Minnesota Public Utilities Commission Planning Meeting

Green Ammonia for Fertilizer, Fuel, and Energy Storage

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Presented by:
Michael Reese
Director, Renewable Energy Program
University of Minnesota West Central Research and Outreach Center
Program Goal: Reduce fossil energy consumption in production agriculture

- 20 to 25% of GHG in Minnesota and the world attributed to agriculture, forestry, and related industries (MPCA, 2016; IPCC, 2017)

- 1% global GHG emissions attributed to ammonia and nitrogen fertilizer production

- Markets and policies are trending towards the need for GHG reductions in production agriculture
Green Ammonia

University of Minnesota is a global research leader in this field

In 2013, we established the first-in-the-world Wind-to-Ammonia Pilot Plant at the UMN WCROC, Morris, MN
U of MN 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

Slide 4
Wind Energy + Water + Air = Nitrogen Fertilizer

Step 1. Electrolysis of Water

\[ 2\text{H}_2\text{O} \rightarrow 2\text{H}_2 + \text{O}_2 \]

Step 2. Air Separation / Pressure Swing Absorption:

Oxygen (O\textsubscript{2}) and argon (Ar) are absorbed in a molecular sieve leaving nitrogen

\[ \rightarrow \text{N}_2 \]

Step 3. Haber or Haber-Bosch Process:

\[ \text{N}_2 \text{(g)} + 3\text{H}_2 \text{(g)} \leftrightarrow 2\text{NH}_3 \text{(g)} \quad \Delta H = -92.4 \text{ kJ} \]
US wind resource is synergistic with Midwest corn production and nitrogen fertilizer demand – inherently distributed

US nitrogen fertilizer demand could be met with approximately 50,000 MW of nameplate wind energy capacity – current US wind generation is 105,583 MW of nameplate capacity

Opportunity to utilize “stranded” wind and solar resources (and excess nuclear)

New technology and/or policy is needed for green N fertilizer to compete
Why green ammonia and why now?

Convergence of three primary factors:

1. Increased motivation on a global basis to address a changing climate
   - Current, N fertilizer production is responsible for 1% of all global greenhouse gas emissions
   - Policy and investment dollars are moving towards technologies (and companies) that support lowering GHG emissions

2. Financial motivation to store low cost intermittent renewables and excess nuclear power (caused by increased renewables on grid)

3. Storage is needed to achieve high renewable energy generation penetration and realization that ammonia is the best option to store and transport hydrogen
Green ammonia for fertilizer:
Transformational: Green ammonia is a drop-in replacement

Potential to reduce fossil energy use in corn production over 90% using ammonia (NH₃) produced using wind energy.

J. Tallaksen, 2016. UMN West Central Research and Outreach Center

Ammonia as regional-scale energy storage –
(Coupling Energy and Agriculture – “Sector Coupling”)

• Provides both distribution and transmission-scale energy storage,

• Wide range of fuel uses (Stationary ICE gensets, turbines, fuel cells, vehicles, marine, and thermal energy)

• Seasonal storage capability,

• Grid stabilization,

• Readily dispatchable generation capacity (Peak load and peak fertilizer months are complementary or rather during opposite seasons),

• Enables utilization of excess generation of wind, solar, and nuclear (low and negatively priced power within the Regional Transmission Organization / Independent System Operator),

• Provides emergency backup outside of traditional energy sources (E.g. Polar vortex when natural gas supply was maxed out),

• Flexibility between renewable and non-renewable generation (allows choice of carbon intensity of fuel between green, blue, and brown ammonia)

• Significant levels of ammonia storage already in the Midwest (and usually near distribution and transmission lines), and

• Multiple avenues of green synthesis (electricity, methane from manure, gasification, etc)
Economics of hydrogen and ammonia energy storage

- Islanded renewable energy systems with 1000 kW annual average demand
- Combined optimal sizing and scheduling to minimize LCOE
- NREL data bases for weather/demand

Combining ammonia and hydrogen gives lowest cost in all locations
Optimal economics: Levelized cost of energy

- Batteries alone are expensive (especially for significant long-term storage)
- Hydrogen provides improvement
- Hydrogen and ammonia is optimal – Hydrogen is better short-term storage but, ammonia is better long-term storage as it is significantly less costly to store
Estimated cost of ammonia per ton at regional-scale with new distributed production technology

Ammonia production cost sensitivity to electricity price at 50,000 tonNH₃/year

Palys et al. (2019)
Large-scale ammonia storage is already in place:

CF Industries Glenwood Ammonia Terminal
- Capacity of 60,000 tons of NH$_3$
- Equivalent to an estimated 111,000 MWh of electricity
- Wind and solar PV in close proximity
- Capex 500 kV line in close proximity
- Hub for wind energy transmission
Proposed 1 MT/day Ammonia Technology Integration

Renewables-based Market
- Midwestern market ideally located with access to renewables
- Well-developed market for fertilizers; potential for storage

Integration with existing NH₃ plants
- Drop-in opportunity for greenfield plant designs
- Debottleneck existing plants

Modular Process Design
Low temperature ammonia synthesis
Low-cost separation to minimize cost
Integration with state-of-the-art feed supply
Operational flexibility for load following
Conclusions:

✓ The agriculture industry should play a significant role in green ammonia production and utilization

✓ Conventional nitrogen fertilizer production represents approximately 1% of all global greenhouse gas emissions

✓ The carbon-intensity of grain, meat, milk, ethanol, and other agricultural products is highly influenced by the conventional production of nitrogen fertilizer

✓ The distributed nature of renewable electricity generation favors regional production of green nitrogen fertilizer over centralized plants

✓ Coupled with the declining costs of wind and solar generation, green ammonia production technologies are becoming cost competitive

✓ Hydrogen is ideal for short-term energy storage (higher efficiency) while ammonia is ideal for long-term energy storage (low-cost storage)

✓ Green ammonia can play a transformational role to de-carbonize agriculture and in achieving 100% renewable energy generation
Moving forward:

1. Pilot and demonstration projects are needed
   - US DOE REFUEL program ($14.5 million proposal)
   - XCEL RDA bill at MN legislature ($5 to $20 million)

2. Education, organization, and advocacy
   - Central States Hydrogen Roundtable

3. Green ammonia certification and tracking
   - M-RETS

4. State and national green ammonia policy to encourage
devlopment of a promising industry
   - Perhaps similar to ethanol policies

5. Regulatory questions — RECs, certification / tracking, fuel usage,
   permitting generators, emissions, cross-sector applications, etc

Green ammonia is ready for the next step! Minnesota can continue to play a
leadership role in this emerging industry while creating new businesses and
jobs. How will Minnesota position itself moving forward?
Acknowledgements

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- United States Department of Energy ARPA-E REFUEL Program
- University of Minnesota College of Food, Agricultural, and Natural Resource Sciences (CFANS)
- Clean Energy Resource Teams (CERTS)
- Electric Power Research Institute (EPRI)
Resources and Contact Information:

https://extension.umn.edu/crop-production#nutrient-management

https://wcroc.cfans.umn.edu/research-programs/renewable-energy/ammonia

https://www.nass.usda.gov/

https://www.fertilizer.org

https://www.ammoniaenergy.org/

Contact Information:
Michael Reese
Director, Renewable Energy Program
West Central Research & Outreach Center
University of Minnesota
Phone during COVID: (320) 760-6016
Email: reesem@umn.edu
Website: https://wcroc.cfans.umn.edu
BACKUP SLIDES
Cost Targets and Formulations for Common Ag Fertilizers:

- Nearly all synthetic forms of N fertilizer use ammonia (NH₃) in the production process
- US nitrogen fertilizer market is roughly a $6 billion industry
- Minnesota farmers spend between $500 to $800 million per year on N fertilizer
- US nitrogen fertilizer market could be supplied 100% by adding ~50,000 MW of wind capacity
- Farmers could participate in ownership of green ammonia production

### US Retail Agricultural Fertilizer Prices

<table>
<thead>
<tr>
<th>Common Fertilizer Types</th>
<th>N-P-K or Percent Available</th>
<th>Retail Price / Short Ton¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anhydrous Ammonia (NH₃)</td>
<td>82-0-0</td>
<td>$450</td>
</tr>
<tr>
<td>Urea</td>
<td>46-0-0</td>
<td>$360</td>
</tr>
<tr>
<td>UAN 28% Liquid</td>
<td>28-0-0</td>
<td>$275</td>
</tr>
<tr>
<td>MAP</td>
<td>11-52-0</td>
<td>$455</td>
</tr>
<tr>
<td>DAP</td>
<td>18-46-0</td>
<td>$430</td>
</tr>
<tr>
<td>Potash</td>
<td>0-0-60</td>
<td>$330</td>
</tr>
<tr>
<td>Sulfur</td>
<td>90%</td>
<td>$1,000</td>
</tr>
<tr>
<td>Zinc</td>
<td>35%</td>
<td>$2,000</td>
</tr>
<tr>
<td>Boron</td>
<td>12%</td>
<td>$2,000</td>
</tr>
</tbody>
</table>

¹(11/10/2020 retail prices from a Minnesota ag cooperative)
## Estimated US Agriculture Fertilizer Market for Major Crops

<table>
<thead>
<tr>
<th>Crop</th>
<th>Acres planted in US&lt;sup&gt;1&lt;/sup&gt; (in millions)</th>
<th>Est. Nutrient Requirement/ ac N-P-K-S-Zn-B</th>
<th>Est. Total N (Short tons)</th>
<th>Est. Total P (Short tons)</th>
<th>Est. Total K (Short tons)</th>
<th>Est. Total S (Short tons)</th>
<th>Est. Total Zn (Short tons)</th>
<th>Est. Total B (Short tons)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn</td>
<td>92.0</td>
<td>180-80-80-15-1-0</td>
<td>8,280,000</td>
<td>3,680,000</td>
<td>3,680,000</td>
<td>690,000</td>
<td>46,000</td>
<td>0</td>
</tr>
<tr>
<td>Soy</td>
<td>83.8</td>
<td>18-46-60-10-0-0</td>
<td>754,200</td>
<td>1,927,400</td>
<td>2,514,000</td>
<td>419,000</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Wheat</td>
<td>44.3</td>
<td>80-40-40-10-1-0</td>
<td>1,772,000</td>
<td>886,000</td>
<td>886,000</td>
<td>221,500</td>
<td>22,150</td>
<td>0</td>
</tr>
<tr>
<td>Cotton</td>
<td>12.2</td>
<td>80-40-40-10-1-0.5</td>
<td>488,000</td>
<td>244,000</td>
<td>244,000</td>
<td>61,000</td>
<td>6,100</td>
<td>3050</td>
</tr>
<tr>
<td>Alfalfa</td>
<td>11.7</td>
<td>0-90-90-10-0-1</td>
<td>0</td>
<td>526,500</td>
<td>526,500</td>
<td>58,500</td>
<td>5,850</td>
<td>5850</td>
</tr>
</tbody>
</table>

### Fertilizer Retail Value<sup>2</sup>

<table>
<thead>
<tr>
<th></th>
<th>$6.2 to $8.1 Billion (NH₃/urea)</th>
<th>$6.8 Billion</th>
<th>$4.3 Billion</th>
<th>$1.6 Billion</th>
<th>$458 Million</th>
<th>$148 Million</th>
</tr>
</thead>
</table>

<sup>1</sup>USDA Acreage Report, National Agriculture Statistics Service (NASS), June 30, 2020 ISSN: 1949-1522

<sup>2</sup>A portion of the nutrients will be supplied by livestock manure and other organic fertilizers.
Optimal economics: LCOE cost breakdown for H₂ and combined systems

- Renewable generation infrastructure costs dominate: 55-75%
- Ammonia production costs not significant: 11-16$/MWh

Why do we need ammonia?
Hydrogen and Ammonia Renewable Energy Storage Systems

Optimal Schedules: Minneapolis, MN

Hydrogen: fast / ammonia: slow (seasonal) → efficiency vs. storage cost
Large-scale ammonia storage is already in place: