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Renewable Hydrogen and Chemicals:

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University of Minnesota
Initiative for Renewable Energy and the Environment

A $20 million initiative over 5 years for research at the University

Legislative mandate funded by Xcel from CIP and RDF funds

Interdisciplinary
Agriculture
Biology
Technology
Policy

Clusters
Hydrogen
Efficiency
Bioproducts and bioenergy
Policy and the environment

Hydrogen from Wind

Greg Cuomo
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Search for Local Solutions First

Minnesota versus US

Rural versus Urban areas

Minnesota versus China

Minnesota versus world

Different resources, feedstocks, technologies

Expand and modify local solutions to country and world

Minnesota is Making Progress

20% of gasoline now supplied by ethanol from Corn

10% in fuel, 10% exported
15% of corn crop
could supply 100%

6% of diesel from biodiesel from Soy Beans

could supply 100%

5% of electricity from Wind

Enough biofuels to eliminate all gasoline and diesel in Minnesota

All price competitive
Most locally owned
All sustainable

Would keep more than $6 billion/year in Minnesota

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The Hydrogen Economy

There is no shortage of hydrogen

All we need is supplied from reformers in Indiana

$1 to $6 per gallon of gasoline equivalent

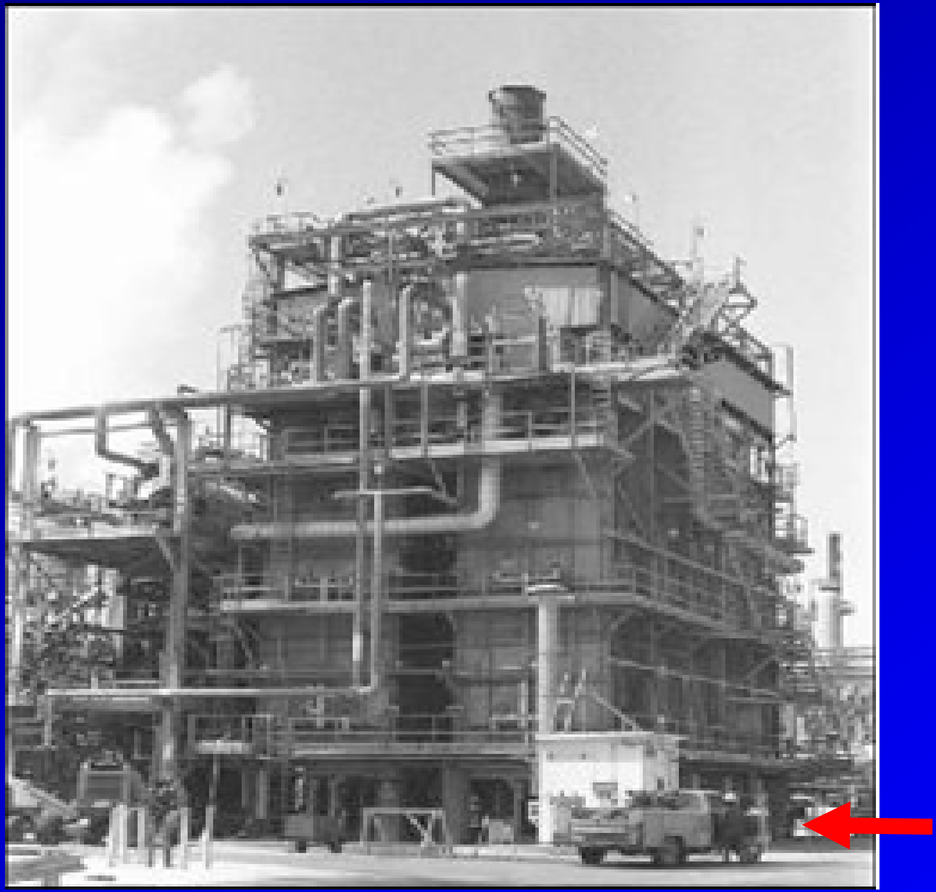
There will be no major demand for more hydrogen soon

a few hydrogen fueling stations will satisfy demand

Hydrogen is an energy carrier, not a source

water is for drinking and drowning, not for energy

Steam Reformer for Hydrogen Generation



Replace by system smaller than truck

Enough hydrogen for house in size of coffee cup

The Hydrogen Economy

Code words for fuel cells

- 60% versus Carnot efficiency of thermal engines
- PEM fuel cells require hydrogen

Need hydrogen

- wind power with electrolysis for hydrogen storage
- fossil fuel reforming is next generation
- use hydrogen for storage and transportation of energy
- hydrogen fueling station

Distributed energy

- no megaplants and power lines
- better esthetics and safety
- rural areas and third world will adopt first

The Hydrogen Economy

Nothing gained if fossil fuels are source of hydrogen

- reduced efficiency in reforming
- CO_2 global warming not helped

Need renewable fuels

- solves all problems
- helps economic development
- use for chemicals

The Future of Hydrogen

Essential role in future energy technologies

Wind

Biomass gasification

biomass → H_2+CO → dimethyl ether
→ methanol
→ synthetic fuels
→ electricity

DME is LPG and diesel fuel substitute

Biomass electricity

combined cycle power
gas turbine followed by steam turbine
combined heat and power

<50% efficiency to electricity

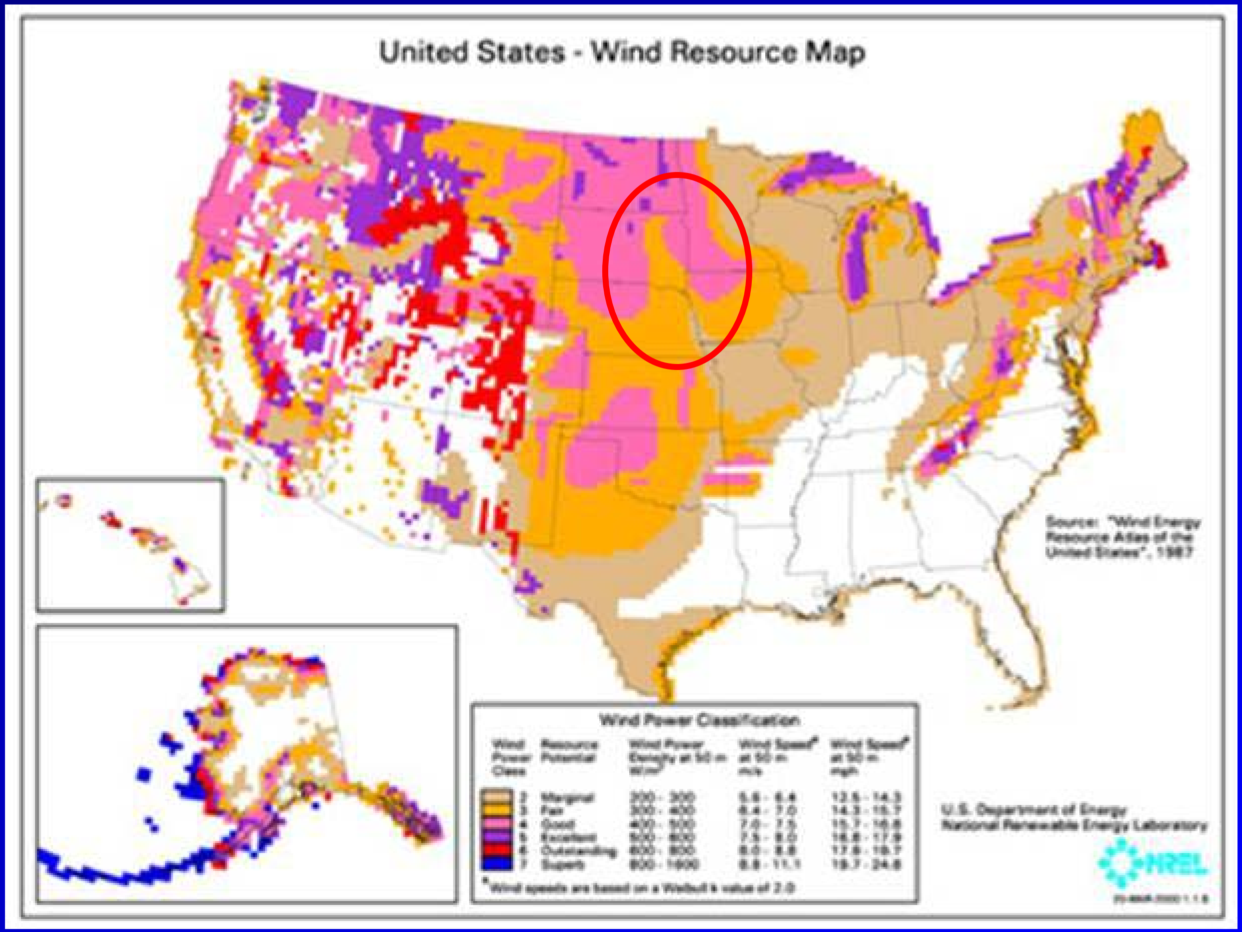
Hybrid Wind System

University of Minnesota
West Central Research & Outreach Center - Morris

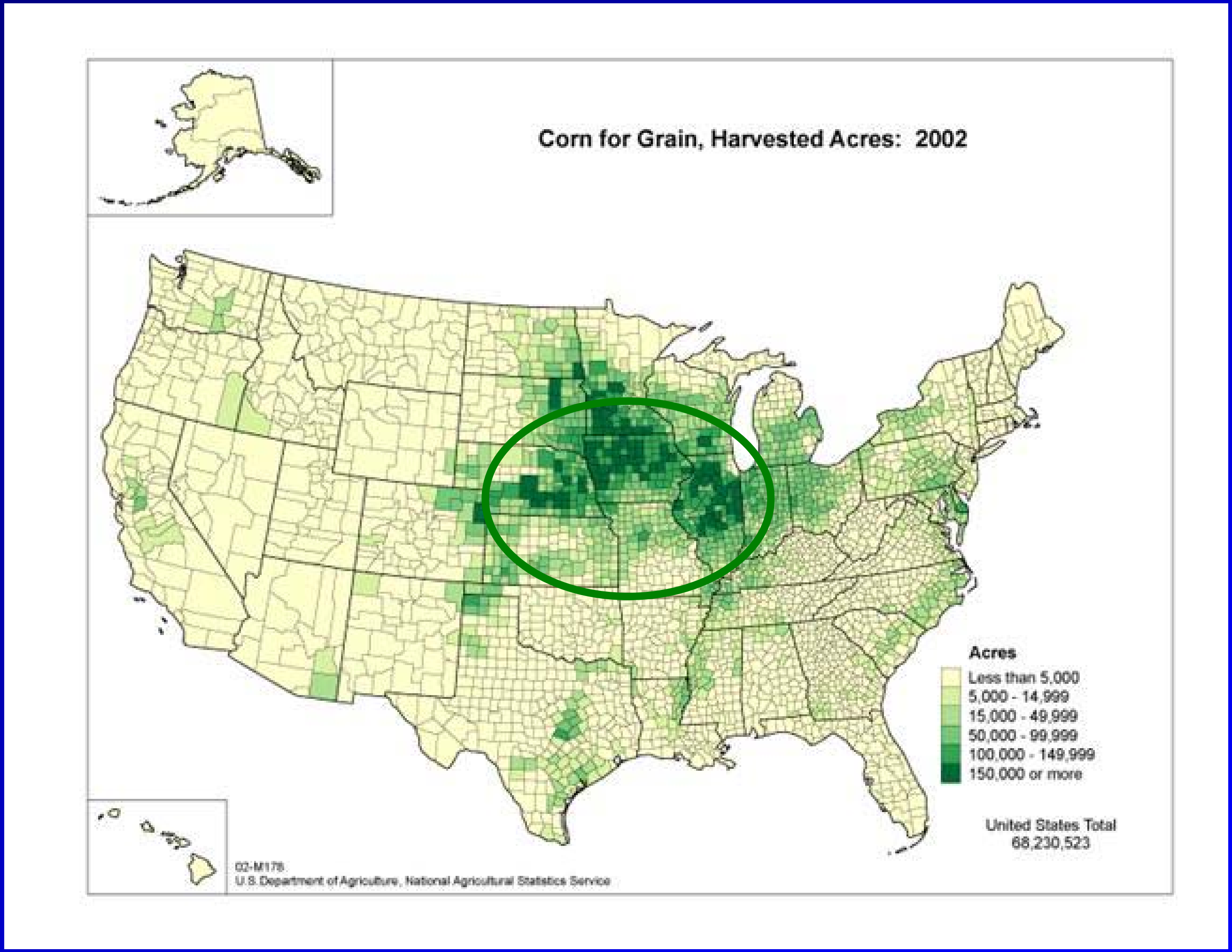
Electrical Energy Use in the United States

The College of Agricultural, Food and Environmental Sciences

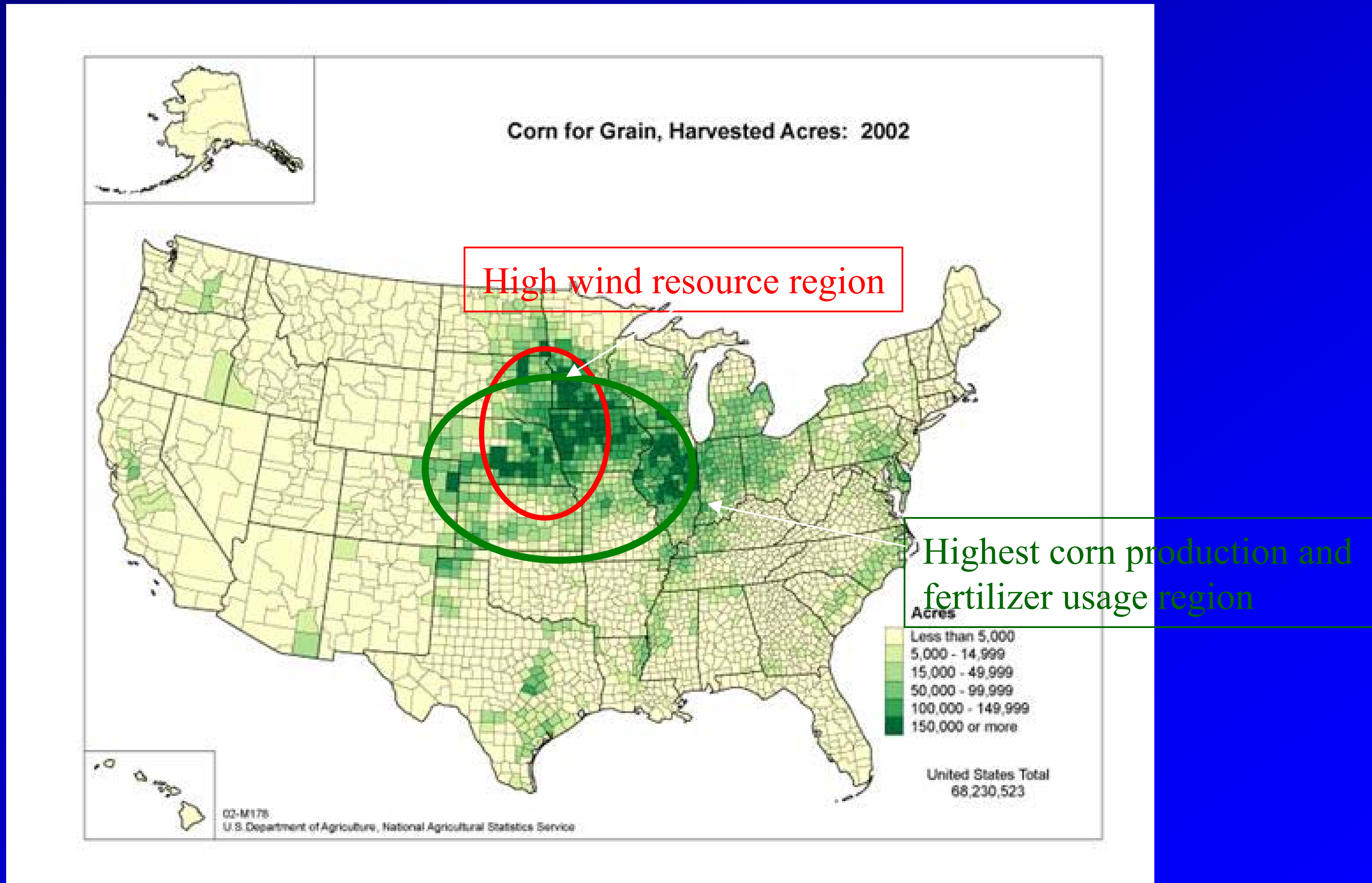
Great Wind Resource



Midwest: Largest Corn Producing Region of the Nation



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



One of Four Core Systems:

1. WCROC Hybrid Wind Renewable Energy System
2. UMM Biomass District Heating and Cooling System
3. WCROC Renewable Energy Research & Education
4. Community Anaerobic Digester System

Hybrid Wind System

WCROC Wind Turbine:

- Research tool *and* functioning, production system.
- 1.65 MW V 82 Wind Turbine
- 5.6 million kWhr per year projected production
- 3 million kWhr actual production at 6 months
- Direct line to the University of Minnesota Morris campus.
- Projected to supply over 60 % of the Morris campus electrical needs (First priority for energy is research.)

WCROC Hybrid Wind System

Wind to Hydrogen Research and Demonstration

Objectives:

1. Provide systems to “store” wind energy for base load / dispatchable / on-demand power.

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

3. Combine these technologies and systems into innovative models to optimize efficiencies and economics.

Wind to Hydrogen System

Phase I – H_2 Generation & Electrical Energy Production*

1. Electrolyzer – 400 kW
2. Compressor
3. Hydrogen Storage – Tube tanks
4. H_2 IC Engine Generator
5. Electrical Interconnection

- ➢ Completion targeted for Winter 2007

Wind to Hydrogen System

Phase II Value Added Wind Energy & Bridge Technologies

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

2. Production of Transportation Fuel
   - -Fleets
   - -Service vehicles
   - -Cars and pickups

Wind to Hydrogen System

Phase III   Hybrid Hydrogen Systems

1. Hythane Turbine (2-3 MW)
2. Hydrogen Pipeline System
3. Hythane Heating & Cooling Systems
4. Combined Power Generation, Valued Added Products, and Natural Gas Displacement

West Central Research & Outreach Center
Morris, Minnesota

Fuel Cell Bus and H_2 Fueling Station: Reykjavik, Iceland

Hydrogen Bus Fueling Station: Reykjavik, Iceland

Hydrogen for Farms: Typical Rural NH_3 Storage

Hydrogen for Farms: NH_3 Filling Station and Field Nurse Tanks

Senarios:

Farmer and Community Owned Hybrid Wind Systems

- -Produce electricity, hydrogen, ammonia
- -On site or central location
- -Reduces the need for transmission into population centers
- -Dynamic models (peak power, ammonia, base load, etc)
- -No need for MISO study or Utility Power Purchase Agreement

Projected Prices of Hydrogen from Wind Energy

equivalent to
price of gasoline
per gallon

NREL, 2005

Renewable Hydrogen and Chemicals: "Hydrogen for the Farm"

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Hydrogen and Chemicals in Millisecond Reactors

Hydrogen Economy

Distributed power

Fuel cells

Pollution abatement

Renewable energy

Renewable chemicals

"Hydrogen for the Farm"

Hydrogen and Chemicals in Small Systems

Biomass processing

hydrogen and syngas

Electricity

$H_2 + O_2 \rightarrow H_2O$ + electricity

Fertilizer

$3H_2 + N_2 \rightarrow 2NH_3$

Fuels

$H_2 + CO \rightarrow CH_3OH$

$H_2 + CO \rightarrow CH_3OCH_3$

$H_2 + CO \rightarrow$ diesel

"Hydrogen for the Farm"

Hydrogen and Chemicals in Small Systems

Membrane separation	Tsapatsis
Catalytic membranes	Tsapatsis and Schmidt
Micro fuel cells	Smyrl and Mann
Micro pressure swing absorption	Cussler and Mann
Systems and economics	team

“Hydrogen for the Farm”

Hydrogen and Chemicals in Small Systems

corn soy beans biomass wood energy crops	→ hydrogen →	hydrogen electricity ammonia fuels polymers ?

Produce several tons/day

Downscaling is major issue

The basis of a biorefinery

The Future of Hydrogen

Essential role in future energy technologies

Wind

energy storage and fertilizer

Biomass gasification

biomass → H_2+CO → dimethyl ether
→ synthetic fuels
→ electricity

Biomass electricity

combined cycle power
combined heat and power

<50% efficiency to electricity

150 YEARS

Agricultural, Food and Environmental Sciences