# Environment and Natural Resources Trust Fund (ENRTF)
# M.L. 2018 Work Plan

**Date of Submission:** February 15, 2018

**Date of Next Status Update Report:** December 31, 2018

**Date of Work Plan Approval:** 06/05/2018

**Project Completion Date**: June 30, 2021

**Does this submission include an amendment request?** No.

**PROJECT TITLE: Develop Inexpensive Energy from Simple Roll-to-Roll Manufacturing**


**Project Manager: Tianhong Cui**

**Organization: University of Minnesota**

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**City/State/Zip Code: Minneapolis, MN 55455**

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**Web Address:**


**Location: Minneapolis, Minnesota**

| **Total ENRTF Project Budget:** | | |
|---|---|---|
| | **ENRTF Appropriation:** | **$300,000** |
| | **Amount Spent:** | **$0** |
| | **Balance:** | **$300,000** |

**Legal Citation:** M.L. 2018, Chp. 214, Art. 4, Sec. 02, Subd. 07c

**Appropriation Language:** $300,000 the second year is from the trust fund to the Board of Regents of the University of Minnesota to develop inexpensive, high-efficiency solar energy with simple roll-to-roll advanced manufacturing technology, using new materials such as perovskite to make solar cells. This appropriation is subject to Minnesota Statutes, section 116P.10. This appropriation is available until June 30, 2021, by which time the project must be completed and final products delivered.

**I. PROJECT TITLE: Develop Inexpensive Energy from Simple Roll-to-Roll Manufacturing**

**II. PROJECT STATEMENT:**

The objective of this proposal is to develop cheap clean solar energy based on roll-to-roll manufacturing approach (Figure 1). Perovskite is a brand new materials for the next generation of solar cells under development with very high efficiency and super low cost. The proposed advanced manufacturing is a simple roll-to-roll process using low-temperature physical-chemical deposition of perovskite, which is highly energy-efficient and very inexpensive. Potentially perovskite solar cells are one of the most disruptive renewable energy sources, and the proposed new manufacturing is the key to make it happen eventually. The proposed roll-to-roll manufacturing approach will enable the development of high-performance solar cells with extremely lower cost, compared to silicon solar cells. The success of this proposal will provide renewable green energy as centralized power plants to reduce the imports of energy from foreign countries. In addition, as low-cost distributed energy sources, the perovskite solar cells can be easily adopted by families or individual electronics customers, which will significantly improve the energy efficiency of all economic sectors. Through the proposed roll-to-roll manufacturing, perovskite solar cells can become a truly clean, low-cost, renewable energy source as an effective energy sources in Minnesota State. This project is intended to provide foundational knowledge of the technique and prove its feasibility of cheap perovskite solar cells. In the next phase of the research, we will closely collaborate with state manufacturers and energy providers in Minnesota to further develop an implementation and commercialization plan.

Upon completion of the project, cheap and high-efficiency perovskite solar cells for outdoor solar to electricity conversion will be developed. The knowledge learned throughout the project will provide a solid foundation for further research and development efforts that would lead to implementation of the new solar cells for residential, power plants, or consumer electronics. Eventually, cheap, clean, renewable, and high-efficiency solar energy sources will be installed in Minnesota. In addition to the low-cost of roll-to-roll manufactured solar cells, the cost of transportation, installation and support system will also decrease drastically due to their lighter weight and flexibility. This will potentially provide a supplementary energy solution to current energy sources in Minnesota, ultimately help implement the renewable energy policy, and thus enhance the economic and ecological benefits of Minnesota.

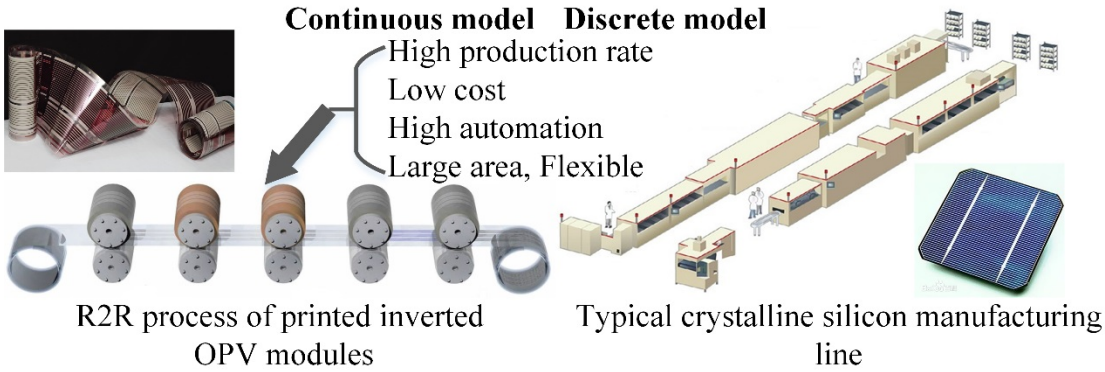


Figure 1. A comparison between roll-to-roll (R2R) manufacturing processes (left) and typical silicon solar cells manufacturing processes (right).

**III. OVERALL PROJECT STATUS UPDATES:**

**Project Update December 31, 2018:**

**Project Update June 30, 2019:**

**Project Update December 31, 2019:**

**Project Update June 30, 2020:**

**Project Update December 31, 2020:**

**Final Update June 30, 2021:**

**IV. PROJECT ACTIVITIES AND OUTCOMES:**

**ACTIVITY 1:** Development of low-cost roll-to-roll manufacturing for perovskite solar cells
**Description:** The objective of this activity is to develop cheap advanced manufacturing technique based on roll-to-roll low-temperature processes and to build economical perovskite solar cells accordingly. New perovskite solar cells will be designed and fabricated for high-efficiency solar energy to electricity conversion. Through this new advanced manufacturing, the target is to develop perovskite solar cells with a power conversion efficiency of 15% ~ 25% comparable to silicon solar cells and the fabrication cost at 1/10 ~ 1/100 of silicon-based solar cells, resulting in an overall installation cost at least 5 times lower than the existing silicon photovoltaics.

We propose to address the following issues of the roll-to-roll manufacturing processes for solar cells: (1) Choosing appropriate flexible substrate materials. (2) Fabricating high-performance functional materials. (3) Integrating a series heterogeneous manufacturing processes. We will come up with solutions for the manufacturing of perovskite solar cells.

Specific tasks will be:
1. Roll-to-roll manufacturing processes set-up, coupled with low-temperature chemical-physical vapor deposition
   a. Design hardware set-up for roll-to-roll manufacturing process based on the chemical-physical vapor deposition facility available at Dr. Cui's Lab
   b. Fabricate and assemble roll-to-roll manufacturing process set-up
   c. Test roll-to-roll manufacturing process set-up

2. Design and experiments of roll-to-roll manufacturing processes for perovskite solar cells
   a. Design roll-to-roll manufacturing processes for perovskite solar cells
   b. Test, characterize and optimize roll-to-roll manufacturing processes for perovskite solar cells

3. Design, fabrication, and characterization of perovskite solar cells in lab using the developed roll-to-roll manufacturing processes
   a. Design and simulate perovskite solar cells using the developed roll-to-roll manufacturing processes

b. Fabricate solar cells using the developed roll-to-roll manufacturing processes
c. Characterize solar cells using the developed roll-to-roll manufacturing processes

4. Comprehensive assessment of the new perovskite techniques and silicon solar cells
   a. Assess the design of roll-to-roll processes set-up, and compare to silicon solar cells
   b. Assess the roll-to-roll fabrication techniques of perovskite solar cells, and compare to silicon solar cells
   c. Assess the performance of perovskite solar cells including power conversion efficiency, cost, and stability in lab, and compare to solar cells

**Summary Budget Information for Activity 1:**

**ENRTF Budget: $ 201,002**
**Amount Spent: $ 0**
**Balance: $ 201,002**

| Outcome | Completion Date |
|---|---|
| *1. Roll-to-roll manufacturing processes set-up, coupled with low-temperature chemical-physical vapor deposition* | *6/30/2019* |
| *2. Design and experiments of roll-to-roll manufacturing processes for perovskite solar cells* | *6/30/2019* |
| *3. Design, fabrication, and characterization of perovskite solar cells in lab using the developed roll-to-roll manufacturing processes* | *6/30/2020* |
| *4. Comprehensive assessment of the new perovskite techniques and silicon solar cells* | *6/30/2020* |

**Project Update December 31, 2018:**

**Project Update June 30, 2019:**

**Project Update December 31, 2019:**

**Project Update June 30, 2020:**

**Project Update December 31, 2020:**

**Final Update June 30, 2021:**

**ACTIVITY 2:** Development of perovskite solar cells and field test
**Description:** A prototype panel of perovskite solar cells will be designed and constructed to demonstrate the feasibility. Field testing protocol and hardware will be developed and tested. Field testing will include setting up a test site in Minnesota. Upon completion of the project, we will demonstrate the perovskite solar cells panel to the stakeholders and LCCMR committee members and officials.

Based on the roll-to-roll manufacturing processes, we will focus on fabricating a prototype panel of perovskite solar cells and field testing of the solar panel. The specific objectives of the development of perovskite solar cells and field testing are (1) to develop a prototype panel of perovskite solar cells based on the fabricated solar cells using roll-to-roll manufacturing, (2) to develop field testing protocol

and hardware, and (3) to test real-time solar irradiation of perovskite solar cells by setting up the prototype unit on an outdoor site.

Specific tasks will be:
1. A prototype panel of perovskite solar energy will be developed, based on the fabricated solar cells using roll-to-roll manufacturing
   a. Design prototype perovskite solar panel, based on the fabricated solar cells using roll-to-roll manufacturing techniques
   b. Assemble a prototype perovskite solar panel

2. Field testing protocol and hardware will be developed
   a. Design field testing protocol and hardware for a prototype panel of perovskite solar energy
   b. Characterize the protocol and hardware for a prototype panel of perovskite solar energy on power conversion efficiency and stability

3. The prototype unit will be set up on an outdoor site and real-time solar irradiation of perovskite solar cells will be tested.
   a. Design a field site used to long-term test the prototype unit outdoors. Environmental condition, transmission method and the surroundings will be arranged appropriately for a long-term and precise test.
   b. Develop a system which can test and record the illumination intensity of sunshine and the current-voltage data of the prototype unit running in sunshine outdoors.

**Summary Budget Information for Activity 2:**

**ENRTF Budget: $ 98,998**
**Amount Spent: $ 0**
**Balance: $ 98,998**

| Outcome | Completion Date |
|---|---|
| *1. A prototype panel of perovskite solar energy will be developed, based on the fabricated solar cells using roll-to-roll manufacturing* | *6/30/2021* |
| *2. Field testing protocol and hardware will be developed* | *6/30/2021* |
| *3. The prototype unit will be set up on an outdoor site and real-time solar irradiation of perovskite solar cells will be tested.* | *6/30/2021* |

**Project Update December 31, 2018:**

**Project Update June 30, 2019:**

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**Project Update June 30, 2020:**

**Project Update December 31, 2020:**

**Final Update June 30, 2021:**

**V. DISSEMINATION:**

**Description:**

The findings will be disseminated through:
(1) On site demonstration as described in the activities
(2) Public seminars
(3) Progress update on www.me.umn.edu/labs/tianlab
(4) Presentations at national and international technical conferences
(5) Communications with interested entrepreneurs
(6) Peer reviewed papers
(7) Collaboration with Solar Cell Manufacturers

The technologies, if demonstrated successfully, may be implemented to many fields and residentials in the State of Minnesota and beyond. Any intellectual properties and related revenues as a result of the program will be shared between UMN and LCCMR.

**Project Update December 31, 2018:**

**Project Update June 30, 2019:**

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**Project Update June 30, 2020:**

**Project Update December 31, 2020:**

**Final Update June 30, 2021:**

**VI. PROJECT BUDGET SUMMARY:**
**A. ENRTF Budget Overview:** See attached budget spreadsheet

**Explanation of Use of Classified Staff: N/A**

**Explanation of Capital Expenditures Greater Than $5,000: N/A**

**Number of Full-time Equivalents (FTE) Directly Funded with this ENRTF Appropriation: 0.61 FTE**

**Number of Full-time Equivalents (FTE) Estimated to Be Funded through Contracts with this ENRTF Appropriation: 0**

**B. Other Funds:**

| Source of Funds | $ Amount Proposed | $ Amount Spent | Use of Other Funds |
|---|---|---|---|
| The university overhead unpaid | $137,587 | $0 | Develop Inexpensive Energy from Simple Roll-to-Roll Manufacturing |
| **TOTAL OTHER FUNDS:** | **$137,587** | **$0** | |

**VII. PROJECT STRATEGY:**

## A. Project Partners:

Tianhong Cui, professor in Department of Mechanical Engineering and affiliated graduate faculty in Department Electrical and Computer Engineering, will serve as PI and project manager. He will be responsible for overseeing the project, all reports, and deliverables. He will also design the roll-to-roll manufacturing processes and perovskite solar cells based on the advanced manufacturing technique. Under Professor Cui's supervision, the Ph.D. student will be responsible for the manufacturing facility and the outdoor experimental test set-up, and he will also be in charge of design, fabrication, and characterization of perovskite solar cells.

## B. Project Impact and Long-term Strategy:

Given the state's latitude, many people are surprised to learn that Minnesota has annual solar radiation similar to portions of Florida and Texas, with sunshine for about 5 hours per day in average in Minneapolis. Solar energy production is a small but exponentially growing resource in Minnesota, where we now have more than 15 Megawatts (MW) of solar electric capacity. In May 2013, the Minnesota legislature adopted a mandate on investor-owned utilities in the state that requires them to produce 1.5% of their electricity from solar power by 2020. The Minnesota Legislature established a solar photovoltaic and solar thermal incentive program for consumers who install photovoltaic and solar thermal systems using solar modules and collectors certified as manufactured in Minnesota.

Solar energy out-powers anything that human technology could ever produce. However, today's commercial solar cells, most often made from silicon, typically convert sunlight into electricity with an efficiency of about 10 percent to 20 percent, although some test cells do a little better. Given their manufacturing costs, modules of today's cells incorporated in the power grid would produce electricity at a cost roughly 3 to 6 times higher than current prices. To make solar economically competitive, engineers must find ways to lower their manufacturing costs and to improve the efficiency of the cells. This project will provide one solution for lowering the cost and improving solar efficiency is to use new materials perovskite together with low-cost roll-to-roll advanced manufacturing techniques.

Upon completion of the project, cheap and high-efficiency perovskite solar cells for outdoor solar to electricity conversion will be developed. The knowledge learned throughout the project will provide a solid foundation for further research and development efforts that would lead to implementation of the new solar cells for power plants or consumer electronics enabling very cheap, clean, renewable, and high-efficiency solar energy sources in Minnesota eventually. This will potentially provide a supplementary energy solution to current energy sources in Minnesota, ultimately help implement the renewable energy policy, and thus enhance the economic and ecological benefits of Minnesota.

**C. Funding History:**

| Funding Source and Use of Funds | Funding Timeframe | $ Amount |
|---|---|---|
| Mocon Inc., Graphene gas sensors | Nov. 2014 - July 2016 | $173,199 |
| Alexandria Extrusion Inc., Microstructures for Heat Transfer | Nov. 2011 - Dec. 2015 | $165,516 |
| DARPA, MEMS-Based Active Heat Sink Technology | Jan. 2009 - Sept. 2013 | $2,579,025 |
| MN Partnership, Nano-Sensors | Jan. 2010 – Dec. 2012 | $637,500 |

**VIII. REPORTING REQUIREMENTS:**

- The project is for 3 years, will begin on 07/01/18, and end on 06/30/21.
- Periodic project status update reports will be submitted *[06/30]* and *[12/31]* of each year.
- A final report and associated products will be submitted between June 30 and August 15, 2021.

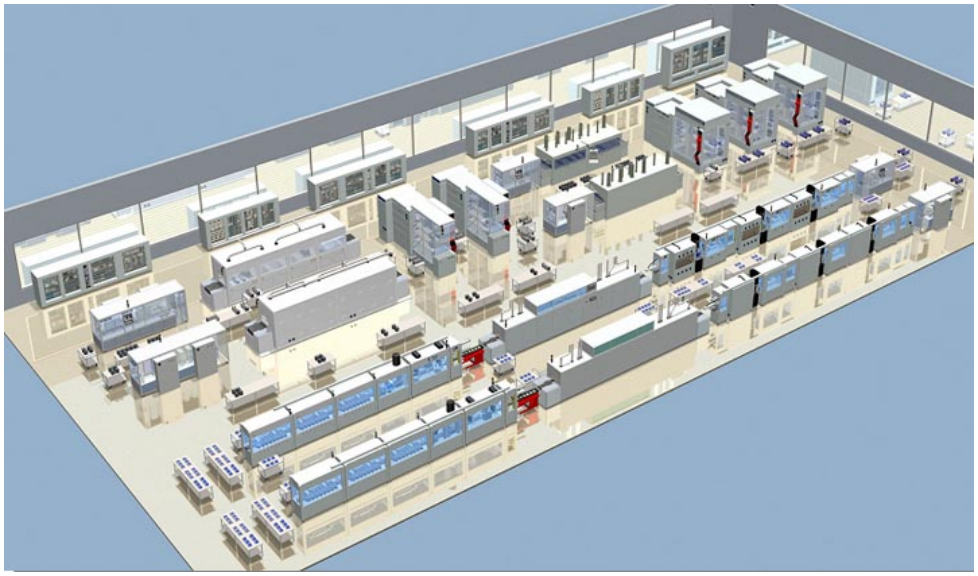
**IX. VISUAL COMPONENT or MAP(S):**

See the appendix.

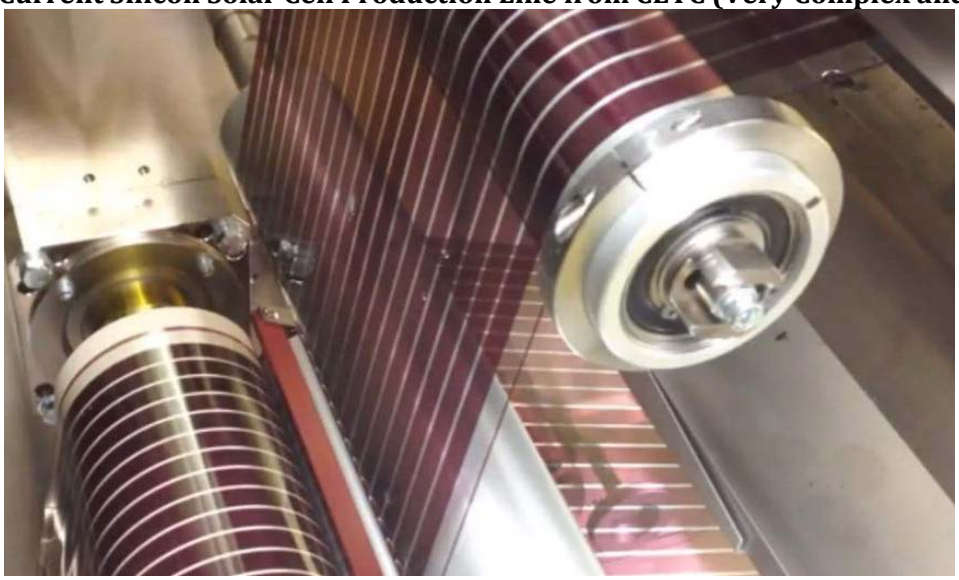
**X. FEE TITLE ACQUISITION/CONSERVATION EASEMENT/RESTORATION REQUIREMENTS:**

N/A

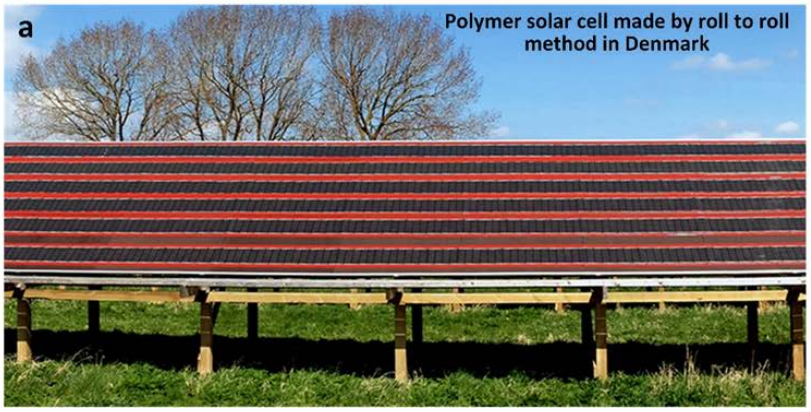
**Appendix: Visual Component**



**Current Silicon Solar Cell Production Line from CETC (Very Complex and Expensive)**



**Proposed Roll-to-Roll Processing of Perovskite Solar Cells (Very Simple and Cheap)**





**Future Applications of Proposed Cheap Solar Cells (Cheap, Clean, and Renewable)**
**(a) Solar Power Plant, (b) Soar Powered Consumer Electronics**

**Environment and Natural Resources Trust Fund**
**M.L. 2018 Budget Spreadsheet**

**Project Title:** Develop Inexpensive Energy from Simple Roll-to-Roll Manufacturing
**Legal Citation:** M.L. 2018, Chp. 214, Art. 4, Sec. 02, Subd. 07c
**Project Manager:** Tianhong Cui
**Organization:** University of Minnesota
**College/Department/Division:**
**M.L. 2018 ENRTF Appropriation:**
**Project Length and Completion Date:** Three years - June 30, 2021
**Date of Report:** 02/15/2018

| ENVIRONMENT AND NATURAL RESOURCES TRUST FUND BUDGET | Total Budget | Amount Spent | Balance |
|---|---|---|---|
| **BUDGET ITEM** | | | |
| **Personnel (Wages and Benefits) - Overall** | $215,465 | $0 | $215,465 |
| Dr. Tianhong Cui, PI, 1 month summer salary (11% FTE) & 33.5% fringe for 3 years (Total estimated amount $70,903) | | | |
| Graduate Research Assistant, 50% FTE (fall & spring semesters include 16.9% fringe plus $18.94/hour tuition, summer 15% fringe only) for 3 years (Total estimated amount $144,562) | | | |
| **Professional/Technical/Service Contracts** | *$31,500* | $0 | $31,500 |
| *Sceintific Services: User fees at Minnesota Nano Center and Characterization Facility at the University of Minnesota. The cost is about $875 per monthfor the research assistant for 3 years.* | | | |
| **Equipment/Tools/Supplies** | $48,035 | $0 | $48,035 |
| Lab Materials & Supplies: fabrication materials & supplies including silicon wafers ($8,000), polymer substrates ($9,000), chemicals ($9,035), roll-to-roll manufacturing set-up items ($16,000), bottles, gloves, other electronics for testing, etc. ($6,000) | | | |
| **Travel expenses in Minnesota** | $5,000 | $0 | $5,000 |
| Travel- Cui Domestic travel year 2 & 3: Mileage, lodging, and meals for travel to and between the solar testing sites and the university based on the university compensation policy | | | |
| **COLUMN TOTAL** | $300,000 | $0 | $300,000 |