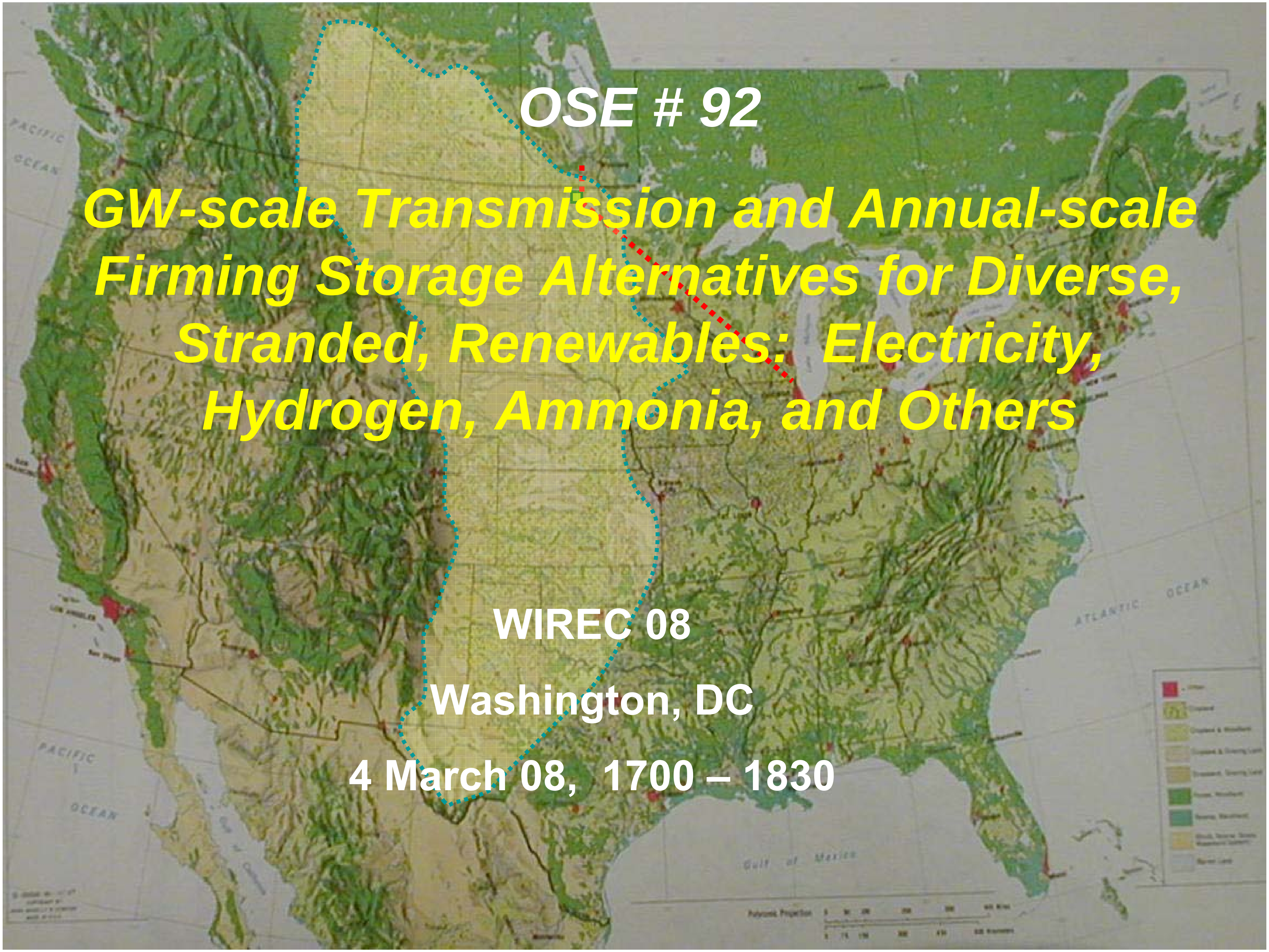


OSE # 92

GW-scale Transmission and Annual-scale Firming Storage Alternatives for Diverse, Stranded, Renewables: Electricity, Hydrogen, Ammonia, and Others

WIREC 08

Washington, DC

4 March 08, 1700 – 1830

OSE # 92

Format:

45 minutes: six speakers (handout)

45 minutes roundtable

Co-sponsors:

Union of Concerned Scientists
Electricity Storage Association
Ammonia Fuel Network
Iowa Renewable Energy Association
University of Minnesota – Morris
National Hydrogen Association
Environmental Law and Policy Center
Stanford Atmospheric / Energy Engineering program
Xcel Energy
NaturalHY Project
Hydrogen Discoveries, Inc
Iowa Farmers Union
The Leighty Foundation

Run the World on Renewables

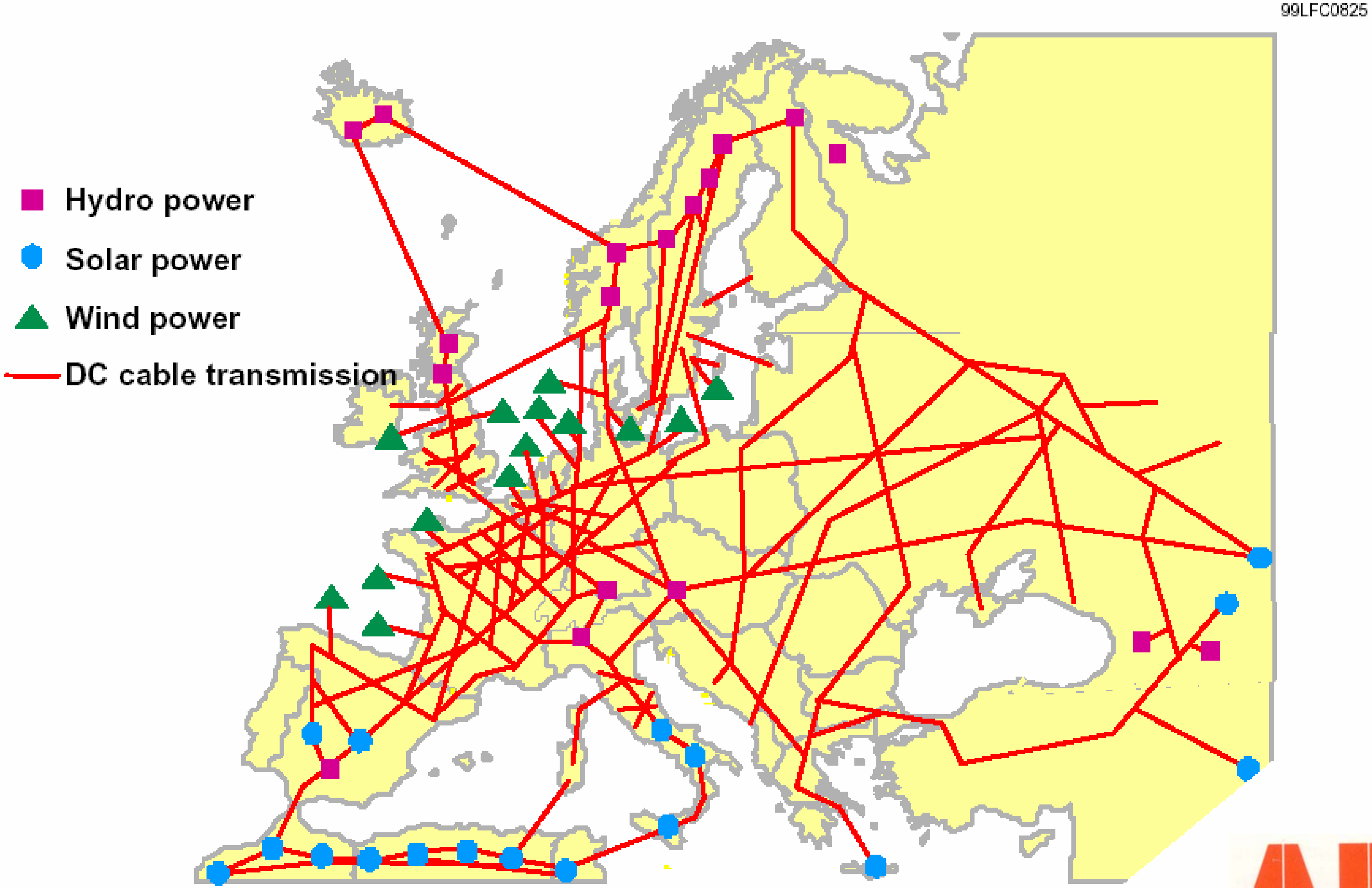
- EREC: 20% by 2025
- 25 x ’25
- Only 200 years of coal; less O+G
- Emergencies ?
  - Climate change
  - Energy cost
  - Energy security

Run the World on Renewables

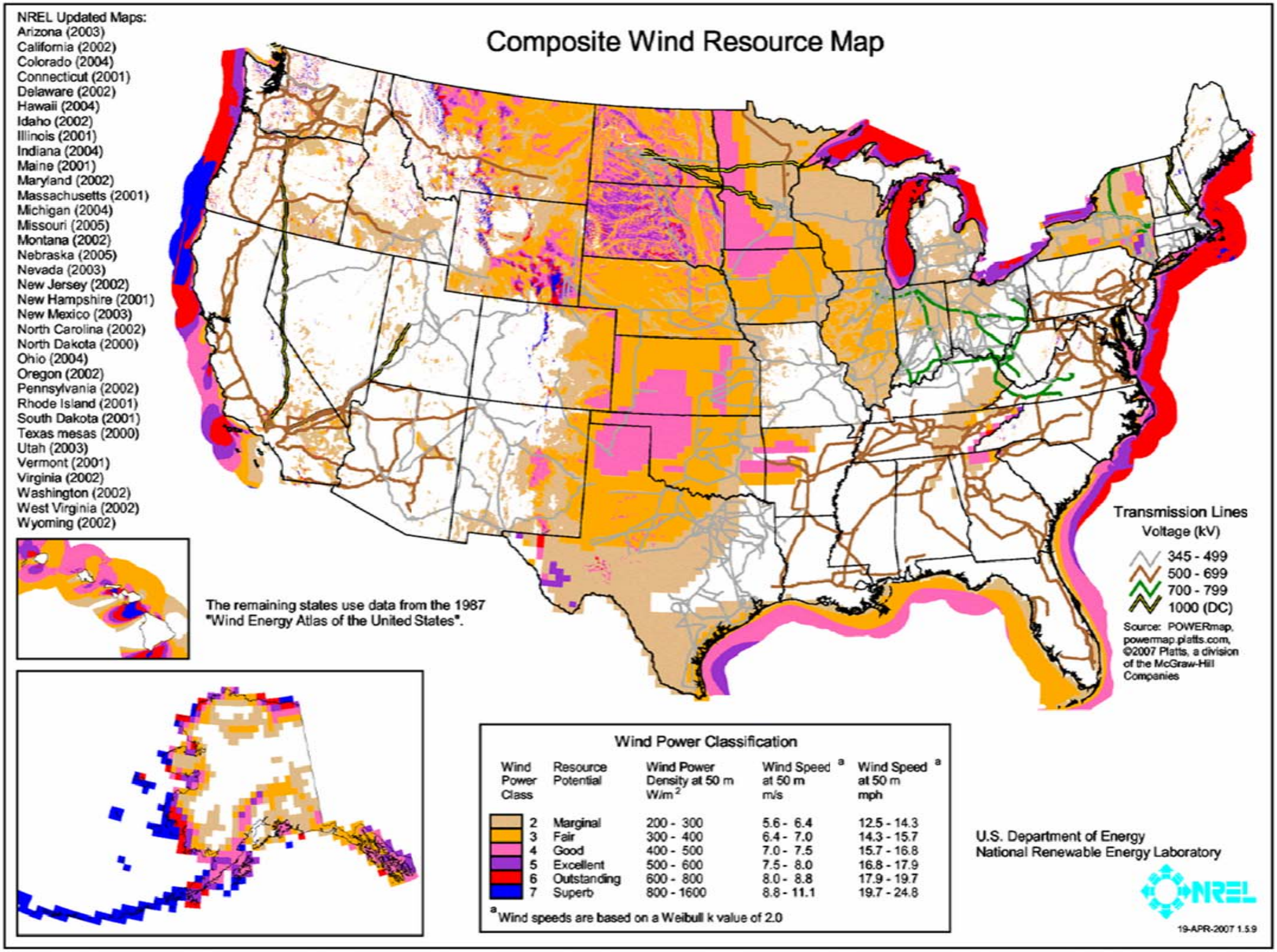
- Richest renewables stranded
  - High intensity
  - Large geographic extent – dispersed
  - Far from markets
  - No transmission
- Time-varying output – except
  - Except geothermal, currents
  - Seconds to seasons
- ABB, ISET “huge catchment area”

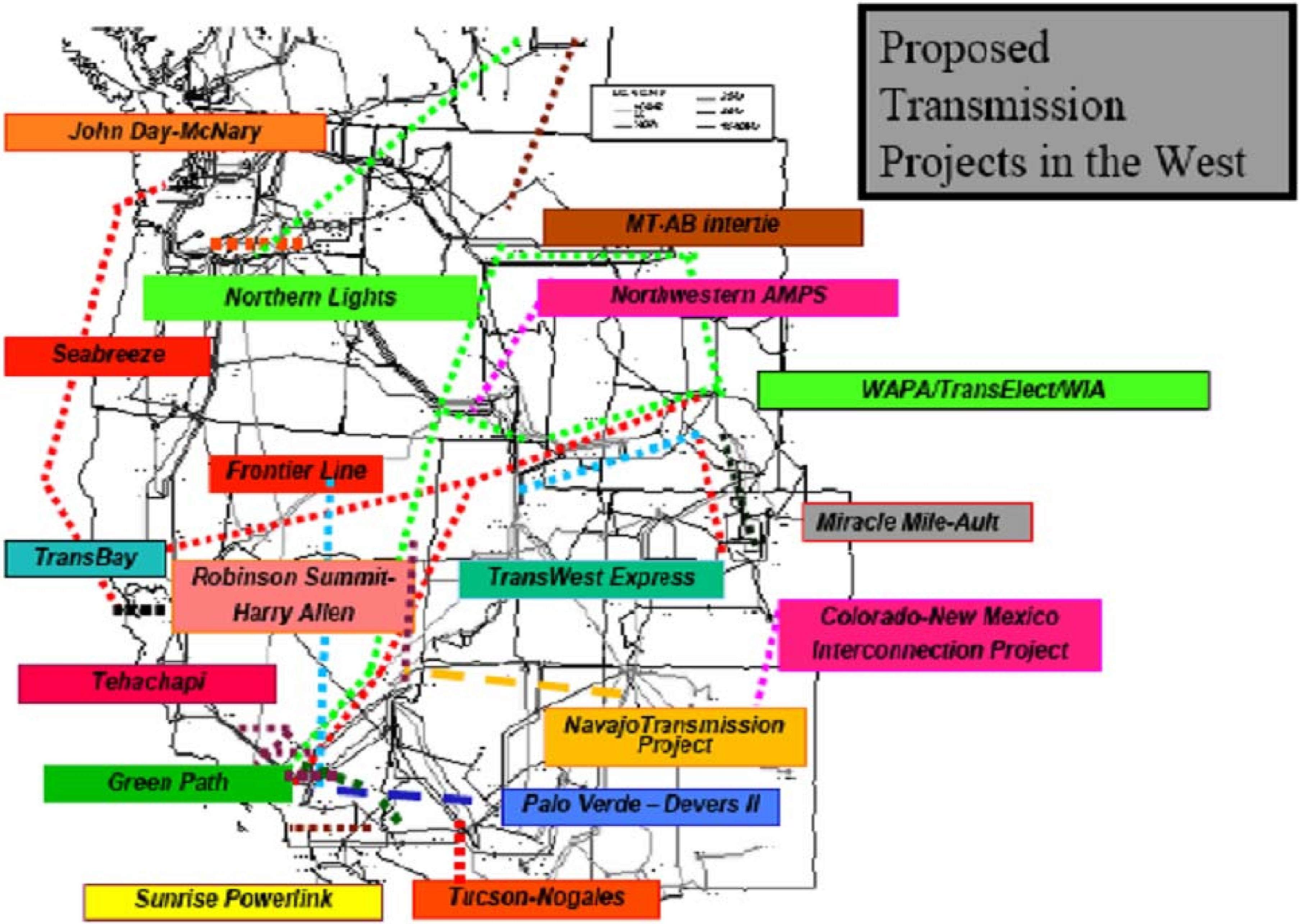
Vision: Remote renewable energy sources

connected to loads by DC grid



ABB


Composite Wind Resource Map
NREL Updated Maps:
Arizona (2003)
California (2002)
Colorado (2004)
Connecticut (2001)
Delaware (2002)
Hawaii (2004)
Idaho (2002)
Illinois (2001)
Indiana (2004)
Maine (2001)
Maryland (2002)
Massachusetts (2001)
Michigan (2004)
Missouri (2005)
Montana (2002)
Nebraska (2005)
Nevada (2003)
New Jersey (2002)
New Hampshire (2001)
New Mexico (2003)
North Carolina (2002)
North Dakota (2000)
Ohio (2004)
Oregon (2002)
Pennsylvania (2002)
Rhode Island (2001)
South Dakota (2001)
Texas mesas (2000)
Utah (2003)
Vermont (2001)
Virginia (2002)
Washington (2002)
West Virginia (2002)
Wyoming (2002)
The remaining states use data from the 1987 "Wind Energy Atlas of the United States".
Transmission Lines
Voltage (kV)
345 - 499
500 - 699
700 - 799
1000 (DC)
Source: POWERmap, powermap.platts.com, ©2007 Platts, a division of the McGraw-Hill Companies
Wind Power Classification
Wind Power Class
Resource Potential
Wind Power Density at 50 m W/m2
Wind Speed a at 50 m m/s
Wind Speed a at 50 m mph
2 Marginal 200 - 300 5.6 - 6.4 12.5 - 14.3
3 Fair 300 - 400 6.4 - 7.0 14.3 - 15.7
4 Good 400 - 500 7.0 - 7.5 15.7 - 16.8
5 Excellent 500 - 600 7.5 - 8.0 16.8 - 17.9
6 Outstanding 600 - 800 8.0 - 8.8 17.9 - 19.7
7 Superb 800 - 1600 8.8 - 11.1 19.7 - 24.8
a Wind speeds are based on a Weibull k value of 2.0
U.S. Department of Energy
National Renewable Energy Laboratory
NREL
19-APR-2007 1.5.9



Proposed
Transmission
Projects in the West
John Day-McNary
MT-AB intertie
Northern Lights
Northwestern AMPS
Seabreeze
WAPA/TransElect/WIA
Frontier Line
Miracle Mile-Ault
TransBay
Robinson Summit-
Harry Allen
TransWest Express
Colorado-New Mexico
Interconnection Project
Tehachapi
NavajoTransmission
Project
Green Path
Palo Verde – Devers II
Sunrise Powerlink
Tucson-Nogales

Run the World on Renewables

- Distributed + centralized
- Transmission + storage
- Need “Firm” unless MO and lifestyle changes
- Firm: deliver contracted energy every hour of every year

Run the World on Renewables

- Can't do it with electricity alone
  - –NIMBY delays, costs
  - –Vulnerable: acts of God or man
  - –High capital costs:
    - Gathering
    - Access -- substations
  - –Low CF
  - –O&M cost, losses
  - –No affordable annual-scale storage
- Bigger markets than grid ?
    - Transportation fuel
    - DG fuel, CHP

250 hydrogen "gas stations"

Of 10,000 CA total

Whence the hydrogen ?

CA Annual Hydrogen Fuel Demand

- 20% of 45M vehicles H2 fueled by 2030
- 9M vehicles @ 78 mpg = 78 miles / kg H2
- 12,000 miles / year → 150 kg H2 / year
- 1,350 M kg H2 / year = 1.35 M tons H2 fuel
- @ 50 kWh / kg at windplant gate:
  - 90 x 10^9 kWh / year = 67,500 GWh / year
  - @ 40% CF → 19 GW nameplate wind
  - 3 GH2 pipelines, 36”, 500 miles long
  - @ 4 caverns / GW = 80 storage caverns: firm
- OR: 6 electric lines, biggest: not firm
- How fuel the other 80% ?


www.qtww.com
Hydrogen - fueled
2005 Prius
ICE Hybrid

Back-up Power System
Fleet Fueling
Community Fueling
Industrial Application
ACME ELECTRONICS
Home Fueling
Primary Electricity
Hydrogen
Hydrogen-Generated Electricity
H_2 Generation Module
H_2 Storage Module
Power Module
Fuel Dispensing Module
Personal Energy Station (PES)
PES Storage Module
Hydrogen Tank

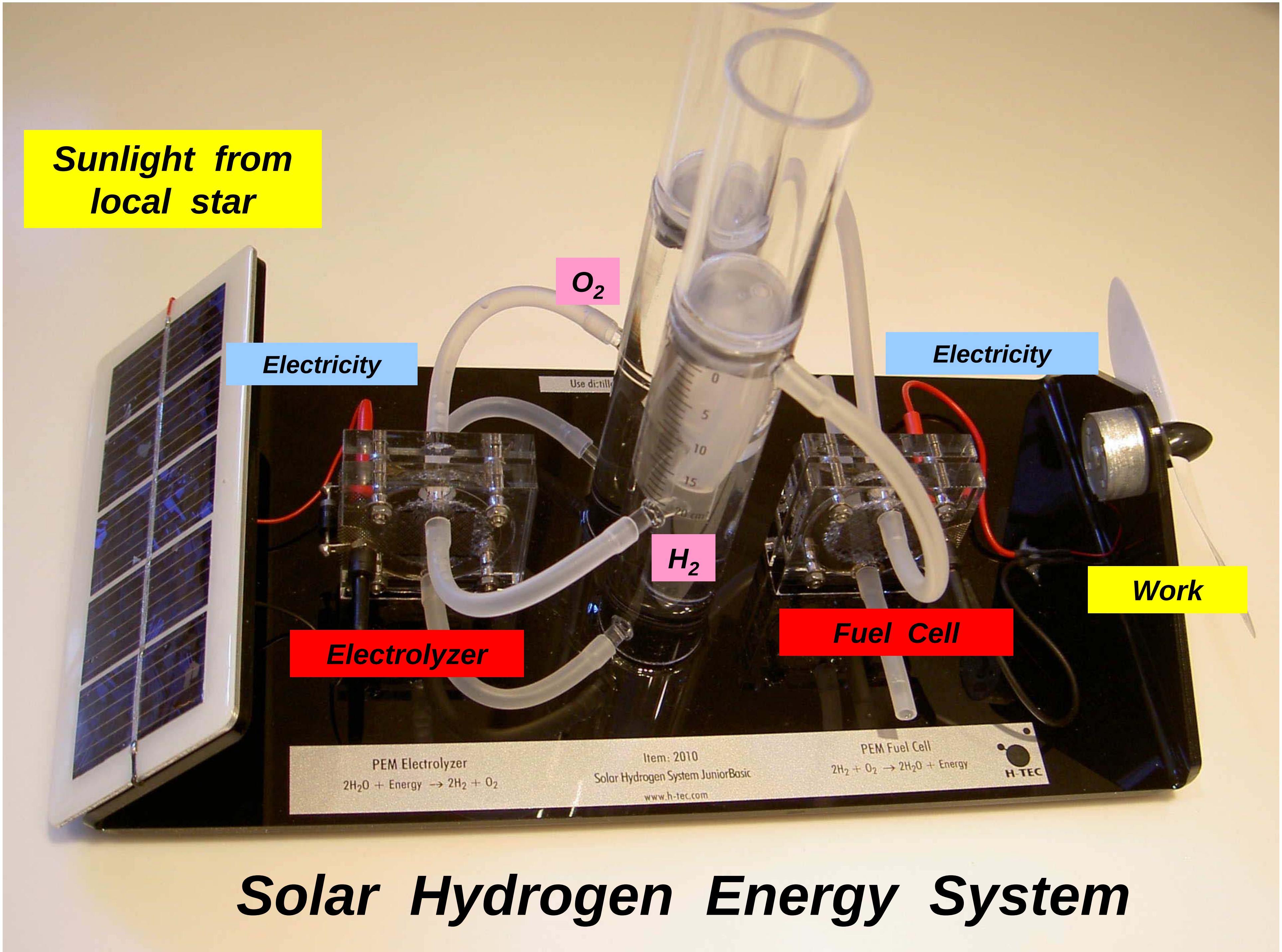
Renewables Focus

- Centralized production
  - Electricity
  - Direct hydrogen (bio, photochem)
- GW (Gigawatt = 1,000 MW) scale
  - Economy of scale
  - Run the world
- Gaseous hydrogen (GH2)
- Anhydrous ammonia (NH_3) –
  - ✓ Better than hydrogen ?
  - ✓ Need hydrogen

Hypothesis:

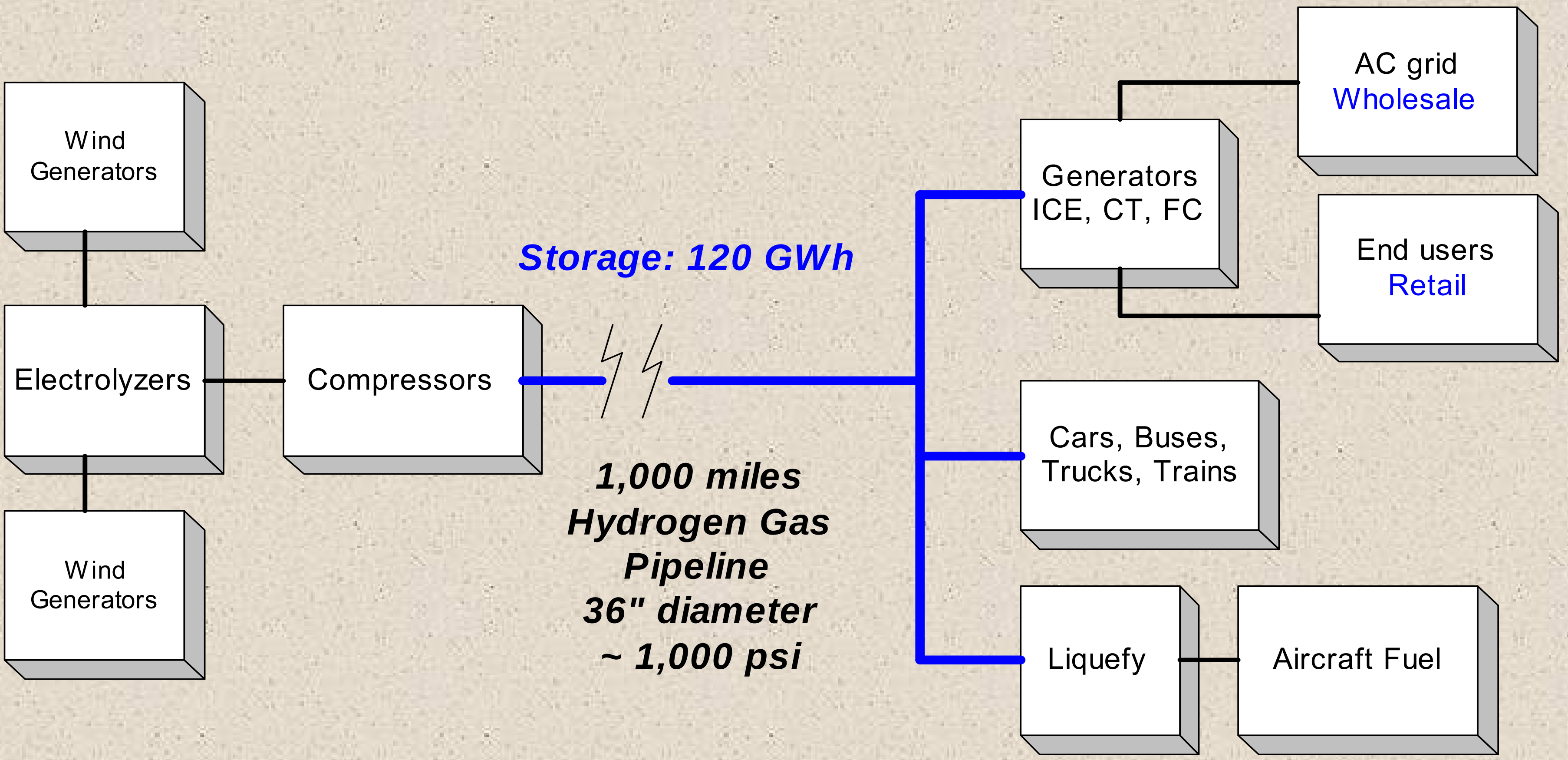
Hydrogen’s greatest value to humanity:

- Not fuel for fuel cell cars
- Means to gather, transmit, firm, deliver, use
- Diverse, large-scale, stranded renewables

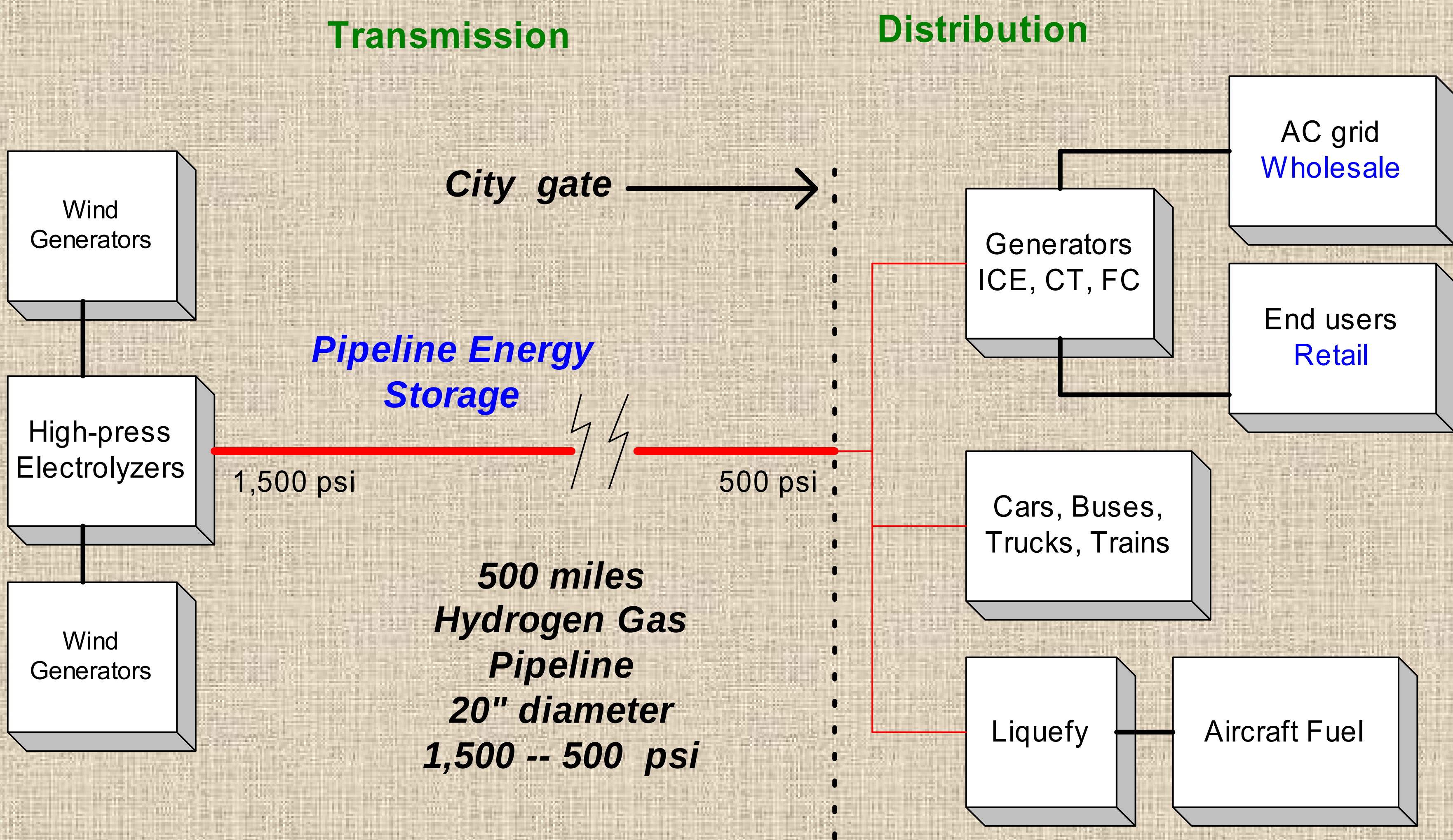

Sunlight from local star
Electricity
O_2
H_2
Electricity
Electrolyzer
Fuel Cell
Work
Use distill
PEM Electrolyzer
$2H_2O$ + Energy → $2H_2 + O_2$
Item: 2010
Solar Hydrogen System JuniorBasic
www.h-tec.com
PEM Fuel Cell
$2H_2 + O_2$ → $2H_2O$ + Energy
H-TEC
Solar Hydrogen Energy System

Hydrogen Transmission Scenario

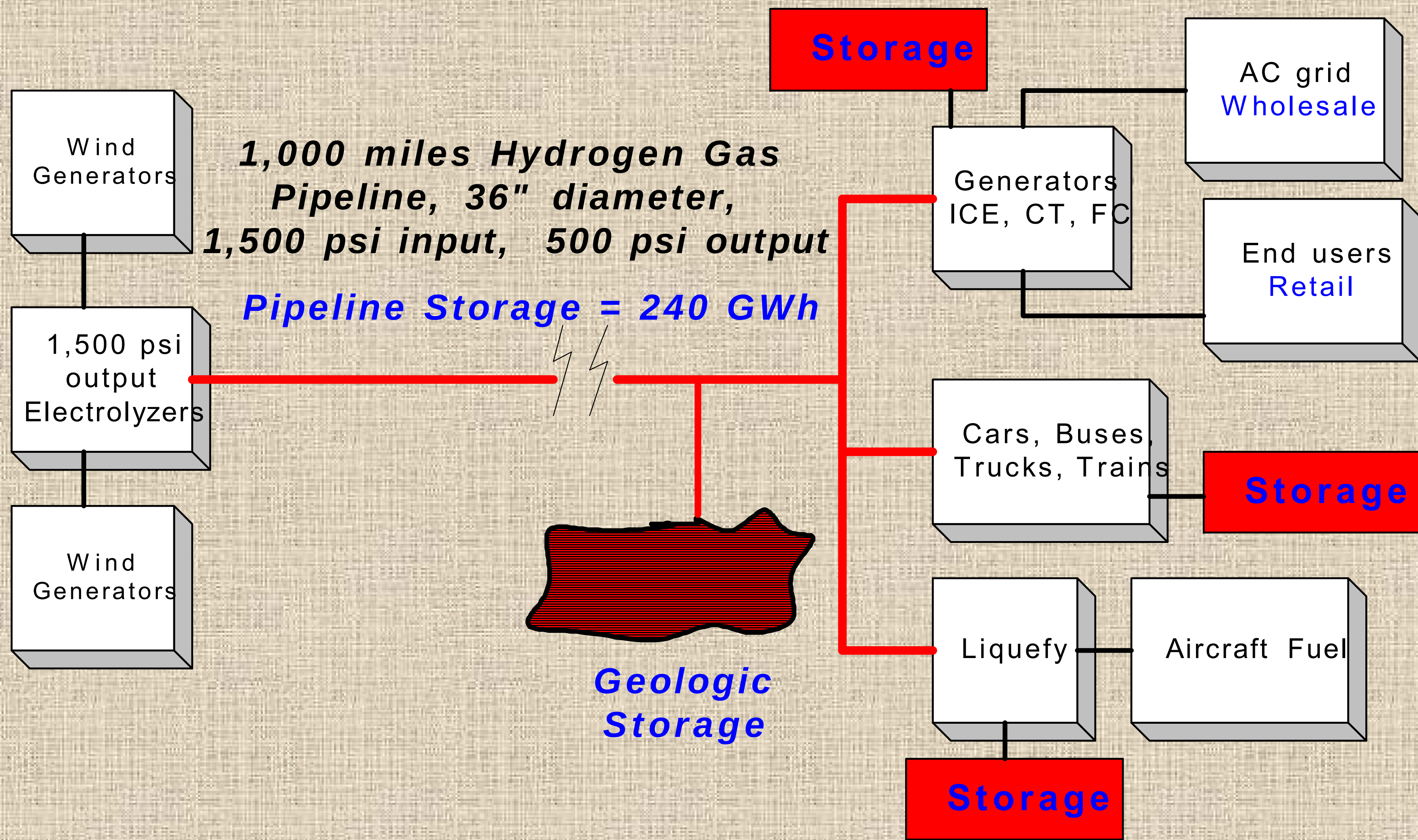
- ***Low-pressure electrolyzers***
- ***"Pack" pipeline: ~ 1-2 days' storage = 120 GWh***

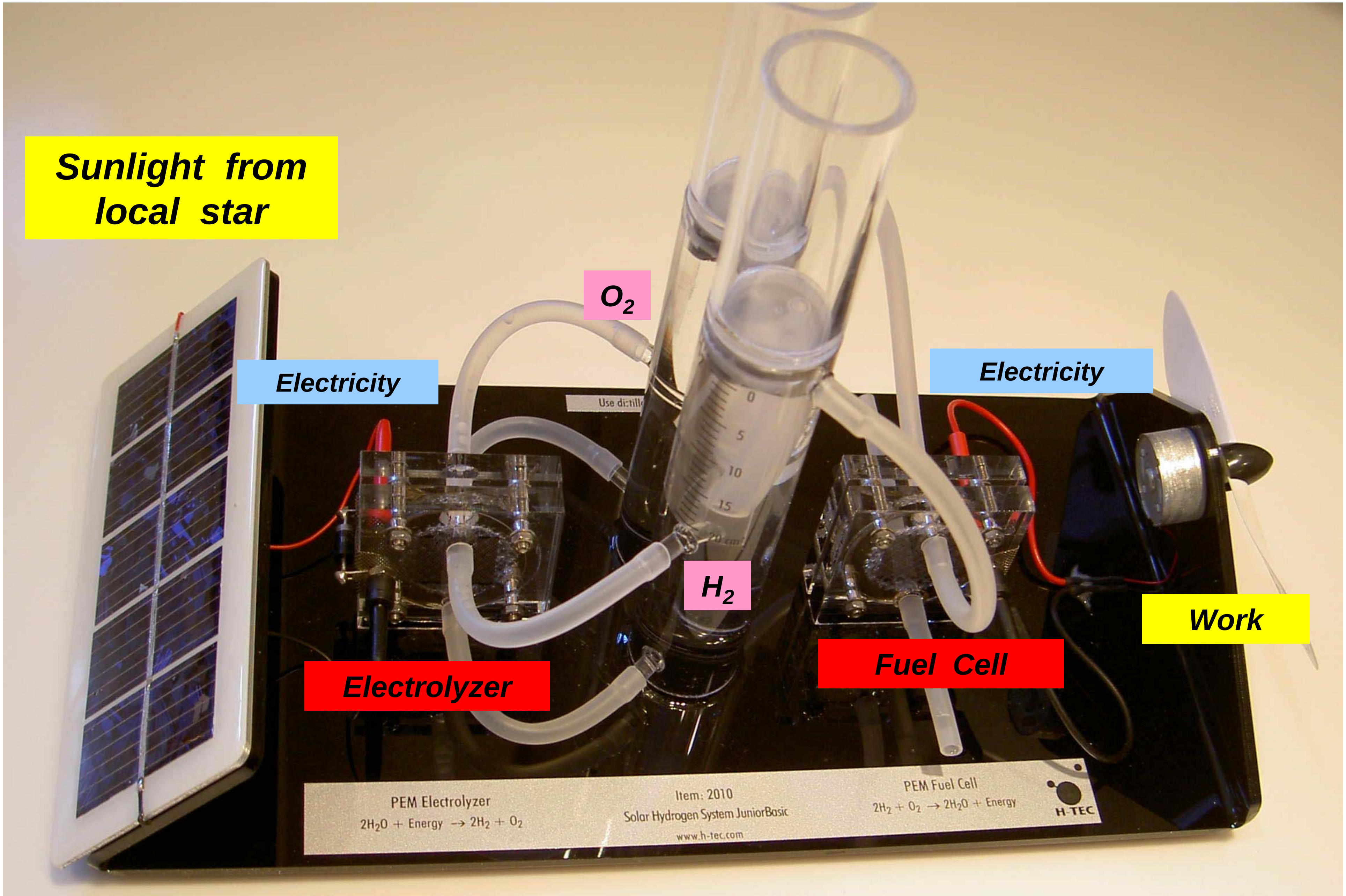


Compressorless system: No firming storage



Compressorless Renewables - Hydrogen System with Annual Firming storage





Solar Hydrogen Energy System

Storage: Hour – Week Scale

- Distributed
  - Buildings to blocks
    - Thermal: space heat + cool, DHW
    - Chemical – Hydrogen, ammonia
    - Reversible fuel cells – Hydrogen, ammonia
    - Battery, flywheel, VRB-ESS *
  - Vehicles
    - BEV (battery electric)
    - Hydrogen-fueled FCEV, HICE
- Centralized
  - VRB-ESS *
  - Compressed Air (CAES)
  - Concentrated Solar Power CSP thermal

* Vanadium Redox Battery Energy Storage System

Storage: Annual-scale "Firm"

- Every hour of every year: contracted amount
- Adds great value: strategic, market price
  - "Run world on renewables"
  - Without MO, lifestyle changes
    - Manufacture when sun shines
    - Vacation on winter wind
- Except:
  - Geothermal
  - Biomass stockpiled
  - OTEC
  - Ocean current
- Requires large storage
  - GW scale
  - Hydrogen: pipelines + caverns
  - Ammonia: pipelines + tanks

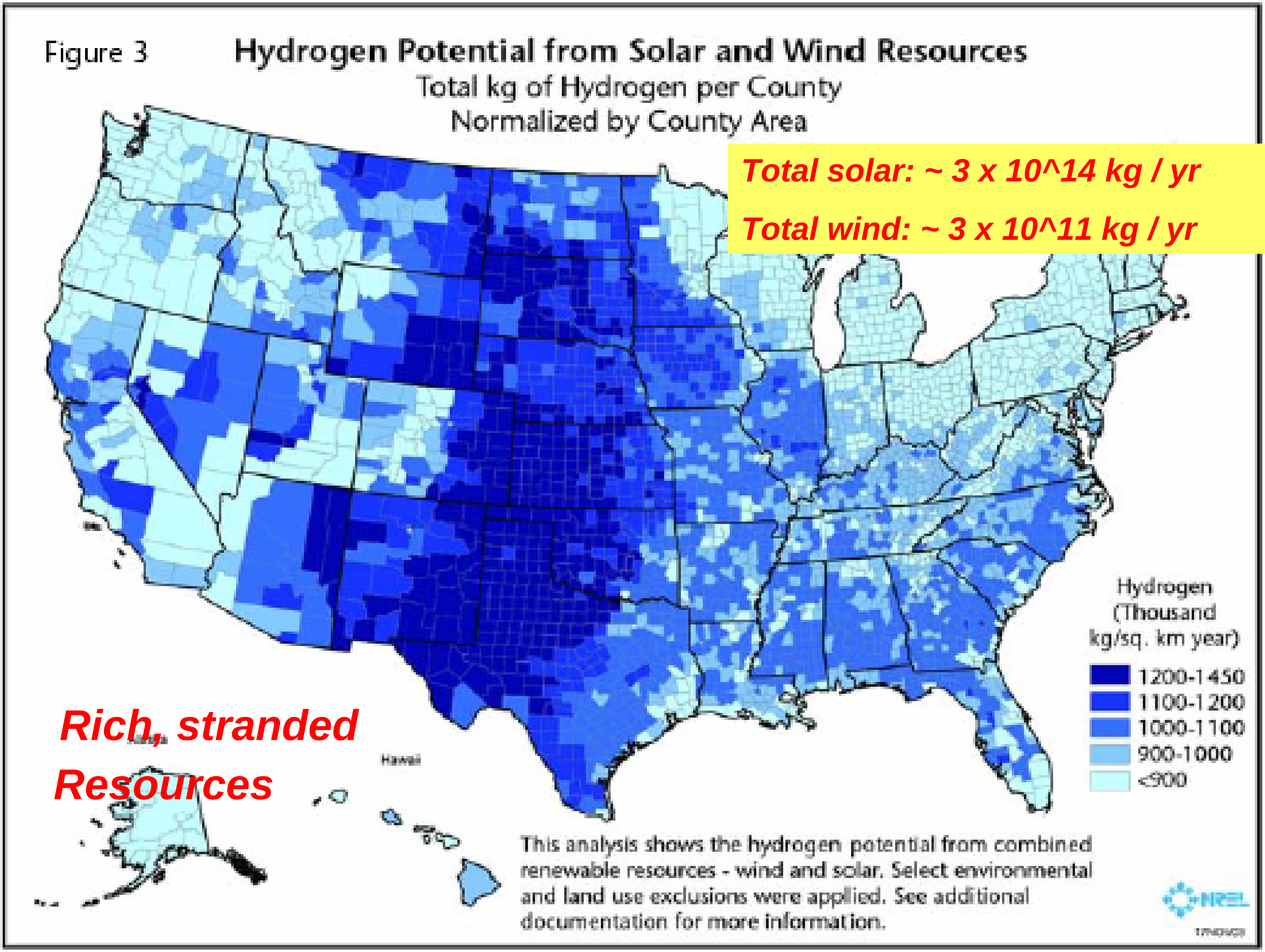
The Great Plains Wind Resource

Exporting From 12 Windiest Great Plains States

Number of GH2 pipelines or HVDC electric lines necessary to export total wind resource

Wind energy source: PNL-7789, 1991 * at 500 miles average length

State	AEP, TWh	Wind Gen MW (nameplate) (40 % CF)	6 GW 36" GH2 export pipelines	$ Billion Total Capital Cost *	3 GW export HVDC lines	$ Billion Total Capital Cost *
North Dakota	1,210	345,320	50	50	100	60
Texas	1,190	339,612	48	48	100	60
Kansas	1,070	305,365	43	43	100	60
South Dakota	1,030	293,950	41	41	100	60
Montana	1,020	291,096	41	41	90	54
Nebraska	868	247,717	35	35	80	48
Wyoming	747	213,185	30	30	70	42
Oklahoma	725	206,906	29	29	60	36
Minnesota	657	187,500	26	26	60	36
Iowa	551	157,249	22	22	50	30
Colorado	481	137,272	19	19	40	24
New Mexico	435	124,144	17	17	40	24
TOTALS	**9,984**	**2,849,316**	**401**	**$ 401**	**890**	**$ 534**

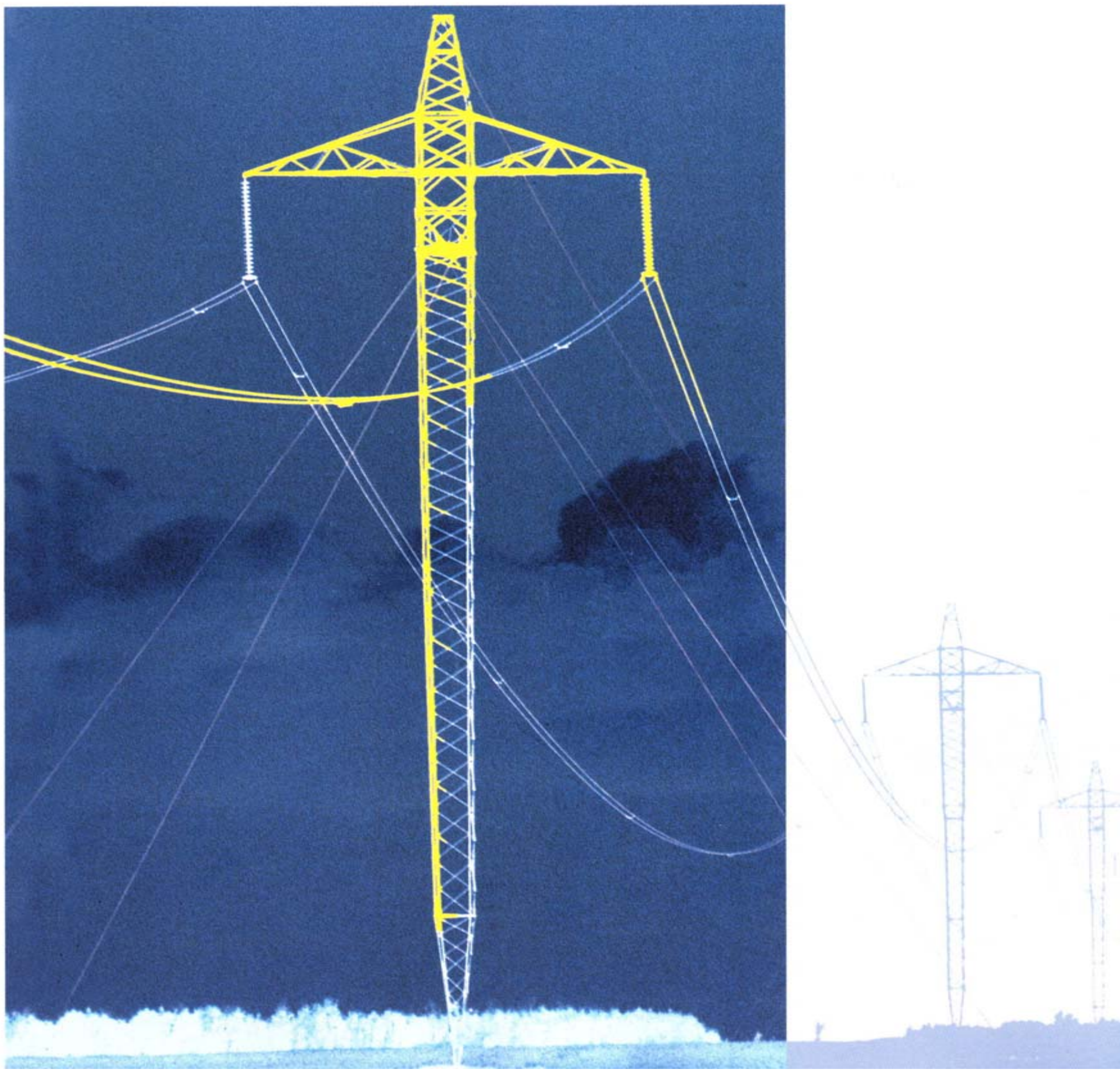


Total solar: ~ 3 x 10^14 kg / yr

Total wind: ~ 3 x 10^11 kg / yr

Rich, stranded Resources

High Voltage
Direct Current Transmission

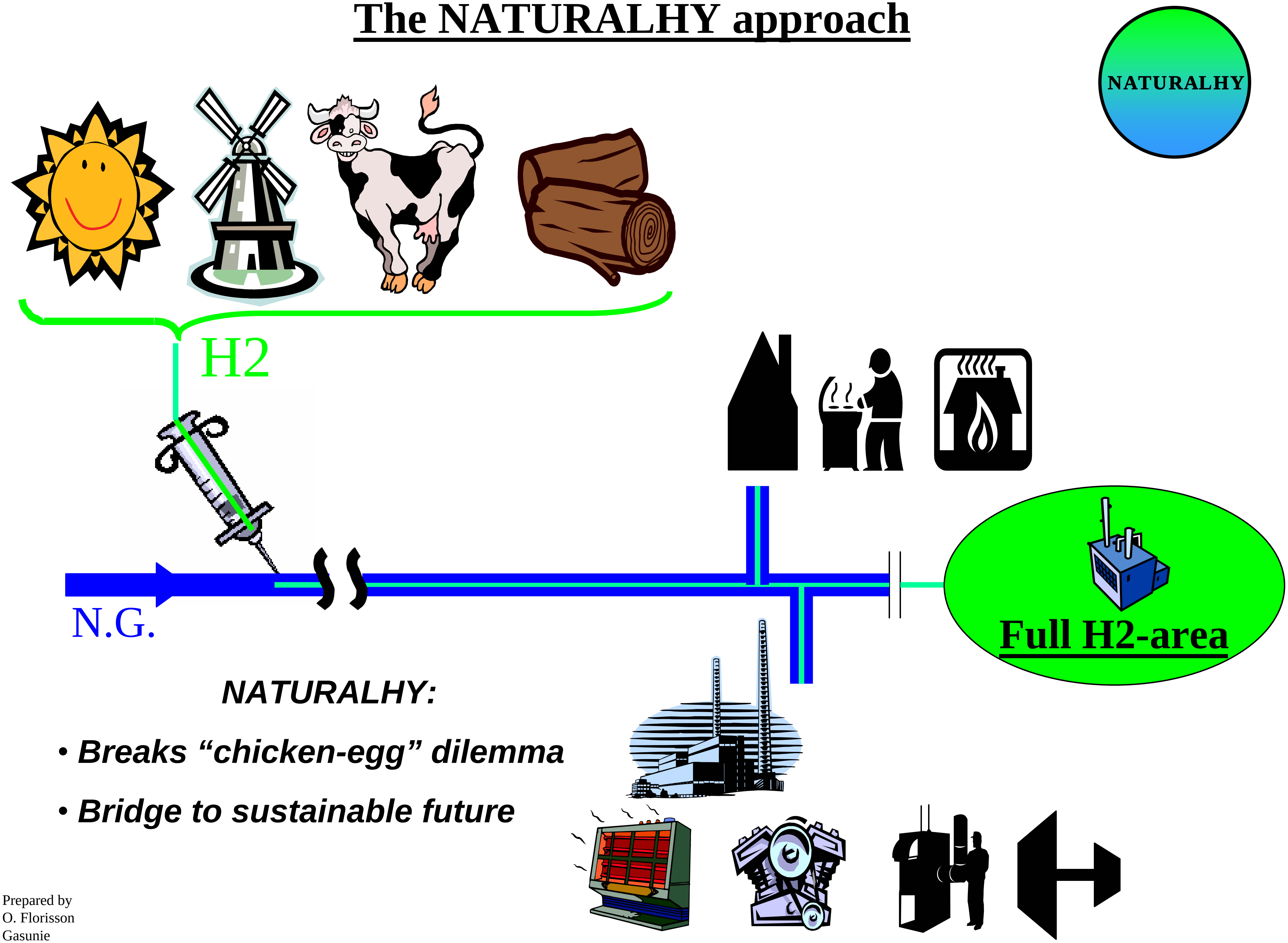


North Dakota wind needs
115 new lines
at 3,000 MW each

Twelve Plains states wind needs
890 new lines
at 3,000 MW each

SIEMENS
HVDC line
+/- 500 kv

The NATURALHY approach



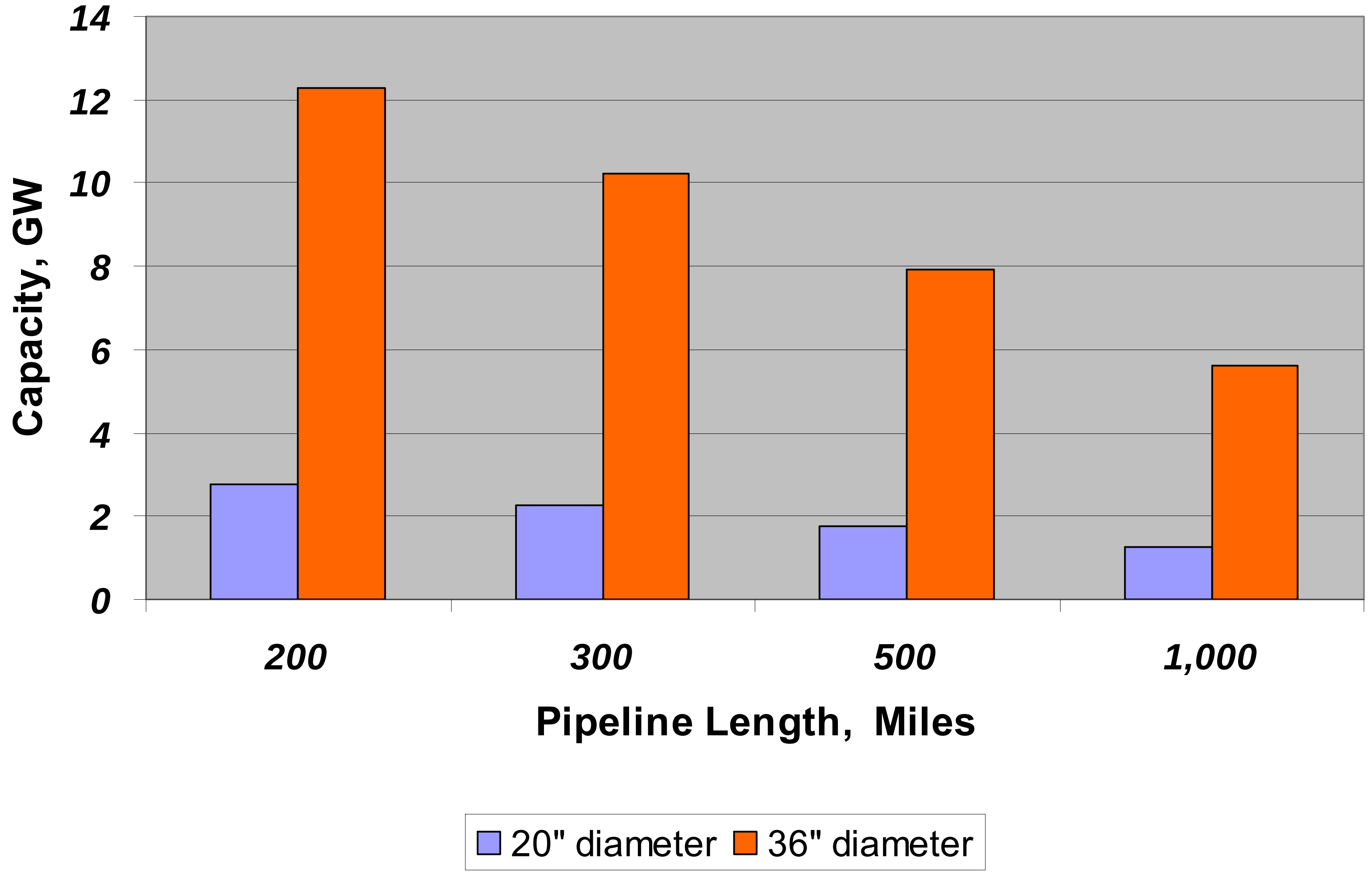
NATURALHY:

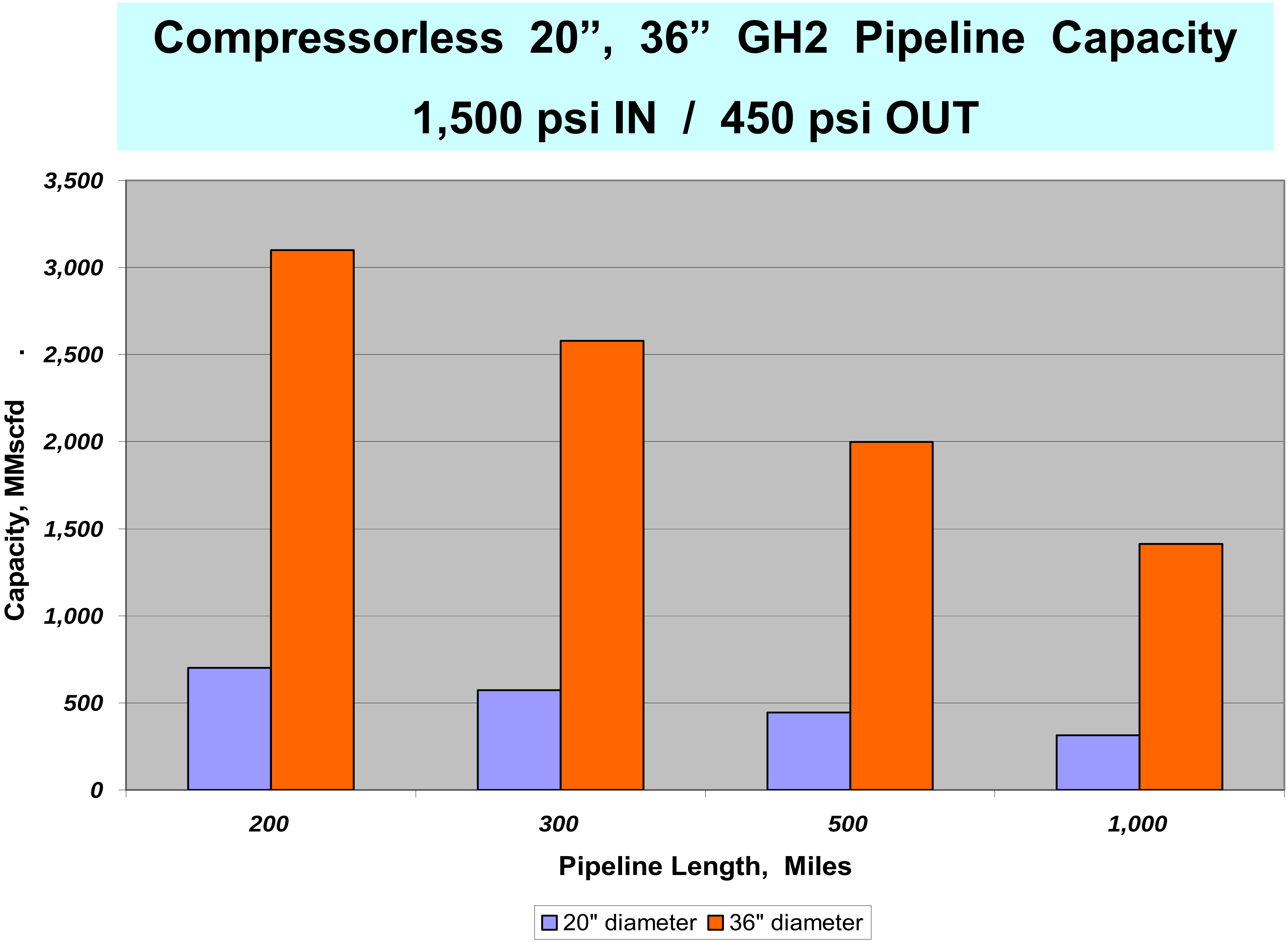
- ***Breaks "chicken-egg" dilemma***
- ***Bridge to sustainable future***

Prepared by
O. Florisson
Gasunie

Compressorless 20", 36" GH2 Pipeline Capacity

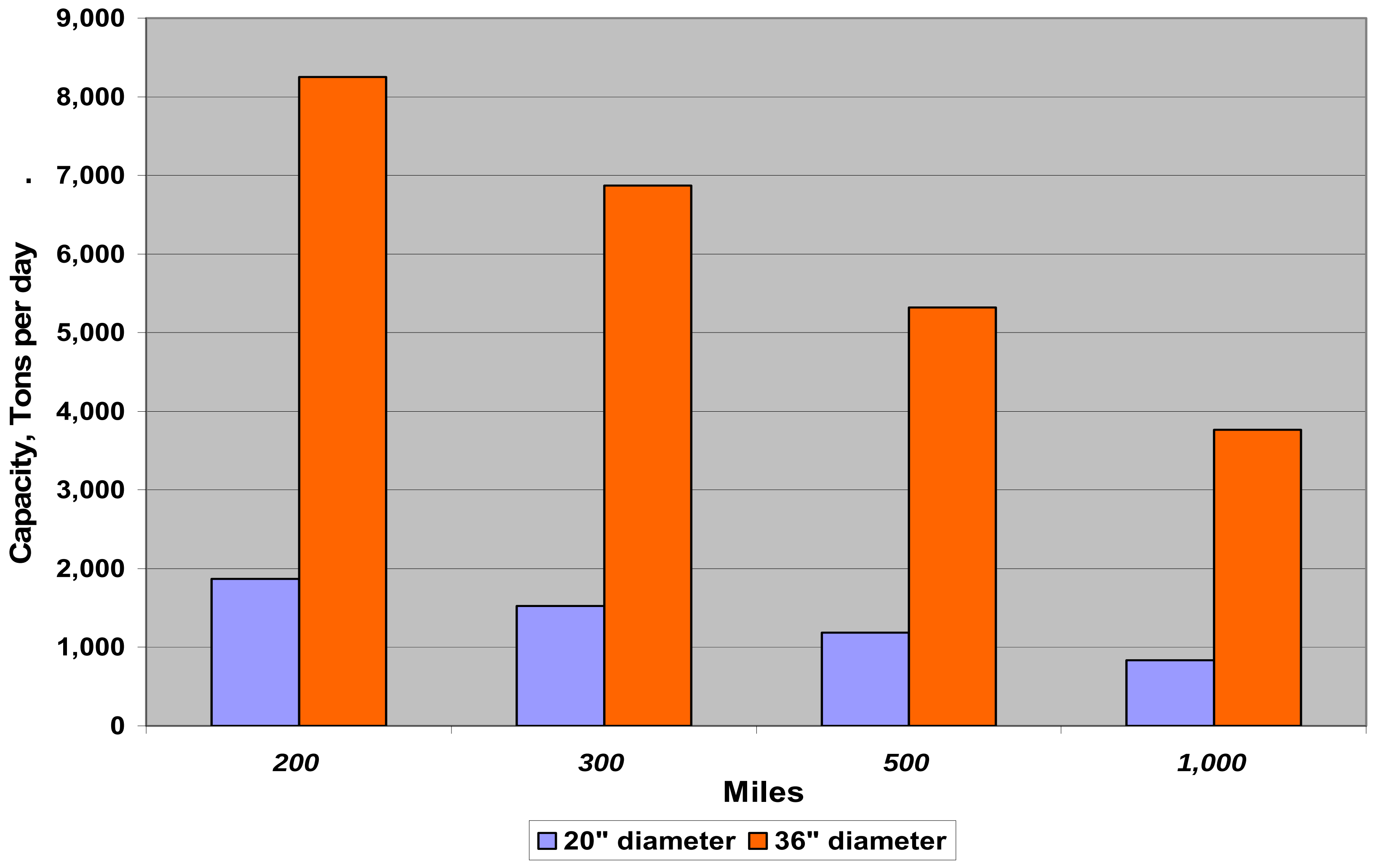
1,500 psi IN / 500 psi OUT




Compressorless 20", 36" GH2 Pipeline Capacity
1,500 psi IN / 450 psi OUT
Capacity, MMscfd
3,500
3,000
2,500
2,000
1,500
1,000
500
0
200
300
500
1,000
Pipeline Length, Miles
20" diameter
36" diameter

Compressorless 20", 36" GH2 Pipeline Capacity

1,500 psi IN / 450 psi OUT



Wind seasonality, Great Plains

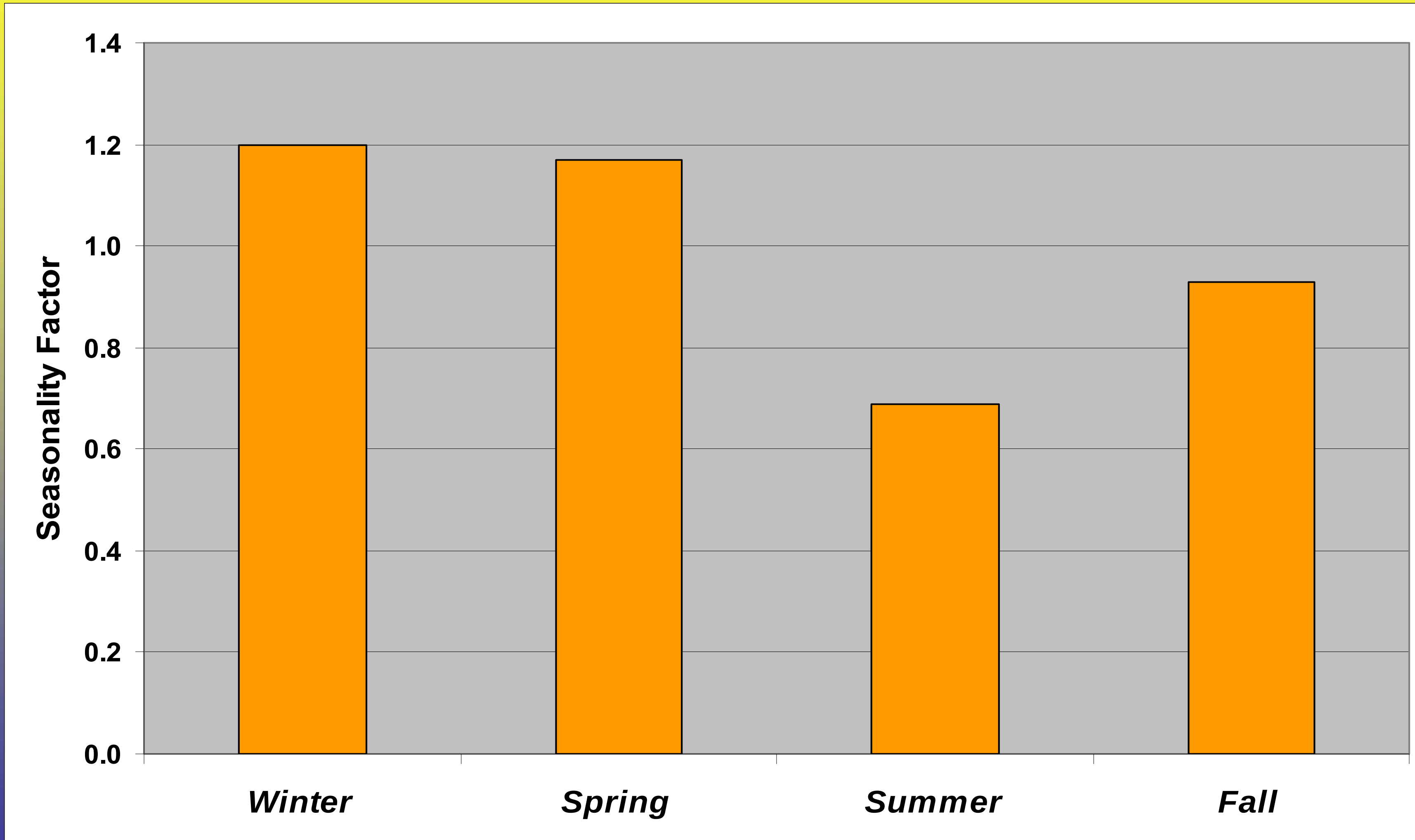
- Winter = 1.20
- Spring = 1.17
- Summer = 0.69
- Autumn = 0.93

Source: D. Elliott, et al, NREL

The Great Plains Wind Resource

Wind Seasonality, Northern Great Plains

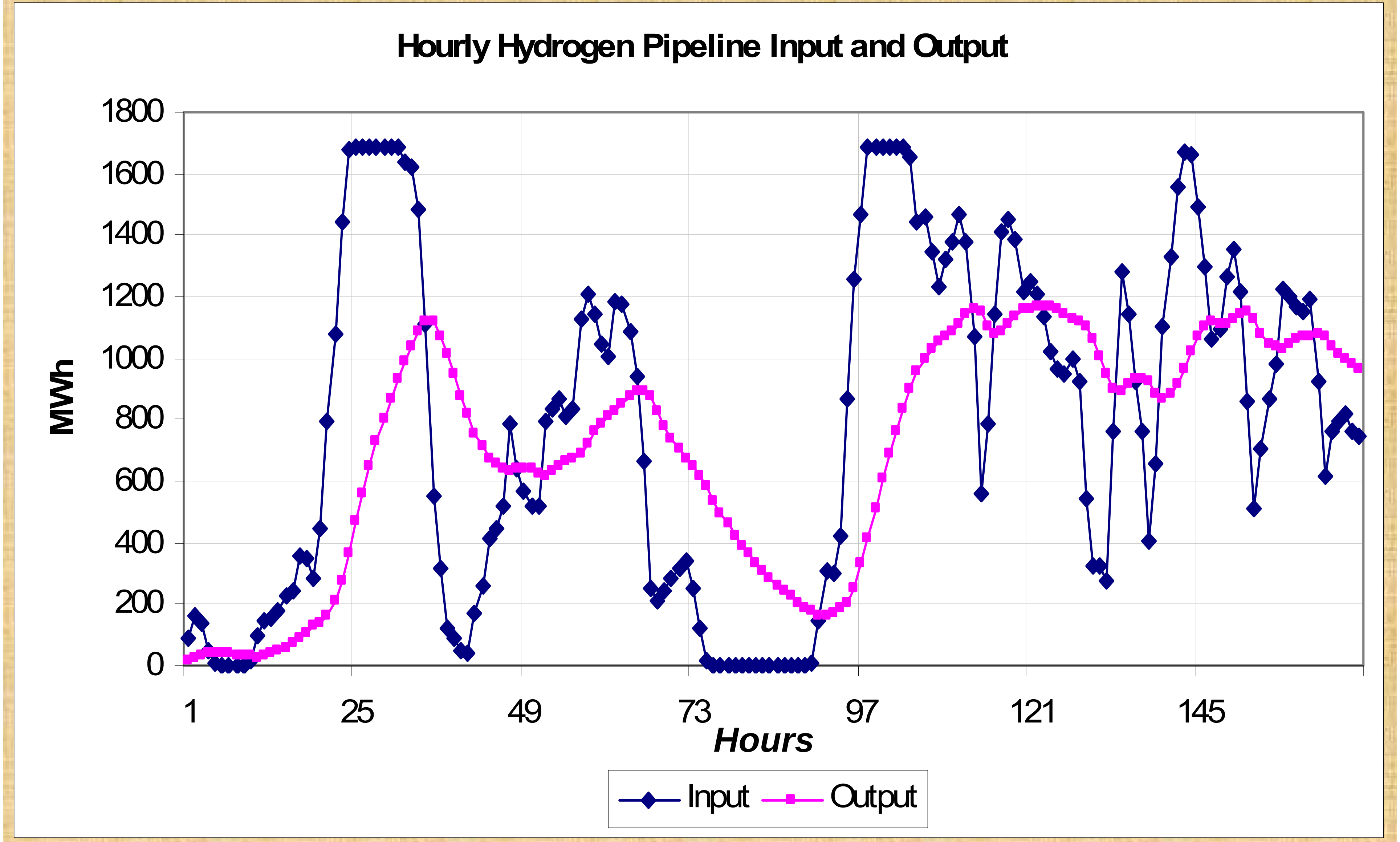
Normalized to 1.0 per season



Annual – scale "Firming" Great Plains Wind

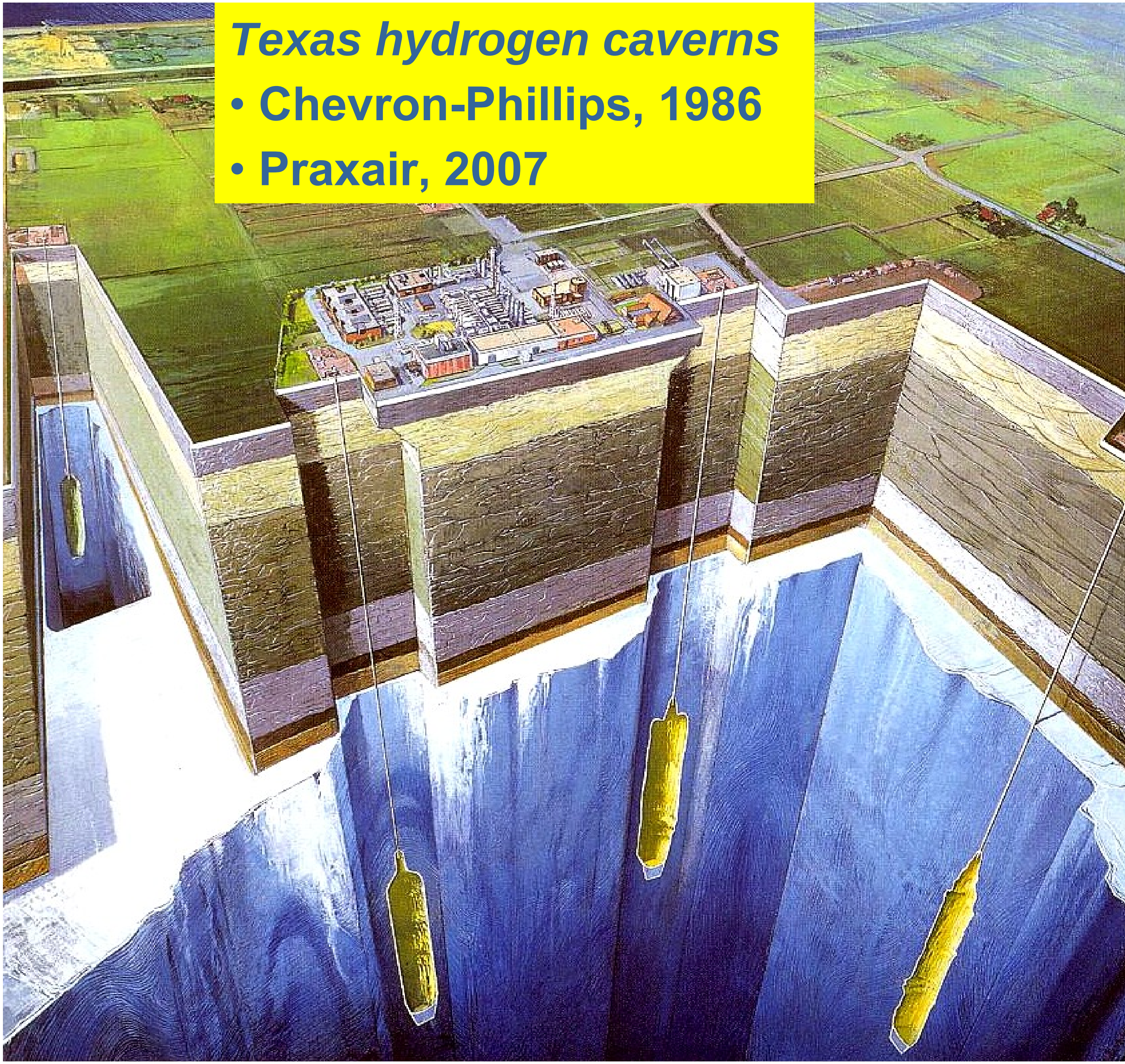
- **Potential, 12 states, ~50% land area:**
  - **10,000 TWh = 100 quads = entire USA energy**
  - **2,800,000 MW nameplate**
- **Seasonality:**
  - **Summer minimum**
  - **Spring – Summer maximum storage**
  - **"Firming" energy storage, per 1,000 MW wind:**
    - **as electricity = 300 GWh**
    - **as GH2 = 15,000 Mt @ 2,500 tons / cavern = 6 caverns**
  - **"Firming" energy storage, all great Plains wind:**
    - **as GH2 = 17,000 caverns @ $15M each = $264 billion**

Great Plains Windplant, Pipeline Hourly Output for Typical Week



Texas hydrogen caverns

- **Chevron-Phillips, 1986**
- **Praxair, 2007**



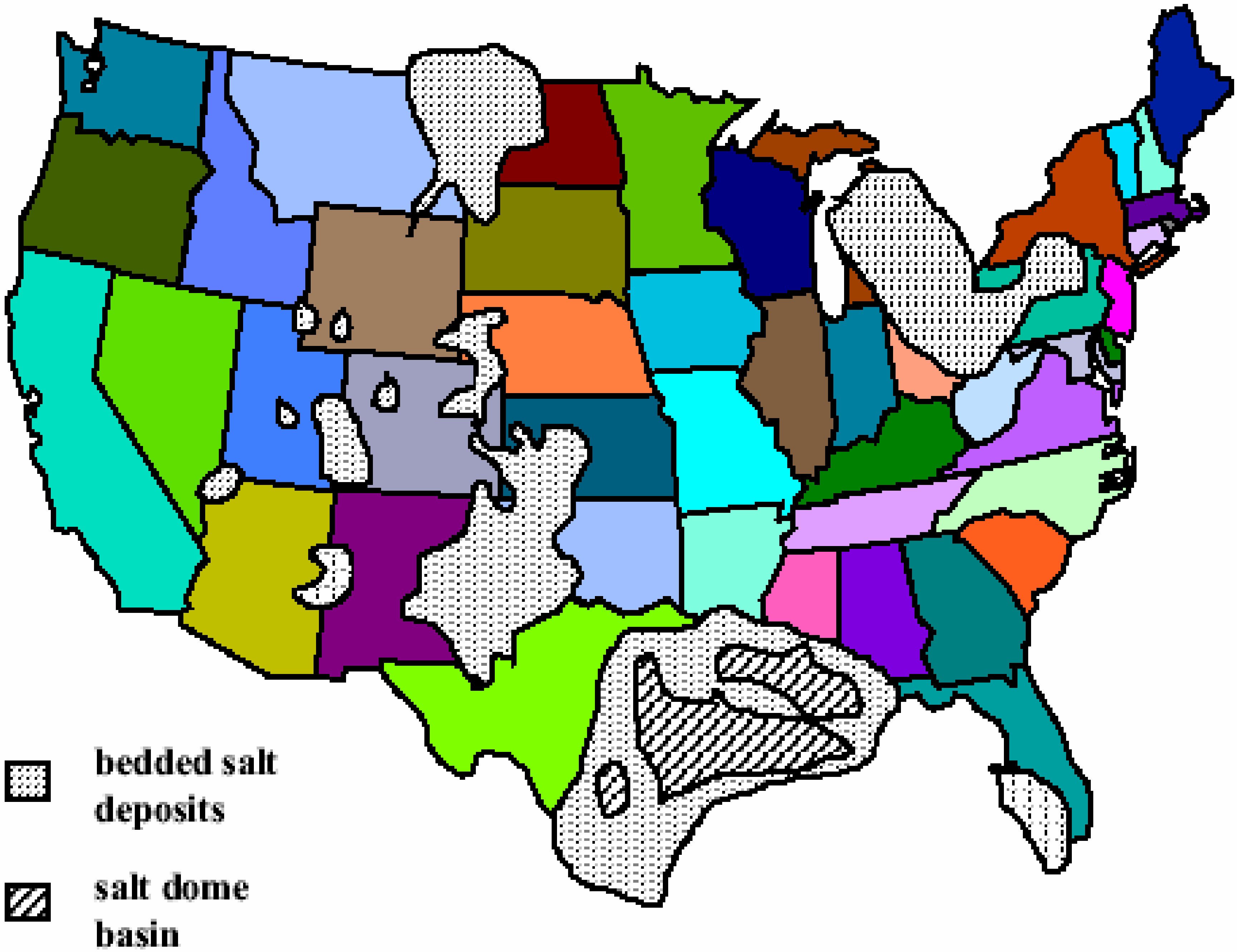
Domal Salt Storage Caverns

$5-15M each

PB ESS

Wellhead, new Gaseous Hydrogen Storage Cavern

- PRAXAIR
- Commissioned 2007
- In domal salt, in Texas


bedded salt deposits
salt dome basin

Solution-mined Salt Caverns assume

- "Clemens Terminal"
  - 6.4 M ft^3 = 580,000 m^3 gross
  - 2,200 psi MAOP → 1,000 psi min
  - 2,300 ft to cavern top
- Arrays of 10 – 100 caverns
- Same pressure: manifold
- Low input / output flowrate
- Minimum BOS
- Favorable conditions:
  - geography
  - geology
  - water supply
  - brine disposal

Optimistic: *Total Installed Capital Cost*
1,000 mile Pipeline
“Firming” GH2 cavern storage

Windplant nameplate		**2,000 MW**
Wind generators		$ 2,000 million
Electrolyzers		1,000
Pipeline, 20”		1,100
# storage caverns	[8]	
Caverns @ $10M ea		80
Cushion gas @ $5M ea		40
TOTAL		$ 4,220

Cavern storage: ~ 3 % of total capital cost

Pessimistic: *Total Installed Capital Cost*
1,000 mile Pipeline
“Firming” GH2 cavern storage

Windplant nameplate		**2,000 MW**
Wind generators		$ 2,000 million
Electrolyzers		1,000
Pipeline, 20”		1,100
# storage caverns	[8]	
Caverns @ $50M ea		400
Cushion gas @ $5M ea		60
TOTAL		$ 4,560

Cavern storage: ~ 10 % of total capital cost

Optimistic: *"Firming" Storage Capital Cost for ALL Great Plains Wind*

Adds VALUE: strategic, market

- Salt caverns: ~ 17,000
  - Excavate: $10 M each $ 170 B
  - Cushion gas: $5 M each $ 85 B
  - Total **$ 255 B**
- Ammonia (NH_3) tanks: ~ 5,000
  - Capital $25 M each **$125 B**

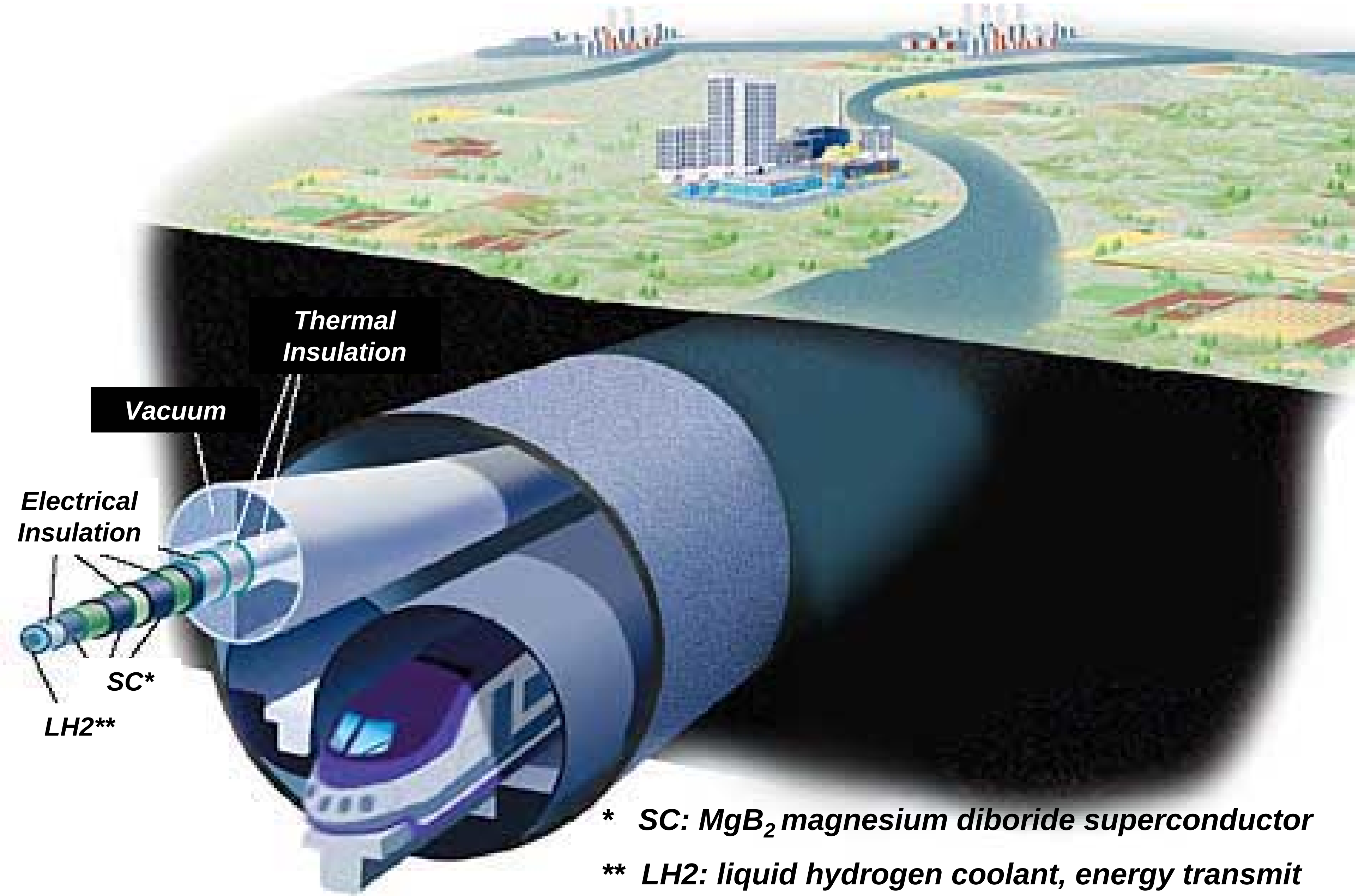
Pessimistic: "Firming" Storage Capital Cost for ALL Great Plains Wind

Adds VALUE: strategic, market

- Salt caverns: ~ 17,000
  - Excavate: $50 M each — $ 850 B
  - Cushion gas: $5 M each — $ 85 B
  - Total — **$ 935 B**
- NH3 tanks: ~ 5,000
  - Capital $25 M each — **$125 B**

Other

- EPRI “Energy Pipeline”
- Aluminum – gallium
- Fischer – Tropsch Liquids (FTL’s)
- Hythane ™
- Nuclear nexus



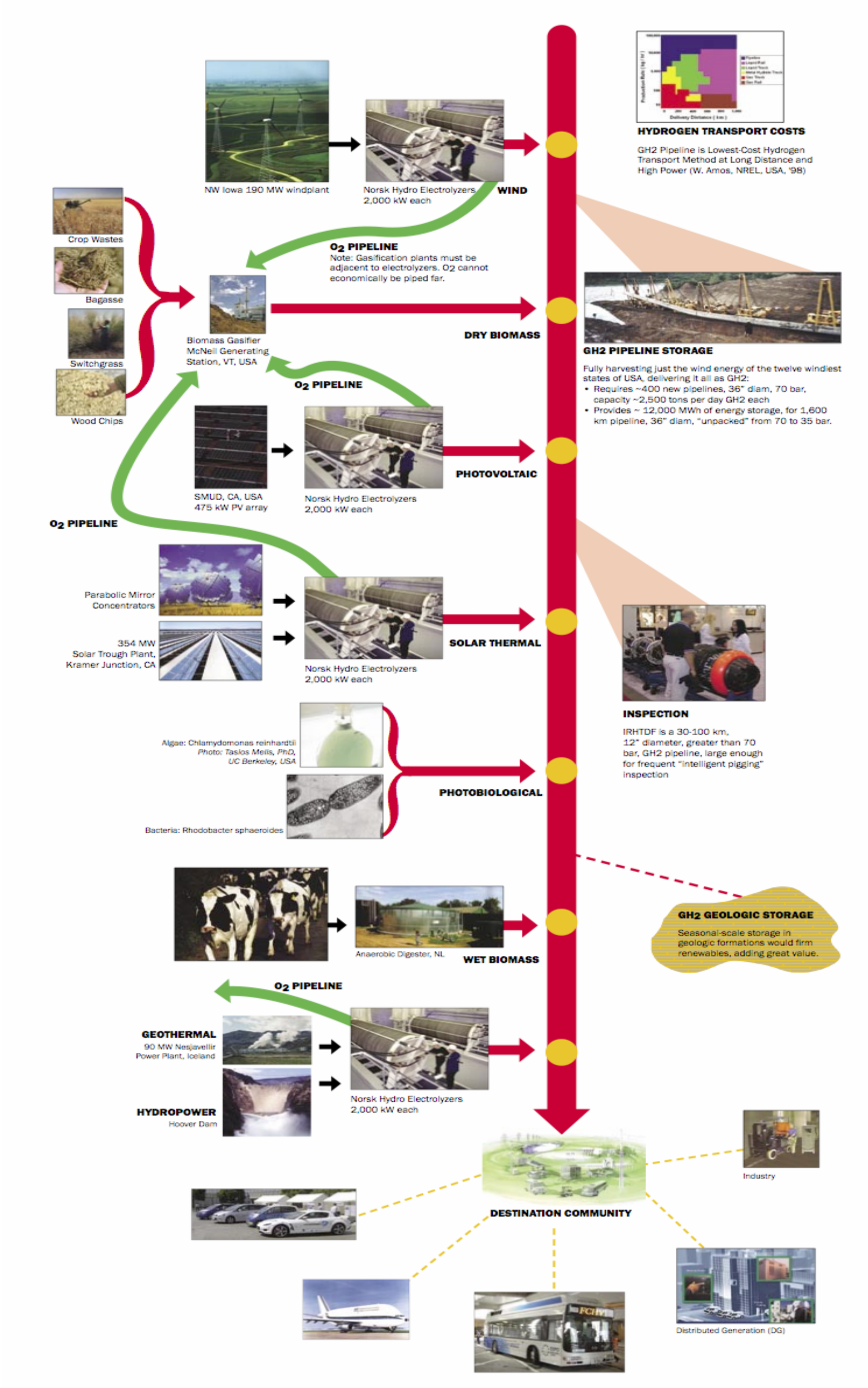
* SC: MgB_2 magnesium diboride superconductor

** LH2: liquid hydrogen coolant, energy transmit

Continental Supergrid – EPRI concept “Energy Pipeline”

Hypothesis:

- Hydrogen's greatest value to humanity:
  - Not fuel for fuel cell cars
  - Means to gather, transmit, firm, deliver, use
  - Diverse, large-scale, stranded renewables
- Test: build pilot plants
  - Induce upstream R+D
  - Discover tech + econ feasibility
  - Assure public, business
  - Ready solutions: emergencies



International Renewable Hydrogen Transmission Demonstration Facility

(IRHTDF)

Pilot plant

Global opportunity: IPHE project

Back-up Power System
Fleet Fueling
Community Fueling
Industrial Application
ACME ELECTRONICS
Home Fueling
Primary Electricity
Hydrogen
Hydrogen-Generated Electricity
H_2 Generation Module
H_2 Storage Module
Power Module
Fuel Dispensing Module
Personal Energy Station (PES)
PES Storage Module
Hydrogen Tank

Commercializing Renewable Energy in the Heartland: Resource Opportunity and Transmission Constraints

in

GW-scale Transmission and Annual-scale Firming Storage Alternatives for Diverse, Stranded, Renewables: Electricity, Hydrogen, Ammonia, and Others

John N. Moore
Senior Attorney
Environmental Law & Policy Center
jmoore@elpc.org

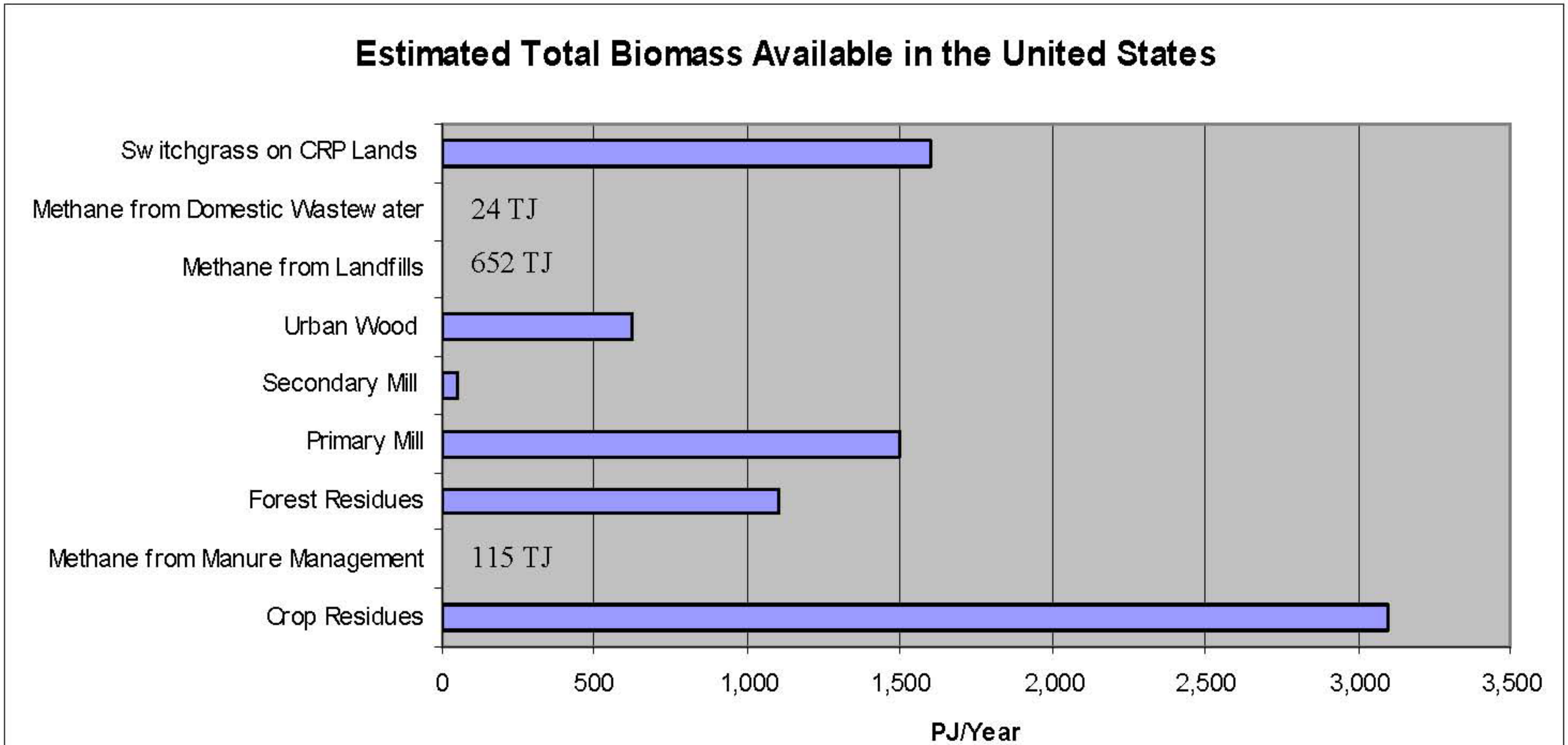
•Summary

- Biomass – Strong potential for hydrogen supply through biofuels and direct hydrogen production.
- Wind power – strong resource, but intermittency and transmission constraints may limit growth for grid use.

•Biomass Potential

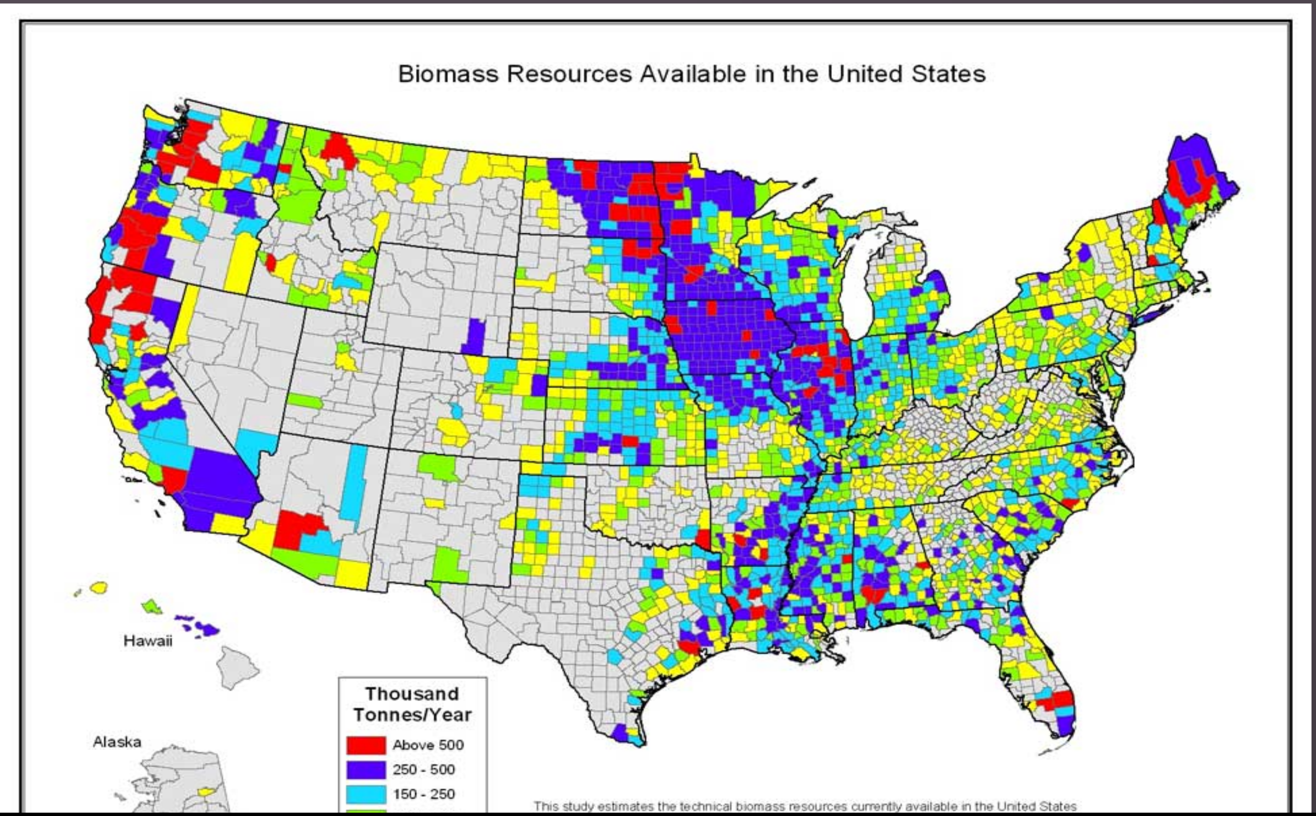
- Biomass currently supplies about 3 quads of energy nationwide.
- Supplies over 3% of total energy consumption in US.
- Vision (2002 Biomass R&D TAC) - by 2030:
  - Biopower will supply 4.8 quads.
  - Biofuels will supply 7 quads.
- Major resource potential in ag residues and perennial crops.

•National Biomass Resource Availability



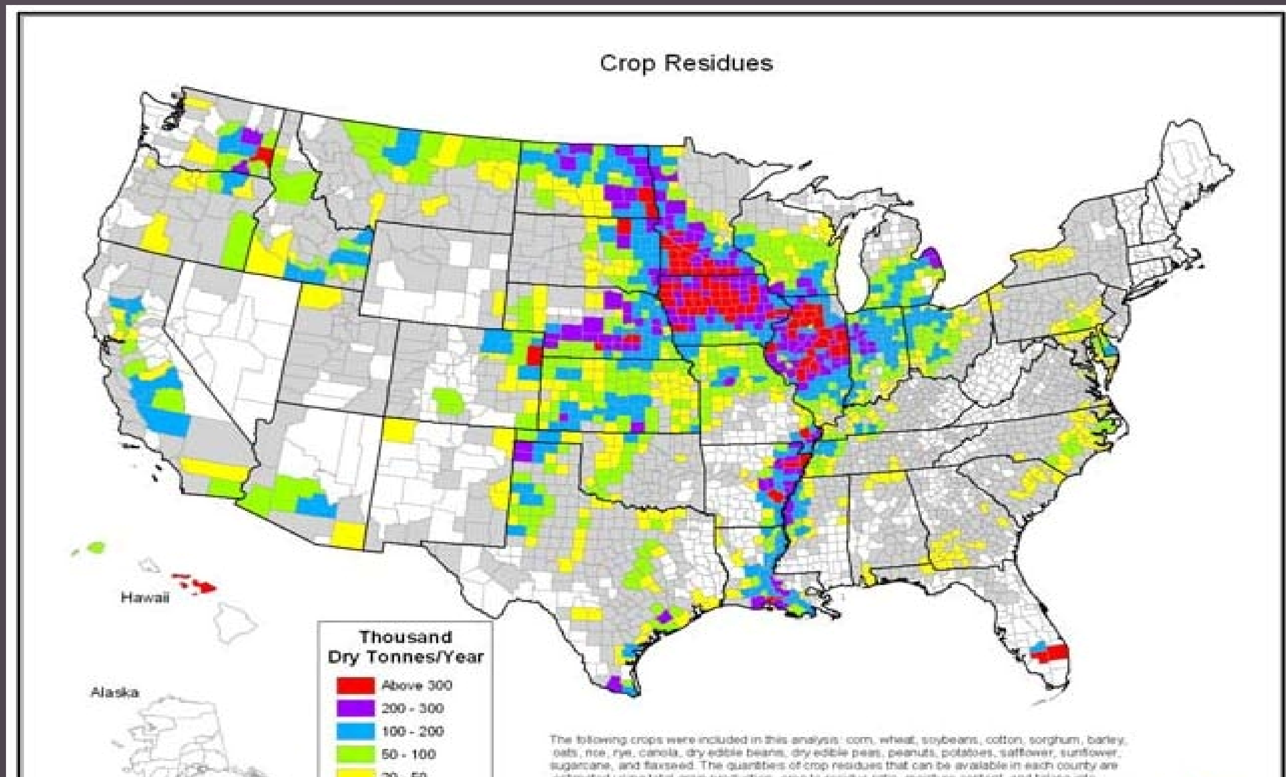
Total Current *Available* Biomass: 8,000 petajoules or 7.6 Quads

•National Biomass Resource Availability



Biomass Resources Concentrated in Midwest, South, West Coast

•Crop Residues – Current



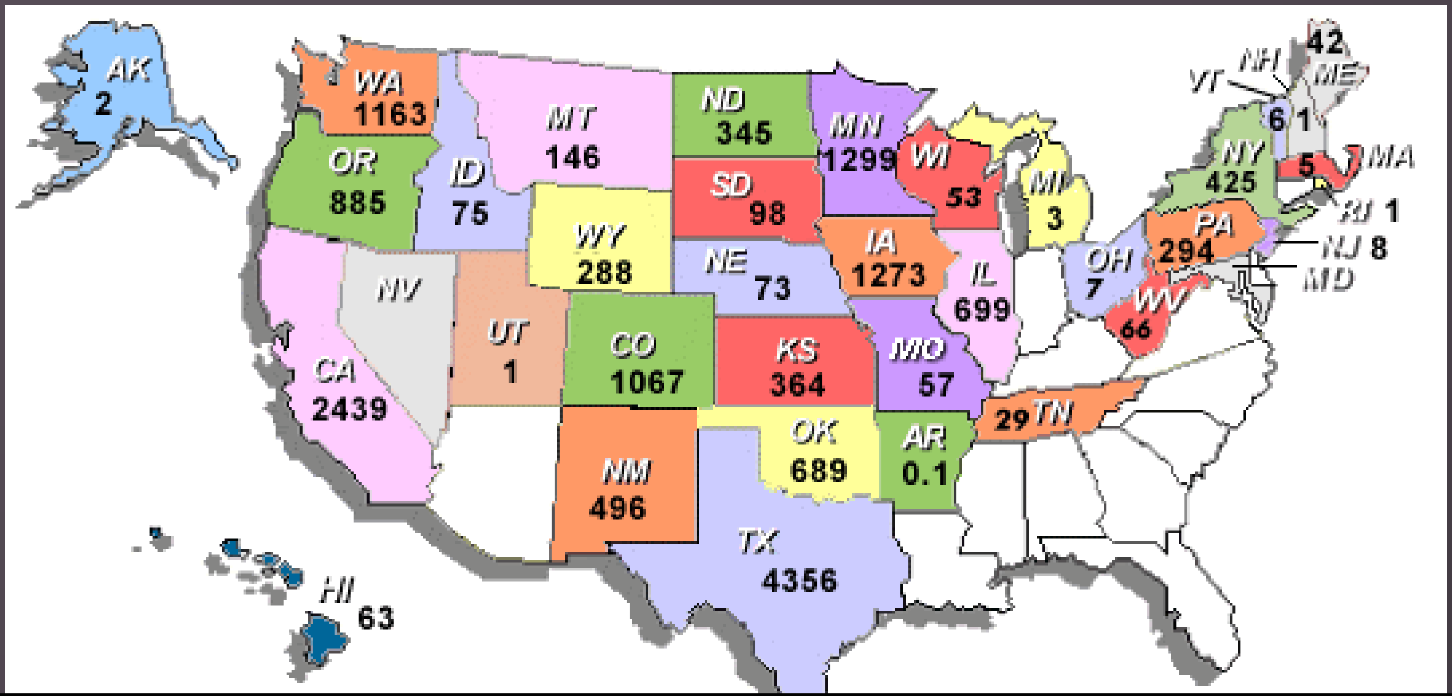
Total Current *Available* Crop Residues: 1.65 Quads (113 million dry tons)

•Perennial Crops and Ag Residue Potential

- 256 million tons corn stover (3.5 quads)
- 366 million tons perennial crops (6-8 quads)
  (from 2005 DOE/USDA Billion Ton Vision)

- Challenges: Fuel production, feedstock development and handling, other infrastructure issues.
- Biopower may be a near-term option to maximize energy crop development.

•Installed Wind Power

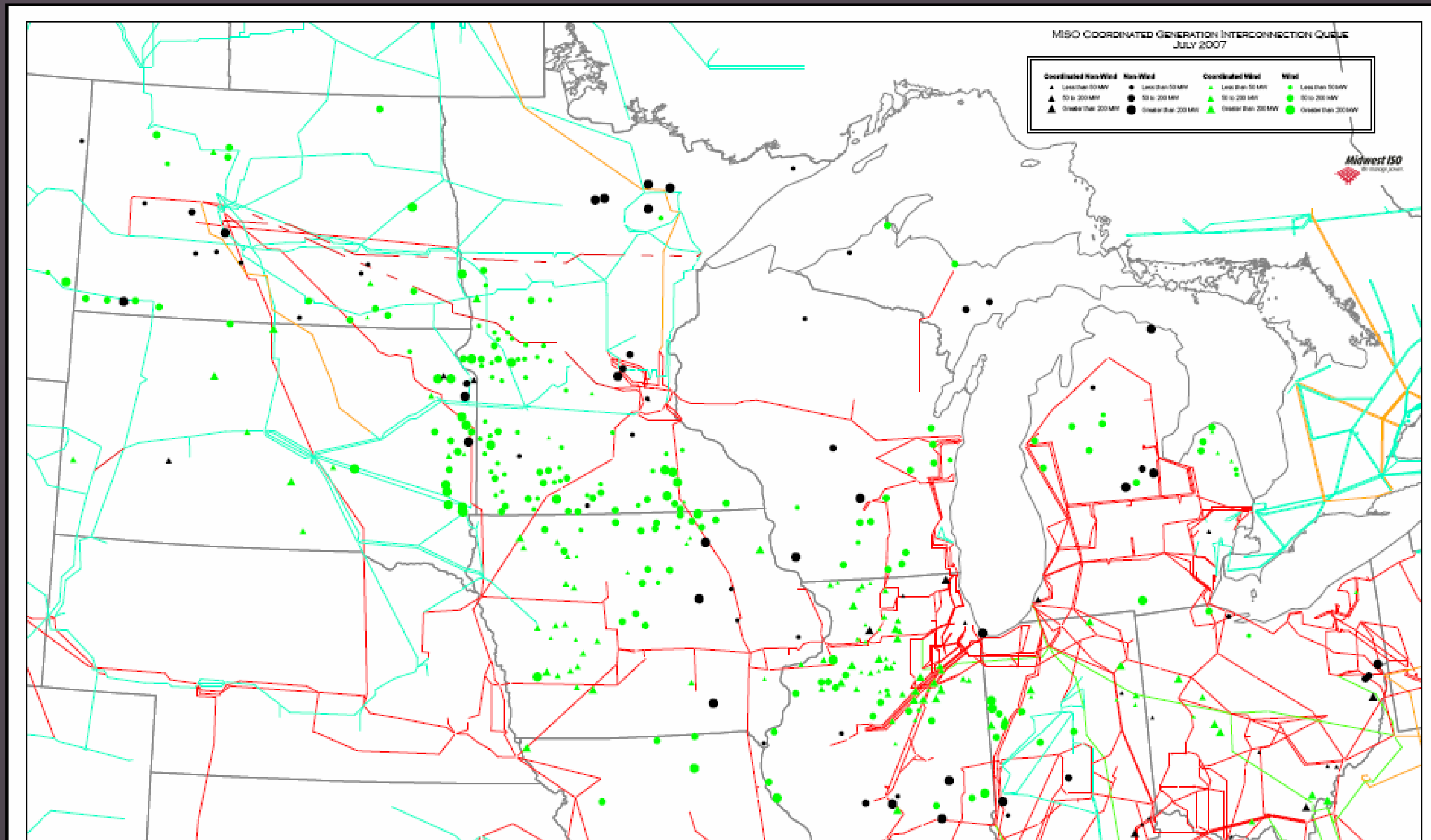


Existing: 16,818 MW

Under Construction: 3,626 (4th Quarter 2007)

Average Capacity Factor Nationwide: ~ 30% (2005)

•Transmission and Wind Don’t Always Match



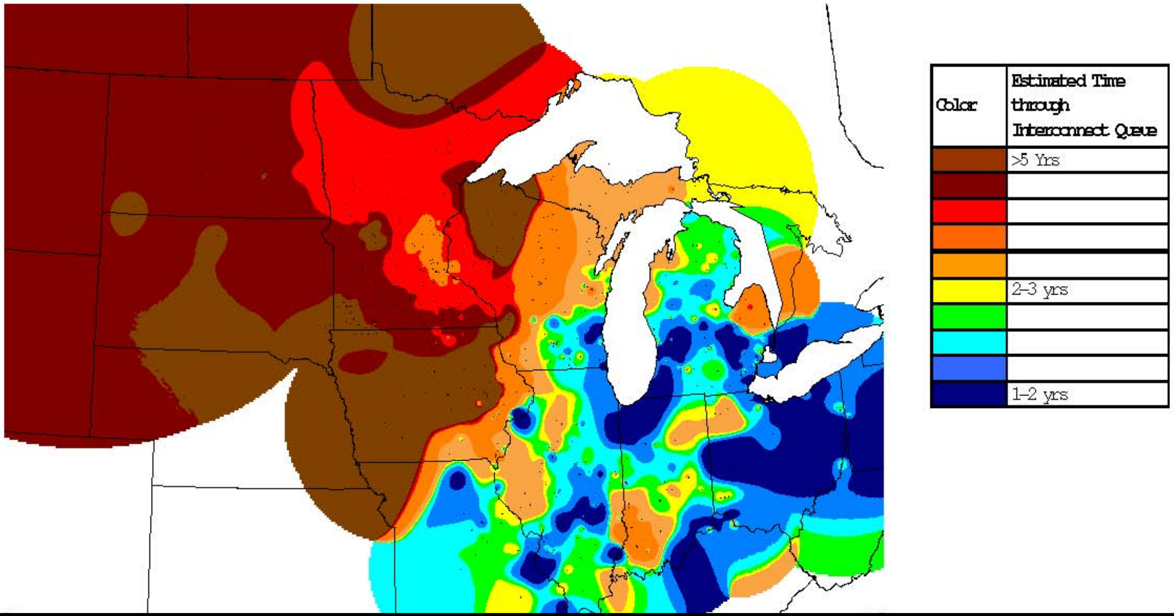
Midwest ISO Generation Interconnection Queue Siting with Transmission Grid Overlay

•MISO Interconnection Queue Backlog

- 71,372 MW of total generation in queue (291 requests), of which 55,537 MW is wind.
- Under current MISO processing methods, MISO would not be able to clear the queue until 2050.
- Total $40 billion or more cost for transmission.
- Another consideration – wind will not contribute significantly to MISO's electric reliability needs (per MISO).

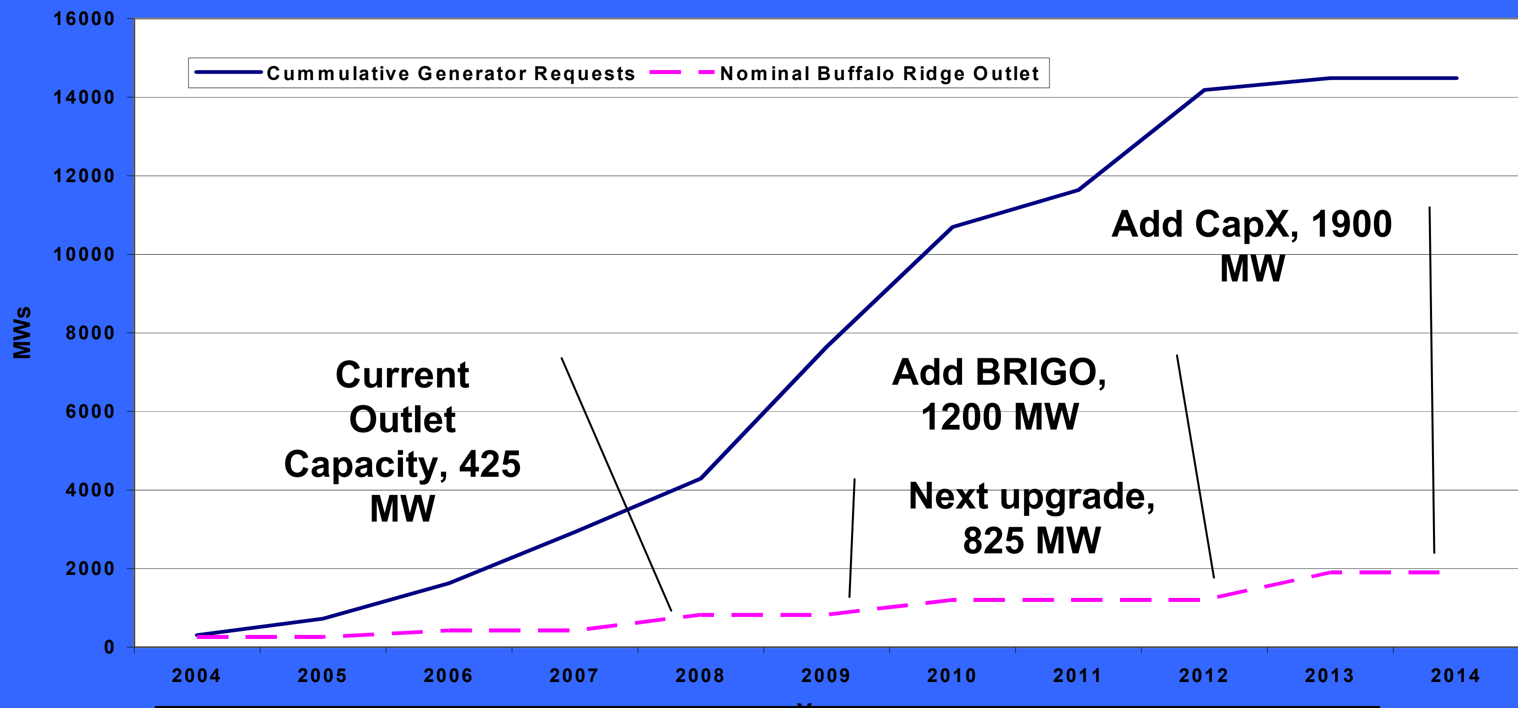
•MISO Interconnection Queue Backlog

Sample Contour Map for Generation Interconnection Feasibility



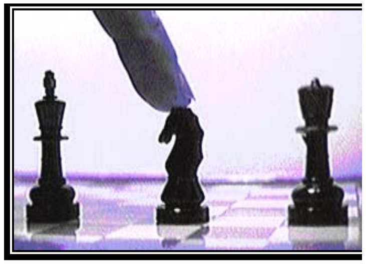
Current Queue Process in Excess of 5 Years in Upper Midwest (DRAFT INFORMATION)

•Buffalo Ridge, MN Transmission Constraints



Buffalo Ridge, MN – Generator Interconnection Requests Are 10 Times Projected Transfer Capacity (now 22,000 MW in queue in area)

Pumped Storage Benchmark and New CAES (Compressed Air Energy Storage)



TVA's Raccoon Mountain PH Plant Generator Room (1660 MW – 22 Hr)

Alabama Electric Cooperative's CAES Plant (110 MW-26 Hr)

WIREC08 "Official Side Event"

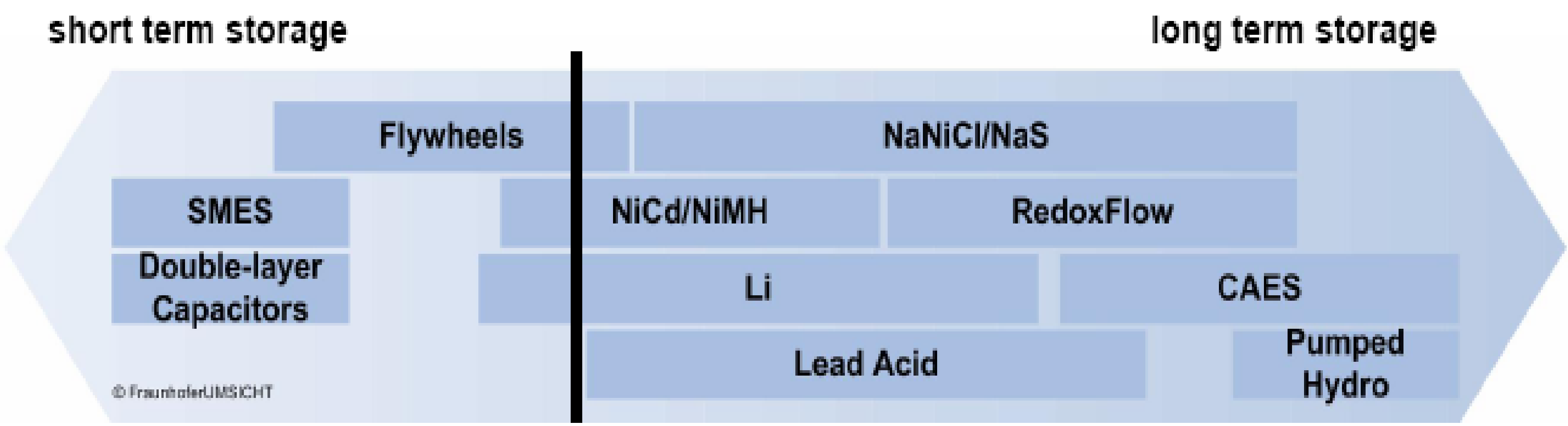
Tom Key
tkey@epri.com
EPRI

and

Robert B. Schainker
rschaink@epri.com
EPRI

March 4, 2008

Pumped Hydro is 99% of World's Electrical Storage



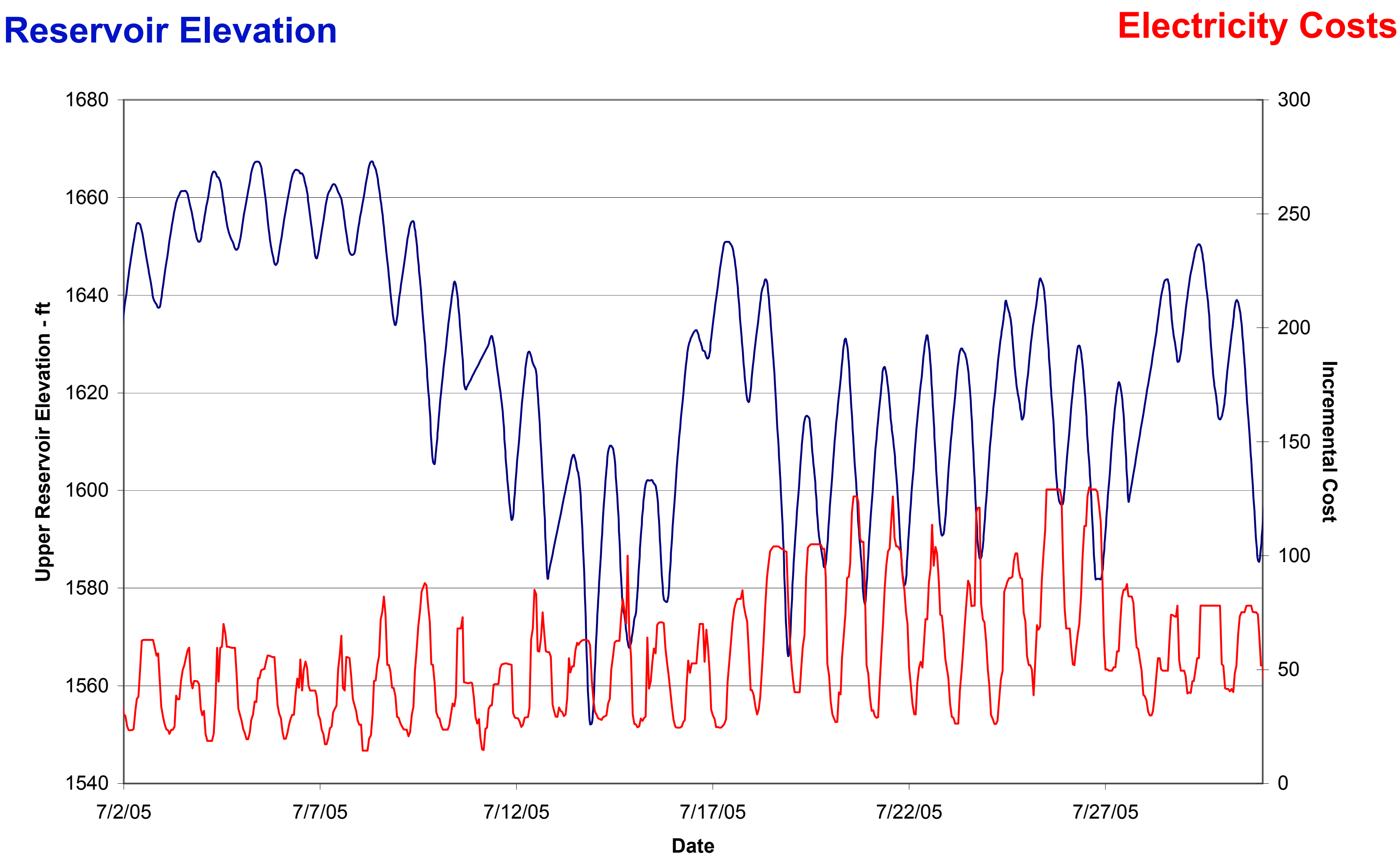
- 110,000 MWe of Pumped Storage
- 477 MWe of Compressed Air Energy Storage (CAES)
- 339 MWe of Battery Storage (NAS, LA, Redox, NiCad)

From Fraunhofer Institute, S. Wolf, State of World's energy storage technologies

Flexibility, providing 1660 MW to the System

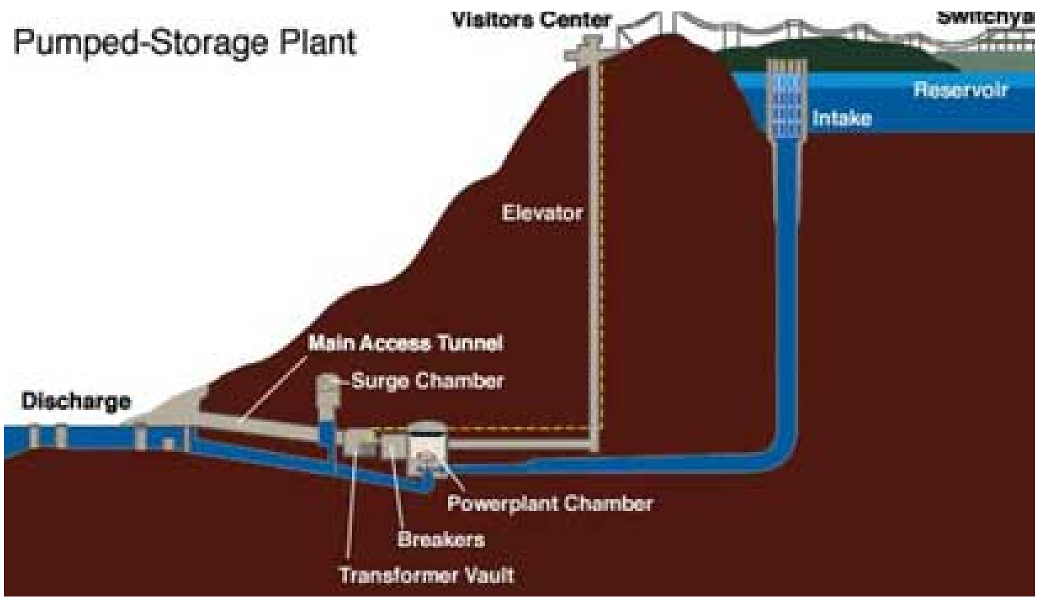
- Store off-peak power for use on peak, maximizes value of energy
- Reduce thermal cycling of fossil plants
- Offer ancillary services
  - Regulation
  - Voltage control
  - Spinning reserve (if pumping – potential 3320 MW energy swing available)
  - Supplemental reserves of 1660 MW in less than 10 minutes
  - Black Start (must have a 300 MW load)

TVA Raccoon Mountain July 2005



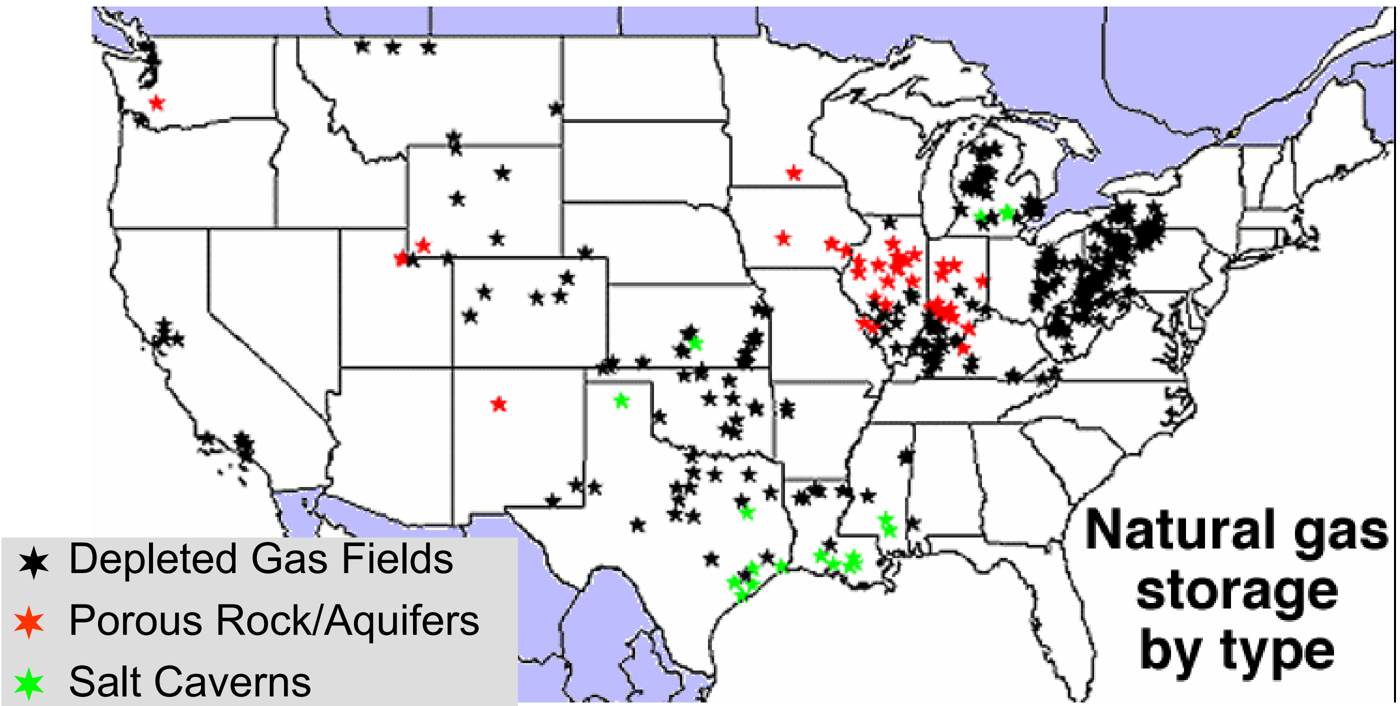
Need for New Development of Pumped Storage?

- Pumped storage in U.S. is ~ 2% of generation compared to 8% in Europe.
- In 1992 FERC license applications for ~18 GW (42 plants, 31 in the west) only one was built…Rocky Mountain 95'
- Conditions at the time…investors were private, applications limited to peaking, cheap natural gas high environmental resistance.
- Different conditions today
  – Natural gas price volatility
  – Nearly all low carbon emitting options are non-dispatchable.
  – Increased value of storage

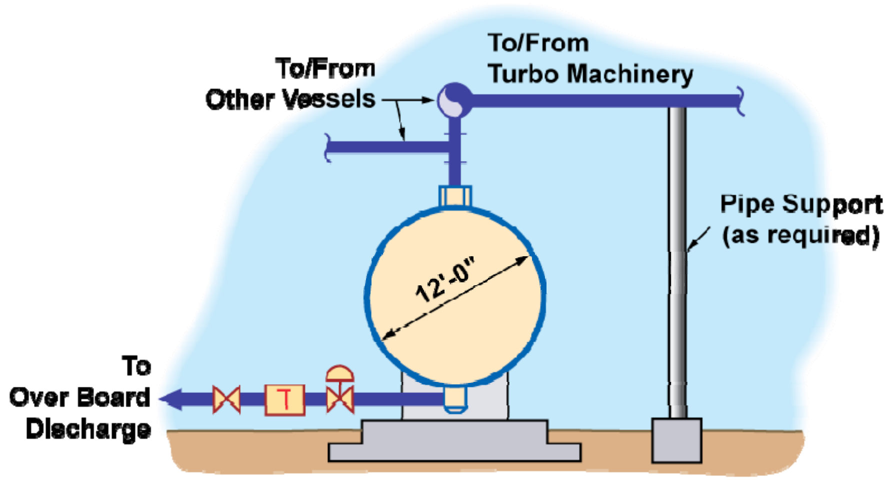


Underground Natural Gas Storage Facilities in the Lower 48 States Are Shown Below

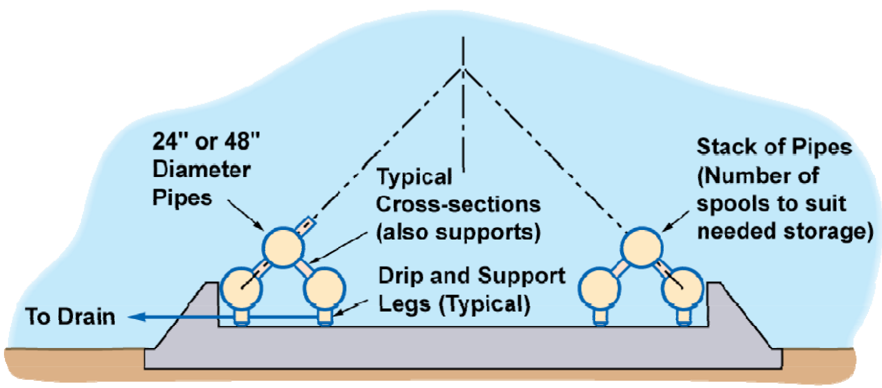
- Assess and Demonstrate Porous Rock/Aquifer Storage
- Plant Size: Above 300 MW
- Advanced Design and Performance Assessment
- Proceed to Demo Plant Based On Results from Phased Approach



Above Ground CAES Provides Smaller Scale Options



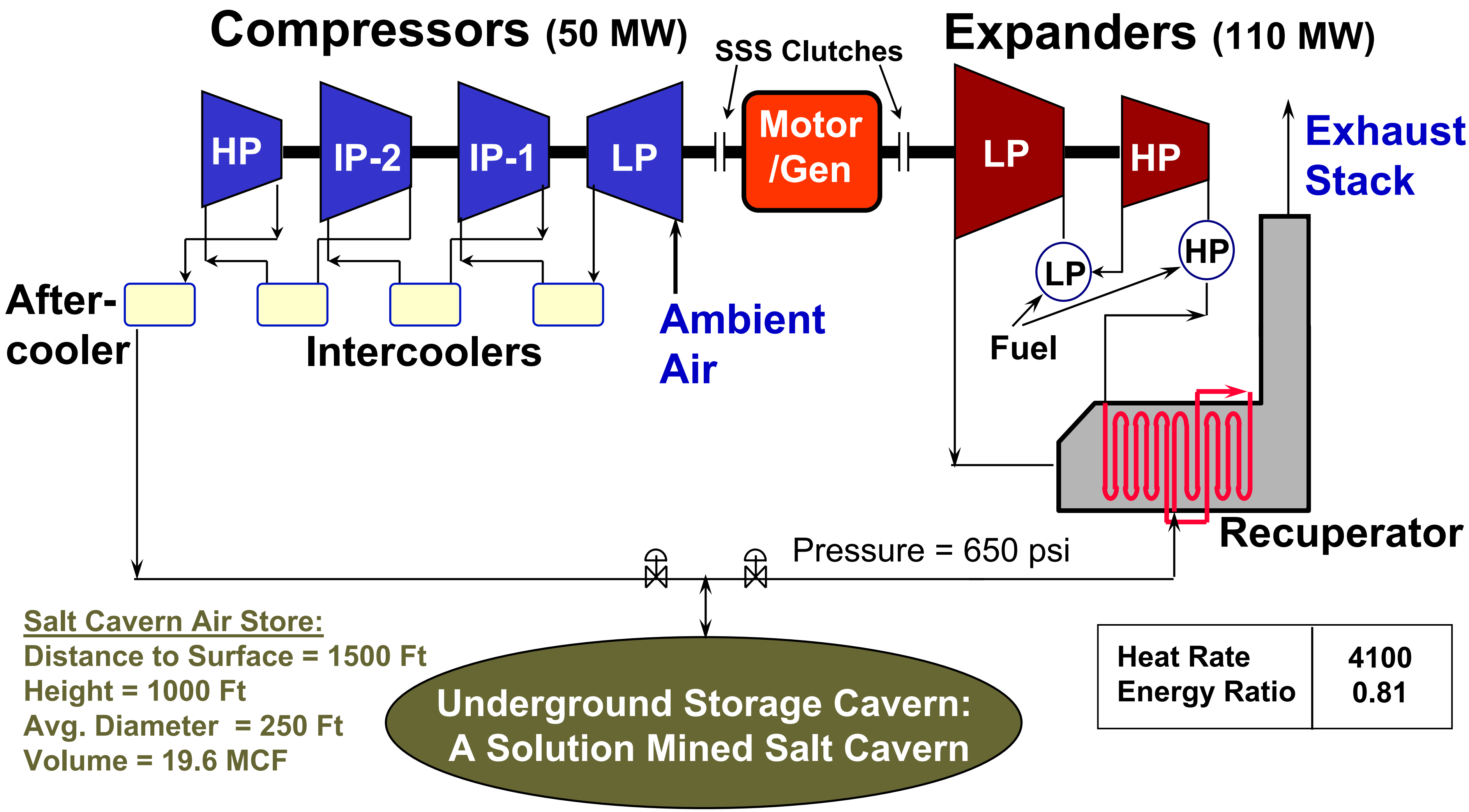
Section A-A
End View



Detail A-A
Cross Section of Power Piping Storage

- **Above Ground CAES**
  - Assess Economic Feasibility of Pipe and/or Vessel Based Above Ground Air Storage
  - Plant Size: 10MW To 20MW With 2 To 3 Hours Of Storage
  - Design & Performance Assessment
  - Proceed To Demo Plant Based On Results from Phased Approach

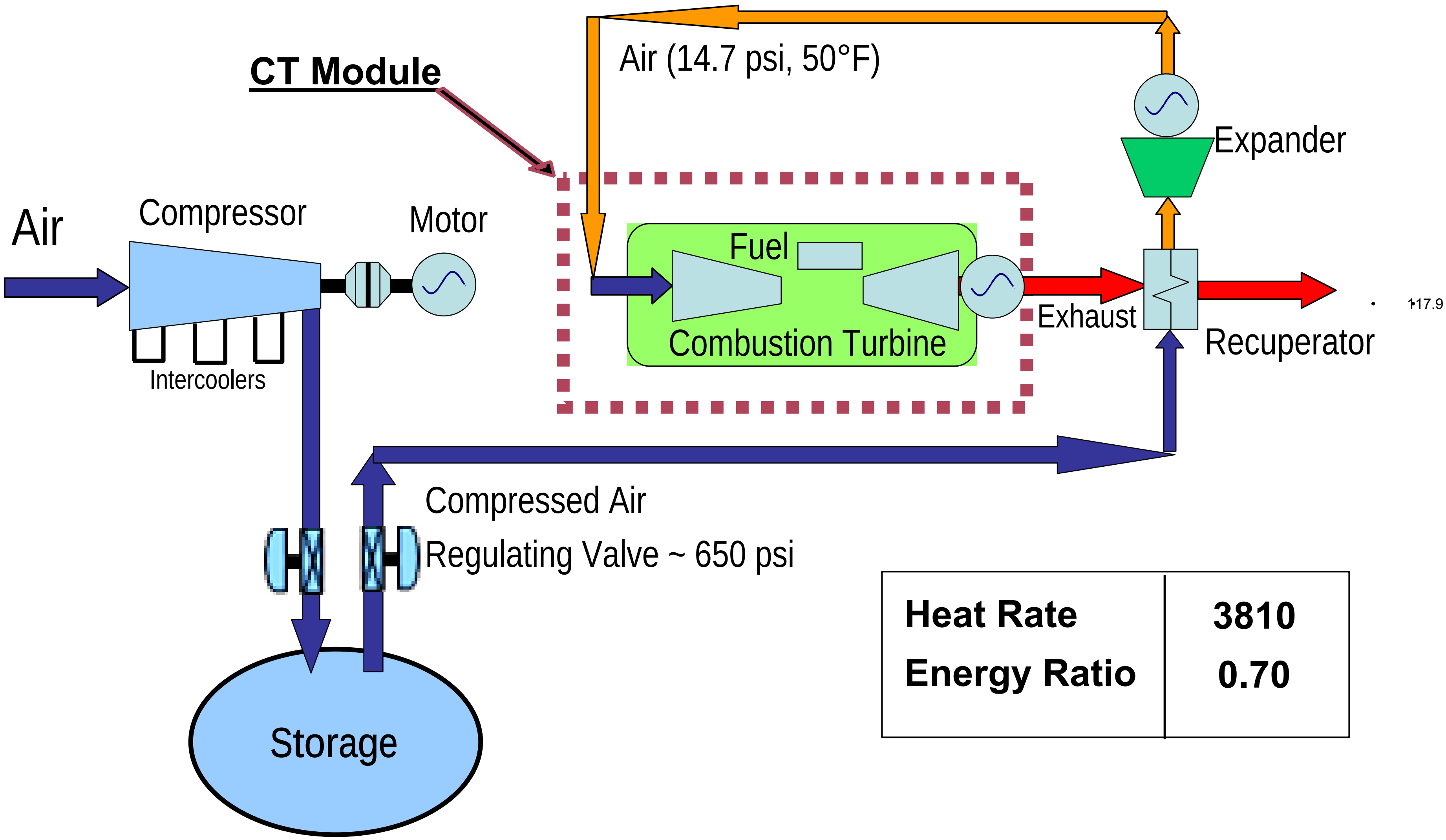
Alabama CAES Plant: Schematic, “Old” Design Approach ~ 750/kW



Salt Cavern Air Store:
Distance to Surface = 1500 Ft
Height = 1000 Ft
Avg. Diameter = 250 Ft
Volume = 19.6 MCF

Heat Rate	4100
Energy Ratio	0.81

Advanced CAES Plant: Schematic, 2nd Generation “Chiller Option” ~ $530/kW



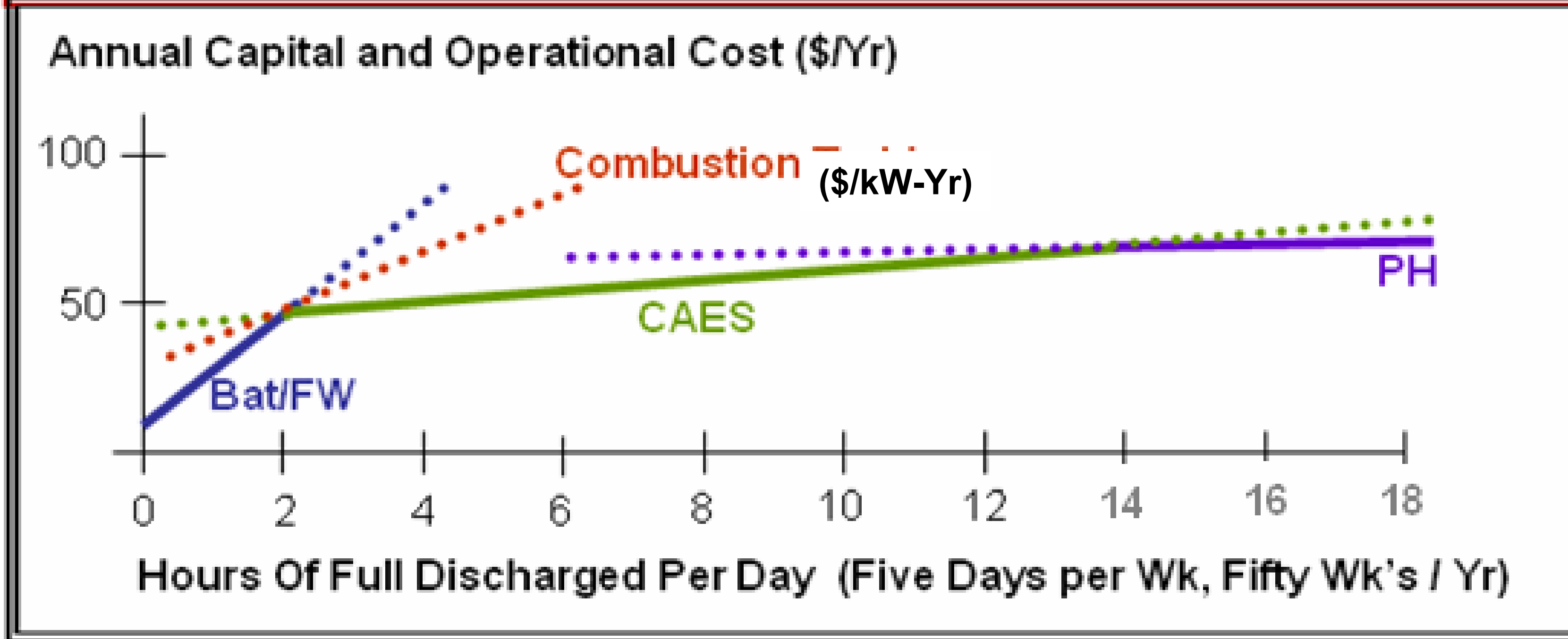
Heat Rate	**3810**
Energy Ratio	**0.70**

Energy Storage Plants Fall Into Three Economically Attractive Regions

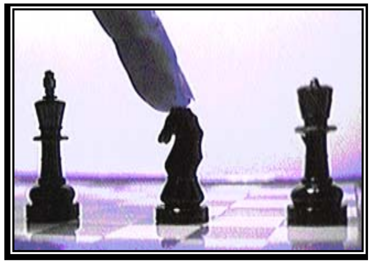
Pick the Storage Option That Has the Lowest Cost for the Hours of Storage Needed For The Application Needed (e.g., Wind)

Economic Attractive Regions for Energy Storage Plants, If Have One Discharge/Day:

Battery ((BAT), Flywheel (FW)	≤ 2 Hours Discharge
Compress Air (CAES)	≥ 2 Hours Discharge and ≤ 14 Hours Discharge
Pumped Hydro (PH)	≥ 14 Hours discharge



Conclusions and Summary



- *Pumped Hydro and CAES have excellent operating characteristics, second to minute time response characteristics, which enable ramping, frequency regulation, and/or spinning reserve duty.*
- *Pumped Hydro (PH) plants are 500 - 1500MW scale, long lead time, difficult to site and cost in the range of $1500/kw.*
- *Underground CAES plants at ~ 300 MW scale, easier to site, could be built in 3 years and cost in the range of $500/kw.*
- *PH and CAES plants respond well to the growing need to mitigate problems with regulation, intermediate generation, and moving off-peak wind generation to on-peak use.*
- *What is the next move for these technologies?*

WIRE C

March 4, 2008

THE NATIONAL HYDROGEN ASSOCIATION

SHAPING the HYDROGEN ECONOMY

Jerome Hinkle

Vice President, Policy and Government Affairs

National Hydrogen Association

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Strategic Value

- Remedy poor U.S. fuel diversity
- 1/3 of carbon emissions are from the transportation sector
- Shift toward a more domestic resource base
- Reduce international security maintenance—large budget and diplomatic costs
- Grow new domestic primary and supplier industries
- U.S oil import bill over $3.3 T in next ten years
- Fuel and feedstock concentrated in vulnerable areas
- Fuel demand growing, price climbing

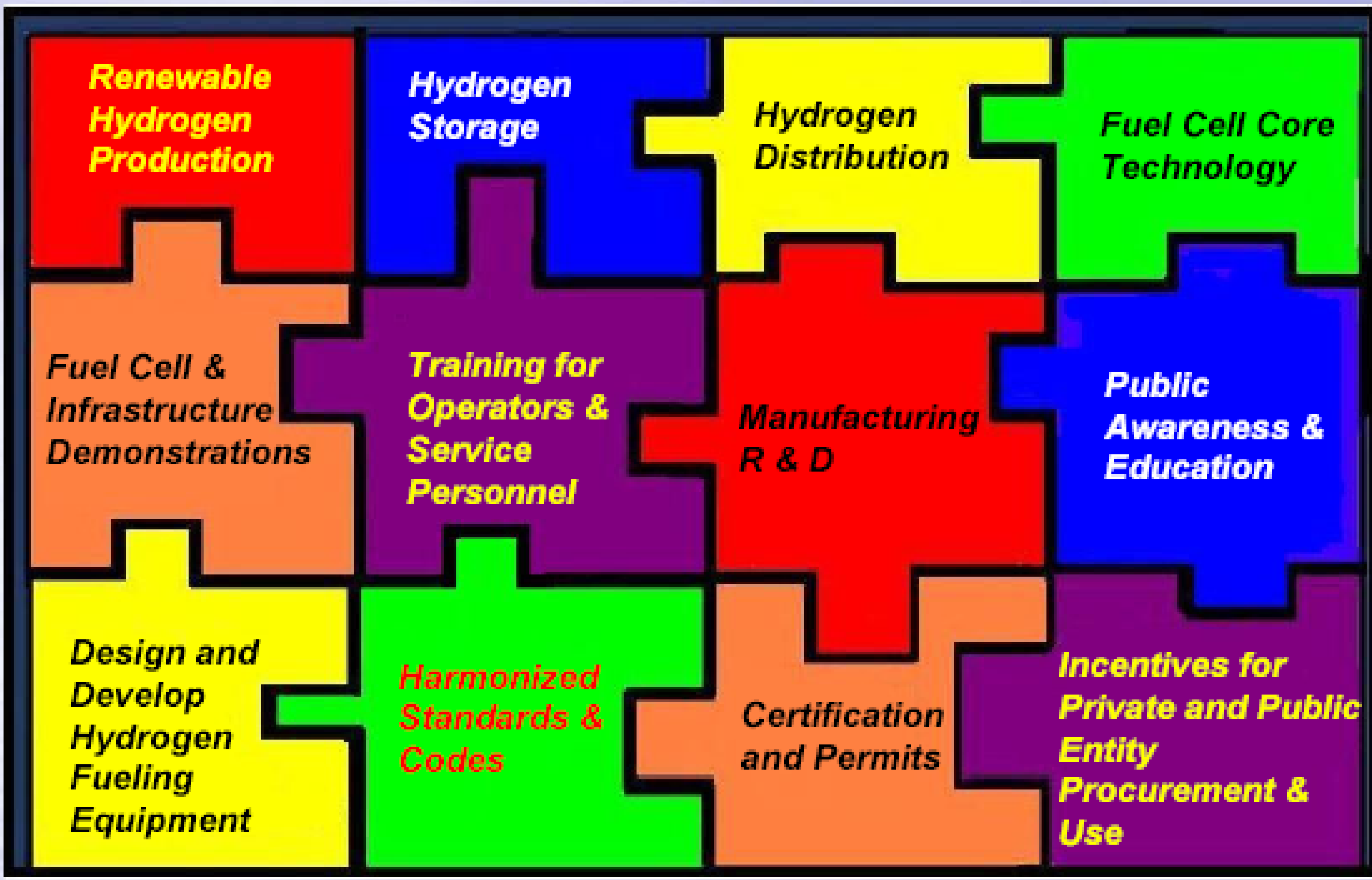
Environmental Quality

- **H2 may promise dramatic lowering of combustion emissions at end use**
- **Must design for best achievable carbon footprint**
- **Evolving industry needs to capture full efficiency gains throughout fuel cycle**
- **Wider benefits internalized through investment and market decisions**
- ***Stakes are high***

Searching for Alternatives

- 30% demand growth by 2030, 50% by 2050?
- Flat oil production?
- Higher oil prices bring alternatives closer
- Begin to replace hydrocarbons
- H2 made from multiple sources, U.S. wide
- Transforms both supply and demand
- *A family of advanced technologies, deployed in concert to realize benefits*

The Hydrogen Economy
All the pieces need to fit!



On the Way

- 11 Mt of H2 made in U.S. today, 45 Mt worldwide—gasolines, fertilizers
- 50% of U.S. LDV fleet by 2050 needs ~50 Mt
- ~228 M LDVs in 2007, ~380 M by 2050
- Eliminates 2/3 of petroleum imports (~10 Mb/d; 35 Bgal of biofuels is ~2.3 Mb/d) up to 300 Mt carbon equivalent (60% of LDV)
- Transition— auxiliary and backup power, microcells for electronics, forklift trucks, bus and delivery fleets
- Markets building and evolving—expect the services, freely purchase them
- Must compete with more conventional systems

Varied Sources of H2

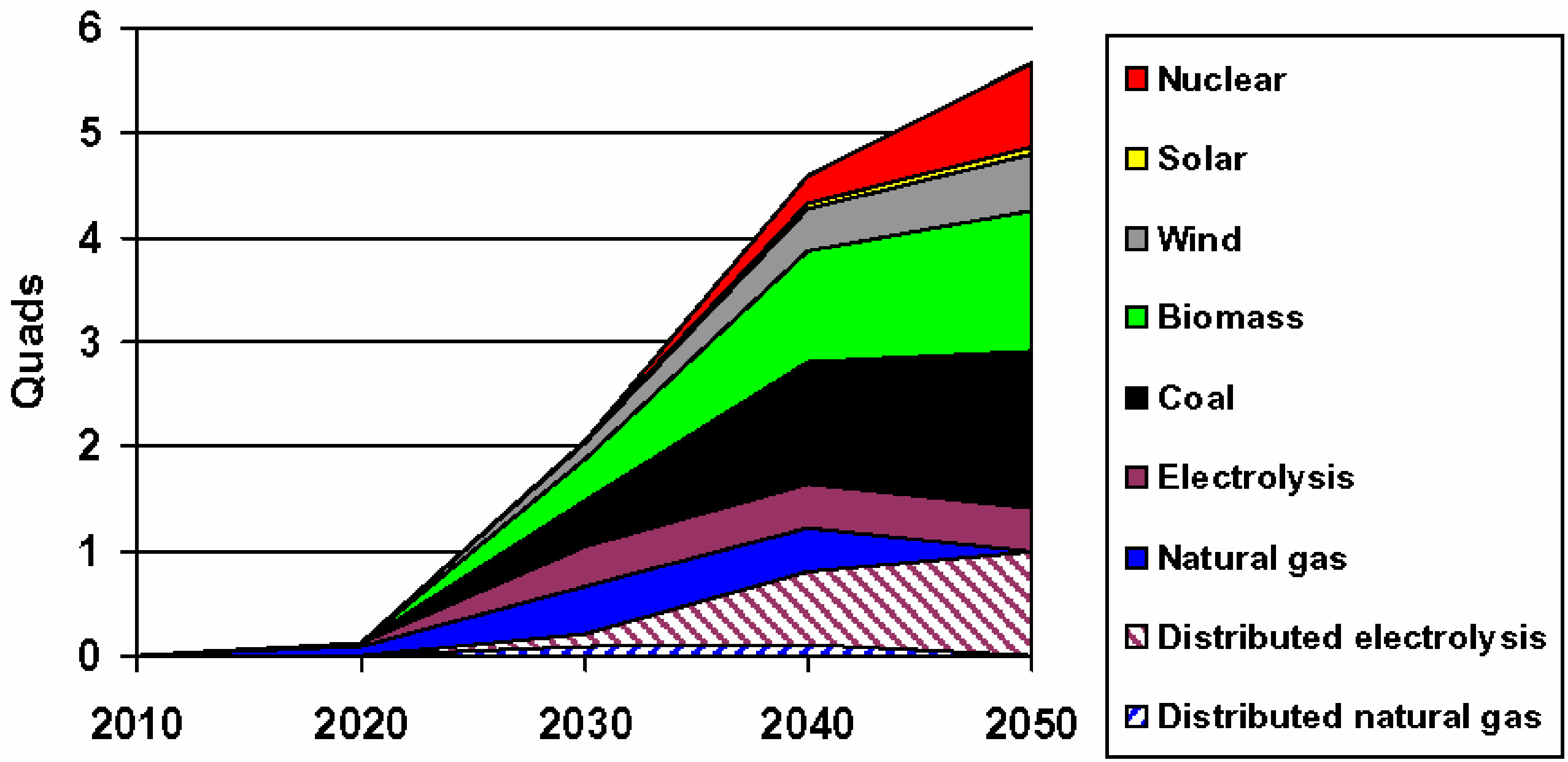
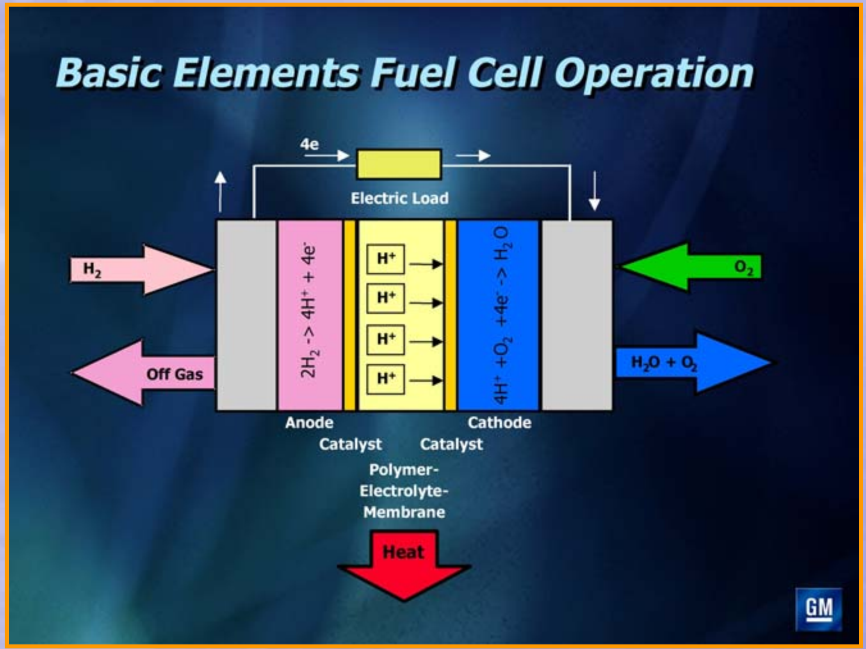


FIGURE 3.8 Resource Fuels Used to Produce H_2 in GYOW: United States

Fuel Cells: The Silicon Chip of the Hydrogen Age

- Developed for space exploration
- Electrochemically converts hydrogen to electricity:
- $H_2 + \frac{1}{2}O_2 \rightarrow H_2O$ + electricity + heat
- Only water vapor and electricity produced
- Used for portable applications, power generation and vehicles
- And don't forget about hydrogen engines



Many Fuel Cell Applications

UTC Power's Diverse Portfolio

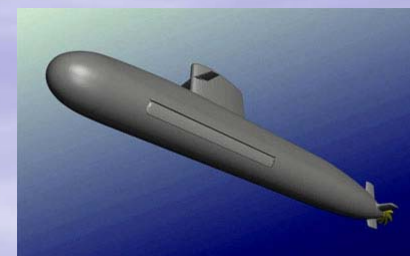
Stationary 200 kW PAFC

Transit bus 120 kW PEM

Space 12 kW Alkaline

Auto 80 kW PEM

Automotive APU 5 kW PEM



Submarine 300 kW PEM

Back up Power 5 kW PEM

What's Happening Today?

The Hydrogen Journal

Fueling Infrastructure

- 51 Fueling Stations Open in N. America
- 28 more planned in next 12 months (5/07)

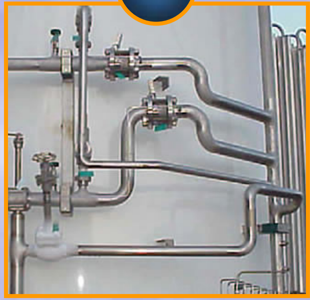
Automobile Announcements

- 2007 100 Chevrolet Equinox SUV FCVs
- 2007 BMW --100 dual-fuel Hydrogen 7 ICEVs
- Daimler and Chrysler have more than 100 FCVs in operation
- Honda FCV Sedan for lease/purchase in 2008

Hydrogen Products Available Today

- Portable cameras, professional video, surveillance
- 1-30 kW fuel cell systems for back-up & remote power (including cell phone towers)
- Hydrogen Generators
- Hydrogen Injection Technology

When Will The Transition Be?



TODAY - 2010

- RD&D
- Portable and stationary, backup power
- Materials handling
- Battery replacement

- H ICE-Hybrid vehicles in fleets—buses
- Model safety regulations
- Early FC vehicles sold and leased

2010

- More Fleets
- New FCVs, distributed generation
- Merchant H2
- H2 "Clustering" —power parks, hubs

2015

- DOE RD&D market milestones
- Will large-scale production begin?

2020

- Widely marketed light duty vehicles
- Emissions, Café gains
- Oil imports drop

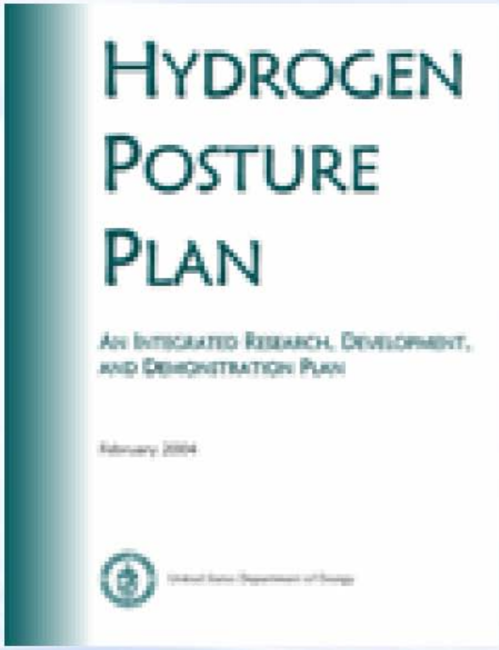
DOE's Hydrogen Program

Critical Path Technology Barriers:

- Hydrogen Storage (>300-mile range)
- Hydrogen Cost ($2.00 - 3.00 per gge)
- Fuel Cell Cost ($30 per kW), **$22 per hp**

Economic/Institutional Barriers:

- Codes and Standards (Safety, and Global Competitiveness)
- Hydrogen Delivery (Investment for new Distribution Infrastructure)
- Education


HYDROGEN POSTURE PLAN

AN INTEGRATED RESEARCH, DEVELOPMENT, AND DEMONSTRATION PLAN

Posture Plan identifies major milestones related to each barrier in an integrated department schedule so that progress can be tracked.

Energy Policy Act of 2005 – H2 Legislative Goals

- Government needs to be a more reliable and durable partner with industry
- Larger public investments needed to ease the risk of developing transformational technologies
- Broader authority, permanent program authorization, and more resources to build on the President's *Hydrogen Fuel Initiative*
- Enhance R&D in critical areas
- Accelerate progress — reshape programs to create more quality technical solutions more quickly
- Help drive market transition by early USG adoption, tax incentives

TITLE VIII-HYDROGEN

- *802. Purposes*
  - enable and promote comprehensive development, demonstration and commercialization with industry
  - make critical public investments that build links to industry and the research community
  - build a mature H2 economy that creates fuel diversity
  - sharply decrease US dependency on foreign oil
  - create, strengthen and protect a sustainable energy economy

How Do We Redesign Government's Toolkit?

- RD&D, Learning Demonstrations, recycle & revise R&D concepts
- Make systems that will roll out of the hanger and fly
- Buy them early because you're smart, determined and brave (Title VII—extend to DOD?)
- Tax credits, loan guarantees, accelerated depreciation, alternative minimum tax reform, grants, loans, interest buy downs, stock warrants, JIPs, feed-in tariffs
- Needs comprehensive approach: w/tax/incentive RD&D—H.R 805, S. 2129; Senate Finance, Energy, Agriculture Committees; House Ways and Means; H Prize, FAA reauth.; robust RD&D funding, national RPS

The Classic "S" Curve

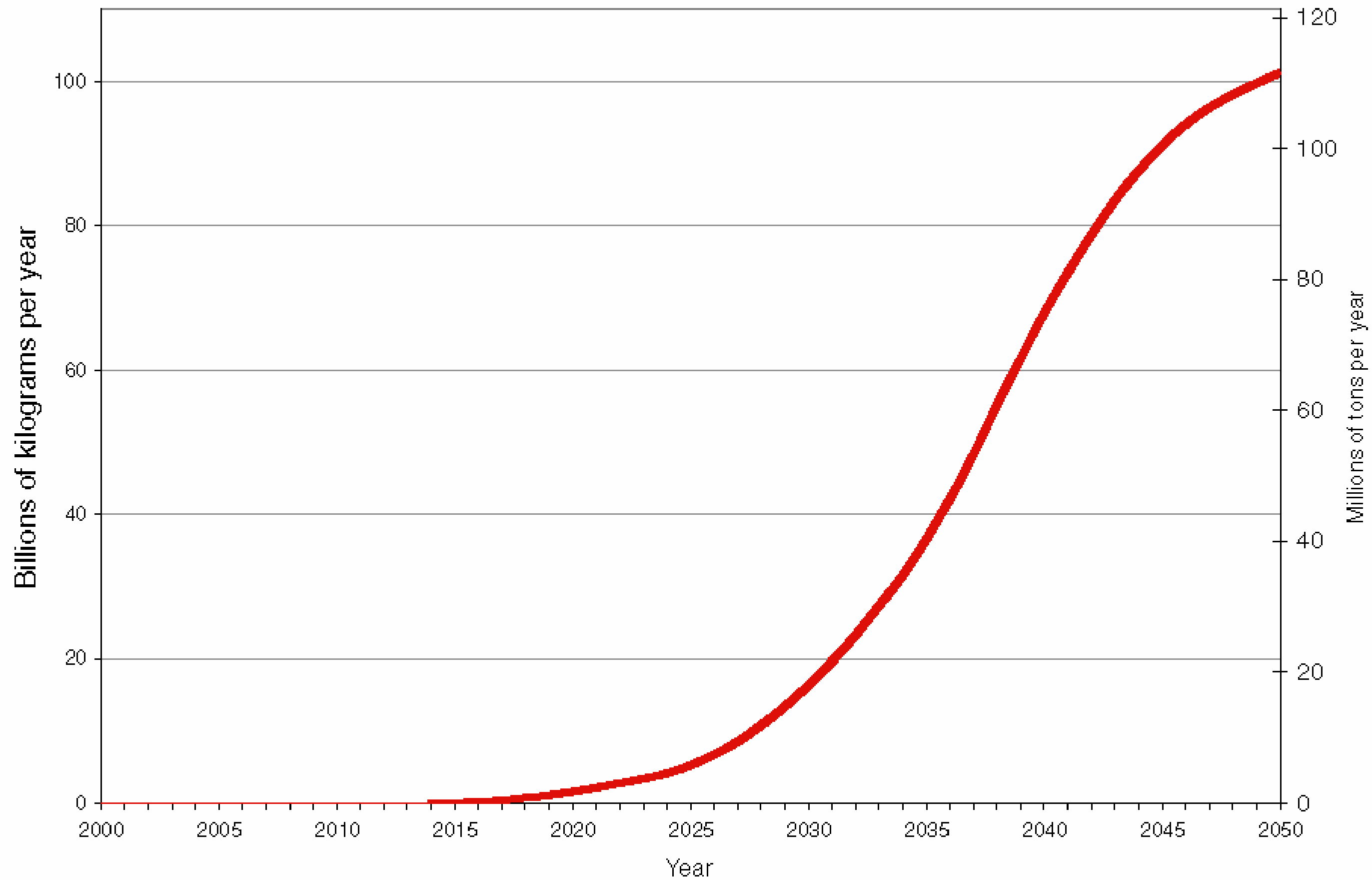
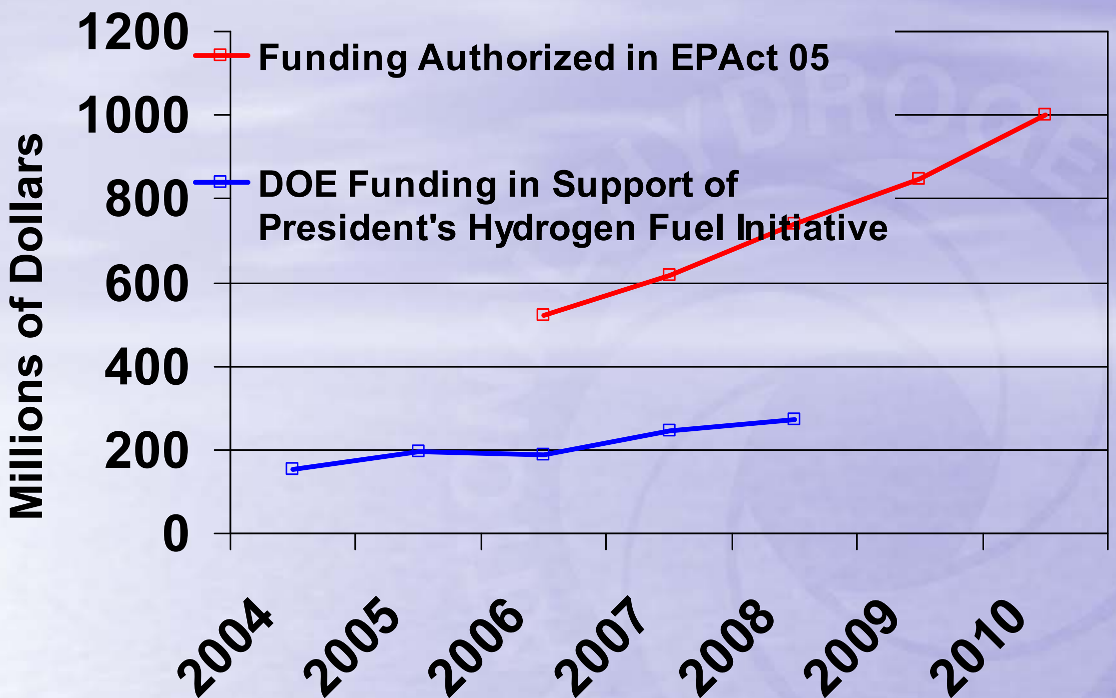


FIGURE 6-3 Light-duty vehicular use of hydrogen, 2000–2050, based on the optimistic vision of the committee.

Different Visions

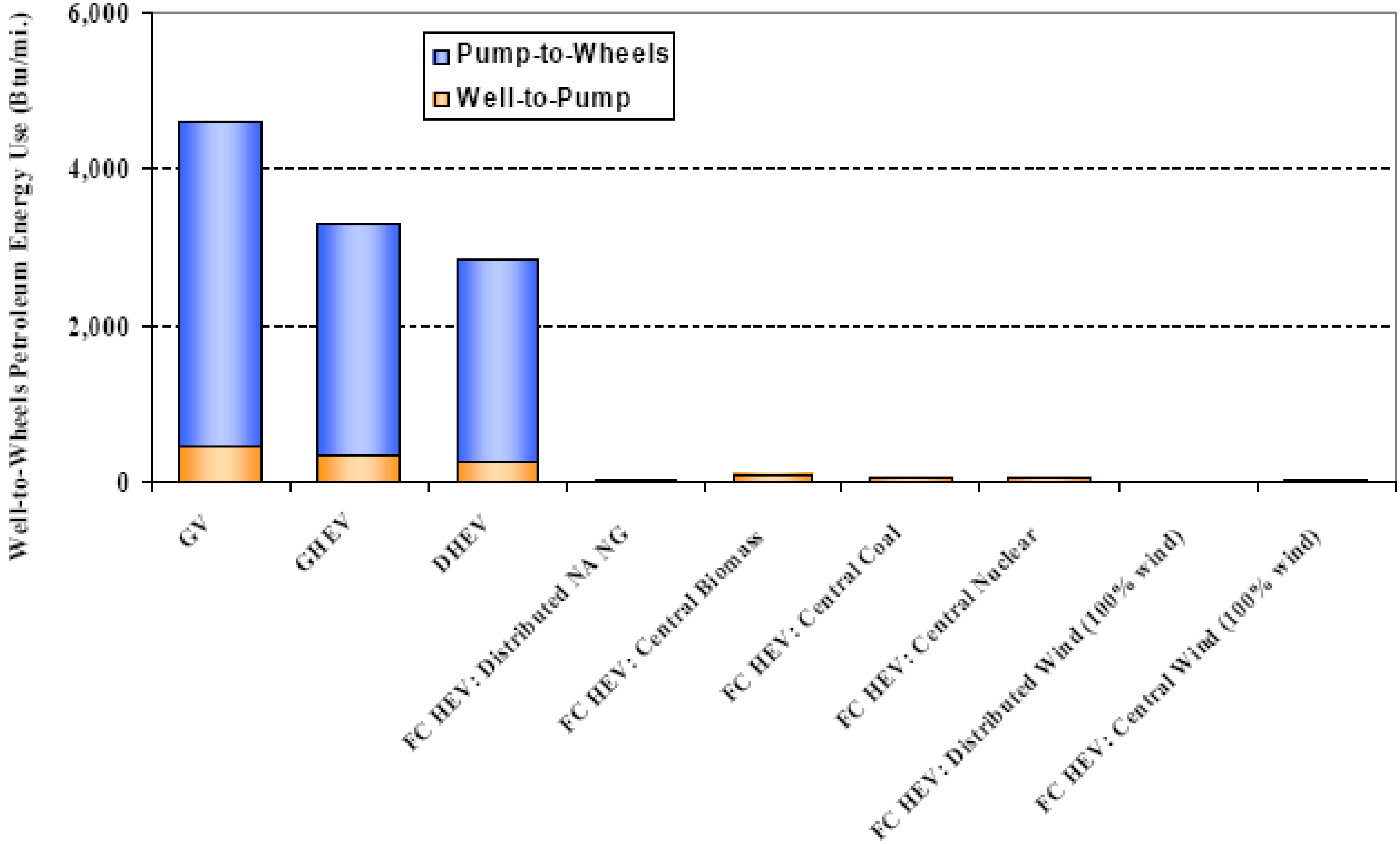


- ***Permanent Authorization***
- ***Build Program, Industry Capability***
- ***More Partnerships and Learning Demonstrations***
- ***Accelerate RD&D, Commercialization***

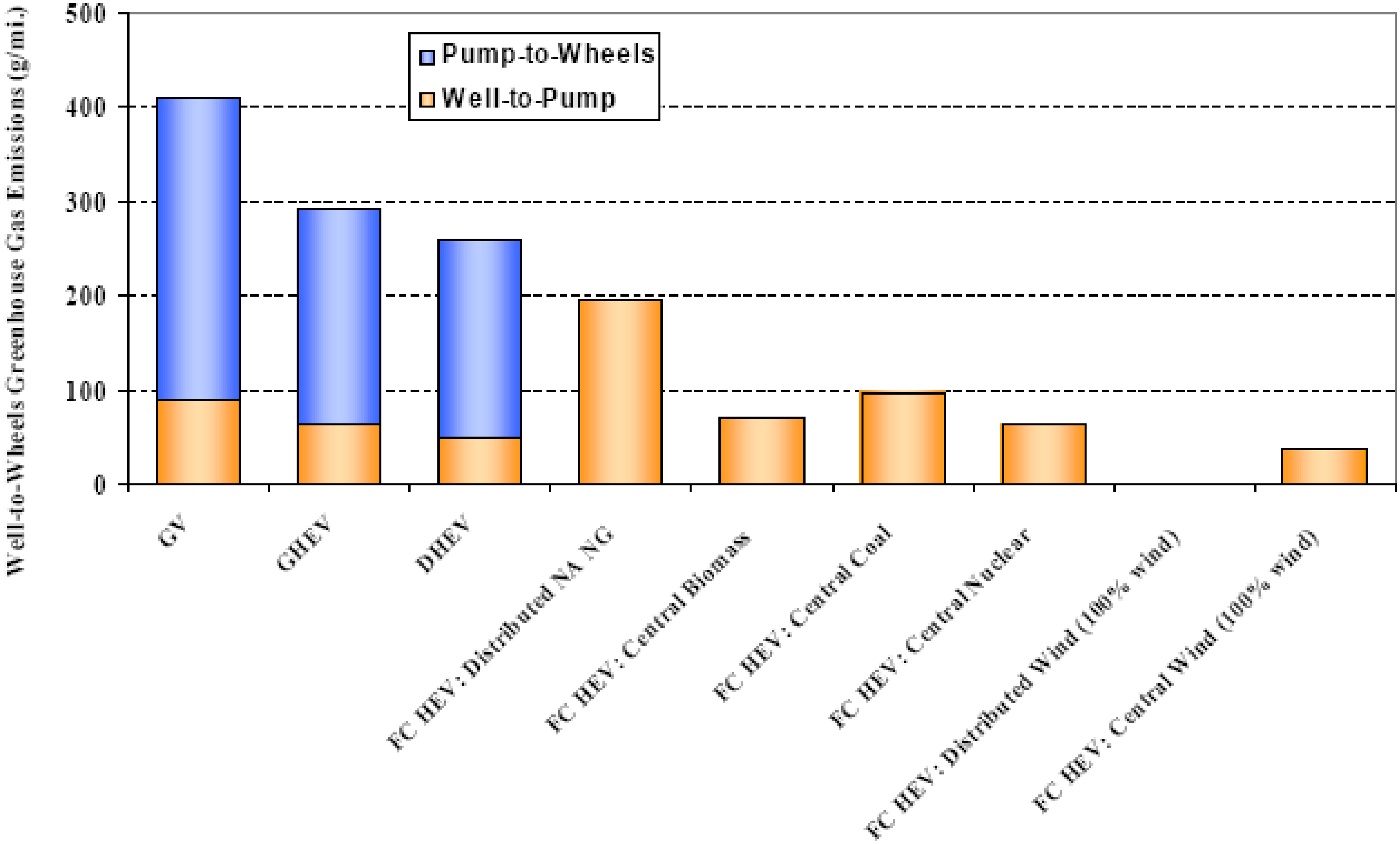
- EPAct 05 data includes authorizations from Titles VII and VIII, covering EERE and Science
- EPAct 05 authorized $3.73 B,
- Equivalent Hydrogen Fuel Initiative ~ $950 M

- 2007-8 are requested $, includes EERE and Science
- DOE values for 2004-6 are appropriated $

Well-to-Wheels Results: Petroleum Energy Use (Mid Term)



Well-to-Wheels Results: Greenhouse Gas Emissions (Mid Term)



H2 Driven By Carbon Prices

- *Prospects for Hydrogen and Fuel Cells* (OECD, International Energy Agency, 2005): **many more H2 FCVs as carbon prices move from $10-$50/ton**
- *World Energy Technology Outlook-2050:H2 (European Community,* 2006): **more sensitive price response**
- Senate energy tax pkg: $20/ton (inflated) tax credit for industry capture and storage
- Bingaman/Specter climate bill (+ others): $7-12/ton, rising cap

A Formidable Undertaking

- **H2 and F/C cars — making a bulletproof ultratech device for noble savages**
- **Unparalleled in U.S. history?**
- **Apollo and Manhattan had a single customer —enabling narrow, non-commercial technologies to flourish outside a market**
- **A different measure of science and technology for mass benefit — key symbolic value**
- ***Brave and patient private energy investment — more R&D $ spent on Rogaine and Viagra?***

Just Remember This...

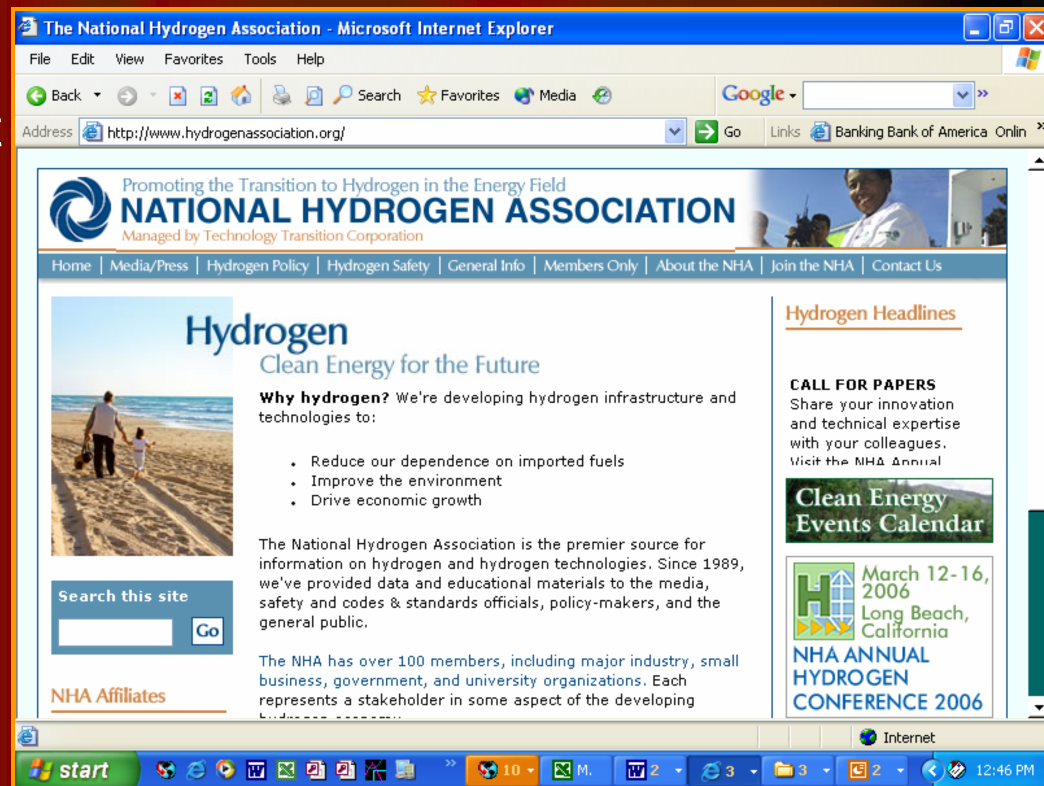
- Large strategic value
- Helps solve big import and climate problems — stakes are high
- Much work to be done
- Premium public investment — fund EPAct 05
- As Dan Quayle once remarked: "The future will be better tomorrow."

Who is the National Hydrogen Association?

NHA Website

[www.HydrogenAssociation.org]

- 2 million + visitors since 2001
- New Job Board (3,000 views/mo)
- Powerpoint modules for fleet operators (5,000 downloads/mo)
- Online searchable Fueling Station Database (1,500 views/mo)
- Online, searchable Product Catalog (new!)
- More



Polymer/Metal Pipelines and Pipes for Transmitting, Distributing and Storing Hydrogen Gas

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Simon L. Marshall, and
Michael T. Naney
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HYDROGEN DISCOVERIES

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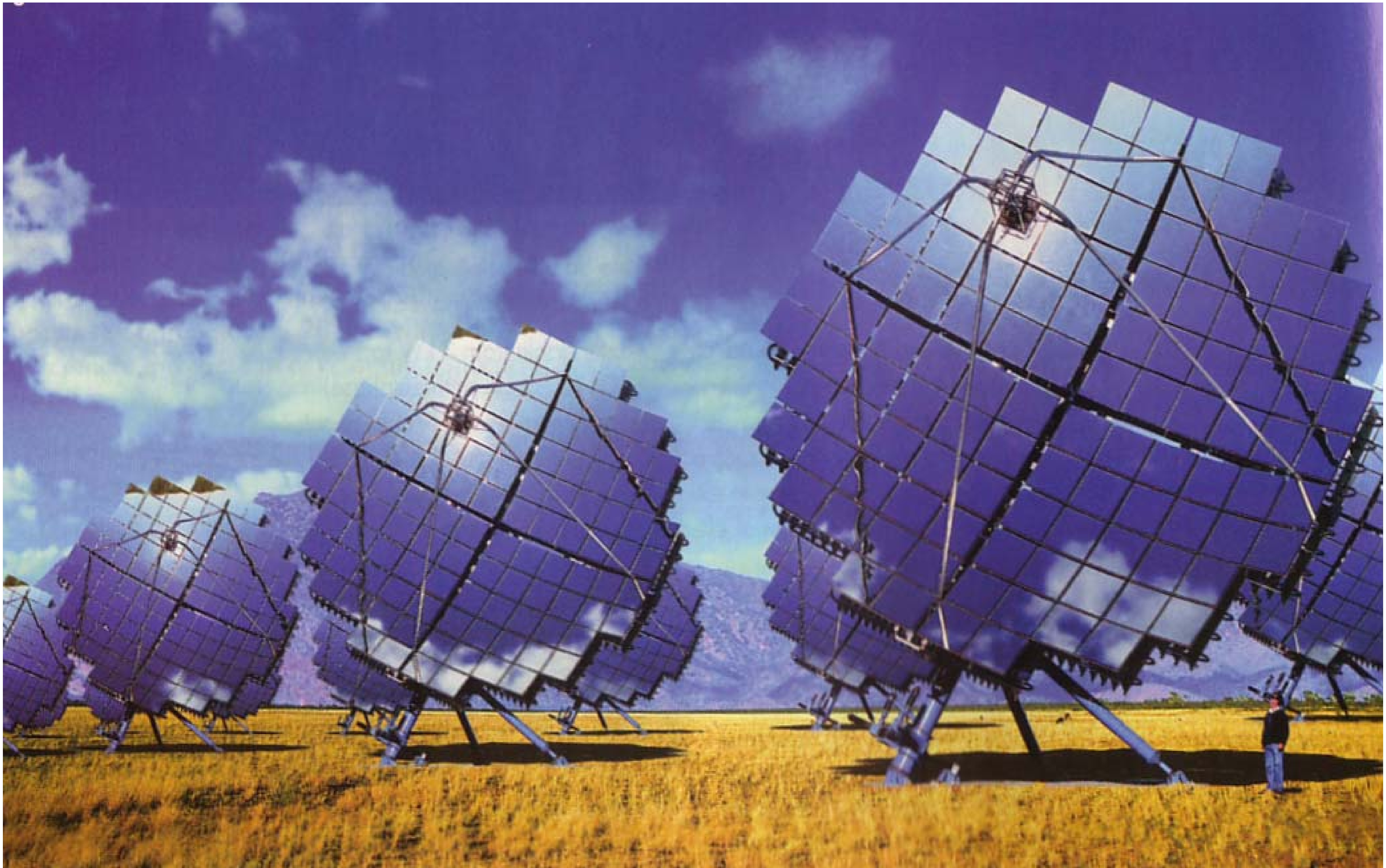
Overview

- The growing need for fully functional, flexible, reliable, <u>and affordable</u> pipelines for hydrogen service
- Hydrogen embrittlement of carbon-steel pipes
- Polymer/metal pipes for (long-distance) transmission and distribution of hydrogen
- Simple technologies for “managing” escape of hydrogen from connections along polymer/metal pipelines
- Conclusions

The Great Plains Wind Resource



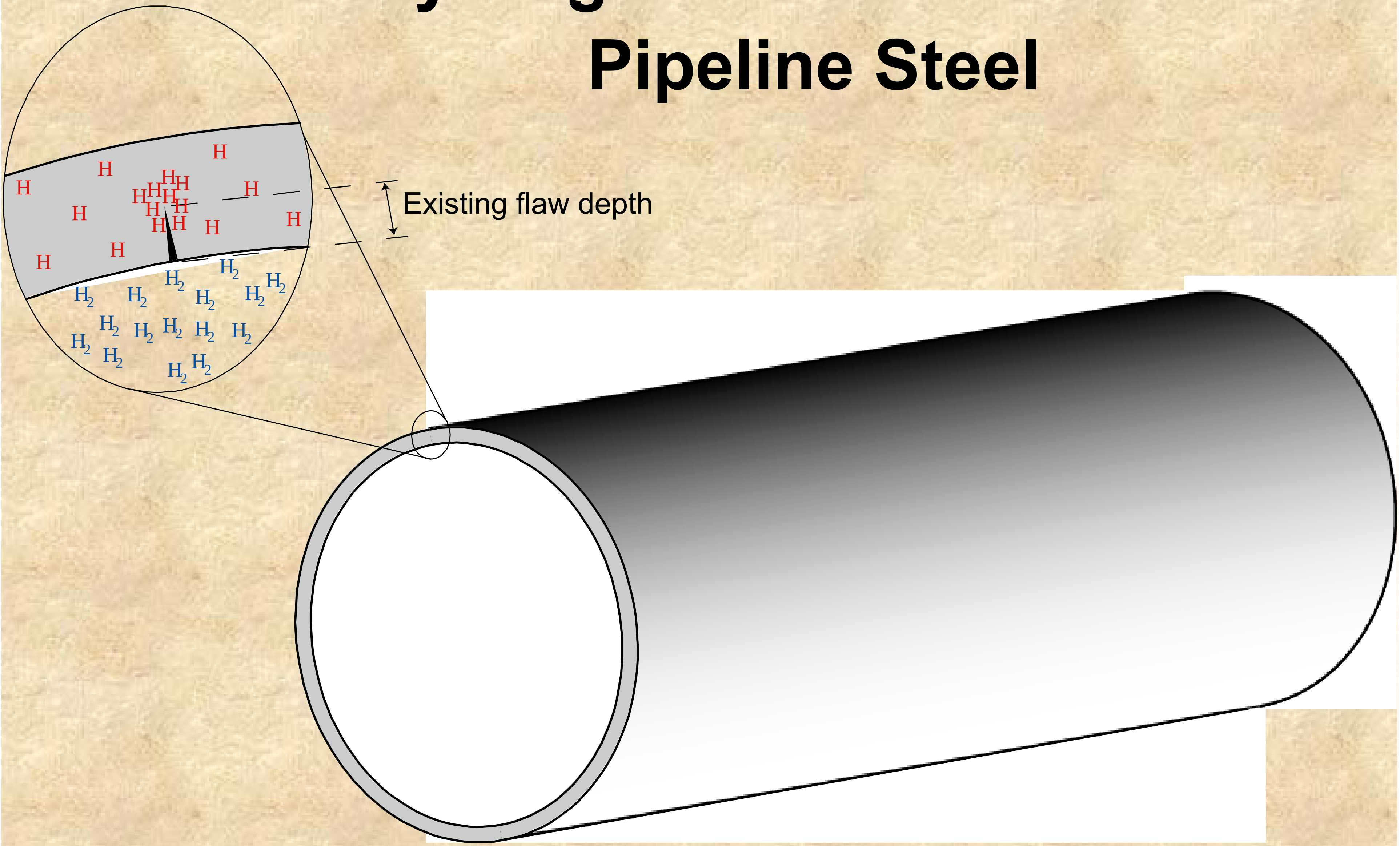
Concentrated Solar Power (CSP)

Thermal, Photovoltaic

Hydrogen Embrittlement of Pipeline Steel

- Hydrogen embrittlement is typically manifested by surface cracking, crack propagation, decreases in tensile strength, loss of pipeline ductility, and reduced burst-pressure rating.
- Hydrogen embrittlement can lead to premature failure of one or more segments of a pipeline, resulting in leakage of gas—or in extreme circumstances, bursting of a pipe.

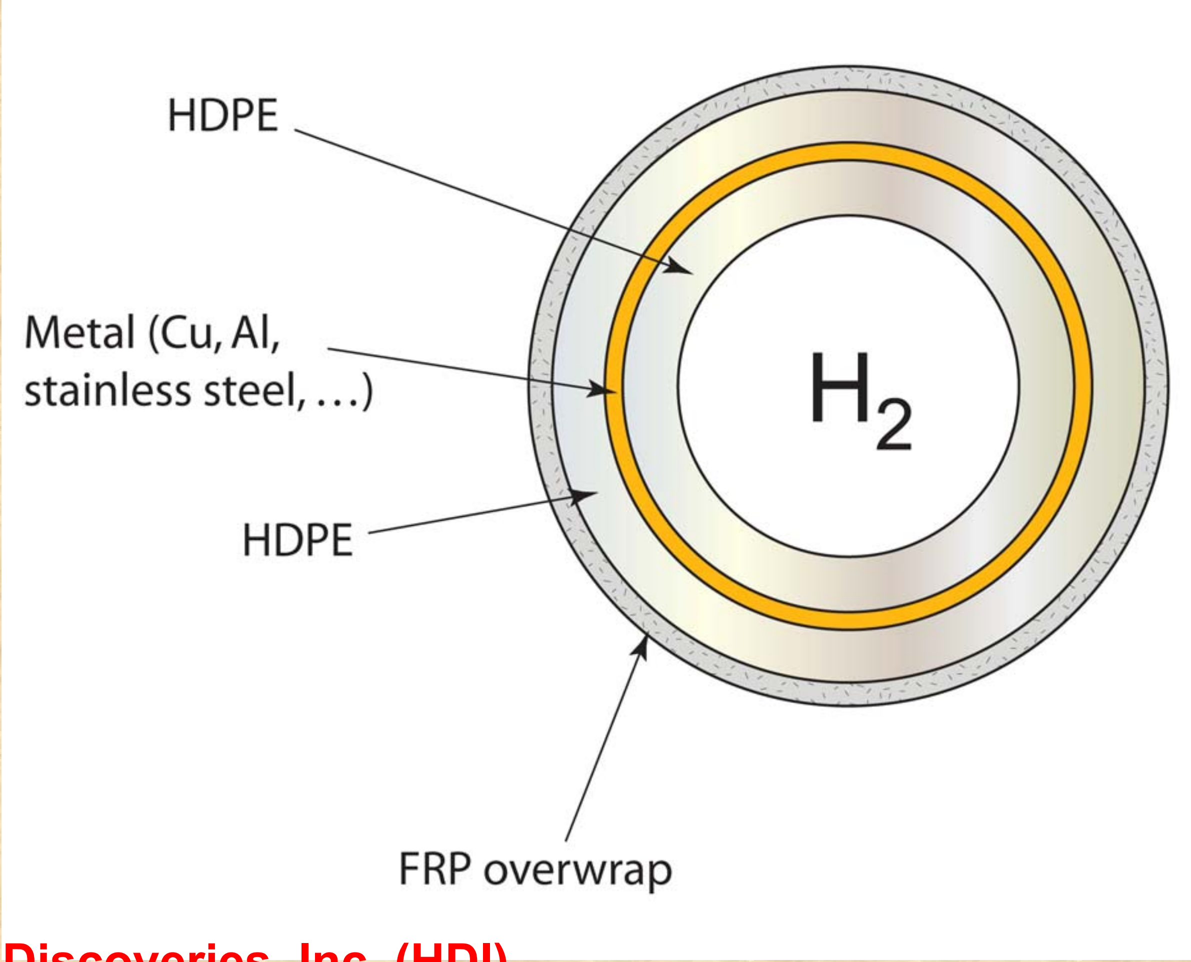
Hydrogen Embrittlement of Pipeline Steel



HDI Polymer/Metal Tube Technologies

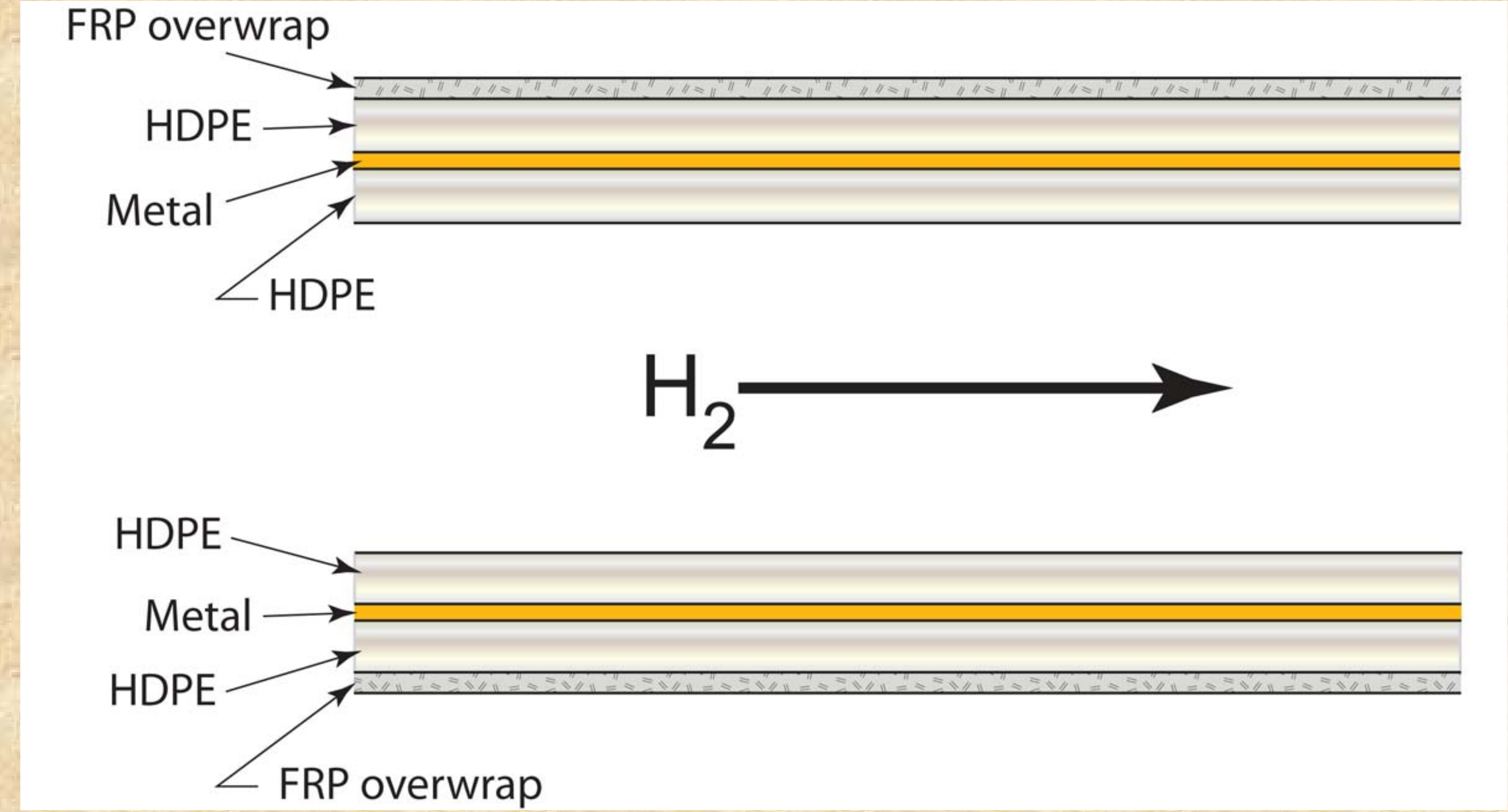
- Scientists at HDI have invented new methods of tube design and component/facility construction that greatly reduce: (i) the diffusive flux of hydrogen through the walls of hollow cylinders, and (ii) the escape of hydrogen from hydrogen pipelines where connections are made.
- The techniques involve use of one or more layers of homogeneous or laminated polymeric material and a thin metal interlayer to create multiple equilibrium and kinetic barriers to hydrogen diffusion.

HDI Polymer/Metal Pipe Technology: Transverse Cross-Section

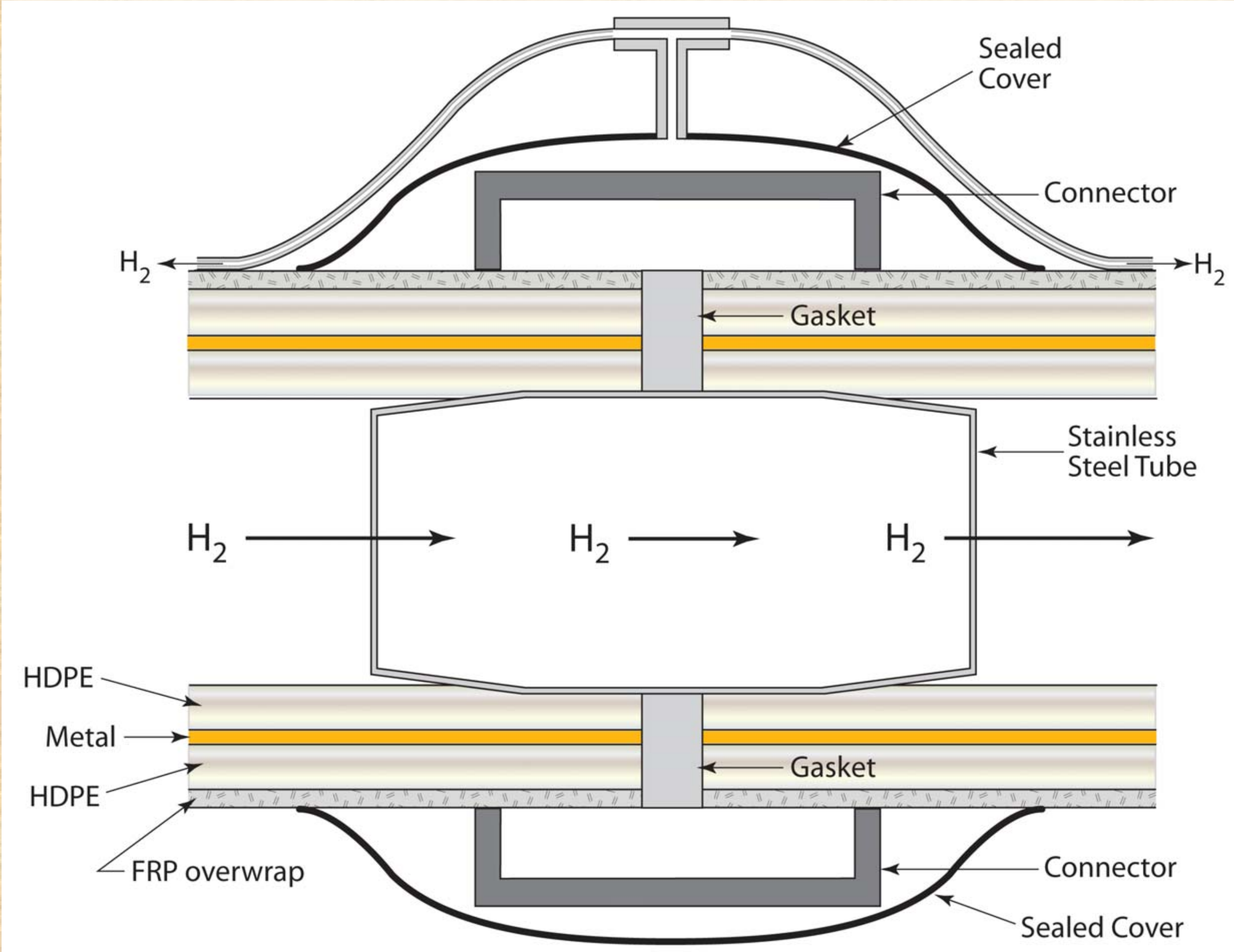


Hydrogen Discoveries, Inc. (HDI)

HDI Polymer/Metal Pipe Technology: Longitudinal Cross-Section



Hydrogen Discoveries, Inc. (HDI)



Hydrogen Discoveries, Inc. (HDI)

Conclusions

1. A thin, continuous metal (Cu, Al, or stainless steel) interlayer is extremely effective in blocking hydrogen permeation through the walls of polymer/metal pipes. Therefore, it is not necessary to develop a new polymeric material to achieve that containment performance.

2. HDI's fully scalable, polymer/metal pipe technologies use:
   - proven materials of construction (HDPE, FRP, and metal films), and
   - proven manufacturing techniques for creating multi-layer pipes

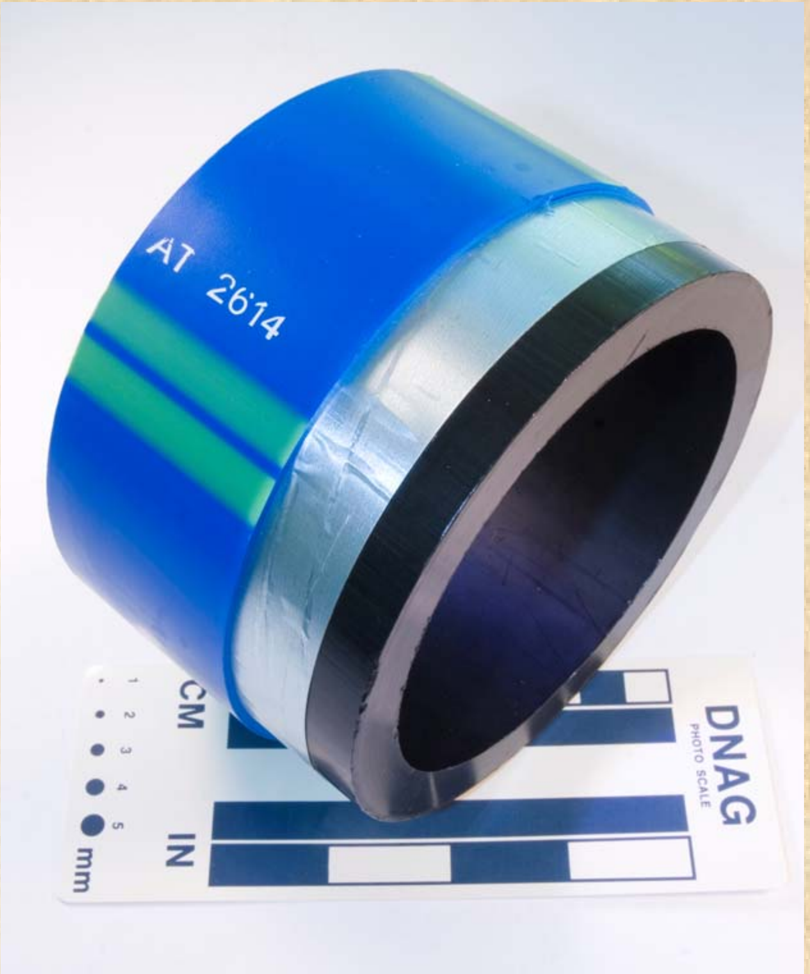
Conclusions (Cont'd)

3. Existing connecting technologies can be used to link multi-layered polymer/metal pipes of any diameter, wall thickness, and length.

4. HDI's simple hydrogen-capture technologies can be used to "manage" escape of hydrogen from places where multi-layered polymer/metal pipes are connected.

5. HDI's polymer/metal pipe technologies have the potential to meet <u>all</u> of the Department of Energy (DOE) technical and cost targets for high-capacity (pipeline) hydrogen delivery.

Seeing is believing!



A close-up photograph of a 3” long, 4” I.D. pipe specimen consisting of two layers of HDPE with a thin aluminum interlayer.

Anhydrous Ammonia (NH_3) for Transmission and Storage of Renewable Energy: Fertilizer and Fuel

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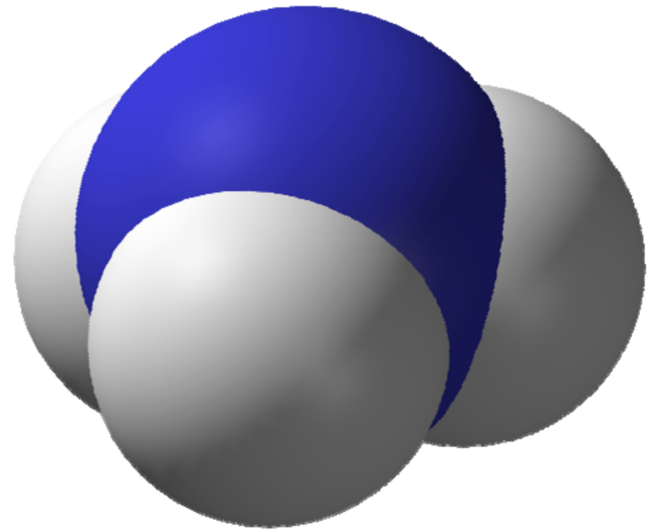
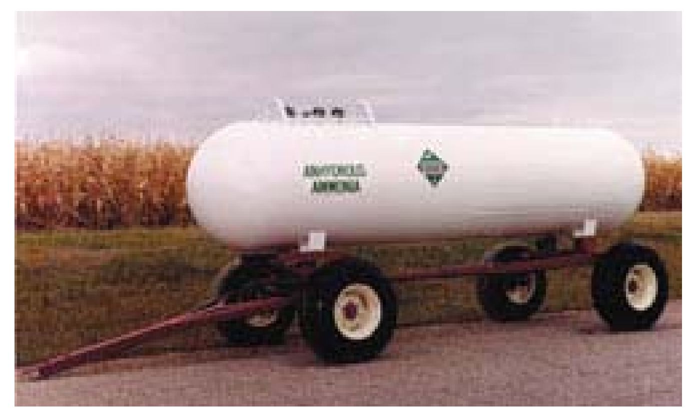
Department of Chemical Engineering
Washington, DC
(202) 806-4796
jganley@howard.edu

Facts About Ammonia (NH_3)

- **One of the most widely used chemicals worldwide**
  - > 100 million tons/year
  - 80% used as fertilizer
  - Refrigeration and cleaning
  - Purification of water supplies
  - Manufacture of plastics, dyes…



- **Easily stored as a liquid**
  - Compressed (~10 atm at 25°C)
  - Refrigerated (-33°C at 1 atm)



- **Strong odor, easy to detect leaks**

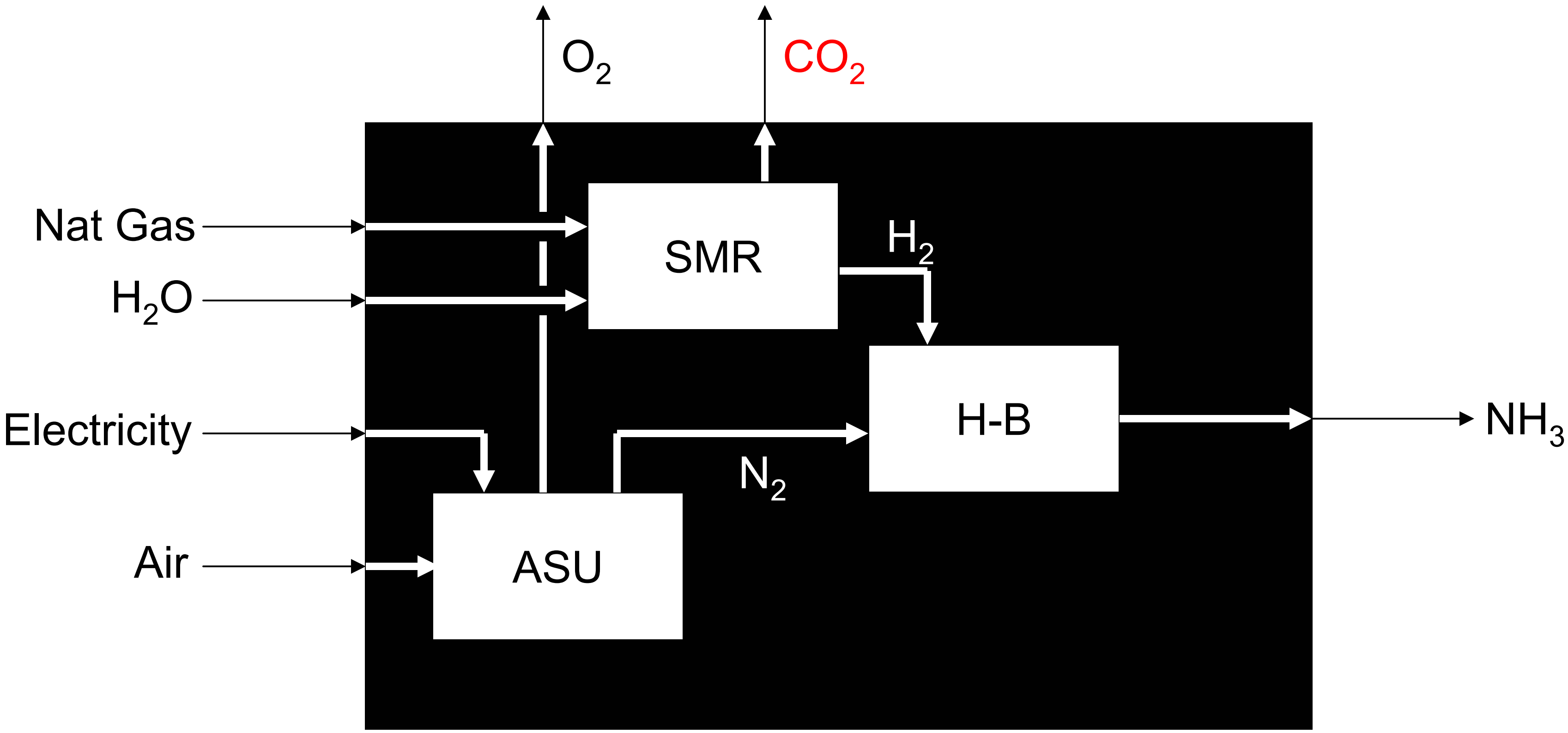
Ammonia as a Fuel

$$2\,NH_3 \longrightarrow 3\,H_2 + N_2 \qquad \Delta H^\circ = 46\ kJ\,/\,mol$$

- Very mild enthalpy of reforming, if H_2 is required
- NH_3 is typically stored and transported as a liquid
  - Power density is comparable to other liquid fuels
  - Vaporizes when throttled (no flash line required)
- Classified as non-flammable, non-explosive
- Suitable fuel for internal combustion engine
  - Spark ignition
  - High-compression diesel
- Suitable fuel for fuel cells
  - Cracked ammonia for PEMFC, AFC, PAFC
  - Direct ammonia for SOFC, PCFC, MCFC, MSAFC

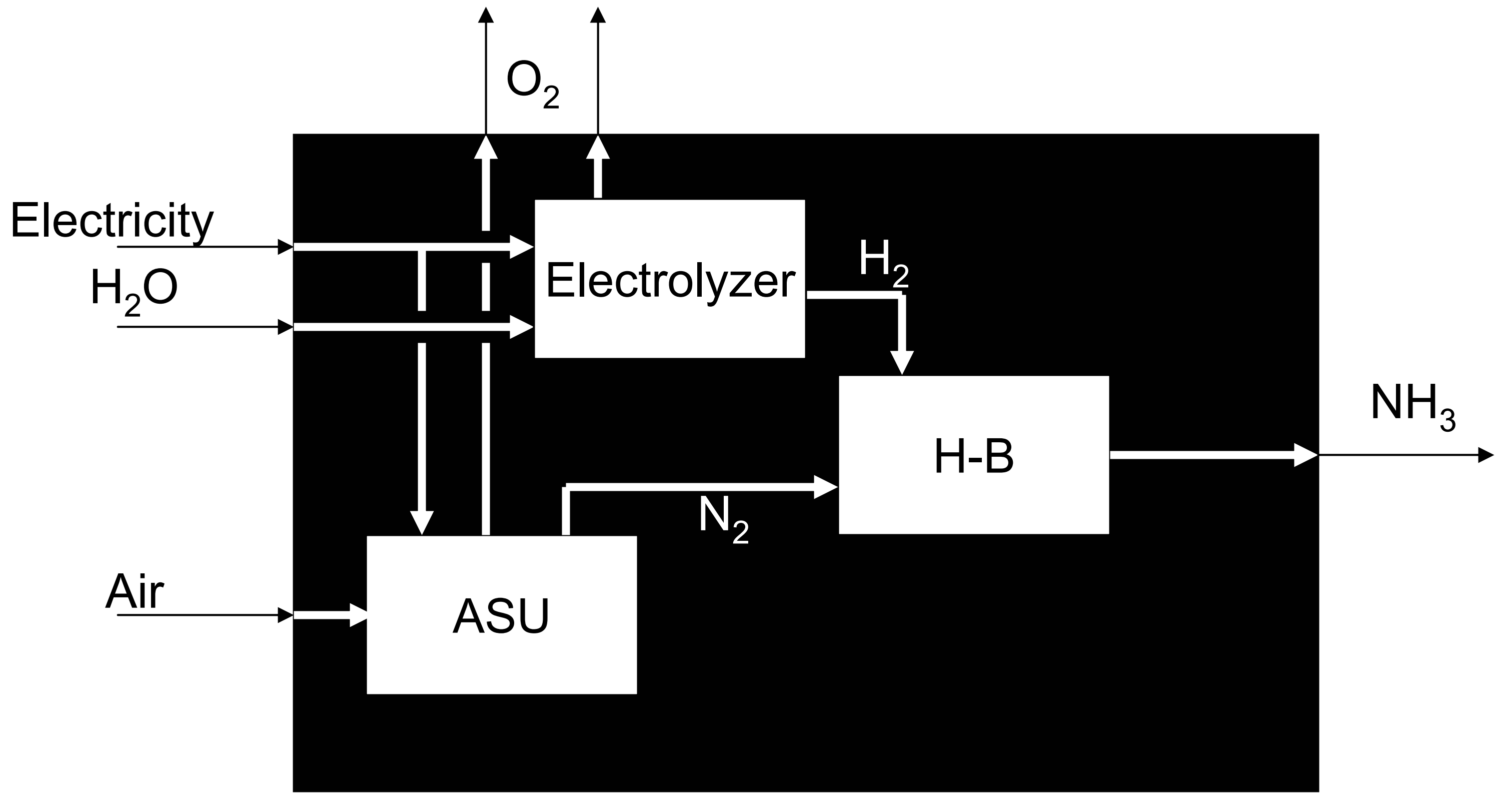
Ammonia Manufacturing: The Haber-Bosch Process

$$3\ CH_4 + 6\ H_2O + 4\ N_2 \rightarrow 3\ CO_2 + 8\ NH_3$$



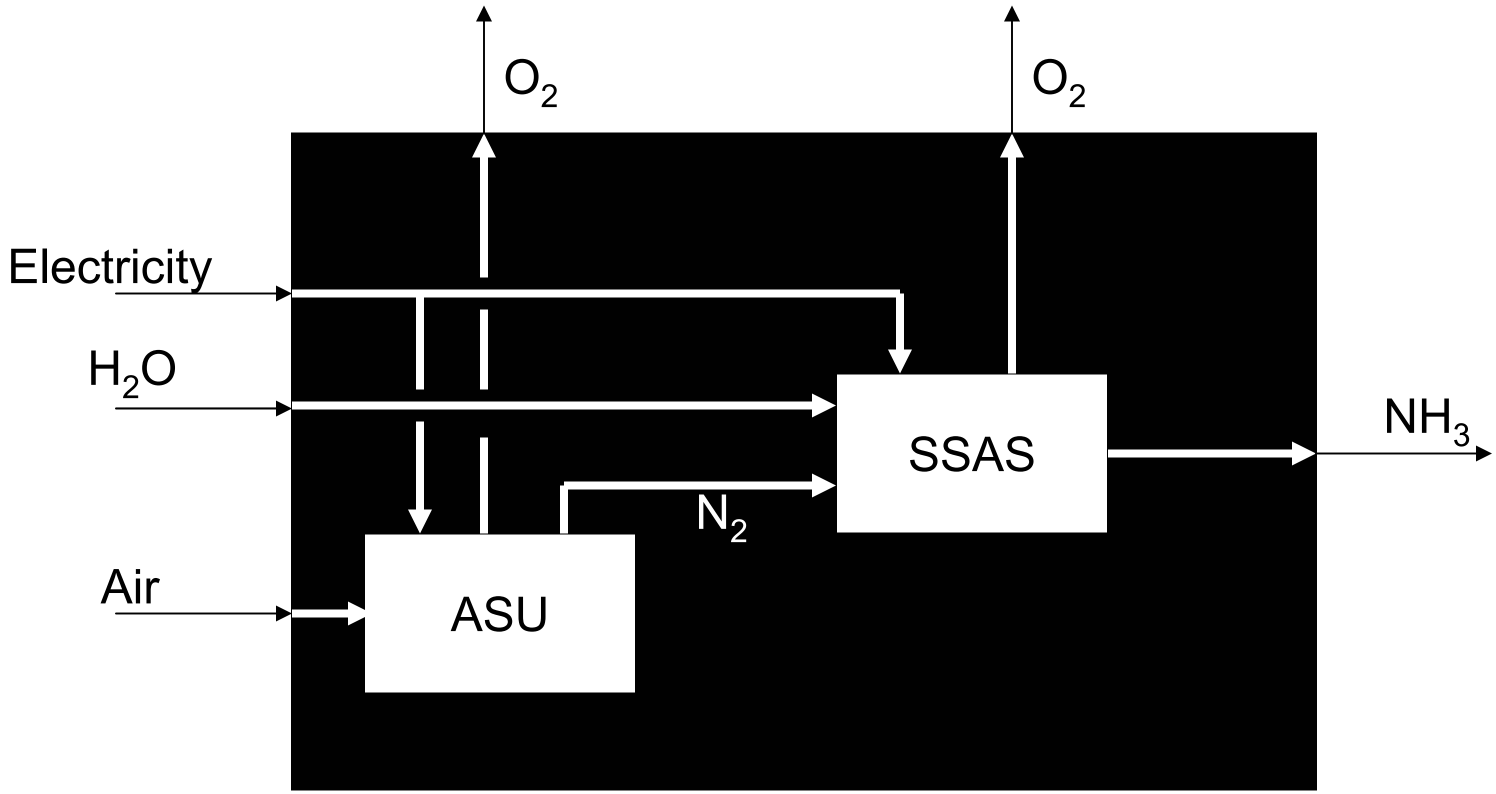
A Renewable Alternative: Electrolysis + Haber-Bosch

$$3\ H_2O \rightarrow 3\ H_2 + 3/2\ O_2$$
$$3\ H_2 + N_2 \rightarrow 2\ NH_3$$



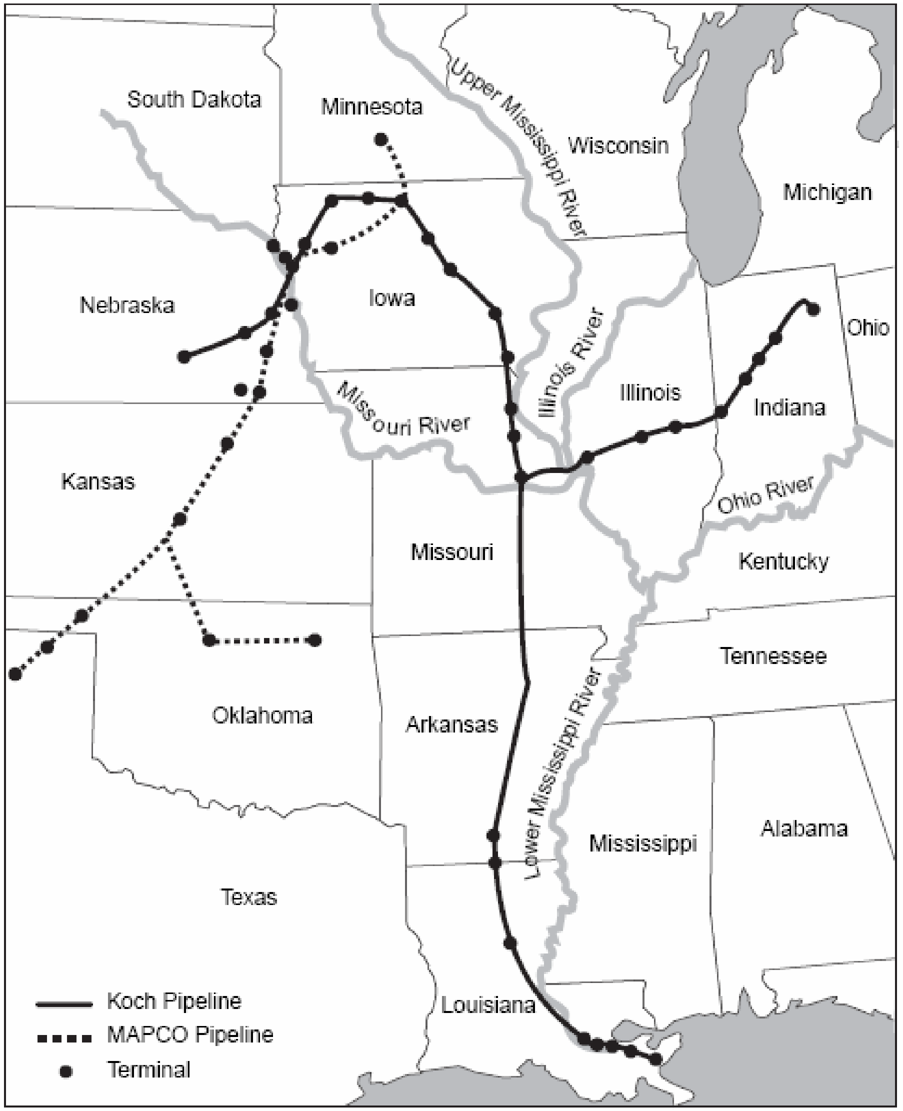
Alternative to Haber-Bosch: Solid State Ammonia Synthesis

$$6\ H_2O + 2\ N_2 \rightarrow 3\ O_2 + 4\ NH_3$$

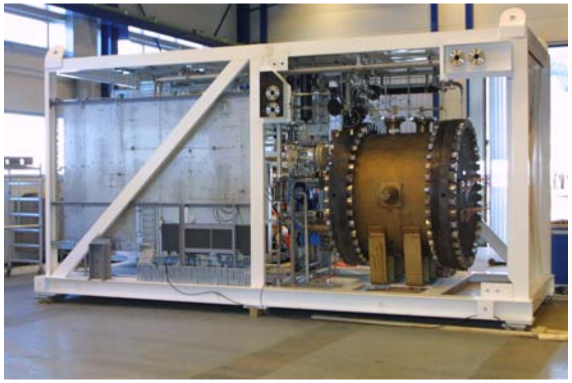


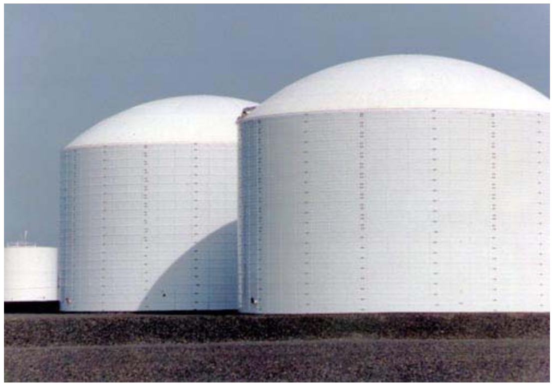
NH_3 Transport: Pipelines

- **Pipelines provide much of the NH_3 used in the Midwest**
  - Local production: 47%
  - Pipeline: 33%
  - River barge: 14%
  - Rail shipment: 6%
- **Service is unique**
  - Many local markets
  - High seasonal demand
- **Pipeline construction: mild carbon steel**



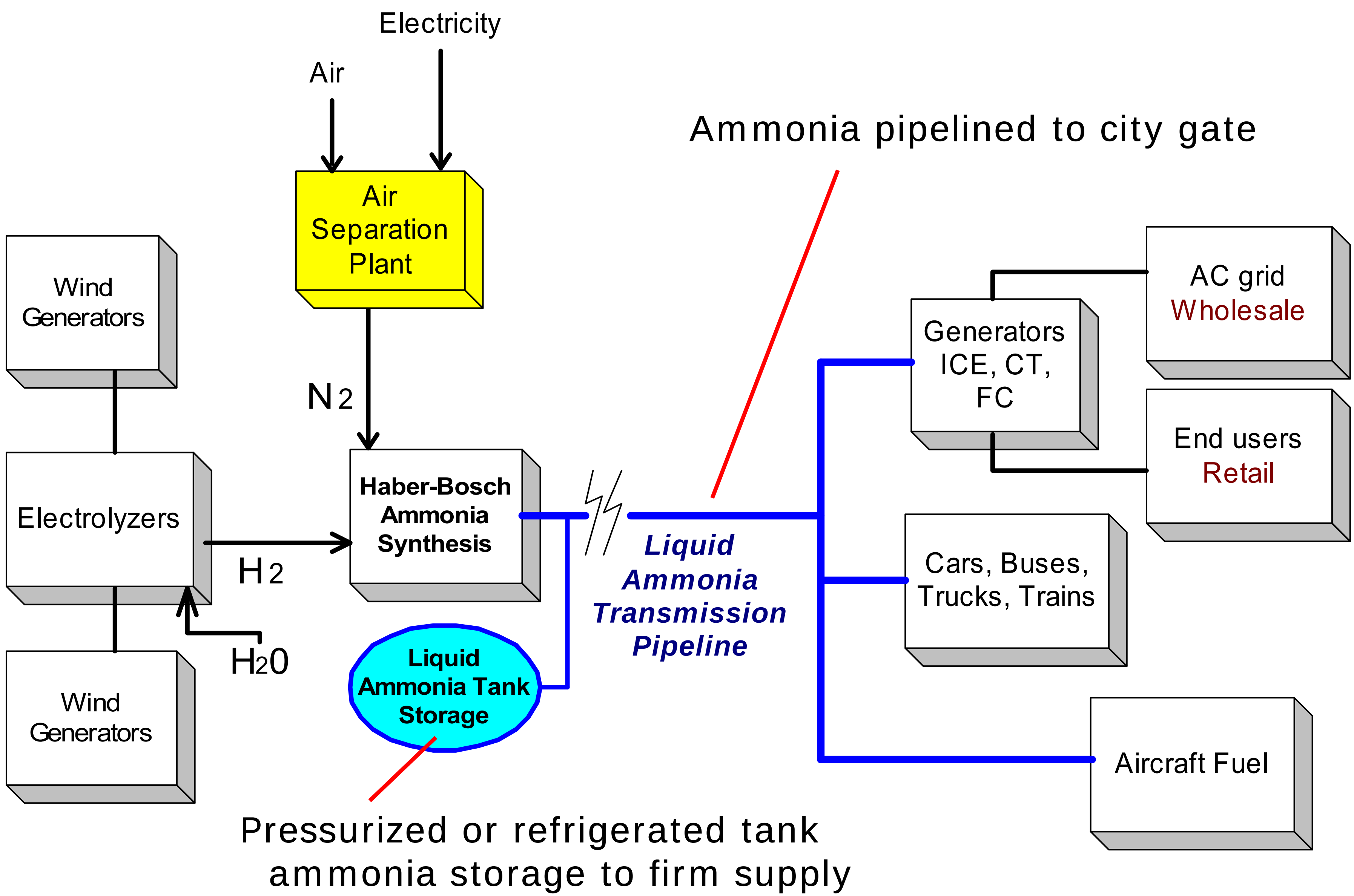
Wind-to-Ammonia Concept





Only requirements for renewable NH_3: Air, Water, Electricity.

A Vision for Renewable Ammonia



’07 Senate Farm Bill

Sec. 9019 “Renewable Nitrogen Fertilizer”

- Research initiative
- “... identify key tech and econ barriers to producing commercial-scale quantities of nitrogen fertilizer from renewable energy sources.”

Questions / Discussion

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Summary

- "Transmission" must include alternatives to electricity
  - Gaseous hydrogen, GH2
  - Liquid anhydrous ammonia, NH_3
  - Others
- "Run the World on Renewables" requires:
  - Annual-scale firming storage
  - Synergy among renewables
- Think energy systems

OSE # 92 Roundtable, Q+A

Your card, please

Speakers:

Bill Leighty, The Leighty Foundation
John Moore, Environmental Law and Policy Center
Tom Key, EPRI
Jerome Hinkle, National Hydrogen Association
Jim Blencoe, Hydrogen Discoveries, Inc.
Jason Ganley, Howard University

Co-sponsors:

Union of Concerned Scientists
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