Today’s Talk

• Review Motivations for this Project
• Update Progress
• Identify Plans for Engineering and Economic Analysis
Project Drivers

1. Stranded wind resource due to low transmission capacity
2. High ammonia / nitrogen demand and developed infrastructure
3. Nitrogen fertilizer prices have risen while natural gas has declined
4. We seek security for domestic food, feed, and bio-fuel production
5. More value gathered, if windpower is utilized locally
6. Use of ammonia from wind reduces greenhouse gas emissions
7. Hydrogen economy transition bridge
Excellent Wind Resource
High Demand for Ammonia

Corn for Grain, Harvested Acres: 2002

& Excellent Wind Resource
# Nitrogen Fertilizer Market in Minnesota

<table>
<thead>
<tr>
<th>Crop</th>
<th>Statewide Acres*</th>
<th>Avg. Yield/Ac (bu.)*</th>
<th>Statewide Yield (bu.)</th>
<th>Estimated N Required (lbs NH3)**</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn</td>
<td>8,234,507</td>
<td>146.0</td>
<td>1,201,898,815</td>
<td>901,424,111</td>
</tr>
<tr>
<td>Barley</td>
<td>108,268</td>
<td>53.6</td>
<td>5,801,418</td>
<td>4,351,063</td>
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<tr>
<td>Wheat</td>
<td>1,718,565</td>
<td>48.1</td>
<td>82,554,282</td>
<td>61,915,712</td>
</tr>
<tr>
<td></td>
<td></td>
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<td>Total NH3 Req. (lbs)</td>
<td>967,690,886</td>
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<td></td>
<td></td>
<td></td>
<td>Total NH3 Req. (tons)</td>
<td>483,845</td>
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<td>Retail Value ($800 / ton)</td>
<td>$387,076,354</td>
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</tbody>
</table>

*Production Data from USDA NASS (2007)

**Based on a requirement of 0.75 lbs of NH3 per bushel of yield
Worldwide Ammonia Production
(1,000 of Metric Tonnes)

Source: Orci, Ammoniakproduction. U.S. Geological Survey Data
Annual Prices of Anhydrous Ammonia and Corn per Ton from 1984-2010
Sources: NASS and ERS

![Graph showing the annual prices of anhydrous ammonia and corn from 1984 to 2010. The x-axis represents the years from 1984 to 2010, and the y-axis represents the price in dollars per ton. The graph compares the price fluctuations of ammonia and corn over the years.](image-url)
Transmission vs. Local Ammonia Production

High Level / Back of the Napkin Comparison:

- Each cost ~$1 million / MW nameplate capacity (+ / - 50%)
- Each result in ~$300,000* annual retail revenue / MW nameplate
- Ammonia production keeps dollars local and potentially has less development constraints (NIMBY Issues, Permitting, Siting, etc)
- Wind energy has a utilization problem more than a transmission and technology problem (net present value of wind is excellent)

*Transmission Case - 1 MW Wind Generation Equals 3,328,800 kWh / yr (times $0.08 per kWh ) equals $266,304.00

*Nitrogen Fertilizer Case - 1 MW Ammonia Plant Equals 1,460,000 lbs NH3 (times $0.40 per lb) equals $584,000.00
Key Challenges with Electrochemical NH₃ Production

A. Capital Costs
   - Equipment
   - Storage
   - Other Infrastructure

B. Energy Costs
   - Direct
     (5.5 to 7 kWh per lb NH₃)
   - Indirect (eg. Refrigerated Storage, Glenwood, MN = 3 MW load)
Key Challenges with Electrochemical NH3 Production

C. Operation, Maintenance, Repairs

- Need to replace plates / cells on electrolyzers every 3 to 7 years
- Catalysts (Relatively inexpensive but can damage reactor vessels)
- 24 / 7 Operation and Oversight

D. Market

- Competition (Fluctuating NG prices)
- Seasonality of Demand
- Lack of long-term contracts and /or federal and state policy
Key Challenges: Electrochemical NH3 Production

E. Logistics
- What is the appropriate size and scale to optimize logistics?

F. Business Model
- What is the optimum size for financial viability?
- What ownership organizations will be most favorable?

G. Electric Energy Industry
- Regulated industry with “service territories”
- FERC, MISO, PUC
- Retail wheeling (May need to separate wind business from NH3)
- Socialized costs - transmission, emissions
Key Challenges with Electrochemical NH3 Production

H. Current policies and ownership models may be a poor fit for Wind to Ammonia

- ITC Grant, ITC, PTC----- equity “flips” favor investment by passive investors for wind, Power Purchase Agreements provide stability

I. Commercial Technology

- Lack of equipment and contractors for desired scale
- Difficulties attracting investment in new technologies
- Lack of commercially proven equipment usually leads to higher equity investments and / or higher debt costs
Key Opportunities with Electrochemical NH3 Production

A. As Nat. Gas has gotten cheaper prices of NH3 have risen
   - Net present value of wind energy is a good value versus mid and long term natural gas prices
   - The cost of electrical energy is relatively stable

B. Opportunity for Vertical Integration
   - Farmers represent the NH3 fertilizer demand - Minnesota market ranges between $400 – $800 million per year
   - Farmers own the land needed for wind energy
   - Possible to take advantage of existing cooperative structures
Key Opportunities with Electrochemical NH3 Production

C. Production Possible in Close Proximity to Market

- Less Transportation Costs
- Fewer Middlemen / Margins
- 20 MW nameplate wind farm potentially produces N for 57,000 acres of corn

D. Market Flexibility

- Great opportunity for smart grids
- Multiple markets – release purchased power, sell stored power, sell H2, NH3, carbon credits, other forms of N fertilizer, ammonia for SCR in coal plants, refrigeration, cosmetics, etc.
Key Opportunities with Electrochemical NH3 Production

E. CO2 / Greenhouse Gas Reductions vs. NG in crop production

F. Renewable Energy Mandates and Cost of Transmission

- In regions with excellent wind resources, transmission can be expensive
- Utilities are not requiring additional power
- 25 x 25 mandate – Wind energy penetration needs to be high.

“Why not develop energy intense industry to utilize renewable energy in close proximity to where it is produced rather than exclusively build expensive transmission lines?”
Renewable Hydrogen and Ammonia Pilot Plant

Hydrogen and Nitrogen Production Building

Ammonia Production Building
Renewable Hydrogen and Ammonia Pilot Plant

- Hydrogen Storage Tanks
- Nitrogen Storage Tank
- Safety Equipment & Shower Building
- Ammonia Product Storage (3000 Gallons)
- 12.5 kV to 480 V Transformer
- Ammonia Pump and Loadout
Renewable Hydrogen and Ammonia Pilot Plant

60 kW HEC Hydrogen Engine Genset

Switch Gear
Renewable Hydrogen and Ammonia Pilot Plant

- Hydrogen Storage Tanks
- Hydrogen, Nitrogen, and Ammonia Production Buildings
- Nitrogen Storage Tank
- Safety Equipment & Shower Building
- 12.5 kV to 480 V Transformer
- Ammonia Product Storage (3000 Gallons)
- Ammonia Pump and Loadout
Another View
Water Deionization Unit and Safety Shower Pump
Hydrogen Electrolyzer (Proton Energy 10 kW)
Hydrogen Electrolyzer (Proton Energy 10 kW)
H2 Booster Diaphragm Compressor (220 to 2450 psi)
H2 and N2 Gas Storage Tanks (2450 psi)
Air Compressor and Dryer          N2 Gas Generation
N2 Booster Compressor (50-120 to 2450 psi)
H2 and N2 Gas Dew Point Detectors and Power Meters
Interior of H2 and N2 Production Building
HEC Oxx Power 60 kW Hydrogen Engine Generator
Data Acquisition to Determine Inputs and Outputs
NH3 Load Out, Storage, Nurse Tanks, & Application
New Goal – Carbon Balanced Agriculture

1. Reduce the utilization of fossil fuels in agricultural production systems
2. Increase local markets for renewable energy
3. Decrease economic and financial risk associated with fossil fuel based agricultural / rural economies
4. WCROC is ideal research location due to diverse production systems
   ▪ Conventional Crop and Livestock Systems
   ▪ Organic Crop and Livestock Systems
     ▪ No synthetic pesticides, commercial fertilizers, and pharmaceuticals for livestock
     ▪ “Hybrid Carbon-Balanced Crop and Livestock Systems”
       ▪ No fossil fuel based energy and fertilizer - limited use of synthetic pesticides
Opportunities for Wind to Ammonia

- Seek opportunities to be cost competitive, independent, and green
- Test novel catalysts and other techniques
- Can smaller scaled units be established?
- Investigate opportunities to buy power from wind resources that get “curtailed.”
- Determine opportunities for local investments to produce fertilizer inputs.
Plan of Investigation

- Determine factor inputs—kWh per Ton of H₂
- Determine power requirements to segregate the N₂
- Determine power required to synthesize the NH₃
- Study costs of U of M unit
- Model reasonable cost assumptions for scale-up
Other Avenues of Inquiry

- Determine competitiveness of greener NH$_3$ when markets or regulations penalize greenhouse gas emissions of farm inputs.
- GHG emissions from embedded natural gas used in NH$_3$ production to support corn production--- huge challenge for agriculture of U.S. and Minnesota
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