Environment and Natural Resources Trust Fund (ENRTF)
M.L. 2019 ENRTF Work Plan (Main Document)

Today's Date: February 11, 2019

Date of Next Status Update Report:

Date of Work Plan Approval: June 5, 2019

Project Completion Date: June 30, 2022

Does this submission include an amendment request? __

PROJECT TITLE: Development of Clean Energy Systems for Farms

Project Manager: William Northrop

Organization: University of Minnesota

Mailing Address: 111 Church Streetd

City/State/Zip Code: Minneapolis, MN 55455

Telephone Number: (612) 625-6854

Email Address: wnorthro@umn.edu

Web Address: www.merl.umn.edu

Location: Minneapolis (Hennepin County), Morris (Stevens County)

Total Project Budget: $650,000

Amount Spent: $0

Balance: $650,000

Legal Citation: M.L. 2019, First Special Session, Chp. 4, Art. 2, Sec. 2, Subd. 07a

Appropriation Language: $650,000 the first year is from the trust fund to the Board of Regents of the University of Minnesota for the West Central Research and Outreach Center at Morris to develop and test novel clean energy storage systems for farms using wind-generated ammonia to displace fossil fuels and reduce greenhouse gas emissions. This appropriation is subject to Minnesota Statutes, section 116P.10.

I. PROJECT STATEMENT:

We propose to develop and test a clean energy storage system for farms using anhydrous ammonia produced from wind energy. Currently, the West Central Research and Outreach Center (WCROC) is operating a pilot plant that uses wind energy to drive an ammonia production process. Further, the University of Minnesota's Thomas E. Murphy Engine Research Laboratory (MERL) has developed a unique method for combusting ammonia that can efficiently utilize renewable ammonia as a fuel for on-farm purposes like grain drying burners or engines. In this project, ammonia will be tested as fuel for grain drying and for on-farm engines using this technology. Successful development of an ammonia-based farm energy storage system will have a dramatic impact on reducing fossil energy consumption and greenhouse gas emissions in grain, feed, meat, milk, and biofuel production.

In studying the energy and carbon footprint of crop production at the WCROC, results indicated that grain drying made up 41.6% of the fossil energy attributed to grain production. Nitrogen fertilizer was the second highest fossil energy consumer at 36.4% while tractor field work was at 13.9% and transportation at 1.18% (Tallaksen et al, 2016). Conventional fuels used in these processes include propane and natural gas for grain drying, natural gas steam methane reforming for nitrogen fertilizer production, gasoline and diesel for on-site electricity generation, and diesel fuel for field work and transportation. We currently are testing the near-zero carbon ammonia as nitrogen fertilizer and for displacing diesel fuel in tractors. If this same ammonia can displace propane and natural gas for grain drying and power generation, we have a system that can eliminate over 90% of the fossil energy use of corn production using renewable sources! This impact has a significant ripple effect, substantially lowering the energy and carbon footprint of meat and dairy products as well as ethanol production.

The ability to store wind and solar energy is key to an efficient and effective energy system especially for farms. In general, batteries are considered to be the most logical source of energy storage. However, batteries are costly and can only store energy for short durations. The U.S. Dept. of Energy indicates that using ammonia for energy storage is much more cost effective than batteries and other forms of storage (Soloveichik, 2016). Also, if ammonia is produced from wind and solar, it can be stored and used seasonally. It can be used for nitrogen fertilizer and tractor fuel in the spring and for powering irrigation and backup generators in the summer. In fall, it can be used for grain drying, fertilizer, and tractor and transport fuel. In winter, ammonia can fuel furnaces and for electrical power generation needs. Therefore, wind and solar energy paired with ammonia production, can provide a comprehensive, dynamic, cost-effective, and year-round clean energy system for farms.

II. OVERALL PROJECT STATUS UPDATES:

First Update March 1, 2020

Second Update September 1, 2020

Third Update March 1, 2021

Fourth Update September 1, 2021

Fifth Update March 1, 2022

Final Report between project end (June 30) and August 15, 2022

III. PROJECT ACTIVITIES AND OUTCOMES:

ACTIVITY 1 Title: Develop and test catalytic ammonia decomposition on a laboratory combustion system
Description: A combustion system using a catalytic reformer will be developed and tested in partnership between the MERL team and UMN Duluth team using a small-scale burner. Testing will include ignition, flame and heat control, emissions, fuel mixing, heat rates, residence times, and catalytic, thermal, and combustion efficiency. Emissions measurements will also be made to determine the impact of burning ammonia-derived fuels on nitrogen oxides (NOx). Experiments will be conducted at the UMD and UMN-MERL. The experimental campaign will be conducted with the benchtop burner over the range of experimental conditions shown in the table below.

Variable	Units	Range
Thermal Input	kW	1-10
Ammonia Flow Rate	SLPM	4.4-44
Eq. Natural Gas Flow Rate	SLPM	1.8-18
Equivalence Ratio	-	0.5-1.0
Decomposition Fraction*	%	10-50
Fuel Energy Fraction for Decomp.	%	1.5-7.3
Air Flow Rate	SLPM	3.3-66

* Decomposition fraction will be evaluated numerically using CFD simulations and will be as required through gas-cylinder supplied burner experiments.

Flame stability of the benchtop burner will be evaluated over the thermal input, equivalence ratio and decomposition fraction range indicated in the table. Decomposition fraction is the amount of ammonia decomposed to $H_2 + N_2$. It is the product of fuel fraction sent to the reactor and the catalyst conversion. The energy required to decompose ammonia over the decomposition fraction range shown in the table as a fraction of the thermal input. Although some energy (up to 7.3% of thermal input) is used to decompose ammonia to H_2, some of that energy is recovered in through an increase in fuel heating value.

Instrumentation to be used during the experiments will include temperature and pressure transducers and mass flow controllers for air and ammonia. Analytical instruments including Fourier Transform Infra-Red (FTIR) analyzer and Raman Laser Gas analyzer will measure emissions of hydrogen, ammonia, and nitrogen oxides from the burner. Additional diagnostics including optical instruments may be applied as needed and as available.

ACTIVITY 1 ENRTF BUDGET: $209,519

Outcome	**Completion Date**
1. Design review completed for an ammonia-fueled combustion system.	*1/1/2020*
2. Fabrication of an ammonia-fueled combustion system completed.	*6/30/2020*
3. Ammonia-fueled combustion system tested and refined.	*1/1/2021*

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Fourth Update September 1, 2021

Fifth Update March 1, 2022

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ACTIVITY 2 Title: Field testing of a catalytic ammonia decomposition fuel system on a farm-scale grain dryer
Description: A prototype catalytic reformer and combustion system will be developed at the UMN Duluth and UMN MERL and then retrofitted to a grain dryer for field testing at the WCROC research farm. Industry

representatives from grain dryer manufacturers will be invited to discuss and provide feedback to the design process. Ammonia produced using wind energy will fuel the prototype combustion system. The system will first be tested in an empty grain dryer. Once the system has been fully commissioned, several batches of corn grain will be dried. In addition to flame stability and efficiency characteristics, grain residence time and moisture levels into and out of the grain dryer will be measured as well as unburned ammonia emissions. The experiments will be conducted at the WCROC. Experiments using the grain dryer burner will be conducted over the range of operating conditions shown in the table below.

Variable	Units	Range
Thermal Input	kW	500-1,000
Ammonia Flow Rate	SLPM	2,200-4,400
Eq. Natural Gas Flow Rate	SLPM	910-1,830
Equivalence Ratio	-	0.7-1
Decomposition Fraction	%	10-50
Fuel Energy Fraction for Decomp.	%	1.5-7.3
Air Flow Rate	SLPM	1,650-4,720

When demonstrating the farm-scale burner only one of two burners installed in the currently installed grain dryer at the WCROC will be converted to operate on ammonia. The other will remain fueled by LPG. The relative performance of each burner will be evaluated during the final demonstration phase. In addition to flame stability and efficiency characteristics, grain residence time and moisture levels into and out of the grain dryer will be measured as well as unburned ammonia emissions from the integrated farm-scale burner.

ACTIVITY 2 ENRTF BUDGET: $244,494

Outcome	**Completion Date**
1. *Design and fabricate prototype ammonia-fueled combustion system for a grain dryer.*	*6/30/2021*
2. *Prototype ammonia combustion system installed and commissioned on a grain dryer.*	*9/30/2021*
3. *Grain dried and field-testing completed within the ammonia-fueled grain dryer.*	*12/31/2021*
4. Perform a life-cycle assessment to determine impact on GHG emissions.	*6/30/2022*

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Fifth Update March 1, 2022

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ACTIVITY 3 Title: A catalytic reformer developed and tested on a spark-ignition engine: A catalytic ammonia decomposition fuel system for a spark-ignition engine will be designed, fabricated, and tested at the UMN MERL. The experiments will be conducted on a flexible research spark-ignition engine to determine the acceptable range of operation when used in electricity generator applications. The engine will be tested for performance and emissions characteristics using instruments available at the laboratory. The goal of the activity will be to demonstrate that an exhaust-heated ammonia decomposition system is superior to operating the engine on ammonia alone. Emissions will be measured in the experimental campaign to determine whether species like nitrogen oxides (NOx) are reduced using the developed fuel system. Experiments will be conducted at the UMN MERL.

ACTIVITY 3 ENRTF BUDGET: $195,897

Outcome	Completion Date
1. Design review completed for an ammonia-fueled single-cylinder engine.	*1/1/2020*
2. Fabricate reactor and test an ammonia catalytic composition system on engine.	*1/31/2021*
3. Complete emissions and performance testing on the engine at the MERL	*6/20/2021*

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Final Report between project end (June 30) and August 15, 2022

IV. DISSEMINATION:

Description: Results regarding the ammonia decomposition system used in grain drying will be disseminated through journal papers in scientific publications and through presentations at conferences. The Program Manager Northrop will also work with the WCROC and UMD partners to schedule tours and activities during the grain dryer demonstration phase of the project (Activity 2).

The Minnesota Environment and Natural Resources Trust Fund (ENRTF) will be acknowledged through use of the trust fund logo or attribution language on project print and electronic media, publications, signage, and other communications per the ENRTF Acknowledgement Guidelines.

First Update March 1, 2020

Second Update September 1, 2020

Third Update March 1, 2021

Fourth Update September 1, 2021

Fifth Update March 1, 2022

Final Report between project end (June 30) and August 15, 2022

V. ADDITIONAL BUDGET INFORMATION:

A. Personnel and Capital Expenditures

See attached budget

Explanation of Capital Expenditures Greater Than $5,000:
NA

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

Enter Total Estimated Personnel Hours for entire duration of project: 4794	Divide total personnel hours by 2,080 hours in 1 yr = TOTAL FTE: 2.30

B. Other Funds

SOURCE OF AND USE OF OTHER FUNDS	**Amount Proposed**	**Amount Spent**	**Status and Timeframe**
Other Non-State $ To Be Applied to Project During Project Period:			
Other State $ To Be Applied To Project During Project Period:	$326,347	$ 0	Pending
In-kind Services To Be Applied To Project During Project Period:			
Past and Current ENRTF Appropriation: Appropriations related to this project includes: 1. A 2006 ENRTF project to produce hydrogen from wind energy ($800k). 2. A 2015 ENRTF project to research new renewable nitrogen fertilizer production technologies ($1 million - in progress), and 3. A 2016 ENRTF project 'Hydrogen fuel from Wind-Produced Ammonia" to displace diesel fuel in tractors ($250K - in progress).	$2,050,000	$2,050,000	Secured
Other Funding History: $2.95 million was provided by the University and State to complete the renewable hydrogen and ammonia pilot plant at WCROC. $500k and $400k was provided by UMN MnDRIVE and UMN IREE respectively to refine ammonia production technologies, develop policy, and evaluate economics. $180K was provided by Mn Corn to evaluate a novel production technology and evaluate initial economics. $2.9 million was awarded by the US Dept of Energy ARPA-E REFUEL program to develop and test a pilot-scale production unit of a novel ammonia production technology developed within the U (in progress).	$6,930,000	$6,930,000	Secured
TOTAL OTHER FUNDS:	**$9,306,347**	**$ 8,980,000**	

VI. PROJECT PARTNERS:

A. Partners outside of project manager's organization receiving ENRTF funding

Name	**Title**	**Affiliation**	**Role**
Dr. Will Northrop	Assoc. Prof., MERL Director	UMN Dept of Mech Eng.	PI
Mr. Eric Buchanan	Scientist, Renewable Energy	UMN WCROC	Co-PI
Dr. Alison Hoxie	Associate Professor	UM-Duluth Dept of Mech & Industrial Eng.	Co-PI

B. Partners outside of project manager's organization NOT receiving ENRTF funding

Name	**Title**	**Affiliation**	**Role**
NA			

VII. LONG-TERM- IMPLEMENTATION AND FUNDING:

The main goal of this project is to show that ammonia can be effectively used within a farm energy storage system. The long-term goal is to develop commercially viable near zero carbon technologies that can be implemented on farms.

VIII. REPORTING REQUIREMENTS:

- Project status update reports will be submitted March 1 and September 1 each year of the project
- A final report and associated products will be submitted between June 30 and August 15, 2022

IX. SEE ADDITIONAL WORK PLAN COMPONENTS:

A. Budget Spreadsheet
B. Visual Component or Map
C. Parcel List Spreadsheet
D. Acquisition, Easements, and Restoration Requirements
E. Research Addendum

Attachment A:
Environment and Natural Resources Trust Fund
M.L. 2019 Budget Spreadsheet

Legal Citation: M.L. 2019, First Special Session, Chp. 4, Art. 2, Sec. 2, Subd. 07a
Project Manager: William Northrop
Project Title: Development of Clean Energy Storage Systems for Farms
Organization: University of Minnesota
Project Budget: $650,000
Project Length and Completion Date: 36 months, June 30, 2022
Today's Date: February 11, 2019

ENVIRONMENT AND NATURAL RESOURCES TRUST FUND BUDGET	Budget	Amount Spent	Balance
BUDGET ITEM			
Personnel (Salary)	$504,290	$0	$504,290
PI Northrop $50,324 (75% salary, 25% benefits) 0.08 FTEx3 yrs			
Lab Manager MERL $51,968 (75% salary, 25% benefits) 0.19 FTEx3 yrs			
Undergrad Intern - Engines $17,804 (100% salary, 0% benefits) 0.25 FTEx3 yrs			
Co-PI Allison Hoxie $20,000 (75% salary, 25% benefits) 0.04 FTEx3 yrs			
UMD Graduate Student $80,000 (60% salary, 40% benefits) 0.04 FTEx3 yrs			
Joel Tallaksen $44,852 (75% salary, 25% benefits) 0.25 FTEx2 yrs			
Cory Marquart $31,464 (75% salary, 25% benefits) 0.25 FTEx2 yrs			
Co-PI Eric Buchanan $33,888 (75% salary, 25% benefits) 0.1 FTEx3 yrs			
Farm Technician $18,661 (75% salary, 25% benefits) 0.25 FTEx2 yrs			
Undergrad Intern $6,000 (100% salary, 0% benefits) 0.1 FTEx3 yrs			
MERL Grad Research Assistant $149,331 (60% salary, 40% benefits) 0.5 FTEx3 yrs			
Professional/Technical/Service Contracts			
Mechanic for grain dryer install at WCROC	$9,000	$0	$9,000
Hydrogen and Ammonia Safety Trainer for Team	$4,500	$0	$4,500
Emissions calibration at MERL (1/4 yearly PM on emissions equipment)	$10,000	$0	$10,000
PHA Engineering 3rd Party Review for grain dryer at WCROC	$5,000	$0	$5,000
Equipment/Tools/Supplies			
Plumbing, electrical supplies, consumables, test cell parts at MERL	$22,000	$0	$22,000
Parts for lab decomposition system including metal parts	$4,000	$0	$4,000
Consumables and saftey equipment for ammonia at MERL	$6,000	$0	$6,000
Maintenance and repair parts for ammonia production at WCROC	$8,000	$0	$8,000
Lab consumables at UMD	$15,000	$0	$15,000
Catalysts from Johnson Matthey and Metal Substrates	$23,000	$0	$23,000
Sensors, meters, and vented container at WCROC	$5,000	$0	$5,000
Mass flow controllers and control equipment at MERL	$6,000	$0	$6,000
Sensors, meters for ammonia safety at UMD	$4,000	$0	$4,000
Grain Drying Burners for Modification in Activity 2	$6,000	$0	$6,000
Capital Expenditures Over $5,000			
	$0	$0	$0
Travel expenses in Minnesota			
Northrop and staff - Travel to Morris 3 trips/year	$7,380	$0	$7,380
Hoxie and staff - Travel to Morris and Minneapolis 3 trips/year	$7,380	$0	$7,380
Buchanan and staff - Travel to Minneapolis and Duluth 3 trips/year	$3,450	$0	$3,450
Other			
	$0	$0	$0
COLUMN TOTAL	$650,000	$0	$650,000