

Wind to Ammonia: An Update

Presenter

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**West Central Research
& Outreach Center**

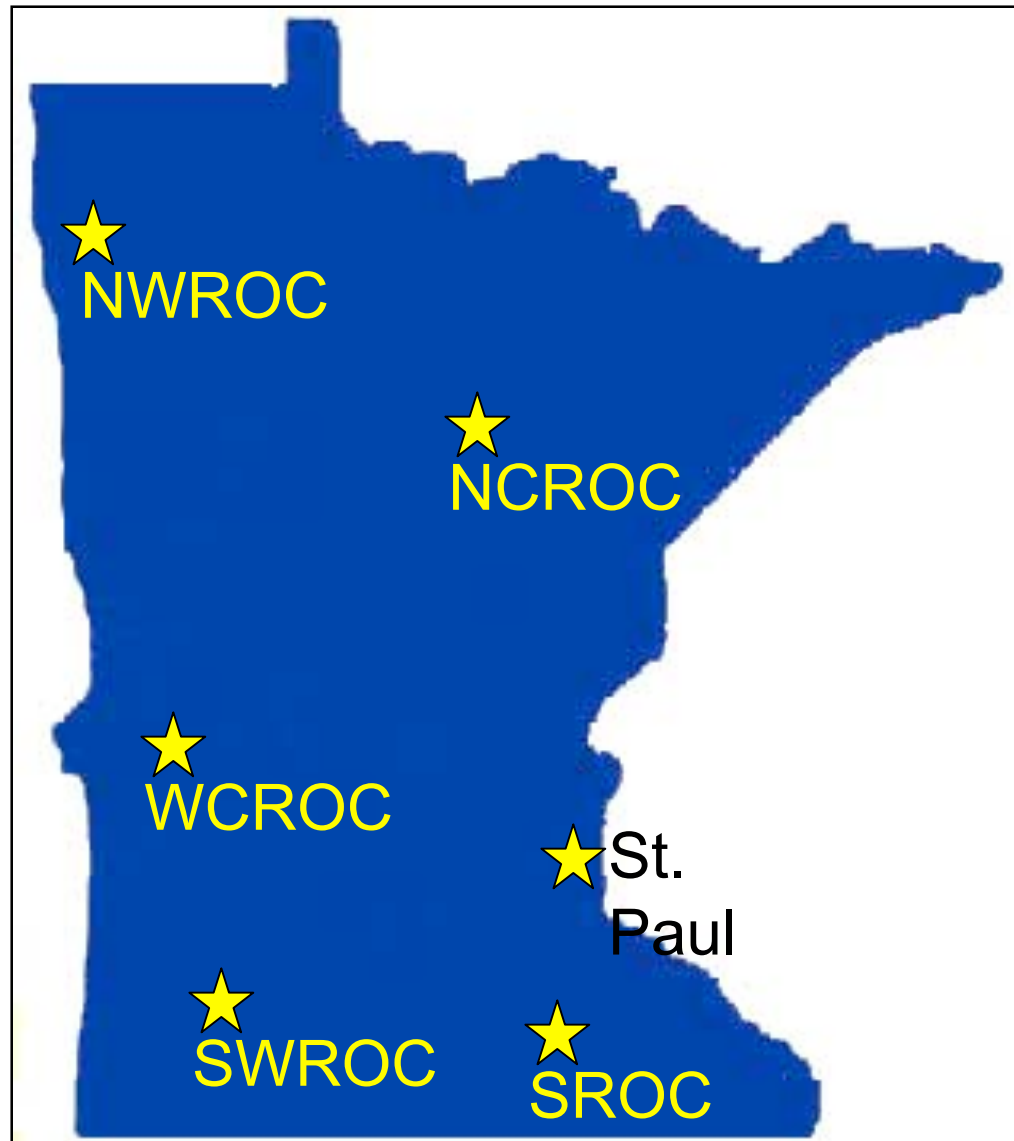
October 15, 2007



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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**
- **Norsk Hydro**
- **Xcel Energy**
- **State of Minnesota**
- **Minnesota Environmental Trust Fund**
- **National Renewable Energy Lab**





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



First Wind to Hydrogen System in Utsira, Norway



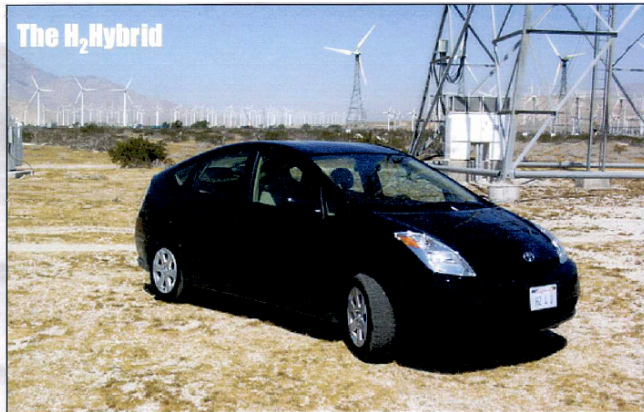
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Hybrid Wind System

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**

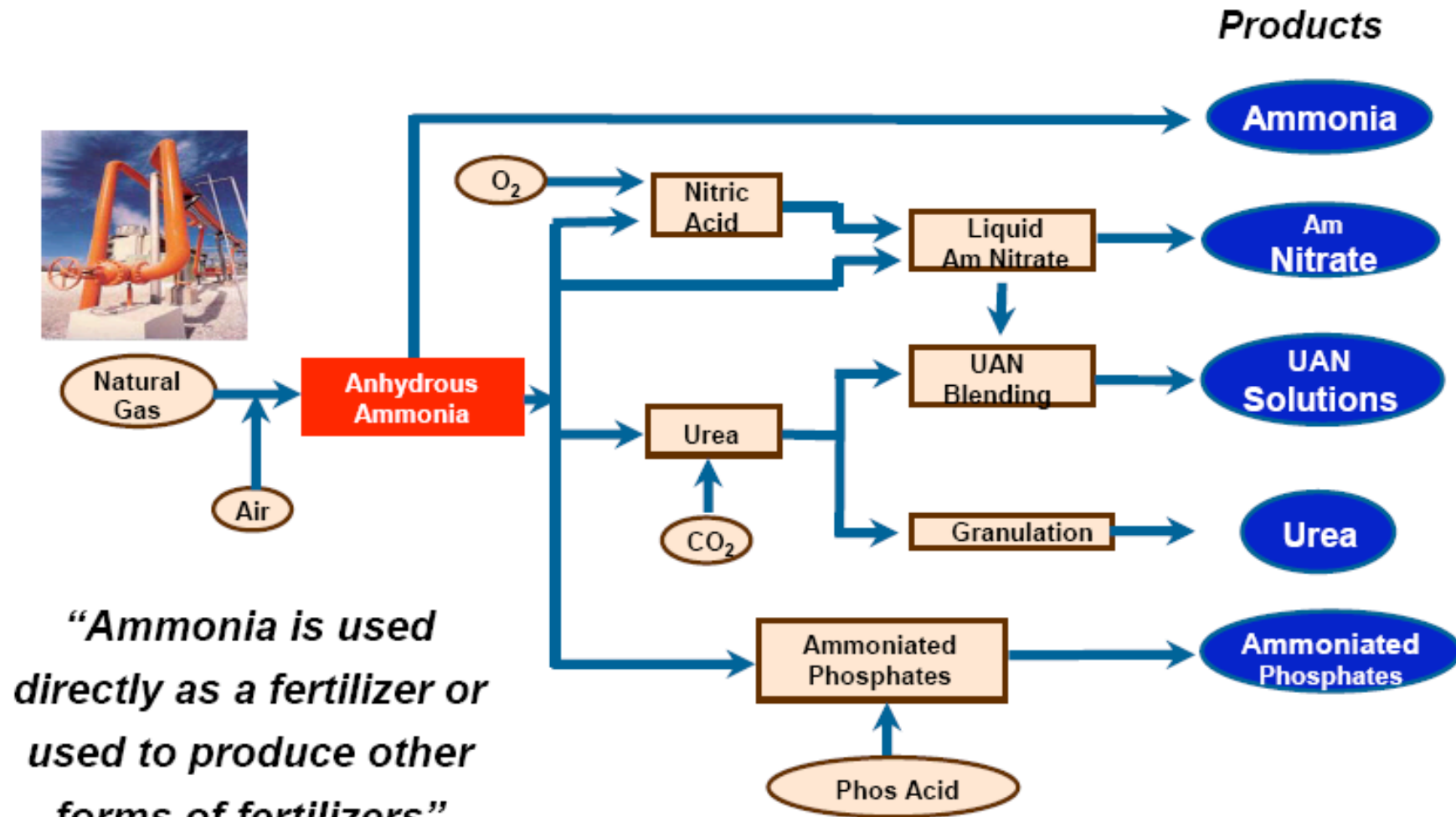


Wind to Ammonia Drivers

- 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 bio-fuel production**
- 6. Success of producer owned ethanol**
- 7. Hydrogen economy bridge**



Nitrogen Fertilizer Production



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

Source: Agriculture Energy Alliance, 2006

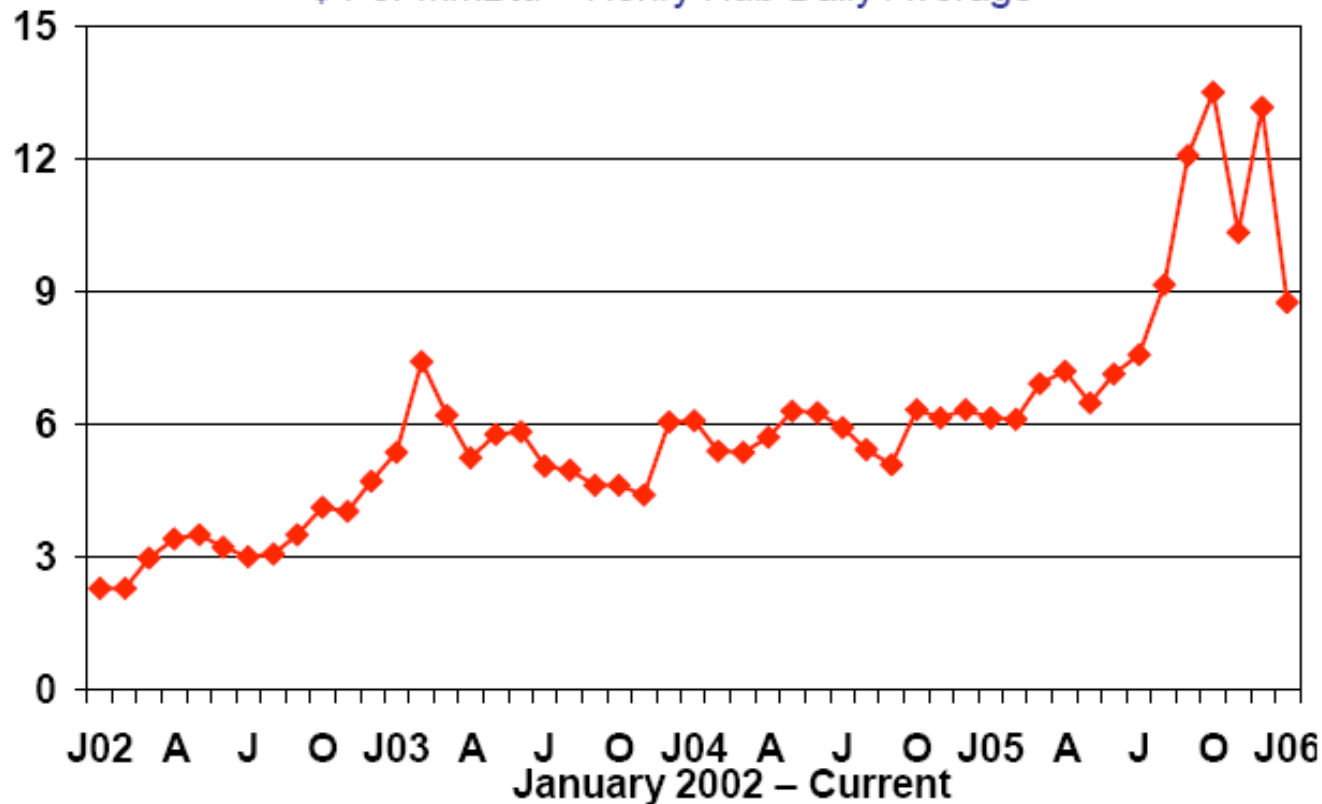


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Natural Gas Market

Average Monthly U.S. Natural Gas Prices

\$ Per MMBtu – Henry Hub Daily Average



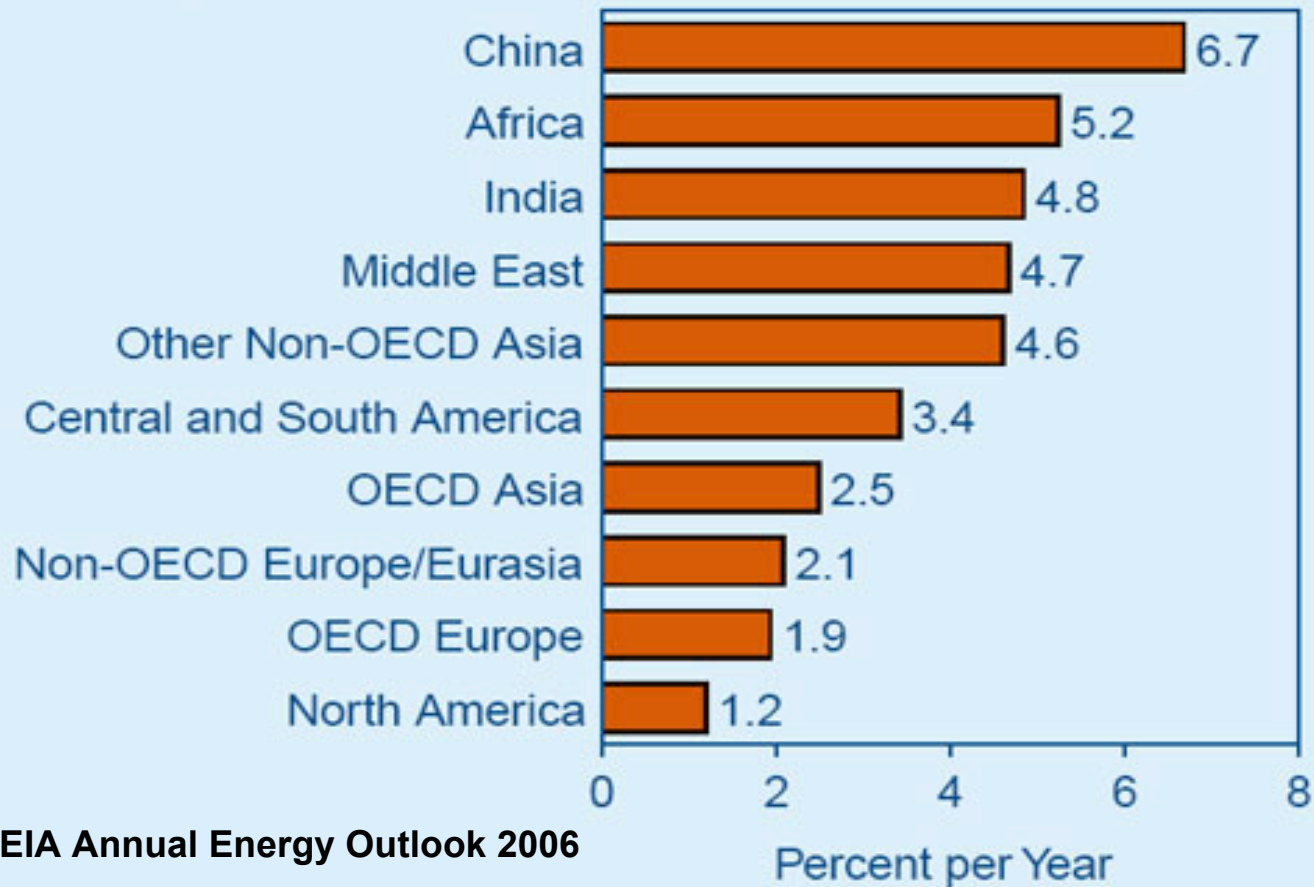
Source: Gas Daily



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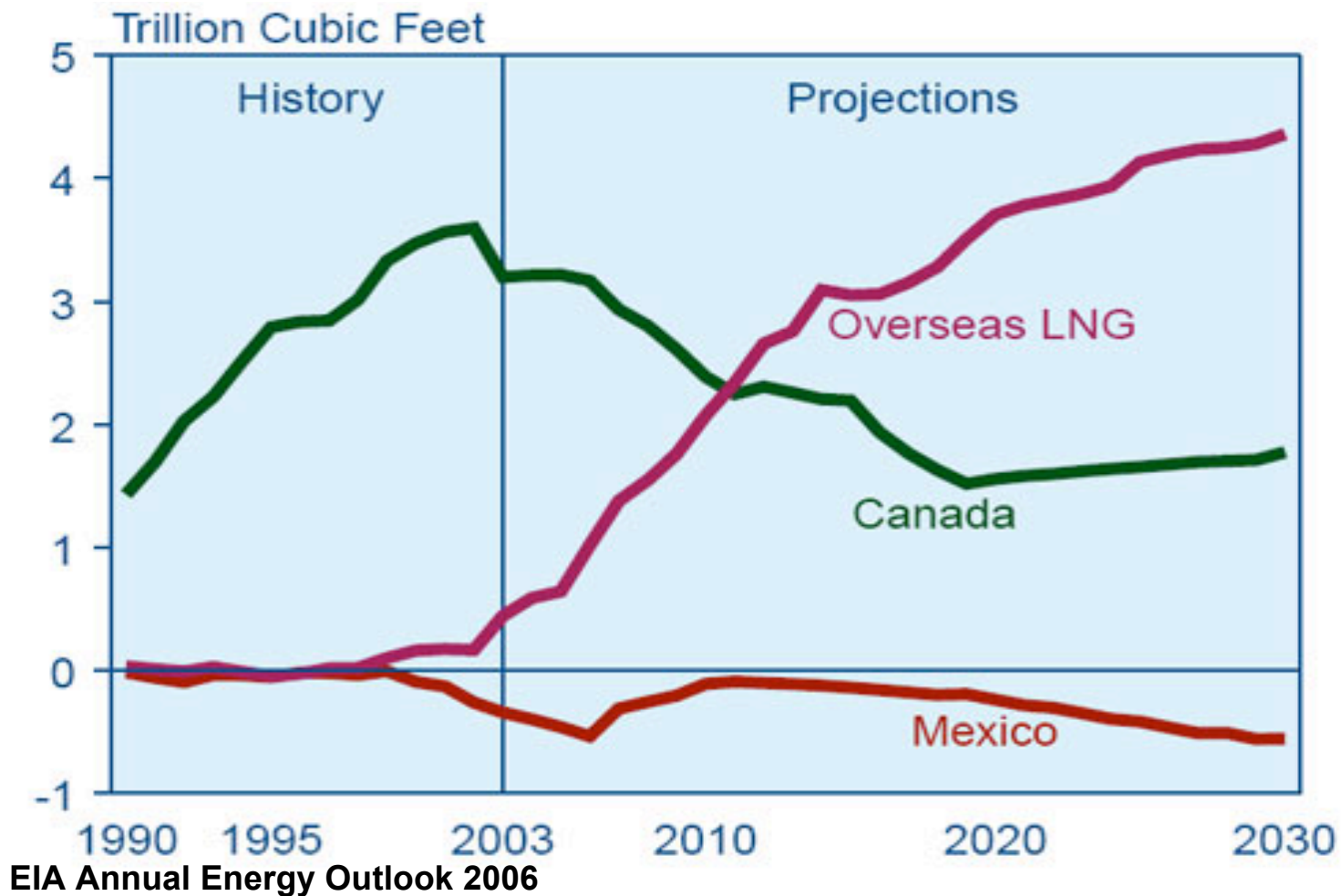
Natural Gas Market

Average Annual Increases in Industrial Natural Gas Consumption, 2003-2030, by Region and Country



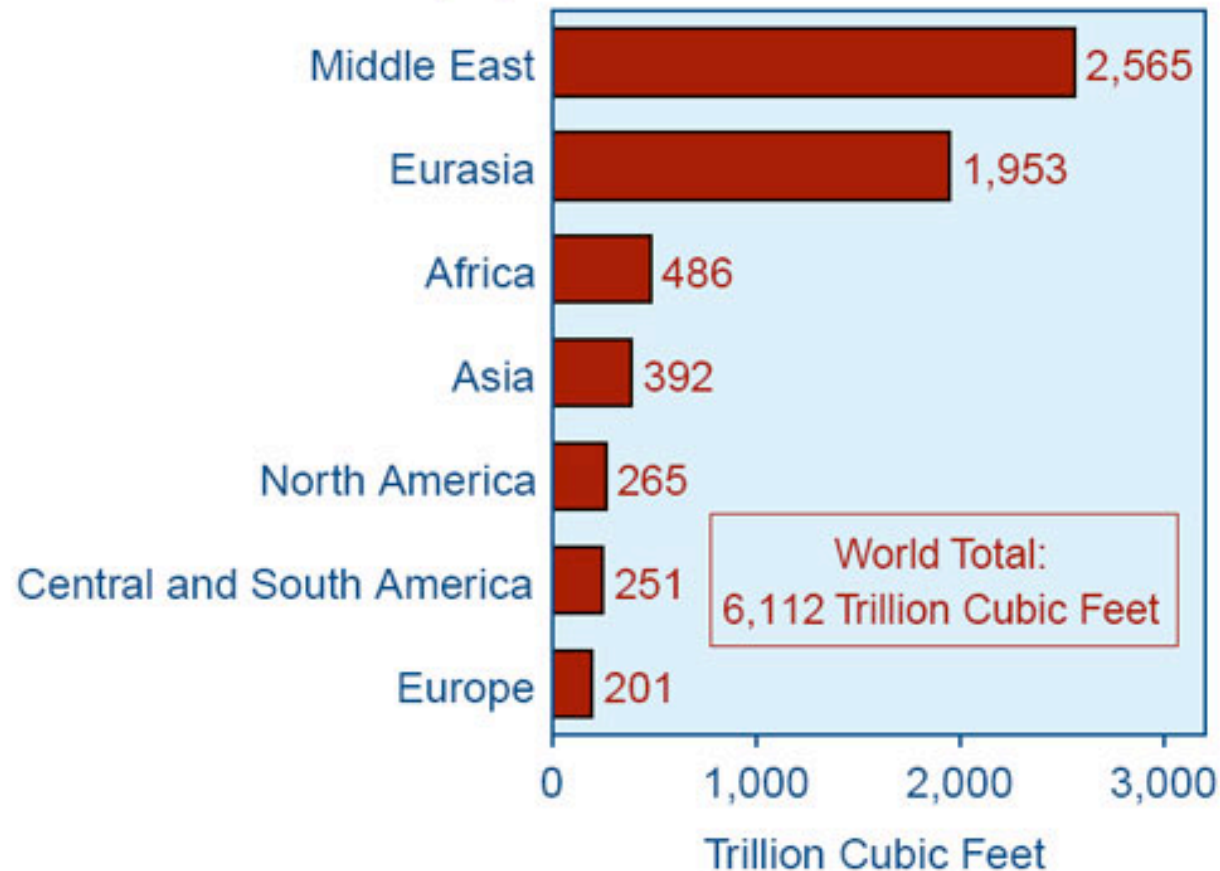
Natural Gas Market

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



Natural Gas Market

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

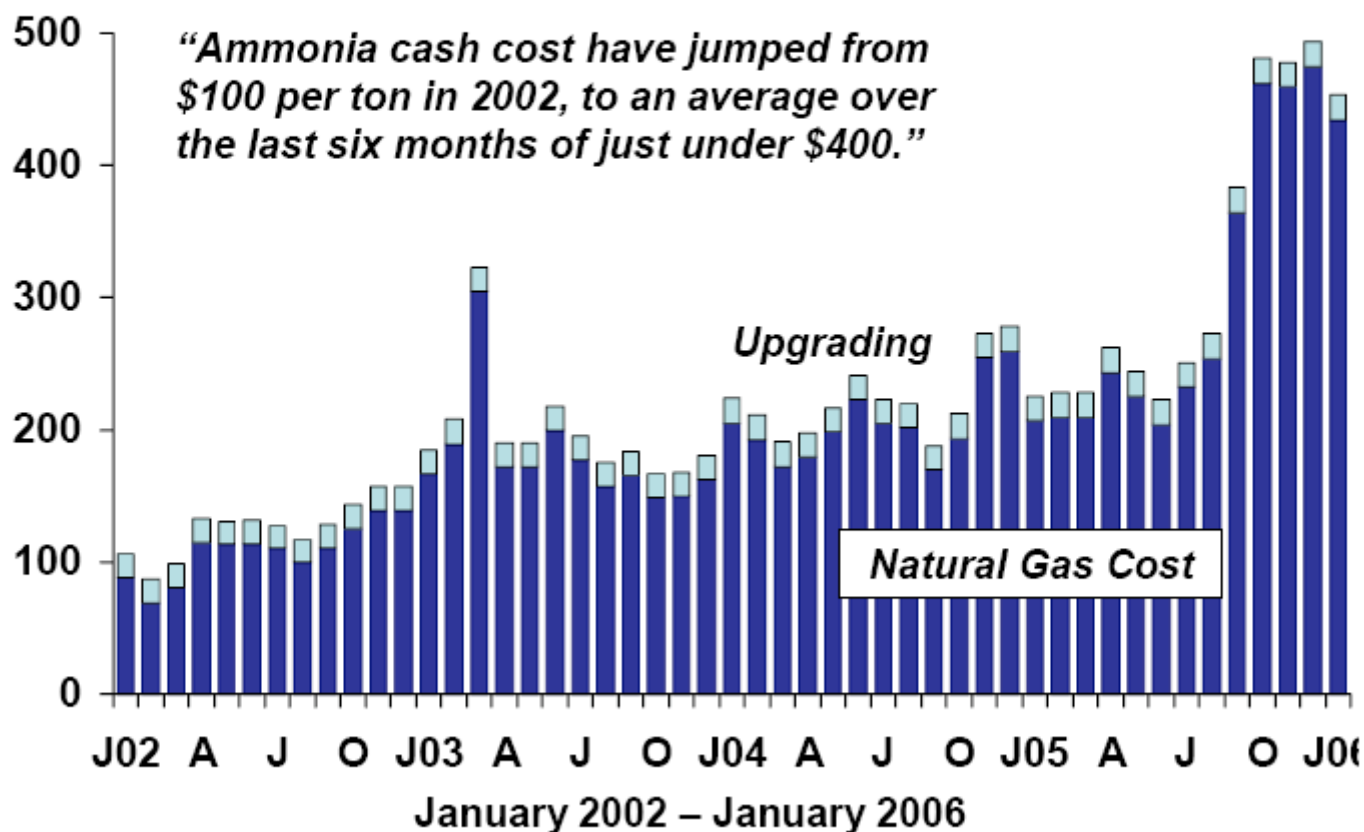


Source: "Worldwide Look at Reserves and Production," *Oil & Gas Journal*, Vol. 103, No. 47 (December 19, 2005), pp. 24-25.

Declining Domestic Production

*U.S. Ammonia Production Cost**

\$ Per Ton – Typical Gulf Producer



* Cost based on FERC monthly prices

Source: Agriculture Energy Alliance, 2006



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Declining Domestic Production

U.S. Nitrogen Production Capacity Change between 1999 and 2005

| | <u>Ammonia</u> | <u>Urea</u> 000 Tons | <u>UAN 32%</u> |
|---------------------------|----------------|-------------------------|----------------|
| Capacity Beginning FY1999 | 19,946 | 10,277 | 11,701 |
| Permanent Closures | 8,405 | 3,671 | 2,475 |
| Additions to Capacity | | | |
| New Capacity | 640 | 190 | 525 |
| Expansions/Debottlenecks | <u>241</u> | <u>109</u> | <u>101</u> |
| Total | 881 | 299 | 626 |
| Net Change | <u>-7,524</u> | <u>-3,372</u> | <u>-1,849</u> |
| Total | 12,422 | 6,905 | 9,852 |
| % Reduction in Capacity | 38% | 33% | 16% |

Source: Agriculture Energy Alliance, 2006

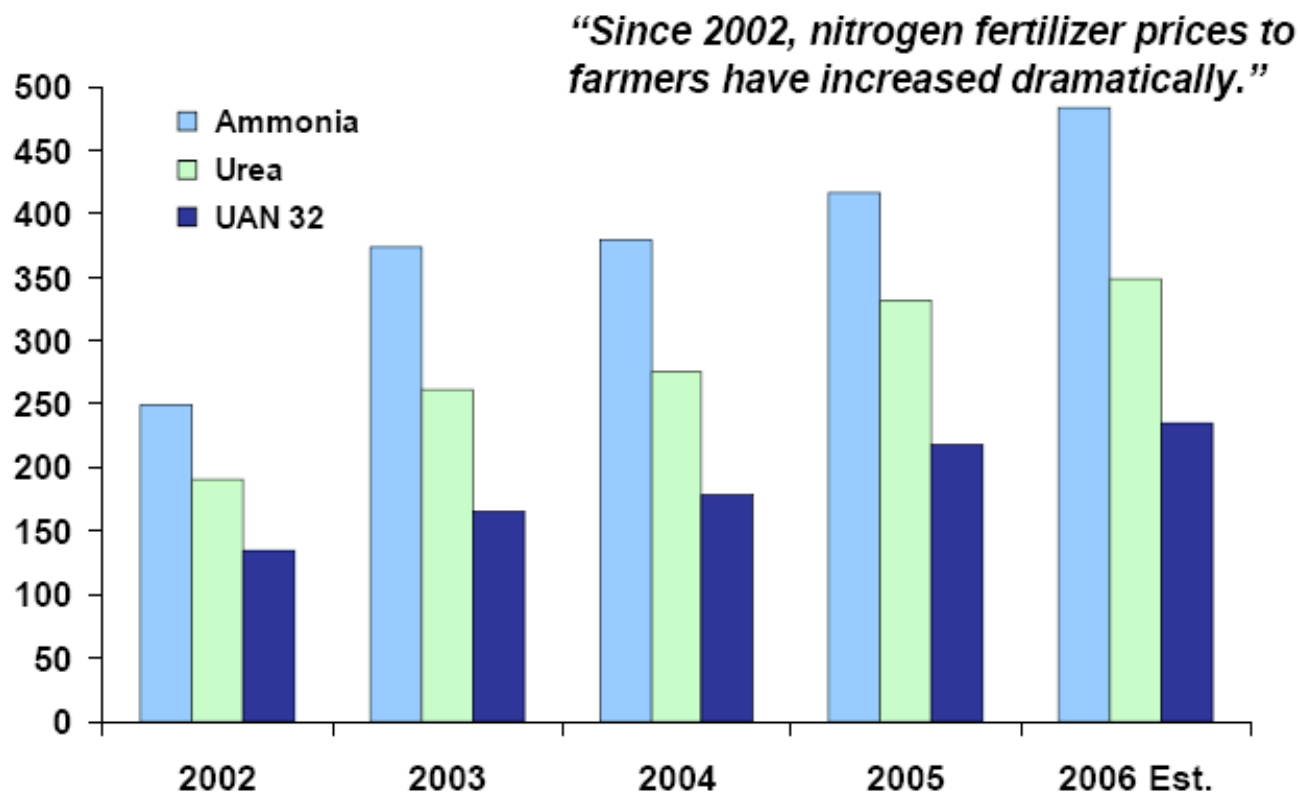


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Increasing Ammonia Prices

U.S. Farm Level Fertilizer Prices

\$ Per Short Ton



Source: Agriculture Energy Alliance, 2006

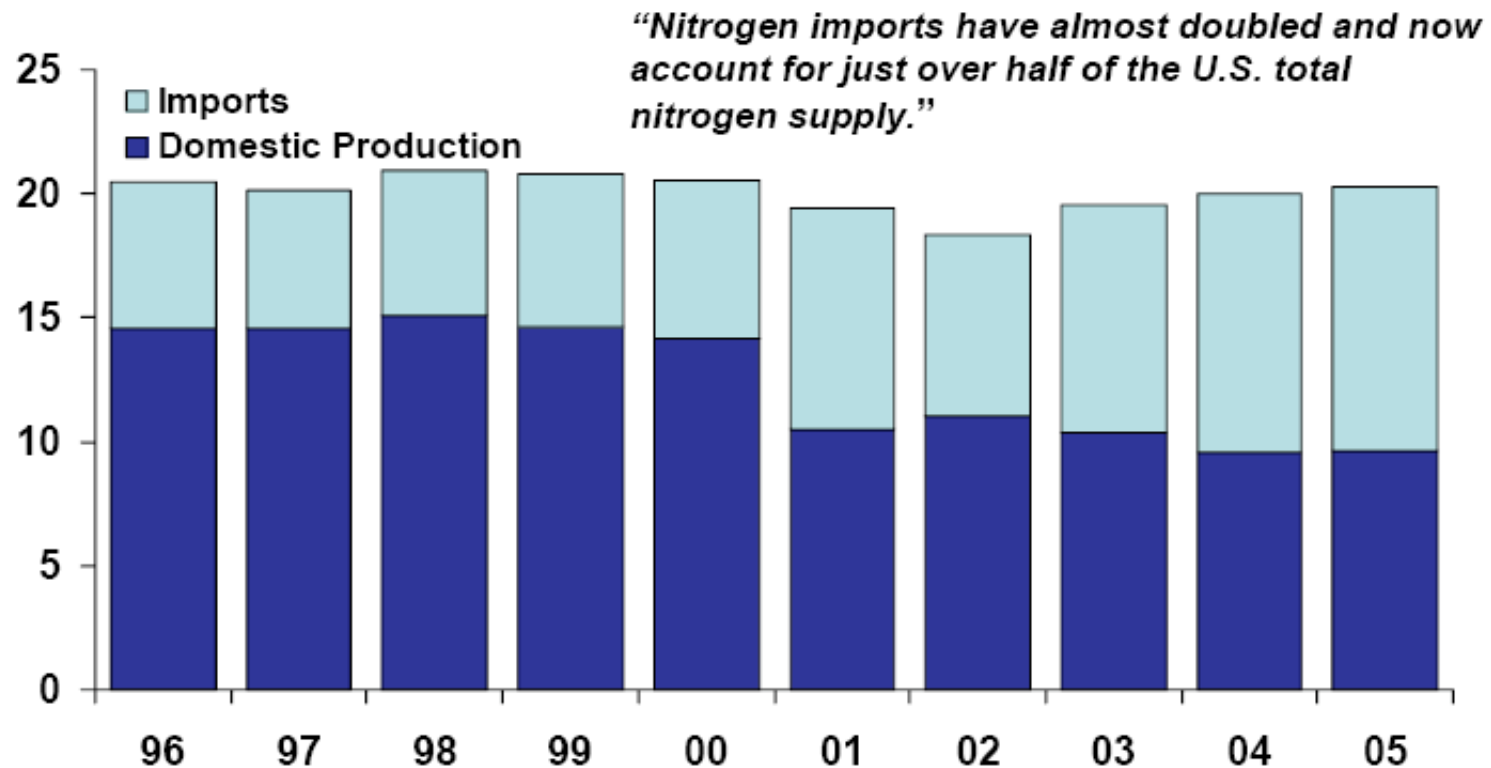


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Increased Imports

U.S. Nitrogen Supply

Million Tons N



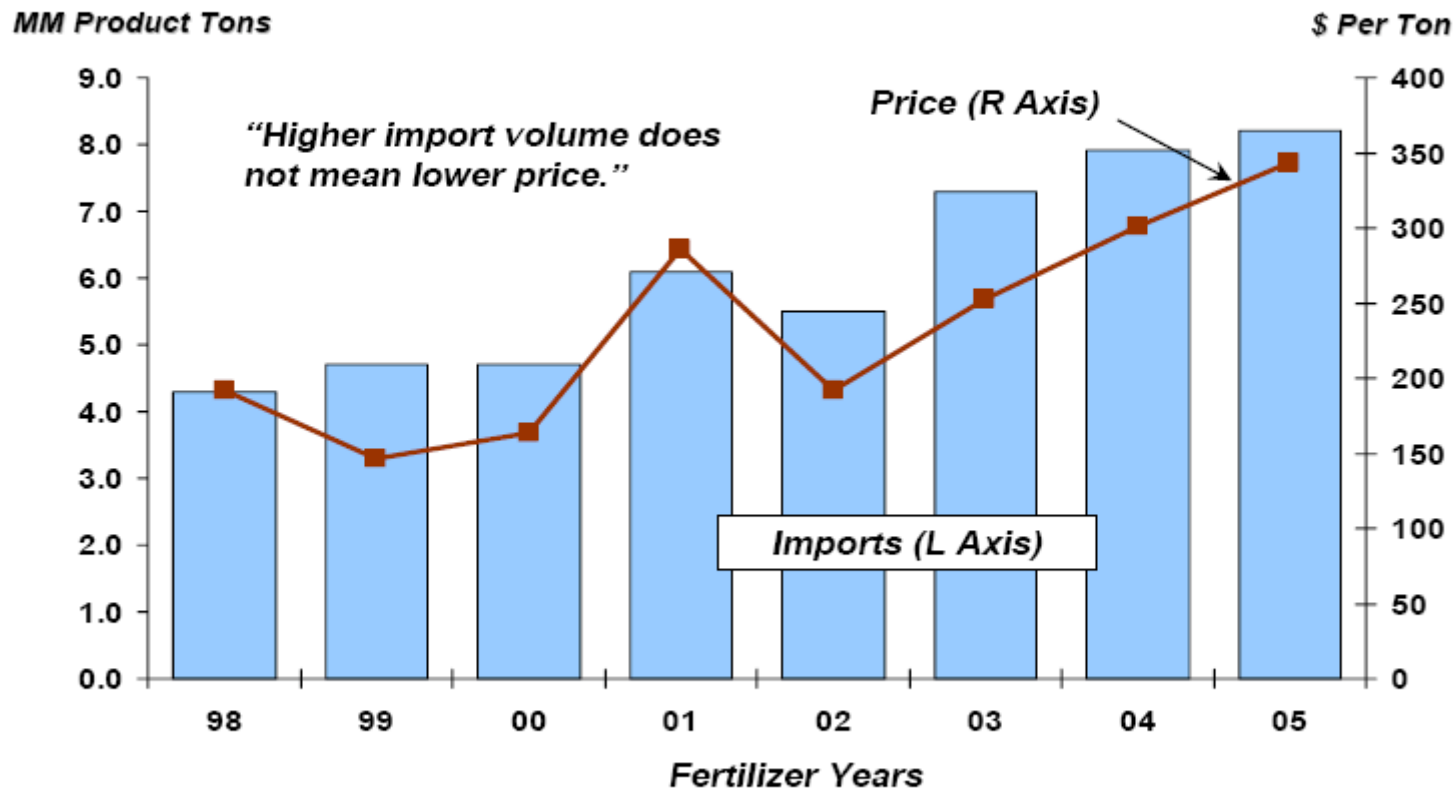
Source: Agriculture Energy Alliance, 2006



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Increased Costs

U.S. Ammonia Imports vs. Midwest Dealer Price



Source: Agriculture Energy Alliance, 2006



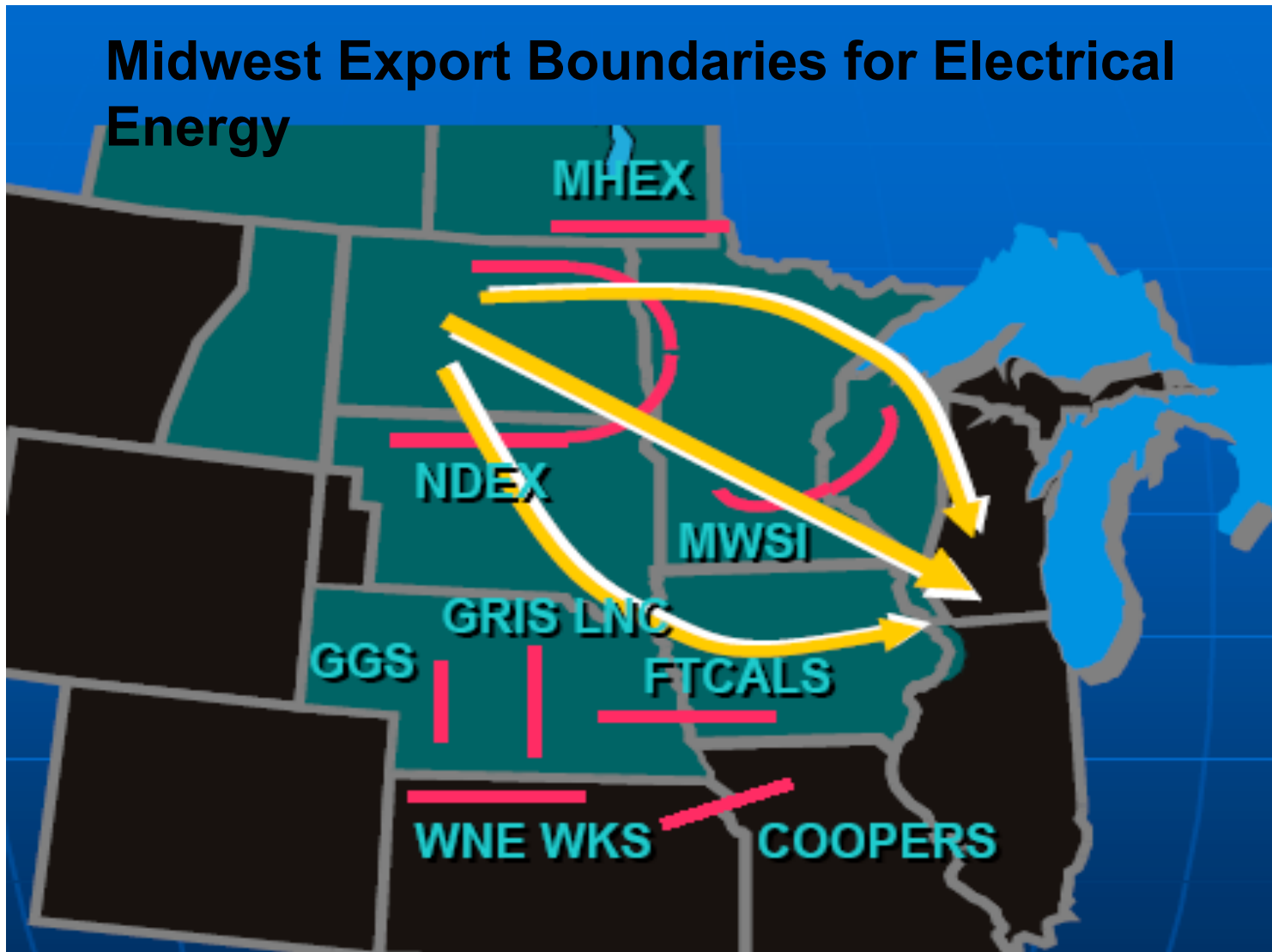
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Stranded Wind Resource



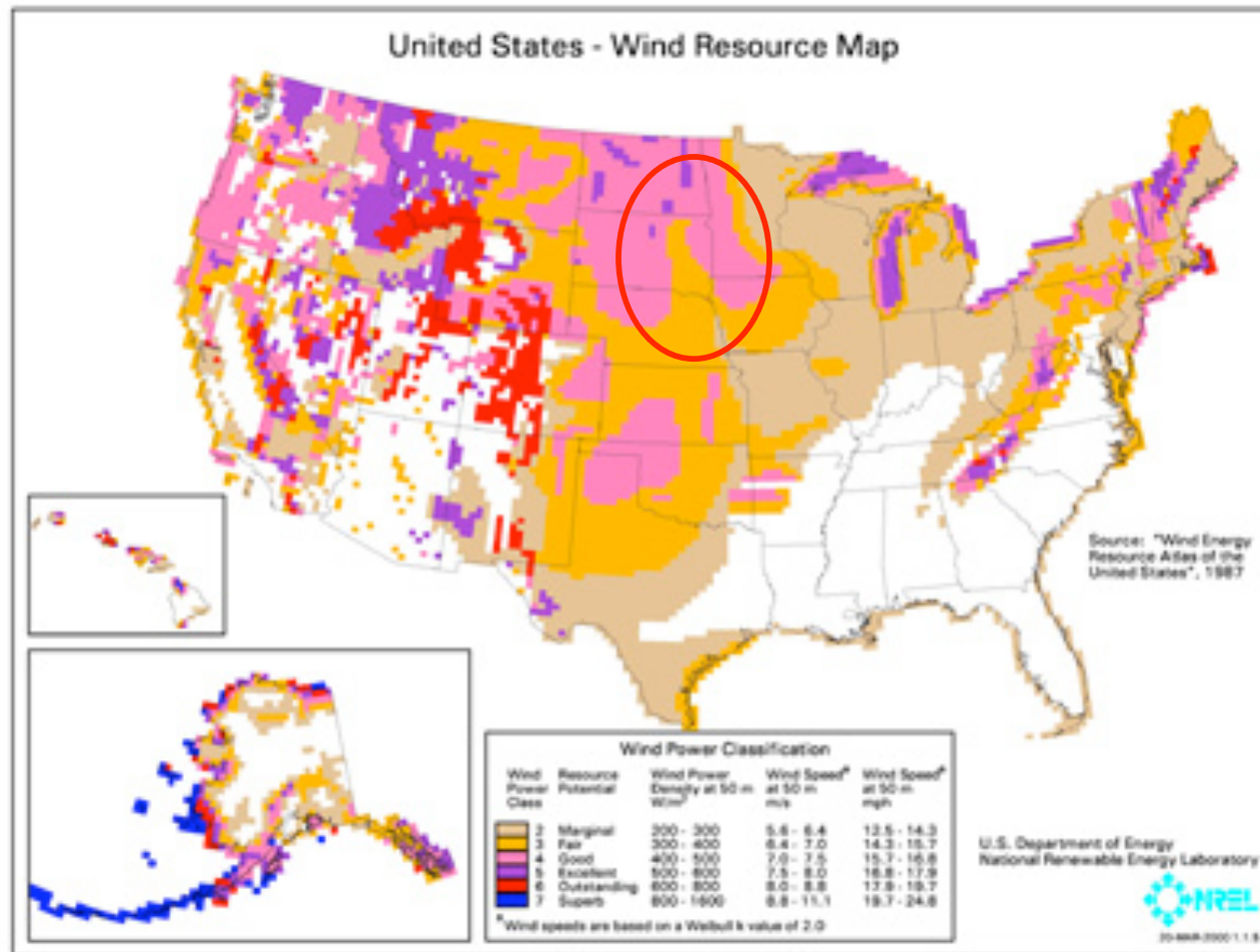
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Stranded Wind Resource



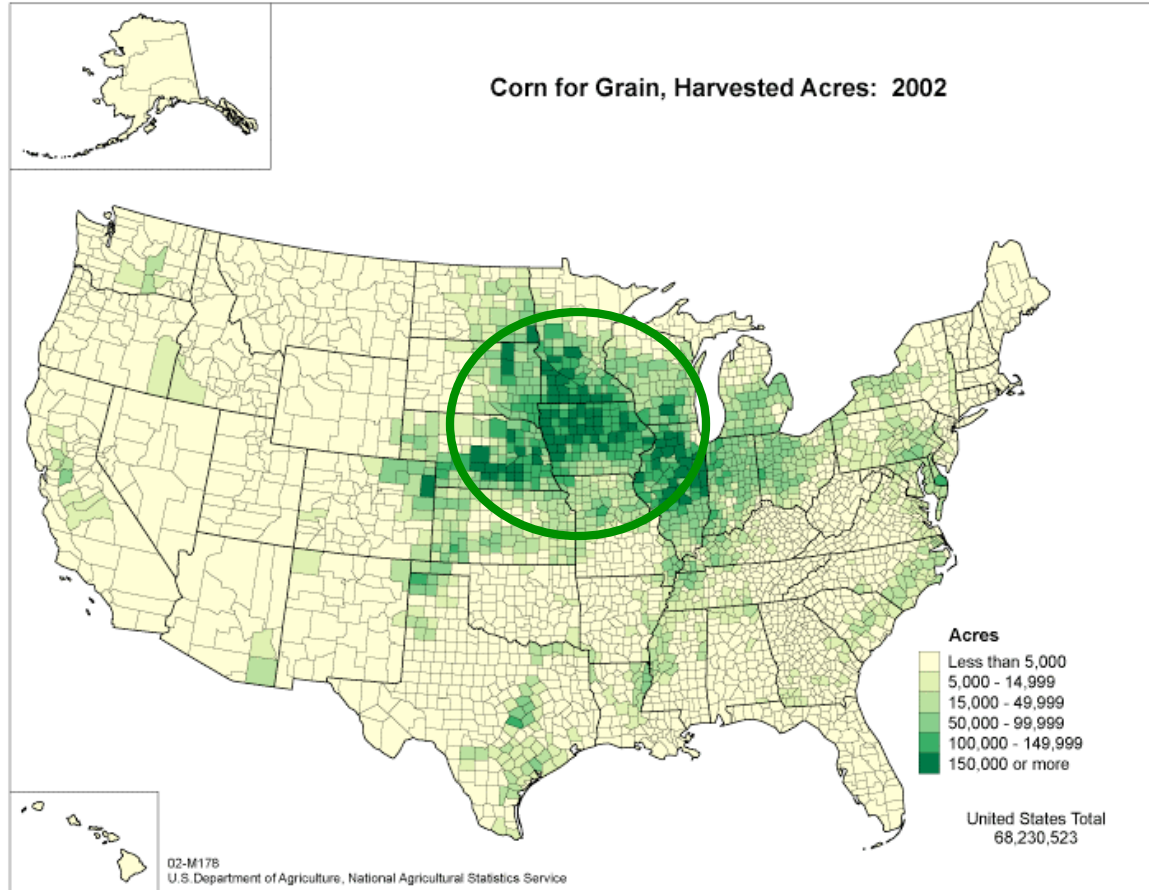
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Excellent Wind Resource



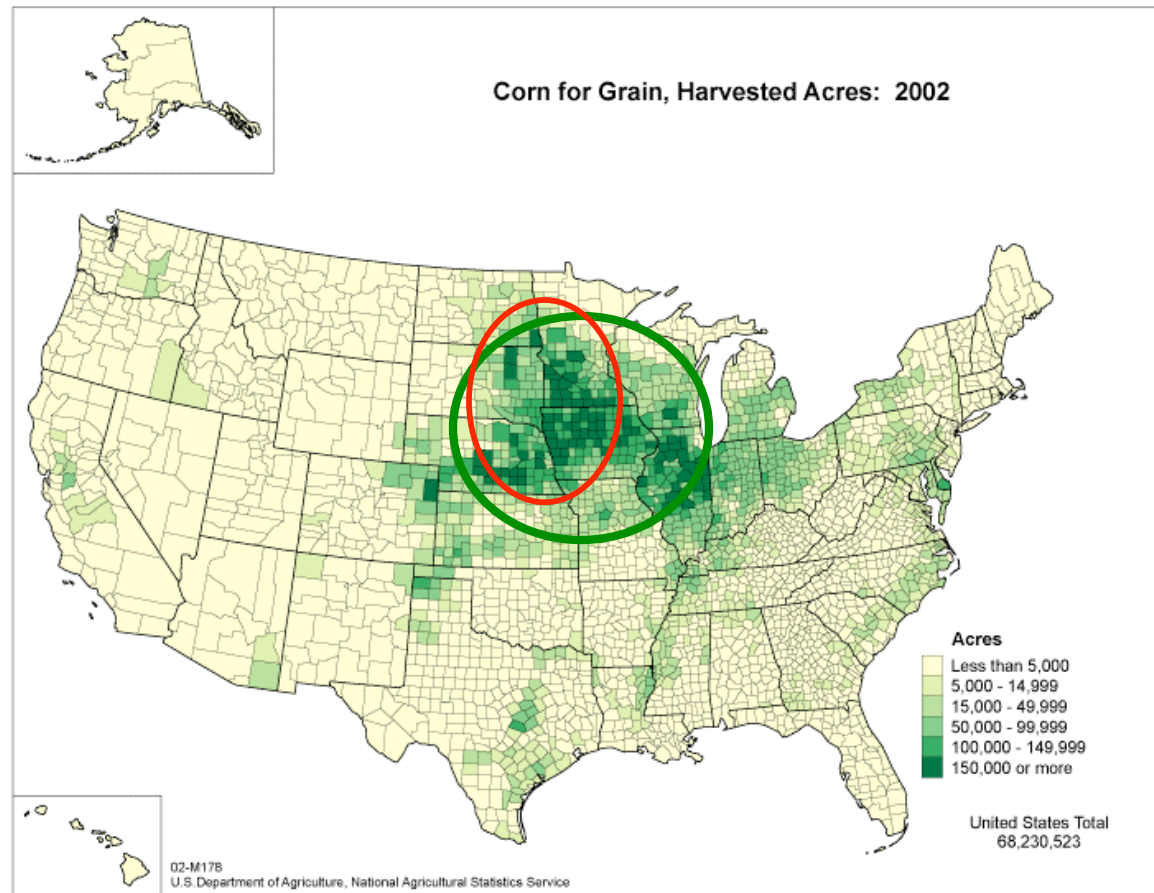
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High Demand for Ammonia



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High Demand for Ammonia



& Excellent Wind Resource



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Robust Ammonia Infrastructure



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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**



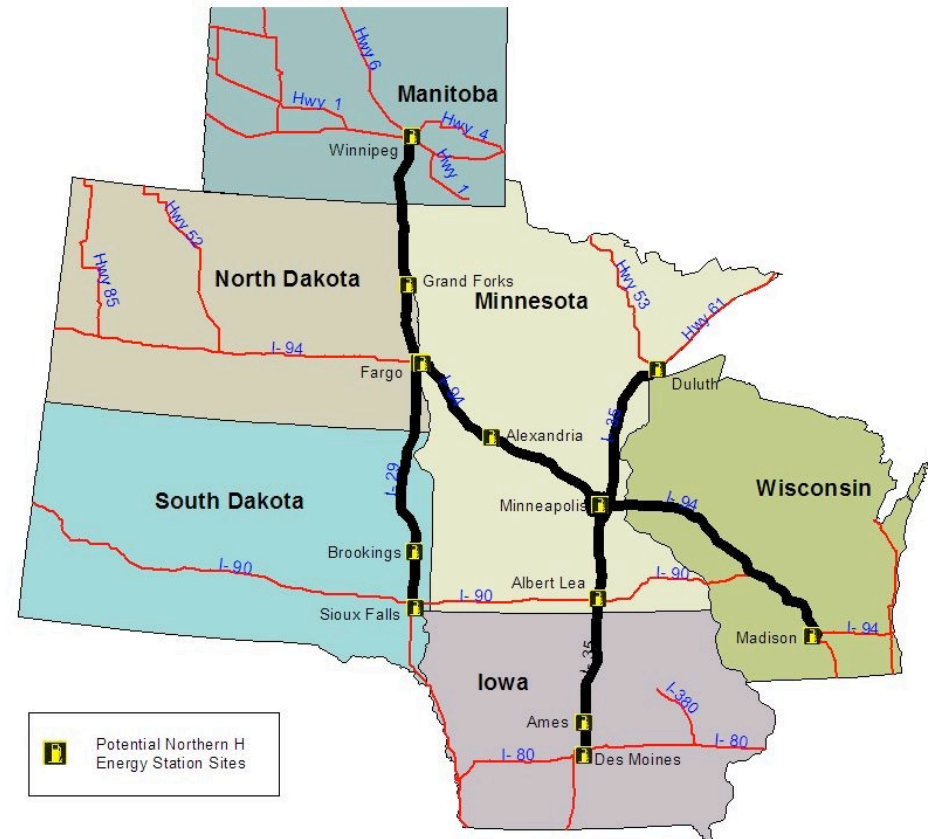
Success of Producer-Owned Ethanol

- 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



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

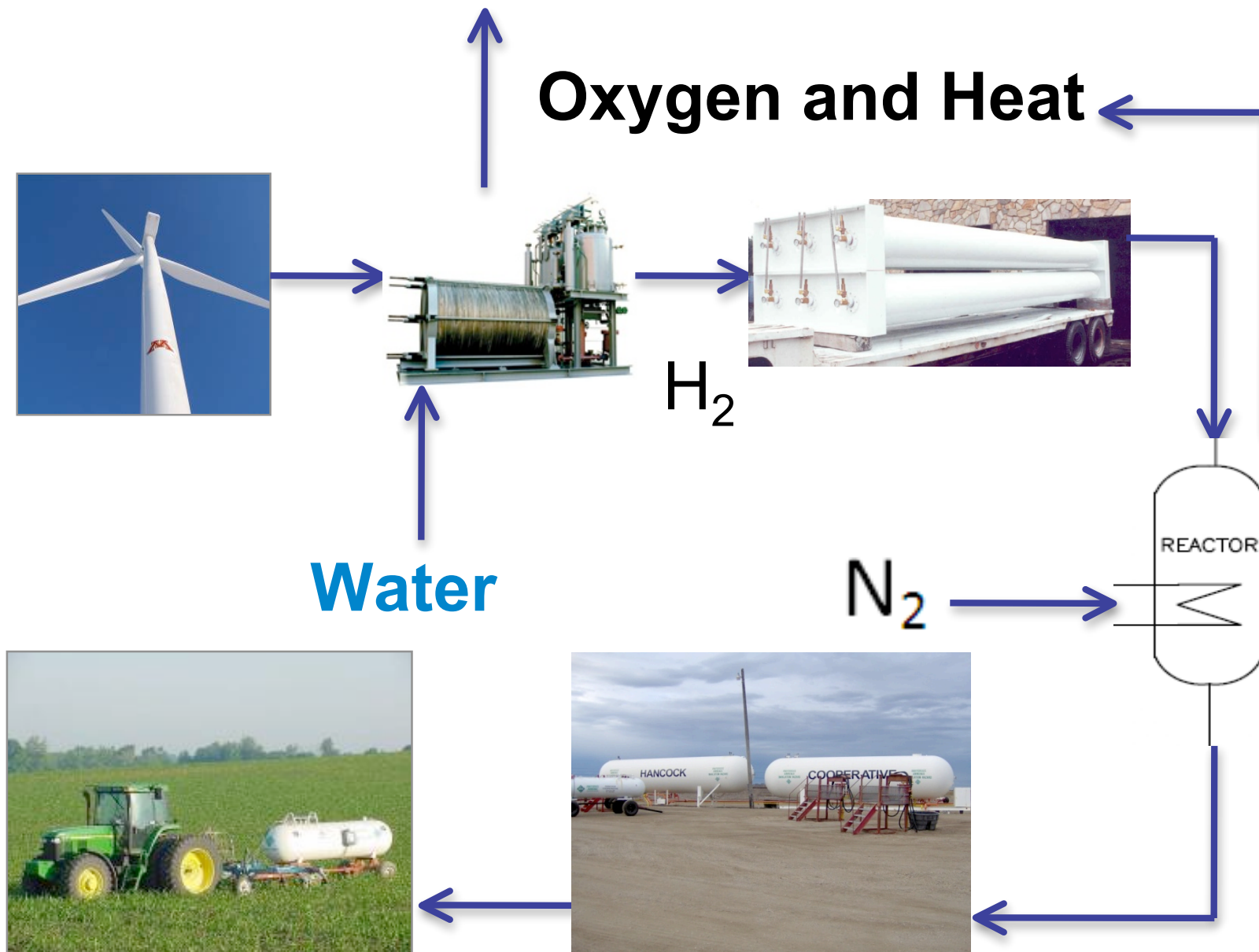
- **Small reactor for pilot facility (~size of 50 gallon drum)**
- **Simple reactor design and construction**
- **Process is very scalable (SMR requires large facilities)**
- **Pilot facility will produce a maximum of 1 ton per day**
- **Reactor pressure 60-80 Atmospheres (800 to 900 PSI)**
- **Scheduled to be operational Fall 2008**
- **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**







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Ammonia Demand in Minnesota:

- Minnesota farmers apply approximately 1.2 billion lbs NH₃
 - 7.2 million acres of corn planted
 - 146 bushel yield per acre
 - 970,900,000 bushels total produced
- Two gigawatts of nameplate wind energy is required to produce enough ammonia for Minnesota



Renewable Ammonia Supply:

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

So what does this mean:

- 1000 two-megawatt wind turbines \$3.5 billion
- Ammonia production facilities \$3.5 billion
(estimated)

*Two 750 KV lines from Dakotas to Chicago - \$4 billion / yr




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Economics of Wind to Ammonia

- Long term – good
- Mid term – okay
- Short term – problematic

 Cost of production \$.30 to \$.60 / lb of NH₃ (estimate)

 Cost of energy \$.18 to \$.36 / lb of NH₃ (estimate)

 High capital costs – No economies of scale in manufacturing



Potential Policy for Wind to Ammonia (MN)

- 5-20% renewable ammonia mandate
- Production incentive \$.05 to \$.15 / lb NH₃ produced
- Blenders tax credit
- And / or equipment and operating grants



Putting it together:

- Currently Minnesota uses approximately 1.2 billion lbs or 600,000 tons of NH₃ (\$300 million)
- A 10% mandate would require 60,000 tons of Renewable NH₃
- 200 MW Wind Turbines - \$350 million
- \$1000 per ton of renewable ammonia and \$500 per ton of conventional ammonia would result in an **additional \$30 million per year** in rough numbers (\$300 vs \$330 million)



Putting it together:

- 200 MW Wind Turbines - \$350 million
- Renewable ammonia production facility - \$350 million
- \$60 million / yr renewable ammonia sales
- \$12 million / yr renewable ammonia production incentives
- \$14 million / yr wind energy production tax credits
- **Can \$86 million revenue pay for \$700 million capital costs plus operating plus a return on investment?**



Key questions:

- Is there a competitive response? What are the financial and economic impacts? Will a competitive response act to cover public costs to a renewable ammonia policy?
- How do we simultaneously ramp up renewable ammonia production levels while reaching economies of scale and mass manufacture of equipment?
- What are the economic implications?
 - \$7 billion in construction materials and labor
 - Monetization of a stranded resource
 - Cost avoidance of transmission (\$4 billion per yr)
 - Future NG hedge
 - Competitive market



Scenario 1: Farmer and Community Owned Hybrid Wind Systems

- ✓ Wind enterprise “sells” electricity to hydrogen and ammonia enterprise
- ✓ Federal Wind Production Tax Credits
- ✓ Farmers have contracts to accept set amounts of anhydrous ammonia as part of participation in the wind farm.
- ✓ Farmers participate in financially viable wind farms while creating and utilizing a firm supply and moderately priced nitrogen fertilizer.



Scenario 2: Farmer and Community Owned Hybrid Wind Systems

- ✓ Partnership with Utility, Wind Farm, and Ethanol Plant
- ✓ Utility uses ammonia production as energy sink and storage
- ✓ to manage transmission grid
- ✓ Co-locate with ammonia production with ethanol plant
- ✓ Federal Wind Production Tax Credits
- ✓ Farmers have contracts to accept set amounts of anhydrous ammonia as part of participation in the wind farm.
- ✓ Farmers participate in financially viable wind farms while creating and utilizing a firm supply and moderately priced nitrogen fertilizer.

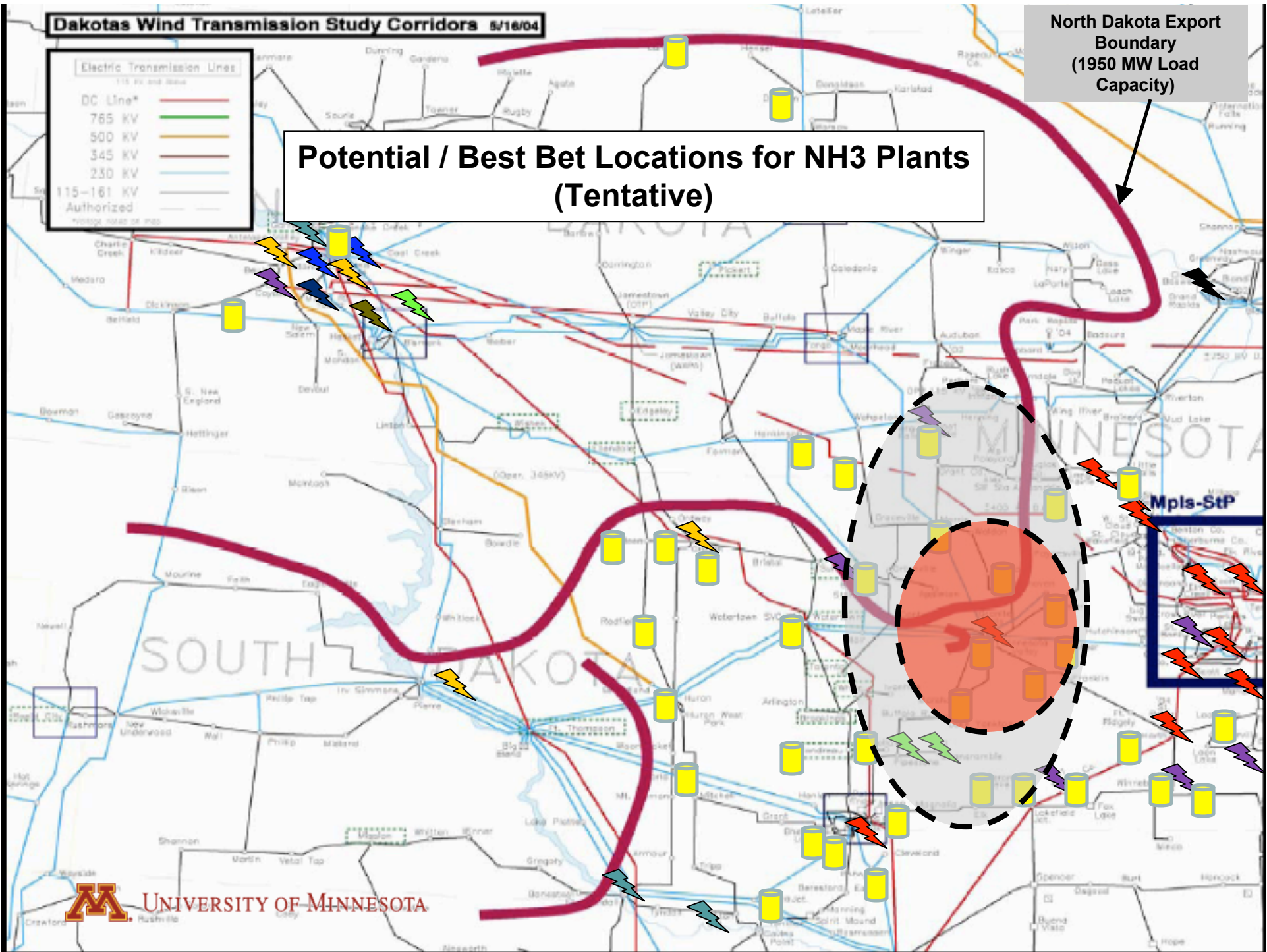


Dakotas Wind Transmission Study Corridors 5/16/04

| Electric Transmission Lines | |
|-----------------------------|--|
| 115 KV and above | |
| DC Line* | |
| 765 KV | |
| 500 KV | |
| 345 KV | |
| 230 KV | |
| 115-161 KV | |
| Authorized | |
| Voltage not on map | |

**Potential / Best Bet Locations for NH3 Plants
(Tentative)**

**North Dakota Export
Boundary
(1950 MW Load
Capacity)**



Scenario 3: Farmer and Community Owned Hybrid Wind Systems

1. Partnership between Utility and Ag Producers
2. Locate ammonia production facilities at areas of constraint on transmission grid
3. Utility uses ammonia as energy sink and storage to manage transmission system

Wind farm purchases energy at reduced rate

Ag producers participate in the business and have long term contracts to accept ammonia



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 Conclusions

- 1. The University of Minnesota is developing a globally unique Wind to Hydrogen to Ammonia Pilot System with many partners.**
- 2. Ammonia costs are anticipated to rise through the next decade under current production and markets**
- 3. A valid Wind to Hydrogen to Ammonia Model may lead to:**
 - a stable nitrogen fertilizer supply and price,**
 - increased utilization of wind energy,**
 - opportunities for rural economic development,**
 - and the Hydrogen Economy!**



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