M.L. 2014, Chp. 226, Sec. 2, Subd. 08e Project Abstract

For the Period Ending June 30, 2017

PROJECT TITLE: Life Cycle Energy of Renewably Produced Nitrogen Fertilizers
PROJECT MANAGER: Joel Tallaksen
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WEBSITE: https://wcroc.cfans.umn.edu/green-nh3-lifecycle
FUNDING SOURCE: Environment and Natural Resources Trust Fund
LEGAL CITATION: M.L. 2014, Chp. 226, Sec. 2, Subd. 08e
APPROPRIATION AMOUNT: $250,000
AMOUNT SPENT: $237,184
AMOUNT REMAINING: $12,816

<u>Overall Project Outcomes and Results</u>

The Minnesota landscape supports over 14 million acres of grain production, requiring almost 600,000 tons of nitrogen fertilizers and costing over $400 million annually. Producing this fertilizer consumes the equivalent of 3,000,000 barrels of oil, which is a significant use of fossil fuels resulting in a considerable amount of greenhouse gas emissions. Minnesota has renewable technologies that are capable of the constant energy generation needed to produce ammonia, which would promote economic development, spur job creation in rural areas and improve the overall sustainability of agriculture. This project examined the viability of developing these baseload renewable energy sources for ammonia production.

Using life-cycle assessment and techno-economic modeling, the research examined ammonia production with three renewable energy options; gasification, anaerobic digestion and hydroelectric systems. The findings indicate that from both a technical and environmental standpoint, these renewable production systems can produce renewable ammonia fertilizer. However, the present economics make investing in renewable ammonia production unfeasible at this time. The current and continued low price of natural gas prices suggests that low cost fossil-based ammonia is a more economical option at this point. Past shortages and price spikes in ammonia fertilizers indicate that the economics and need for the systems might re-appear under different conditions. Yet, it is unlikely that these renewable ammonia systems would be viable in the short term without a significant consumer or other regulatory demand. Ammonia fertilizer is critical to Minnesota's agriculture and the information from this study is available should alternative ammonia production need to be implemented on short notice.

<u>Project Results Use and Dissemination</u>

The project used two main paths to disseminate scientific, technology, and economic information. The first was in-person via presentations to the wide variety of stakeholders interested in ammonia, agriculture, sustainability and rural development. Many of these interactions are during facility tours of the West Central Research and Outreach Center's agricultural renewable energy facilities and production systems. However, team members have given a variety of presentation and talks on renewable ammonia production and renewable energy to the chemical engineering and ammonia energy interests. This is in addition to general discussions on farming energy inputs and improving farming sustainability that we normally have at conferences, in classrooms, and at farming events. The international members of the team have broadened the in-person dissemination beyond the Midwest.

The other main focus of dissemination is print and online media. Both can be used for reaching audiences that are not able to physically visit or meet with us at conferences. These formats also allow for informing audiences with a wide range of skills and interests. For the more academic audiences, we are developing a technical paper that will be published in an academic journal. The findings of the study are being written up as an internally published white-paper document for those interested in the practical finding from the work. Smaller summaries were developed as a handout for general audiences. All of these documents are or will be available on the project's website at https://wcroc.cfans.umn.edu/green-nh3-lifecycle. The site also has links to other ammonia, agriculture, and research topics being studied by the West Central Research and Outreach Center and University of Minnesota Researchers.

Environment and Natural Resources Trust Fund (ENRTF) M.L. 2014 Work Plan

Date of Report: Sept 6th, 2017

Date of Next Status Update Report:

Date of Work Plan Approval: June 4, 2014

Project Completion Date: June 30, 2017

Does this submission include an amendment request? NO

PROJECT TITLE: Life Cycle Energy of Renewably Produced Nitrogen Fertilizers

Project Manager: Joel Tallaksen

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Location: Statewide

Total ENRTF Project Budget: $250,000

ENRTF Appropriation:	$250,000
Amount Spent:	$237,184
Balance:	$ 12,816

Legal Citation: M.L. 2014, Chp. 226, Sec. 2, Subd. 08e

Appropriation Language:
$250,000 the second year is from the trust fund to the Board of Regents of the University of Minnesota for the West Central Research and Outreach Center in Morris to calculate fossil fuel energy savings and greenhouse gas reductions resulting from the use of local renewable energy technologies, including biomass gasification, anaerobic digestion, and hydroelectricity to produce fertilizer. This appropriation is available until June 30, 2017, by which time the project must be completed and final products delivered.

I. PROJECT TITLE: LIFE CYCLE ENERGY OF RENEWABLE PRODUCED NITROGEN FERTILIZERS

II. PROJECT STATEMENT:

The Minnesota landscape supports over 14 million acres of cropland in grain production. Almost 600,000 tons of nitrogen fertilizers are needed annually to maintain productivity on this land. In energy terms, production of Minnesota's nitrogen fertilizer requires the equivalent of 3,000,000 barrels of oil annually and costs farmers over $400 million. This is a significant use of fossil fuels in the state and results in a considerable amount of greenhouse gas (GHG) emissions. In addition, the absence of fossil energy resources in the State means that these synthetic nitrogen fertilizers must be imported into Minnesota from the other states and overseas.

As an initial step towards developing a renewable nitrogen fertilizer for the State, a pilot plant at the University of Minnesota, West Central Research and Outreach Center (WCROC) uses wind turbine electricity to produce ammonia, the most commonly used nitrogen fertilizer in Minnesota. Initial life cycle assessment (LCA) has shown that the wind to ammonia system is capable of producing ammonia fertilizer with very low fossil energy inputs and fewer GHG emissions; however, intermittent production of wind power would limit ammonia production during calm periods. Minnesota has a broad portfolio of other base-load renewable energy sources renewable technologies capable of more constant generation of the hydrogen rich precursors needed for ammonia production; among these are biomass gasification, anaerobic digestion, and hydropower (using electrolysis). We have designed this project to examine the viability of these base-load renewable energy sources for ammonia production. The work brings together chemical engineering researchers, industry professionals and life cycle assessment specialists to examine the feasibility of producing nitrogen fertilizers using renewable energy sources other than wind.

To analyze these systems, researchers will examine Minnesota gasification, anaerobic digestion and hydroelectric systems to collect data for building computer models of the systems. One type of model will be a life-cycle model that will assess all inputs and outputs to calculate total greenhouse gas emissions and fossil energy input. The other will be a chemical process model that will examine the amount of raw materials and energy needed to make ammonia and the relative efficiency and cost of the process. For each of these models, the work is done in two phases; building the model from energy production data and ammonia production equipment specifications, and then working with the model to accurately predict the operations of the technology. A final piece of this project is working to disseminate project information via our website, print media, and stakeholder meetings.

A key objective in developing this information is to *identify the viability of producing nitrogen fertilizers using different renewable energy technologies*, which could significantly reduce fossil energy consumption and GHG emissions from the large agricultural sector in the State. Another important objective is to *provide options for expanding local renewable energy use in Minnesota's industrial base*. This would help *promote economic development and spur job creation in rural areas* and thus, extend the economic benefits beyond agriculture. The project also examines a potential strategy of improving the overall sustainability of agriculture as desired by the market place. A final objective is to *further develop the knowledge base of Minnesota researchers to conduct LCAs and techno-economic feasibility analyses of renewable energy and nitrogen fertilizer production systems.* We feel that these project objectives fit very well with WCROC's overall goal of *reducing fossil energy use in agriculture and enhancing rural communities.*

III. PROJECT STATUS UPDATES:

Project Status as of *(November 30, 2014)*:
Administratively, during the first project period, researchers have established research contracts with the respective institutions and are beginning to prepare to work on contracts with industry collaborators.

The research team is currently establishing the parameters for the different models for the life cycle assessment and techno-economic work that will be developed. This involves reviewing the current state of renewable energy system technology and deployment and looking at technologies that are likely to be used should renewable ammonia production become established.

Project Status as of *(June 30, 2015)*: During the last reporting period, the Swedish members of the collaboration visited Minnesota as part of a related project, which allowed the opportunity to discuss the current project. After visiting both a local anaerobic digestion facility and the Chippewa Valley Ethanol Cooperative, the project team was able to refine the framework for analysis and better understand the scale and boundaries for the systems being analyzed. Specifically in the case of gasification of biomass to make ammonia at an ethanol facility, the analysis will include the ethanol facility and how inputs and outputs of the combined ethanol/ammonia system would differ from separate ethanol and fossil ammonia production.

Project Status as of *(November 30, 2015)*: Over the last reporting period, researchers have developed LCA and chemical engineering models for the integrated ammonia ethanol production system. Work is currently focused on harmonizing modeling assumptions for the "nitrofinery" so that carbon footprint, energy use, and economics can be compared. The modeling of the anaerobic digestion based ammonia production system is being discussed, with a focus on designing a model that would be practical under Minnesota conditions.

Project Status as of *(June 30, 2016)*: Final work is being done on the "nitrofinery" model, which uses biomass at an ethanol facility to produce process heat and ammonia fertilizer. The anaerobic digestion ammonia production facility model needs modifications to meet the unique demands of fertilizer production at a viable scale for Minnesota dairy systems. The hydropower ammonia production modeling has begun, with initial estimates of production at different existing Minnesota hydropower plants completed.

Project Status as of *(November 30 , 2016)*: Much of the technical work on analysis of the "nitrofinery" and hydrogen systems has been completed. Technical reports are being started for those areas. These will include life cycle, economics, and facility design information. A peer reviewed scientific paper is planned for the "nitrofinery" model. The Anaerobic digestion work is less complete, with overall models and options still being finalized. Additional modeling and analysis work will be completed for all areas for the final report. As the project begins to wind down in spring of 2017, outreach activities will be expanded prior to completion of the project.

Overall Project Outcomes and Results (June 30, 2017):

The research conducted for this project examined technical, environmental, and economic barriers to adopting renewable ammonia based nitrogen fertilizer production for Minnesota's agricultural sector. Using life-cycle assessment and techno-economic modeling, the project examined scenarios for ammonia production systems using current economical and production data. From both a technical and environmental standpoint, these renewable systems are a possibility. However, the findings indicate that the current economics of fossil-based ammonia production compared with renewable production systems make invest in renewable ammonia production unfeasible at this time. The rapid reduction and likely continued low price of natural gas prices suggests that low cost fossil-based ammonia is a more economical option at this point. Past shortages and price spikes in ammonia fertilizers indicate that the economics and need for the systems might re-appear under different conditions. Yet, it is unlikely that the renewable ammonia systems examined would be viable in the short term without a significant consumer or other regulatory demand for locally produced or more sustainable fertilizer.

Ammonia fertilizer is critical to Minnesota's agriculture, this information from this study is available to assure we have the background data for new local production ready should alternative ammonia sources be needed on short notice. Should economic or resource conditions change in the future, the findings of this project are a useful tool to gauge whether renewable technologies could be deployed. They are also useful in comparing new renewable ammonia production and technologies that are being developed for agriculture in Minnesota.

IV. PROJECT ACTIVITIES AND OUTCOMES:

ACTIVITY 1: Life Cycle Assessment Modeling of Renewable Nitrogen Production
Description:

LCA modeling for renewable energy systems will use data from facilities such as the biomass gasification system located at Chippewa Valley Ethanol Cooperative, in Benson, MN, a local anaerobic digestion system, and a representative Minnesota hydroelectric production system. The research will be based on standard ISO14040 life cycle assessment methodology and examining energy (both renewable and fossil) and GHG emissions. The first major tasks to complete this activity is working to collect data at the renewable energy facilities and documenting all inputs and outputs needed in the energy production process. This includes understanding the operation of the renewable energy technology, assessing the amount of infrastructure needed, and fully examining potential impacts of each input and output. Once this information is documented, then the next task is to create a model that allows all the data to be used in an integrated manner to calculate the overall energy use and GHG emissions. The primary focus of these efforts will be on the biomass gasification and anaerobic digestion modeling as these are most common in the agricultural regions of the state and have more potential for future installations in Minnesota. Hydro-electric based fertilizer production modeling will be somewhat less detailed and rely more on database data as an overview of the technology for determining life-cycle impacts.

Summary Budget Information for Activity 1:

ENRTF Budget:	**$ 98,879**
Amount Spent:	**$ 93,931**
Balance:	**$ 4,9848**

Activity Completion Date:

Outcome	Completion Date	Budget
1. Life Cycle Assessment of Ammonia Production Via Biomass Gasification	9/2015	$32,959
2. Life Cycle Assessment of Ammonia Production Via Anaerobic Digestion	4/2016	$32,959
3. Life Cycle Assessment of Ammonia Production Via Hydro-electric Power	11/2016	$32,959

Activity Status as of *(November 30, 2014)*:
During the reporting period, the LCA team is focusing on how the model will be built to represent likely scenarios for renewable ammonia production in Minnesota and what data will be most critical for those models. Energy production for the system is one of the two main components. The other is the efficiency and scale of producing ammonia using the scale of renewable energy resources available in Minnesota.

Activity Status as of *(June 30, 2015)***:** Work on the gasification pathway for ammonia production has begun with an examination of the biomass feedstocks used for gasification. This includes looking at the energy used to grow, harvest, and process biomass. It was decided for sustainability and gasifier operational reasons, that corn cobs would be the biomass used for LCA models. Examination of Minnesota-based hydropower is beginning. Work on that system is focusing on the size and scale of hydropower likely for an ammonia system in Minnesota and the inputs and outputs for a system at that scale.

Activity Status as of *(November 30, 2015)***:** A spreadsheet model has been set up for the ammonia via gasification production method, with the collection data for generation of biomass feedstocks well documented. The model examines corn cultivation, cob harvesting and transport of raw material to the 'nitrofinery'. Work on the life cycle impacts once the feedstocks enter the ethanol facility is being coordinated with the technoeconomic team conducting activity 3 to keep the model assumptions synchronized.

Activity Status as of *(June 30, 2016)***:** Completed modeling includes agricultural aspects of the "nitrofinery" system (corn cultivation, cob harvesting, transport of raw material). Changes in soil carbon due to harvesting of corn cobs have been integrated in the model. Further data from the Aspen modeling of the "nitrofinery" inputs and outputs is also now integrated in the model. LCA modeling of the anaerobic digestion production of ammonia is progressing. However, it is likely that the LCA model will need to include another feedstock, in addition to dairy manures. The energy in dairy wastes is not sufficient on its own to supply the hydrogen for ammonia production. Hydroelectric ammonia production modeling is underway and preliminary results should be available in the next few months.

Activity Status as of *(November 30, 2016)***:** Life cycle work for the "nitrofinery" model has been completed with the addition of soil carbon data to address changes to cropping systems with removal of biomass. Energy use data from the hydroelectric production system is being used to finalize the LCA results from the hydroelectric based ammonia production. Anaerobic digestion based ammonia production LCA work is being expedited to meet the project completions date. The model for energy and material flows through the system needs to be finalized before major LCA work can be completed.

Final Report Summary: During the last six months of the project, Dr. Tallaksen and Dr. Ahlgren have been compiling and organizing the lifecycle information for the different technologies of the project. The life cycle assessment goals were to calculate the fossil energy and greenhouse gas emissions for each technology as it could be used in Minnesota agricultural/industrial applications. The following brief summary covers the life cycle analysis for the three systems studied:

Nitrofinergy Life Cycle Assessment

The nitrofinery model examined ammonia production at a combined corn grain to ethanol and corn cobs to ammonia gasification facility (Figure 1). Using this system, Minnesota's agricultural resources can be used synergistically for both ethanol and ammonia production. The aim of this Life cycle assessment work was to examine the fossil energy use and greenhouse gas emissions of the ammonia-ethanol production facility (nitrofinery) and compare it with a conventional ammonia production facility. The ammonia and ethanol production technology is described more completely in the Activity 2; However, figure 1 below provides the overall materials flows into and out of the system, which are used for life cycle assessment calculations.

Life Cycle Assessment Methodology For Nitrofinery Model

The nitrofinery model examined how biomass gasification based ammonia production could be added to the typical Minnesota ethanol production plant setup. The model uses a 55 million gallon per year ethanol facility as the beginning point for adding the gasification system. Using the corncob biomass requirement determined in the technology assessment in Activity 2 below, the LCA calculated energy use and greenhouse gas for production of cobs and corn grain. The LCA covers the entire production chain, as illustrated in figure 1, including cultivation of corn, transport of feedstocks, gasification, ammonia production and ethanol production. Emissions from cultivation of grain/biomass feedstock is often a large share of the emissions in bio-based refineries.

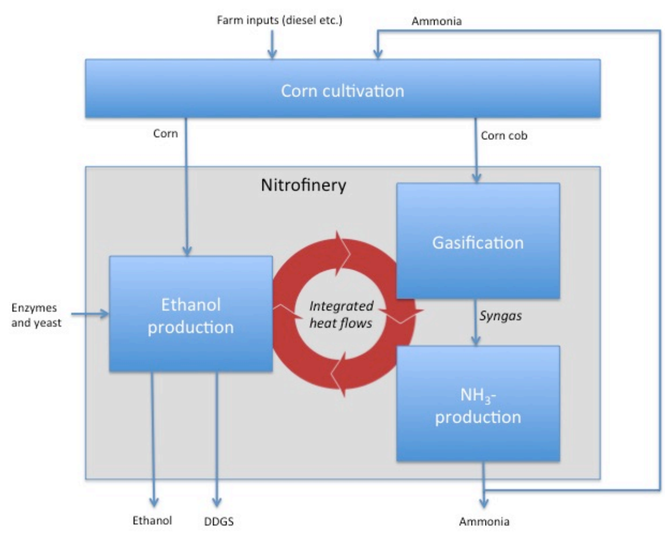

Figure 1. Schematic Model of Nitrofinery Mass and Energy Flows. The diagram shows the major flows needed for production of ethanol and ammonia in the nitrofinery model. Agriculture provides both the chemical feedstock for the production of ethanol (grain) and ammonia (cobs) as well as the thermo-chemical mass needed to for distillation energy.

For this model, corn grain and cobs are assumed to be locally sourced in Minnesota. The corn yield was set to 10.3 metric dry ton per hectare and year, which is the state average yield between 2011 and 2015. Many of the corn production inputs were modeled using data from GREET (Greenhouse gases, Regulated Emissions, and Energy use in Transportation Model, Argonne National Lab) or a review done in 2014 by Kim and Dale. The ammonia that is produced at the nitrofinery is assumed to be used in the cultivation of corn, with any excess sold to the local market. The transportation distance was modeled assuming a circular collection area around the nitrofinery facility. The transport distance is dependent on the biomass requirements of the plant, road winding factor and the amount of biomass available in the area. In this study, we assumed a winding factor of 1.3 and that 45% of the land surrounding the nitrofinery is planted with corn. For the cobs, we assumed a 45% participation rate of farmers- primarily based on their concerns of soil health impacts from biomass removal.

When collecting cobs from corn a field, carbon is removed that if left there, could have helped maintain soil carbon. In this study, we model this lost opportunity of soil carbon sequestration as an emission. The soil carbon changes were evaluated with the Introductory Carbon Balance Model (ICBM) An soil to air emission factor of 1.525% N_2O-

N per kg of N supplied from ammonia was used to account for the direct and indirect nitrous oxide emissions. Other inputs to the facility (e.g. enzymes, yeast) are based on data in GREET.

Energy inputs into the system are primarily diesel fuel for crop cultivation and transportation. However, some energy is needed for herbicide production, grain drying, fertilizers (other than nitrogen). Energy use assumptions for cropping primarily used data from Kim and Dale.

Life Cycle Results for Nitrofinery Model

Energy estimates for the system show that primary energy (Table 1) used in the system was the cultivation of corn grain, which far exceeded other areas of energy inputs. This included primarily the tractor fuel, drying, and irrigation energy. The major direct energy output from the system was ethanol, which yields roughly 3 times the amount of energy inputs. Indirect energy outputs include the energy in dried distillers grain solids (DDGS) and ammonia not used in crop cultivation. As an overall estimate, for every unit of energy required by the system, roughly 8 units of energy come out of the system in ethanol, ammonia, or DDGS. Figure 2 shows how much primary energy is used per kg of each product. Conventional production of ethanol is currently using roughly 10 MJ of energy per kg, thus this system is increasing the renewable nature of ethanol production. Ammonia produced with this system is much less energy intense (2.4MJ/kg) than from conventional steam methane reforming using natural gas (35 MJ/kg).

Table 1. Energy Use In Nitrofinery Production. This is the net primary energy after using the ammonia that was produced in the nitrofinery for production of the corn and cobs used at the facility.

Primary energy input	(GJ/year)
Cultivation of corn	1,285,300
Harvesting of cobs	17,300
Transport of corn cobs	42,000
Transport of corn grain	27,300
Ethanol production inputs	800
Sum	1,372,800
Energy Output from Facility	
Ethanol	4,676,900

Table 2. Primary energy allocation for Production of products. Primary energy input was allocated based on total chemical energy embodied in the output mass for each output.

	MJ primary energy/kg product
Ethanol	3.3
DDGS	2.5
Ammonia	2.4

Greenhouse gas (GHG) emissions, as expressed by tons or kg of carbon dioxide (CO_2) equivalents emitted, are the other major life cycle data analyzed for the model. Table 3 Shows the GHG emissions for the nitrofinery system.

Table 3. Greenhouse gas emissions from the nitrofinery (metric ton CO_2-eq/year)

Process	**ton CO2-eq/year**
Cultivation of corn	137,600
Harvesting of cobs	14,800
Soil carbon losses, cob harvesting	54,100
Transport of corn cobs	2,300
Transport of corn	1,500
Ethanol production inputs	100
Sum	210,400

Table 4. Greenhouse Gas Emissions Assigned to Nitrofinery Products. Kg of CO_2 Equivalents allocated to each of the nitrofinery co-products based on lower heating value

Product	g CO_2-eq /kg product
Ethanol	509
DDGS	381
Ammonia	373

As with the primary energy analysis, cultivation of corn yields the primary environmental impact for the system. In terms of GHG per kg or per liter of ethanol produced, the emissions are roughly 1/3 of those by conventional ethanol production methods. Renewable ammonia production yielded a product with roughly 15% of the GHG emissions of fossil based ammonia production.

Life Cycle Technical Implications for the Nitrofinery Model

The findings from this model indicate that ethanol/ammonia production using this type of facility would meet the goal of reduced environmental impacts of GHG emissions and fossil energy use. The large reductions in energy demands and GHG emissions indicate that this technology is a feasible improvement of ammonia production when considering the environmental impacts of fossil fuel depletion and greenhouse gas emissions.

Anaerobic Digestion Life Cycle Assessment

The anaerobic digestion model studied the production of ammonia at dairy facilities in Minnesota. If focused on large dairies, which would have the manure production capacity to serve a modest sized ammonia production plant. The ammonia could then be used on area farms. The aim of this life cycle assessment work was to examine the fossil energy use and greenhouse gas emissions of and compare it with a conventional ammonia production facility. From a technology standpoint, the anaerobic production of ammonia is not significantly different than typical natural gas based systems. However, to further increase gas production, which raises ammonia production, crop residues (corn stover) were added to the
digestion process. This makes a slightly more complicated system, which is represented in the life cycle assessment schematic (Figure 2). As can be seen from this diagram, the biogas based ammonia production is being compared with a base case in which manure is applied as it would be normally at the dairy without an anaerobic digestion system.

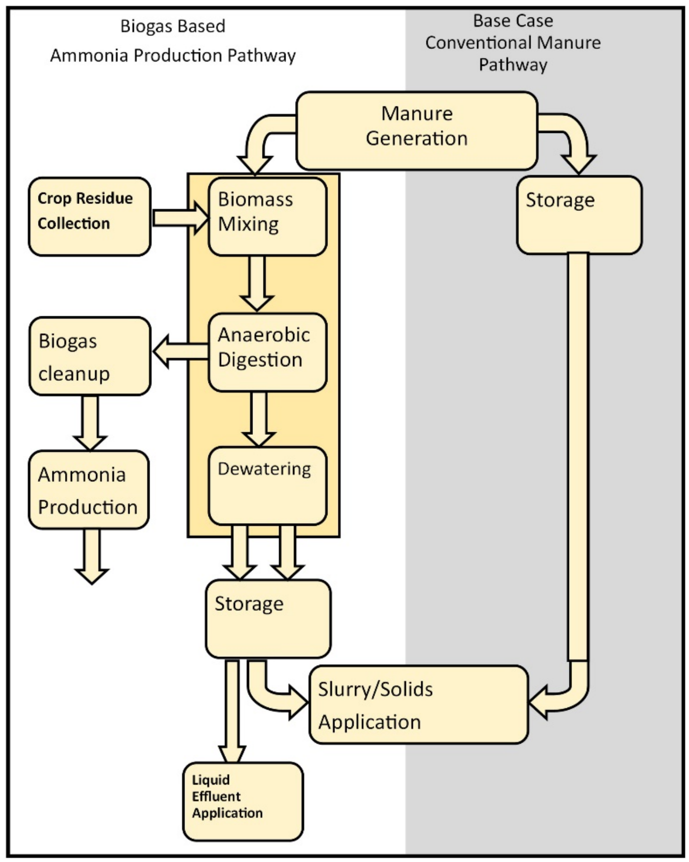

Figure 2. Anaerobic Digestion Schematic. The diagram shows the major flows needed for production of ammonia and handling of manures and digestate in the anaerobic digestion model. The activities of the reference system are shown as well.

<u>Life Cycle Assessment Methodology for Anaerobic Digestion Model</u>

The life cycle assessment model used a dairy facility that housed 5000 cows. Each cow was assumed to excrete 120 pounds of manure per day. On a dry weight basis, this yields roughly 15 pounds of total solids. Corn Stover biomass was added to the system at 1:1 ratio of the excreted manure (wet basis). It was assumed that there were no changes to the base dairy system, with the addition of a new anaerobic digester. In terms of the digestion process, manure and biomass are mixed and flow through the digester as microorganisms breakdown the carbon containing materials in the digestate into biogas. The biomass that does not break down in the system is removed and a screw press is used to press liquid out of the remnant biomass. The manure liquid and dewatered digestive are stored until field application. Biogas removed from the anaerobic digester is cleaned to remove moisture and contaminants and then goes into the ammonia production system.

Corn stover production uses significant amount of energy and emits carbon dioxide as well. The model assumes that biomass was harvested from approximately 40% of the land planted to corn within several miles of the facility. However, to maintain soil health, biomass was harvested from one rotation of corn every two corn crops. Based on previous work with soil carbon models, it was assumed that soil carbon levels would stay relatively constant at this harvest level. Although there are two parts of this model where nitrogen fertilizer is an output (ammonia production and manure/digestate), it was not guaranteed that the fertilizer or manure would be applied directly back to fields that were part of producing crops (grain or stover) going into the anaerobic digestion system. Therefore, corn production assumes application of fertilizer independent of fertilizer production. The fuel use for harvesting and transporting biomass was calculated using past data from the WCROC and scientific literature.

The anaerobic digestion system and ammonia production equipment, both discussed below in task 2, were assumed to be current technology in use in other areas. Relative to the LCA work, the system was assumed to have a 2% methane leakage rate. Electricity use was modeled at 12.9 kWh per ton of dry solids. Three percent of methane was assumed to be used internally in the gas clean-up process.

<u>Life Cycle Assessment Results for the Anaerobic Digestion Model</u>

Net energy use (Table 5) for the production of ammonia was 8.9 MJ per kg, this was after factoring out the energy saved by not sending the manure through the base (reference) system where it is stored and directly applied to the soil. The primary use of energy in the system was harvest and transport of corn crop residue. The additional use of crop residue in the digestion system significantly increased the amount of digestate that needed to be spread on fields, which increased the energy significantly. The anaerobic digestion system also required grid power to agitate and move digestate through the system.

Table 5. Net Daily Primary Fossil Energy for Ammonia Production in the Anaerobic Digestion Model. Energy use for each activity needed in the AD ammonia production system in megajoules of primary energy after factoring out energy that is used in the reference system

Activity	Primary Energy
Residue Production	334,008
AD Facility	75,555
Field application	88,776
Total Fossil Energy (MJ)	498,339
Energy per kg ammonia	8.90 MJ

Table 6. Net Daily Greenhouse Gas Emissions for the Anaerobic Digestion Model. Daily greenhouse gas emissions in kgs of CO_2 equivalents for each activity needed in the AD ammonia production systems. Emissions are calculated after factoring out avoided emissions from the reference manure application system.

Activity	GHG Emissions
Residue Production	17,716
AD Facility	33,792
Storage Emissions	5,907
Field Application	3,874
Soil Emissions	0
Total kg CO_2 Eq.	49,476
CO_2 Eq. per kg Ammonia	0.882 kg

Greenhouse gas emissions for the anaerobic digestion model were 0.882 kg CO_2 equivalents for each kg of ammonia produced after factoring out emissions for the reference system. The largest area of emissions was from the use of fossil fuels in harvesting biomass materials. Another major source of emissions was the leakage of ammonia from the biogas production system. The total emissions of 0.882 kg CO2 Eq. is significantly less than would be expected for a fossil based production system, which would emit 2.5 kg

<u>Life Cycle Analysis Technical Implications</u>

Both life cycle impact measures indicate that anaerobic digestion based ammonia production would yield life cycle benefits in ammonia generation. Therefore, from a LCA perspective, this system is a feasible alternative to reduce environmental impacts in ammonia production and nitrogen fertilizer use in agriculture.

Hydroelectric Ammonia Production Model Life Cycle Assessment

The hydroelectric system was not examined in as much detail as the other system. As described below in activity 2, ammonia based hydropower uses technology similar to wind based electricity ammonia already examined by WCROC. It is very similar to wind system examined in a previous LCCMR project. The main difference is that hydropower is a more stable baseload resource that produces a consistent amount of electricity. In this study, a complex model was not built because the previous wind-based study successfully examine the ammonia production part of the system and the hydropower has similar greenhouse gas and life cycle impacts to wind.

<u>Life Cycle Assessment Comparison</u>

Life cycle impacts of this system are essentially zero. In the case of existing Minnesota hydroelectric, most plants have been in production more than 50 years. Any emissions or fossil resources used for construction are typically accounted for in the first 20 years of plant life. While there may be some additional impacts due to operations, maintenance, and renovations, these would likely be negligible. None of the renewable energy systems examined for this study have included the embodied energy of the ammonia plant. Using that criteria, there are no impacts considered on the ammonia plant side. Therefore, the overall impact (emissions and fossil fuel) of this system are near zero. However, it should be noted in this model that the 'zero impact electricity' is being taken away from other uses for use in ammonia production.

Discussion of Life Cycle Results of Alternative Ammonia Production System

After modeling the life cycle impacts from the systems (Table 7), The results indicate that all three production system were a significant improvement over fossil based ammonia production in terms of fossil energy use and greenhouse gas emissions. The nitrofinery model also provides ethanol and DDGS with a much lower carbon footprint. The anaerobic digestion system has greater environmental impacts, but is still about 30% of the impacts of fossil-based fertilizer. The hydro-electric ammonia production system would likely have almost no impacts if additional hydro-electricity became available.

Table 7 Life Cycle Comparison of Ammonia Production Methods

	Fossil Based	Nitrofinery	Anaerobic Digestion	Hydro-electric*
Fossil Energy (MJ)	35	2.4	8.90	0*
GHG Emissions (kg CO_2 Eq.)	2.5	0.373	0.882	0*

*This is an approximation, small impacts would be seen due to repair and upkeep, does not include diversion of 'green' electricity

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ACTIVITY 2: ***Technological and Economic Feasibility of Renewable Nitrogen Fertilizer Production***

Description: The technological and financial feasibility of adding ammonia production capabilities onto existing Minnesota commercial scale renewable energy facilities will be studied. As with LCA analysis in Activity 1, the first step is to collect data on the renewable energy technology and its inputs into ammonia production. However, the data collection will review aspects related to the chemistry, electronics, and types of equipment used in the processes. Process modeling will then use the Aspen+ modeling tool to examine simulations of production process chemistry, equipment needs, and facility costs. Logistical considerations such as biomass and manure processing and transport will be added to the models to make them more applicable to real-world situations. The output from these analyses will be used to estimate capital costs and economic viability of the production technologies. The primary focus of these efforts will be on the biomass gasification and anaerobic digestion modeling as these are most common in the agricultural regions of the state and have more potential for future installations in Minnesota. Hydro-electric based fertilizer production modeling will be somewhat less detailed and rely more on database data as an overview of the technology for determining life-cycle impacts.

Summary Budget Information for Activity 2: **ENRTF Budget: $ 127,129**
Amount Spent: $122,231
Balance: $4,898

Activity Completion Date:

Outcome	Completion Date	Budget
1. Techno-Economic Model of Ammonia Production Via Biomass Gasification	9/2015	$ 42,376
2. Techno-Economic Model of Ammonia Production Via Anaerobic Digestion	4/2016	$ 42,376
3. Techno-Economic Model of Ammonia Production Via Hydro-electric Power	11/2016	$ 42,376

Activity Status as of *(November 30, 2014)*:
The techno economic team is looking at which ammonia production technologies will fit the scale of renewable energy production that would is now or would likely be used in Minnesota.

Activity Status as of *(June 30, 2015)***:** The chemical engineering group has developed Aspen+ process models for both the gasification to ammonia system and ethanol production system. In developing the gasification model, it was decided to include the most well suited gasification system for ammonia production. This would be slightly different than that seen at Chippewa Valley Ethanol Cooperative, which was designed for syngas production.

Both models (gasification and ethanol production) will be integrated during the next reporting period. More specific data on Minnesota ethanol production is being collected to increase the accuracy of the modeling efforts.

Activity Status as of ***(November 30, 2015)*****:** The techno-economic team at Lund University has completed the basic Aspen+ model for the ammonia via gasification . Data on typical Minnesota ethanol production plants has been incorporated into the ethanol aspects of the model. Chippewa Valley Ethanol Cooperative has been asked to provide some general data based on their gasification system. Though CVEC's gasification system is different than the one modeled, they are one of few facilities that have worked with agricultural biomass. Using their data, the team hopes to model an ethanol/ammonia production system that is more representative of what would be possible in Minnesota.

Activity Status as of ***(June 30, 2016)*****:** During the first half year of 2016, the major focus of the work at Lund University has been on assessing the modelling of anaerobic biogas production. The current Aspen model has been reviewed and an effort vs. potential reward assessment has been performed. The outcome of the assessment was that the effort required for improving the model with respect to biogas production to a level of detail desired for more accurately assessing the biogas potential in mixed crops was too high.

Activity Status as of ***(November 30, 2016)*****:** During the second half year of 2016, the major focus of techno-economic analysis has been to improve the modelling of ammonia production using dairy manure based biogas and economic modelling of both the nitro refinery concept and the biogas route. The current Aspen model has been adapted to utilize a raw biogas based on the co-digestion of dairy manure and corn stover that are available in Minnesota. Economic modelling work is continuing with the nitro refinery concept and the smaller scale ammonia production from biogas produced by dairy manure co-digestion. The industry feedback and outreach efforts are beginning to be more actively worked on as the project is entering the final 6 months. The study is examining how production of ammonia from renewable will be perceived as part of a transition to a bio-economy.

Final Report Summary:

The assessment of the technical and economic feasibility of these projects was led by the Dr. Christian Hulteburg and his chemical engineering team at Lund University. Using data collected by Dr. Tallaksen at the West Central Research and Outreach Center covering Minnesota based agriculture, ethanol, and dairy systems the technology and economics was examined for each of the systems. The following brief summary covers the techno-economic results for the three systems analyzed:

Techno-economic Feasibility of Nitrofinery Based Ammonia Production

The nitrofinery model examined ammonia production at a corn ethanol plant. Ammonia is produced using energy from gasification of corn cob biomass. The advantage of combining the ammonia plant and the ethanol plant is a heat exchange system that uses excess energy (heat) from the biomass gasification process to power ethanol distillation and other heating needs at the ethanol facility. The techno-economic assessment examination examine the technology, inputs, and outputs of the system, and then places economic values on the flows of resources.

From a broader technical standpoint, many of the technologies examined for the biomass-based production of renewable ammonia are standard industrial processes. Gasification is a thermochemical process that breaks down the long chains of carbon molecules in biomass to release small gaseous hydrocarbons like hydrogen, methane, and carbon monoxide, which can be used as chemical feedstocks for ammonia production. These are used in the same way that natural gas is used to produce ammonia.

<u>Technological and Resource Assessment for the Nitrofinery</u>

In developing the techno-economic aspects of this model, the agricultural systems were assumed to be already existing and part of the local agricultural market. It was assumed that with current technology, the products needed at the nitro finery facility could be purchased on the open market, although long-term contracting would likely provide a more stable feedstock supply for the nitro finery.

The model of ammonia production (Figure 3) begins with receipt of the biomass at the nitrofinery facility. First, the biomass is ground into smaller particle sizes and dried, if needed. The biomass is put into a low-oxygen, high-temperature gasification chamber, where it is thermochemically converted into a low quality flammable gas. A number of gas cleanup steps are needed to remove particulate matter, sulfur, and other impurities. The gas is then compressed and added to the ammonia synthesis system. Ammonia synthesis is done using steam methane reforming, which is the industry standard for fossil fuel based ammonia production. During many of these steps, thermal energy is being released and captured for use in the ethanol production system. Therefore, there is little need for additional energy during the ethanol production process.

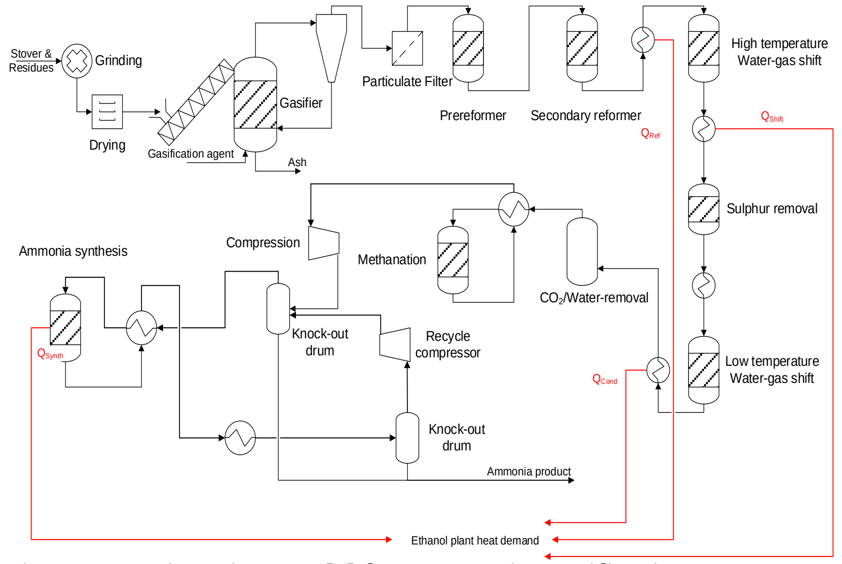


Figure 3 Engineering Model for Ammonia Gasification System. The diagram shows the major steps in the ammonia production nitrofinery process. Lines in red indicate the heat co-product that is used in the ethanol plant operations.

Table 8 Ethanol Production Assumptions. The ethanol production assumptions used to estimate biomass energy demands from the ammonia production system, which were taken from GREET 2014.

Corn ethanol yield	2.82	gal/bu
Energy use at plant	26,000	Btu/gal
Natural gas	24,000	Btu/gal
Electricity use	0.75	kWh/gal
DGS	15	dry lb/bu
Corn oil	0.53	dry lb/bu

Table 9 Process Input and Output Flows. Yearly mass flows of major feedstocks and products. Does not account for internal flows of on-site heat or electricity.

In			
	Corn	506,800	Metric ton/yr
	Corn cobs	422,400	Metric ton/yr
Out			
	Ethanol	173,200	Metric ton/yr
	DDGS	167,000	Metric ton/yr
	Ammonia	166,700	Metric ton/yr

For this model, the ammonia production system was scaled to provide the energy for a standard ethanol plant with a capacity of 55 million gallons of ethanol per year, the 2015 average for plants in Minnesota. Using the inputs needed for a facility of this size (Table 8), the model factored the amount of corn gran and cobs inputs needed and the amount of outputs for each of the products the facility produces (Table 9). The amount of corn cobs needed is significant and would like require collecting most of the cobs from several Minnesota sized counties to supply the facility, based on current yield and farmer participation estimates. The ammonia produced from a facility of this size would fertilize an roughly 2 million acres if used at 150 lbs per acre. The ethanol and DDGS production of the facility would be unaffected by the addition of ammonia production. Ethanol production would be 173,000 metric tons (55 MGY) and DDGS would yield 167,000 metric tons per year.

Economic Assessment for an Ammonia-Ethanol Nitrofinery

Economics of this system were examined in a very general sense, with rough numbers derived from the engineering modeling software Aspen Plus. This type of modeling looks at overall values for the equipment designed, the inputs into the system, and outputs produced by the system. It's numbers are intended to be a starting point for a system economic analysis. A much more detailed economic analysis would be required for designing a specific plant at a specific location. For this analysis, the grain and ethanol economics were not considered, but would be assumed to be the same as plant built using current technology. The first costs to be considered are the capital costs, which were based on building a new combined ethanol-ammonia facility at a brownfield development site. For a facility at this scale, there are significant capital costs (Table 10). Though the base equipment costs will likely be around $82 million, the extra infrastructure, contingencies, auxiliary equipment and financing are likely to drive the facility costs to roughly $150 million.

The next set of costs examined are the yearly operational costs of the facility. Because labor costs vary considerably based on location, employee numbers/duties, salaries, and taxes, these costs were not included in the results. One of the largest operation costs (Table 11) for the facility would be electricity, which is over $3 million per year.

Table 10 Capital Costs for Nitrofinergy Based Ethanol Ammonia Production System.

Base module cost	$82,000,000
Contingency	$15,000,000
Total module cost	$97,000,000
Total plant cost	$130,000,000
Auxiliary	$20,000,000
Depreciation (years)	15
Interest rate	10%
Total investment	$150,000,000

Table 11 Yearly Facility Operating Costs

Biomass	Varies
Electricity	$3,200,000
Depreciation	$20,000,000
Total yearly expenditure	$28,000,000

Another important cost is corn cob biomass, whose value at this point is not well understood as there is not an established biomass market. Early estimates by the USDA and EPA suggested that industrial scale biomass could be priced at between $30 to 50 a ton. However, work by WCROC and others indicates that it would likely be between $50 and 90 a ton. The impact of the price point for biomass for this project can be seen in Table 12. The unknown value of biomass and the fact that farmers may not be interested in supplying biomass makes this a key detail in interpreting models such as this. Though the variability of estimates cannot be directly accounted for in numbers, the risk associated with it is a likely factor for those potentially investing in biomass based 'green' projects.

Table 12 Total Feedstock Costs of Purchasing Cobs At Different Price Points.

Metric Tons /yr	422,400
@ $60	$27,936,945
@ $70	$32,593,102
@ $80	$37,249,260

Because these facilities would be located in agricultural regions, they would be in a unique position to market their products directly to farmers or agricultural cooperatives. Depending on the going rate for ammonia, this could greatly impact the facilities income stream (Table 13) for ammonia and increase the potential for profits.

Table 13 Value of Ammonia Sales Direct to Market.

Metric tons/yr	166,720
@ $300	$55,132,637
@ 500	$91,888,562
@ 700	$128,643,986
Wholesale	$48,700,000

Overall, there is a potential for a nitrofinery facility to make a profit. The key driver would be the market price of ammonia. A rough look at the major input costs suggests that at higher ammonia prices, the facility could pay for its feedstocks, operations, and capital costs. This assumes that the biomass feedstock costs and labor are within reason.

Implications from Technoeconomic Analysis

From both a technical and economic standpoint, the nitrofinery model could be a feasible system under the right circumstances. Much of the equipment has been used for other applications and is relatively well understood. The feedstock inputs are available in the community, provided the facility is willing to pay for feedstocks at a price that farmers will accept. However, as is discussed further in Activity 3, the ammonia production system is large and has significant uncertainties in terms of the availability of low cost agricultural biomass feedstocks. It is not likely that there would be a willingness to invest in a nitrofinery facility given the current low cost of ammonia.

Techno-economic Feasibility of Anaerobic Digestion Based Ammonia Production

The anaerobic digestion based ammonia production model focused on using biogas from cow manure as the energy source for production of ammonia. This model was scaled to represent an ammonia production system at relatively large Minnesota-based dairy, with 5000 head. In addition, corn stover biomass is added to the system to increase the yield of biogas. The model assumed an existing dairy with only a few modifications to aid in the collection of manure and storage of both liquid and solid digestate. It also assumed standard technologies for biogas production, cleanup, and ammonia synthesis. Areas not considered in the analysis include the agricultural system used to produce biomass used in the system, and the added equipment needed for spreading waste digest date on fields after biogas production has removed most of the easily converted hydrocarbons.

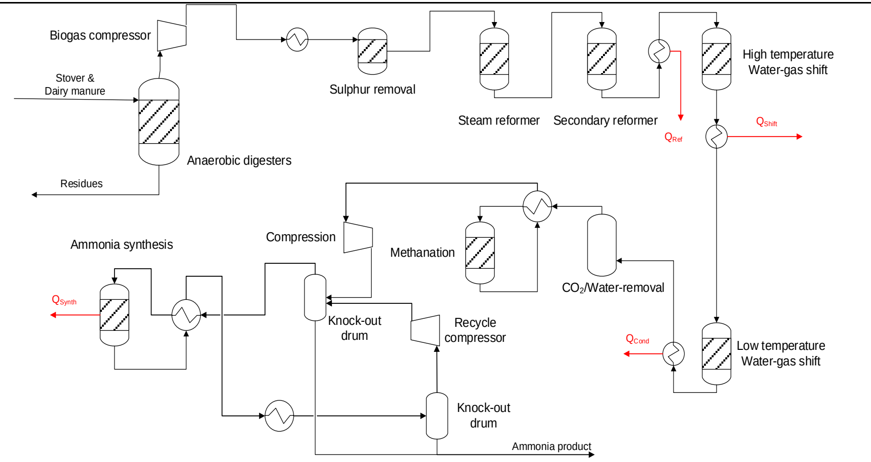


Figure 4 Engineering Model of Anaerobic Digestion System.

Technology and Resource Assessment

In terms of the technology, almost all the equipment used in the system is standard for production of high-grade biogas currently used in locations across the world. After the high-quality gas is produced, it flows into an ammonia synthesis unit that uses standard steam methane reforming to produce the final ammonia product. Both of these technologies are in use now; however, the ammonia synthesis system is used in this model is at a much smaller scale than is typically used in industrial ammonia production. A smaller scale system may have some losses of efficiency that could put it at a disadvantage over larger units. The high temperature, high-pressure equipment is also a poor fit for this scale because it would require a relatively large on-going investment in highly trained technical personnel to operate and maintain. The relatively small output of ammonia makes trained labor expenses high for a small facility.

The major inputs for the systems are the dairy manure and corn stover biomass. Both are added to the system at a rate of 300 tons per day (110,000 tons per year) on a wet weight basis. The cows are assumed to excrete 120 lbs per day at 88% moisture. The corn stove is assumed to be at 15% moisture. Other inputs include a relatively small amount of water. Much of the liquid in the system can be recycled after being removed from the biomass leaving the system. Electricity will also be needed to power digester agitation equipment and ammonia plant pumps and motors. It is assumed that any process heat needed would be generated with biogas and any excess heat from ammonia production would be available to heat the anaerobic digester.

Table 14 Inputs for Anaerobic Digestion Based Ammonia Production System

Dairy operation:
5000 cow
110,000 tons per year
Biomass requirements
110,000 tons stover per year
22,000 Acres at 5 tons/acre
Other Inputs
Water
40 MWhr/day electricity
Animal/Crop Waste Handling
185 tons per day mixed digestate
32 wagon loads solids/day
53.5 tons liquid/day

Economic Assessment of Anaerobic Digestion Based Ammonia

The two primary costs for the system are capital costs (Table 15) for building the biomass digestion and ammonia production system and, the on-going purchases of biomass and other daily expenses (Table 16). It was assumed that manure would be free and that auxiliary costs included in the facility would cover the additional expense of digestate application to cropping systems It was assumed the dairy was an existing facility whose operation (costs) would not be substantially impacted by the ammonia production system. As with the nitrofinery model, labor is not included in the plant costs.

Table 15 Capital Costs for Anaerobic Digestion Ammonia production Facility	
Base module cost	$18,000,000
Contingency	$3,000,000
Total module cost	$21,000,000
Total plant cost	$26,000,000
Auxiliary	$7,800,000
Depreciation	15
Interest rate	10%
Total investment	$34,000,000

Table 16 Anaerobic Digestion Based Ammonia Costs	
Biomass ($M)	Varies
Power ($M)	$280,000
Depreciation ($M)	$4,400,000
Total yearly expenditure ($M)	$6,700,000
Ammonia sales ($M)	Varies

The economics of this smaller scale production are not currently viable. The current low cost of natural gas has significantly reduce the price of conventional anhydrous ammonia from where it was seven or eight years ago. The economic viability could significantly change if ammonia prices returned to their previous higher levels. However, this is unlikely in the short term. Another potential future income stream may be the environmental benefits of producing a 'green' renewable based ammonia, which has the potential to be monetized if a carbon market is established. However for the moment, the system is not economically feasible.

Implications from Technoeconomic Analysis

The technology and economic analysis indicates that this system will not likely be feasible at Minnesota dairies in the near future. The large investment, combined with relatively complex equipment that doesn't produce huge ammonia volumes makes the system impractical and uneconomical for Minnesota. It would take a very significant change in the market place to have this system financially break even. I think many farmers and dairy operators would be very hesitant to install the industrial equipment on their farm (see Activity 3).

Hydroelectric Ammonia Production System

As explained in activity 1, the analysis of the hydroelectric powered ammonia production system (Figure 5) was simplified due to the fact that it had significant similarities to a prior analysis of wind based ammonia production system. The preliminary examination also indicated that there were issues with the assumption that current Minnesota hydroelectric capacity was a viable renewable source of energy for this technology, due to its existing use as 'green' energy in the Minnesota grid.

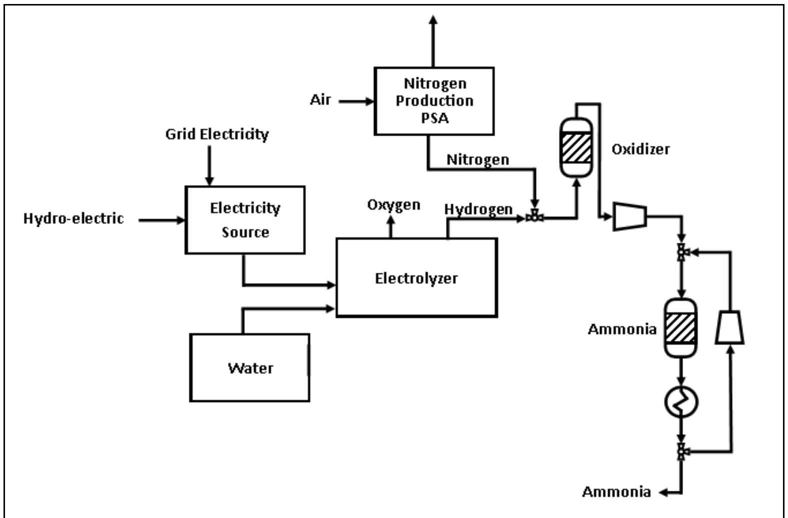


Figure 5 Hydroelectric Ammonia Production System Diagram. The process diagram shows the ammonia production process and equipment needed to generate hydrogen and nitrogen, then put them in a Haber-Bosch reactor. Multiple types of electricity (wind, hydro, solar) can be used to power the process.

Technology and Resource Assessment

The technology examined in this model is used frequently in other applications, so most of it can be considered off-the-shelf equipment. However, The scale of the some of the equipment is a bit different and would be considered very small by most industry standards.

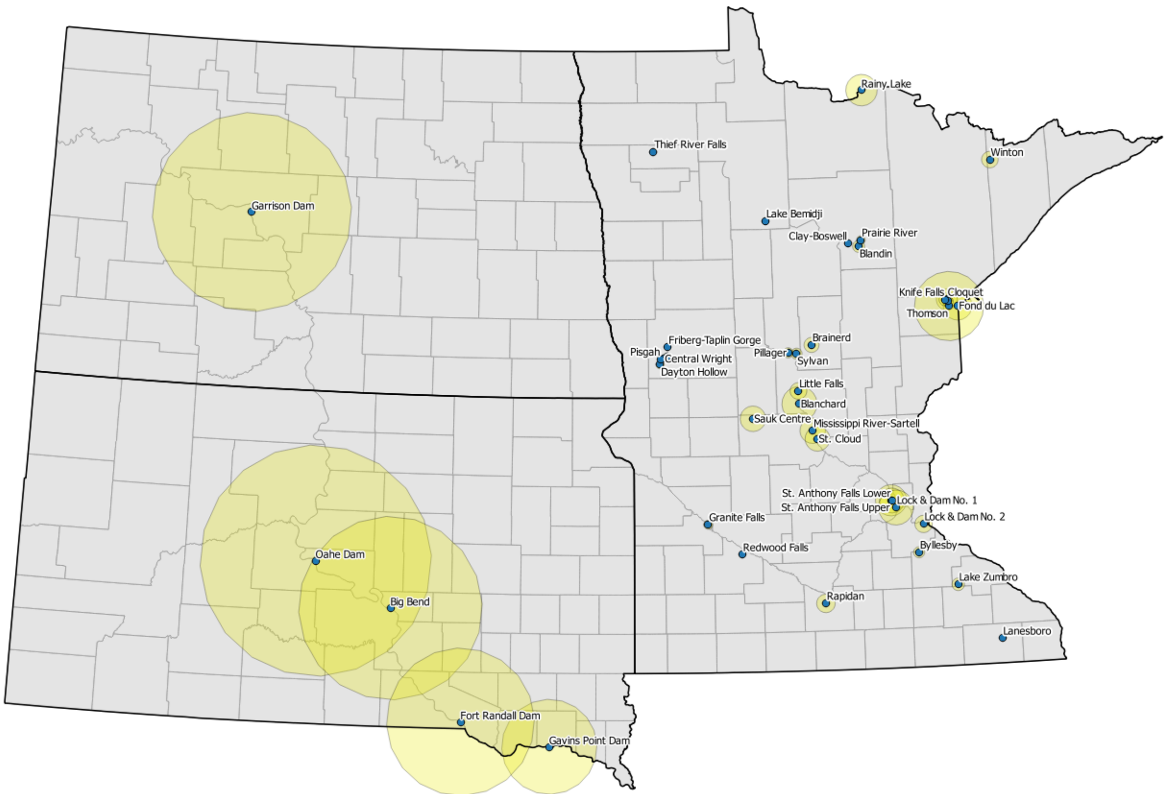


Figure 6 Potential of Hydroelectric Based Ammonia Production. Each dam on the map (blue dot) has the area that could be fertilized using ammonia generated from the dams full electricity output (yellow circle).

In terms of resources, it became very clear in examining the hydroelectric resources that Minnesota did not have consistent, spare electricity capacity to meet the added needs of ammonia production (Figure 6). Nearby states have much more potential of hydroelectric ammonia production. Based on the water volumes and elevations in Minnesota, it is not likely large hydroelectric dams could or would be built. Therefore, for the most part, one would not expect new hydropower resources to be built in Minnesota. A deeper look at electricity rates did indicate that there was periodic spare electricity capacity for ammonia production. During the overnight periods (Figure 7), excess power on the grid creates low power prices to the point where power is occasionally free.

Economics of Hydroelectric Ammonia Production

Because of the lack of spare capacity during the entire day, an analysis of production economics using daytime power was not conducted. Instead, two other models were studied to see if economical production would be feasible based on purchasing power at different rates. The first model was a fairly simple time of day pricing that used electricity during the night for ammonia production. This model assumed, for simplicity, that the ammonia production equipment would function effectively in a daily on-off mode. However, it was shown that the capital costs for a system large enough to overcome the daily 12 hour down time were too high. The resulting ammonia cost was near $1000 per ton, which is nearly

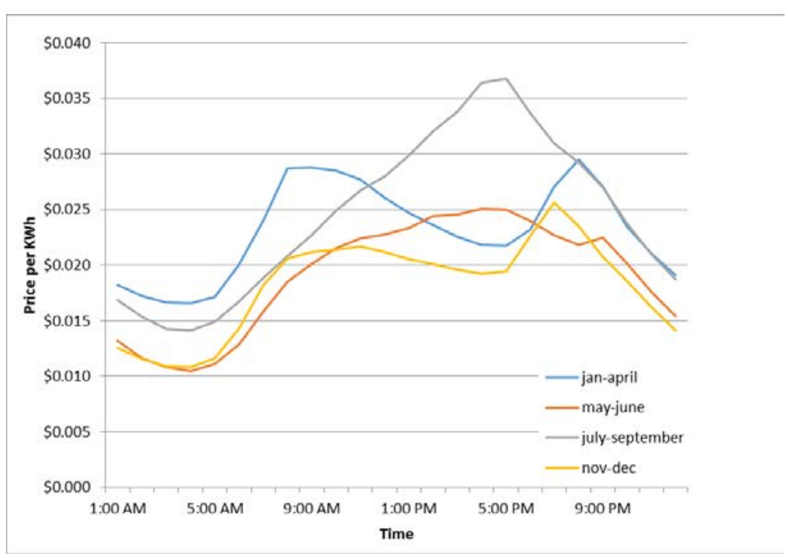


Figure 7 Seasonal Wholesale Electricity Rates For An Average Day. The daily price averages for the four quarters of the year were examined for each hour of the day.

double current wholesale costs. The assumption that the system be cycled on and off regularly is also a major problem and would likely lead to premature equipment failure and higher maintenance costs.

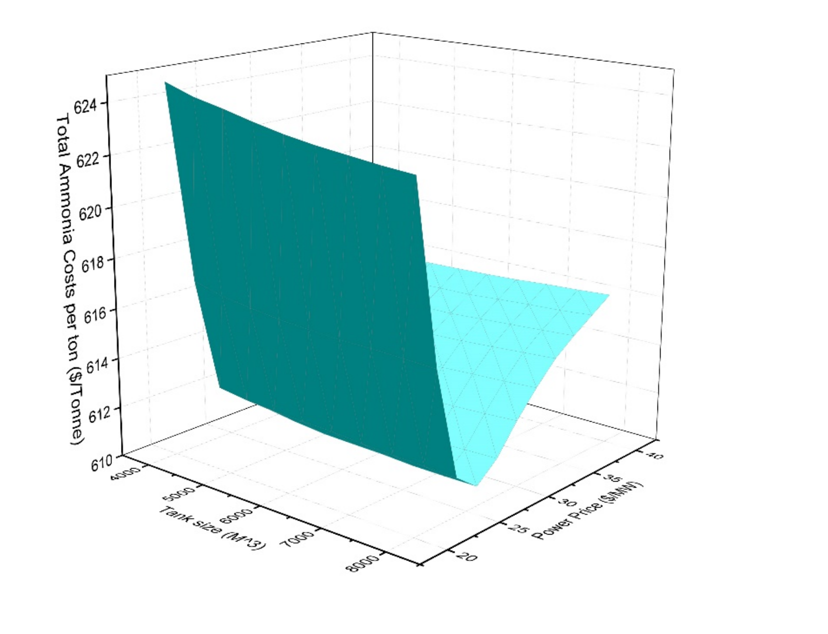


Figure 8. Modeling Output Data of Hydroelectric Ammonia Production with Hydrogen Storage and Pricing Controls. The model tested how storage size and power pricing affected final ammonia price at a hydroelectric plant that could store hydrogen for off peak production.

A more complex hydroelectric production system was examined using a computer model that evaluated an ammonia plant with hydrogen storage. As hydrogen is the major energy consumer in the ammonia production system, the system had a large hydrogen production/storage capacity for use when power was cheap. The other components were smaller and would use less energy throughout the day and the stored hydrogen when power demand (prices) were higher. The hydrogen storage was an added capital expense, as was the oversized hydrogen system. However, the balance of the system was designed for constant production and its capital costs were in line with other similar sized ammonia production plant models. The model predicted that using power pricing data from recent years, ammonia production costs would be between $600-625 per ton (Figure 8).

Implications from Technoeconomic Analysis

At the present time, Minnesota hydroelectricity is not a viable means to power anhydrous ammonia production. Economically, the high capital costs limit the abilities of small facilities to produce ammonia at a marketable price. The price of ammonia produced by natural gas would need to be near $1000/ ton before Minnesota's smallest facilities would be considered competitive, even considering the advantages of a local supply.

Producing ammonia using off-peak power may be able to reduce the cost of ammonia production for larger facilities, but not in the way modeled in this study. This study assumed that all processes would happen during off-peak power hours only, and nothing would be done the rest of the day. In future studies, it is worth considering what would happen if electrolysis happened only during off-peak hours. Since electrolysis is the most energy intensive aspect of ammonia production this could result in lower costs. Hydrogen could then be stored in bulk and used during the day when power prices are higher, at which point electrolysis would stop until prices drop again.

Summary of Techno-Economic Feasibility from All Three Systems system.

From a technological standpoint, both Nitro and AD are feasible. The Hydro model is not feasible because the energy from the existing small amounts of hydroelectricity is already used in the power system and major new hydro-electric facilities are unlikely in a relatively flat state like Minnesota. However, the current economics do not suggest that these are currently profitable. In addition, the amount of biomass needed for either of these would be difficult to achieve at a reasonable cost. In order to make these systems viable options, ammonia prices would need to be higher or demand for ammonia would need to outstrip current capacity. Another factor that could impact the system is a financial incentive to reduce carbon emissions, either implementation of a carbon market or through commodity markets for lower carbon crops.

Table 17 Comparison of Facility Economics

	Nitrofinery	Anaerobic digester
Biomass ($M)	4.8	2
Power ($M)	3.2	0.28
Depreciation ($M)	20	4.4
Total yearly expenditure ($M)	28	6.7
Ammonia sales ($M)	48.7	6.4
Yearly earnings ($M)	20.7	-0.3

ACTIVITY 3: ***Analysis of Impacts on Agriculture and Information Dissemination***
Description: The results from activities 1 and 2 will be used to generate Minnesota specific energy and greenhouse gas statewide impact estimates of using renewable energy sources to produce ammonia fertilizers. The data will also be used to estimate impacts on the lifecycle energy and emissions of Minnesota agriculture and agricultural products. Results will be disseminated to stakeholders via stakeholder meetings, web publication of study findings, hard copy distribution of information, and publication of scientific papers.

Summary Budget Information for Activity 3: **ENRTF Budget: $ 23,992**
Amount Spent: $21,022
Balance: $2,970

Activity Completion Date:

Outcome	Completion Date	Budget
1. Assessment of Fossil Energy Impacts on Agriculture	5/2017	$ 15,000
2. Industry Report on Feasibility of Different Renewable Production Systems	5/2017	$ 5,000
3. Information Dissemination Via Meetings and Print and Web Publications	6/2017	$ 3,992

Activity Status as of *(November 30, 2014)*:
This activity is centered on model results and will be started after modeling has begun.

Activity Status as of *(June 30, 2015)***:**
Work is beginning to be done that documents the gasification to ammonia modeling for inclusion in a peer-reviewed research paper. Work on project outreach will be increase as more data is collected and analysis is completed.

Activity Status as of *(November 30, 2015)***:** The impact of low input ammonia has been initially examined using a standard industry model (GREET), with a focus on corn grain and ethanol production. The modeling methods and assumption used in these models will be modified either in the original model software or spreadsheet models to continue this work. As specific data from activities 1 and 2 become available, it will be incorporated into these modeling efforts.

Activity Status as of *(June 30, 2016)***:** The impact of the introduction of renewable ammonia is continuing to be studied. A draft paper of the ammonia industrial development and innovation system has been prepared. The empirical part will consist of interviews with stakeholders in agriculture and other businesses. A couple of these stakeholders, representing technology companies, users and producers, have already been contacted for setting up interviews. The interviews will be conducted during the fall of 2016.

Activity Status as of *(November 30, 2016)***:** Data from the LCA of each system is being used to examine how 'renewable' ammonia could impact agricultural sustainability. The results of this work will be in individual reports for each technology. One aspect that is difficult to accurately assess is the economic impacts. However, the final reports for each technology will use estimates of costs for each technology to examine costs for the ammonia and downstream costs for agriculture. Because the economic costs are still being worked on, we have held off on meeting with industry to discuss their thoughts on these systems. This will occur as we have economic models of the technology and economic impacts on agriculture.

LCA Activity Final Report Summary: One of the important areas of the project was researching existing ammonia production and the ability of those markets to transform to more distributed production in the agricultural regions needing ammonia. This work was done in order to look at the potential impacts of local ammonia production systems on agricultural and as part of the feasibility determination for the ammonia systems modeled in this project. The following sections summarize the work done to examine these issues:

Transformation of Ammonia Production
Agriculture is at a crossroads in terms of where new innovations will occur to move it forward over the next few decades. In the past, farmers were tasked solely with producing cheap food and feed for growing consumer appetites.

However, some consumers have begun to realize that there are environmental and other sustainability impacts when simply looking at costs and quantity in agricultural innovations. At the consumer level, people are beginning to ask for food produced more sustainably. This trend is already seen by companies manufacturing and marketing food, who are under pressure from both consumers and their downstream retailers to deliver sustainable innovations.

One of the most significant uses of fossil energy in agricultural is the production of ammonia-based nitrogen fertilizers. Particularly in corn production, nitrogen fertilizers are hugely important for productivity. Between the higher application rates for corn and the large amounts of fossil energy needed to make nitrogen fertilizer, they are the single largest energy input into corn production in the Midwest. Additionally, they are one of the larger supply expenses for corn cropping. Therefore, finding less expensive, local sources of renewable ammonia would help improve the sustainability of corn production, which is Minnesota's largest crop, and could reduce production costs.

Industrial Ammonia Production Systems

This research and a full writeup was conducted by Fredric Bauer, Ph.D. a student at Lund University, who worked to document the current industrial-scale ammonia production systems and the particular niches where small scale distributed systems might get a foothold in what has been a closed market for his Ph.D. thesis. The following section is a smaller write-up loosely based on of his efforts, with Minnesota specific information added.

Ammonia production is part of a much bigger chemical industry, which uses roughly around 27% of petroleum and natural gas worldwide to produce chemicals for energy and as feedstocks to make chemicals. However, with an emphasis on sustainability, the chemical industry is beginning to look at moving beyond fossil fuels to a more carbon free production systems. This is especially true in countries with hard targets for greenhouse gases.

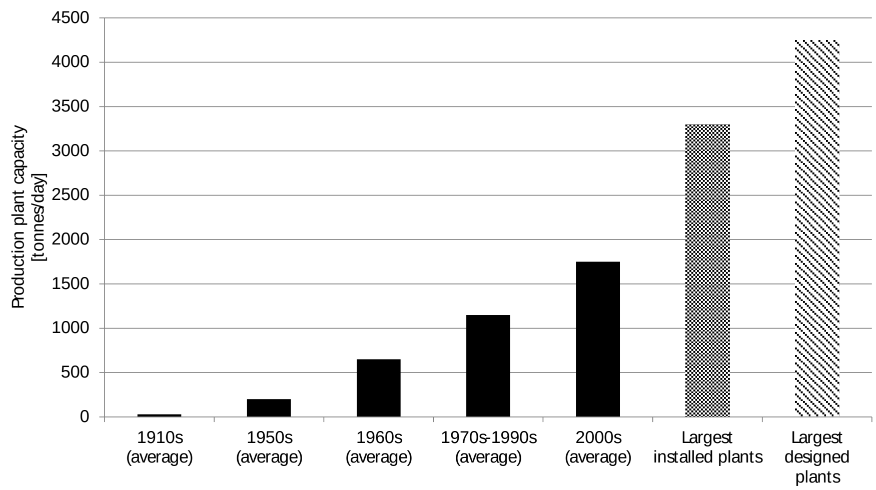


Figure 9. The average capacity of single-train ammonia production plants. Plants constructed during the 20th century and the capacity of the largest plants currently constructed. Adapted from Moulijn et al. (2013, p.173) with additional data from Connock (2008).

Changing chemical production systems is difficult because the business model within basic chemical markets is to produce and sell products which are on a molecular level identical with as high purity as feasible. Most manufacturers use similar production methods that were developed decades ago to produce standardize chemicals. It is very difficult to develop innovations on the chemical product, which could give the producer a market advantage. It is a highly concentrated industrial sector, with a few major, multinational enterprises dominating each market of the sector and having done so for a very long time. Large existing firms are thus favored and the entry of new entrepreneurial firms is uncommon

When looking at the historic development, it is clear that scale has been a very important characteristic for ammonia production (Figure 9). This is illustrated with how the average production capacity of ammonia plants have increased from 200 tonnes per day in the 1950s to 1750 tonnes per day in the 2000s. New plants have been constructed which have a single-train capacity of 3300 tonnes per day, i.e. almost double the current average size. Plants as large as 4250 tonnes per day have been designed and plant capacities up to 5000 tonnes per day are being considered. Scale has remained a critical characteristic in reaching technologic and economic efficiency, which these companies need to compete.

The importance of scale has thus become a key feature of the technological regime for ammonia production. However, almost half of currently active plants are more than 30 years old, showing low rates of change in industry. But the aging of these facilities provides possibilities for investments in change and innovative technology. The energy efficiency of ammonia production has been significantly improved over the last decades – from about 50 GJ/ton in the 1950s to about 28 GJ/ton in modern process designs, as shown in Figure 10. The difference between currently used and best available technology is also apparent in the benchmarking project including 93 plants which was conducted by the International Fertilizer Association in 2008, showing an average energy efficiency of 36.6 MJ/ton NH_3 (IFA, 2009).

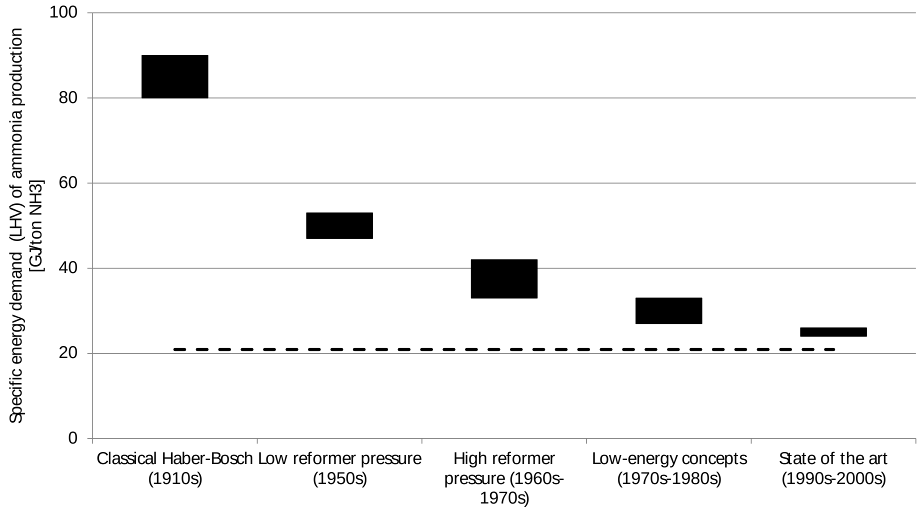


Figure 10. Specific energy demand of ammonia production. Energy of using different process technologies developed during the 20th century. Dashed line shows the theoretical minimum energy demand of the process. Based on data from Moulijn et al. (2013, p. 182).

Naturally, there are several important issues relating to efficiency that can be dealt with in larger plants, such as energy recovery and complex heat exchanger networks, but the logic that efficiency demands ever larger scale of production does not hold. Alternative processes have been developed with the clear intention of enabling high efficiencies also for smaller plants.

Beginning a transition out of the current ammonia production pathways requires overcoming of the persistent resistance and existing technology lock-in of the industry. To date, the largest innovative efforts towards reducing the intensity of fossil resource use have been centered on increased energy efficiency. This is being done more to avoid expensive energy, rather than to develop more sustainable energy production. Thus, the economics of profits and loses is the current primary driver for many manufactures. They are not actually confronting the fundamental dependency on fossil resources.

To enable the transition from the current production regime to a low-carbon regime, new technological innovations are needed. Policies aiming to guide a low-carbon transition must not further entrench the fossil lock-in that persist, but aim to support a new view of technological innovation in the sector. Developing niches for new technology must involve adding other factors to the drivers for innovation, including new sustainable feedstocks and alternative energy sources. Correctly balancing these needs will have to include all three of the aspects of the triple bottom line, social impacts, financial impacts, and environmental impacts. As these niches develop, proper management may allow them to begin competing with the current large scale production systems. But, it should be remembered that these changes might be difficult as the scale of production is immense and the scope of use is extremely wide.

The modeling work in this project was intended to examine how some of the technology approaches discussed below would fit in the niche ammonia market of anhydrous ammonia for agriculture in the Upper Midwest. Admittedly, the project was begun at a time when ammonia prices and supplies were much less stable. As discussed above, there was a need to innovate to find new production technologies that was not reliant on fossil energy. However, ammonia prices began to stabilize during the progression of the study. Likely as a result of a drop in demand due to lower corn prices, low cost natural gas, and increased production capacities. Natural gas, the main feedstock for US production of ammonia is likely to remain cheap as many states have increased fracking based natural gas production. Therefore, what would have been a traditional driver for innovating in the ammonia production field, economics, has vanished.

Potential Areas for Changes In Ammonia Production

Renewable Electricity For Ammonia Production

Renewable electrical energy is still a small part of global energy supply but growing rapidly, thanks to innovations in generation technology and improved manufacturing. These renewable sources could be used for to meet demand for high temperature thermal energy in some parts of the chemical industry, rather than combusting fossil fuels.

Electrochemical processing can be used to generate some key molecules such as hydrogen. Hydrogen is needed in many processes, with ammonia production being one of the largest demands. The fossil hydrogen used today could be directly substituted with hydrogen produced from electrolysis of water, enabling a pathway out of the fossil dependency.

An important difference between the existing fossil based systems and renewable electrical systems is the decentralized nature of renewables versus the large central infrastructure need for fossil energy. Large chemical industry clusters have developed in areas where fossil feedstocks have been easily accessible – but where renewable energy might not be – this is important to acknowledge. The distributed nature of most renewable energy would suggest that smaller plants might fit in with rural ammonia needs.

<u>Biorefining of Organics</u>
Another approach that could transform ammonia production is biorefineries. These systems use organic matter from plants and animals as the feedstocks for fractionation of many of the precursor chemicals needed in the chemical manufacture industry and several other fields as well. The biorefinery is the facility that is capable of refining a complex organic feedstock to produce multiple products. In addition, this process can also produce heat to displace fossil energy based heat. So far, the main efforts within biorefining have been directed either at producing a few high value chemicals from complex bio-based organic feedstocks, together with lower value byproducts such as biogas or to produce biofuels such as bioethanol in large volumes with possible other byproducts.

The wide distribution of the organic feedstocks would means that biorefinery systems are somewhat distributed. However, these system usually take large investments and are likely to be more efficient at larger scales. But, this is balanced with the fact that transportation of the organic feedstocks they need involves moving large quantities of low density materials. Therefore, biorefinery systems will likely be spread-out in a regional fashion. This can be seen in the existing ethanol facilities, which try to collect grain from within a given region.

<u>Recycling of Exist Materials</u>
A third possible transition strategy for the chemical industry would be to focus on the closing of the manufacturing loop – recycling materials and producing chemicals from wastes and secondary product streams. Large amounts of wastes exist that contain useable chemicals and energy that can be extracted to make new products or produce heat. Many of these recycled materials could go into local biorefinery like facilities that process them into usable products.

Developing a Niche: Ammonia for Minnesota Agriculture
Each of the technologies examined in this project uses one the three identified pathways above for innovation in the chemical industry. In all cases, they were focused on resources available in Minnesota's agricultural regions. The other key in selecting these technologies was their ability to help keep the money typically spent on ammonia imported by Minnesota producers in our communities.

The Nitrofinery based system would be considered a variation of the biorefinery model. The different main products from corn where separated prior to arriving at the facility, then the grain is further processed in ethanol and the non-grain biomass is used for ammonia and heat production. Anaerobic digestion production of ammonia would be both an example of recycling existing materials and a bio-refinery. In addition to the biogas produced, the digestion process yields a heat-treated lignin material that can be used for animal bedding and gardening. Generation of ammonia with Hydroelectricity is clearly a use of renewable electric production. However, unlike solar or wind, it is not necessarily a well distributed system. The electricity would likely be used at large dams, along major waterways.

Industry Stakeholder and Information Dissemination

For this work, we chose to work with outside industrial stakeholders who could provide valuable information on the feasibility of these projects. At the onset of the project, they were able to help us better understand industry needs and how industry might approach these projects. Following much of the modeling activity, we again consulted these groups to provide feedback on our findings and specifically point out the strengths and weaknesses of the models we made. Another benefit of engaging industry stakeholders is that they are often in contact with others in the industry and can talk with others in the industry about the concepts and technologies being studied.

Nitrofinery

Chippewa Valley Ethanol Cooperative (CVEC) consulted with us on developing the nitrofinery model. They are of farmer owned ethanol Cooperative with roughly 1000 members and a production plant rated at 50 million gallons per year. Their prior work in the gasification area, along with ethanol production, was important in helping us understand how facility scale and biomass feedstocks would impact the feasibility of setting up a biomass supply chain for an extremely large biomass gasification system. They also provided project staff with tours of their facility and were willing to answer technical and business related questions about their previous gasification work and their attempts to improve their ethanol production system. At a feedback session in May 2017, several senior staff and a board member of CVEC met to discuss the nitrofinery model and provide feedback on the model.

Selected Comments on the Nitrofinery Model:

- In terms of economics, there was consensus that it did not appear there was an economic need or reward for adopting the nitrofinery technology at this time. The amount of investment required for a project of this size would not likely provide enough return on investment with ammonia prices at their current levels. The desired return on investment for a new facility would be a 8 to 12 year payback for the major new capital investment.
- The scale of the facility was a very important topic of discussion. The amount of biomass required by the modelled facility would essentially cover the entire corn crops of a 7 to 9 county area. At this scale, the feedstock supply logistics becomes incredibly complex. It would likely require supply depots in several locations to store materials and manage collection operations each focused on a portion of the overall biomass supplier area. This logistics system would require a dedicated year-round labor force that would be difficult to find in many rural communities. Additionally, it would require a very high percentage of farmers participating in harvesting activities or allowing materials to be harvested from their land. From an economic perspective, this could be accomplished if the price of corn cob biomass was high enough. However, the difficulties in finding both the farm labor and the supply chain logistics labor may limit participation even with high biomass prices.
- One suggestions to make nitrofinery concept more compatible with the needs of ethanol production facilities was to adjust the scale of the ammonia facility so that less biomass was needed. Instead of replacing all of the ethanol process heat and electricity energy needs, focused primarily on combined heat and power to replace the high cost coal-based electricity needed for the ethanol production operation.
- Another major suggestion was that the project needed community support and tying ammonia production to the farmers producing the biomass feedstock was key. Therefore, the farmers who were supplying grain and biomass would have the first option to use the facilities ammonia products. These are the individuals who were willing to invest their money in an ethanol concept before it really was an industry and shows their importance in driving rural economic development. Maintaining their involvement would spread the benefits from the facility to the broader community and make that community more aware of the benefits of the facility for their local economy.
- An important observation from CVEC's point of view was that there was not enough interest in 'green' energy or sustainable ammonia production at this time to put any premium on 'green' ammonia.

The overall view of the CVEC ethanol stakeholders was that there were many complicated issues with the nitrofinery model. Each of these issues could be overcome if the economics or necessity allowed for a large enough profit margin to justify deploying new technologies and/or accepting added risks. However, at this time, the project simply did not appear to be economically viable. Future viability would depend on a number of factors including natural gas price, the price/availability of ammonia, farmer willingness to participate, and available labor. It is not likely that these factors will substantially change in the near term.

Anaerobic Digestion Model

For assistance in looking at anaerobic digestion based ammonia production, the project team had informal discussions with Riverview LLC, who has operated several anaerobic digestion systems at their large-scale dairy farms in West central Minnesota. They began adding anaerobic digesters to their dairy systems in the mid-2000's, and had a total of four built by around 2015. Therefore, they had valuable experience from project designed to operation of the systems. However, It should be noted that at the time of our final discussions on the anaerobic digestion model, Riverview was beginning to shut down their anaerobic digesters due to poor economic performance as their long-term 'green' energy contracts had begun to expire. For final comments on the digester model, the project team spoke with Mr. Jeff Boyle who was in charge of their anaerobic digester operations. It was understood that he was speaking in a general sense and giving his impressions, his comments were not to imply that Riverview LLC as an organization had thoroughly reviewed the model and provided an official company opinion.

Selected comments on the anaerobic digestion model:

- The scale of the ammonia digestion system is fairly large considering the additional corn stover biomass. At that volume, there would likely have to be a significant amount of infrastructure added for staging biomass and protecting it from the elements after it had been collected. This would add significant expense and labor.
- One concern was the amount of variation in the corn stover biomass. Riverview's experience with changes in materials going into the digester suggested that even small changes in biomass would greatly impact biogas production. Therefore, extra effort would be needed to maintain consistency of corn stover.
- There were also some issues with modeling the end products from anaerobic digestion, solid wastes and liquid wastes. Riverview currently pumps liquid wastes onto many of their fields near their facilities. While solid wastes are trucked to more distant fields using semi-trucks and applied with tractors and spreaders. The current anaerobic digestion LCA work assumes solids and liquids are spread roughly evenly.
- Currently, review did not see any benefits from using renewable based ammonia products. Their milk purchasers were not asking about the sustainability of their product at this point. Therefore, there did not appear to be a benefit for 'green' ammonia.
- Riverview as a company is very responsive to the economics of new activities. If it looks like there would be a long-term benefit to producing ammonia at their dairy operations, they would be willing to hire and train staff to work with the production technology.

From Riverview's perspective, they do what makes economic sense. However, they are interested in long term economic viability. The current rapid changes in the ammonia market place do not suggest that this is an area for safe long term investment. On the agricultural side, they have no interest in ammonia production because the supply of ammonia is sufficient for their agricultural systems and the costs are reasonable. This may change in the future, but it is likely to be in the long term rather than the short term.

Impacts of The Ammonia Production Technologies on Agriculture and Rural Communities

In looking at the impacts of this technology on rural communities, four main categories were analyzed, economics, infrastructure, employment, and environment. The hydroelectric based ammonia system in not likely to have much direct impact on agricultural or rural communities. Many of the hydroelectric facilities in the state are at locations where historic water-powered grain milling built up towns around waterfalls, thus are not necessarily that rural. Additionally, these hydroelectric facilities require few resources one constructed. The two other systems, nitrofinery and anaerobic digestion, would have broader impacts on agriculture and rural communities.

Rural Economic

The overall economic impact of building and operating these facilities would be significant in the communities hosting them. With current spending on ammonia in Minnesota at roughly $400 million dollars per year, having these facilities in the state would keep much more of the farmers input costs circulating in Minnesota's rural communities. Both the anaerobic digestion and nitrofinery model would be purchasing biomass from farmers, thus providing an addition revenue stream to farmers. Ammonia production facilities would need additional labor to handle plant operations, biomass logistics, and for plant management. Construction work would further contribute to the community. In Minnesota's rural areas, businesses like these are often set up as cooperatives and have farmers as their owner-investors. In these cases, profits would also flow back into the community. Main street businesses would likely see added spending by employees and contractors. Thus, there would be a significant economic development associated with these facilities.

Infrastructure

Although there would be added economic inputs to the communities around these plants, added infrastructure would be needed to handle the increased resources moving in and out of the facilities. Upgraded roads and rail systems may need to be built for the biomass, ethanol, digestates, or water effluent materials flowing in and out of the site. Communication services, including telephone and internet, would have to be enhanced. Depending on the system, water, sewer, and cleanup ponds many need to be scaled up. Another important area is the training and readiness of local emergency responders to incidents at the facility. These are mostly community resources that would need to be enhanced to meet the needs of a facility handling more slightly hazardous materials. Local and state governments would probably have to add regulation and enforcement activities to oversee and protect some of these systems. All of this would have a cost, which taxes or investments by the facility would have to bare. Provided there are profitable prices for ammonia, these facilities would be able to generate the tax base and investment returns for the community.

Rural Employment

An issue that is both a positive and a negative in locating these plants in rural Minnesota is the available labor pool. Because of the long-term stable jobs they provide, the ammonia production facilities would likely be able to find general labors in the community to meet their needs. However, farmers would likely have trouble finding the additional labor for biomass collection they would need around harvest time. Over the last several decades, farm operations have reduced their labor requirements because of shrinking farm family size and the need to operate a lean operation to maintain profitability. Many of the young people move to urban areas for employment or find full-time jobs outside of agriculture. Thus, there are simply not as many extra farm labors ready to help for a short period in fall. Larger farms can't wait to harvest biomass until after grain is collected because the grain harvest window is too large, so the grain and biomass harvest operations must be integrated. This would likely require one extra person per farm. More efficient grain/biomass harvesting equipment could help, but it would still likely be a burden farmers don't want to deal with.

Environmental

The two ammonia technologies examined in-depth in this study used agricultural biomass feedstocks as energy sources for ammonia production. One concern that has been expressed by famers and soil scientists is the potential for biomass removal to reduce soil carbon. In the models examined, specific measures were taken to reduce soil carbon losses. The anaerobic digestion model assumed that stover biomass harvests would occur every other corn crop, but adds back nutrient rich digestate. Cob harvesting removes roughly 10-15% of the available stover biomass. Soil carbon levels were analyzed for corn cob harvesting using the ICBM soil carbon model (Figure 11). Results indicate that that there could be a reduction of soil carbon over a 100 year period if all conditions stay the same except the removal of biomass. However, plants are increasing the amount of biomass residues they produce as crop genetics improve. Therefore, the removal of corn cobs is not likely to have a significant effect over the long term.

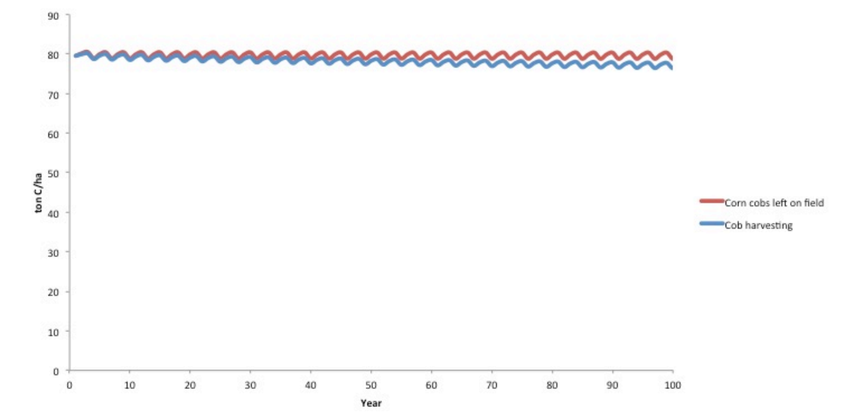


Figure 11. Reduction of Soil Carbon Levels With Corn Cob Harvesting. Modeled using the ICBM model, the levels of soil carbon are estimated over the next 100 years under current corn cropping and yield data.

Farmer Participation

A final summary topic that blends many of the concept discussed in the preceding paragraphs is the amount of participation or 'buy in' from farmers. For these systems, they would be both the consumer of ammonia fertilizer and the supplier of biomass. Depending on the financing, they could also be major investors. Therefore, their level of commitment to these alternative ammonia production systems would be key. They would likely be weighing out their potential for profit, the additional burdens of supplying biomass (labor, equipment, timing), and their need for ammonia.

One topic that the interviews with stakeholders and the research team's general background farm knowledge indicated was that there would be little concern on the part of farmers about the sustainability aspects of these renewable ammonia production platforms. Profitability and necessity would be the primary drivers for engaging farmers in this technology. Even factors such as local self-reliance or agricultural resilience did not seem persuasive compared with the economic arguments.

V. DISSEMINATION:

Description:

There are several audiences for the information from this project, including farmers, businesses, investors, scientists, and community development organizations. Connecting with these audiences will involve several strategies. Project staff will conduct stakeholder meetings and speak at regional/national talks and conferences about the project goals and findings. The project will be documented in a final comprehensive white-paper report geared toward industry and investor audiences. A web page will be set up on WCROC's existing renewable energy websites (renewables.morris.umn.edu & wcroc.cfans.umn.edu) to provide project information, updates, and the final report. The findings will also be available for use in peer-reviewed scientific journal articles prepared by the study's technical staff. WCROC staff will also maintain a collection of printed and digital outreach material for distribution to interested parties.

Status as of *(November 30, 2014)*:

Plans are being made to set up a webpage for this project at http:/renewable.morris.umn.edu

Status as of *(June 30, 2015)***:** Content is beginning to be created for the information dissemination for the project. The website address http://renewables.morris.umn.edu/GreenAg has been established and will be used as the initial online hosting site for the information.

Status as of *(November 30, 2015)***:** Further dissemination work will be completed as the project progresses. It is anticipated that as the first part (ammonia via gasification) of activities 1, 2 & 3 are completed, the graphics and texts from those write-ups will be added to the website.

Status as of *(June 30, 2016)***:** Technical dissemination of the projects findings has begun with the ongoing development of draft papers for peer-reviewed scientific journals. Non-technical reports will be developed from these papers. They will also contain the feedback from industry on the overall goals, concepts, and challenges of renewably producing ammonia.

Status as of *(November 30, 2016)***:** The team is working on final reports for each technology that are geared towards a technical and/or policy maker audience. The nitrofinery model is being developed into a manuscript for a peer reviewed scientific publication. A hydropower production model is also being examined for publication. Due to changes in the Universities' website maintenance, it is likely that we will change website hosting of project documents to one administered by the West Central Research and Outreach Center.

Final Report Summary:

The project used two main paths to disseminate scientific, technology, and economic information. The first was in-person via presentations to the wide variety of stakeholders interested in ammonia, agriculture, sustainability and rural development. Many of these interactions are during facility tours of the West Central Research and Outreach Center's agricultural renewable energy facilities and production systems. However, team members have given a variety of presentation and talks on renewable ammonia production and renewable energy to the chemical engineering and ammonia energy interests. This is in addition to general discussions on farming energy inputs and improving farming sustainability that we normally have at conferences, in classrooms, and at farming events. The international members of the team have broadened the in-person dissemination beyond the Midwest.

The other main focus of dissemination is print and online media. Both can be used for reaching audiences that are not able to physically visit or meet with us at conferences. These formats also allow for informing audiences with a wide range of skills and interests. For the more academic audiences, we are developing a technical paper that will be published in an academic journal. The findings of the study are being written up as an internally published white-paper document for those interested in the practical finding from the work. Smaller summaries were developed as a handout for general audiences. All of these documents are or will be available on the project's website at https://wcroc.cfans.umn.edu/green-nh3-lifecycle. The site also has links to other ammonia, agriculture, and research topics being studied by the West Central Research and Outreach Center and University of Minnesota Researchers.

VI. PROJECT BUDGET SUMMARY:

A. ENRTF Budget Overview:

Budget Category	$ Amount	Explanation
Personnel:	$ 97,205	Personnel: Project manager/Lead researcher (.5 FTE total over 3 years), Junior scientist (1 FTE total over 1 year), student intern (.25 FTE total)
Professional/Technical/Service Contracts:	$ 145,000	Contracts: Chemical engineering Researcher Team, Lund University Sweden. ($80,000) Responsible for analyzing the feedstocks, chemistry, and equipment, at the renewable energy sites in Minnesota. (Estimated 1 FTE). Lifecycle assessment research team, Swedish agricultural University. ($50,000) Will assist University of Minnesota researchers with fertilizer specific pathways for analyzing lifecycle assessment (Estimate 1 FTE). Funds for Chippewa Valley ethanol Cooperative ($3,750) to compensate for staff time allocated for this project. Similar funds for entity operating and anaerobic digestion system ($3,750), Entity would work with University of Minnesota research staff to identify inputs, outputs, and equipment needed for converting biogas into ammonia fertilizer.
Equipment/Tools/Supplies:	$ 4,295	Equipment/Tools/Supplies: General supplies for production of outreach materials, collection of data, and general project operations. Software updates to LCA software ($1800).
Printing:	$ 1,500	Costs of printing outreach material for use at meetings and for distribution to stakeholders.
Travel Expenses in MN:	$ 2,000	Travel: In-State travel to research facilities being examined over the three-year period of the study. This will include vehicle mileage at standard government rate.
TOTAL ENRTF BUDGET:	**$ 250,000**	

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: 1.75 FTE

Number of Full-time Equivalents (FTE) Estimated to Be Funded through Contracts with this ENRTF Appropriation: 2.0 FTE

B. Other Funds:

Source of Funds	$ Amount Proposed	$ Amount Spent	Use of Other Funds
Non-state			
	$	$	
State			
Univ. of Minn.	$130,000	$ 0	The University of Minnesota is forgoing the typical 52% federally negotiated indirect cost recovery normally associated with research grants. This funding covers facilities, support staff, and other University activities that are not directly part of the research, but must be present to support research activities.
TOTAL OTHER FUNDS:	**$130,000**	**$ 0**	

VII. PROJECT STRATEGY:

A. Project Partners:

This project will bring together a variety of specialists to complete the different technical, economic, energy and agricultural aspects of this project. The University of Minnesota, WCROC will coordinate the research efforts and provide overall project management. WCROC's experience in combining renewable energy systems with ammonia production, along with our interactions with local industry and other stakeholders allows WCROC a unique opportunity to evaluate renewable nitrogen fertilizer production systems. Chippewa Valley Ethanol Cooperative ($3,750) will be assisting with modeling the biomass energy to ammonia production in a gasification system. They have a gasification platform capable of using local biomass to produce hydrogen rich gas needed for ammonia production. We also intend to partner with a regional anaerobic digestion system operator. The team researching technology in these facilities includes Dr. Christian Hulteberg and his research group ($80,000)from Lund University, Sweden. His specialty is chemical engineering and, specifically, methods of production of hydrogen-based chemicals, such as ammonia. His group also examines the economics of production systems. Dr. Serina Ahlgren and her group from the Swedish Agricultural University ($50,000) are experts in life cycle analysis of nitrogen fertilizer production systems. Working with these partners will also allow WCROC to further expand its life-cycle assessment capabilities, and thus grow Minnesota's expertise in what has become an important tool for evaluating industrial systems.

B. Project Impact and Long-term Strategy:

The WCROC Renewable Energy Research Group's overall goal is to assist farmers and rural committees by examining energy technologies to help reduce agricultural energy related production costs, promote rural based renewable energy, and expand opportunities for rural economic development. The long-term strategy is to conduct hands-on research and demonstration on renewable energy or energy conservation technologies that are close to being ready to deploy in rural applications. By examining commercial scale technology in applied situations, we can generate the data that shows our stakeholders the benefits and challenges of the technologies and methods being used to reduce their communities' dependence on imported energy. They can then decide whether these technologies would be of benefit to their farm, business, or local community.

This project is designed to examine the feasibility of using local renewable energy generation to make a value added fertilizer product that is needed for Minnesota Agriculture. The data from the project would be provided to both the private sector and other renewable energy researchers to allow them to consider further work with the technology for making nitrogen fertilizer from renewable energy sources common in Minnesota. Already, the existing project examining wind to nitrogen fertilizer project has garnered a great amount of commercial interest due to the value of fertilizers and the potential for renewable wind energy in Minnesota. We think that other renewable energy technologies could have a place in helping to generate renewable fertilizers needed in the state. This project will provide stakeholders with information about the economics of this process as well as the potential environmental impacts from using renewably produced fertilizers.

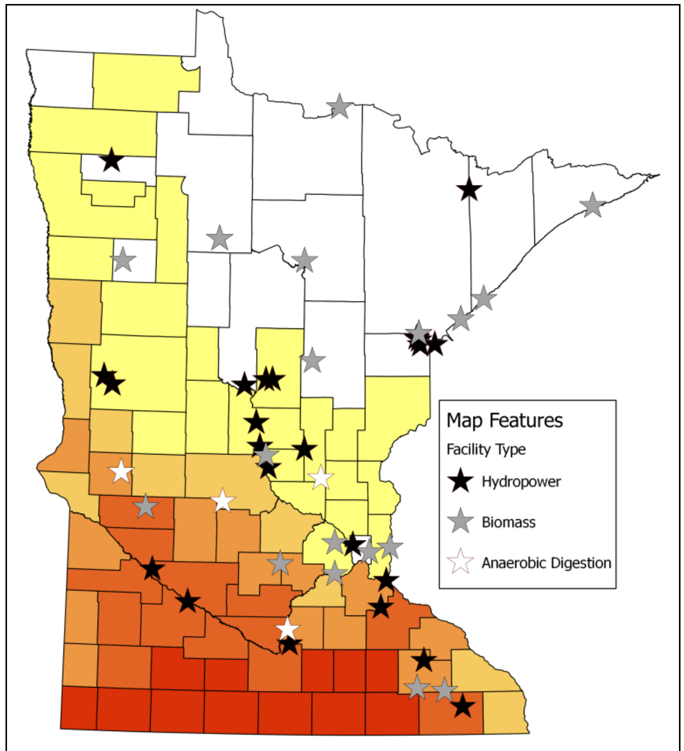
C. Spending History:

Funding Source	M.L. 2008 or FY09	M.L. 2009 or FY10	M.L. 2010 or FY11	M.L. 2011 or FY12-13	M.L. 2013 or FY14
2005 State of MN Bonding $2.5 M					
LCCMR ($800,000) (M.L. 2005)					
Univ. of Minn. ($430,000- 2005)					
Private Funding			$100,000		
IREE (Univ. of Minn)		$77,606			
Swedish Energy Agency				$120,000	
Note: These funds are for work on the wind energy to ammonia project, which was the first part of the effort to examine renewably produced fertilizer and is the groundwork and comparison used in the efforts for this project. Much of this funding was pledged for planning and construction (well prior to 2009). Operation of the ammonia facility began in 2012).					

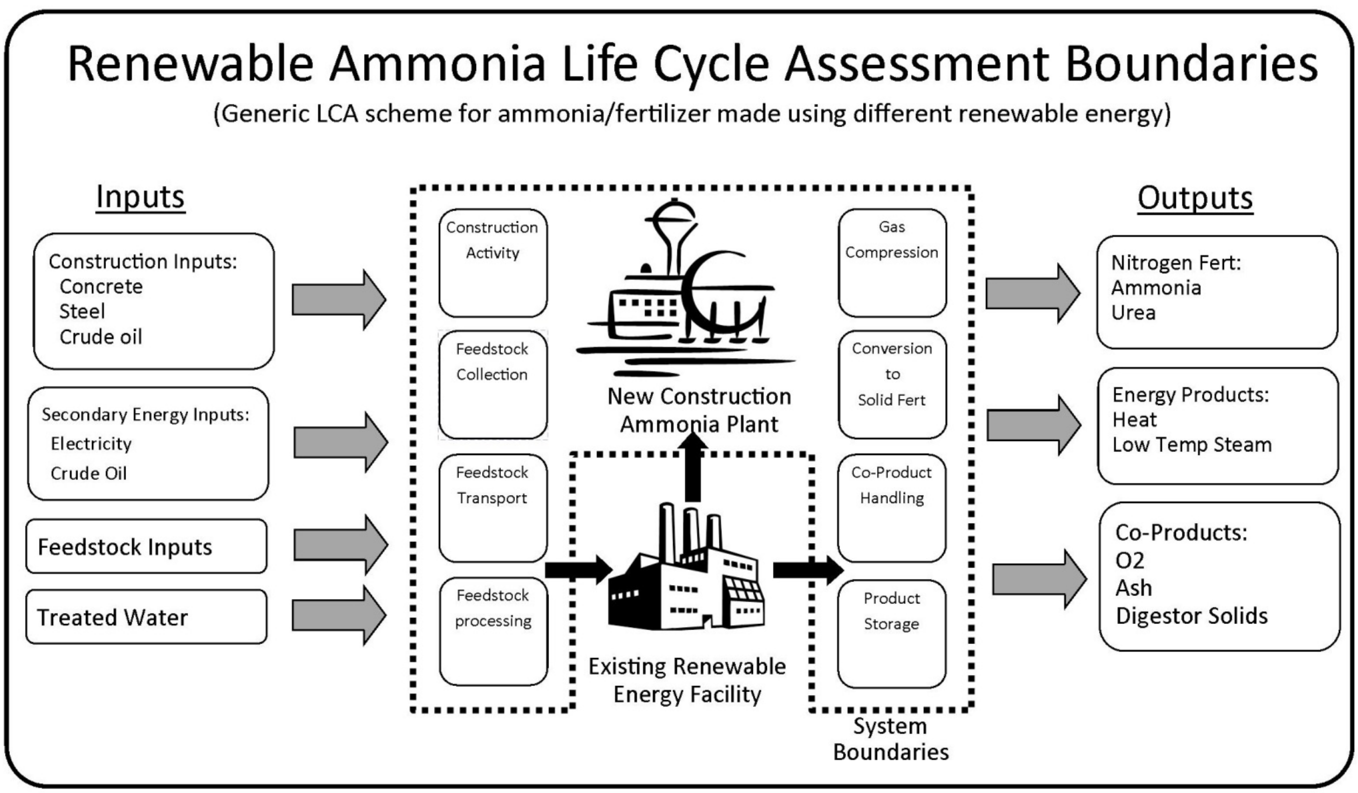
VIII. ACQUISITION/RESTORATION LIST: n/a

IX. VISUAL ELEMENT or MAP(S):

The **map (right)** illustrates the diversity of renewable energy facilities in Minnesota. It shows a selection of Minnesota based renewable energy facilities using biomass, hydropower, and anaerobic digestion to produce electricity, heat, and biomass, plus other co-products. This is overlaid against the areas of the state where there is a significant demand for nitrogen fertilizers. The **figure (below)** shows the major factors considered in a lifecycle assessment of renewably produced ammonia. The inputs included in the assessment would be items needed to build the ammonia production component of the system, secondary fossil energy inputs such as fuel, electricity, plus any treated water needed. The outputs would include the nitrogen fertilizer, any energy such as heat or steam, and co-products such as digester solids, ash, or purified oxygen. The type of renewable system would change some inputs and outputs, with biomass and anaerobic digestion facilities needing significantly more inputs, while hydro power would need less. These same inputs and outputs would be important for the economic assessment of the system, which would also include other logistical considerations depending on the renewable energy source.



Selected Renewable Energy Facilities in Minnesota and Corn Production Regions. Facilities indicated are a representative sampling of gasification, anaerobic digestion and hydropower systems. Darker areas indicated higher corn production, which typically requires more nitrogen.



X. ACQUISITION/RESTORATION REQUIREMENTS WORKSHEET: n/a

XI. RESEARCH ADDENDUM: n/a

XII. REPORTING REQUIREMENTS:
Periodic work plan status update reports will be submitted no later than November 2014, June 2015, November 2015, June 2016, and November 2016. A final report and associated products will be submitted between June 30 and August 15, 2017.

Environment and Natural Resources Trust Fund
M.L. 2014 Project Budget

Project Title: Life Cycle Energy of Renewably Produced Nitrogen Fertilizers
Legal Citation: M.L. 2014, Chp. 226, Sec. 2, Subd. 08e
Project Manager: *Joel Tallaksen*
Organization: *University of Minnesota, West Central Research and Outreach Center in Morris*
M.L. 2014 ENRTF Appropriation: $ *250,000*
Project Length and Completion Date: 3 Year, June 30, 2017
Date of Report: Septempber 2017 (Final)

ENVIRONMENT AND NATURAL RESOURCES TRUST FUND BUDGET	Activity 1 Budget	Amount Spent	Activity 1 Balance	Activity 2 Budget	Amount Spent	Activity 2 Balance	Activity 3 Budget	Amount Spent	Activity 3 Balance	TOTAL BUDGET	TOTAL BALANCE
BUDGET ITEM	LCA of Renewable Nitrogen Production			Techno-economics of Renewable N Production			Impacts on Agriculture and Info. Dissemination				
Personnel (Wages and Benefits)	$38,481	$38,481	$0	$38,481	$38,481	$0	$20,243	$20,243	$0	$97,205	$0
Scientist (0.5 FTE total over 3 years, $ 42,138, 63 % salary & 37% fringe)											
Jr. Scientist (1 FTE total over 1 year, $49,049, 63 % salary & 37 %fringe)											
Student Intern (.25 FTE-14 Weeks, $6,016, 93 % salary and 7 %fringe)											
Professional/Technical/Service Contracts											
Lifecycle assessment research team, Swedish agricultural University. ($50,000) Will assist University of Minnesota researchers with fertilizer specific pathways for analyzing lifecycle assessment (Estimate 1 FTE).	$50,000	$50,000	$0	$0	$0	$0	$0	$0	$0	$50,000	$0
Chemical engineering Researcher Team, Lund University Sweden. ($80,000) Responsible for analyzing the feedstocks, chemistry, and equipment, at the renewable energy sites in Minnesota. (Estimated 1 FTE).	$0	$0	$0	$80,000	$80,000	$0	$0	$0	$0	$80,000	$0
Funds for Chippewa Valley ethanol Cooperative ($3,750) to compensate for staff time allocated for this project. CVEC would work with University of Minnesota research staff to identify inputs, outputs, and equipment needed for converting producer gas into ammonia fertilizer.	$3,750	$3,750	$0	$3,750	$3,750	$0	$0	$0	$0	$7,500	$0
Funds for entity operating and anaerobic digestion system ($3,750), whose staff time would be used to work with University of Minnesota research staff to identify inputs, outputs, and equipment needed for converting biogas into ammonia fertilizer.	$3,750	$0	$3,750	$3,750	$0	$3,750	$0	$0	$0	$7,500	$7,500
Equipment/Tools/Supplies											
General Research supplies - sampling equipment feedstocks/products , tools for measuring, saftey equipment, lab research notebooks	$300	$0	$300	$300	$0	$300	$300	$300	$0	$900	$600
Life cycle assessment software update	$1,750	$1,700	$50	$0	$0	$0	$0	$0	$0	$1,750	$50
Outreach supplies- binders, cd, labels, nametags, and other supplies for outreach meetings as allowed by the Univesity/State	$348	$0	$348	$348	$0	$348	$949	$253	$696	$1,645	$1,392
Printing	$0	$0	$0	$0	$0	$0	$1,500	$0	$1,500	$1,500	$1,500
Travel expenses in Minnesota											
Mileage to research and dissemination sites	$450	$0	$450	$450	$0	$450	$950	$226	$724	$1,850	$1,624
Meals as allowed by University during travel	$50	$0	$50	$50	$0	$50	$50	$0	$50	$150	$150
Other											
COLUMN TOTAL	$98,879	$93,931	$4,948	$127,129	$122,231	$4,898	$23,992	$21,022	$2,970	**$250,000**	**$12,816**