Wind to Ammonia Project Update

Douglas G. Tiffany
University of Minnesota Extension Service

Portland, Oregon

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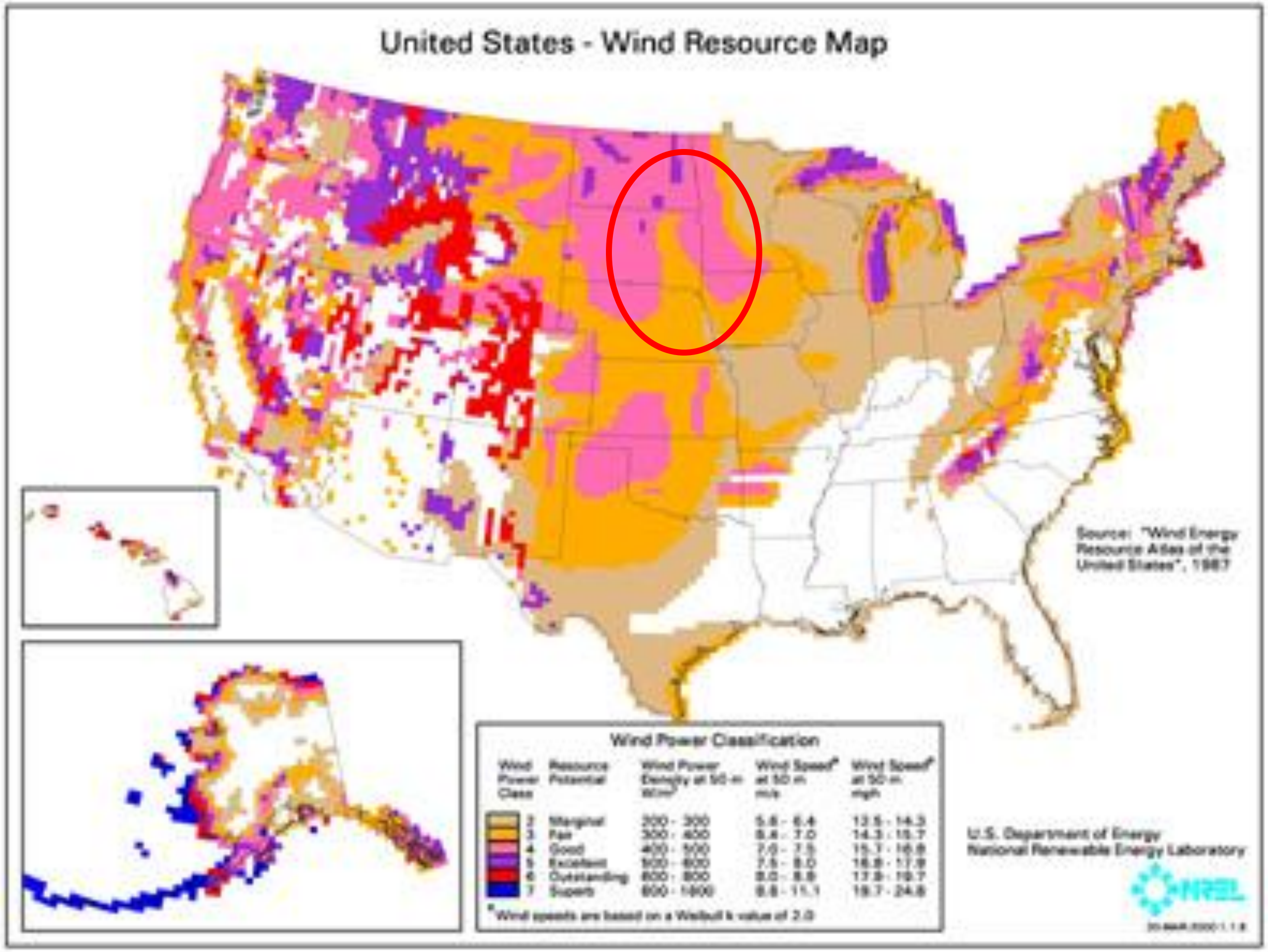
Today's Talk

- Review Motivations for this Project
- Update Progress
- Identify Plans for Engineering and Economic Analysis

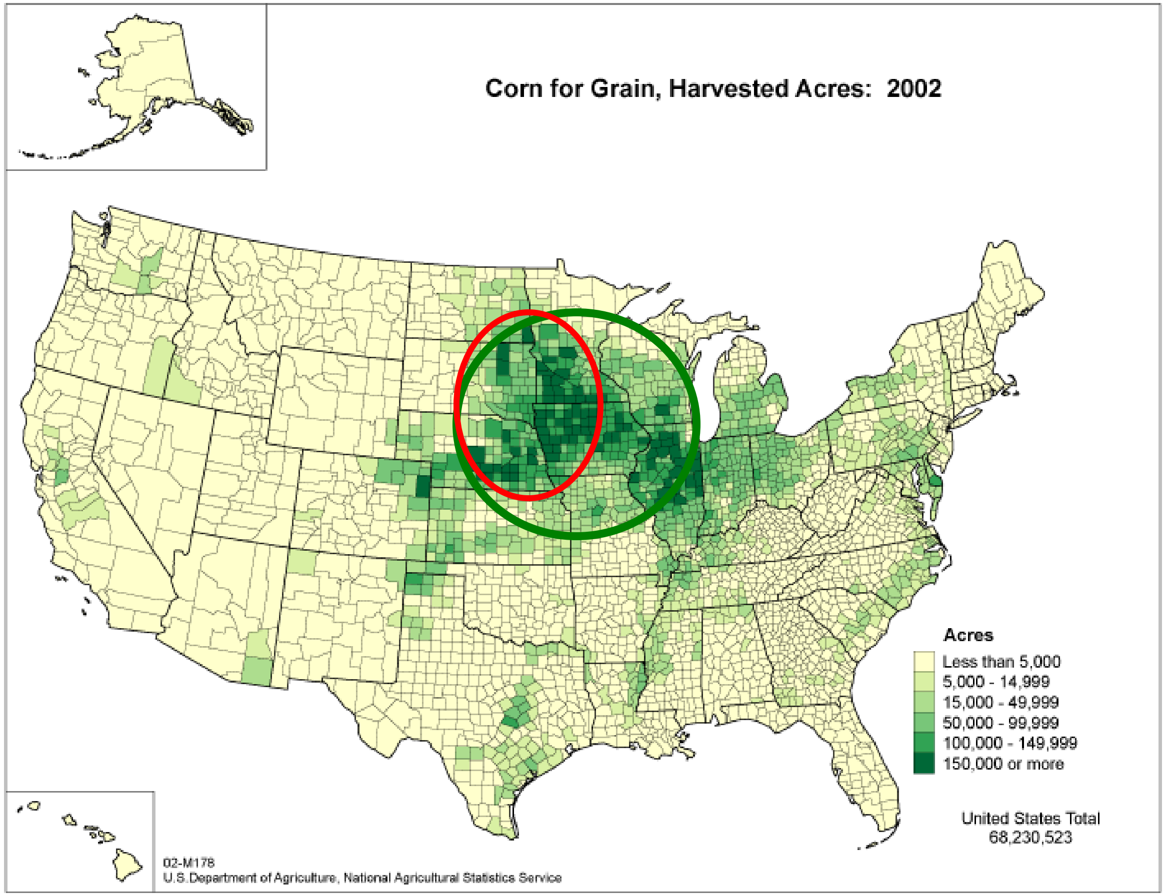
Project Drivers

1. Stranded wind resource due to low transmission capacity
2. High ammonia / nitrogen demand and developed infrastructure
3. Nitrogen fertilizer prices have risen while natural gas has declined
4. We seek security for domestic food, feed, and bio-fuel production
5. More value gathered, if windpower is utilized locally
6. Use of ammonia from wind reduces greenhouse gas emissions
7. Hydrogen economy transition bridge

Excellent Wind Resource



High Demand for Ammonia



& Excellent Wind Resource

Nitrogen Fertilizer Market in Minnesota

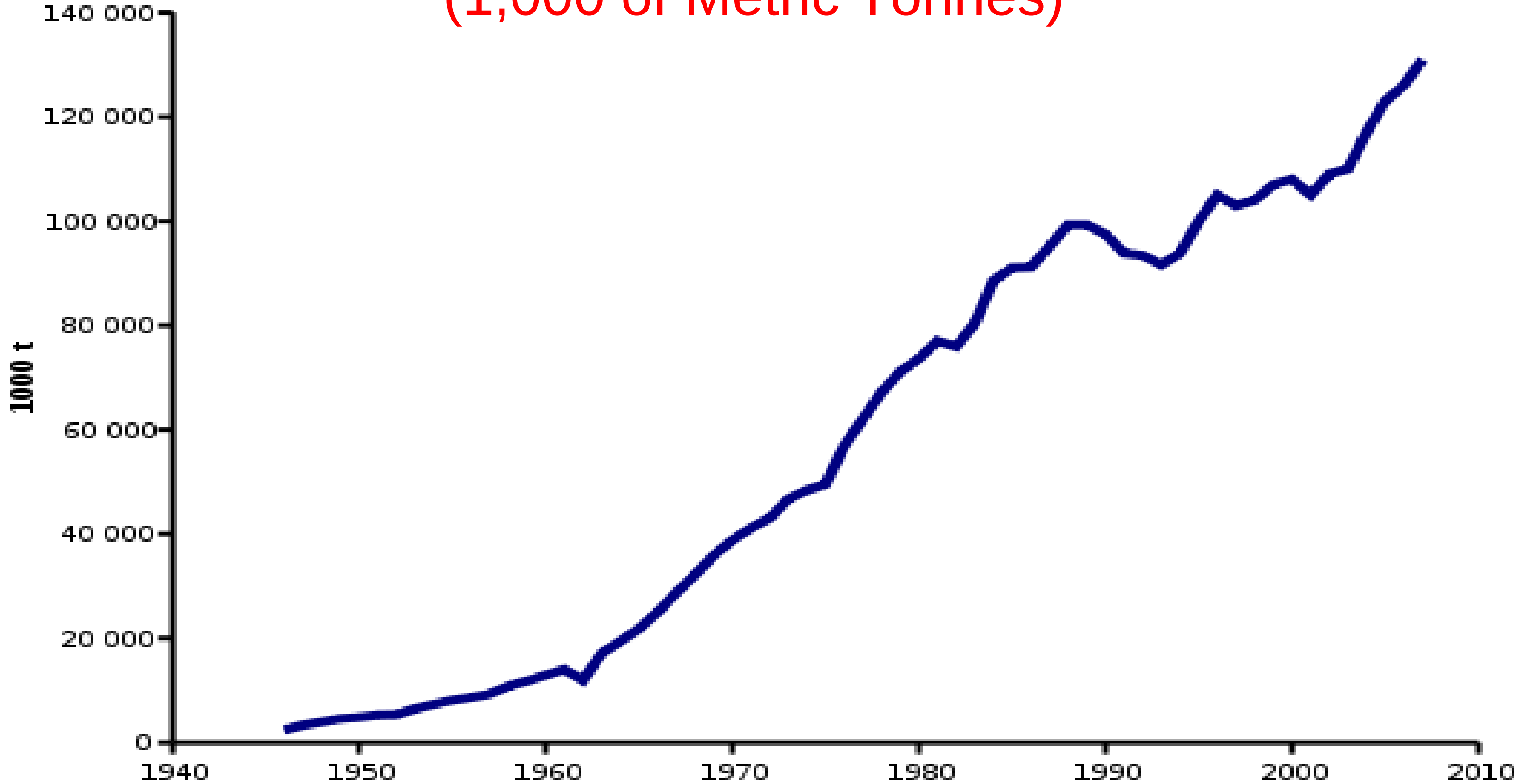
Crop	Statewide Acres*	Avg. Yield/Ac (bu.)*	Statewide Yield (bu.)	Estimated N Required (lbs NH3)**
Corn	8,234,507	146.0	1,201,898,815	901,424,111
Barley	108,268	53.6	5,801,418	4,351,063
Wheat	1,718,565	48.1	82,554,282	61,915,712
			Total NH3 Req. (lbs)	967,690,886
			Total NH3 Req. (tons)	483,845
			Retail Value ($800 / ton)	**$387,076,354**

*Production Data from USDA NASS (2007)

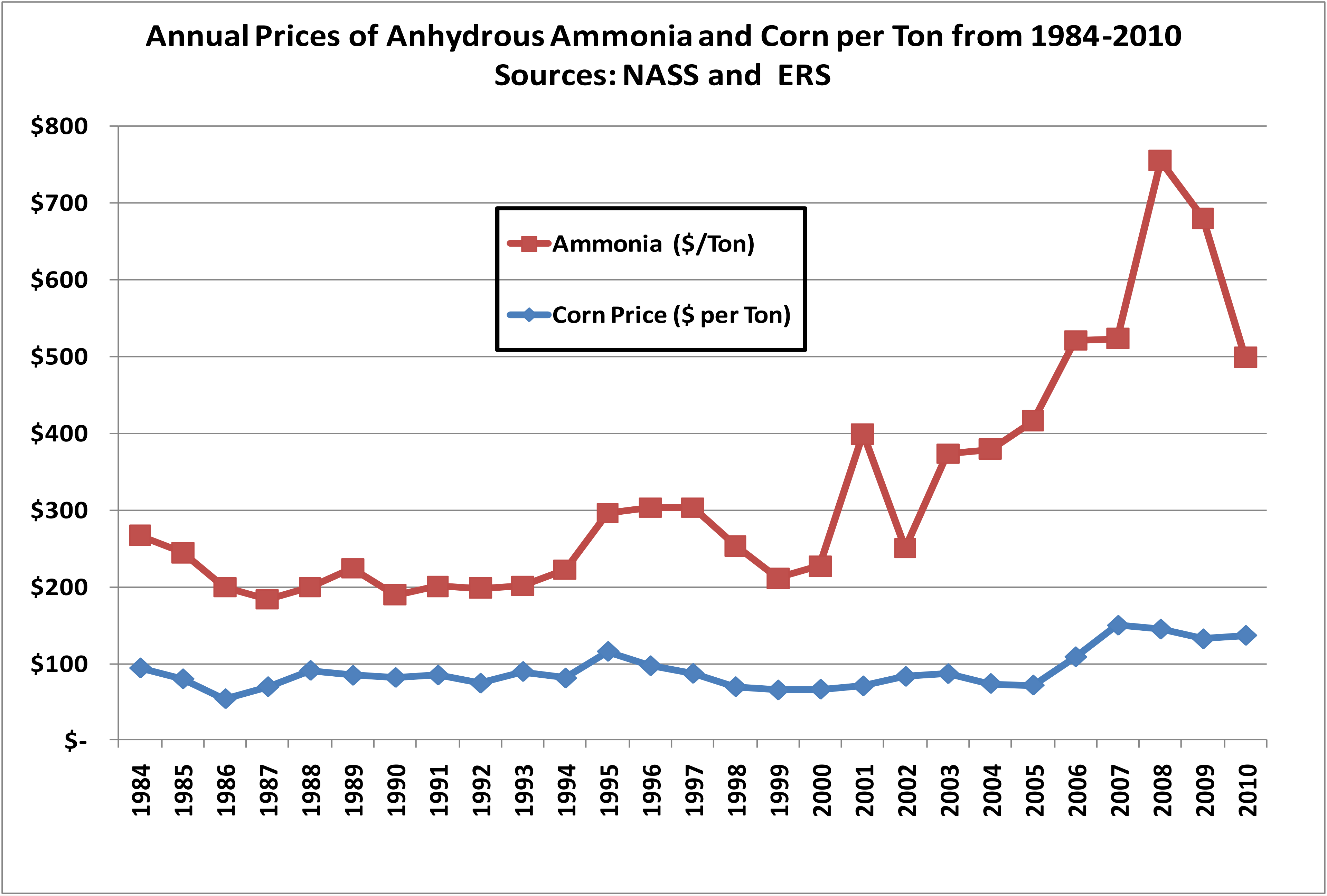
**Based on a requirement of 0.75 lbs of NH3 per bushel of yield

Worldwide Ammonia Production

(1,000 of Metric Tonnes)



Source: Orci, Ammoniakproduction. U.S. Geological Survey Data


Annual Prices of Anhydrous Ammonia and Corn per Ton from 1984-2010
Sources: NASS and ERS
$800
$700
$600
$500
$400
$300
$200
$100
$-
Ammonia ($/Ton)
Corn Price ($ per Ton)
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010

Cost of Natural Gas and Gross Margin in Sale Price of Anhydrous Ammonia

Derived by using Citygate natural gas prices and assuming 32.7 decatherms per ton of anhydrous ammonia.

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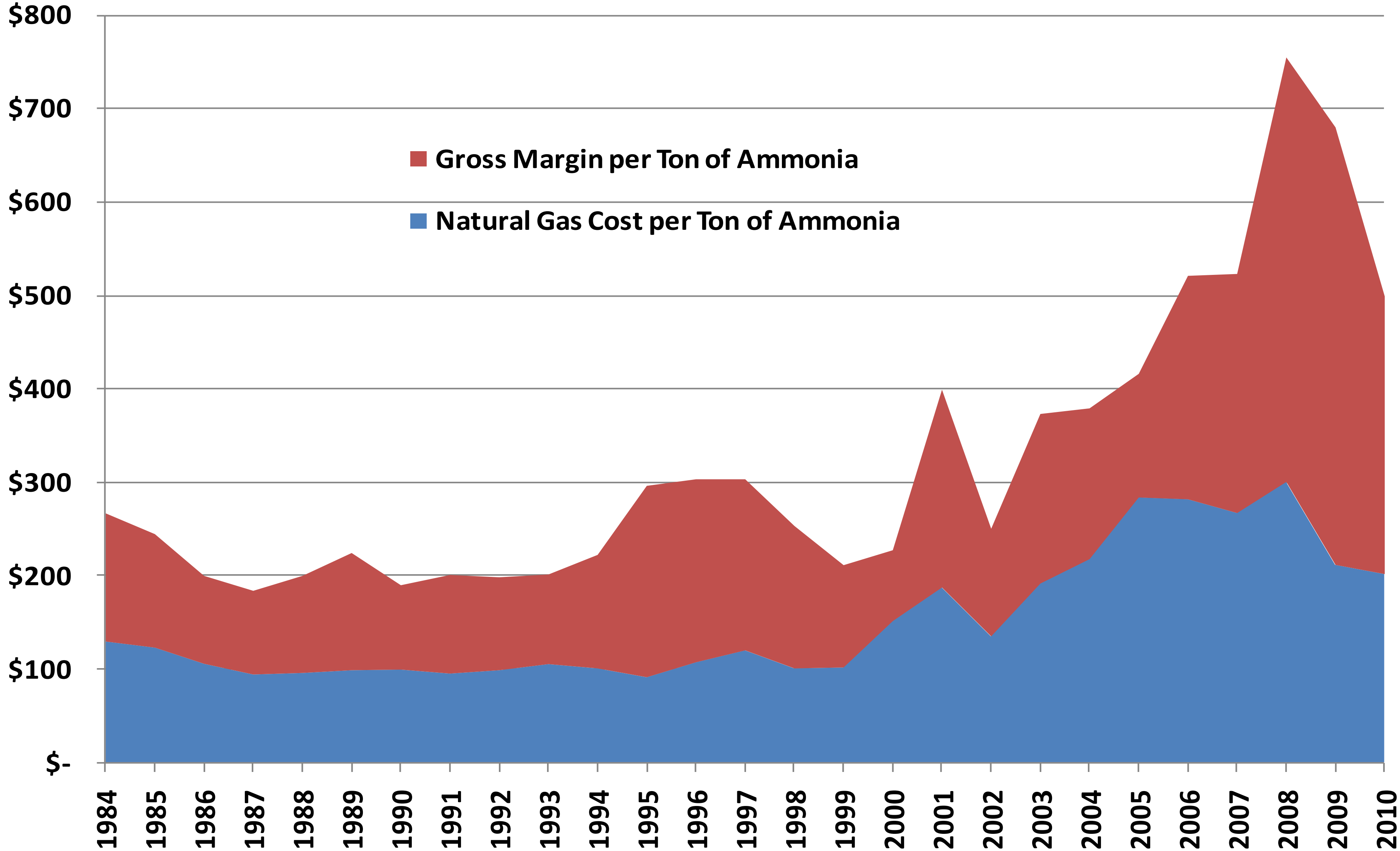


Transmission vs. Local Ammonia Production

High Level / Back of the Napkin Comparison:

- **Each cost ~$1 million / MW nameplate capacity (+ / - 50%)**
- **Each result in ~$300,000* annual retail revenue / MW nameplate**
- **Ammonia production keeps dollars local and potentially has less development constraints** (NIMBY Issues, Permitting, Siting, etc)
- **Wind energy has a utilization problem more than a transmission and technology problem (net present value of wind is excellent)**

*Transmission Case - 1 MW Wind Generation Equals 3,328,800 kWh / yr (times $0.08 per kWh) equals $266,304.00

*Nitrogen Fertilizer Case - 1 MW Ammonia Plant Equals 1,460,000 lbs NH3 (times $0.40 per lb) equals $584,000.00

Key Challenges with Electrochemical NH_3 Production

A. Capital Costs

-Equipment

-Storage

-Other Infrastructure

B. Energy Costs

-Direct

(5.5 to 7 kWh per lb NH_3)

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

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: 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?

-What ownership organizations will be most favorable?

G. Electric Energy Industry

-Regulated industry with “service territories”

-FERC, MISO, PUC

-Retail wheeling (May need to separate wind business from NH3)

-Socialized costs - transmission, emissions

Key Challenges with Electrochemical NH3 Production

H. Current policies and ownership models may be a poor fit for Wind to Ammonia

-ITC Grant, ITC, PTC----- equity "flips" favor investment by passive investors for wind, Power Purchase Agreements provide stability

I. Commercial Technology

-Lack of equipment and contractors for desired scale

-Difficulties attracting investment in new technologies

-Lack of commercially proven equipment usually leads to higher equity investments and / or higher debt costs

Key Opportunities with Electrochemical NH3 Production

A. As Nat. Gas has gotten cheaper prices of NH3 have risen

-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 represent the NH3 fertilizer demand - Minnesota market ranges between $400 – $800 million per year

-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

-20 MW nameplate wind farm potentially produces N for 57,000 acres of corn

D. Market Flexibility

– Great opportunity for smart grids

– Multiple markets –release purchased power, sell stored power, sell H_2, NH_3, carbon credits, other forms of N fertilizer, ammonia for SCR in coal plants, refrigeration, cosmetics, etc

Key Opportunities with Electrochemical NH3 Production

E. **CO2 / Greenhouse Gas Reductions vs. NG in crop production**

F. **Renewable Energy Mandates and Cost of Transmission**

-In regions with excellent wind resources, transmission can be expensive

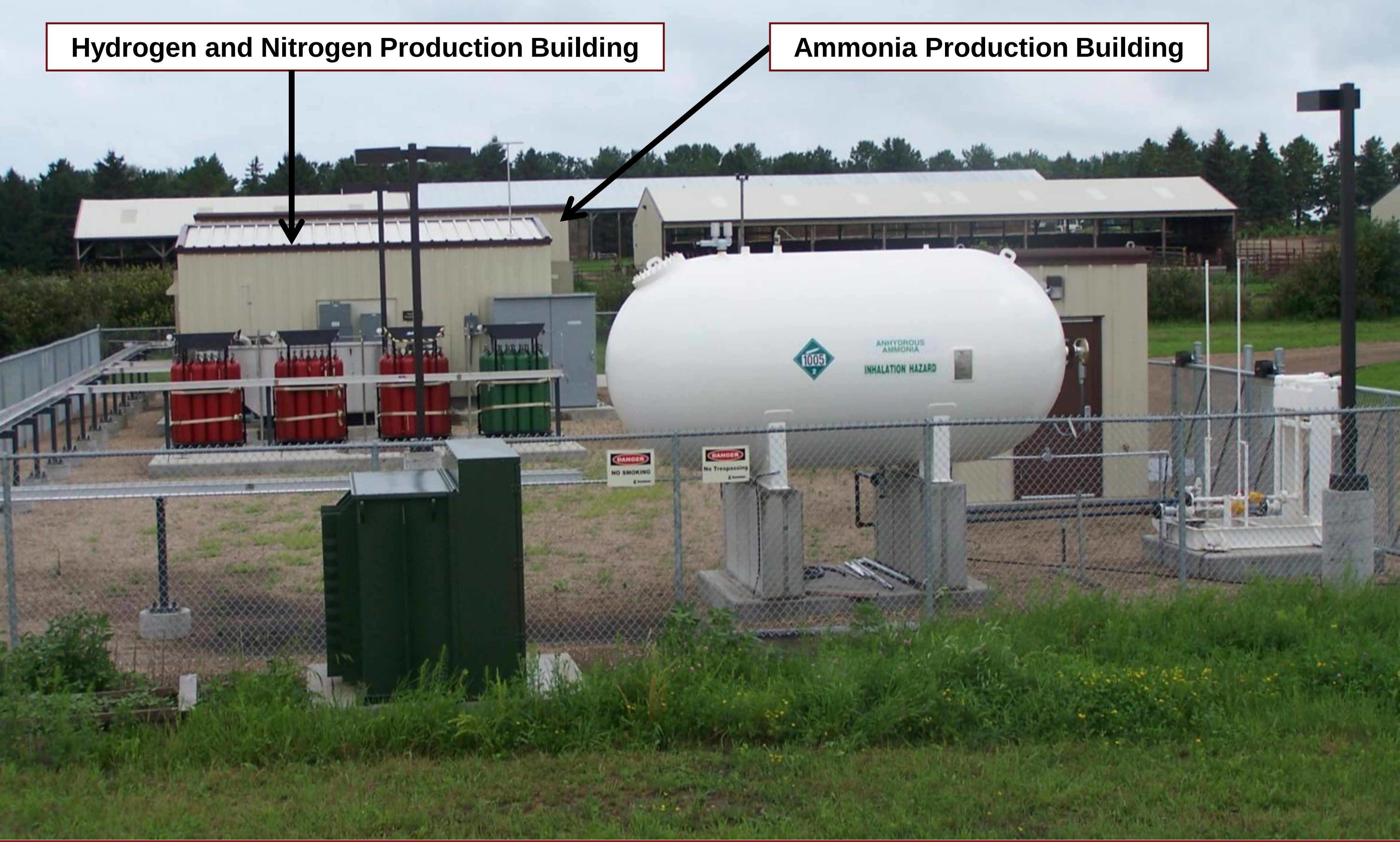
- Utilities are not requiring additional power

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

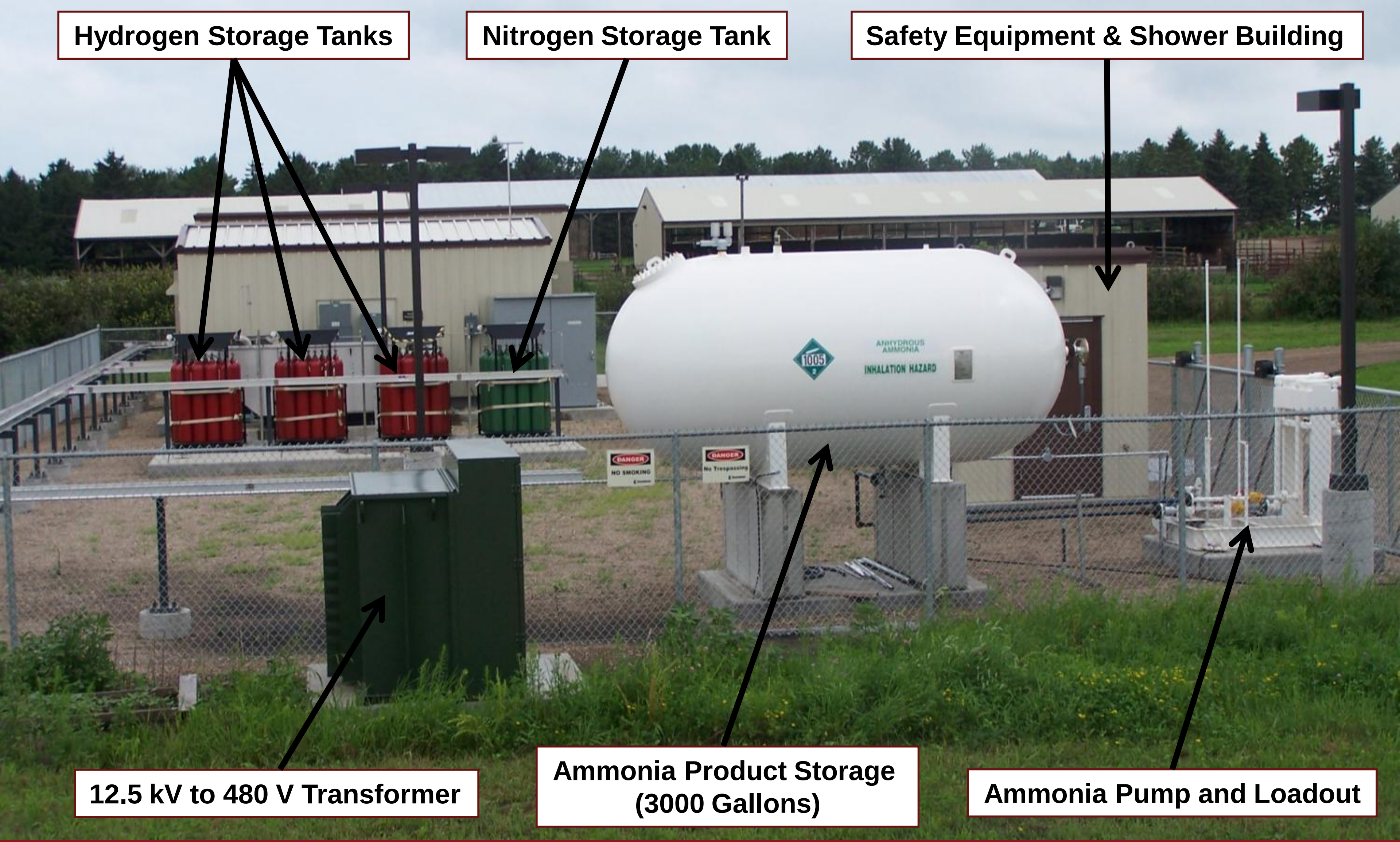
"Why not develop energy intense industry to utilize renewable energy in close proximity to where it is produced rather than exclusively build expensive transmission lines? "

Renewable Hydrogen and Ammonia Pilot Plant

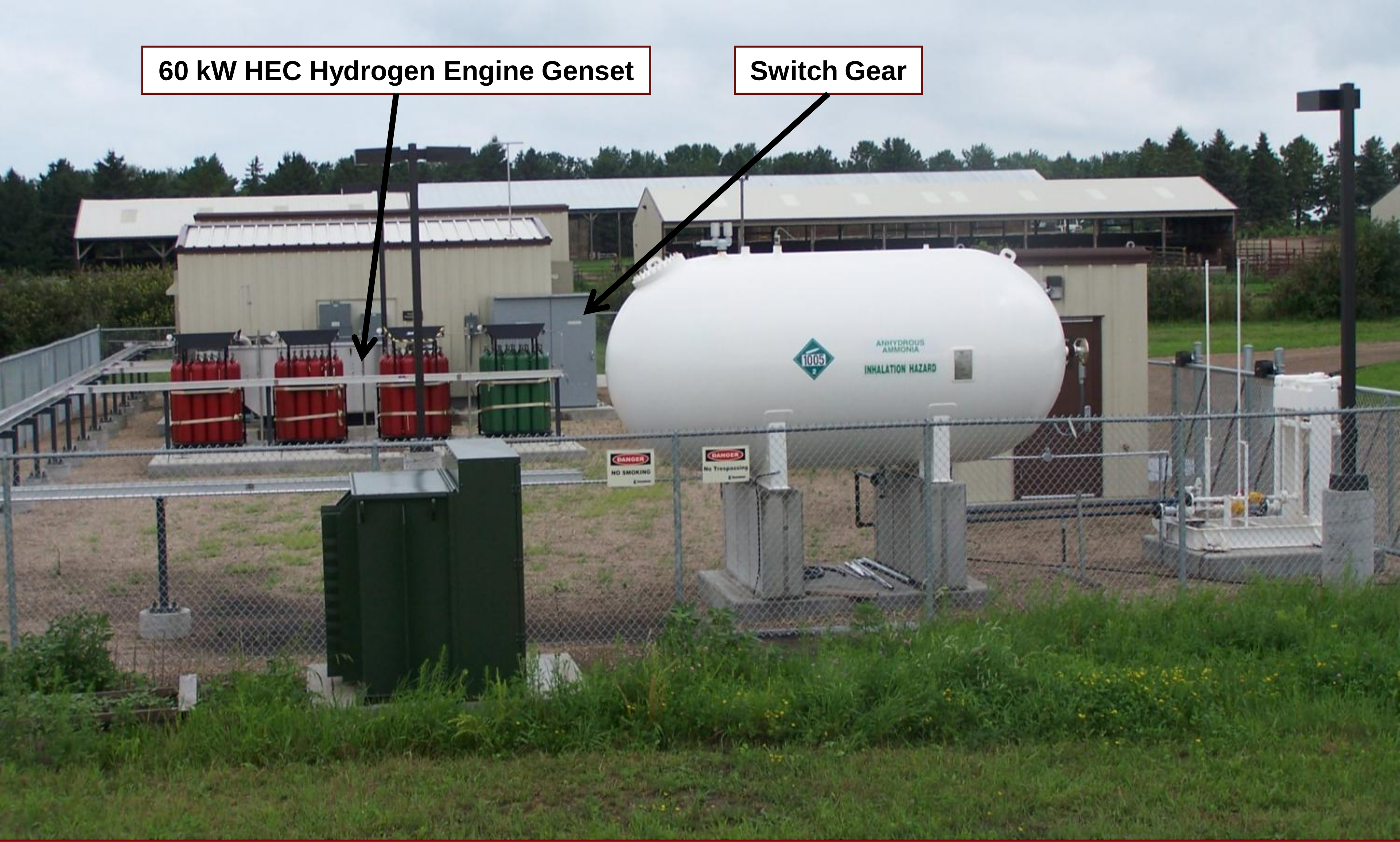
Renewable Hydrogen and Ammonia Pilot Plant



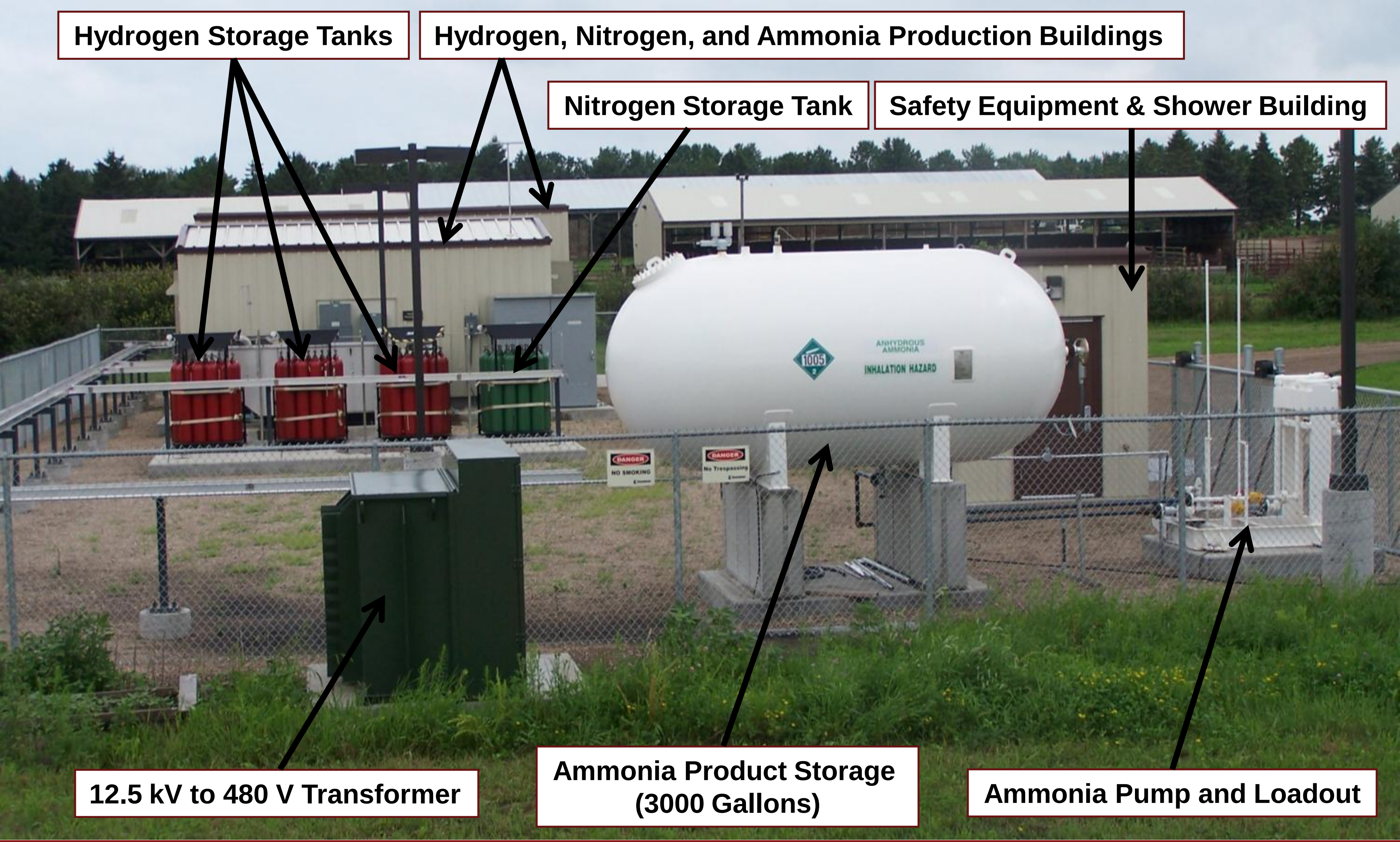
Renewable Hydrogen and Ammonia Pilot Plant



Renewable Hydrogen and Ammonia Pilot Plant



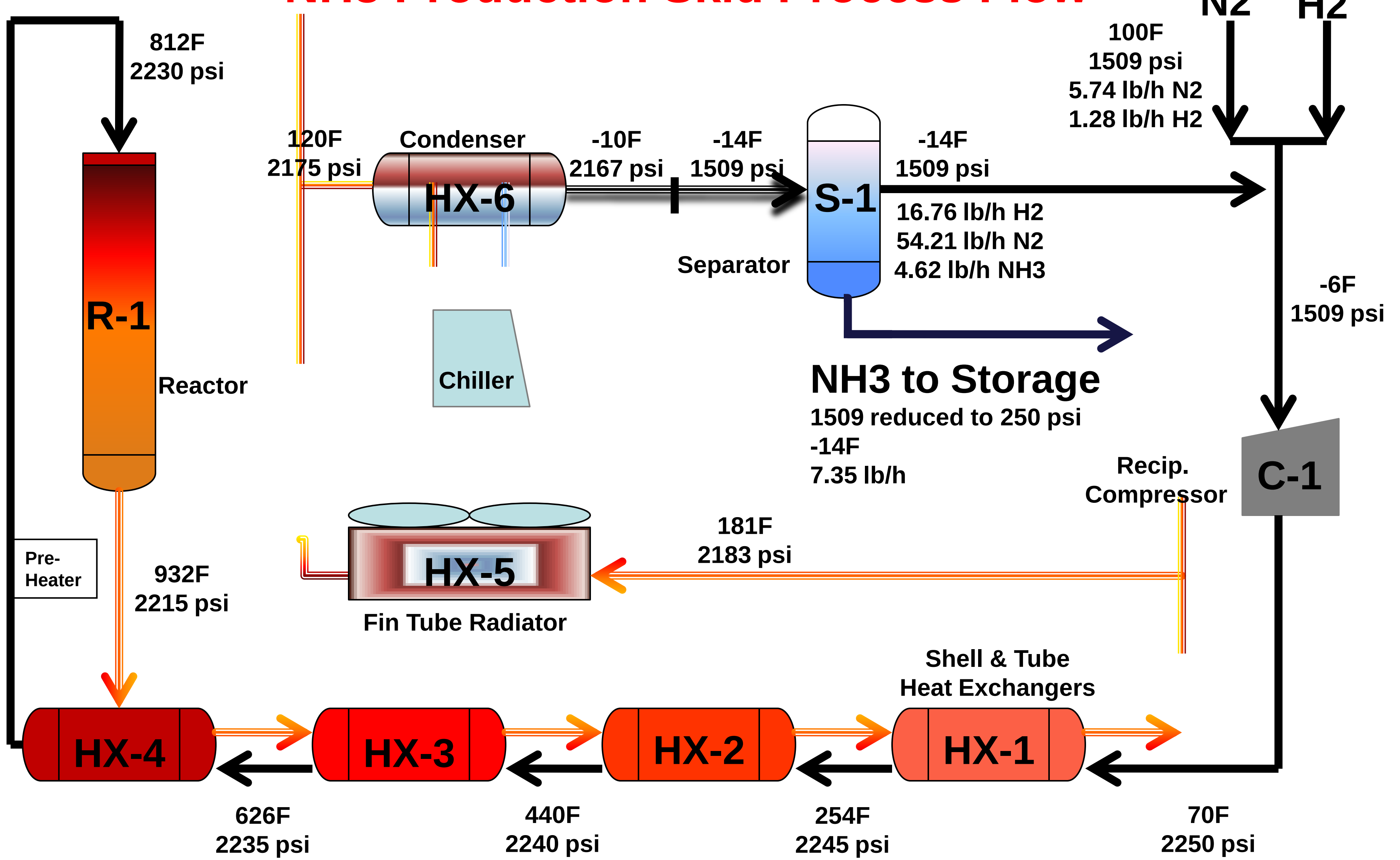
Renewable Hydrogen and Ammonia Pilot Plant



Another View

Another View

NH3 Production Skid Process Flow



Water Deionization Unit and Safety Shower Pump

Hydrogen Electrolyzer (Proton Energy 10 kW)

Hydrogen Electrolyzer (Proton Energy 10 kW)

H2 Booster Diaphragm Compressor (220 to 2450 psi)

H2 and N2 Gas Storage Tanks (2450 psi)

Air Compressor and Dryer

N2 Gas Generation

N2 Booster Compressor (50-120 to 2450 psi)

H2 and N2 Gas Dew Point Detectors and Power Meters

Interior of H2 and N2 Production Building

HEC Oxx Power 60 kW Hydrogen Engine Generator

Data Acquisition to Determine Inputs and Outputs

NH3 Load Out, Storage, Nurse Tanks, & Application

New Goal – Carbon Balanced Agriculture

1. **Reduce the utilization of fossil fuels in agricultural production systems**
2. **Increase local markets for renewable energy**
3. **Decrease economic and financial risk associated with fossil fuel based agricultural / rural economies**
4. **WCROC is ideal research location due to diverse production systems**
   - Conventional Crop and Livestock Systems
   - Organic Crop and Livestock Systems
     - No synthetic pesticides, commercial fertilizers, and pharmaceuticals for livestock
   - “Hybrid Carbon-Balanced Crop and Livestock Systems”
     - No fossil fuel based energy and fertilizer - limited use of synthetic pesticides

Opportunities for Wind to Ammonia

- Seek opportunities to be cost competitive, independent, and green
- Test novel catalysts and other techniques
- Can smaller scaled units be established?
- Investigate opportunities to buy power from wind resources that get “curtailed.”
- Determine opportunities for local investments to produce fertilizer inputs.

Plan of Investigation

- Determine factor inputs– kWh per Ton of H_2
- Determine power requirements to segregate the N_2
- Determine power required to synthesize the NH_3
- Study costs of U of M unit
- Model reasonable cost assumptions for scale-up

Other Avenues of Inquiry

- Determine competitiveness of greener NH_3 when markets or regulations penalize greenhouse gas emissions of farm inputs.
- GHG emissions from embedded natural gas used in NH_3 production to support corn production--- huge challenge for agriculture of U.S. and Minnesota

Contact Information:

Michael Reese
Director- Renewable Energy
West Central Research & Outreach Center
University of Minnesota
Phone: (320) 589-1711
Web: http://renewables.morris.umn.edu
reesem@morris.umn.edu

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