Utilizing Wind Energy to Produce Nitrogen Fertilizer

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Ammonia: Key to Energy Independence Conference

September 29, 2008

University of Minnesota
Driven to Discover℠

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"

Why Renewable Energy?

- ***Environment – Global Warming***
- ***Economy – Good Business / Peak Oil***
- ***Energy Security – Risk Management***

Global Warming & Greenhouse Gases

Peak Oil

- We have reached “Peak Oil”.
- Two-thirds of the world’s “easy oil” is used up!
- Lets put this into context.


SMOOTH TASTING PREMIUM DRAFT
Michelob
Golden
LIGHT
DRAFT

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)

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
- Others

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

Hybrid Wind System

Phase I – Hydrogen & Electrical Energy Production

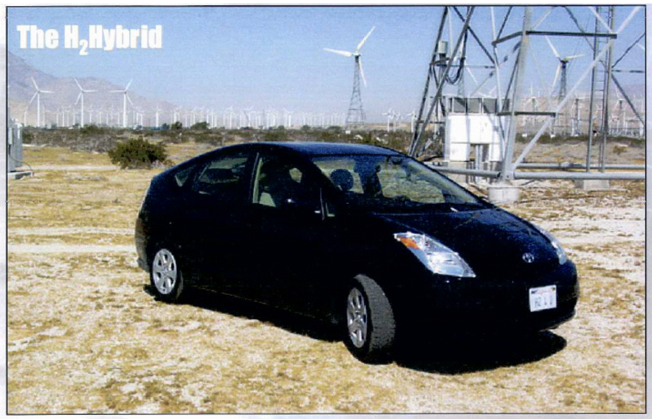
1. Electrolyzer
2. Compressor
3. Hydrogen Storage
4. ICE Engine Generator
5. Grid Interconnection
6. Web Enabled SCADA

First Wind to Hydrogen System in Utsira, Norway

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*

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

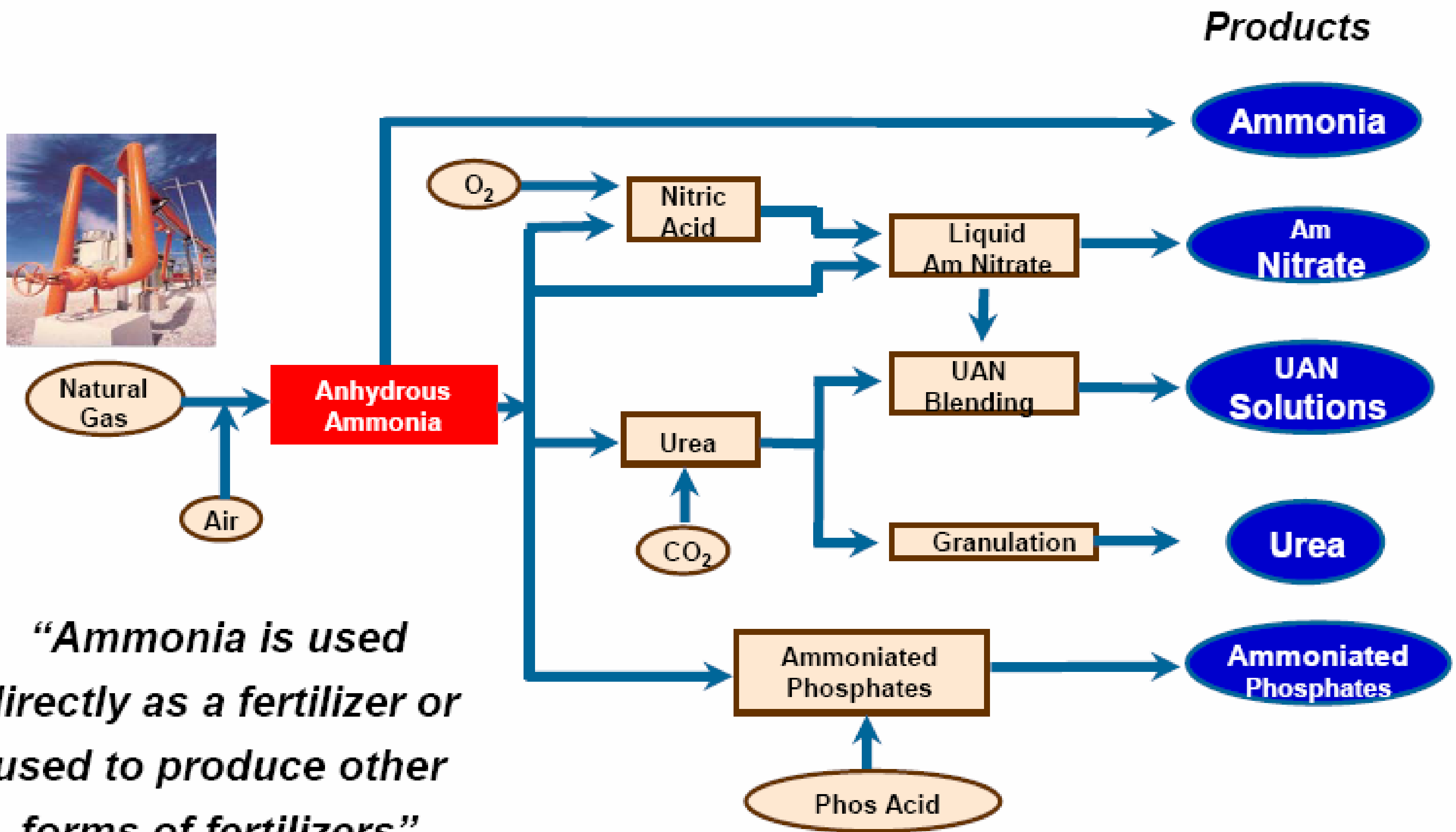
Wind to Ammonia Drivers

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. Success of producer owned ethanol
7. Hydrogen economy bridge

Why Anhydrous Ammonia

- The largest use of ammonia is for nitrogen fertilizer (Midwest)
- Natural gas accounts for over 90% of the cost of producing ammonia (Energy Intense)
- Ammonia has made via electrolysis for ~ 100 years (Proven)
- Electrolysis and other electro-chemical processes will still take considerable energy to produce ammonia (Local Market)
- Will keep dollars local, provide large load centers in areas that have renewable energy resources, and perhaps provide value to the transmission system (10 to 100 MW)
- Provide opportunities to capture wind energy for other uses

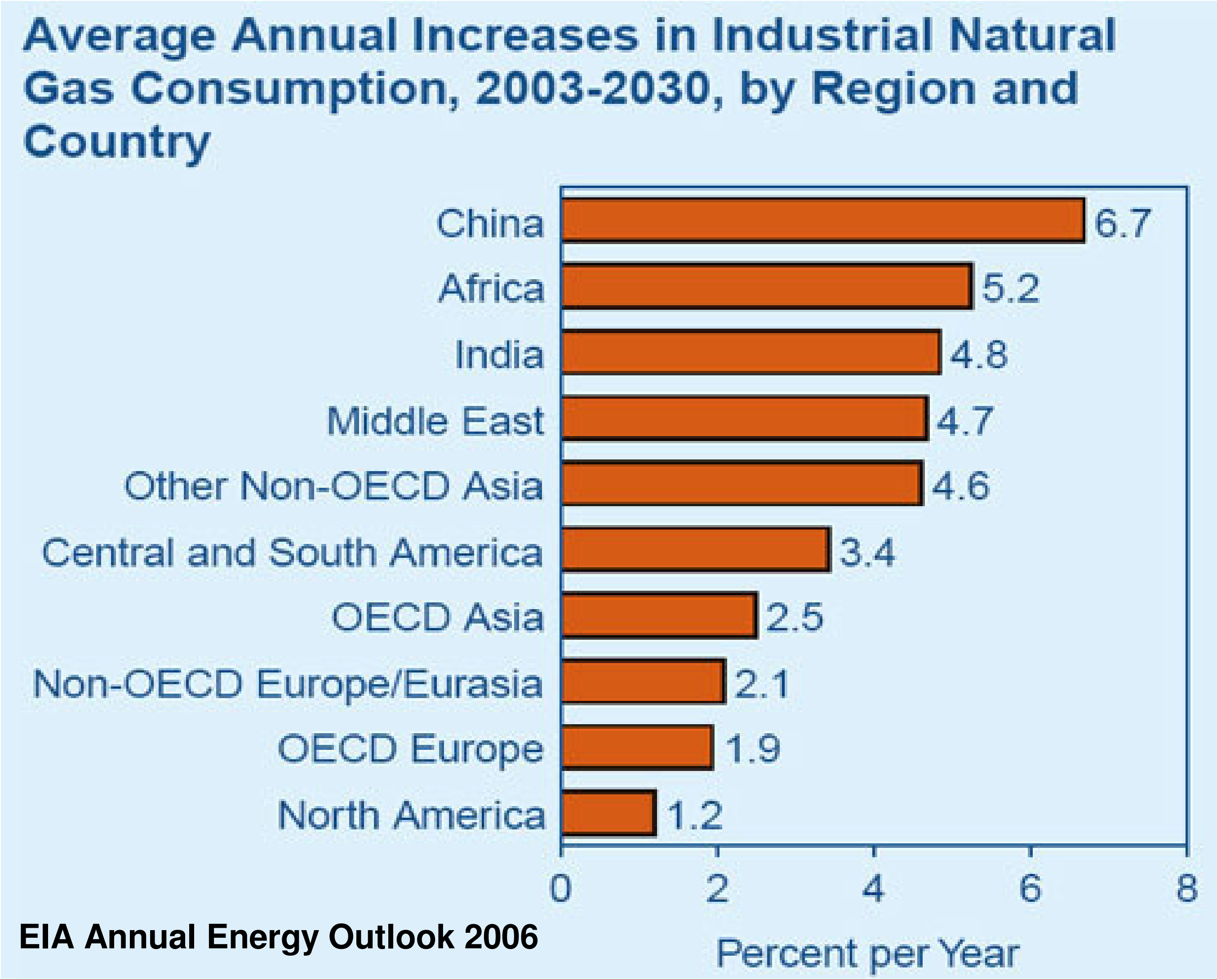
Nitrogen Fertilizer Production



"Ammonia is used directly as a fertilizer or used to produce other forms of fertilizers"

Source: Agriculture Energy Alliance, 2006

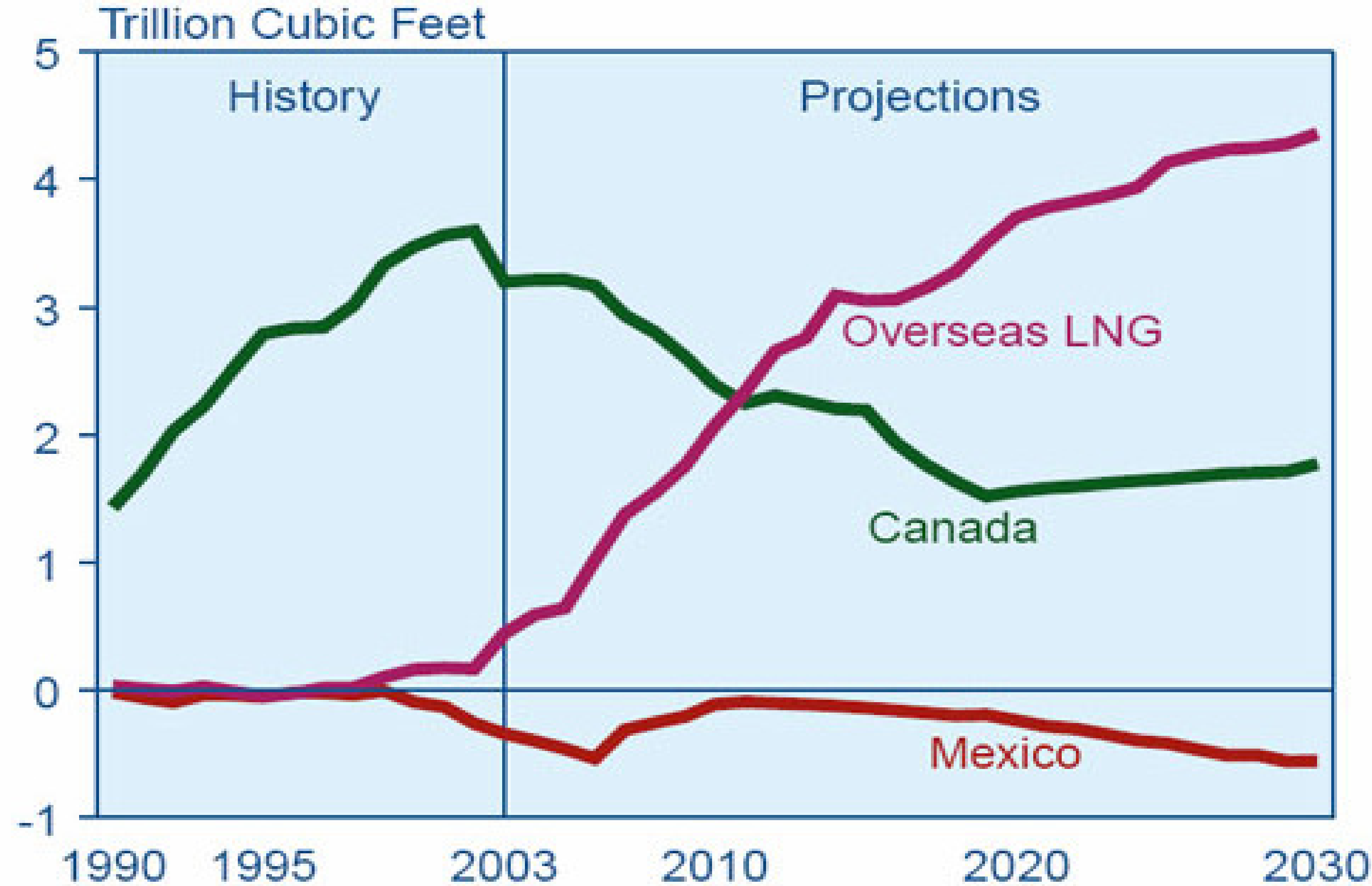
Natural Gas Market



EIA Annual Energy Outlook 2006

Natural Gas Market

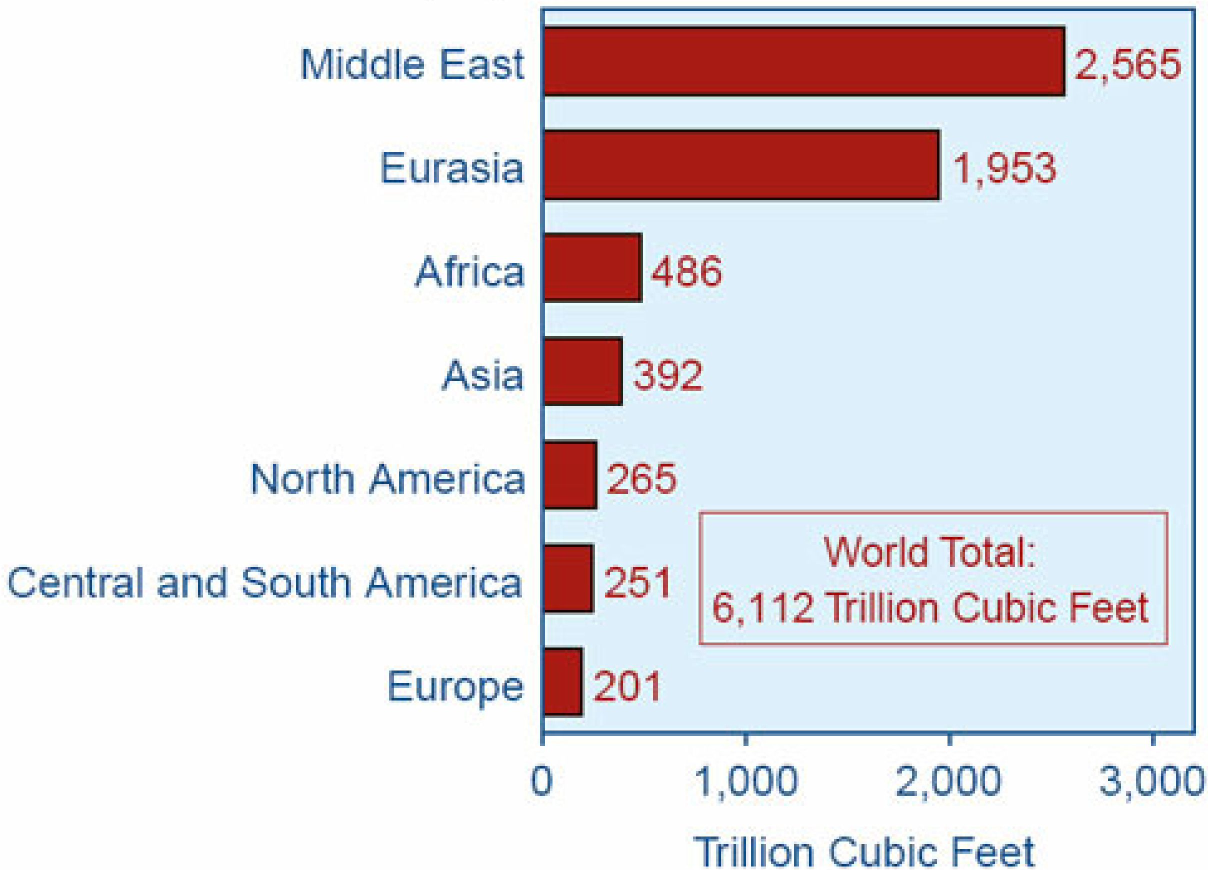
U. S. Natural Gas Supply by Source, 2003-2030



EIA Annual Energy Outlook 2006

Natural Gas Market

Figure 37. World Natural Gas Reserves by Geographic Region as of January 1, 2006



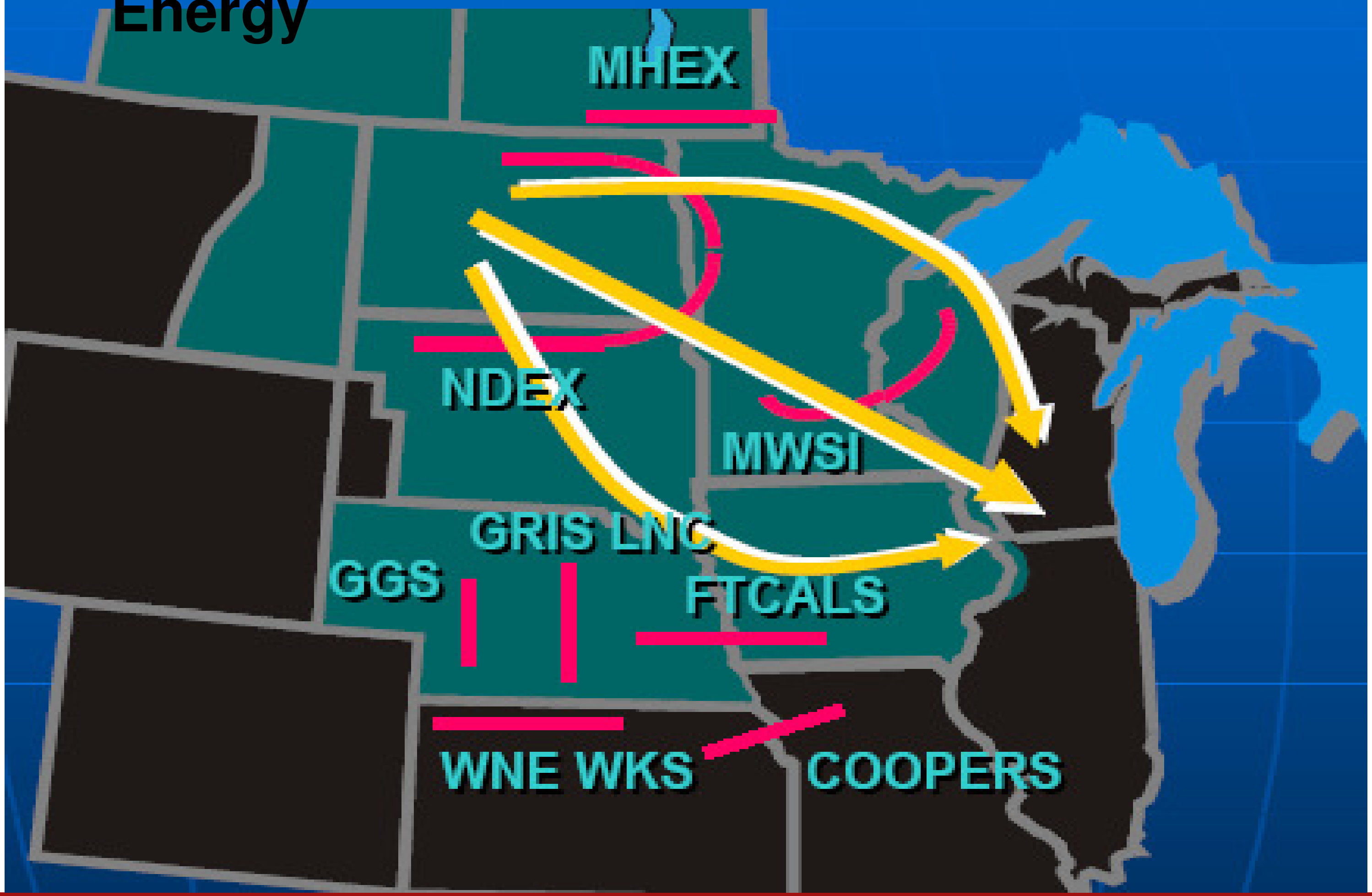
Source: "Worldwide Look at Reserves and Production," *Oil & Gas Journal*, Vol. 103, No. 47 (December 19, 2005), pp. 24-25.

Electrical Energy Use in the United States

NASA

Stranded Wind Resource

Midwest Export Boundaries for Electrical Energy



MISO Queue May ‘00 to Nov ‘07

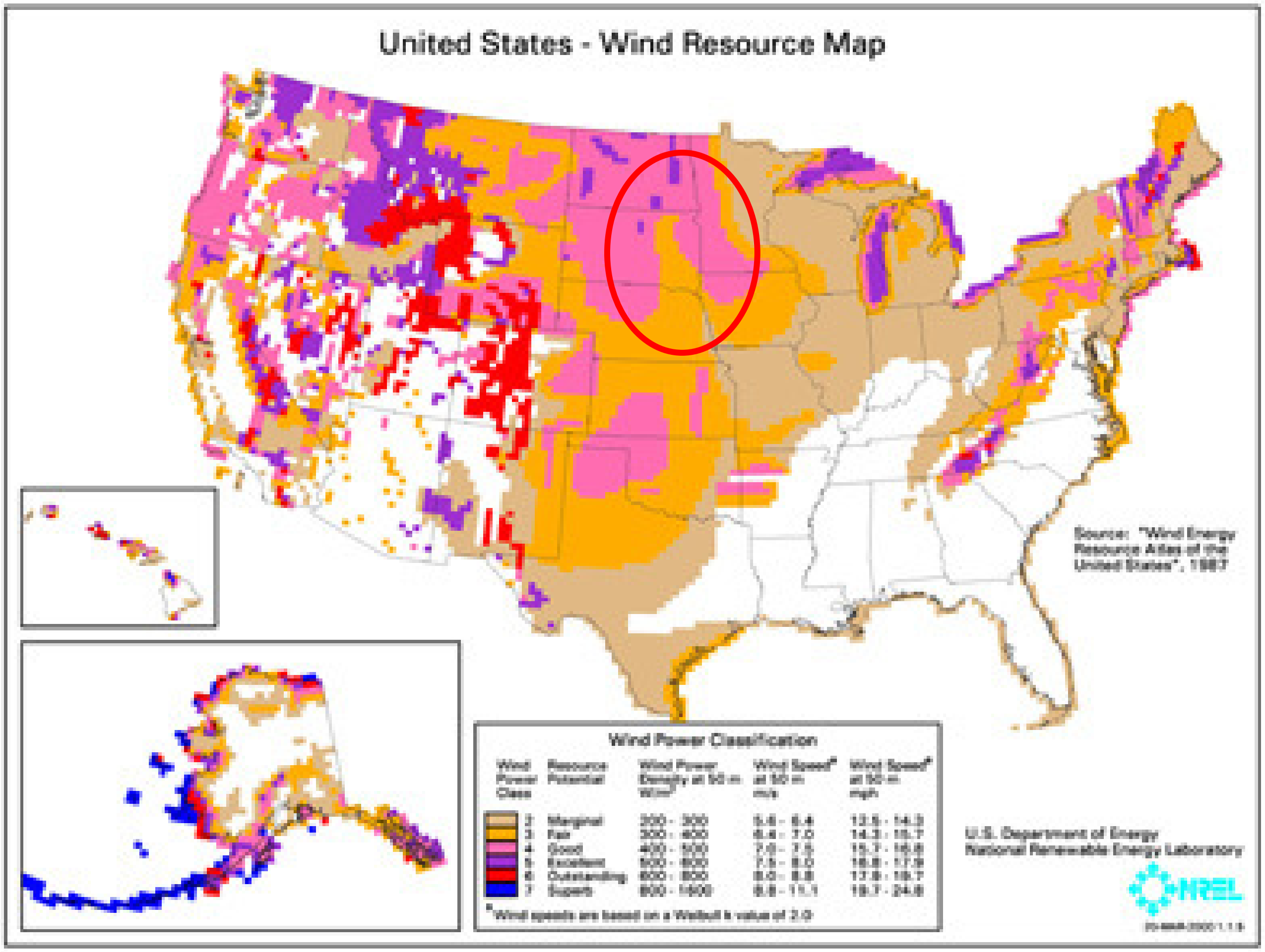
	Wind (MW)	Non-Wind	Total (MW)
MN	25,477	7,855	33,332
ND	7,928	3,950	11,878
SD	17,052	4,503	21,555

Midwest Independent System Operator (Nov 2007)

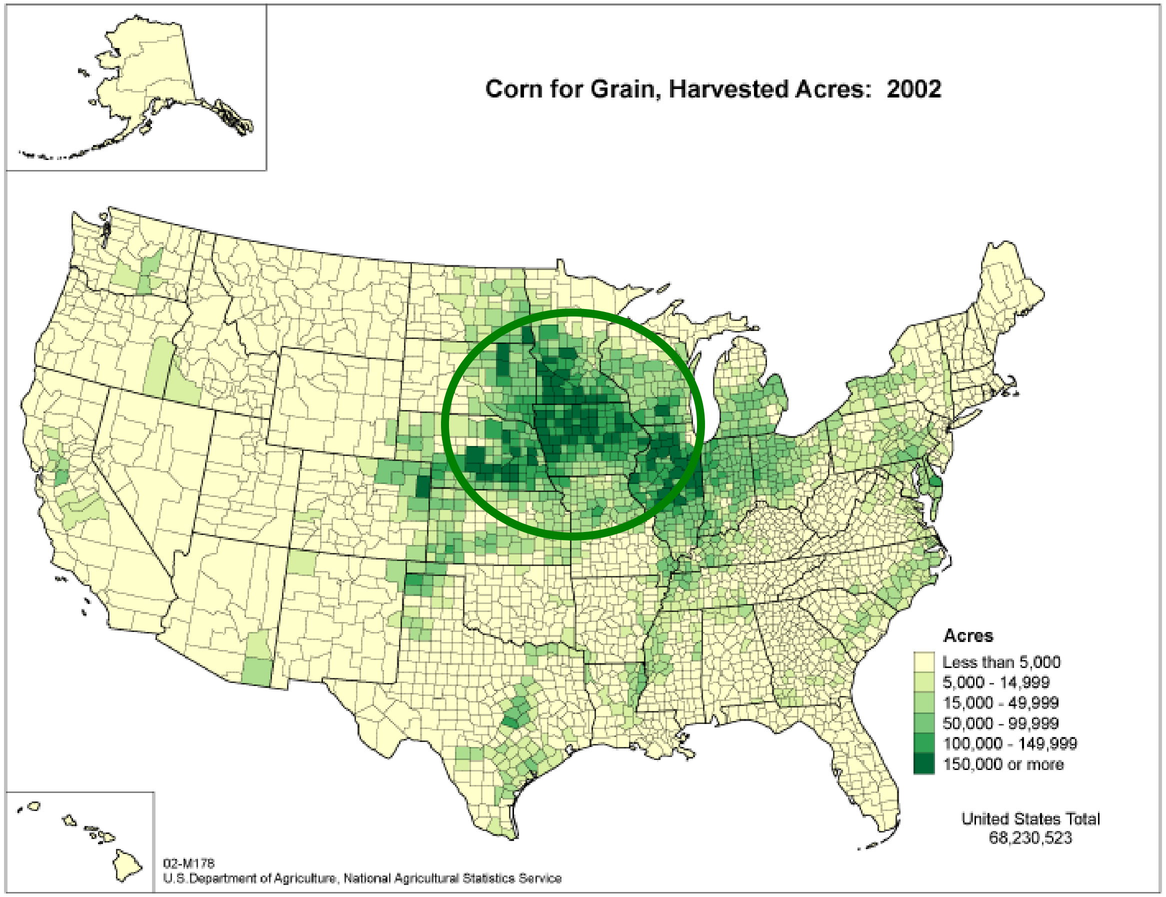
“New” MISO Queue

- Midwest Independent Systems Operators (MISO)
- New interconnection process as of Sept 08
  - Favors interconnection points closest to load
- Over 80,000 Megawatts in the Midwest “Queue”.
- Only 8,800 MW in “fast track” study
- Vast areas with excellent wind resources left stranded – areas that continue to lose pop.

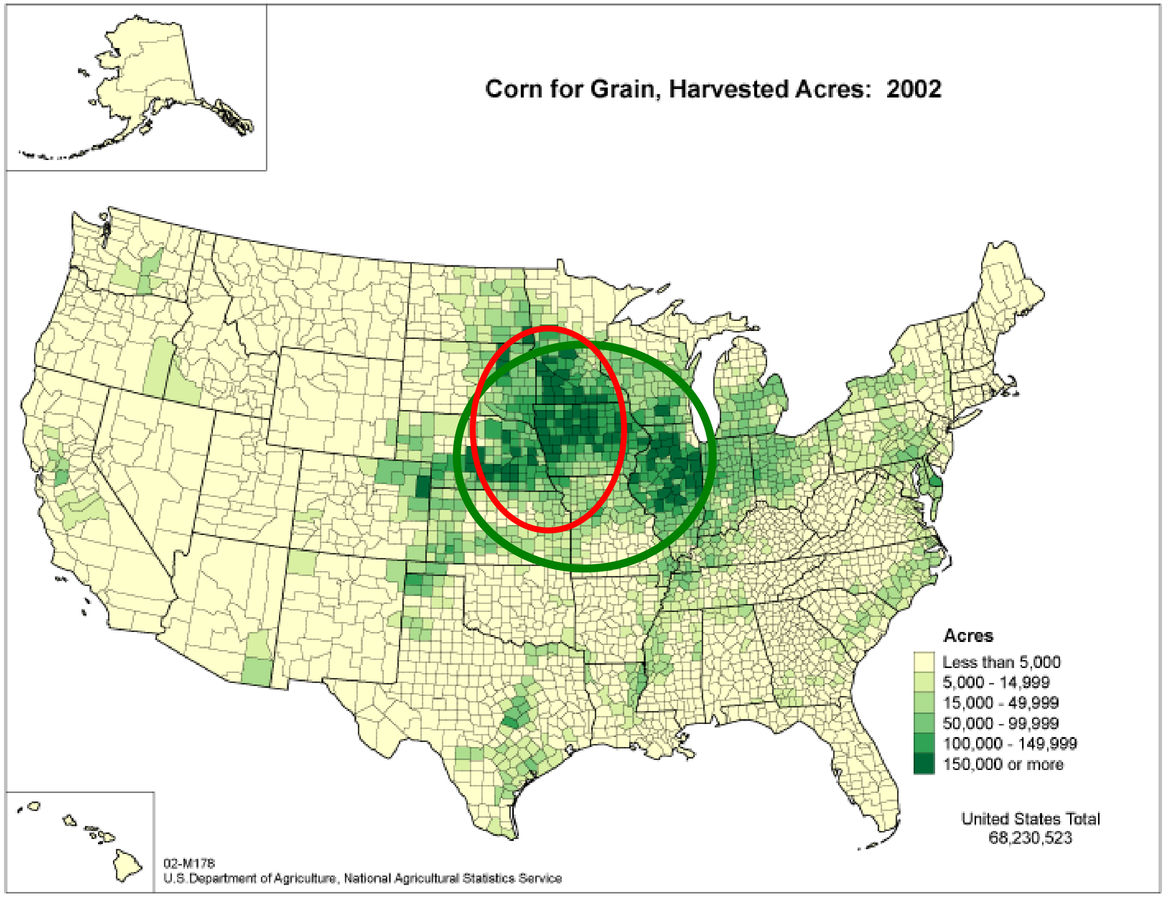
Excellent Wind Resource



High Demand for Ammonia



High Demand for Ammonia



& Excellent Wind Resource

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Robust Ammonia Infrastructure

Security for Domestic Bio-Fuels

1. Corn requires high amounts of nitrogen fertilizer
2. Dramatic increase in corn ethanol production in U.S.
3. Ethanol provides secure, domestic source of transportation fuel
4. However, over 50 % of nitrogen fertilizer for corn is imported!
5. Wind to Ammonia Systems can protect the flank of the bio-fuels industry

Success of Producer-Owned Ethanol

1. Revitalized and rejuvenated rural economies
2. Business experience and models
3. Successful Policy (Minnesota Model)

   -Local and Community Ownership

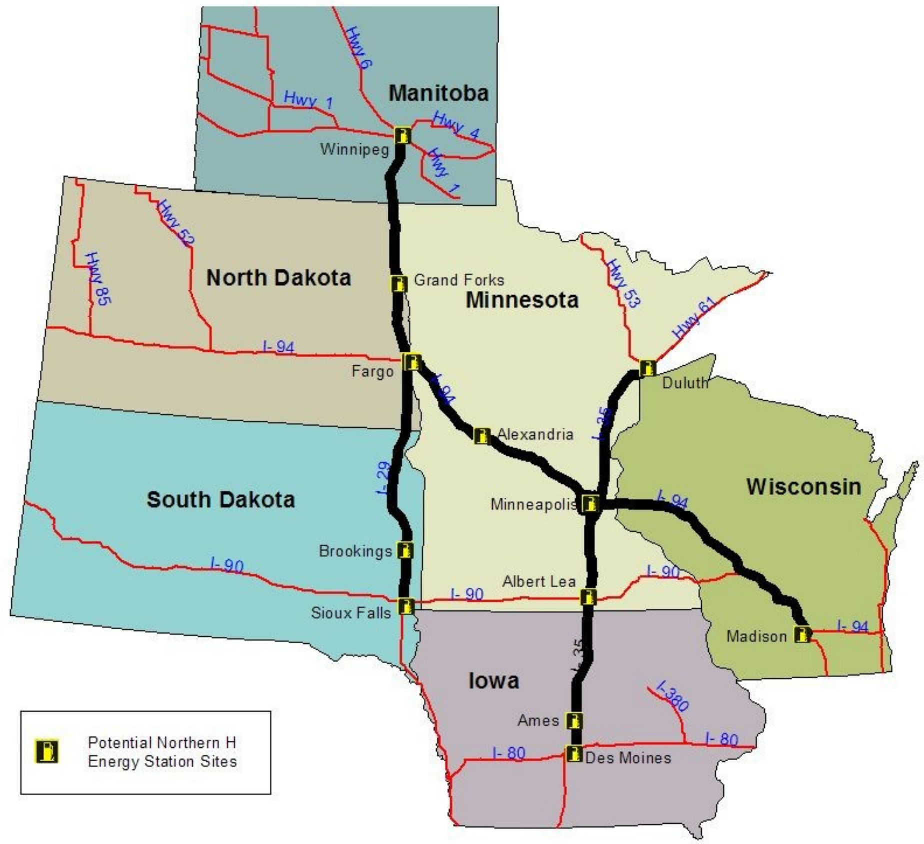
   -Mandate for 10 % Ethanol in Gasoline

   -State Production Incentive

   -Blenders Credit

Hydrogen Economy Bridge

1. Established Market for NH3
2. Allows Renewable H2 Production in Quantity
3. Locally Owned Systems
4. Follows E-85 Model for Grass Roots Expansion
5. Stimulus for Other H2 Applications
6. Breaks "Chicken or Egg" Cycle




HYDRO
ASJON

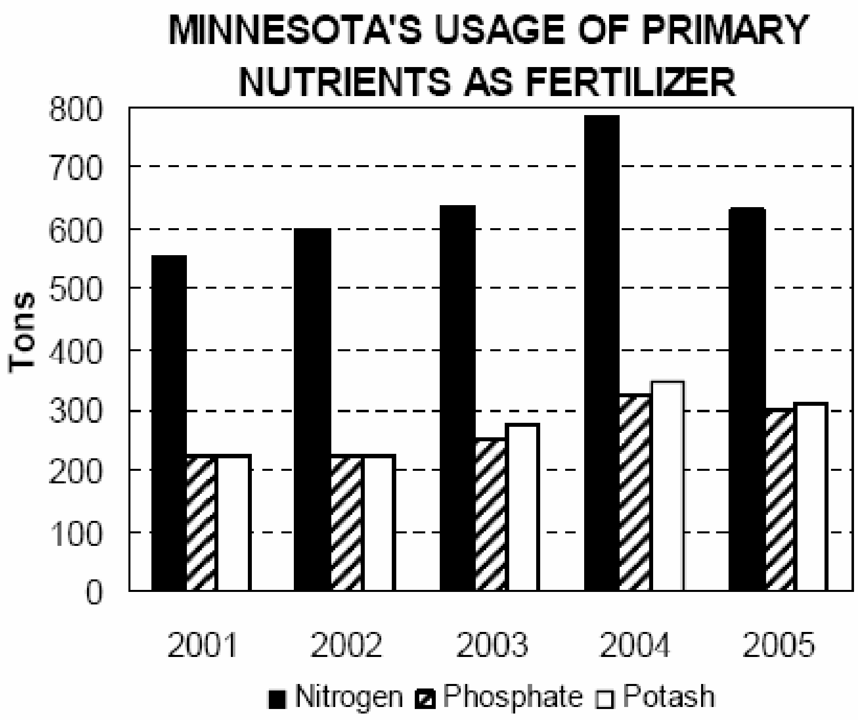

HYDRO
Hydrogen
- null utslipp
Forskningssenteret, Olje og energi

Ammonia Demand in Minnesota

Minnesota farmers applied approximately 954 million lbs N to the 2005 Corn Crop (~1.2 Billion lbs NH_3)
NASS , 2006

~7.2 million acres of corn ~1.1 billion bushels total produced

~Two gigawatts of nameplate wind energy is required to produce enough ammonia for Minnesota



NASS 2006 MN Ag Statistics

Renewable Ammonia Policy Options

- 5-20% renewable ammonia mandate (Sliding Scale?)
- Production incentive \$.05 to \$.15 / lb NH_3 produced
- Blenders tax credit
- And / or equipment and operating grants

Estimated Cost Per Acre for 10% Renewable NH3 Mandate

	Acres of Corn (MN)	NH3 Cost / Ton	Renewable NH3 Cost / Ton	Total Retail Value	Cost of NH3 per Acre
No Policy	7.2 million	$500 / ton	$0	$300 mil.	$41.67
10 % Policy	7.2 million	$500 / ton	$1000 / ton	$330 mil.	$45.83

*2005 MN State average of 167 lbs of NH3 per acre or 137 lbs of N

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 may allow for urea production
- Dynamic model may allow for ammonia production in off-peak hours and electrical energy sales during peak hours

Wind to Ammonia Implications

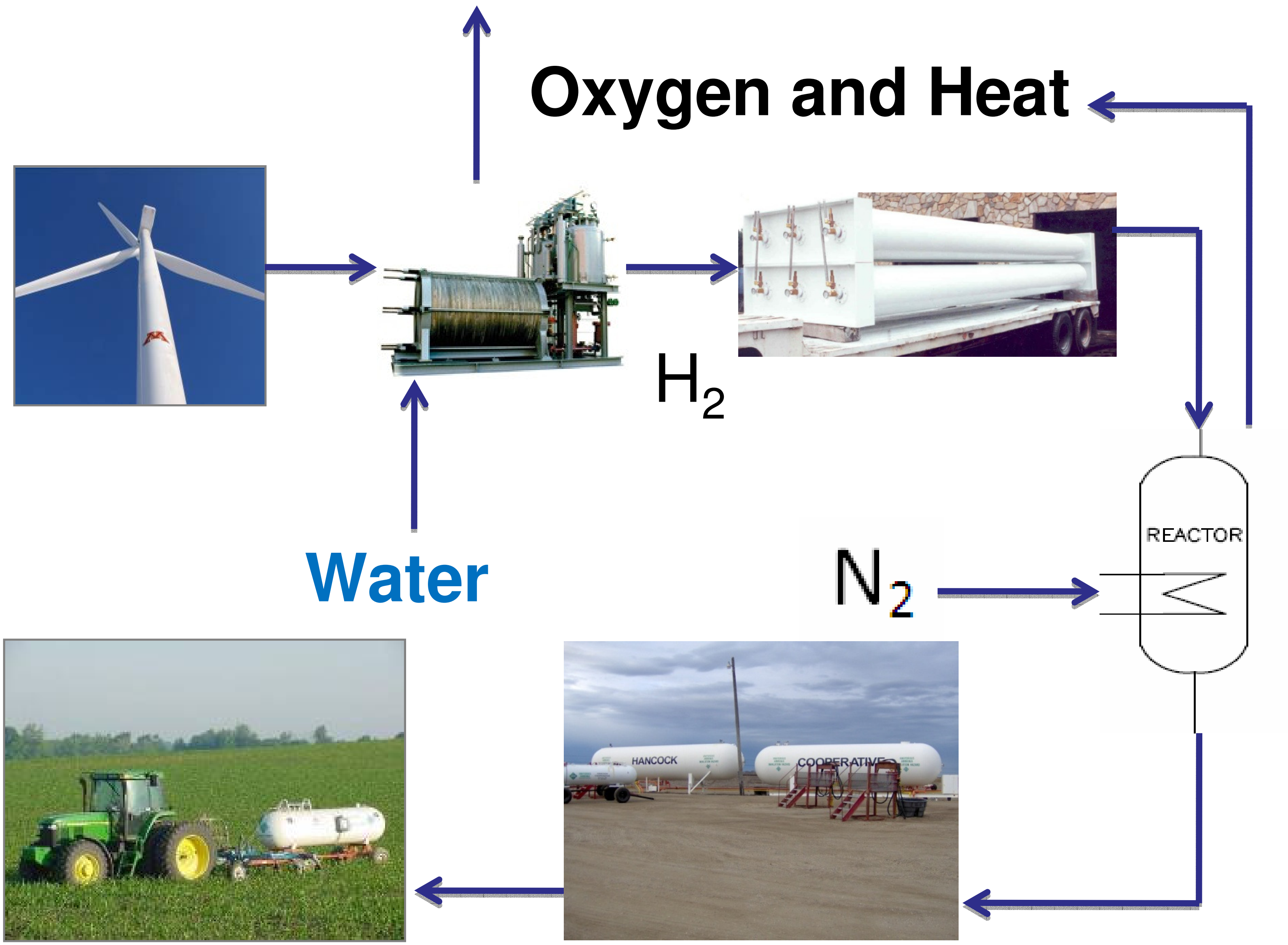
- Opens a new market for an estimated 2 gigawatts of nameplate wind capacity within the state stimulating wind energy development across Minnesota and the Midwest.
- Diminishes the need for additional transmission capacity to accommodate wind energy.
- May enable utilities to manage the variable nature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

Wind to Ammonia Implications

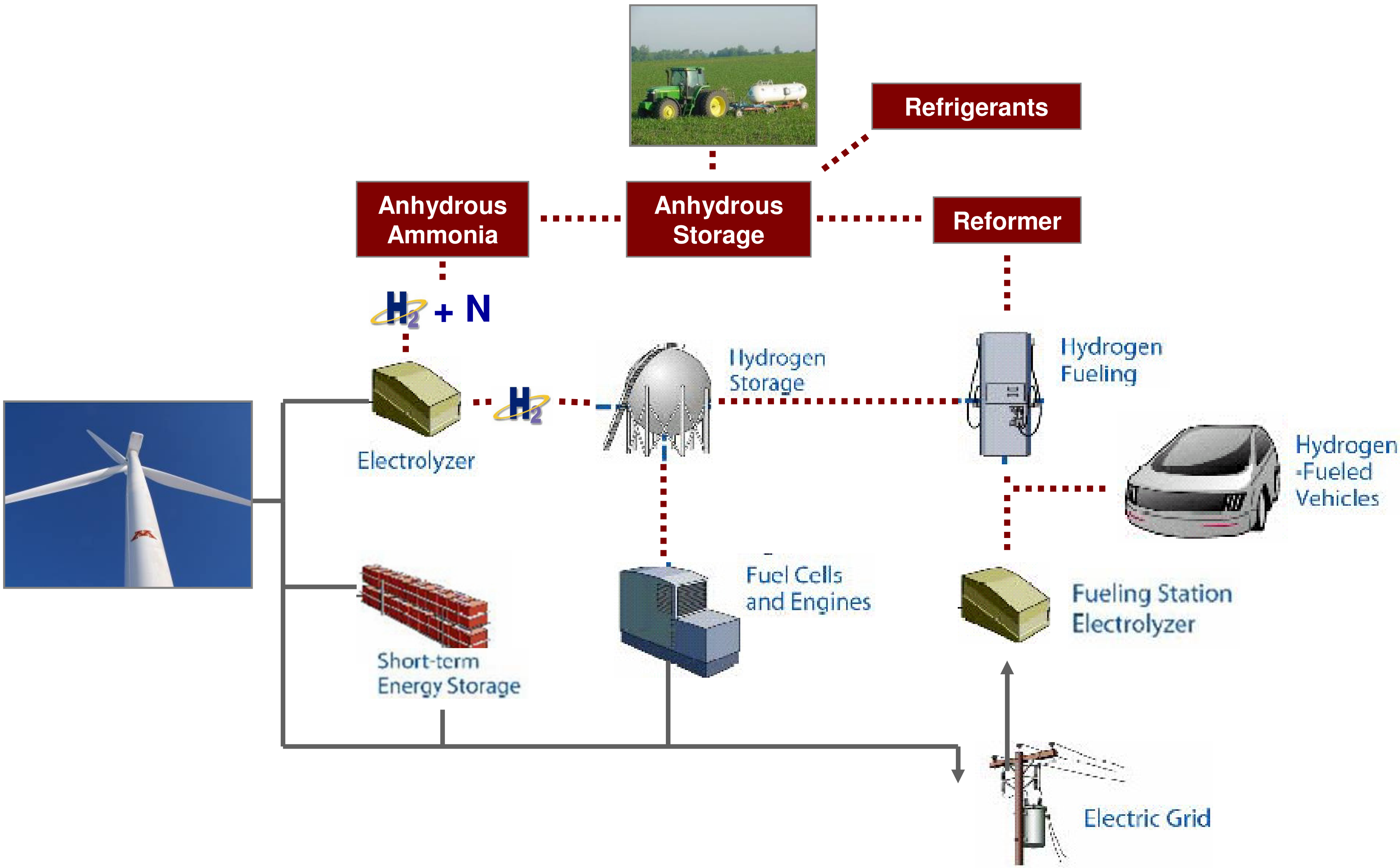
- Decreases green house gas emissions by eliminating fossil fuels currently used in the process.
- Provides a secure, domestically produced nitrogen fertilizer source and protects a vital agriculture industry within the United States.
- Firmly establishes the Midwest as a world leader in renewable hydrogen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

Wind to Ammonia Pilot System

- 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
- NH3 stored and used on WCROC fields


Oxygen and Heat
H_2
Water
N_2
REACTOR
HANCOCK
COOPERATIVE

Renewable Hydrogen Research and Demonstration



Engineering Challenges

- Some things are easier
  - Carbon monoxide and carbon dioxide kill the catalyst
  - Methane inhibits the reaction rate
  - Complete absence of these contaminants is a plus

Some things are harder

- Maintaining overall efficiency
  - Heat of reaction is a source of energy to offset energy of compression
  - Small scale may not justify heat recovery
- Intermittent wind/hydrogen supply
  - Do electrolyzers cycle with the wind?
  - If so, does the ammonia plant cycle too?
  - If not, how do we store unreacted hydrogen?

Economic Challenges

- Labor cost per unit
  - High volume plants have very low labor cost per unit
- Storage
  - Storing anhydrous is expensive and hazardous
  - Is 32% solution the answer?
- Capital intensity
  - How do we contain capital investment/unit


04/22/2007

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