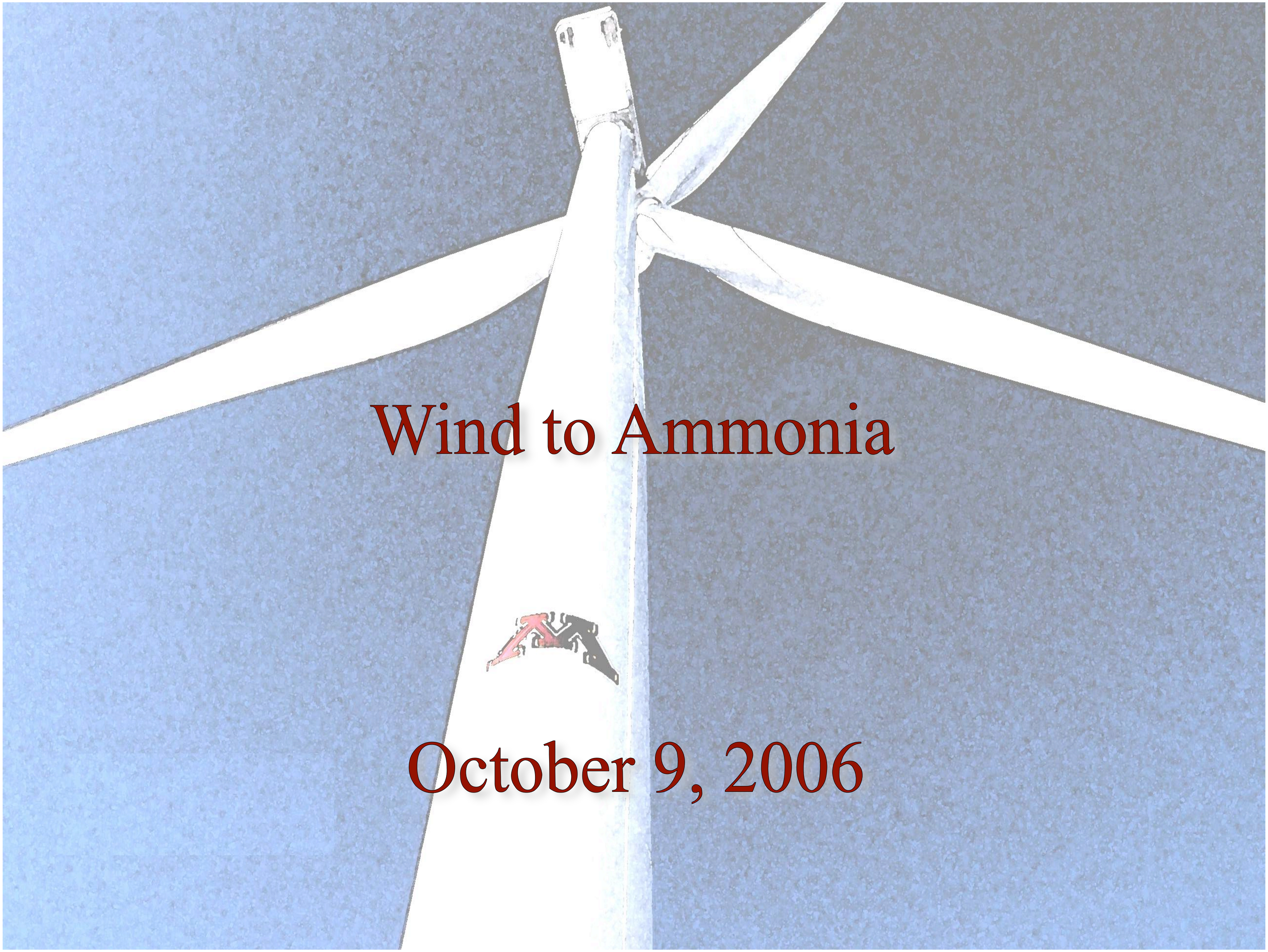


Wind to Ammonia

October 9, 2006

Wind to Ammonia

Ammonia- Key to U.S. Energy Independence Conference

Denver, Colorado

October 9, 2006

Presenter

Michael Reese

University of Minnesota

West Central Research and Outreach Center

Outline:

1. Introduction and Background
2. University of Minnesota Wind to Hydrogen System
3. Economics of Wind Energy Electrolysis
4. Drivers for Wind to Ammonia
5. Scenarios
6. Summary

The Good:

Minnesota has a vast supply of renewable resources including:

Wind Energy, Biomass, Biogas, Solar, Hydro, Geothermal, and others.

The Bad:

Minnesota does not produce any fossil fuels and imports over $12 billion in energy.

And the Ugly!

World energy demand is growing at alarming rates! Global warming!

The Ugly

“Since 2000, Chinese oil consumption has doubled, accounting for almost half the rise in global use. The country's industrial revolution - with huge increases in construction and manufacturing - is highly energy-intensive.

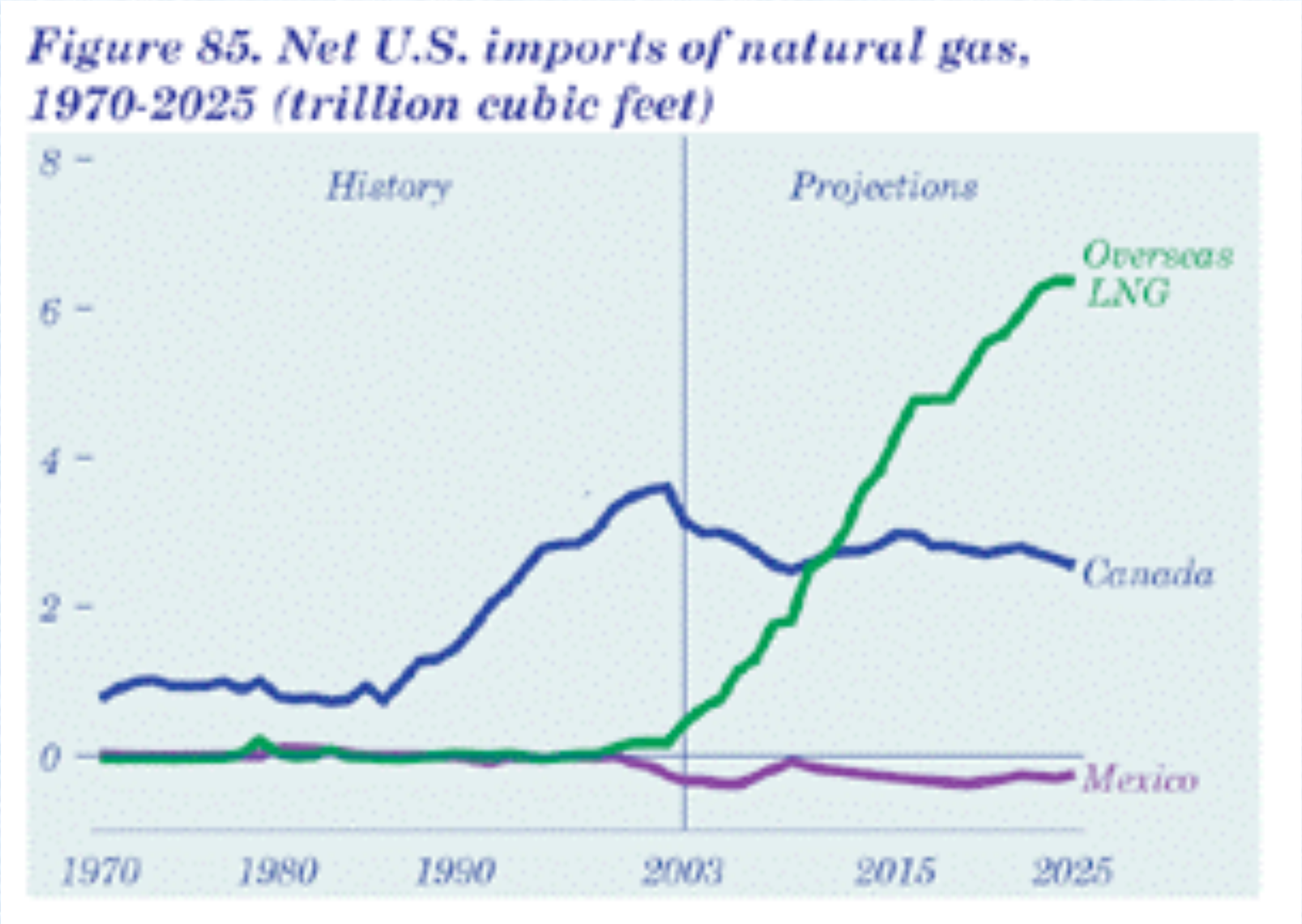
“During the past decade, Chinese car ownership has grown at double-digit or even triple-digit percentage rates every single year. However, there are still only 20 cars per 1000 people in China, compared with 950 in the United States.”

“Much the same situation is occurring in India, Indonesia and Brazil - all of which have huge populations and a growing middle class.”

"The supply margin is so thin, every little blip is going to move the market. And the acute geopolitical risks have lessened but the chronic geopolitical risks are still there," **said Tony Nunan, risk manager at Mitsubishi Corporation”**

Douglas Hamilton, The Herald 9/25/06

The Bad: Projected U.S. Natural Gas Imports



The Good!

The Midwest’s rich renewable resources

Plus

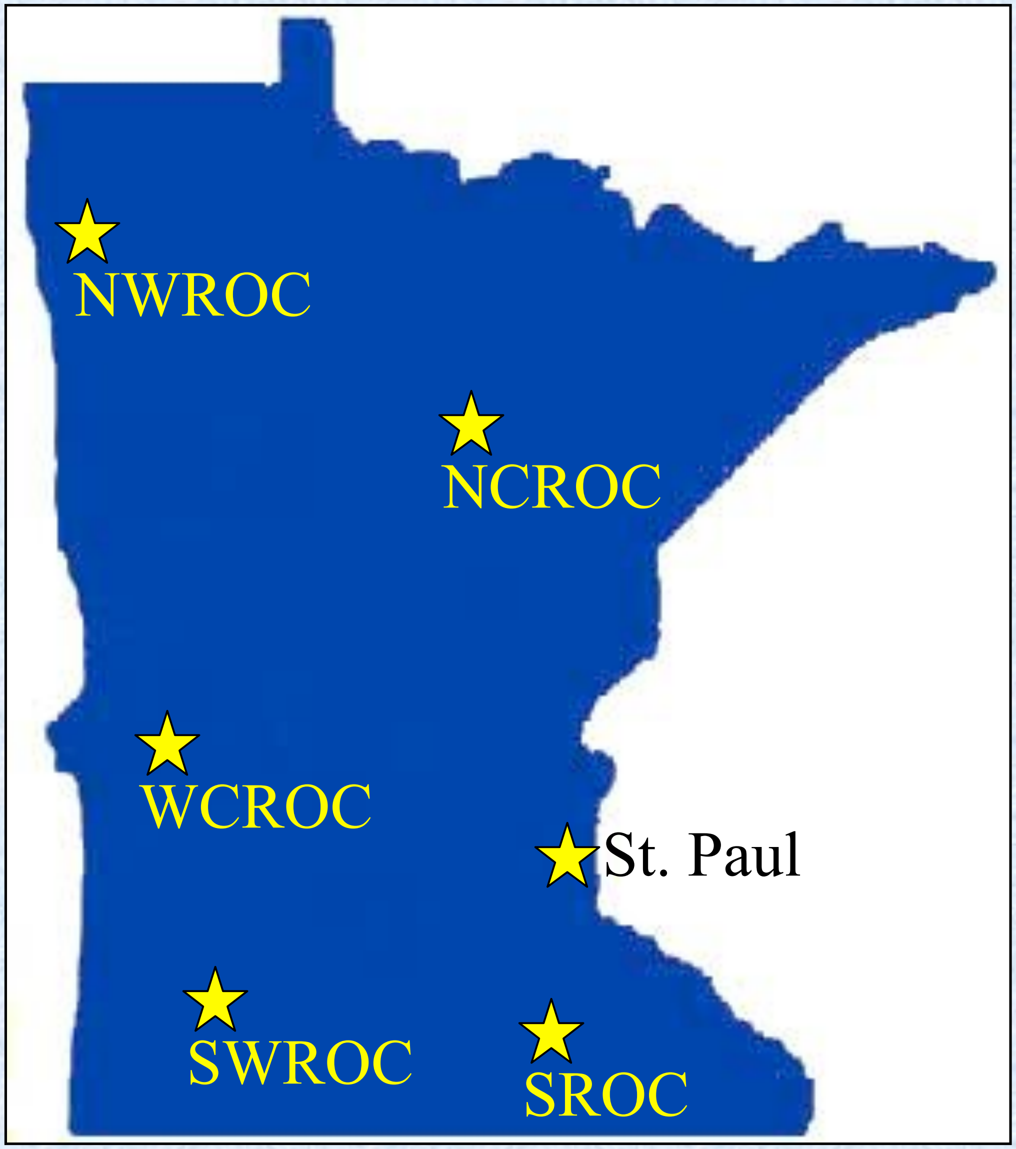
Energy, Environmental, and Economic Concerns

Equals

Healthy Environment for Innovation and Entrepreneurship
And an opportunity to expand on the “Triple Bottom Line”

Renewable Energy and the "Triple Bottom Line"

The **triple bottom line**, aka "People, Planet, Profit", captures an expanded spectrum of values and criteria for measuring organizational (and societal) success - economic, environmental and social. -Wikipedia, 2006


NWROC
NCROC
WCROC
St. Paul
SWROC
SROC

West Central Research & Outreach Center:

-Strong desire to make a positive and substantial impact on the citizens of the state, especially in rural Minnesota.

-Conduct agricultural and rural related research and outreach. Renewable energy is a agriculture resource.

University of Minnesota, Morris:

-Students wanted and requested renewable energy.

-Campus energy costs were growing rapidly.

Other Stakeholder Groups:

-Active and willing participation by a number of people.

-Proactive citizens in the community and region.

-Desire to build on the success of the ethanol industry.

Goal:

To develop a community-scale, integrated, production, research, and demonstration renewable energy center.

Objectives:

1. Develop a renewable energy research and demonstration center focusing on wind, biomass / biofuels, and hydrogen.

2. Facilitate renewable energy projects being done by others in the region and state.

3. Provide a model for rural communities.

Core Systems:

1. **WCROC Hybrid Wind Renewable Energy System**

2. **UMM Biomass Gasification System**

3. **WCROC Renewable Energy Research & Education Addition**

4. **Community Bio-gas / Bio-methane System**

- Practical Production Systems – Not Lab Scale
- Research and Demonstration Platforms
- Utilize Renewable Resources within Geographic Region
- Link systems on Internet to Provide Information World-wide

Hybrid Wind System

WCROC Wind Turbine:

-Research tool *and* a functioning, production system.

-1.65 MW Vestas V 82 Wind Turbine

-5.6 million kWhr per year estimated production

-Direct line to the University of Minnesota Morris campus.

-Supplies over 60 % of the campus electrical needs.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Hybrid Wind System

Wind to Hydrogen Research and Demonstration

Objectives:

1. Provide systems to "store" wind energy for base load / dispatchable / on-demand or peaking power.

2. Develop value added products and hydrogen bridge technologies from wind energy.

3. Combine these technologies, validate systems, and conduct economic analysis.

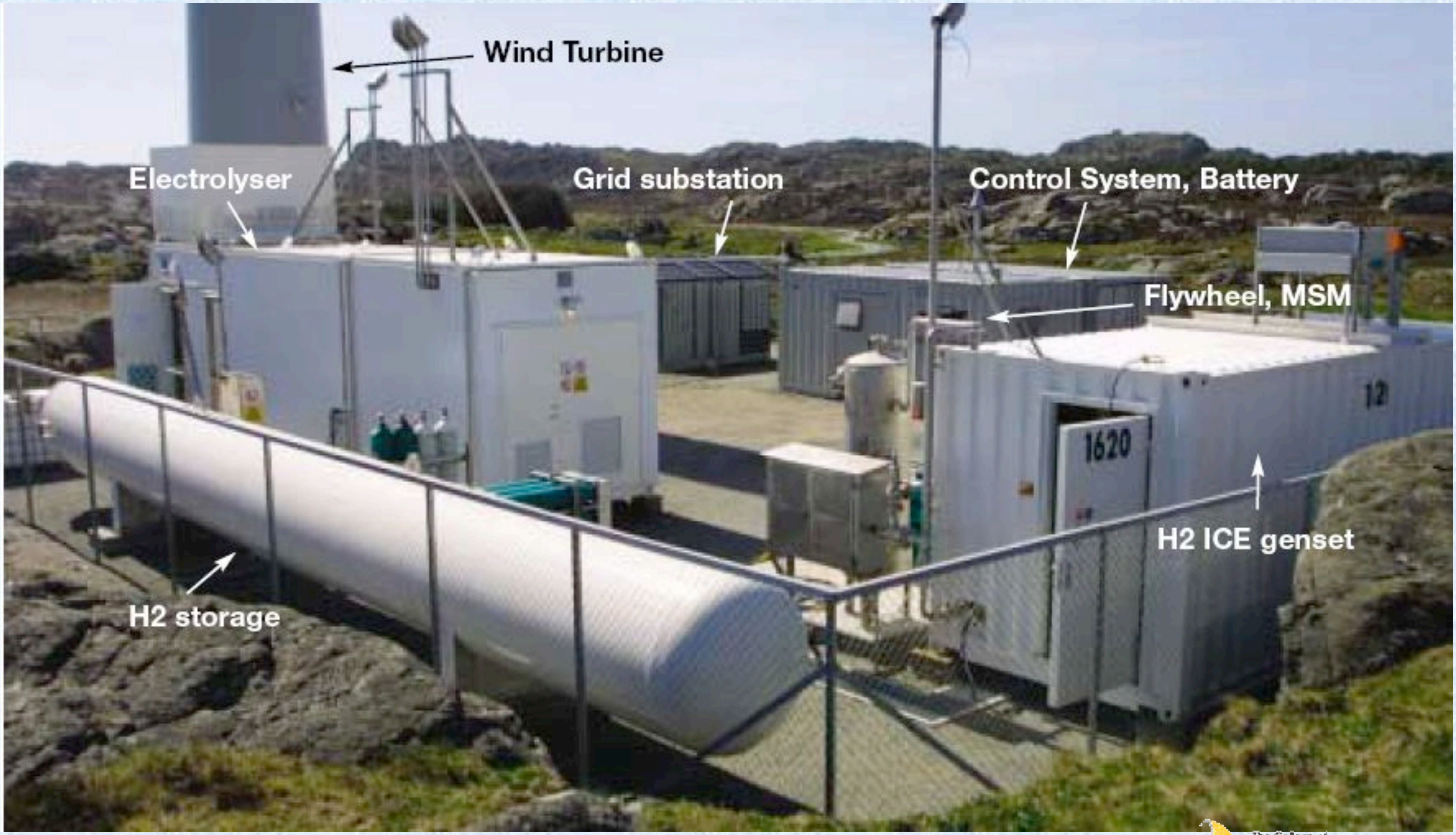
Hybrid Wind System: Wind To Hydrogen Project

*Legislative Commission on Minnesota Resources has provided funding for Phase 1.

Phase I – Hydrogen & Electrical Energy Production

1. Electrolyzer
2. Storage
3. Reciprocating engine generator

Wind to H2-Utsira, Norway



Hybrid Wind System

Phase II: Value Added Wind Energy & Bridge Technologies

1. Production of Anhydrous Ammonia
   - -Nitrogen fertilizer
   - -Refrigeration and other uses

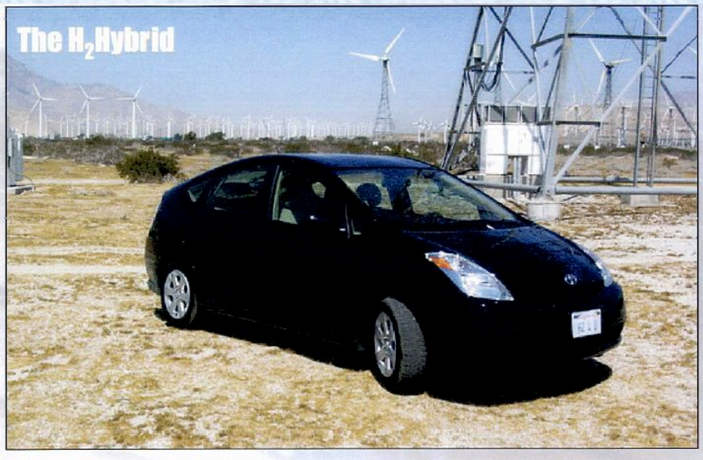
$2.5 million provide by MN Legislature to develop pilot wind to anhydrous ammonia system along with University funding.

2. Transportation Fuel
   - -Fleets (Government, schools, carriers, etc)
   - -Service vehicles (fork lifts, golf carts, lawn tractors)
   - -Cars and pickups

Hybrid Wind System

Wind to Hydrogen

Phase II Value Added Wind Energy & Bridge Technologies



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

Hydrogen Fueling Station - Iceland

Hydrogen Bus and Fueling Station - Iceland

Hybrid Wind System

Phase III: Hybrid Wind and Hydrogen Systems

1. Business / Commercial Modeling – Wind Energy Refinery
2. Hydrogen – Natural Gas Mixed Turbine (2-3 MW) and Boilers
3. Hydrogen or H2 and Natural Gas Pipeline System
4. In depth analysis of combined power generation, valued added products, and natural gas displacement

Key question:

How do we move towards a renewable hydrogen sector?

Price Targets

- ✓DOE Target: 20% of all light duty vehicles running on hydrogen by 2020

- ✓DOE Target: $2.85/kg <u>delivered</u> hydrogen by 2020

To Make The Case For Renewable Hydrogen Electrolysis

- Hydrogen from renewable energy sources must be cost competitive with other methods

- Policy will play important role through tax credits, incentives, etc.

- Electricity and hydrogen from renewable energy sources must be able to get to market

Projected Prices of Hydrogen from Wind Energy

Levine, 2005

✓Current cost projections limit hydrogen use in electrical energy generation and in the short term as a transportation fuel.

Getting To Market

- Existing electric transmission system constraints
- Need to better understand economics:
  - Transport renewable electricity and produce at point of use , OR
  - Electrolyze at wind site and transport as hydrogen?
- Hydrogen storage
- Goal to retain value in rural communities.

Is wind electrolysis viable for the transportation fuel market?

- ✓Mid term "maybe" and long term "yes"

- ✓BUT - How do we get there from here?

Wind To Hydrogen To Anhydrous Ammonia

History

Drivers

Scenarios

-Business and Economic Models

-Example

Bridge Technology to the Hydrogen Economy

Wind To Hydrogen To Anhydrous Ammonia

History

-At the turn of the 20th Century, world food demand was outpacing organic nitrogen supply. Nitrogen is the most limiting nutrient in cultivated crops.

-Companies and academic institutions around the world explored synthetic nitrogen fertilizer production.

Norway's Hydrogen History

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Norsk Hydro:

Company Profile:

- Norwegian Energy and Aluminum Company
- $25 Billion in annual sales
- 36,000 Employees

History:

- Began by producing anhydrous ammonia from hydro electric dams in 1920's initially with plasma technology and then switching to Haber Bosch technology.
- Grew to become the world's largest nitrogen fertilizer company in the world until spinning off fertilizer division in 2004.

Producing hydrogen and nitrogen from hydroelectric energy is a proven technology.

Drivers for Wind to H2 to Ammonia in Minnesota and the Midwest:

1. High wind resource in conjunction with low capacity of the transmission grid.

2. A high local demand for ammonia (N fertilizer) with accompanying storage capacity/ handling infrastructure.

3. High cost of ammonia due to rising natural gas prices.

4. Success of Farmer-owned Ethanol Plants
   -Economic Development
   -Experience
   -Proven Model

Drivers for Wind to H2 to Ammonia:

5. Increasing public will to move towards energy independence, clean energy, and a hydrogen economy.

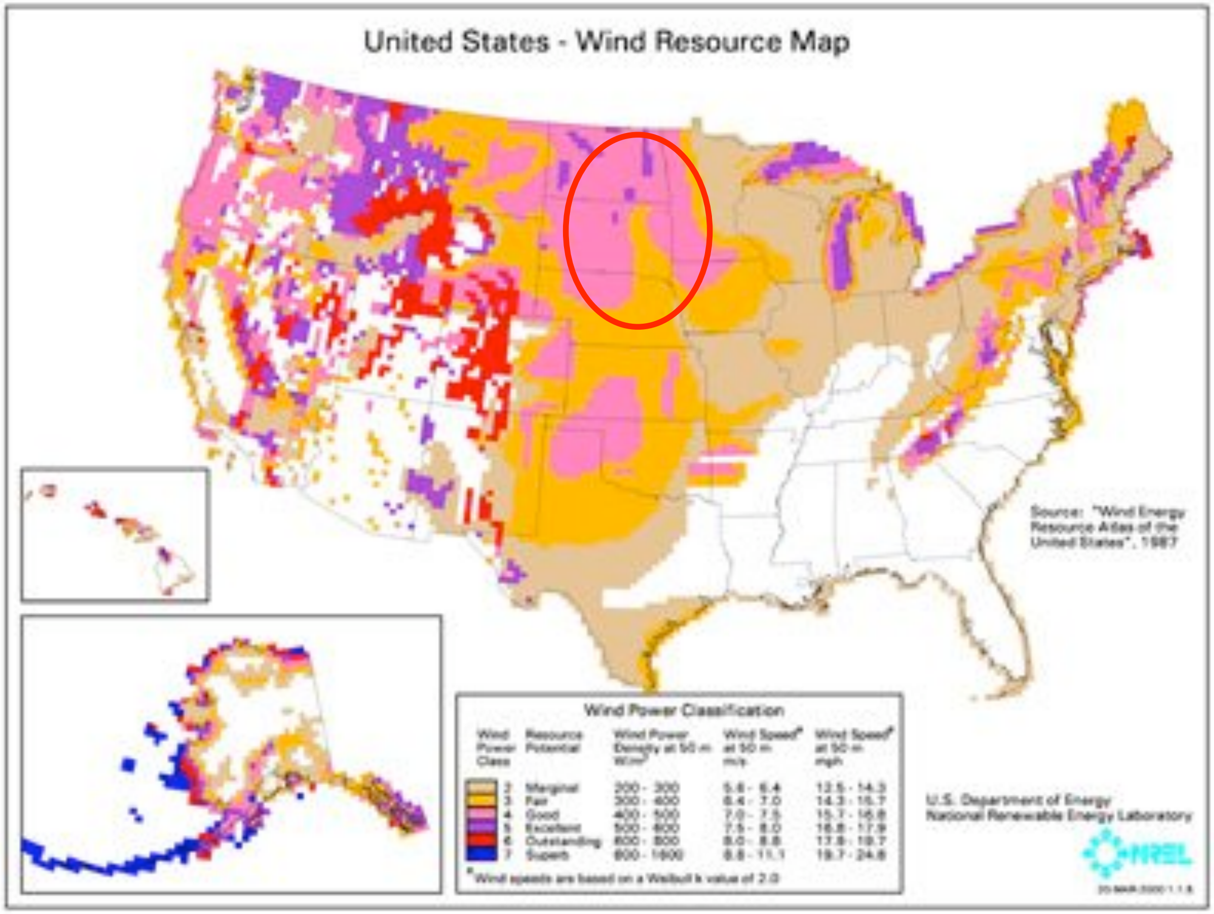
6. Minnesota's industry and business portfolio with companies strong in fuel cell components.

7. No requirement for MISO Study and Approval and for a utility Power Purchase Agreement – The two largest bottlenecks for wind energy development.

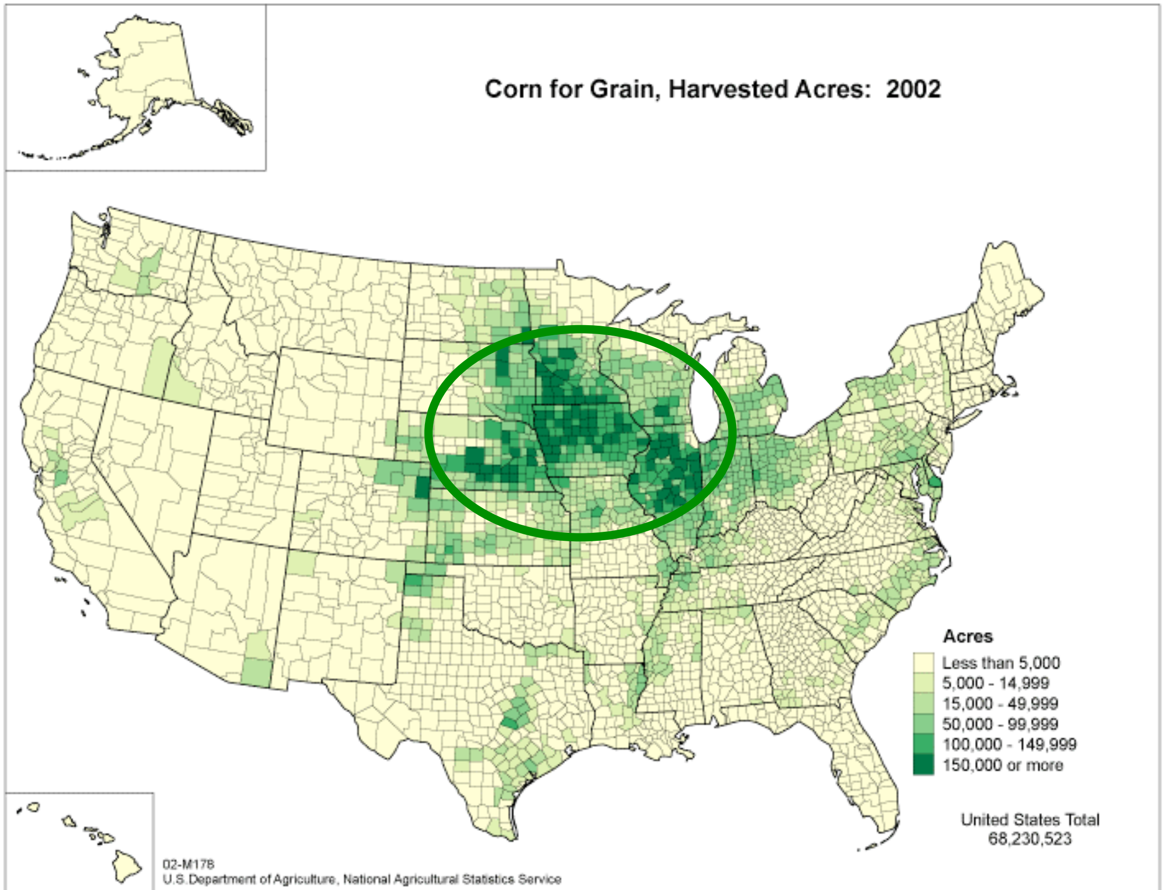
9. Minnesota Becomes a National Leader in Renewable Hydrogen Production! "Technology Dividend"

Electrical Energy Use in the United States

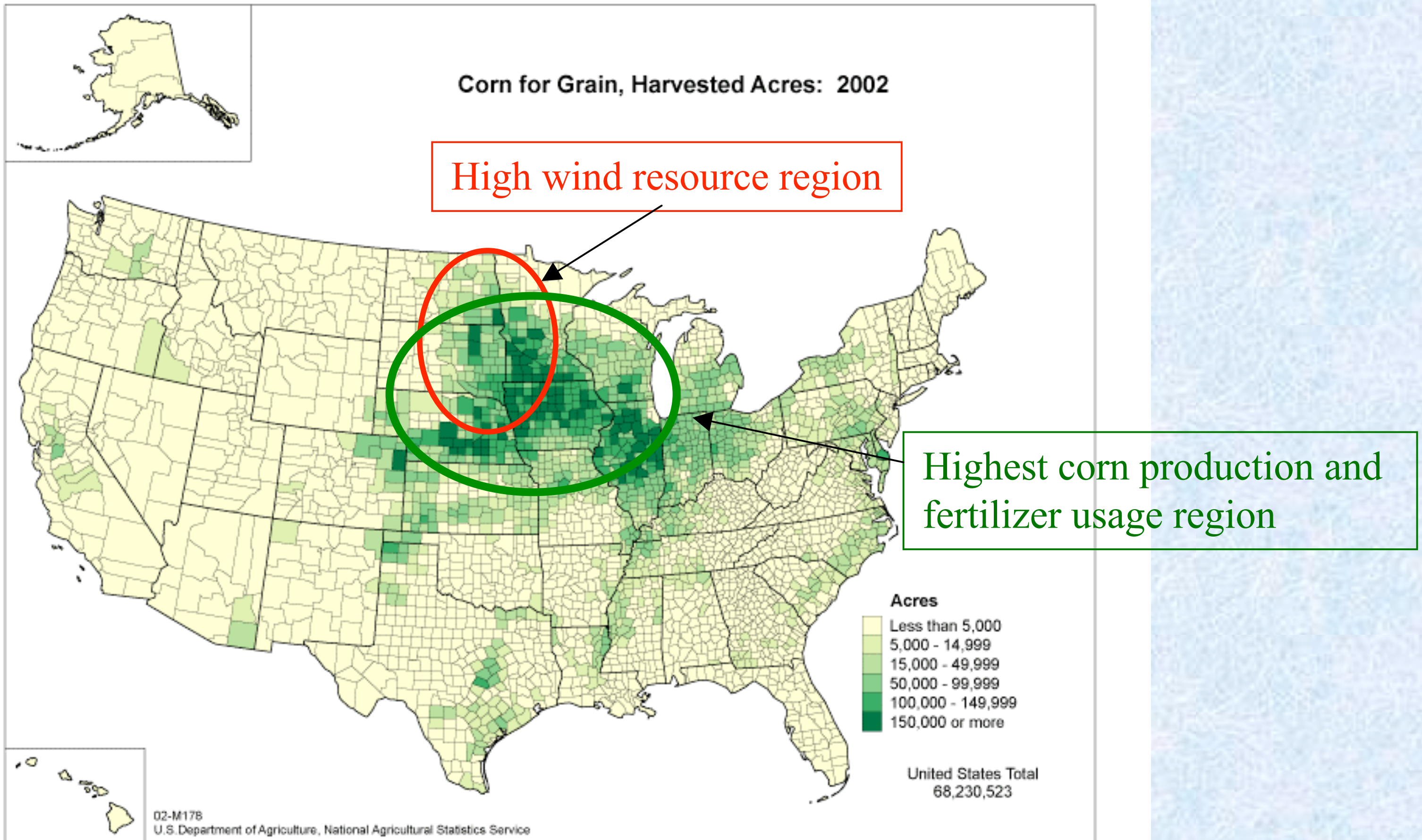
U.S. Wind Resource Map



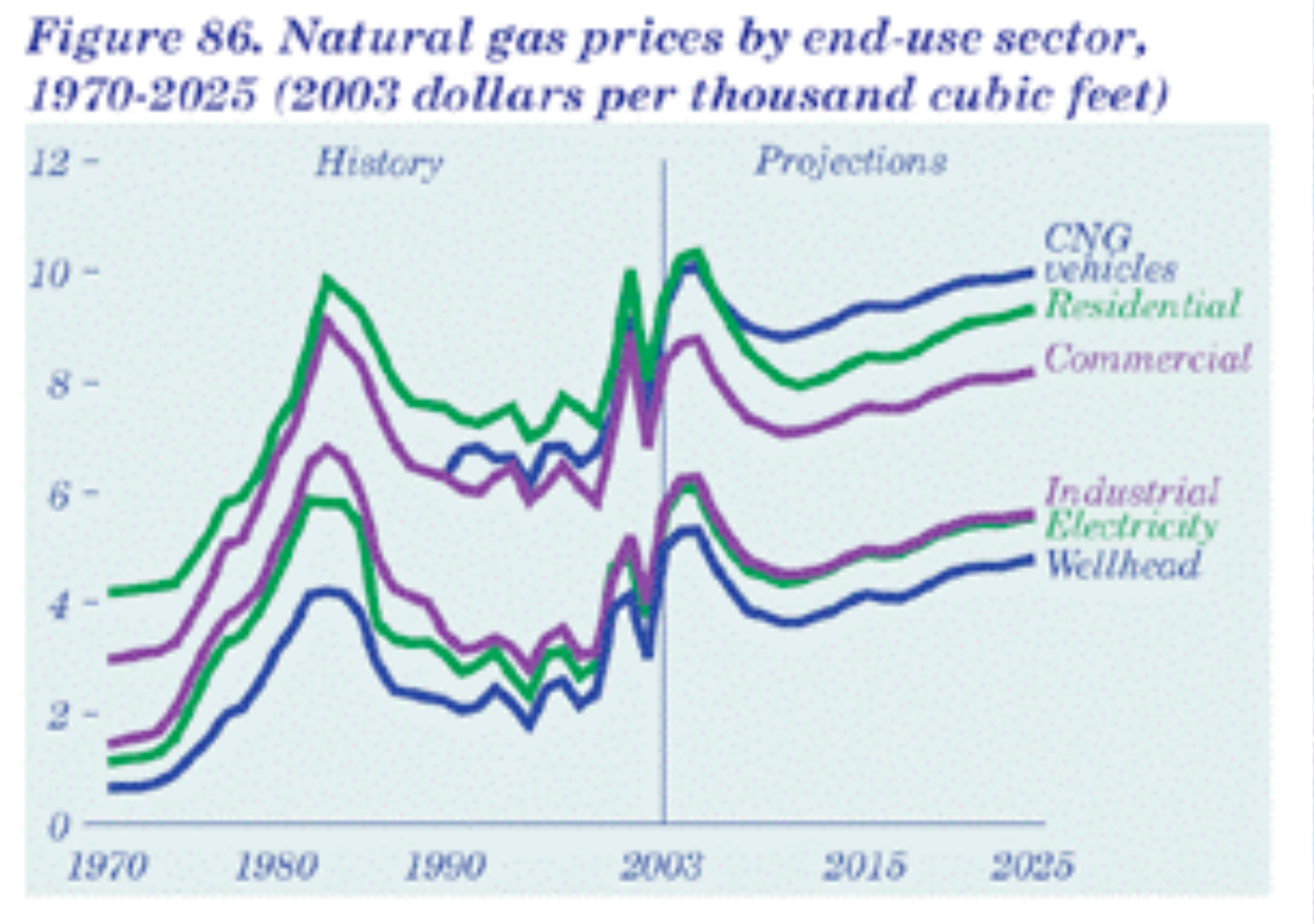
Largest Volume of Corn Production & Anhydrous Ammonia Demand



High *supply* of wind energy and high *demand* for ammonia

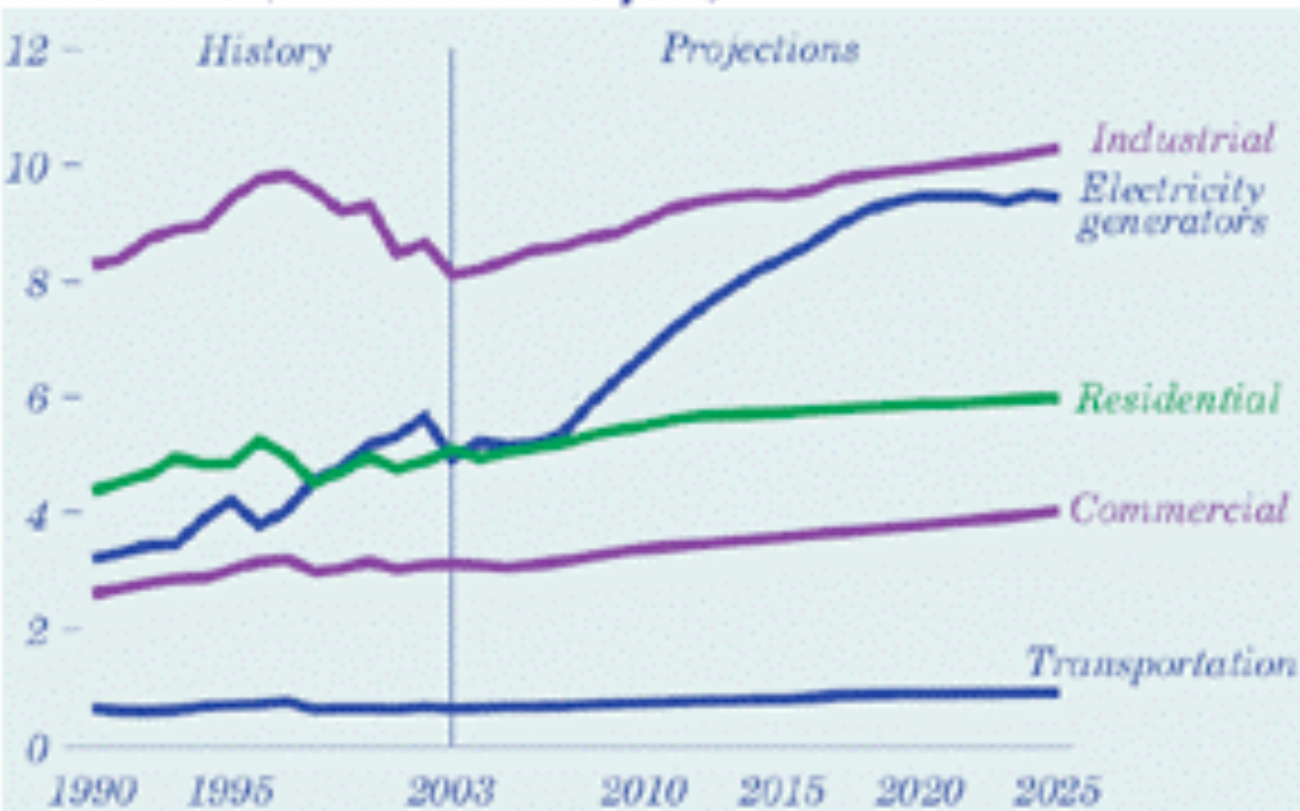


Projected Natural Gas Prices By Sector

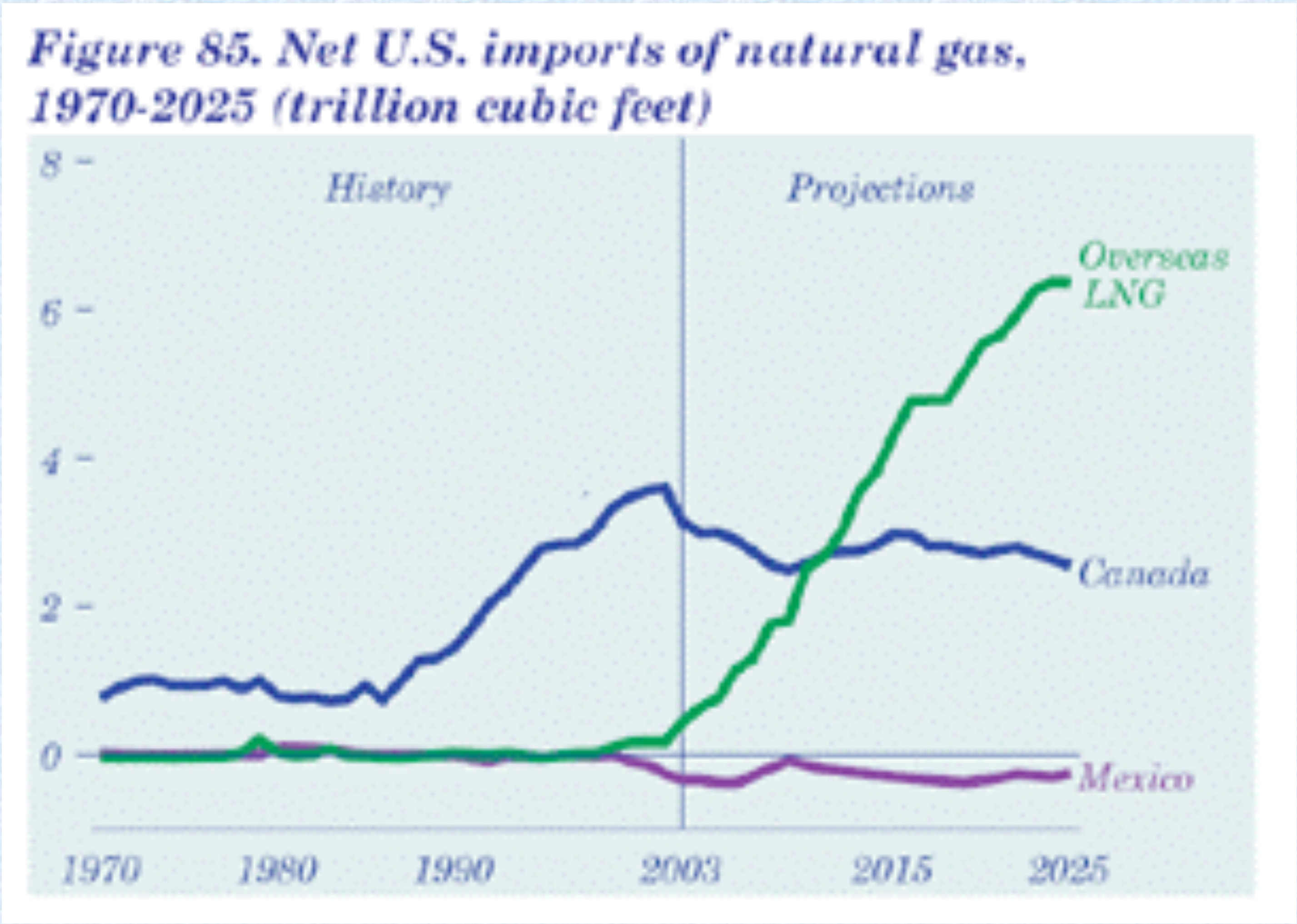


Projected Natural Gas Consumption

Figure 82. Natural gas consumption by sector, 1990-2025 (trillion cubic feet)



Projected U.S. Natural Gas Imports



Anhydrous Ammonia:

➢Opportunity to Jump Start Renewable Hydrogen Production in the Midwest. $300 million gross sales of NH3 in Minnesota alone.

Anhydrous Ammonia Storage and Transport

➢Storage facilities in most every small community in corn growing regions of the Midwest

Hydrogen Production Perspective:

•Minnesota farmers applied 836 million pounds of N in 2003.

- 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**

Example potential of one county in Minnesota:

Stevens County (Morris area) produces:
~135,000 acres of corn per year
~150 bushel yield of corn per acre

Stevens County corn production requires:
~20 million pounds of nitrogen per year
~$5 million of nitrogen

Stevens County ammonia production would require:
~116 million kWh of electrical energy
~20 wind turbines (2 MW turbines assuming 6 mil kWh each)

Farmer Owned Ethanol Model:

- There are 16 farmer owned ethanol companies in Minnesota.
- Financial success story.
- Combination of state and federal incentives combined with a state mandate of 10% blend of ethanol in most gasoline.
- Farmers have contracts which require delivery of corn.
- The price paid for a bushel of corn grain has increased over traditional markets.
- Farmers also share in the profits of the ethanol company.
- Major factor Minnesota leads the nation in E-85 fueling stations.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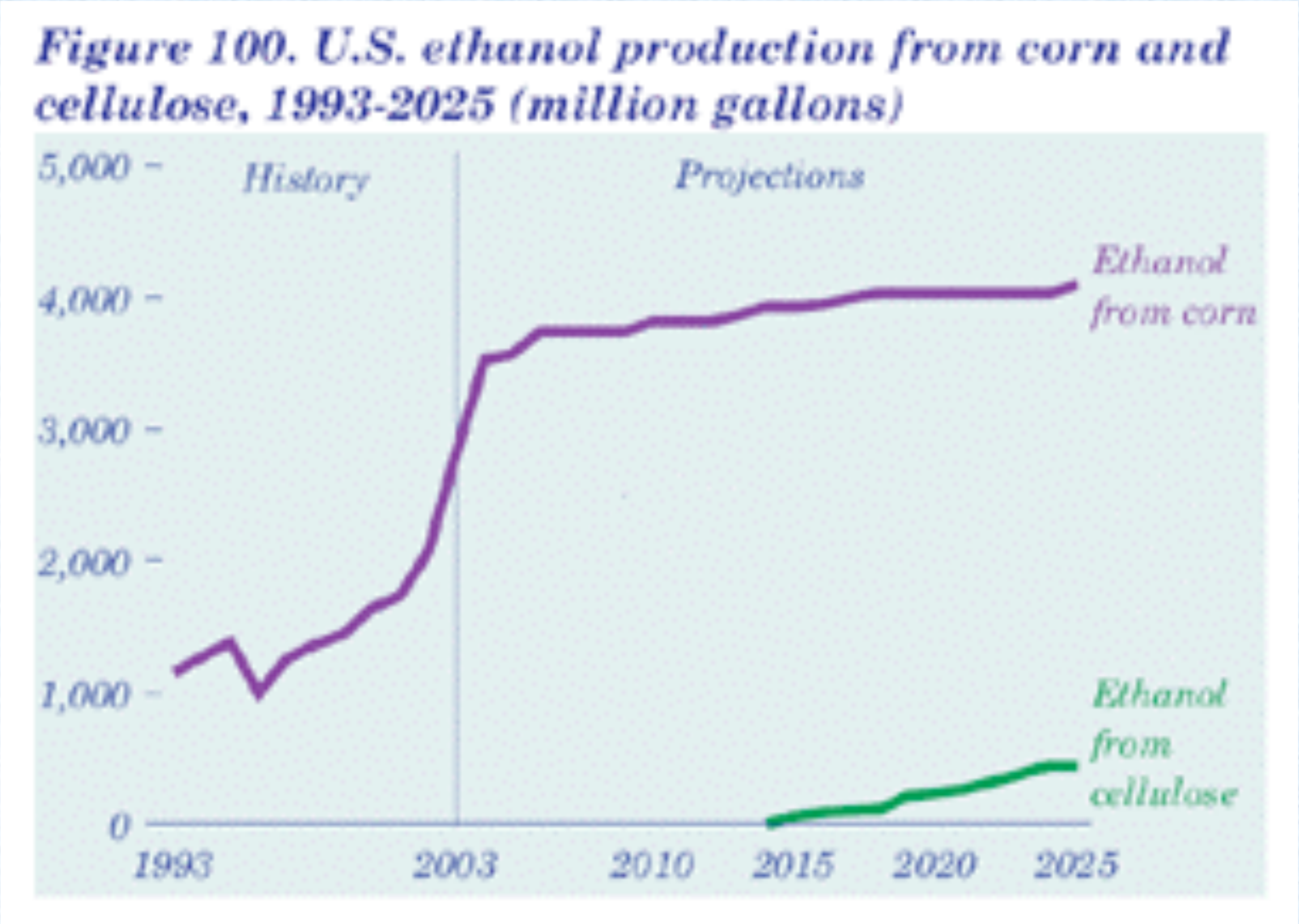
MN Ethanol Model: Locally Owned



E-85 Stations in the Region

Senarios:

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.

Stevens County Model: Potential of one county in Minnesota:

- 20 wind turbines
- 6 million kWh each per year
- $5 million in ammonia production

$5 mil / 20 turbines = $250,000
+Plus $.018 per kWh production tax credit = $108,000
+Plus possible H2 production incentive = $36,400 ($.48 per kg)
+Plus green credits and availability of grants and low interest loans.

Results in $394,400 /turbine

Current revenue is ~$240,000 or $348,000 with the PTC

Key Point for the Steven County Model:

Results in estimated:

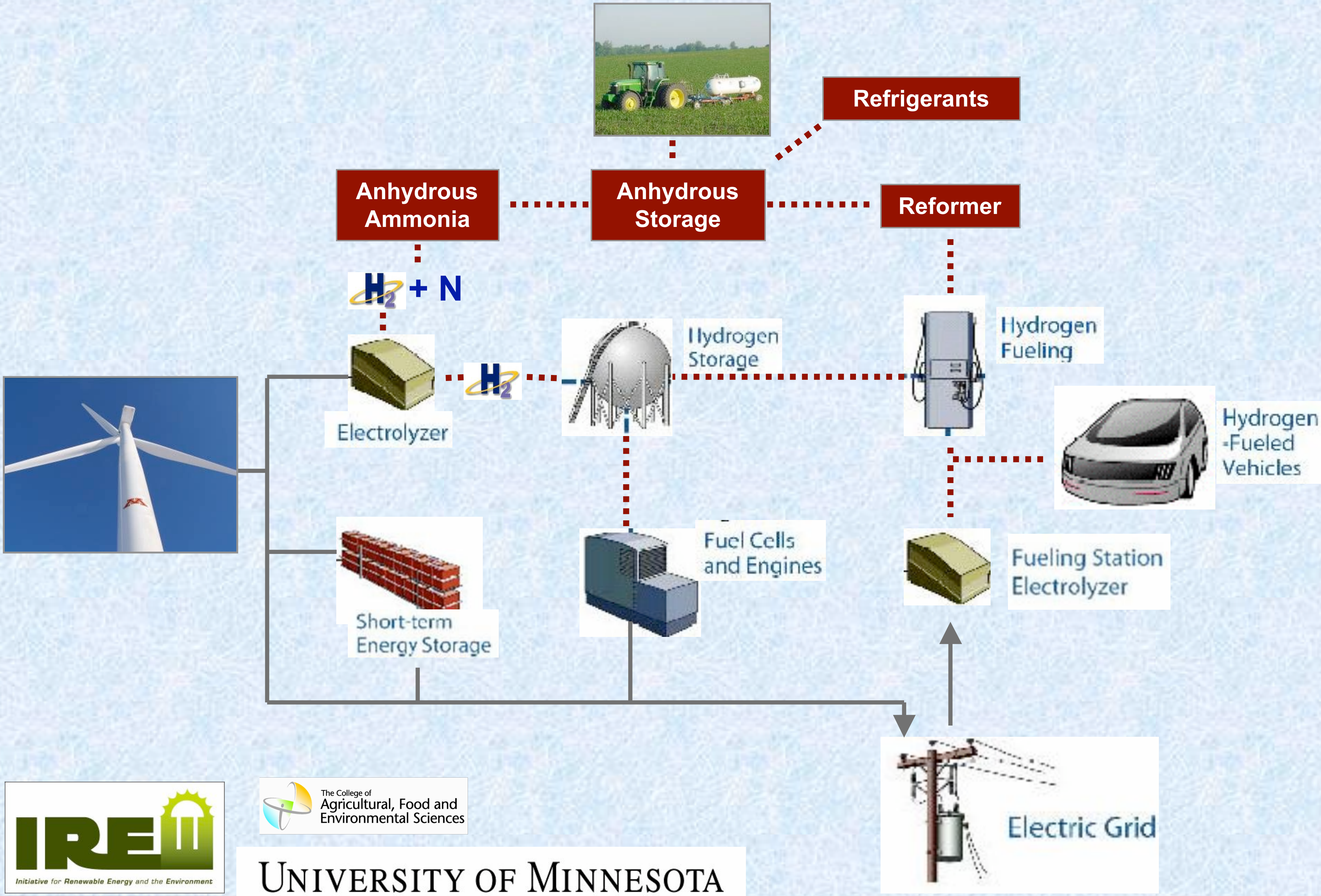
- Potential financial impact of $7.9 million per year for the wind and ammonia production facility.

- Potential economic impact of $39 million per year for Stevens County.

University of Minnesota Role:

1. Validation of Financial Model
2. Technology Refinement and Intellectual Property Development
3. Size and Scale Modeling
4. Development of Sound Business Models (farmer contracts)
5. Technology Transfer and Business Incubator
6. Stimulate Private Public Partnership for Commercialization

Renewable Hydrogen Research and Demonstration



IREE
Initiative for Renewable Energy and the Environment

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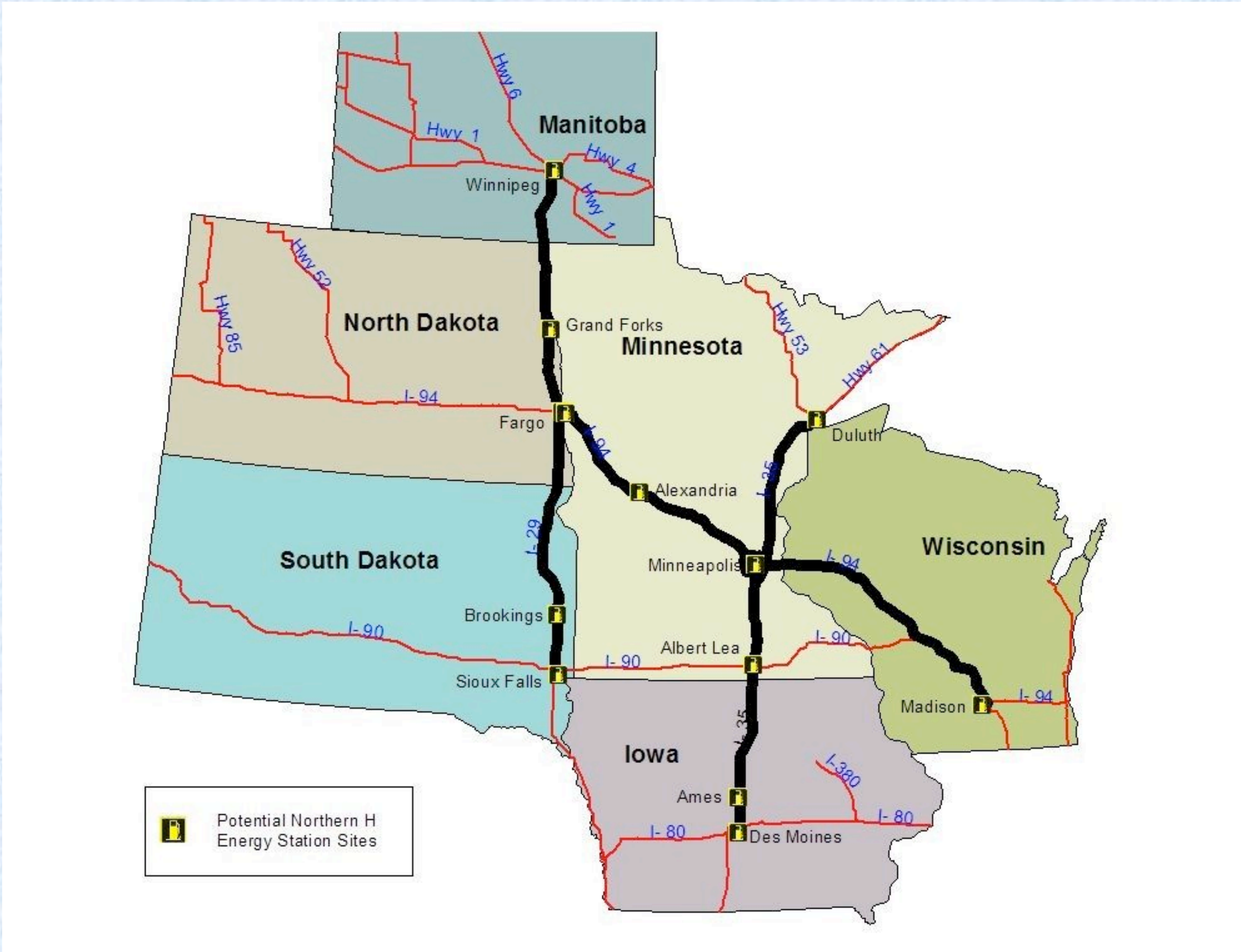
Hydrogen Highways – The Northern H



In Summary:

1. University of Minnesota is developing a Hybrid Wind to Hydrogen System.

2. Midterm economics of utilizing wind energy electrolysis is promising for the production of transportation hydrogen.

3. Producing anhydrous ammonia from wind energy electrolysis and utilizing as nitrogen fertilizer may be a viable bridge to a renewable Hydrogen Economy.

4. The University of Minnesota is developing a pilot scale wind to anhydrous ammonia system to enhance technology, develop business and economic models, and to stimulate commercialization at a grass roots level.

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Questions?

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