

# Ammonia Production Using Wind Energy:

An Early Calculation of Life Cycle Carbon  
Emissions and Fossil Energy Consumption  
NH<sub>3</sub> as a fuel conference

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Renewable Energy Group

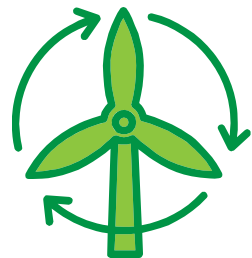
West Central Research & Outreach Center- Morris, MN



College of Food, Agricultural  
and Natural Resource Sciences

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UNIVERSITY OF MINNESOTA



# West Central Research & Outreach Center

- A branch of the University of Minnesota that is located 3 hrs from Minneapolis/St. Paul
- Have been conducting agricultural and rural community research for over 100 yrs
- Our research is based on testing near-term research in an applied setting
- We have a diversified farming operation, with facilities for several other types of research



# Our Interested in Ammonia Production

- \$400 million worth of anhydrous ammonia fertilizer is used annually in Minnesota
- Minnesota has no fossil energy resources, so all ammonia is brought to the state from other locations in the US and overseas
- The state does have abundant wind and solar resources, with potential biomass resources as well



# U of MN Wind

- 1.65 MW Turbine
- Powers a co-located University facility.
- Initially served to demonstrate technology to local investors in wind
- Used by local community college for training



# Minnesota's Wind Resource

- Located on the edge of the Great Plains, Minnesota has an abundant wind resource in the western portion of the state.
- A lack of transmission means the resource is only partially developed.
- Developing the wind resource would mean added jobs and stability in the local rural economy.

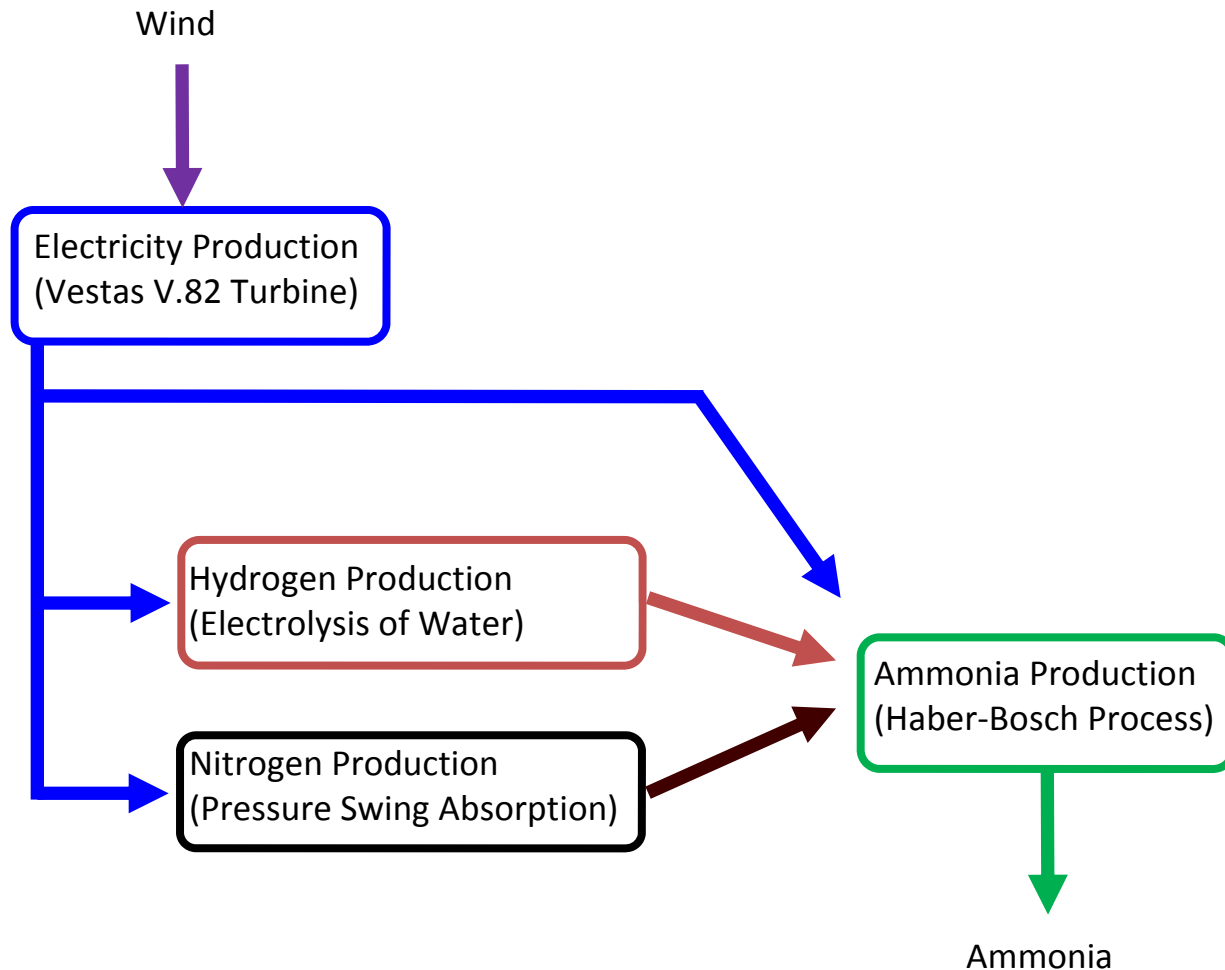


# Wind to Ammonia Concept

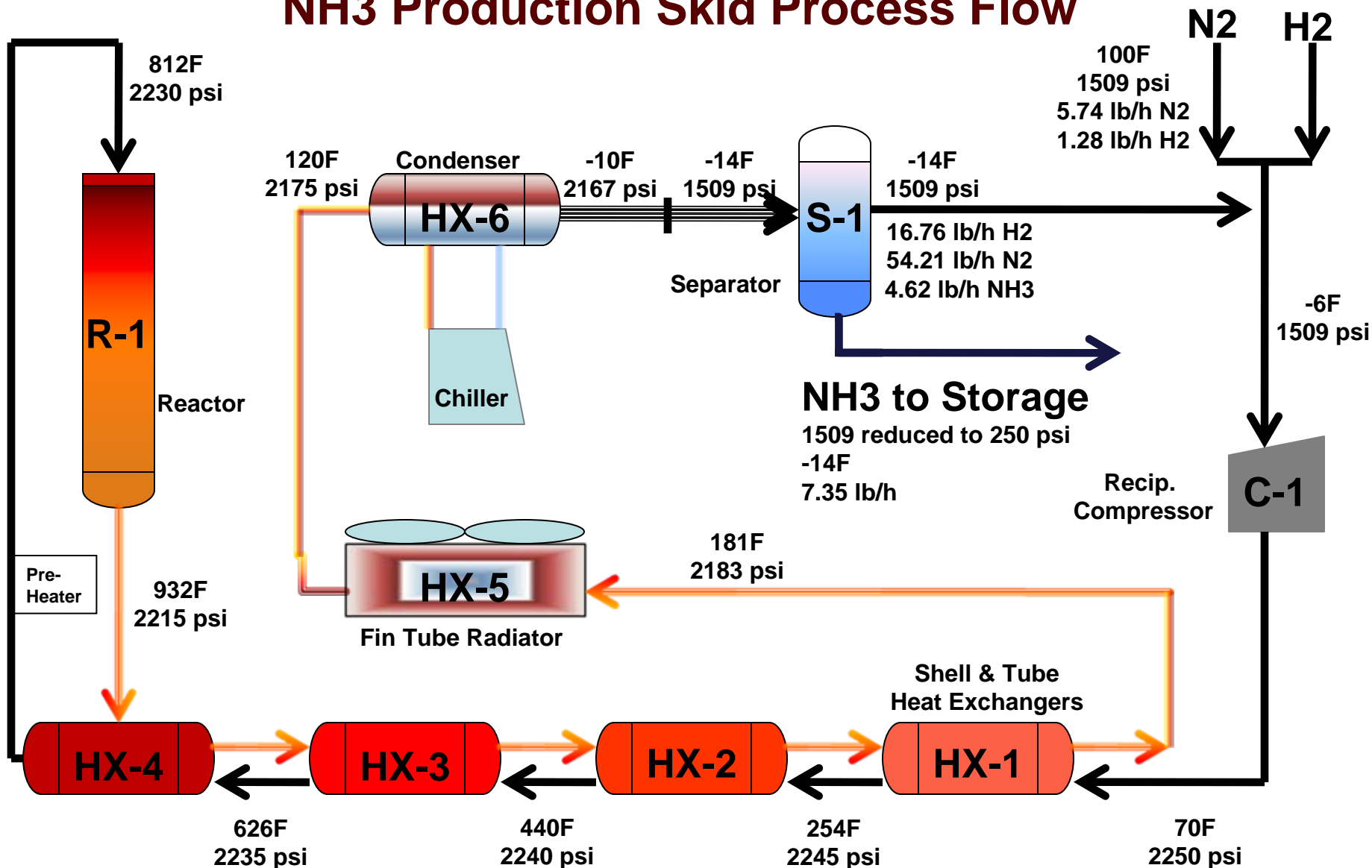
- Use electricity produced from wind power to make a needed product for the local community.
- Makes electric transmission less critical
  - Can produce ammonia during peak wind and maintain a more stable base electric capacity
  - Ammonia plants could be build in areas with little if any major transmission lines. Then ammonia shipped to regions that need it.



# Overview of Ammonia Production

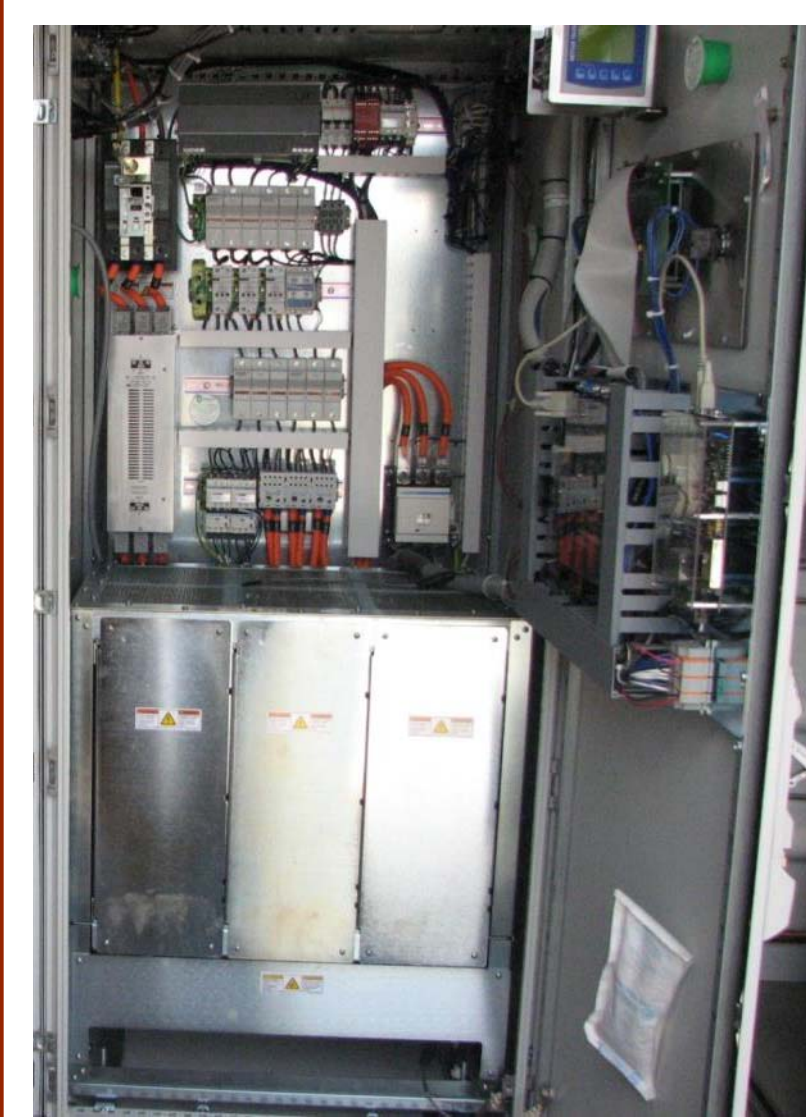


# NH3 Production Skid Process Flow





# Components

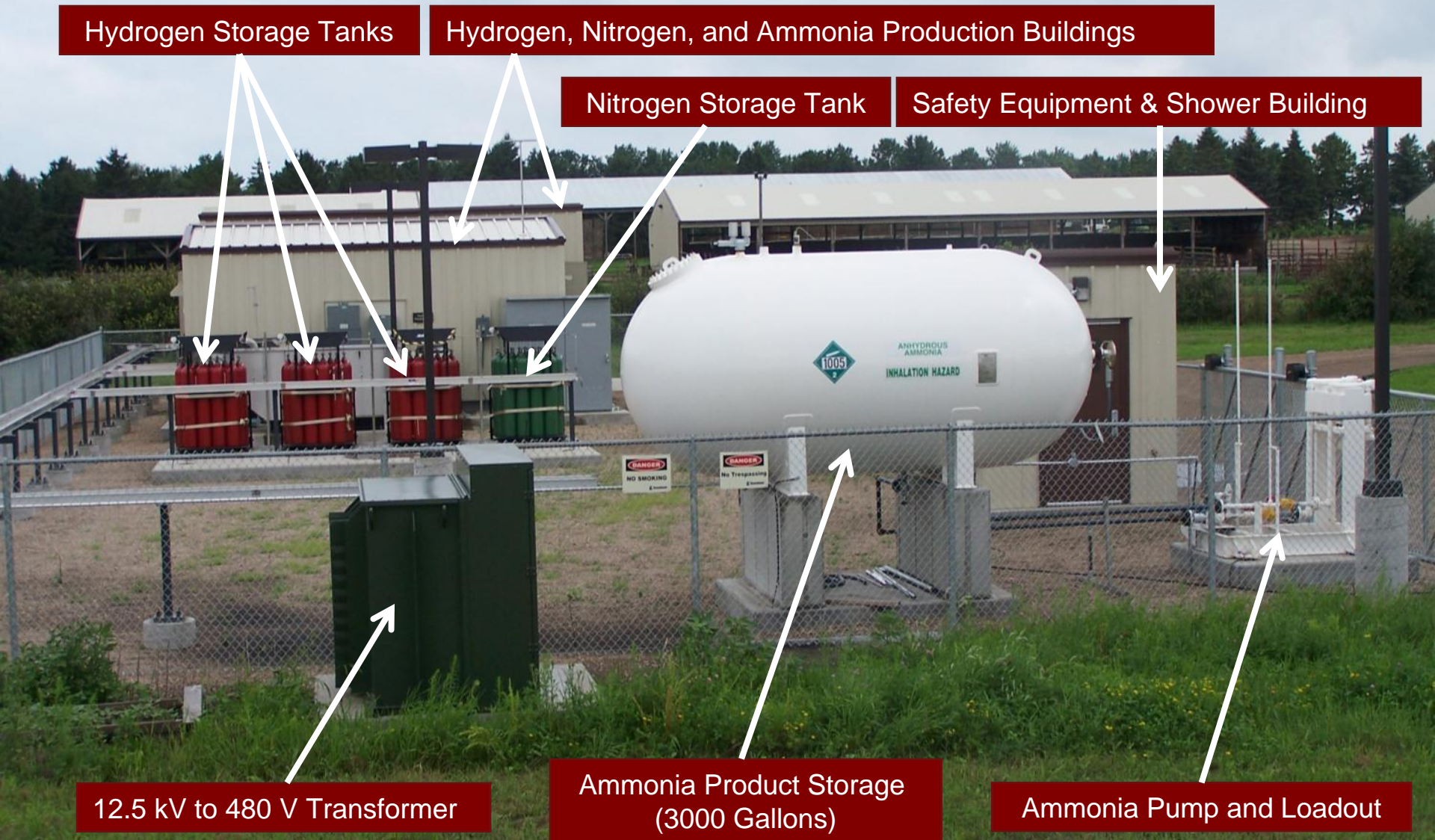


# Ammonia Skid





# Completed Facility



# Project Status

- First Operation-  
Spring 2013
- Still working on construction and engineering issues
  - Plumbing
  - Valves, regulators, sensors
- Reactor seems to work very well!



# Ammonia As a 'Green' Alternative

- Ammonia is being suggested as an alternative to fossil based energy and products for:
  - Industrial Chemicals
  - Fuels
  - Fertilizers
- The implication or desire is that it is could be more environmental friendly
- However, currently ammonia is made from natural gas



# Can Wind Ammonia Be 'Green'?

- Several different measures of environmental impacts can be examined to answer question
- We are interested in:
  - Energy Inputs (focusing on fossil)
  - Greenhouse Gas Emissions
- Selected life cycle assessment (LCA) as the tool to examine these variables



# What is Life Cycle Assessment?

- Developed initially as a method of accounting for the amount of materials being used to make a given product.
- As an example:
  - How much steel is being used to make a compact car?
- Over the last 20 years, LCA work has become much more focused on environmental issues rather than raw resource use.



# LCA Scope and Goals

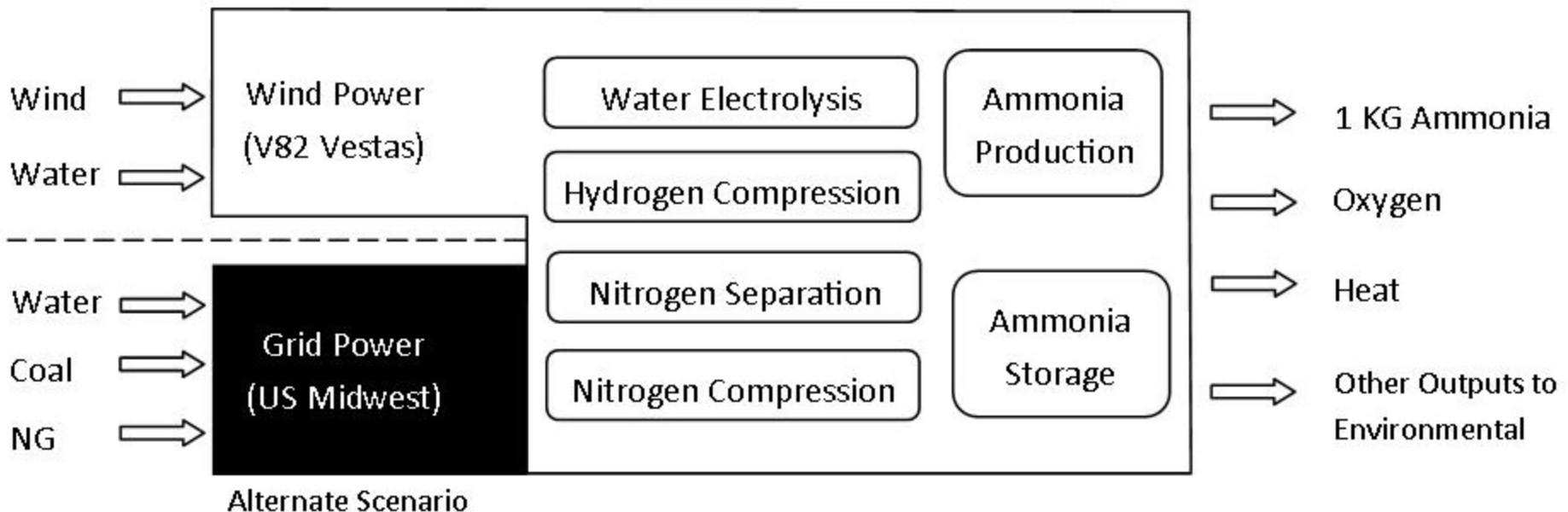
- Determine energy use and GHG emissions for the production of 'renewable' ammonia
- Cradle to Gate (Partial LCA)
  - From energy generation to liquid ammonia in storage tank at 250 psi
  - Answers questions about substituting renewable ammonia for fossil ammonia
- Focused on Local Production
  - Wind energy
  - Commercial scale ammonia production
  - Data to date is from our pilot scale system





# System Boundaries

## Wind to Ammonia LCA System Boundaries



# Energy Inputs and Outputs

## Inputs

- Wind
- Water
- Equipment
- Grid Electric

## Outputs

- Ammonia
- Heat
- Oxygen



# Methodology

- Breakdown the ammonia production system into discrete processes.
- Examine the inputs and outputs of each process.
- Three levels of data collection
  - Manufactures label information
  - Engineering calculations
  - Measured data from operation



# Electricity Production Data

- Used existing LCA for v82 wind turbine
  - Comprehensive study done by 3<sup>rd</sup> party for the Vestas Corporation provides the amount of fossil energy resources and CO<sub>2</sub> equivalents (measure of greenhouse gases)
- Used LCA database for fossil energy and greenhouse gas equivalents for electricity used from the US grid, Western US grid, and Minnesota grid.



# Hydrogen & Nitrogen Components

- Equipment and Maintenance
- Hydrogen
  - Electrolysis
  - Compression
- Nitrogen
  - Pressure-Swing Absorption
  - Compression



# Ammonia Production Components

- Equipment and Maintenance
- Process Gas Heater
- Compression
- Cooling



# Example Process Energy Input

## Hydrogen Production Using Electrolysis



	Resource Description	Predicted Data		Measured Data		LCA Inputs		Data Collection Method
		Qty	Units	Qty	Units	Qty	Units	
<b>Inputs:</b>	DI water at .2 Mpa	5.5	kg/h		kg/h	10.468	kg	SCADA
	electricity	40.8	kW	12.900	kW	24.553	kWh	SCADA
	cooling	23.7	kW	16.881	kW	32.130	kWh	calc.
<b>Outputs:</b>	hydrogen at .15 Mpa	0.54	kg/h	0.525	kg/h	1.000	kg	calc.



# System Operations Data

- Early findings are based on three runs of the system
  - Very early in learning about the operations of the system
- Not yet optimized
  - Don't think we have peak ammonia production
  - Still using electric heating more than desired
    - still identify where process heat is being lost





# Current Status of Data Collection

- Baseline data collected for hydrogen and nitrogen production system is fairly complete
- Need more data on facility construction
- Some uncertainty about energy use and heating and cooling of buildings and equipment.
- Some issues with the background data for US grid, western grid, and Minn. grid



12.7 kg  
(800029) Mixed  
Post Synthesis  
Gas Separation  
50.4 MJ

0.989 kg  
Nitrogen Storage  
800035  
3.42 MJ

0.989 kg  
Nitrogen, Pure  
Compressed, 16.5  
Mpa WCROC  
3.42 MJ

0.989 kg  
Nitrogen, Pure,  
0.6 Mpa bars,  
WCROC (800014)  
3 MJ

5.52 kg  
Air, Dry  
Compressed 0.76  
Mpa WCROC WHA  
2.71 MJ

5.52 kg  
(800012)  
Compressed air,  
0.76 Mpa, WCROC  
2.53 MJ

13.9 kg  
Mixed Gas,  
Pre-Reactor 10.4  
Mpa, (800037)  
55.7 MJ

0.22 kg  
Hydrogen, Pure  
Compressed 10.4  
Mpa (800036)  
33.7 MJ

0.22 kg  
Hydrogen,  
Compressed, 16.5  
Mpa , WCROC  
33.7 MJ

0.22 kg  
Hydrogen, Pure  
1.43 Mpa, WCROC  
(800009)  
28.2 MJ

58.7 MJ  
(800007)  
Electrical Source  
Options WCROC  
58.7 MJ

58.7 MJ  
Electricity, at grid,  
Western  
US/kWh/US  
58.7 MJ

35.2 MJ  
Cooling, Hydrogen  
and Nitrogen  
System WCROC  
12.1 MJ

1 kg  
Fertilizer N as part  
of NH3 at 250 PSI  
(800040)  
58.7 MJ

1.22 kg  
(800032)  
Ammonia,  
Anhydros At  
58.7 MJ

1.22 kg  
(800029) Mixed  
Post Synthesis  
Gas Separation  
58.7 MJ

13.9 kg  
(800028) Mixed  
Post Synthesis  
Condensation  
58.7 MJ

13.9 kg  
(800022)  
Ammonia  
Production Heat  
56.9 MJ

13.9 kg  
(800025)  
Ammonia  
Synthesis Reactor  
49.8 MJ

14.8 MJ  
Ammonia Process  
Cooling (800038)  
13.2 MJ



# Preliminary\* Energy Use

Electrical Energy Required  
For Producing 1 kg of N in  $\text{NH}_3$

Energy Source	Electricity Needed	Fossil Electricity
Wind	58.7 MJ/kg	Trace
Grid	58.7 MJ/kg	58.7 MJ/kg

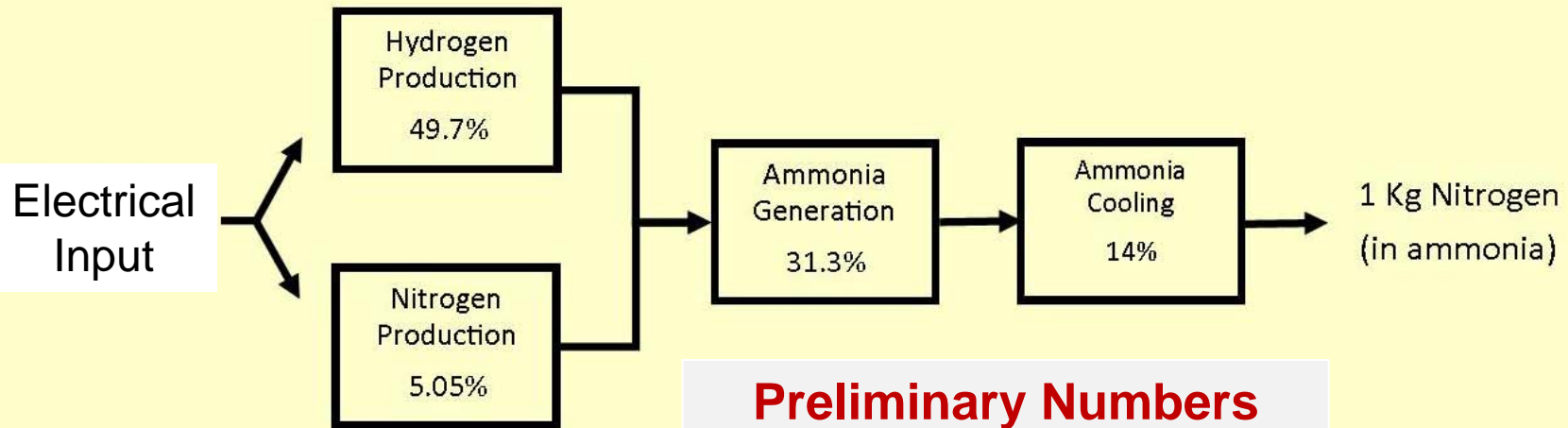
As of Early June 2013

\*This information is evolving as new data is added to the LCA model



# Rough Areas of Energy Use

## Electricity Use in Ammonia Production



**Preliminary Numbers  
Stay Tuned for Final Data**



# Greenhouse Gas Emissions\*

CO<sub>2</sub> Equivalents<sup>1</sup> For Producing 1 kg of N in NH<sub>3</sub>

Energy Source	CO <sub>2</sub> emitted	Notes
Wind	1.85 kg	Used in infrastructure
Grid (US Mix)	12.7 kg	Many older fossil plants
Grid (Western Mix)	9.27 kg	Higher hydropower plants
Grid (Minnesota Mix)	10.6 kg	Fewer hydro, more nucl.

1- Greenhouse gas emissions as measured by CO<sub>2</sub> Equivalents, using IPCC 2007 100a v1.02 method. As of June 2013

\*This information is evolving as new data is added to the LCA model



# Comparison to Natural Gas

- Industrial scale ammonia plants
  - 500,000 to 1,000,000 tons per year
- Modern ammonia production via natural gas requires around 30 MJ/kilogram
  - Roughly half of the wind ammonia
  - ALL fossil carbon emissions
- Carbon emissions are higher as well



# Continuing LCA work

- More data collection on operations
  - Stable operations
  - Finding most efficient operations
- Collection on data for construction
- Better data on equipment manufacturing



# Wind to Ammonia Enhancements

- Lots of room for efficiency improvement in current process. We are only beginning to optimize the system.
- Exciting technologies being looked at:
  - Absorbents
    - Remove ammonia from high temperature stream, lowering energy need to heat and cool the entire mass flow as it goes through each cycle
  - Non-thermal plasma
    - Run a current through N<sub>2</sub> and H<sub>2</sub> at room temp, low pressure.





# Direct Conclusions of This Work

- Wind ammonia is 'greener'
  - Less fossil energy per unit of ammonia
  - Less carbon emissions
- Can help reduce fossil inputs and emissions in downstream products
- Further innovations are needed to lower energy required and CO<sub>2</sub> emitted



# 'Green' Economics

- Renewably produced ammonia will likely be more expensive in the short term
- The value of 'green' ammonia is potentially higher because of the low carbon emission in its production transfers to the final product.
- Minnesota example:
  - Low carbon ammonia to make low carbon corn, which can be made into low carbon ethanol. Low carbon ethanol has higher value in California.



# Related Research

- Impacts of renewable ammonia use on cropping and animal system lifecycle energy.
  - Nitrogen fertilizer is roughly 10% of cropping system energy
  - How do we make lower carbon/energy milk?
- Regional differences in renewable fertilizer production between the Western US and Sweden
  - Differences in electric grids
  - Use of ammonium nitrate in Sweden



# Planned Research

- Study improved technologies
  - Better catalysts
  - Ammonia absorption technologies
- Examine system scaling
- Examine how commercial system might improve efficiency



# Acknowledgements

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