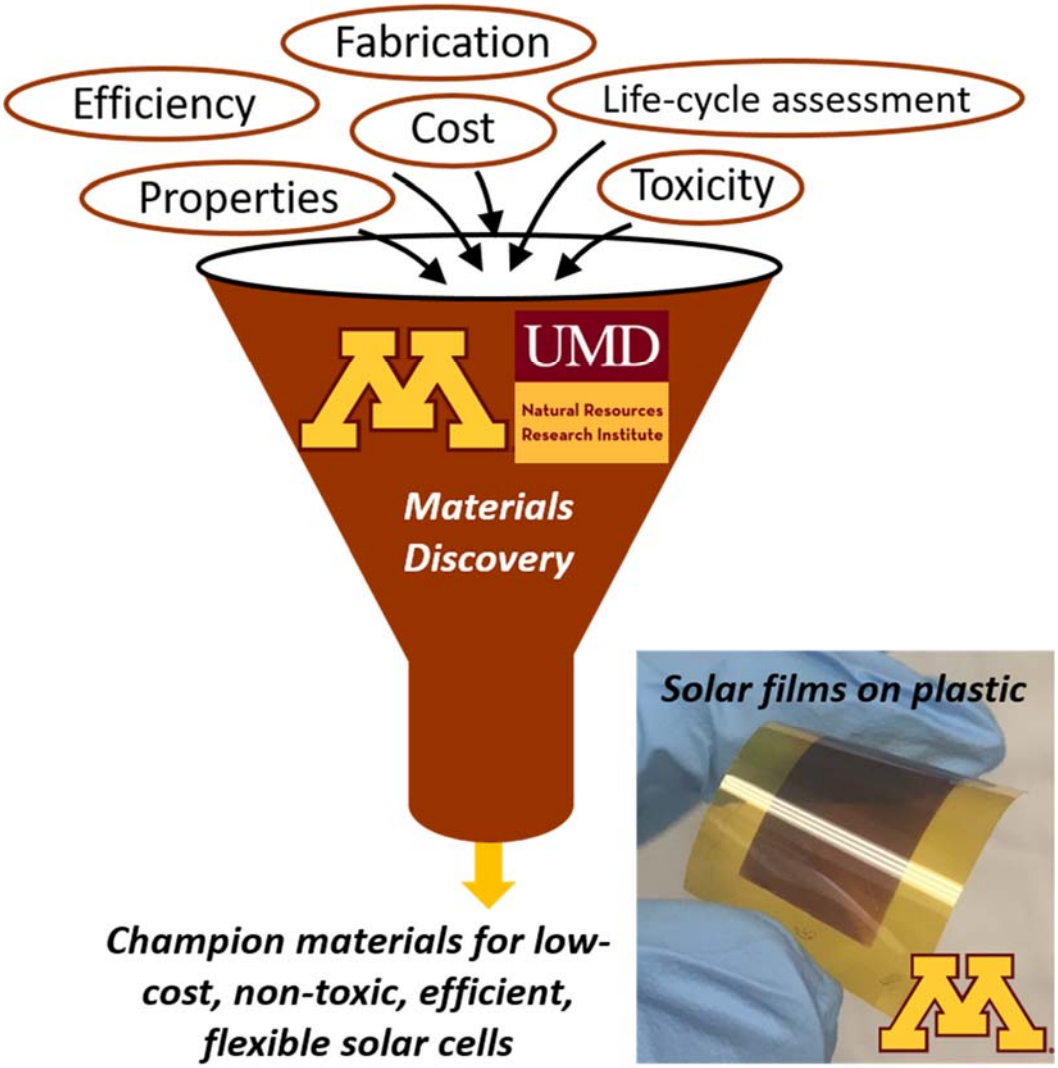
BUDGET ITEM (See "Guidance on Allowable Expenses")	**AMOUNT**	
Personnel:		
Russell Holmes - Holmes will receive 2 weeks of salary+fringe (15.4%) to lead efforts in thin film fabrication and solar cell characterization. Holmes will also co-ordinate the project.	$32,721	
Lee Penn - Penn will receive 2 weeks of salary+fringe (15.4%) to lead efforts in the synthesis of non-toxic, lead free perovskites.	$26,900	
Patrick Schoff - Schoff will lead toxicological assessments of new perovskite materials (66.5% salary, 33.5% benefits) at rates of 5% FTE for Y1, 10% FTE for Y2, 5% FTE for Y3.	$25,006	
Matt Aro - Aro will lead life-cycle assessment (LCA) studies (66.5% salary, 33.5% benefits) at rates of 5% FTE for Y1, 10% FTE for Y2, 15% FTE for Y3.	$29,721	
Ph.D. Graduate Students - Two graduate students will be hired at the University of Minneesota - Twin Cities to work on this project full-time, advised by Holmes and Penn.	$238,257	
Total	$	352,605
Professional/Technical/Service Contracts:	N/A	
Equipment/Tools/Supplies: Equipment - Funds are requested to construct an expanded perovskite vapor deposition system. Components include a tube furnace, quartz reaction tube, gas flow controllers, materials deposition sources, substrate holder, substrate cooling chiller, vacuum pump and components, nitrogen gloxbox.	$60,000	
Consumable Materials and Supplies - Funds requested for reagents, solvents, raw materials, laboratory supplies, glassware, conductive substrates for device fabrication, non-perovskite source materials for device fabrication (metals, organic semiconductors).	$30,909	
Characterization and Analysis - Funds requested for use of shared analytical faciltiies at the University of Minnesota Characterization Facility incluidng scanning and transmission electron microscopy, atomic force microscopy, X-ray diffraction, ellipsometry, profilometry, infrared spectroscopy.	$24,727	
Total	$	115,636
Acquisition (Fee Title or Permanent Easements):	N/A	
Travel: Travel between UMN and NRRI for quarterly project meetings.	$	7,200
Additional Budget Items: Funds are requested for SimaPro life-cycle assessment (LCA) software server-hosting and maintenance fee ($107/month * 36 months)	$	3,968
TOTAL ENVIRONMENT AND NATURAL RESOURCES TRUST FUND $ REQUEST =	$	479,409

V. OTHER FUNDS *(This entire section must be filled out. Do not delete rows. Indicate "N/A" if row is not applicable.)*

SOURCE OF FUNDS	**AMOUNT**	**Status**
Other Non-State $ To Be Applied To Project During Project Period: This amount is the indirect costs that are not being charged to the project by the Universirty of Minnesota. Researchers will still have full access to shared facilities, support staff, and the Office of Technology Commericalization.	$218,647	*Approved*
Other State $ To Be Applied To Project During Project Period:	N/A	
In-kind Services To Be Applied To Project During Project Period:	N/A	
Past and Current ENRTF Appropriation:	N/A	
Other Funding History:	N/A	

PROJECT TITLE: Practical, Inexpensive, and Non-Toxic Solar Cells

Visual Component or Map



Alternate Text: Schematic illustrating the partnership between UMN and NRRI (UMN-Duluth) to realize efficient, non-toxic solar cells by considering both engineering and environmental constraints. Inset is a flexible perovskite solar thin film.

Overview: Perovskites are a seemingly ideal class of materials for cheap and clean renewable energy. They are made from low cost materials using low cost methods that permit integration in mechanically flexible solar cells. Unfortunately, top performing materials are currently based on lead, which is toxic. Our project will develop non-toxic, lead-free perovskites (at UMN) and integrate at an early stage rigorous life-cycle assessments and toxicological assessments of candidate materials (at NRRI). In this way, materials design and engineering will proceed more efficiently, and successful candidate materials will already be vetted for their environmental and societal impacts.

Project Management and Qualifications:

Russell J. Holmes is Professor and Distinguished University Teaching Professor in Chemical Engineering and Materials Science at the University of Minnesota (UMN), where he also serves as Director of Graduate Studies for Materials Science. Holmes earned his B.Sc.(Hons.) in Physics from the University of Manitoba (2000) and his M.A. and Ph.D. in Electrical Engineering from Princeton University (2002 and 2006). Holmes joined the UMN as an Assistant Professor in 2006, and was promoted to the rank of Professor in 2017. His research group consists of student researchers working in the area of organic and hybrid organic-inorganic thin film electronic materials, and associated devices including light-emitting devices, solar cells, and photodetectors.

Lee Penn is the Merck Professor of Chemistry and Distinguished University Teaching Professor in Chemistry at UMN, also serving as Director of Undergraduate Studies. Penn earned an undergraduate degree in Chemistry from Beloit College (1992), M.S. and Ph.D. degrees in Materials Science from the University of Wisconsin (1998), and completed Postgraduate Studies at Johns Hopkins University prior to joining the faculty at UMN. Penn has expertise in the synthesis of a broad diversity of materials, including metal-halide perovskites. In addition, Penn uses a broad range of techniques to characterize the structure, properties, and reactivity/activity of both natural and synthetic materials.

Patrick Schoff is a Senior Research Program Manager at the Natural Resources Research Institute (NRRI) at UMN-Duluth. Schoff holds a B.S. in Biology from the University of Wisconsin, Stevens Point and a Ph.D. in Zoology and Physiology from the University of Wyoming, and has completed postdoctoral fellowships at the University of Wisconsin and at the USEPA through the National Research Council. He has been at the Natural Resource Research Institute since 1995, and teaches in Biology and the Integrated Biosciences graduate program. Schoff's research includes ecotoxicological studies of the effect of anthropogenic chemicals and other stressors on the early developmental stages of fish and amphibians, endocrine disruption, sustainable development involving water, mining, and other natural resource-based industries.

Matthew Aro is a Research Program Manager for Wood-Based Materials in the NRRI's Initiative for Wood Utilization and Bioeconomy. Aro holds a B.S. in Broad Field Science from the University of Wisconsin-Superior and an M.S. in Management of Technology from the University of Minnesota. His responsibilities include providing product, process, and business concept research and development services to OEMs, entrepreneurs, organizations, and agencies associated with the wood products and natural resources sectors. He has completed graduate-level work on environmental life-cycle assessment (LCA) methodologies and his M.S. work was focused on LCA of modified wood products.

Holmes will be responsible for overall project management. Holmes has directed numerous previous sponsored projects from both federal funding agencies as well as from multinational companies. He also currently co-ordinates the Flexible Electronics and Photovoltaics program of the UMN Industrial Partnership for Research in Interfacial and Materials Engineering (IPRIME). Holmes will be responsible for thin film processing and characterization, as well as solar cell fabrication and testing. Penn will lead efforts to design new lead-free perovskites using green chemistry techniques. Schoff and Aro will co-lead activities related to conducting LCA and toxicology research on new solar cell materials. All PIs will co-ordinate effectively to streamline the synthesis of high performance, non-toxic materials, and eventual integration into solar cells.

UMN offers world-class facilities for the completion of this project. Holmes and Penn manage active laboratories that specialize in the experimentally relevant areas of materials synthesis, thin film fabrication and characterization, and solar cell investigations. Efforts in materials characterization are facilitated by the UMN Characterization Facility, which includes a variety of electron microscopes and X-ray diffractometers for inspection. Schoff and Aro are members of the NRRI, an applied research organization whose mission is to deliver research solutions to balance Minnesota's economy, resources and environment for resilient communities.