Environment and Natural Resources Trust Fund
2017 Request for Proposals (RFP)

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

Organic Weed Control Using Solar-Powered Robots

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

Total Project Budget: $ 1,650,000

Proposed Project Time Period for the Funding Requested: 3 years, July 2017 to June 2020

Summary:

Solar-powered robots will be developed and tested for control of weeds in pastures and row crops. We envision significant reductions in fossil-fuel and herbicide use while increasing local energy production.

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Sponsoring Organization: U of MN

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Location

Region: Statewide

County Name: Statewide

City / Township:

Alternate Text for Visual:

The visual shows conventional methods of agricultural weed control using large, diesel-powered tractors to broadcast herbicide across the field. The proposed approach is depicted using different types of solar powered robots to control weeds.

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

PROJECT TITLE: Organic Weed Control Using Solar-Powered Robots

I. PROJECT STATEMENT

Minnesota farmers and land managers are engaged in an annual battle to control weeds. Each year, significant amounts of herbicide, diesel fuel, labor, and money are expended in an effort to stay ahead of weed infestations. Control of weeds is critical in the production of food. Current methods of weed control using herbicides have been very effective, but have unintentional and harmful consequences to our air, land, water, and wildlife resources. We propose to develop better methods using solar-powered robots to control weeds in pastures and within row crops such as corn and soybeans. In accomplishing these goals, we will:

- Replace fossil fuel and resulting air emissions with clean energy produced locally,
- Significantly reduce the use of herbicides on agricultural and natural lands across the State of Minnesota,
- Protect water resources by preventing surface and ground water contamination with herbicides,
- Reduce the impact of herbicide on wildlife, desired native plant species, and the evolution of herbicide tolerant 'super' weeds,
- Develop new time-saving tools for farmers as well as natural lands managers to control weeds,
- Partner with MN companies to development and manufacture cutting-edge robotic technologies.

The project team will develop and test solar-powered robotic systems to control weeds including a pasture mower, a field robot for early weed control in row crops, and inter-row and intra-row weed hunting robots for mid- to late-maturity row crops. The robots will be electric powered fueled by on-board solar PV and a portable solar PV charging station. The robotic pasture mower will be developed in partnership with a Minnesota manufacturing company with assistance from researchers at U of MN, and then field tested in pastures at the U of MN West Central Research and Outreach Center (WCROC). The field robot for early weed control will be jointly developed and field tested within certified organic and conventional corn and soybean fields at the WCROC. The inter-row and intra-row weed hunter robots will be more technically advanced requiring additional engineering, navigation and visual identification hardware and software development, and testing which will be performed at the U of MN Twin Cities campuses. The team will seek opportunities to evaluate the robots on conservation lands and road ditches (perhaps with the MN DNR and DOT). An economic assessment will be completed comparing robotic with traditional weed control. Safety protocols will be developed and tested. Finally, the robots will be demonstrated to farmers and land managers as well as student robotics clubs across Minnesota through a series of workshops, field days, and events such as Farmfest and the Minnesota State Fair.

II. DESCRIPTION OF PROJECT ACTIVITIES

Activity 1: Design, Integrate, and Field Test a Robotic Pasture Mower $519,102

A robotic mower capable of operating in harsh pasture terrains will be jointly developed by the U of MN and a Minnesota turf equipment manufacturer. The mower will feature affordable consumer class sensors and control systems which will allow for autonomous operation. Once developed, the system will be field tested under various operating conditions and scenarios in pastures, fields, grounds, and roadway ditches at the WCROC. We will focus on an "Automated Mow Robot that Learns" concept that optimizes energy and reduces human labor.

Outcome	Completion Date
1. Convert Toro Groundmaster 3280D Mower from diesel to electric power	*5/1/2018*
2. Develop navigation / logic systems to allow for autonomous operation	*7/2/2018*
3. Develop and test safety and fail-safe logic and protocols	*10/1/2018*
4. Integrate and commission mower with navigation and localization systems	*1/1/2019*
5. Field test robot within pastures and grounds at the WCROC	*6/1/2020*
6. Display / demonstrate the mowing robot at state-wide events	*6/30/2020*

Activity 2: Design, Develop, and Field Test a Solar-Powered Smart Charging Station **$206,860**

The team will design, assemble, and test a smart charge station that can be trailered to the field location and allow proof-of-concept for robots to re-charge. On-board solar charging will also be developed and tested.

Outcome	Completion Date
1. Design a portable hybrid solar PV and electric storage system for charging	*2/1/2018*
2. Integrate solar PV, electric storage, and a smart charging station on a trailer	*2/1/2019*
3. Field test the portable solar PV charging station and on-board solar at the WCROC	*6/1/2020*
4. Demonstrate the portable solar PV charging station at state-wide events	*6/30/2020*

Activity 3: Design, Develop, and Test Weed Control Robots for Row Crops **$809,676**

Three robots will be developed for row crop weed control. The first will utilize an autonomous modified electric UTV and custom fabricated implements for early control of weeds in row crops. A second prototype will be designed and developed for inter-row weeding and a third robot for intra-row weeding in mid-to late maturity row crops.

Outcome	Completion Date
1. Design / modify an electric UTV to autonomously weed early-maturity row crops	*3/1/2019*
2. Field test the autonomous UTV in row crop plots and fields at the WCROC	*9/1/2019*
3. Design, develop, and lab-test a prototype inter-row weeding robot	*6/1/2020*
4. Design, develop, and lab-test a prototype intra-row weed hunting robot	*6/1/2020*
6. Display / demonstrate the row crop weed control robots at state-wide events	*6/30/2020*

Activity 4: Economic Evaluation of Solar-Powered Robots for Weed Control **$114,362**

An economic study will compare robotic weed control with the cost of conventional methods.

Outcome	Completion Date
1. An economic evaluation performed on each of the robotic weed control systems.	*6/1/2020*

III. PROJECT STRATEGY

A. Project Team/Partners: Michael Reese (WCROC Renewable Energy Director) will serve as the project manager and will be responsible for all deliverables. Eric Buchanan (Renewable Energy Scientist) will assist as project coordinator focusing on development of the portable solar smart charging station, implements for the early weeding row crop robot, pasture and field testing, and demonstrations. Curt Reese (crop research scientist) will assist with pasture and field studies monitoring weed control. Volkan Isler (Associate Professor - U of MN Computer Science and Engineering) will focus efforts on solar aware navigation, vision processing for crop / row detection, and cover planning. Stergios Roumeliotis (Professor - U of MN Computer Science and Engineering) will provide expertise on autonomous navigation and localization. Jonathan Chaplin (Professor - U of MN Bioproducts and Biosystems Engineering) will liaise with manufacturer(s) on design, focus on robot safety protocols including wildlife avoidance, and complete an economic evaluation of robotic weed control.

B. Project Impact and Long-Term Strategy

Successful development of economic solar-powered robotic systems for weed control in pastures and fields will have significant positive impacts to Minnesota's air, land, water, and wildlife resources. The long term strategy is to develop marketable robotic weed control systems that can be manufactured by Minnesota companies and utilized by Minnesota farmers and land managers; and expand the utilization of solar PV within the State.

C. Timeline Requirements - The project is proposed for three full years beginning July 1, 2017 and ending June 30, 2020. Ideally, two years of field testing will be completed to account for seasonal and annual variation.

2017 Detailed Project Budget

Project Title: Organic Weed Control Using Solar-Powered Robots

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

BUDGET ITEM	AMOUNT
Personnel:	
Project Coordinator - Eric Buchanan (FTEs =40% Year 1, 40% Year 2, 80% Year 3) 33.7 % fringe rate, 2.5% COLA - WCROC	$ 118,549
Researcher 3 - Technician for fabrication, field testing, and data collection (100% FTE - 2.5 Yrs) 27.4 % fringe rate, 2.5% COLA - WCROC	$ 182,287
Undergrad Student Interns - Evaluation of weed control robots in field studies (Four summer interns, fourteen 40 hr weeks each @$12/h) 0% Fringe Rate - WCROC	$ 26,880
Post Doctorate Research Associate (100 % FTE-2.5 Yrs) 22.4% Fringe Rate, 3% COLA - BBE	$ 188,039
Key Personnel (9 mo appt) - Volkan Isler, PhD - 1 mo. summer salary (8% FTE, 33.7% fringe	$ 58,521
Key Personnel (9 mo appt) - Stergios Roumeliotis, PhD - 1 mo. summer salary (8% FTE, 33.7%	$ 68,175
Post Doctorate Research Associate (100 % FTE-2 Yrs) 22.4% Fringe Rate, 3% COLA - CS&E	149,083
Graduate Student Research Assistant to train under Dr. Volkan Isler - CSE (9 mo. 50% FTE, hourly rate $23.83 plus tutition at $18.29 / AY hr, 17.6% fringe)	$ 220,723
Graduate Student Research Assistant to train under Dr. Stergios Roumeliotis - CSE (3 mo. 30% FTE, hourly rate $23.83 plus tutition at $18.29 / AY hr, 17.6% fringe)	$ 45,044
Professional/Technical/Service Contracts:	
Conversion of diesel-powered mower to electric, installation of autonomous operation hardware, and testing and troubleshooting - The Toro Company or equivalent	$ 130,000
Autonmous robot control programming contractor - RFP	$ 28,000
Electrical contractor - Portable charging station design and integration - RFP	$ 18,000
Fabricator - Custom Weeding Implements for UTV- RFP	$ 6,500
Equipment/Tools/Supplies: *In this column, list out general descriptions of item(s) or item type(s) and their purpose - one row per item/item type.*	
Toro Groundsmaster Mower converted to electric power and autonomous operation	$ 95,000
Customized Electric UTV with Capacity for Autonomous Operation (Polaris or Equivalent)	$ 42,000
Robot platform for inter- and intra-row weeding	$ 95,000
Trailer for Portable Solar Charging Station	$ 8,507
Smart Charge Controller and Battery Packs for Solar Charging Station	$ 19,000
Solar PV Panels, Bracketing, and Balance of Plant	$ 12,000
Lab Supplies - CS&E	$ 10,000
Autonomous Hardware and Software, Sensors, Meters, Data Loggers ($10k for CS&E)	$ 51,000
Materials to Fabricate Custom Weeding Implements	$ 12,000
Travel: .	
Twelve trips by CSE and BBE Faculty from Saint Paul to Morris, MN (330 miles @ $.56 / mi)	$ 2,218
Lodging and meals for CSE and BBE Faculty in Morris (4 people / 12 nights @ $80 / room and $40 ea for meals)	$ 5,760
WCROC Staff travel from Morris to Twin Cities (330 miles and 12 trips @ .56, 6 nights @ $129 / room and $40 ea for meals)	$ 3,178
Travel, lodging, and meals for eight in-state outreach events including FarmFest and MN State Fair (2 people, 8 trips, 400 mi @$.56/mi, $110 / room, and $40 ea for meals)	$ 5,984
Additional Budget Items:	
Computer Services (CS&E)	$ 39,152
FarmFest Exhibit Fees	$ 2,400
MN State Fair Exhibit Fees	$ 4,800
Signage and Display Materials for Outreach Events	$ 2,200
TOTAL ENVIRONMENT AND NATURAL RESOURCES TRUST FUND $ REQUEST =	**$ 1,650,000**

V. OTHER FUNDS

SOURCE OF FUNDS	AMOUNT	Status
Other Non-State $ To Be Applied To Project During Project Period:	$ -	*NA*
Other State $ To Be Applied To Project During Project Period:	$ -	*NA*
In-kind Services To Be Applied To Project During Project Period: *The University of Minnesota is forgoing its indirect cost recovery and use as in-kind match.*	$ -	*NA*
Funding History: The West Central Research and Outreach Center is participating in three current, three ENRTF projects with secured funding, and one pending proposal. However, this proposal is a unique and unrelated project.	$ -	NA
Remaining $ From Current ENRTF Appropriation: *See funding history- not applicable.*	$ -	*NA*

Conventional weed control processes typically use large, diesel-powered sprayers and chemical herbicides are broadcast across crop fields and pastures. Control of weeds is very effective, however, there are unintended and potentially harmful consequences.

Our concept is to evaluate the control of weeds in pastures and row crops using robots powered by the sun. Our project team will utilize off-the-shelf as well as pre-commercial technologies which will be modified to operate autonomously in the mowing of pastures and weeding of fields.


Photo courtesy of Bing Photo


Photo courtesy of Rowbot


Photo courtesy of Polaris Ind.

Photo courtesy of Bing Photo


Photo courtesy of The Toro Company

If successful, fossil-based diesel fuel and chemical herbicide use as well as harmful side-effects will be significantly reduced. Local production of clean energy will be increased. Farmers will have new time-saving tools for effective weed control and Minnesota companies will benefit by leading the manufacture of new solar-powered robotic technologies.

Environmental and Natural Resources Trust Fund
2017 Project Manager Qualifications and Organization Description
Project Title: Organic Weed Control Using Solar-Powered Robots

Michael Reese, Principle Investigator / Project Manager
Since 2001, Mr. Reese has been the Renewable Energy Director at the University of Minnesota West Central Research and Outreach Center – Morris. He has overseen the development of the renewable energy program at Morris and has participated as Project Manager on over $15 million of research and demonstration projects including large and small-scale wind energy, biomass gasification, renewable hydrogen and ammonia, and solar electric and thermal energy systems. Specifically, Mr. Reese has overseen the development of the University's 1.65 MW utility scale wind turbine and is the Principle Investigator for the $3.75 million Wind to Hydrogen to Ammonia system. His biomass energy experience includes serving as WCROC Project Manager on a $1.89 million DOE – USDA biomass research and development project in which a Biomass Gasification Tool Box was developed for deployment of community scale biomass systems. Mr. Reese has also served as the Principle Investigator for solar thermal and solar PV research initiatives. He has been an invited speaker for numerous national and regional conferences on the topic of renewable energy. In addition to renewable energy, he continues to maintain a strong focus in agriculture and rural economic development. Mr. Reese serves / has served on several boards including the West Central Initiative Foundation (6 years – final year as Chairman) and the White Bear Lake Insurance Company (25 years – last 7 as President). In addition to Mr. Reese, the project team includes multidisciplinary faculty and industry researchers with significant experience in robotic automation and navigation, computer science, agricultural and mechanical engineering, renewable energy systems, and prototype development.

The primary organization is the University of Minnesota with researchers from the West Central Research and Outreach Center (WCROC), Department of Computer Science, and Department of Bioproducts and Bioengineering departments. The Toro Company, headquartered in Bloomington, MN will provide a critical role in integrating and prototype development of the robots. Technology development for the software logic, navigation systems, and safety protocol programing will largely be performed at the Minneapolis and Saint Paul campuses. The WCROC, located near Morris, will participate in the custom fabrication of weeding implements and will serve as the primary field testing location. The WCROC is a century-old 1,100-acre agricultural experiment station that focuses on applied research. The WCROC has several relevant program areas including renewable energy and conventional and organic crop production. The WCROC was selected as the 2011 Outstanding Conservationist for Stevens County by the Stevens Soil and Water Conservation District Board. The WCROC is ideally positioned to address critical agricultural issues. The staff have considerable experience in developing and effectively implementing applied research, outreach, and extension programs at the farm-level and within agricultural service professions. WCROC has nationally unique facilities and programs that compare conventional and organic / alternative crop and livestock production systems. The dairy program has the only side-by-side comparison of organic and conventional systems in the nation and the swine program is one of a handful to co-locate conventional and alternative production systems. In addition to agricultural production systems, the WCROC has a robust renewable energy program with community and farm-scale production systems. The renewable energy program features solar PV, solar thermal, biomass energy, geothermal, wind energy, and renewable hydrogen and ammonia production systems. These systems are commercially available but have yet to see wide-scale adoption on farms. A primary goal for the renewable energy program is to significantly decrease fossil-fuel consumption in the agriculture sector. Demonstration, outreach, and impact will be state-wide.