Minnesota Senate Energy Committee

Green Hydrogen and Ammonia: Implications for Minnesota

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Presented by:
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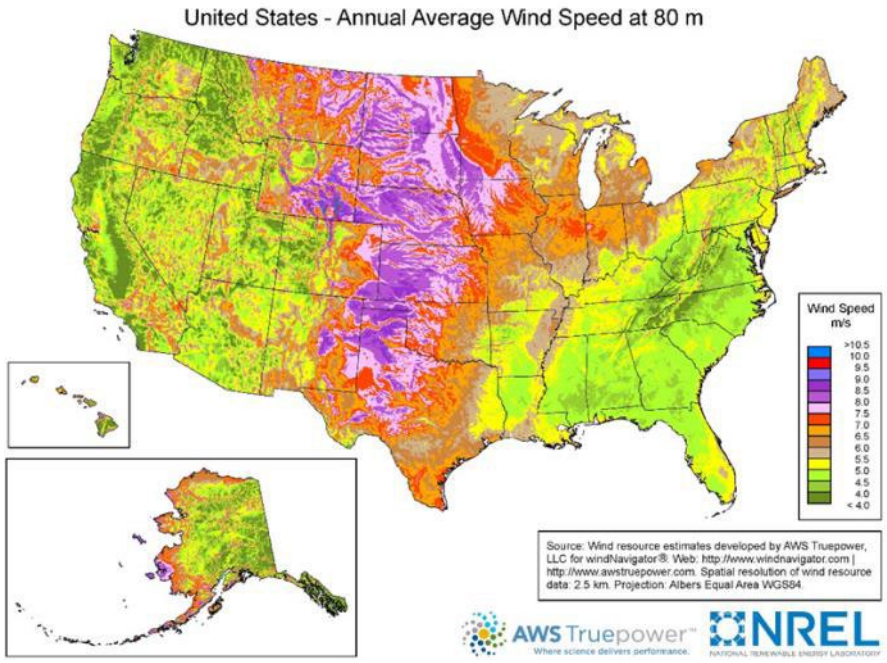
West Central Research & Outreach Center
"Leading innovation in agriculture and beyond"

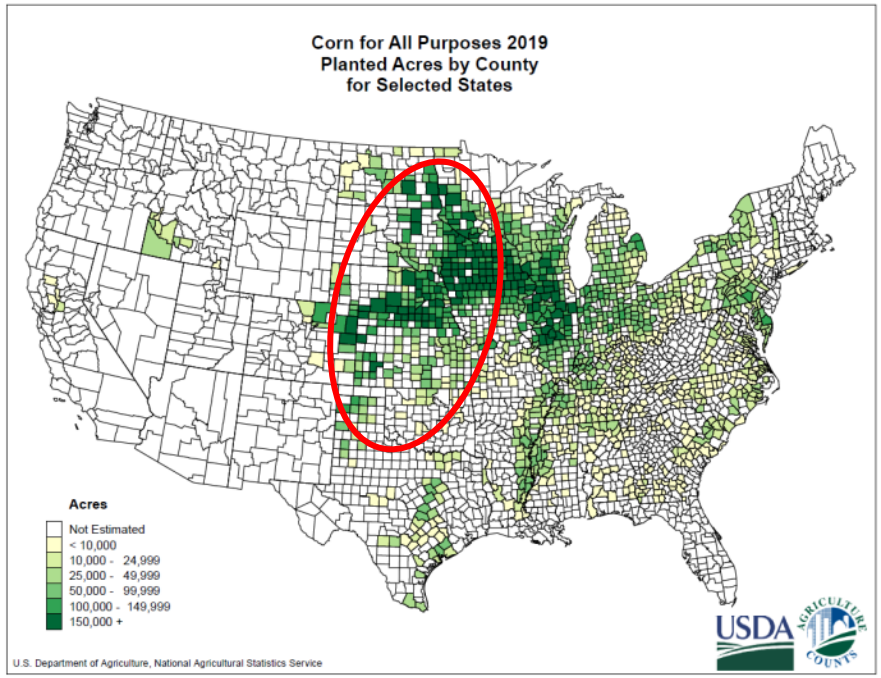
Decarbonizing Midwest Industry and Utilities using Zero-Carbon Hydrogen

Climbing the green hydrogen use-case ladder in Minnesota:

1. **Agriculture** – Drop-in green ammonia and urea fertilizer; use ammonia for fueling grain drying, tractors, and trucks.
2. **Power generation and thermal energy** - Fuel gas turbines, engine gensets, and burners and boilers.
3. **Biofuel production** – Use green hydrogen for production of renewable diesel, jet fuel (SAF), methanol, and ethanol. Capture and recycle CO_2 normally emitted via fermentation to produce these fuels.
4. **Medium and Heavy Transportation Industry** – Switch to hydrogen and ammonia to fuel trucks, mining equipment, tractors, train engines, and ships.
5. **Mining and Steel Making** – Displace energy used in processing ore into iron pellets as well as the carbon purification process within steel making.
6. **Construction** – Use hydrogen and-/- or ammonia to heat kilns used in the production of quick lime. Capture CO2 released during heating of limestone for urea or renewable fuels production.

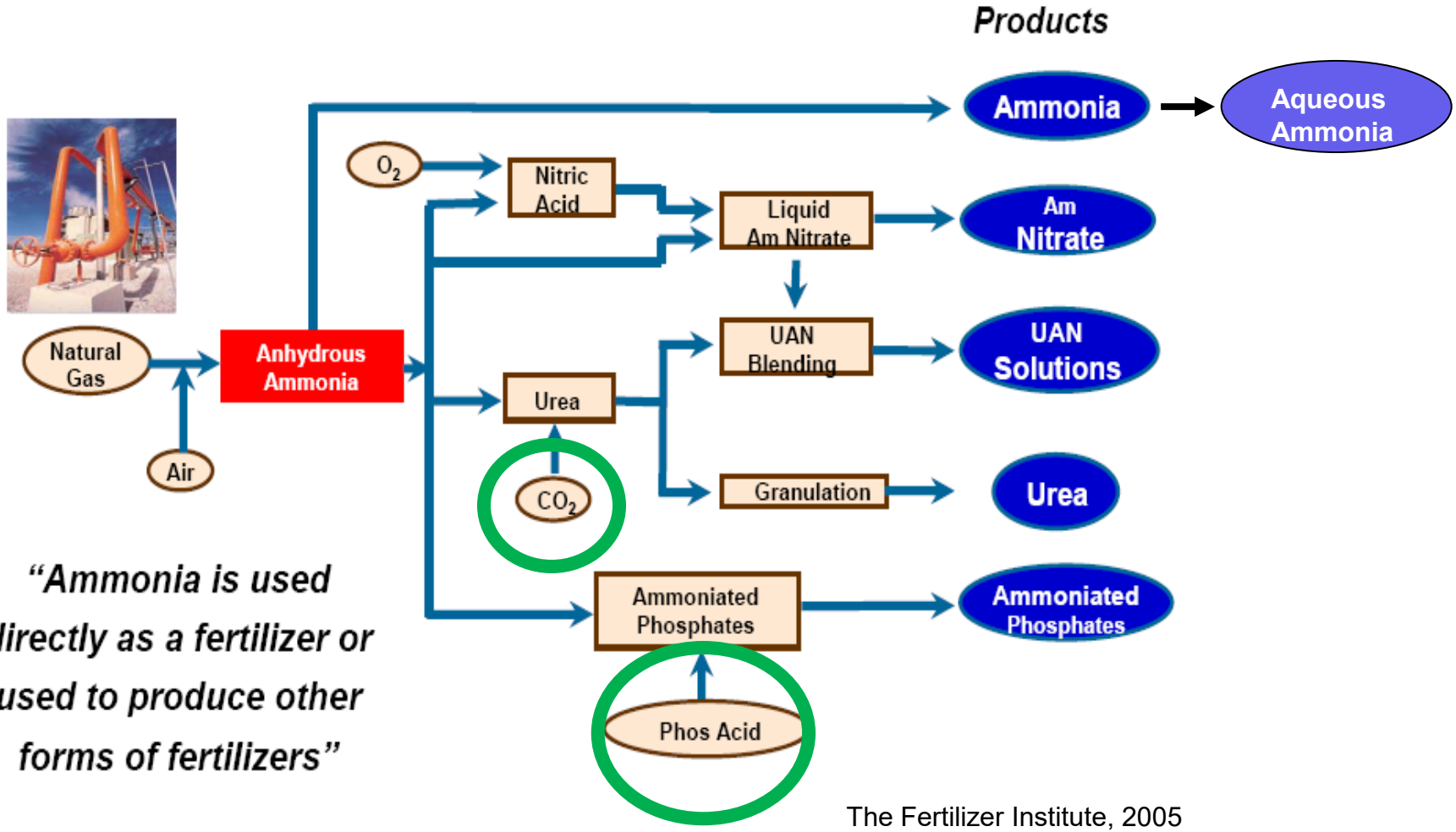
Scale: Green Ammonia





- 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)
- Nitrogen fertilizer is a gateway to other green hydrogen uses – export potential

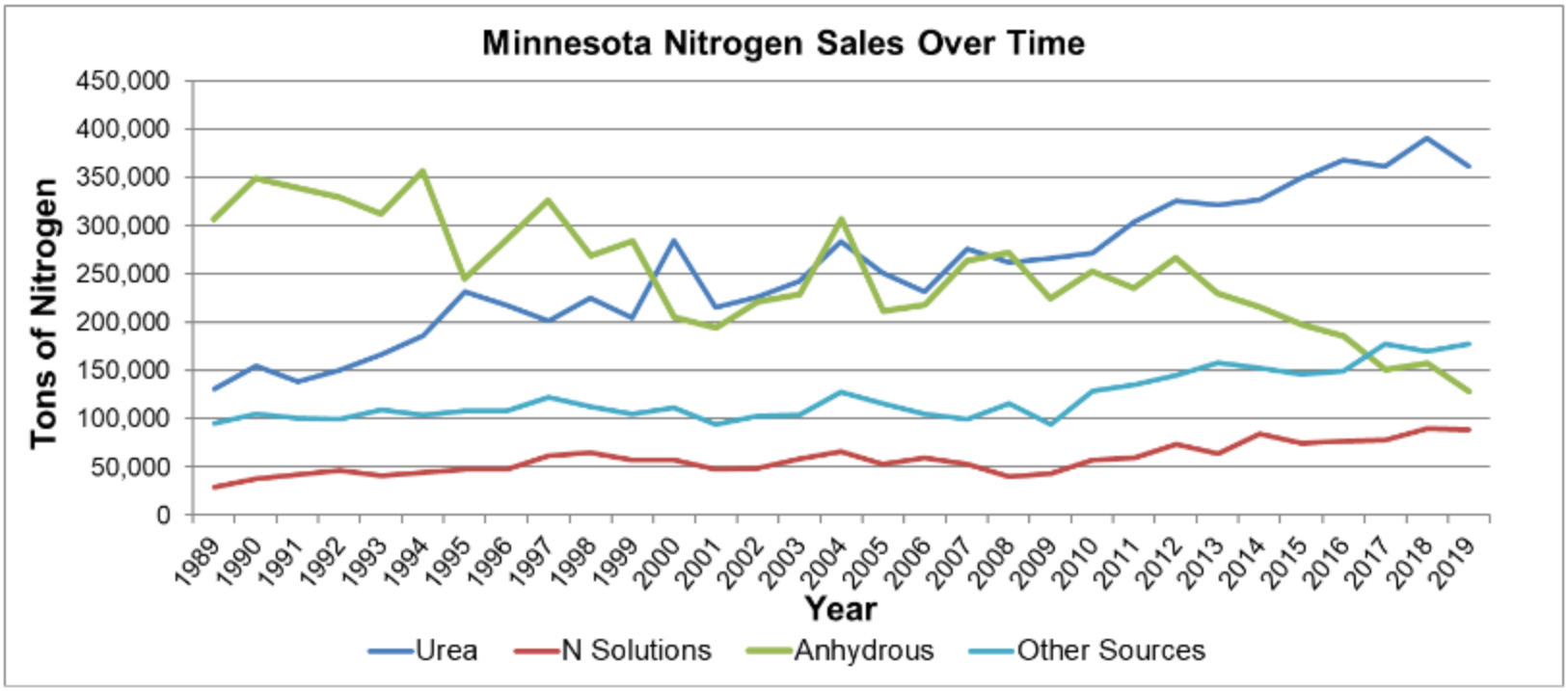
Nitrogen Fertilizer Production



The Fertilizer Institute, 2005

- Proven commercial technology currently available to produce hydrogen, ammonia, urea, and other hydrogen-based fuels in Minnesota.

Bottom-line: With new federal incentives, we can economically meet all nitrogen fertilizer needs in Minnesota /Midwest with green nitrogen fertilizer!



Source: MN Dept. of Agriculture

Green Ammonia: An Elegant Solution

Wind or Solar Energy + Water + Air = Nitrogen Fertilizer

Step 1. Electrolysis of Water

$2H_20 \longrightarrow \mathbf{2H_2} + O_2$

Step 2. Air separation

O_2 and Ar are absorbed in a molecular sieve leaving $\mathbf{N_2}$

Step 3. Haber Bosch Process

$N_{2(g)} + 3H_{2(g)} \rightleftharpoons \mathbf{2NH_{3(g)}}$

$\triangle$ **H = -92.4 kJ**

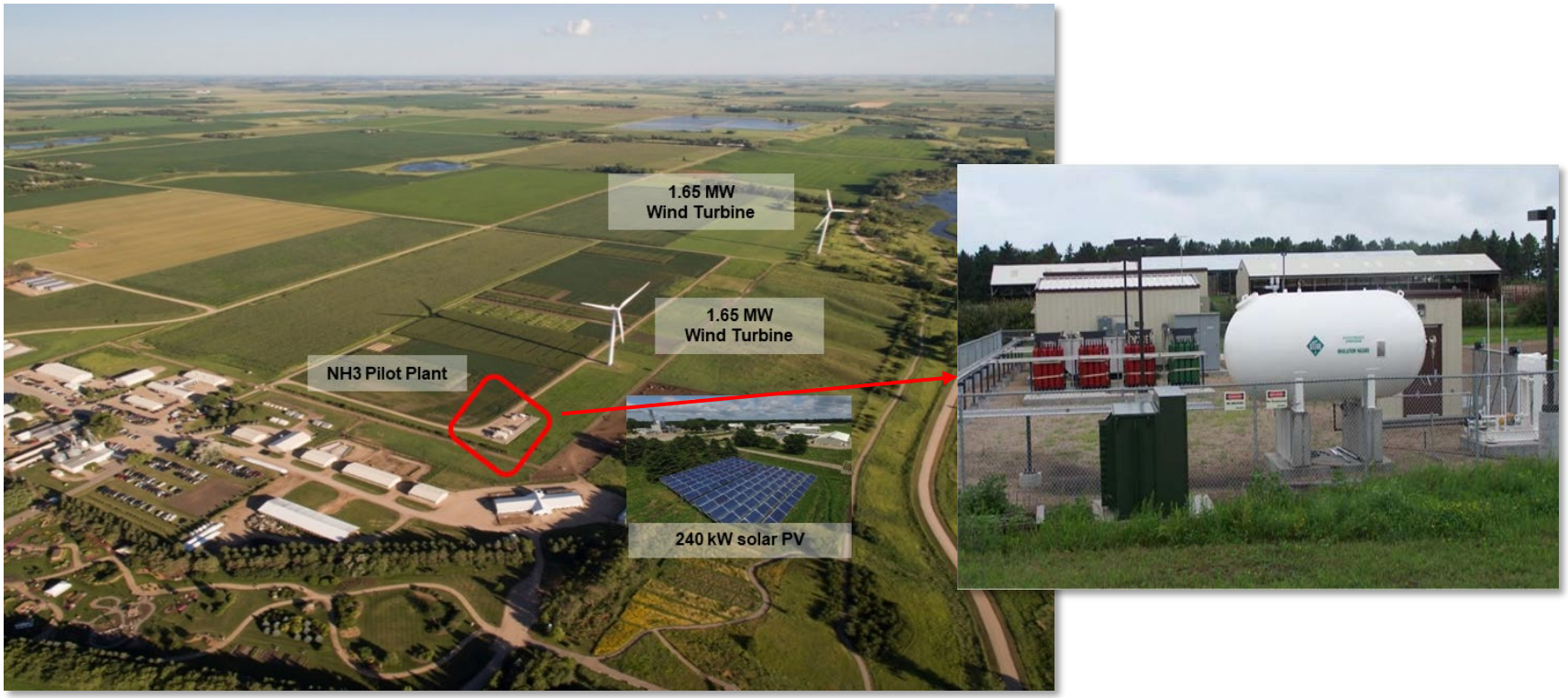
Step 4. Urea Production (Granular N fertilizer)

$2NH_3 + CO_2 \rightarrow NH_2COONH_4$ (ammonium carbamate)

$NH_2COONH_4 \rightarrow H_2O + \mathbf{NH_2CONH_2}$ **(dry, granular urea)**

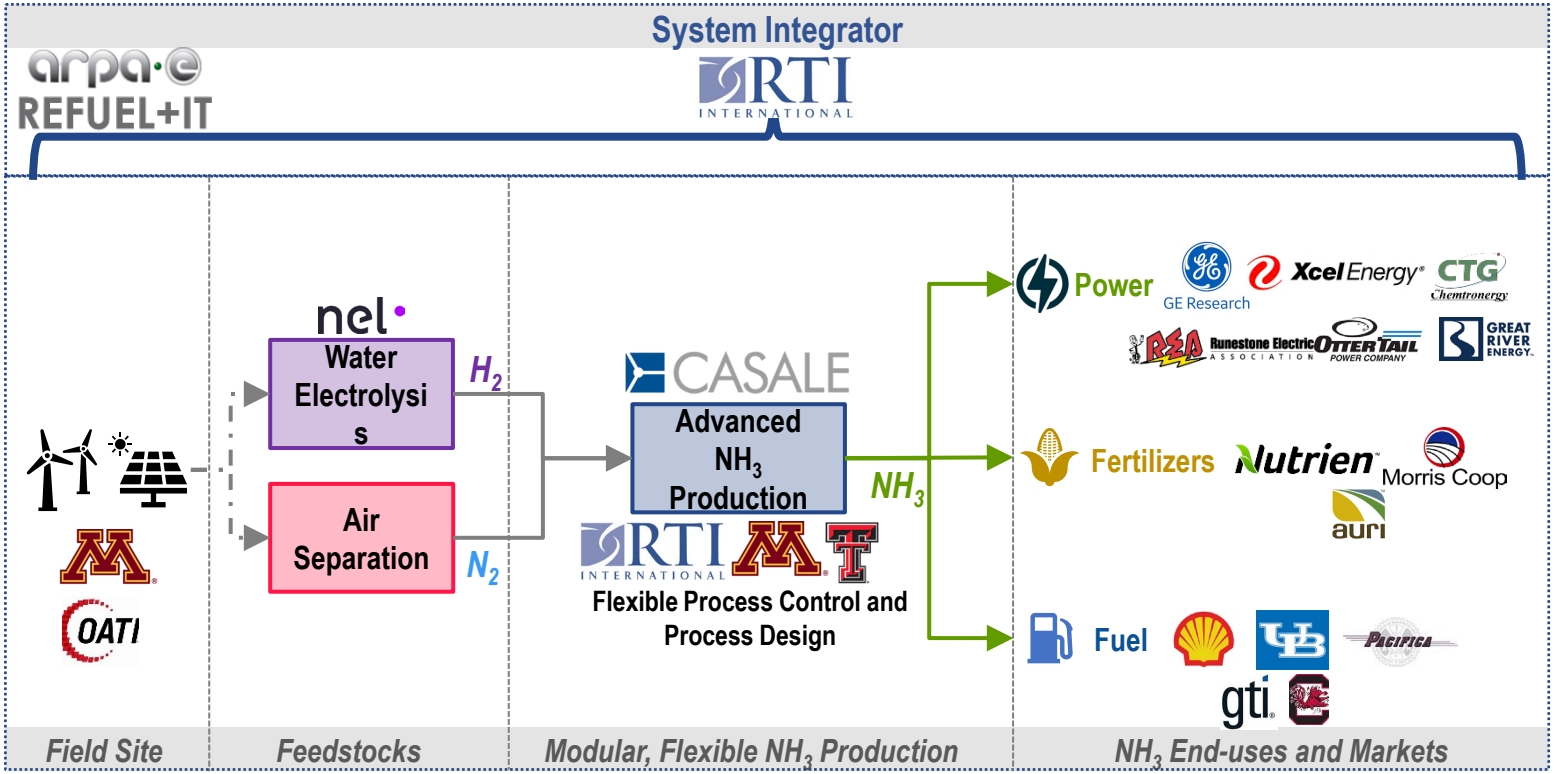
- Carbon capture - Use CO_2 from ethanol production
- circular model

Research to improve efficiency:
US DOE ARPA-E REFUEL Technology Integration Project



~18x scale-up of existing wind-to-NH_3 pilot plant

Next Generation Ammonia Production from Wind and Solar

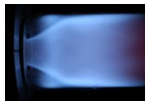


Next-gen NH_3 production and utilization technologies	Demonstrate under real-world conditions	Connect with end-users and markets to accelerate commercialization

What are we doing with the Ammonia?

Power

Retrofit options for aeroderivative gas turbine to burn NH_3



GE Research

Demonstrate a 1-kW direct NH_3 fuel cell

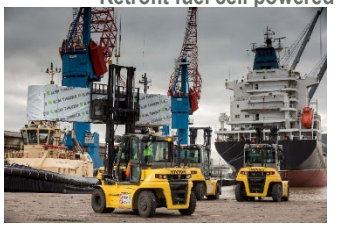
CTG Chemtronergy

- Portable engine genset / non-wire solutions
- Grain dryer
- HRSG duct burner

Fuel

Develop and operate a NH_3-powered forklift

- High purity H_2 from NH_3 cracking membrane
- Retrofit fuel cell powered forklift



gti. PACIFICA

- Ammonia-fueled tractor

Fertilizers

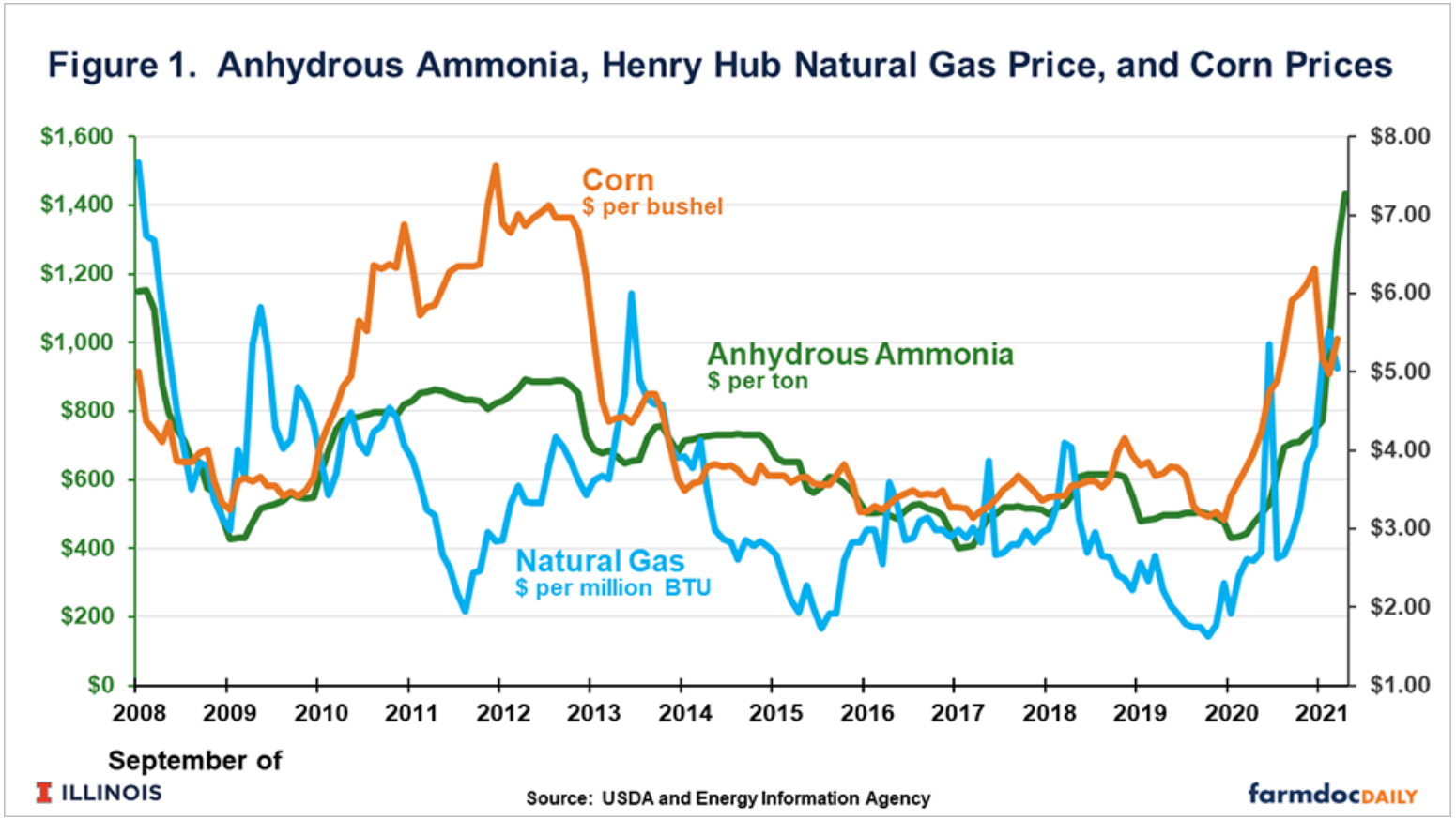
Off-take agreement with local fertilizer co-op

Morris Coop

Demonstrating the full value chain of low- and zero-carbon Ammonia

Why renewable ammonia?

- **Price certainty and stability:** decoupling from global natural gas market
- **Reduce carbon intensity**: >2.6 mt_{CO2}/mt to <0.2 mt_{CO2}/mt
- **United States policy:** Federal clean H_2 production credits up to $3/kg
  - $529/mt ammonia production credit for first 10 years of production!

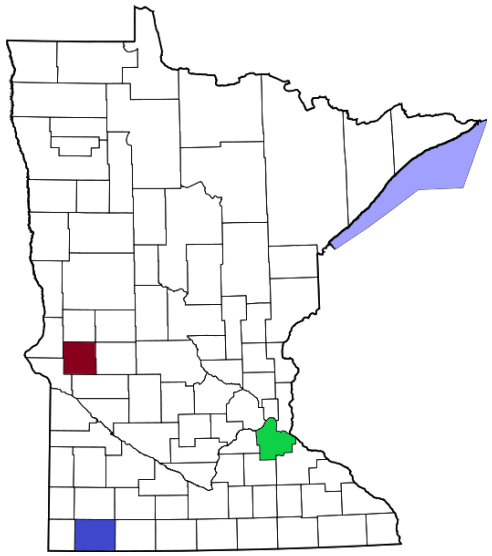


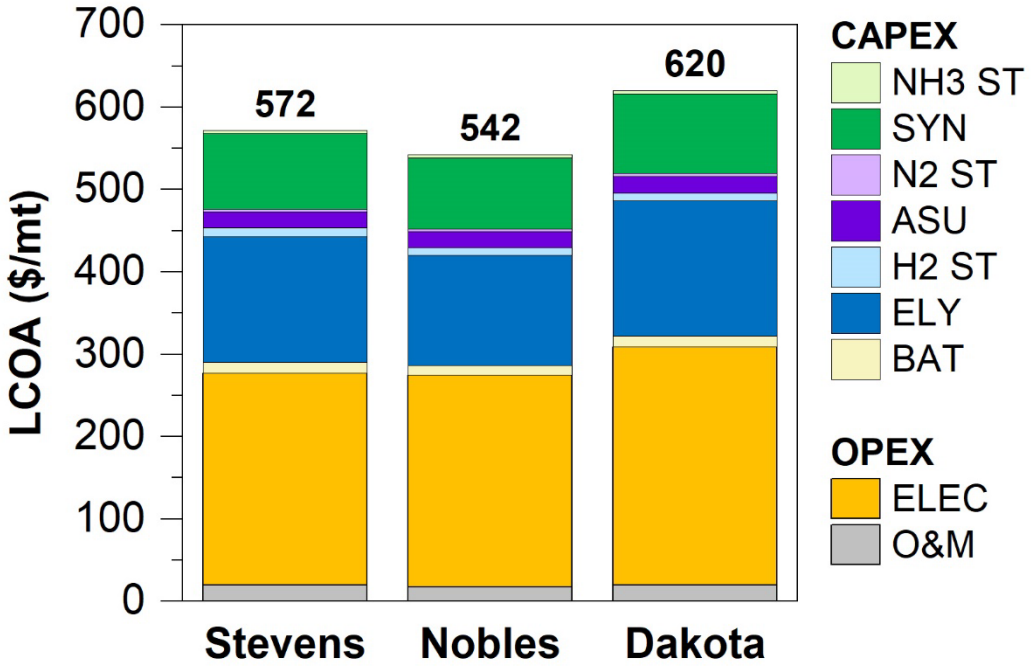
Palys, et. al. 2022

Production cost depends on location

- **Stevens county: 44% wind, 15% PV**
- **Nobles county: 52% wind, 16% PV → *-$30/mt* than Stevens**
- **Dakota county: 36% wind, 15% PV → *+$50/mt* than Stevens**

Does not include $529 / metric ton NH_3 value from H_2 incentive!





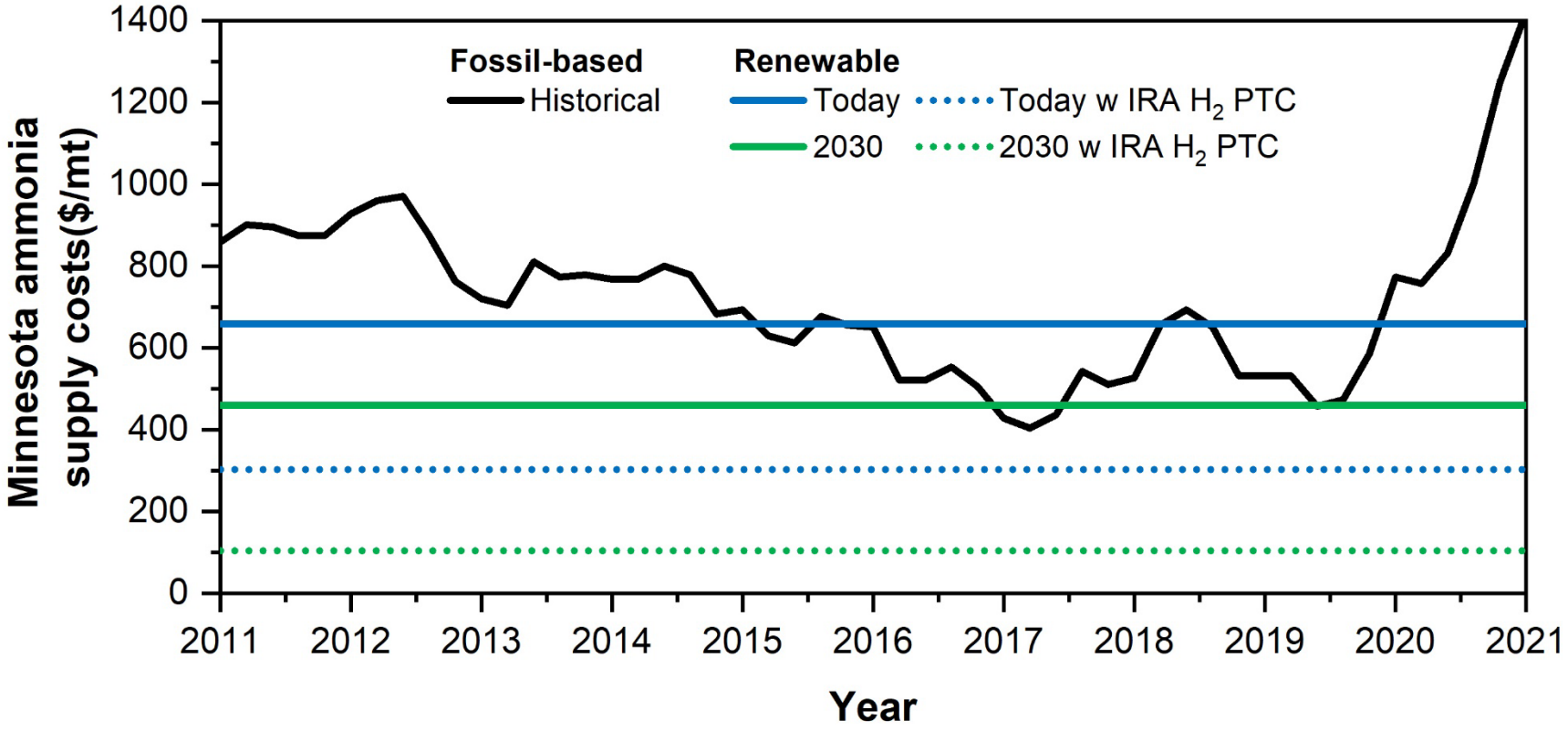
Design for each location to minimize LCOA

Palys, et. al. 2022

IRA H_2 PTC is transformative

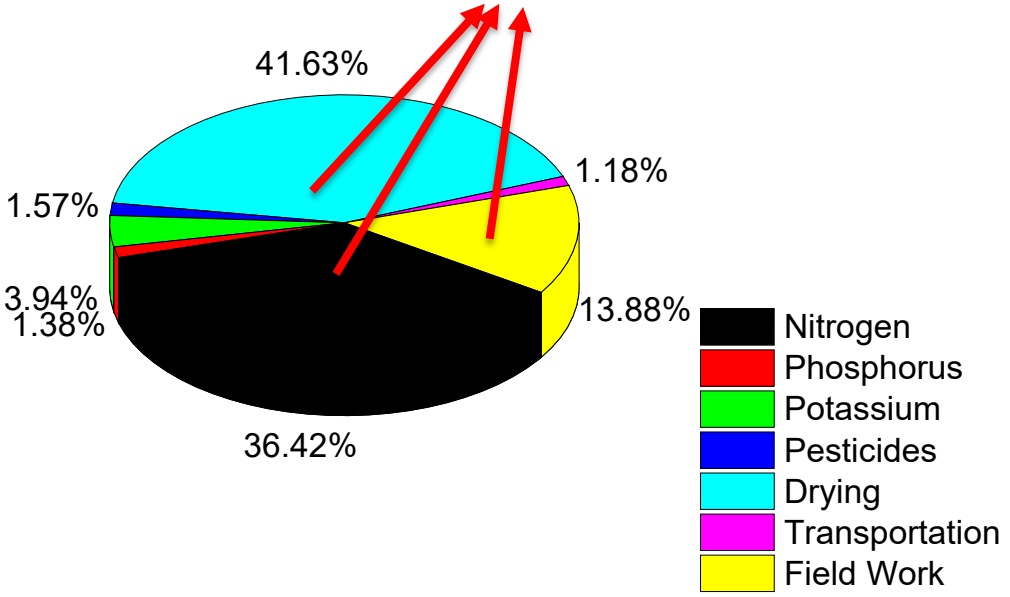
IRA: $3/kg H2 credit for CI<0.45 kg_{CO2}/kg_{H2}, labor/wage requirements met

- **$529/mt ammonia for first 10 years of production (ammonia CI<0.08 mt_{CO2}/mt_{NH3})**
- **$356/mt ammonia levelized over 20 year project with 7.5% discount rate**



Transformational: Green ammonia is a drop-in replacement

Potential to reduce fossil energy use in corn production over 90% using ammonia (NH_3) produced using wind energy.



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

NH_3 – Fueled Grain Dryer Demonstration

- Successfully tested Oct & Nov 2022
- Scaled burner application
- 245 Bushel Capacity
- 20/80 mix of H_2/NH_3

Tractor fueled by renewable ammonia

(Reese, 2019)

Field tested June 2019

Ammonia-fueled tractor and Semi incorporating a cracker and fuel cell

Source: Amogy

Take Home Green Hydrogen and Ammonia Message:

- The Inflation Reduction Act provides a $3 /kg of hydrogen production incentive with a direct pay option and this has dramatically changed the playing field making production and use economical.

- The University of Minnesota is working to improve the technology. However, green hydrogen and ammonia production systems are commercially available and ready for deployment within the State.

- The question now is “How does the State best position itself to take advantage of this opportunity?”

- Our focus is on agriculture and bringing this technology to Minnesota farmers, farm cooperatives, and businesses but there are broad implications for the State.

- Farmer-owned groups could utilize renewable hydrogen for production of anhydrous ammonia, urea, methanol, sustainable aviation fuel, and other molecules.

- Green nitrogen fertilizer (anhydrous ammonia and urea) is a gateway for other green hydrogen energy applications within Minnesota.

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- Clean Energy Resource Teams (CERTS)
- Electric Power Research Institute (EPRI)
- MnDRIVE

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