# Life-cycle Greenhouse Gas And Energy Balance Of Community-scale Wind Powered Ammonia Production



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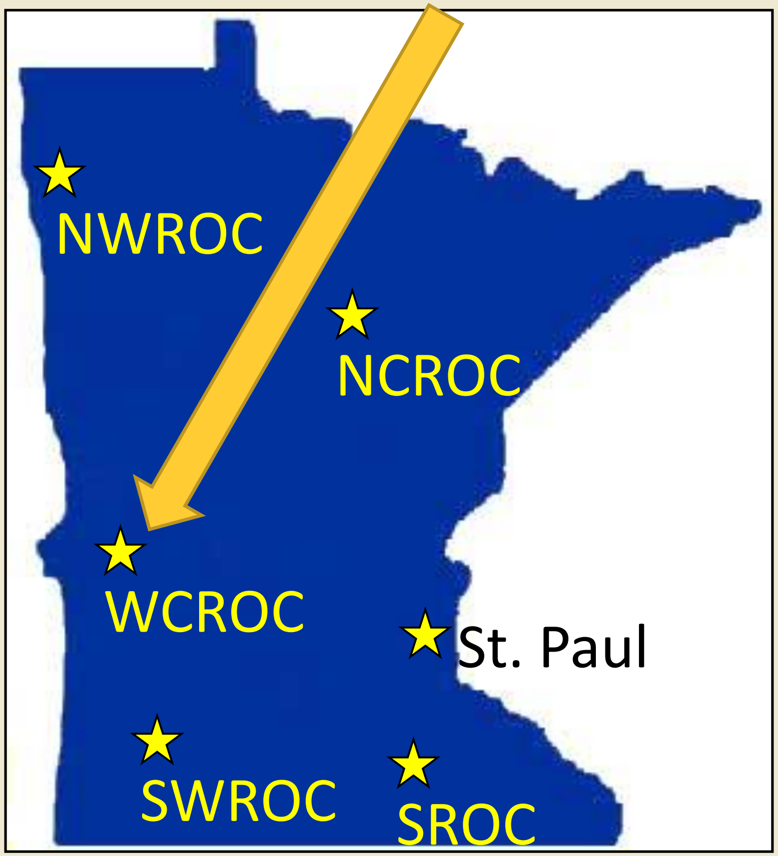
# The WCROC Research Facility

- One of several locations around the state that researches agriculture
- In addition to traditional agricultural topics, we focus on energy and agricultural systems.
- Our energy focus is covers community scale agricultural energy issues.

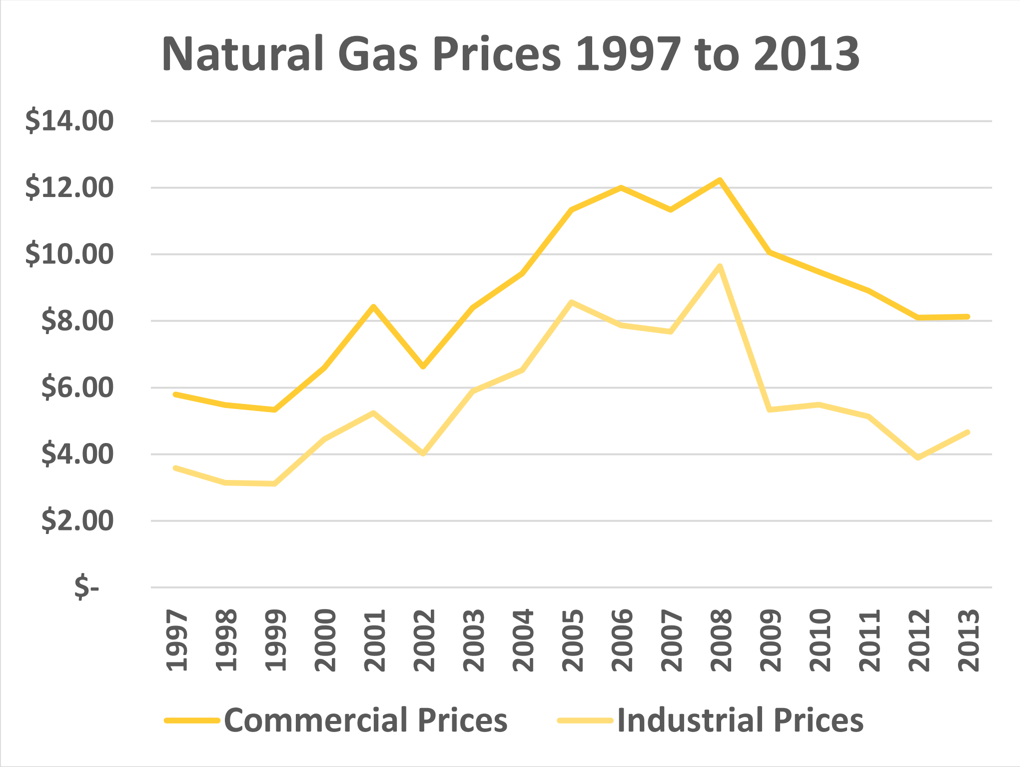


# Several Industrial Uses for Ammonia

- Refrigeration
- Chemical Manufacture
- Agriculture
  - Largest Current use in the US
- As an energy storage medium

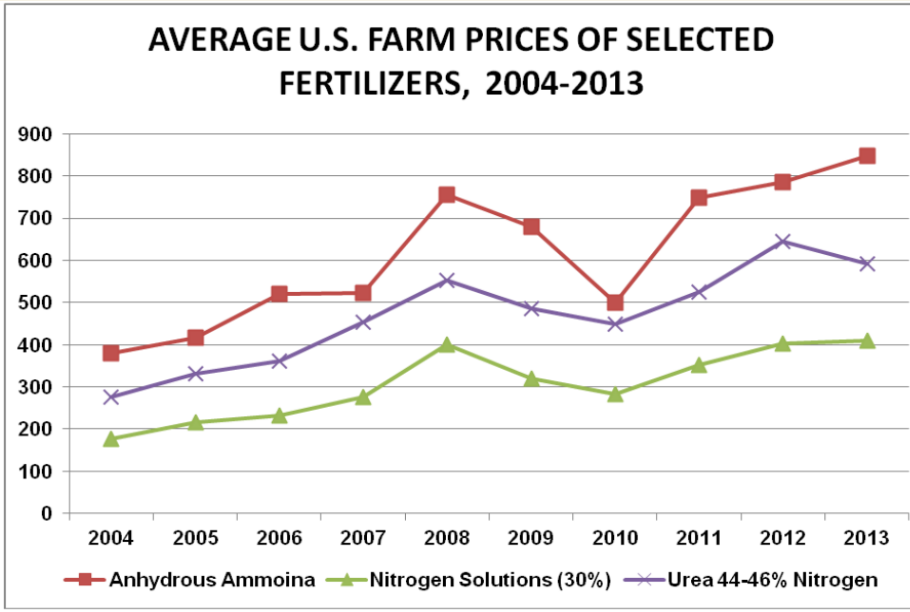
# Traditional Production of Ammonia

- Large Facilities
  - High capital costs
  - Large Resource Demand
    - Production must be located near feedstocks
- Fossil Based- cost linked
  - Natural gas
  - Coal gasification
- Transported great distances



# Issues with Traditional production

- Fossil Energy Use
  - ♦ Both coal and natural gas
- Shortages
  - ♦ Transportation bottlenecks
  - ♦ Demand Spikes in fall and spring
- Cost



# Wind Powered Ammonia Production

- Uses electricity for entire process
  - Commercial scale turbines with grid backup
  - Nitrogen isolated from the air
  - Hydrogen from electrolysis of water
- Done at 'community' scale, where needed
  - Less capital
  - Limited transport needed



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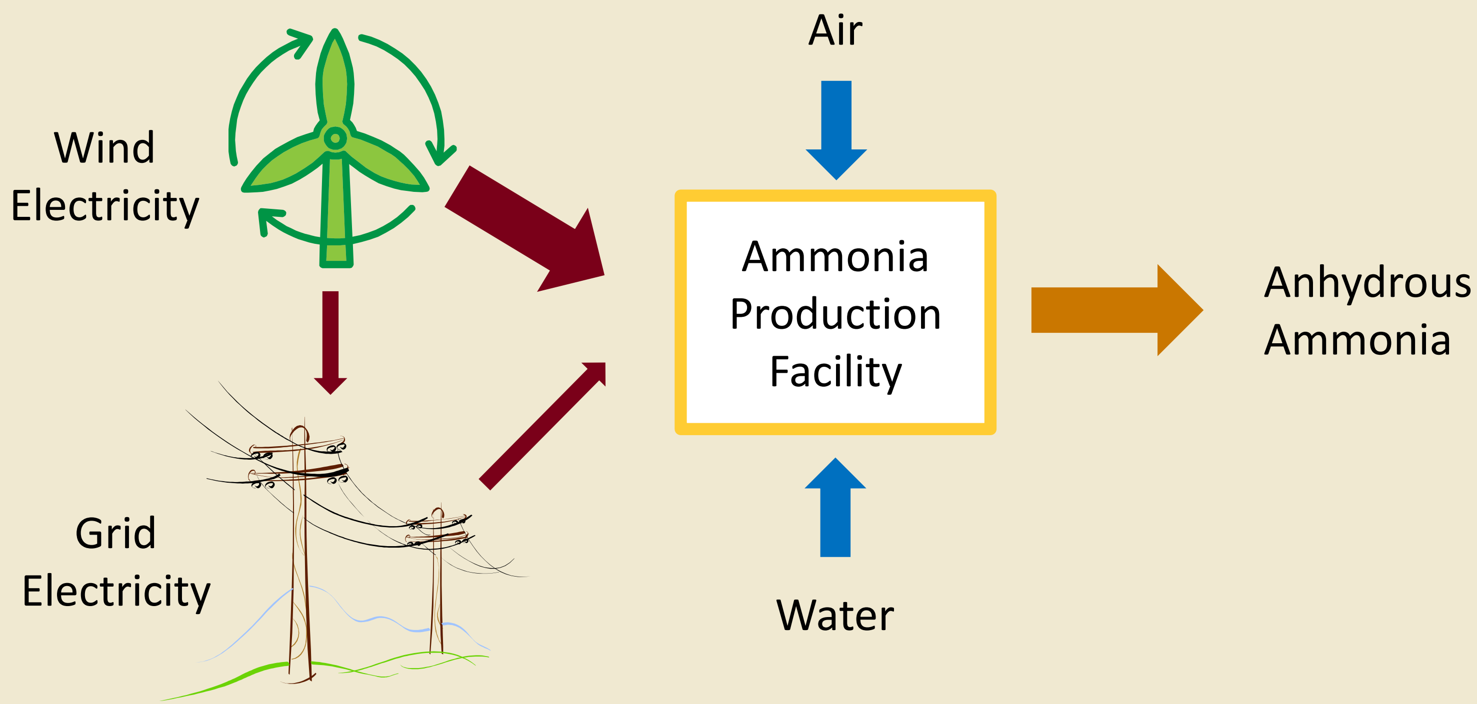
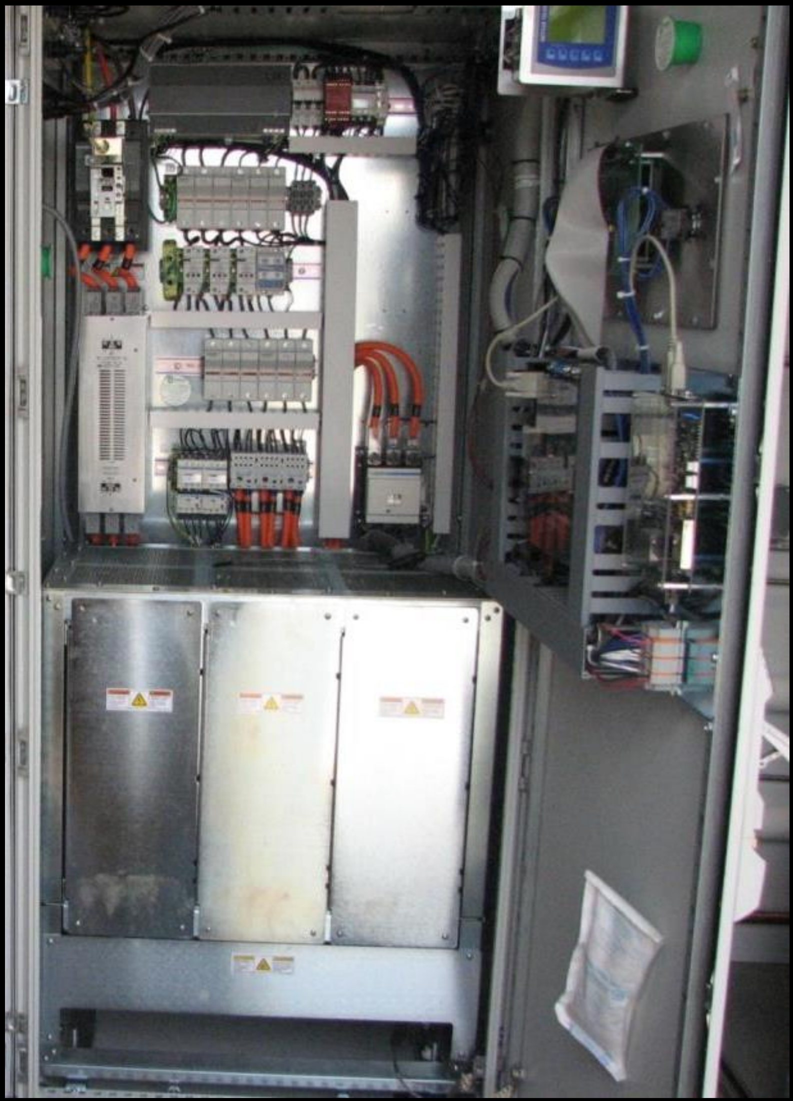
# University of Minnesota Ammonia Facility






OFF ON
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INNOVATIVE GAS SYSTEMS
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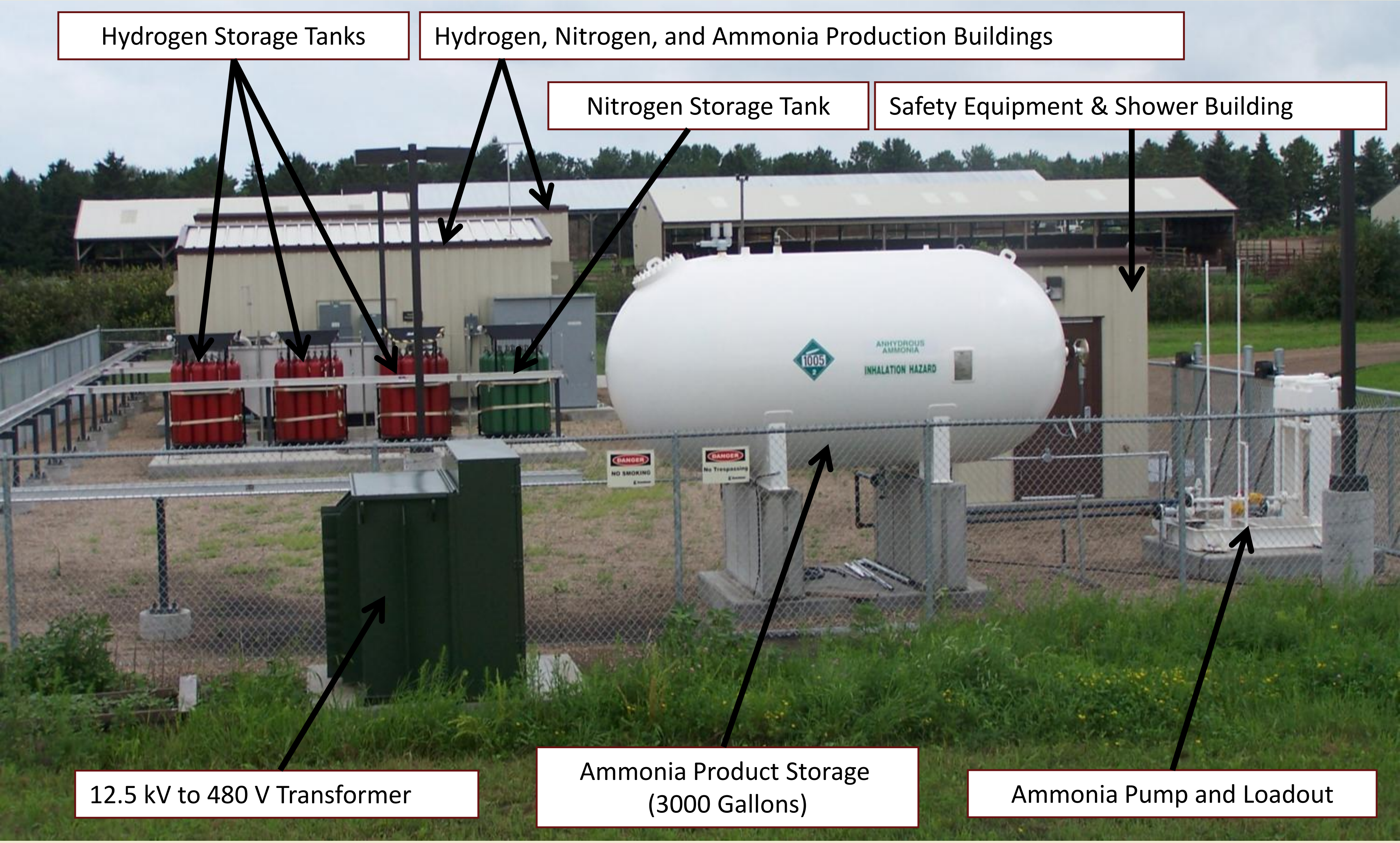
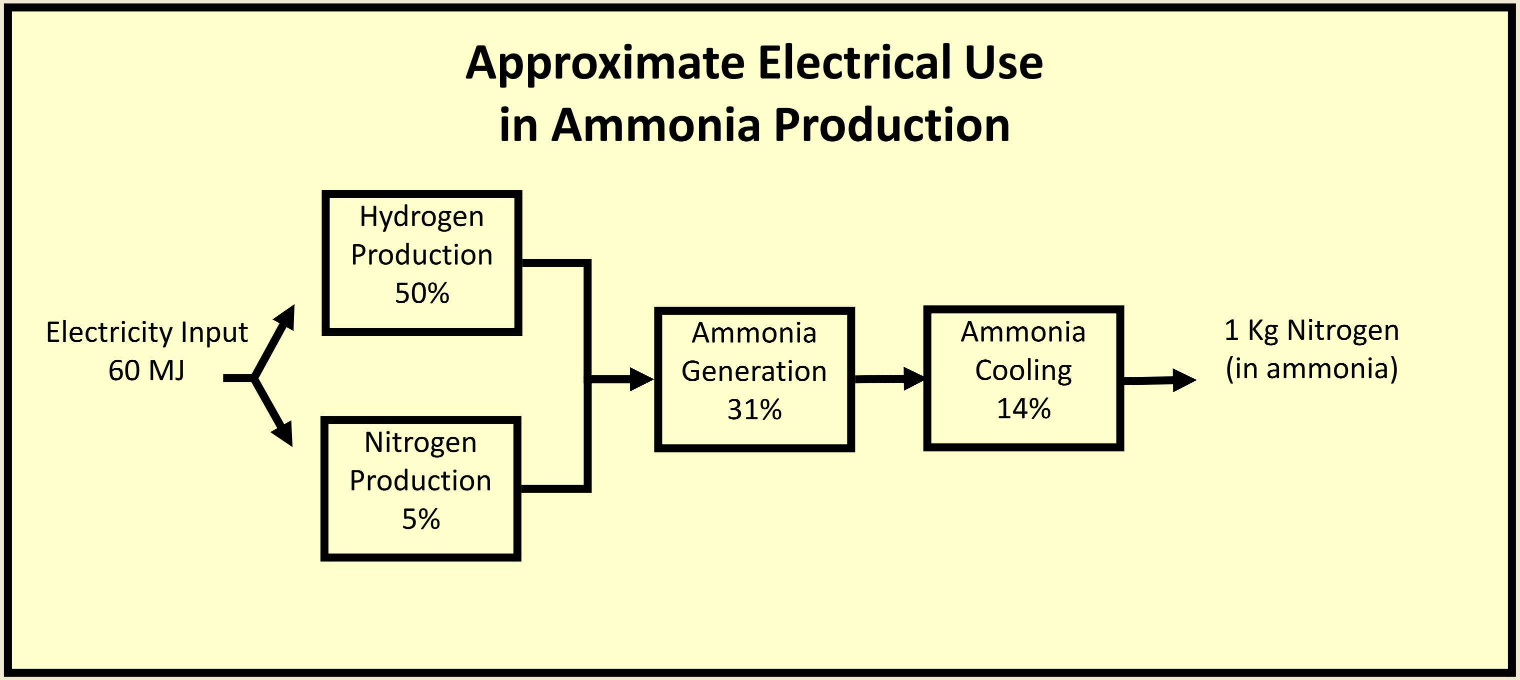

Hydrogen Storage Tanks
Hydrogen, Nitrogen, and Ammonia Production Buildings
Nitrogen Storage Tank
Safety Equipment & Shower Building
INHALATION HAZARD
12.5 kV to 480 V Transformer
Ammonia Product Storage
(3000 Gallons)
Ammonia Pump and Loadout

# Status of Pilot Facility

- Operating and studying the system since early 2013.
- Production chemistry and reactor appear to function well.
- Production capacities seem to be accurate.
- Some issues with supporting equipment systems
  - Modified from off the shelf industrial equipment
    - Little prior experience on how these should be set up
  - Valve and sensor materials
    - Not always compatible with ammonia
    - Sometimes not correct for temperatures seen.

# How Electricity is Used In The System




- **This is the point the work was at last year at this time**

# Environmental Impacts of Wind Based Ammonia Production

- **Environmental impacts are an important consideration**
  - ♦ **Wind based ammonia not likely to be adopted if not a 'green' technology**
  - ♦ **Agriculture under pressure to be more sustainable**

***Research Question:*** **Does using wind energy for ammonia production have less environmental impacts than the traditional fossil methods?**

- ♦ **Fossil energy depletion**
- ♦ **Releases of greenhouse gases**

# Using LCA Modeling To Study Impacts

- Limited life cycle assessment
- 'Cradle to Grate'
  - All resources going into energy production
    - Wind infrastructure construction energy
    - Grid fossil energy and infrastructure construction energy
  - Units of ammonia production
- Analysis ends at production storage tanks
  - At this point wind ammonia and fossil ammonia are identical

# Ammonia Production System Modeled

- Community-scale facility
  - Serve a county sized mid-western agricultural area
    - Based on a Midwestern agricultural coop size
    - Around 150,000 acres of corn
    - 5500 tonnes anhydrous ammonia per year
    - Roughly 630 kg per hour NH3 (520 Kg N)
- Energy demand
  - 7.4 MW constant
  - 8-15 Turbines depending on scenario

# Scenarios Examined

- **Location**
  - ♦ **Sweden**
  - ♦ **United States**
- **Net percent of system electricity produced by wind**
  - ♦ **75% From Wind (25% purchased)**
  - ♦ **100% From Wind (Net 0)**
  - ♦ **125% From Wind (25% excess sold)**


# Data Analyzed

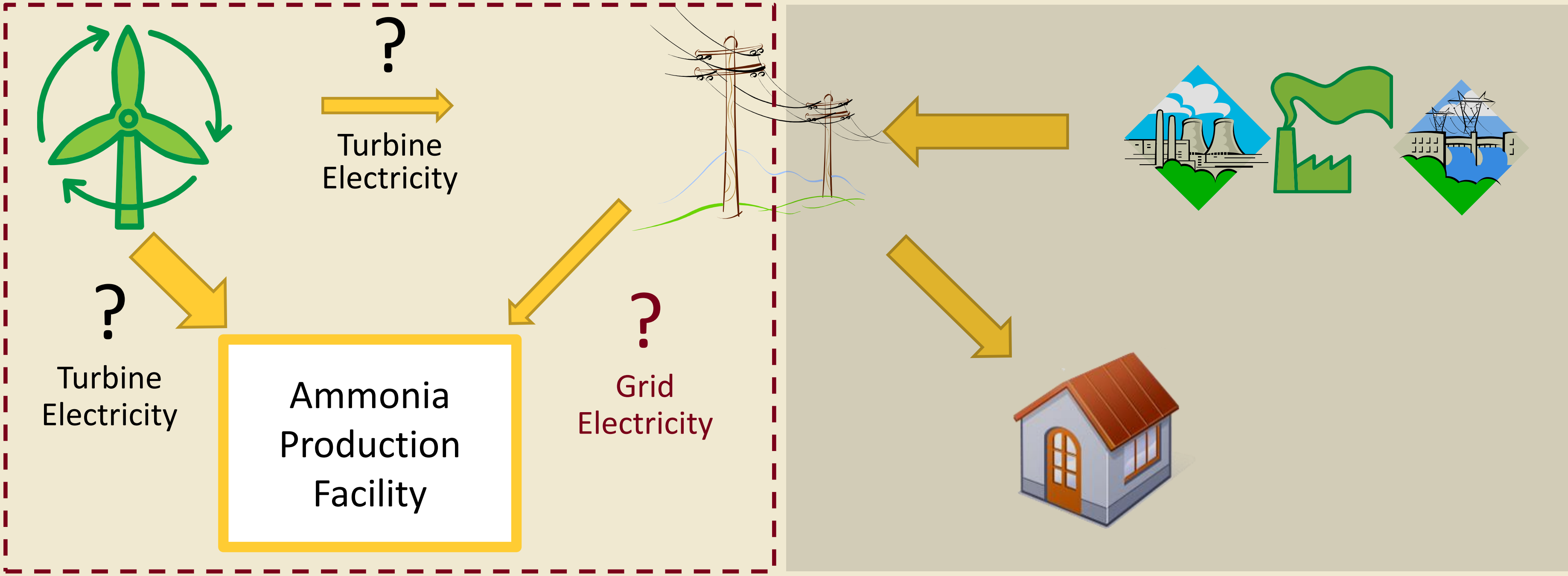
- **Electrical flows**
  - ♦ **Power purchased from the grid**
  - ♦ **Power sold to the grid**
- **Environmental footprint for electricity**
  - ♦ **Types of power generation**
  - ♦ **Percentage of each power type**
  - ♦ **Fossil energy used by power type**
  - ♦ **GHG released by each power type**


# Overall Method of Calculating Emissions*

$$\frac{\begin{pmatrix}\text{Emissions}\\ \text{From}\\ \text{Grid}\end{pmatrix} X \begin{pmatrix}\text{Quantitiy of}\\ \text{Electricity From}\\ \text{Grid}\end{pmatrix} + \begin{pmatrix}\text{Emissions}\\ \text{From}\\ \text{Turbine}\end{pmatrix} X \begin{pmatrix}\text{Quantitiy of}\\ \text{Electricity From}\\ \text{Turbine}\end{pmatrix} - \begin{pmatrix}\text{Emissions}\\ \text{Credit For}\\ \text{Electricity sold}\end{pmatrix} X \begin{pmatrix}\text{Quantitiy of}\\ \text{Electricity}\\ \text{Sold}\end{pmatrix}}{\text{Emissions Per Kg of Ammonia Produced}}$$

*Same Basic Idea for Fossil Energy Use

# Flows of Power



# Modeling Power Flows

- **Began with a wind energy model**
  - **Actual data vs mathematical estimates**
- **Models provided :**
  - **Energy production by the wind farm**
  - **Frequency of specific production levels.**
- **Data was turned into an average for each hour of operation**
- **The end result was a set of number for each scenerio.**

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**Average Hourly Power Flows**
Minnesota
125% production model

13.4 turbines (1.65MW) needed

| | |
|---|---|
| Wind Production: | 9.3 MWhr |
| Grid Purchases: | 2.6 MWhr |
| Net Sales: | 4.5 MWhr |
| Power to Facility | 7.4 MWhr |

# Regional Electricity Grids Compared

- **Minnesota has significant coal generations with nuclear and wind making up most of the rest.**
- **Sweden has mostly hydropower and nuclear. Very little fossil generation**

**Note: regional electricity imports/exports not included in modeling**

| Source | Minnesota | Swedish |
|---|---|---|
| Wind power | 13% | 5% |
| Hydro power | 1% | 51% |
| Gas turbines | 6% | 0.06% |
| Coal | 53% | - |
| Nuclear | 23% | 39% |
| Solar/other renew. | 1% | - |
| Crude Oil | 1% | - |
| Biomass and other | 3% | 5% |

# Fossil Energy and Emissions In Electrical Production

- Fossil energy use for 'green' technologies was in construction of the systems
- In conventional fossil-based electricity, fossil energy use was much greater (as expected)
- Greenhouse gas emissions followed the same patterns

| Technology | Primary energy factors | Associated GHG emissions (g $CO_2$-eq/MJ) |
|---|---|---|
| Wind power | 1.03 | 1.81 |
| Coal | 5.7 | 331 |

Primary energy roughly translates to "natural Energy"- Wind, water, biomass, solar, atoms



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# Grid Electricity Footprint

- Power plant infrastructure construction
- Fossil energy use
- For Minnesota estimates:
  - Database of footprints for each power type
  - Percentages of each type of power
- Estimates for Sweden:
  - Each type of power has documents data
  - Looked at the percentage each contributes

| | MJ primary energy per MJ electricity | g $CO_2$ –eq per MJ electricity |
|---|---|---|
| **Sweden** | 1.87 | 4.88 |
| **Minnesota** | 4.90 | 206 |

# Wind Power Footprint

- **Used Data From Wind Turbine Manufacturer (Vestas)**
  - **A complete life cycle assessment had been done of construction of a 1.65MW turbine**
- **Combined manufacture data with local capacity factors**
- **Energy required to build the turbine per kW hour of power produced by the turbine.**

| | MJ primary energy per MJ electricity | g $CO_2$ –eq per MJ electricity |
|---|---|---|
| **Minnesota** | 1.03 | 1.81 |
| **Sweden** | 1.03 | 2.01 |

Primary energy of wind includes 1 MJ of actual energy in the wind and 0.03 MJ of energy needed for construction

# Overall Method of Calculating Emissions*

$$\begin{pmatrix} Emissions \\ From \\ Grid \end{pmatrix} X \begin{pmatrix} Quantitiy\ of \\ Electricity\ From \\ Grid \end{pmatrix}$$

$$+ \begin{pmatrix} Emissions \\ From \\ Turbine \end{pmatrix} X \begin{pmatrix} Quantitiy\ of \\ Electricity\ From \\ Turbine \end{pmatrix}$$

$$- \begin{pmatrix} Emissions \\ Credit\ For \\ Electricity\ sold \end{pmatrix} X \begin{pmatrix} Quantitiy\ of \\ Electricity \\ Sold \end{pmatrix}$$

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Emissions Per Kg of Ammonia Produced

*Same Basic Idea for Fossil Energy Use

# Fossil Energy Use

Minnesota

Significant fossil energy reduction at 100% and 125%

More fossil energy with only 25% from the grid.

Sweden

Significant fossil energy saving at all levels of production

| Fossil Energy Use In Ammonia Production (MJ/kg of N) | | | | | | |
|---|---|---|---|---|---|---|
| | Minnesota | | | Sweden | | |
| Scenario | 75% | 100% | 125% | 75% | 100% | 125% |
| **Fossil based Ammonia** | 33.1 | 33.1 | 33.1 | 33.1 | 33.1 | 33.1 |
| **Wind based ammonia** | 49.4 | 6.69 | -35.8 | 1.71 | 1.48 | 1.25 |
| **Comparison** | 149% | 20% | -108% | 5% | 4% | 3% |

# Greenhouse Gases

Minnesota

Significant GHG reduction at 100% and 125%

More GHG than fossil ammonia with only 25% from the grid.

Sweden

Significant fossil saving at all levels of production

| Greenhouse Gas Emissions g CO2 Equiv. Per KG N | | | | | | |
|---|---|---|---|---|---|---|
| | Minnesota | | | Sweden | | |
| **Net Wind Production:** | **75%** | **100%** | **125%** | **75%** | **100%** | **125%** |
| **Fossil based Ammonia** | 2150 | 2150 | 2150 | 2150 | 2150 | 2150 |
| **Wind based ammonia** | 2890 | 413 | -2050 | 153 | 116 | 78 |
| **Comparison** | 136% | 19% | -96% | 7% | 5% | 4% |

# Sensitivity Analysis

**Examined model variables that could have important impact on the results**

- **Energy needed to make Ammonia**
  - Increase- linear response
  - Decrease-linear response
- **Reduced Capacity Factor**
  - Set both countries capacity factor to 25%
  - Significant increases in fossil energy and GHG emissions

# Conclusions

- Electricity source and its associated emissions is critical
  - ♦ A heavily fossil dependent grid quickly increases fossil use and carbon emissions in ammonia production
  - ♦ Grid power backup should be minimized in some regions do to the fossil energy use

- More attention should be paid to precursor storage.
  - ♦ Hydrogen production can be ramped up and down quickly
  - ♦ Can be stored in times of high wind energy production

# Future Steps

- Model other base load renewable energy sources
  - Anaerobic digestion
  - Hydro electric
  - Gasification
- Model systems with hydrogen storage
- More data on facility energy use

# Acknowledgment

- **Swedish Energy Agency**
(International Collaboration Funding)

- **Many sponsors for ammonia system**

- **Ongoing Funding from LCCMR**
(Legislative-Citizens Commission on Minnesota Resources)

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# Wind to Ammonia LCA System Boundaries