

Utilizing Wind Energy to Produce Nitrogen Fertilizer: Key Challenges and Opportunities

6th Ammonia As a Fuel Conference

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West Central Research
& Outreach Center

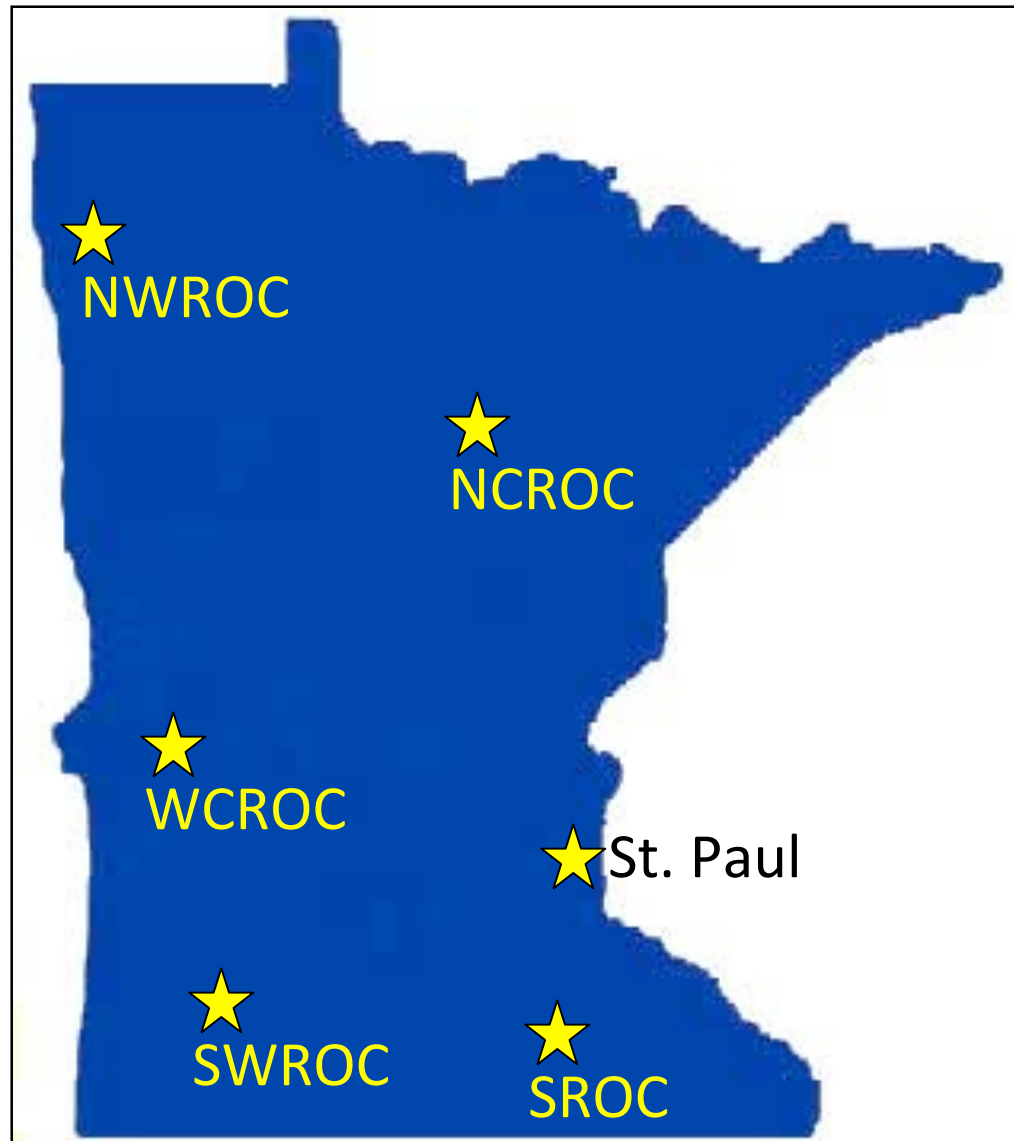
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Overview:

1. Agricultural Research Station
2. Serve as Living Lab and Public Access Point
3. Developing Community Scale Renewable Energy Systems
4. Focus on Local Ownership



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Overview

Community-Scale Renewable Energy Systems:

- Hybrid Wind System
- Biomass Gasification System
- Community Biogas System
- Renewable Energy / Green Office Building

Practical production systems with research and demonstration platforms

“Destination Renewable Energy Research & Demonstration Systems”



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Wind to Ammonia Participants

University of Minnesota

- West Central Research & Outreach Center – Morris
- University of Minnesota, Morris (UMM)
- Institute of Technology
- Initiative for Renewable Energy and the Environment (IREE)
- College of Food, Agriculture, and Natural Resource Sciences (CFANS)



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Wind to Ammonia Participants

Industry & Public Partners

- **Sebesta Blomberg and Associates**
- **Statoil Hydro (formerly Norsk Hydro)**
- **Xcel Energy**
- **State of Minnesota**
- **Minnesota Environmental Trust Fund**
- **National Renewable Energy Lab**
- **Design - build firm**





Wind Turbine:

1. 1.65 MW Vestas V-82
2. Installed March 2005
3. Produces 5.4 mil kWh / yr
4. Energy first used for research
5. Excess sold via direct line to University of Minnesota, Morris
6. Provides campus with over 80% of electrical energy needs



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Hybrid Wind System

Phase I – Hydrogen & Electrical Energy Production

1. Electrolyzer
2. Compressor
3. Hydrogen Storage
4. ICE Engine Generator
5. Grid Interconnection
6. Web Enabled SCADA



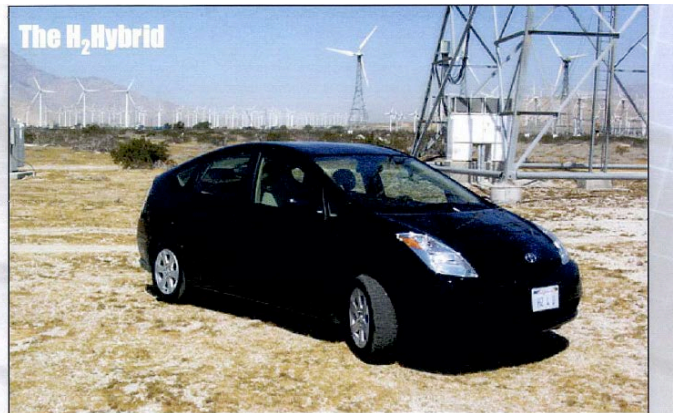
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Hybrid Wind System

Phase II: Value Added Wind Energy & Bridge Technologies

1. Production of Anhydrous Ammonia

- Nitrogen fertilizer*
- Refrigeration and other uses*



A Cost-Effective Low-Emission Hydrogen-Powered Hybrid-Electric Vehicle.



2. Transportation Fuel

- Fleet vehicles*
- Service vehicles*
- Cars and pickups*



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Hybrid Wind System

Phase III: System Integration “Wind Energy Refinery”

1. Business / Commercial Modeling
2. Hydrogen and Ammonia Fuel Cells
3. Hydrogen – Natural Gas Mixed Turbine (2-3 MW) and Boilers
4. Hydrogen or H₂ and Natural Gas Pipeline System
5. Combined power generation, valued added products, energy storage, and natural gas displacement



Norway's Hydrogen and Ammonia History



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Initial Process – Nitric Acid



Early power station dedicated to make fertilizer



Ovens with "standing arcs" to produce NO



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In 1928 – Hydro converted to make fertilizer via hydrogen and ammonia



Electrolysers installed at Rjukan 1930, 150 units, 30 000 Nm³/hr, 150 MW



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In 1928 – Hydro converted to make fertilizer via hydrogen and ammonia

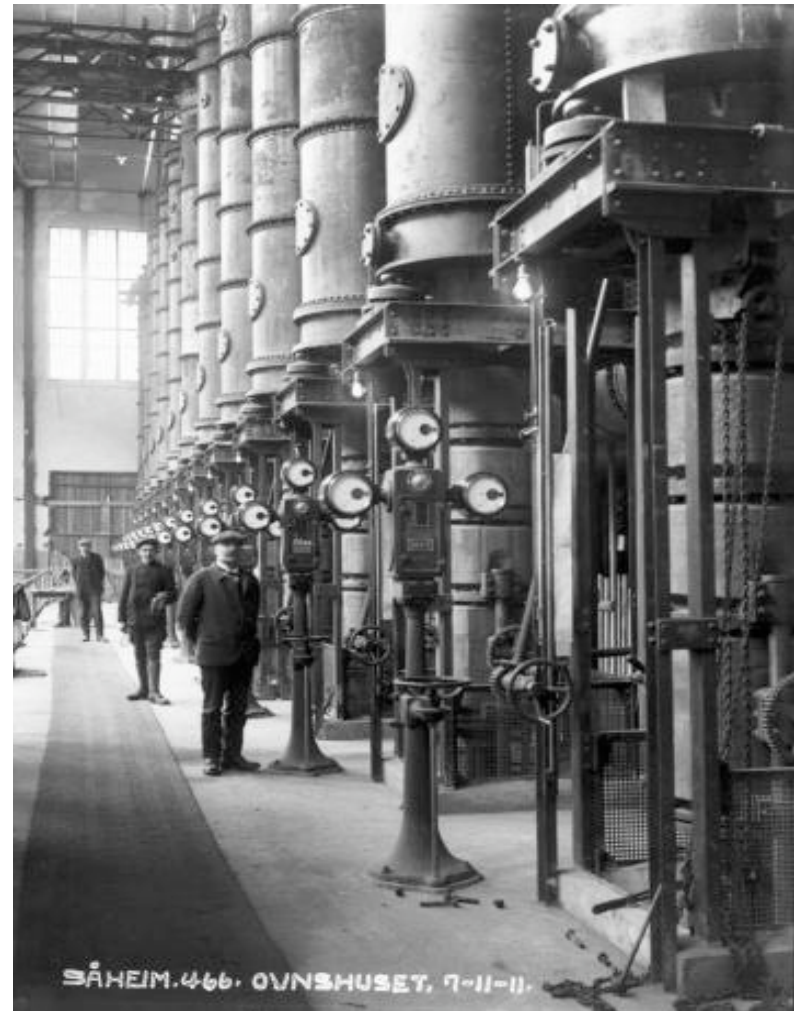
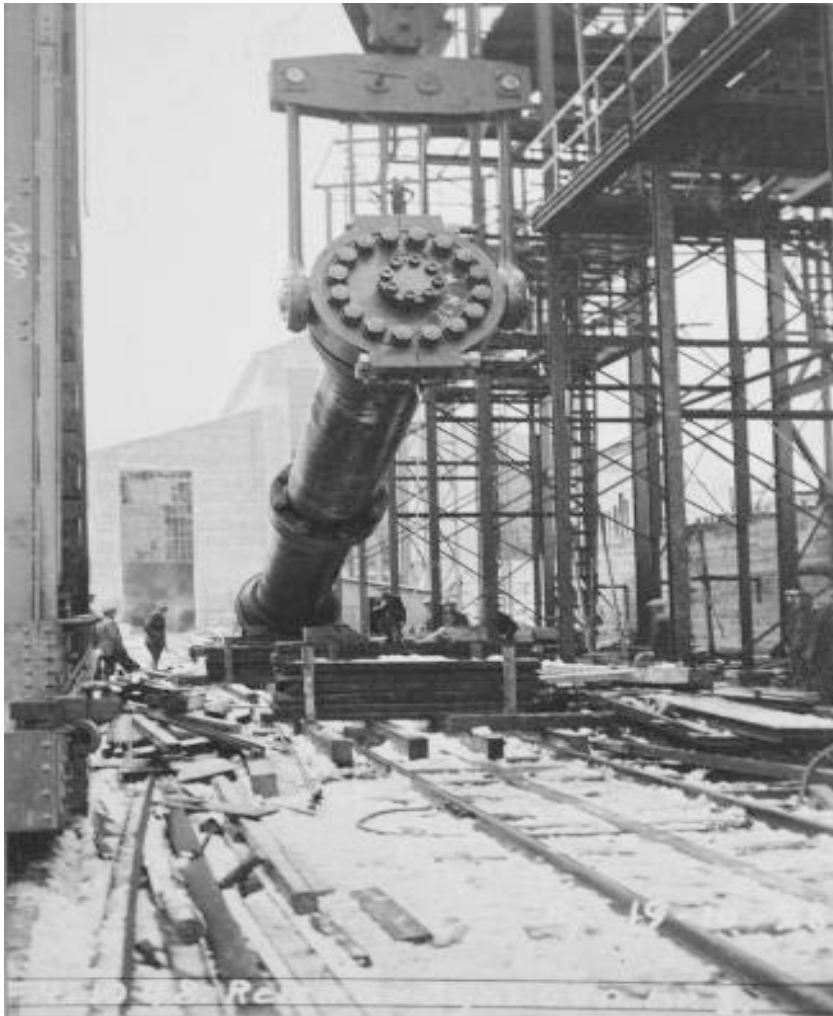


Electrolysers installed at Rjukan 1930, 150 units, 30 000 Nm³/hr, 150 MW



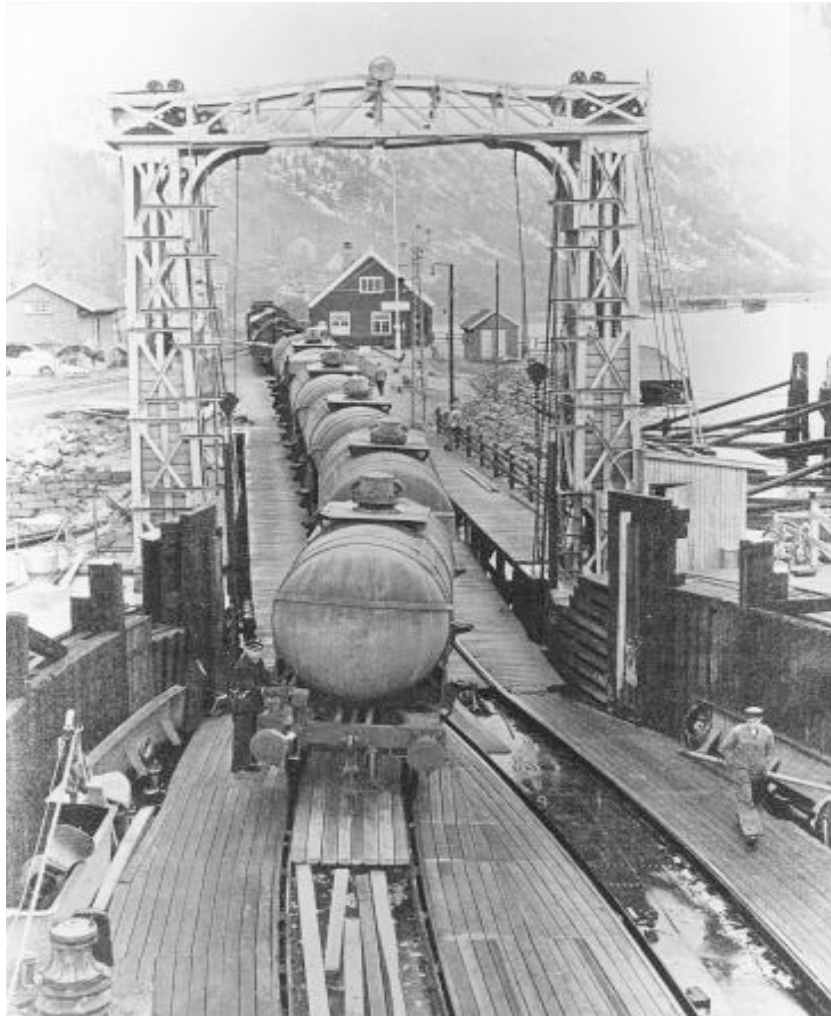
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Hydrogen and nitrogen transported down the valley to Rjukan and made into ammonia



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Ammonia transported 150 miles by rail across inland lakes to the shore at Porsgrunn

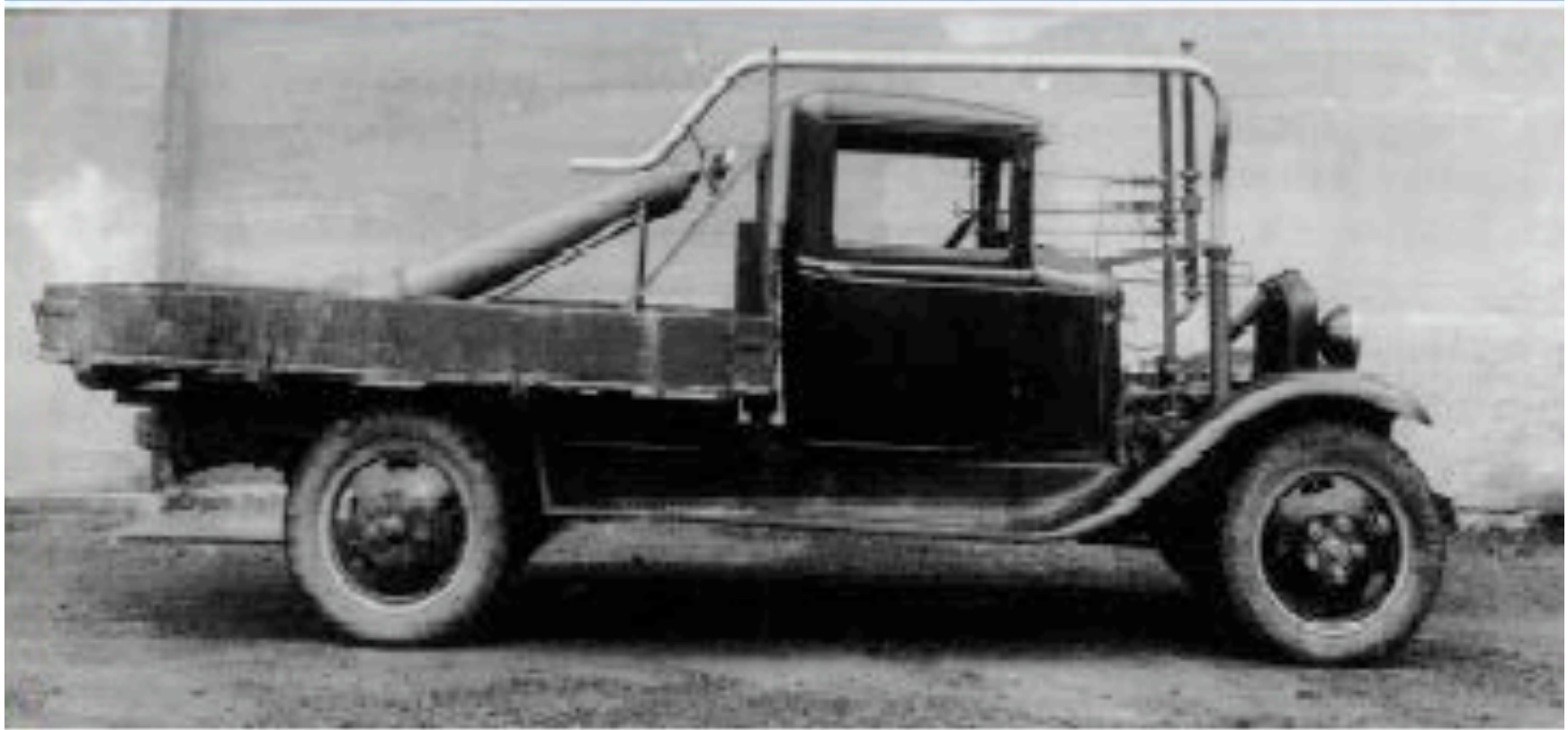


Hydro gradually converted to natural gas based ammonia production from the late 60's
Kept electrolyzers going as a separate business, sold the fertilizer unit in 2004 (now Yara).



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Ammonia Powered Truck - Rjukan



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First Wind to Hydrogen System in Utsira, Norway



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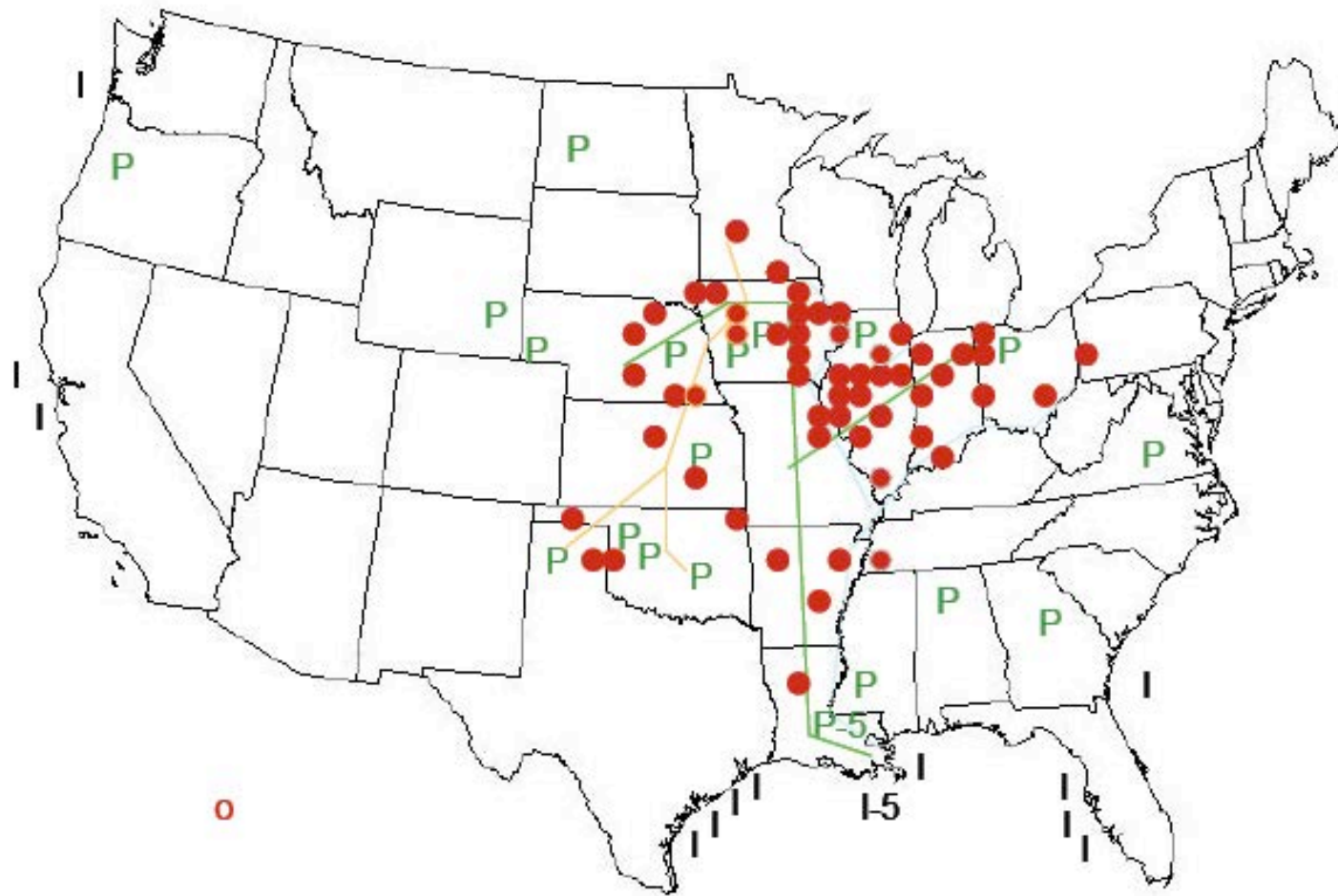


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The Midwest's H₂ and NH₃ History



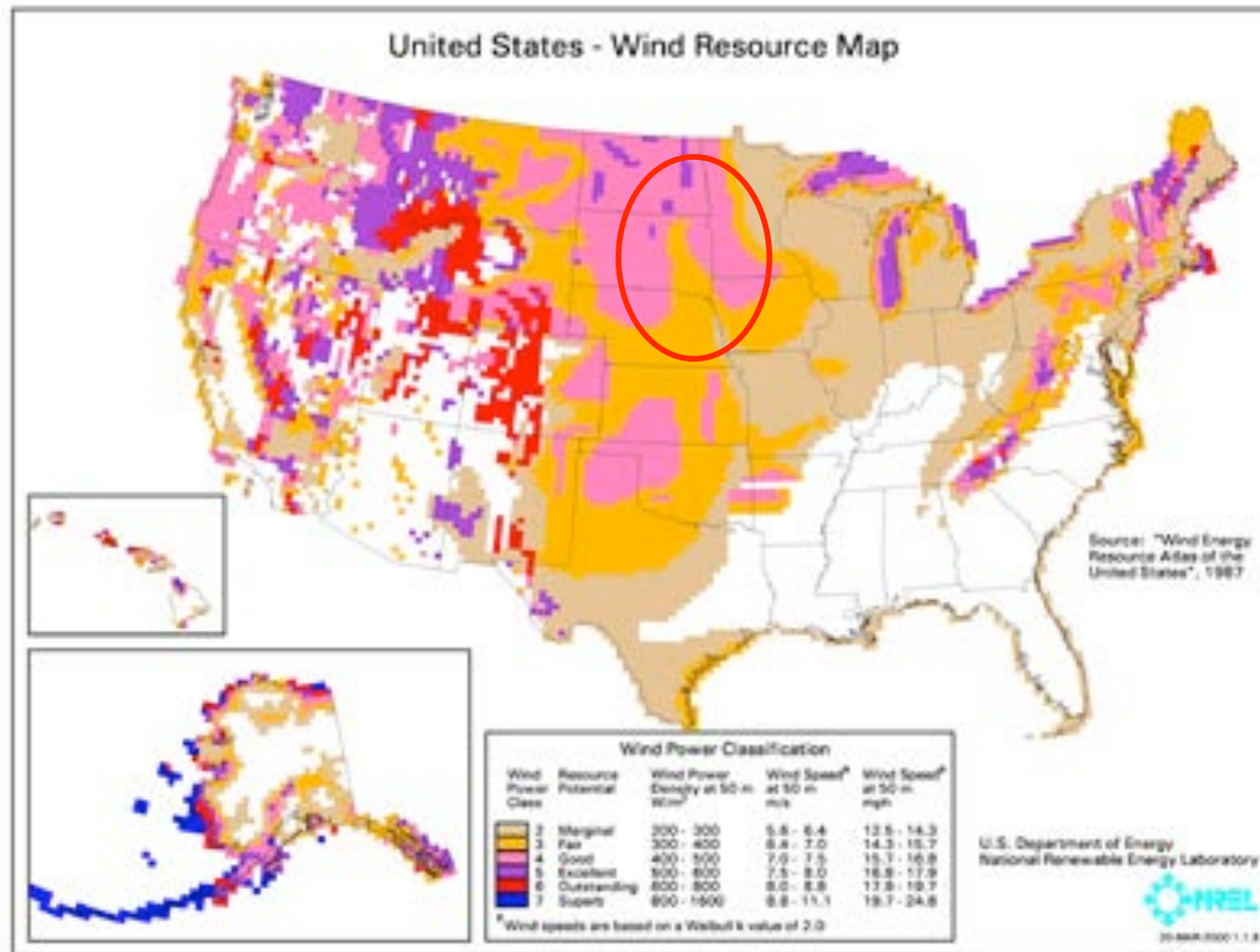
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The Midwest's H₂ and NH₃ History



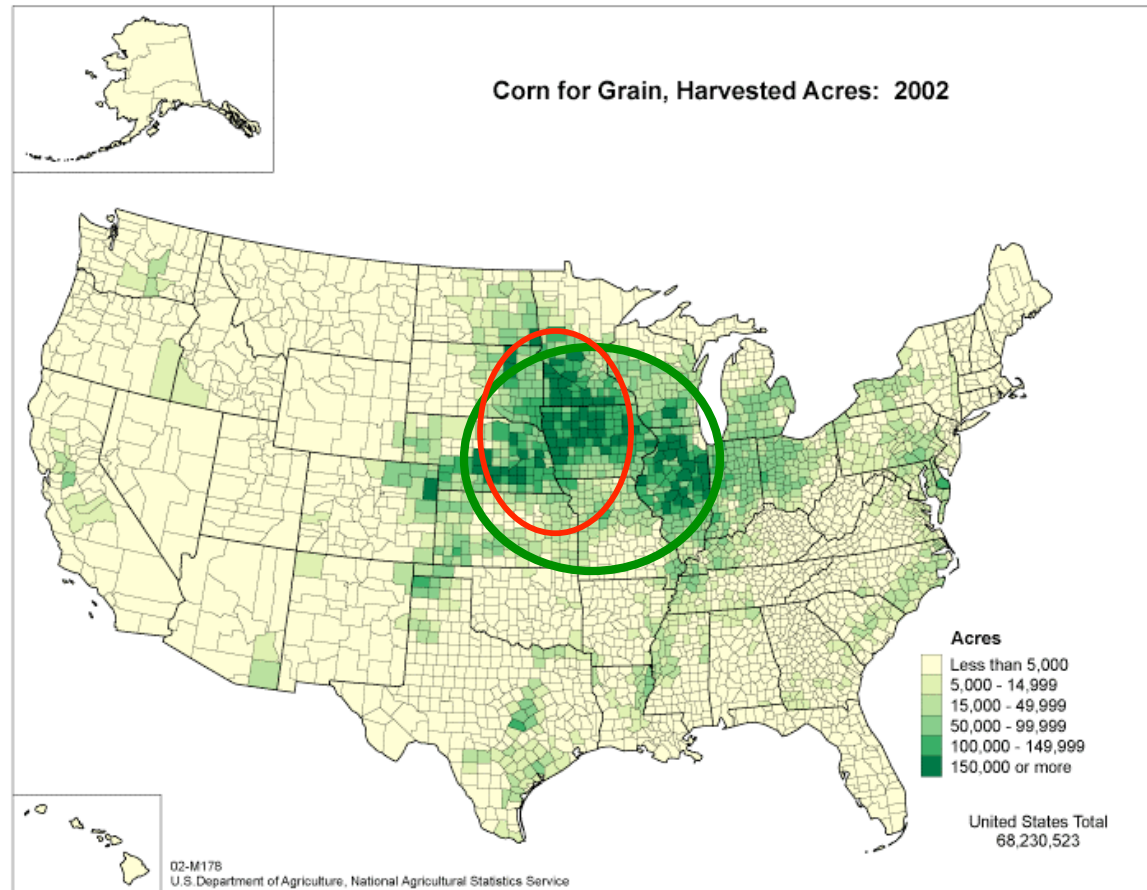
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Excellent Wind Resource



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High Demand for Ammonia



& Excellent Wind Resource



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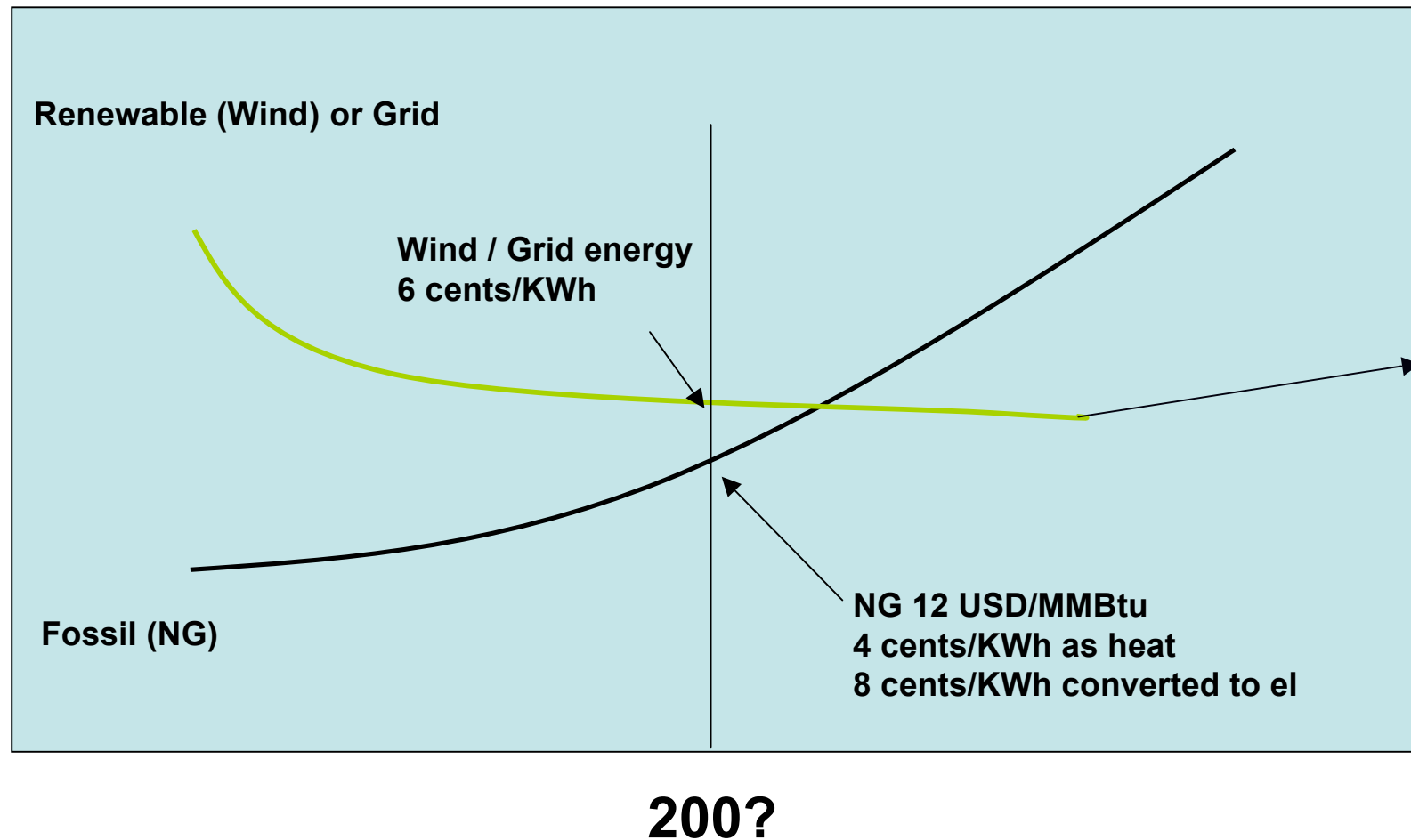
Stranded Wind Resource

Midwest Export Boundaries for Electrical Energy

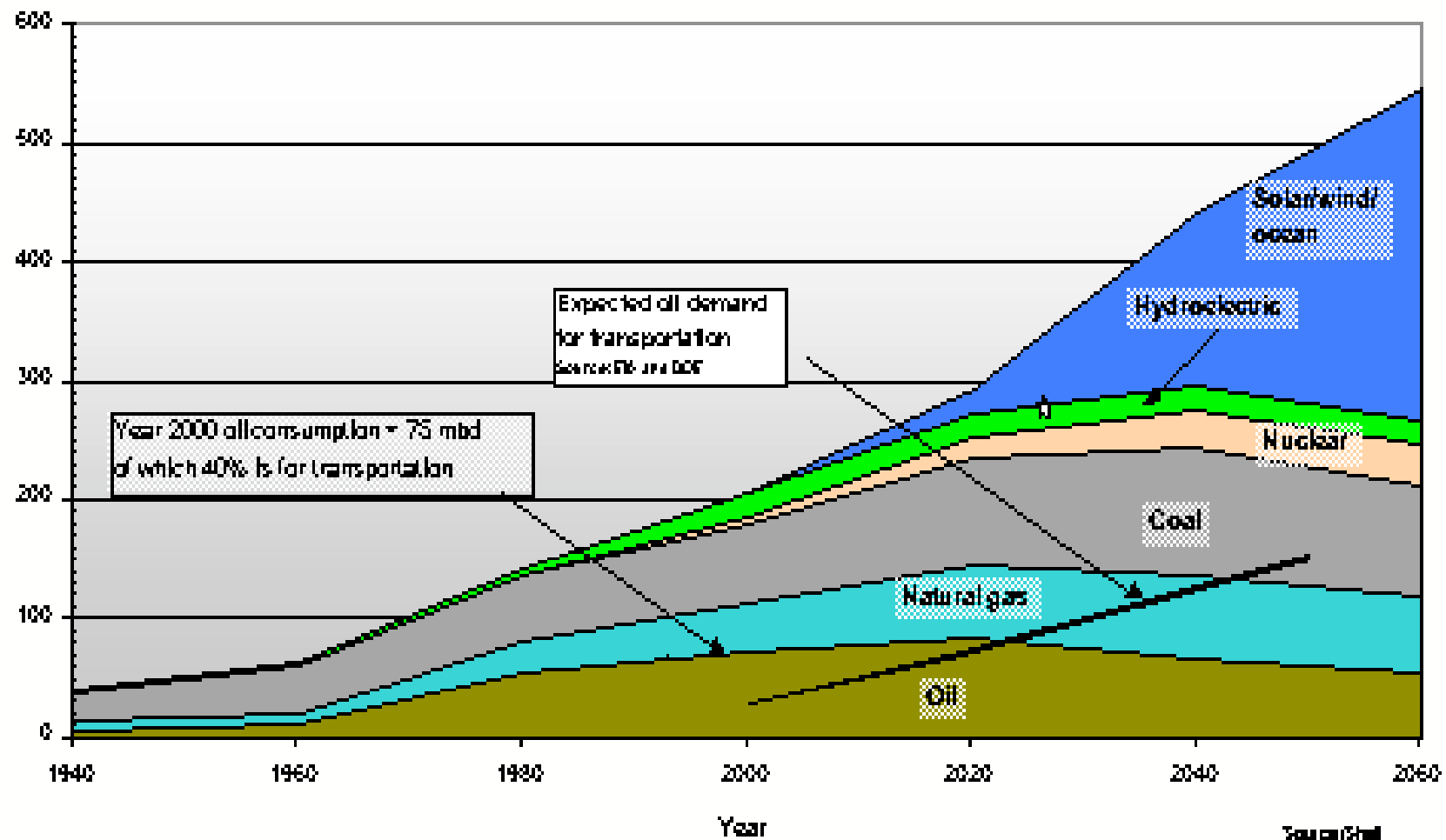


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Key Challenge and Opportunity



Security of Energy Supply



Wind to Ammonia Drivers

- 1. Declining domestic ammonia production**
- 2. Stranded wind resource due to low transmission capacity**
- 3. Natural gas market drives ammonia production costs**
- 4. High ammonia / nitrogen demand and robust infrastructure**
- 5. Security for domestic food, feed, and bio-fuel production**
- 6. Business and policy models from producer owned ethanol**
- 7. Hydrogen economy bridge**



Key Challenges with Electrochemical NH₃ Production

A. Capital Costs

- Equipment
- Storage
- Other Infrastructure

B. Energy Costs

- Direct

(5.5 to 6 kWh per lb NH₃)

- Indirect (eg. Refrigerated Storage, Glenwood, MN = 3 MW load)



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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 with 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?

G. Electric Energy Industry

- Regulated industry but also is similar to a monopoly
- FERC, MISO, PUC
- Retail wheeling (Need to separate wind business from NH₃ but...)
- Socialized costs - transmission, emissions



Key Challenges with Electrochemical NH₃ Production

H. Standard policies including ARRA do not present a good fit for Wind to Ammonia

- ITC Grant, ITC, PTC, 1% reduction in energy sales

H. Commercial Technology

- Lack of equipment and contractors for desired scale
- Difficult to take new technology to market
- Lack of commercially proven equipment usually leads to higher equity investments and / or higher debt costs



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Key Opportunities with Electrochemical NH₃ Production

A. Rising Cost of Fossil Fuel – Natural Gas

- 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 own the NH₃ fertilizer demand
- 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

D. Market Flexibility

- Nice opportunity for smart grids
- Release purchased power, sell stored power, sell H₂, NH₃, Carbon Credits, Other forms of N fertilizer
- Multiple markets



Key Opportunities with Electrochemical NH₃ Production

E. CO₂ / Greenhouse Gas Reductions vs. NG

F. Renewable Energy Mandates and Cost of Transmission

- In regions with excellent wind resources, transmission is costing \$1 million per MW (50 MW = \$50 million)

- Utilities are not requiring additional power

- 25 x 25 mandate – Wind energy penetration needs to be high.

“Why not create an energy intense industry and market for renewable energy in close proximity to where it is produced rather than build expensive transmission lines? ”



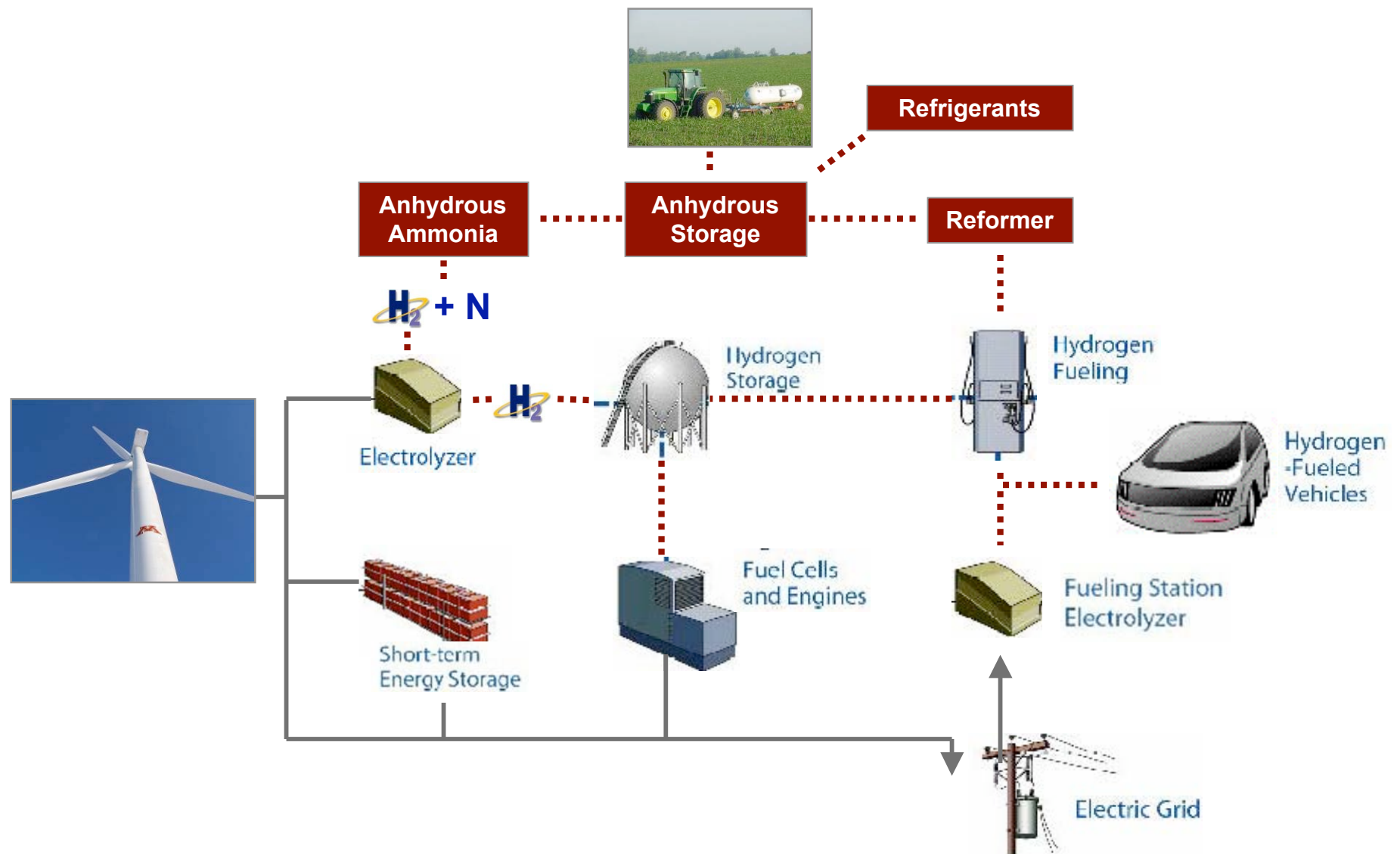
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Key Opportunities with Electrochemical NH₃ Production

- Local ammonia production has immense potential for rural economic development
- By tapping an existing market for nitrogen fertilizer, we can overcome significant barriers in the development of wind and other forms of renewable energy
- Through this process, utilities can increase their energy sales and better manage the existing grid
- Process needs to be cost competitive either directly or through establishing favorable policy



Renewable Hydrogen Research and Demonstration



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Wind to Ammonia Details

- **Modified Haber Bosch Process**
- **Wind energy will drive electrolysis of water**
- **Hydrogen formed via electrolysis will be combined with nitrogen from air**
- **H₂ and N₂ will be combined in a reactor and passed through a catalyst bed**
- **Controlled heat and pressure parameters**



Wind to Ammonia Details

- Small reactor for pilot facility (~size of 50 gallon drum)
- Simple reactor design and construction
- Process is very scalable (SMR requires large facilities)
- Pilot facility will produce a maximum of 1 ton per day
- Reactor pressure 60-80 Atmospheres (800 to 900 PSI)
- Scheduled to be operational Fall 2010
- Pilot facility will be adaptable to research
 - Professor Lanny Schmidt – Modified reactor
 - Professor Roger Ruan – Non-thermal plasma reactor



Wind to Ammonia Details

- Energy efficiency, water usage, cost of production, yield of ammonia, system operation and maintenance, catalyst performance and longevity, and other variables will be tested
- Economics will be modeled
- System will be optimized for commercialization
- Data will be used to determine appropriate policy
- Wind to Ammonia Pilot Cost = \$3.75 million
- Future System Integration – Biomass System, Etc



Cost of Energy / Ton of NH3 – Single Price

Cost/ kWh	NH3 \$/t
\$.020	\$240
\$.025	\$300
\$.030	\$360
\$.035	\$420
\$.040	\$480
\$.045	\$540
\$.050	\$600
\$.055	\$660
\$.060	\$720

*Electrical process....not limited to wind energy!



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Wind to Ammonia Business Models

- Farmers own the nitrogen fertilizer demand as well as the land in which the wind blows across
- Vertically-integrated, locally owned systems will allow for moderately priced nitrogen fertilizer over a long duration
- Allows for market penetration into hydrogen sector and electrical energy generation
- Possible integration with biomass systems will allow for urea and methanol production
- Dynamic model may allow for ammonia production in off-peak hours and electrical energy sales during peak hours



Wind to Ammonia Implications

- Opens a new market for an estimated 2 gigawatts of nameplate wind capacity within the state stimulating wind energy development across Minnesota and the Midwest.
- Diminishes the need for additional transmission capacity to accommodate wind energy.
- May enable utilities to manage the variable nature of wind energy and electrical demand.
- Provides substantial economic development opportunities for farmers and rural communities.



Wind to Ammonia Implications

- Decreases green house gas emissions by eliminating fossil fuels currently used in the process.
- Provides a secure, domestically produced nitrogen fertilizer source and protects a vital agriculture industry within the United States.
- Firmly establishes the Midwest as a world leader in renewable hydrogen production and wind energy.
- Creates a solid foundation from which to grow Midwest manufacturing companies and attract complimentary hydrogen related industries.

