



***Alternatives to Electricity for Transmission,
Storage, and Integration of Stranded
Renewables: Hydrogen and Ammonia for
Transportation and CHP Fuel***

***Fuel Cell and Hydrogen Energy Seminar
Fuel Cell and Hydrogen Energy Association
Los Angeles, CA 10 – 13 Nov 14***

***Renewable Hydrogen Pathways, ENE22
11 Nov 14, 1500 – 1700***

***Bill Leighty, Director
The Leighty Foundation
Juneau, AK***

wleighty@earthlink.net

907-586-1426 206-719-5554 cell



Mendenhall Glacier, Juneau, AK

June '71



Mendenhall Glacier, Juneau, AK
10 October 10



**Mendenhall Glacier, Juneau, AK
10 October 10**



Muir Glacier, Alaska, 1895

Glacier face is 100 m high



Muir Glacier, Alaska, 2005
Out of photo, to left



Muir Glacier, Alaska, 1895
Glacier face is 100 m high



Muir Inlet, Alaska, 2005
Approximate same location, east side



35,000 walrus have come ashore in NW Alaska: usual sea ice is gone



35,000 walrus stranded in NW Alaska: their usual sea ice is gone



Baby walrus are often crushed during stampedes ashore

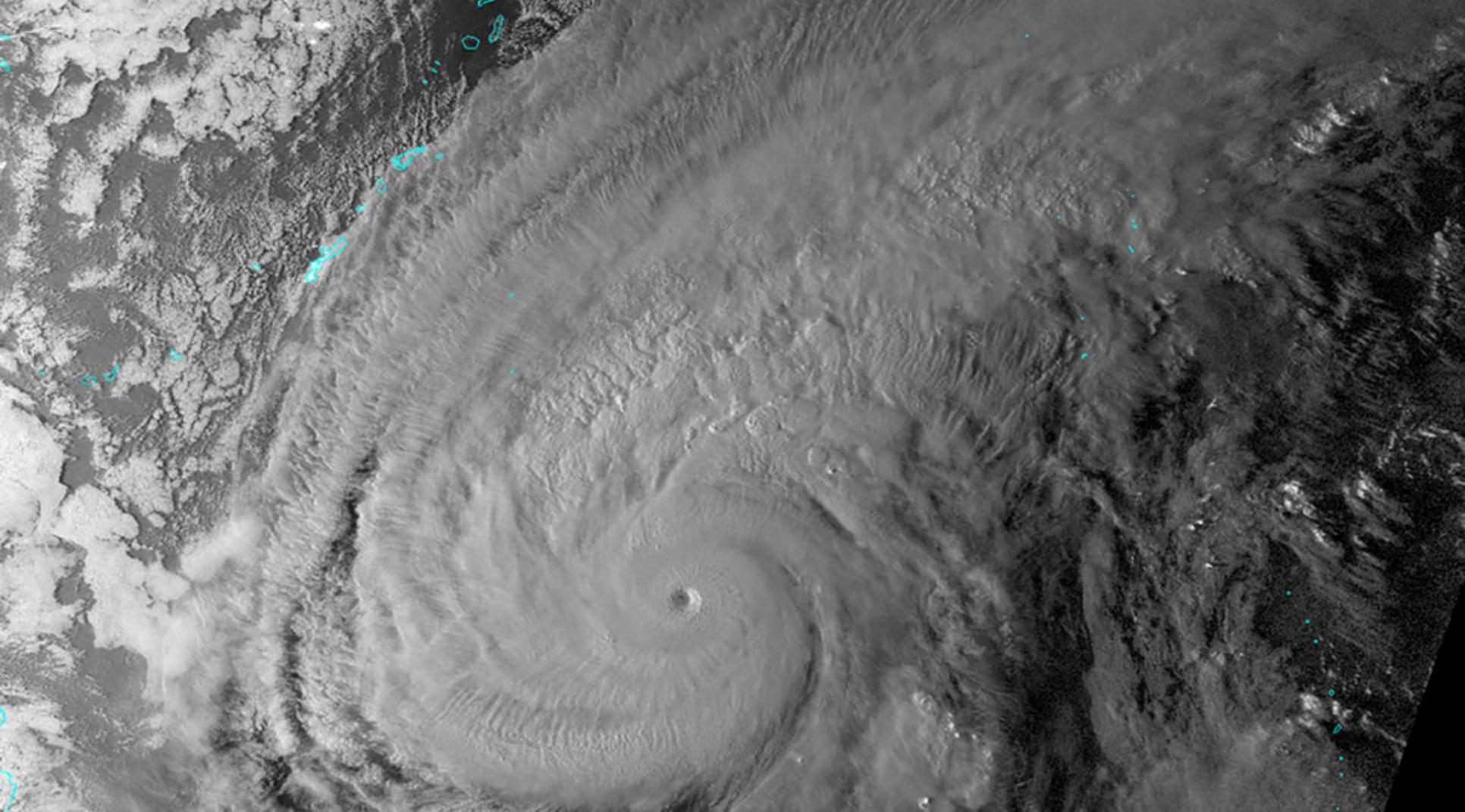
Rapid climate change



Spruce bark beetle kill, Alaska



Shishmaref, Alaska
Winter storms coastal erosion



Super Typhoon Nuri, 5 Nov 14
East of Japan, moving NE

MUST Run the World on Renewables – plus Nuclear ?

- Rapid climate change
- Ocean acidification
- Sea level rise
- Species extinctions



MUST Run the World on Renewables – plus Nuclear ?

- Demand growth
- Water for energy
- War
- Depletion of Oil and Gas
- Only 200 years of Coal left
- Only Source of Income:
 - Sunshine
 - Tides
 - Spending our capital

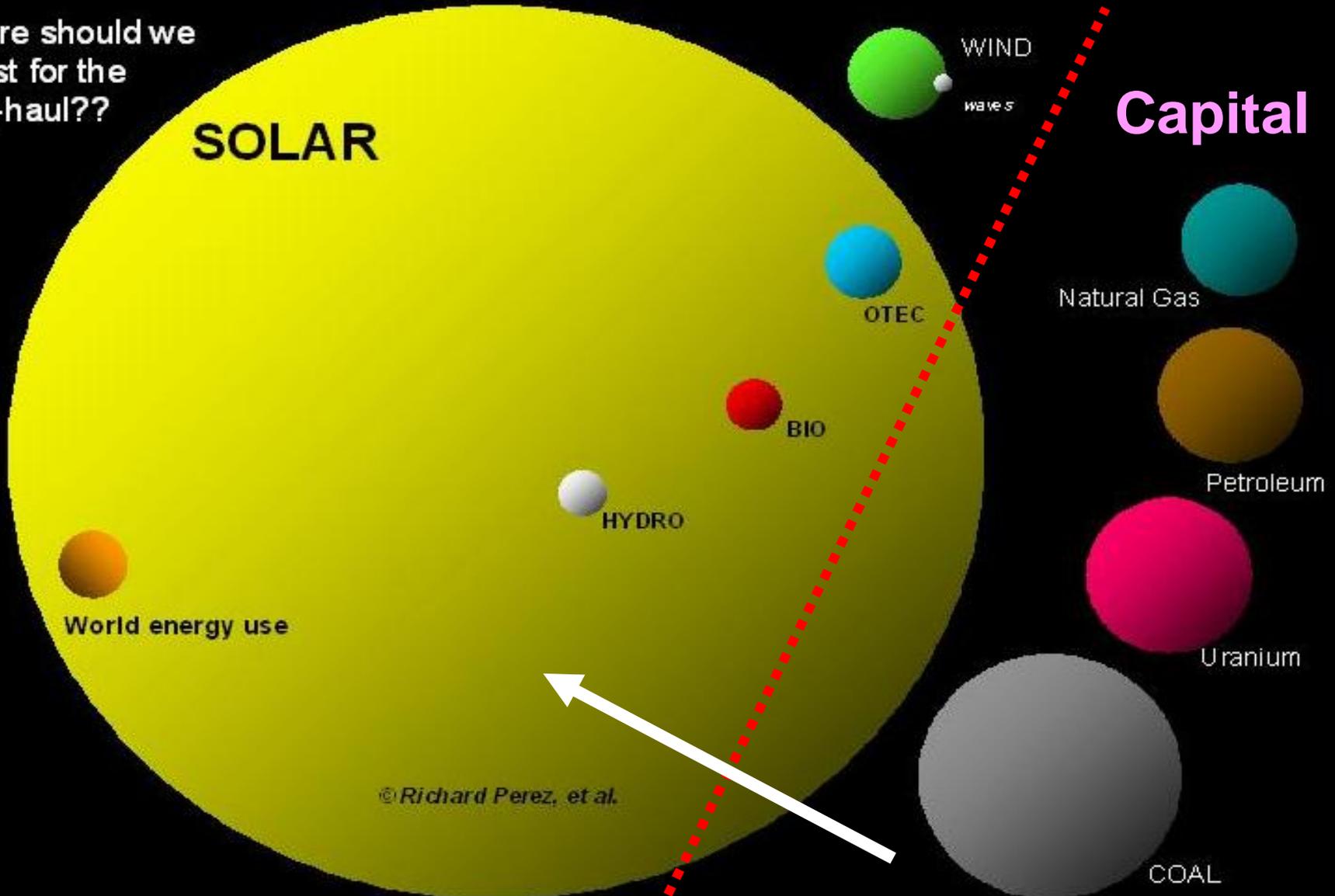


Comparing the world's energy resources*

Annual Income

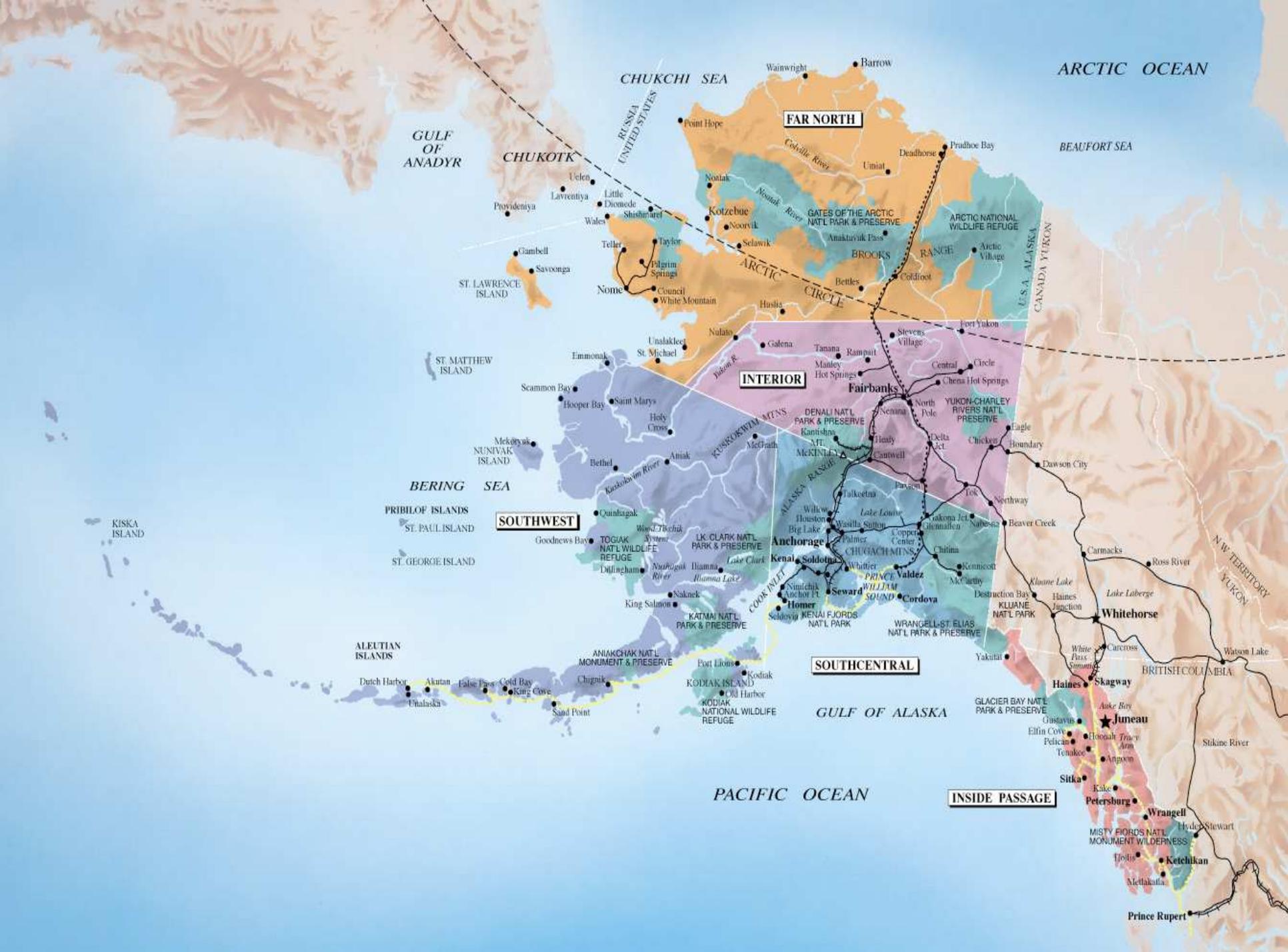
Where should we invest for the long-haul??

Capital



©Richard Perez, et al.

*yearly potential is shown for the renewable energies. Total reserves are shown for the fossil and nuclear "use-them, lose-them" resources. World energy use is annual.



CHUKCHI SEA

ARCTIC OCEAN

GULF OF ANADYR

CHUKOTKA

FAR NORTH

BEAUFORT SEA

ST. LAWRENCE ISLAND

ST. MATTHEW ISLAND

INTERIOR

BERING SEA

SOUTHWEST

KISKA ISLAND

PRIPILOF ISLANDS

ST. PAUL ISLAND

ST. GEORGE ISLAND

ALEUTIAN ISLANDS

Dutch Harbor

Aktutan

False Pass

Gold Bay

King Cove

Chignik

Sand Point

KODIAK ISLAND

Old Harbor

KODIAK NATIONAL WILDLIFE REFUGE

SOUTHCENTRAL

GULF OF ALASKA

PACIFIC OCEAN

INSIDE PASSAGE

RUNSWA UNITED STATES

Point Hope

Wainwright

Barrow

Uelen

Lavrentiya

Little Diomed

Wales

Shishmaref

Teller

Taylor

Ilulissat

White Mountain

Council

Nome

Unalakleet

St. Michael

Emmonak

Scammon Bay

Hooper Bay

Saint Marys

Holy Cross

Mekoryuk

NUNIVAK ISLAND

Bethel

Aniak

Kacholovik River

Quinhagak

Goodnews Bay

TOCIAK NATL WILDLIFE REFUGE

Dillingham

King Salmon

Naknek

King Salmon

ANIAKCHAK NATL MONUMENT & PRESERVE

Port Lions

Kodiak

Old Harbor

KODIAK NATIONAL WILDLIFE REFUGE

Homer

Seward

Soloaivi

Kenai Fjords NATL PARK

Kenai

Soldotna

Kenai Fjords NATL PARK

Whittier

Whittier

Valdez

Valdez

Cordova

Cordova

Whittier

Deadhorse

Prudhoe Bay

Umiat

Nostak

Kotzebue

Noorvik

Selawik

Anaktuvuk Pass

Brooks

Bettles

Coldfoot

Huslia

Stevens Village

Fort Yukon

Central

Circle

Chena Hot Springs

North Pole

Senama

Healy

Chanwell

Delta Jet

Chicken

Boundary

Dawson City

Eagle

Beaver Creek

Lek

Southway

Beaver Creek

Point Hope

Wainwright

Barrow

Uelen

Lavrentiya

Little Diomed

Wales

Shishmaref

Teller

Taylor

Ilulissat

White Mountain

Council

Nome

Unalakleet

St. Michael

Emmonak

Scammon Bay

Hooper Bay

Saint Marys

Holy Cross

Mekoryuk

NUNIVAK ISLAND

Bethel

Aniak

Kacholovik River

Quinhagak

Goodnews Bay

TOCIAK NATL WILDLIFE REFUGE

Dillingham

King Salmon

Naknek

King Salmon

ANIAKCHAK NATL MONUMENT & PRESERVE

Port Lions

Kodiak

Old Harbor

KODIAK NATIONAL WILDLIFE REFUGE

Homer

Seward

Soloaivi

Kenai Fjords NATL PARK

Kenai

Soldotna

Kenai Fjords NATL PARK

Point Hope

Wainwright

Barrow

Uelen

Lavrentiya

Little Diomed

Wales

Shishmaref

Teller

Taylor

Ilulissat

White Mountain

Council

Nome

Unalakleet

St. Michael

Emmonak

Scammon Bay

Hooper Bay

Saint Marys

Holy Cross

Mekoryuk

NUNIVAK ISLAND

Bethel

Aniak

Kacholovik River

Quinhagak

Goodnews Bay

TOCIAK NATL WILDLIFE REFUGE

Dillingham

King Salmon

Naknek

King Salmon

ANIAKCHAK NATL MONUMENT & PRESERVE

Port Lions

Kodiak

Old Harbor

KODIAK NATIONAL WILDLIFE REFUGE

Homer

Seward

Soloaivi

Kenai Fjords NATL PARK

Kenai

Soldotna

Kenai Fjords NATL PARK

Point Hope

Wainwright

Barrow

Uelen

Lavrentiya

Little Diomed

Wales

Shishmaref

Teller

Taylor

Ilulissat

White Mountain

Council

Nome

Unalakleet

St. Michael

Emmonak

Scammon Bay

Hooper Bay

Saint Marys

Holy Cross

Mekoryuk

NUNIVAK ISLAND

Bethel

Aniak

Kacholovik River

Quinhagak

Goodnews Bay

TOCIAK NATL WILDLIFE REFUGE

Dillingham

King Salmon

Naknek

King Salmon

ANIAKCHAK NATL MONUMENT & PRESERVE

Port Lions

Kodiak

Old Harbor

KODIAK NATIONAL WILDLIFE REFUGE

Homer

Seward

Soloaivi

Kenai Fjords NATL PARK

Kenai

Soldotna

Kenai Fjords NATL PARK

Point Hope

Wainwright

Barrow

Uelen

Lavrentiya

Little Diomed

Wales

Shishmaref

Teller

Taylor

Ilulissat

White Mountain

Council

Nome

Unalakleet

St. Michael

Emmonak

Scammon Bay

Hooper Bay

Saint Marys

Holy Cross

Mekoryuk

NUNIVAK ISLAND

Bethel

Aniak

Kacholovik River

Quinhagak

Goodnews Bay

TOCIAK NATL WILDLIFE REFUGE

Dillingham

King Salmon

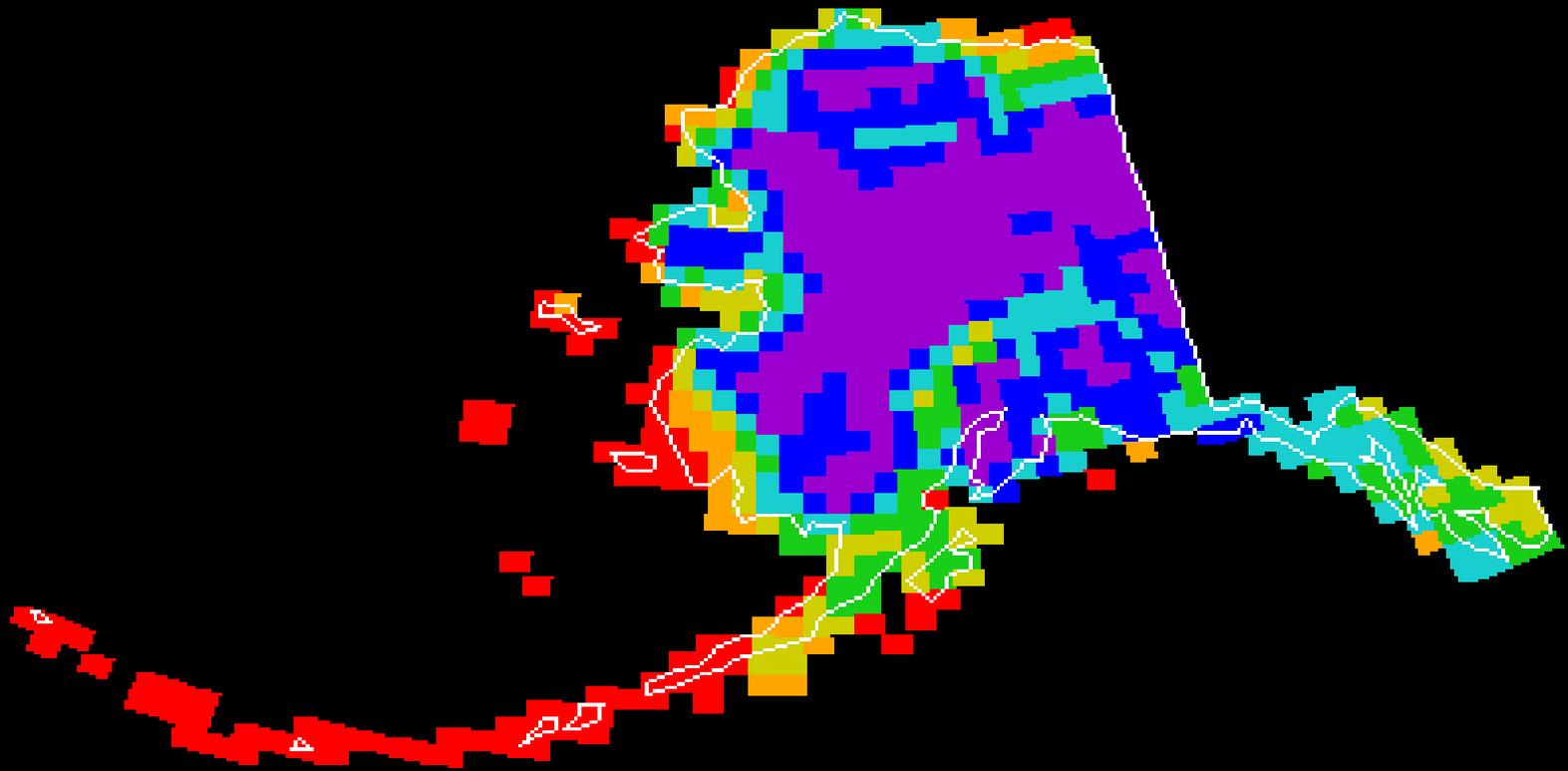
Naknek

King Salmon

ANIAKCHAK NATL MONUMENT & PRESERVE

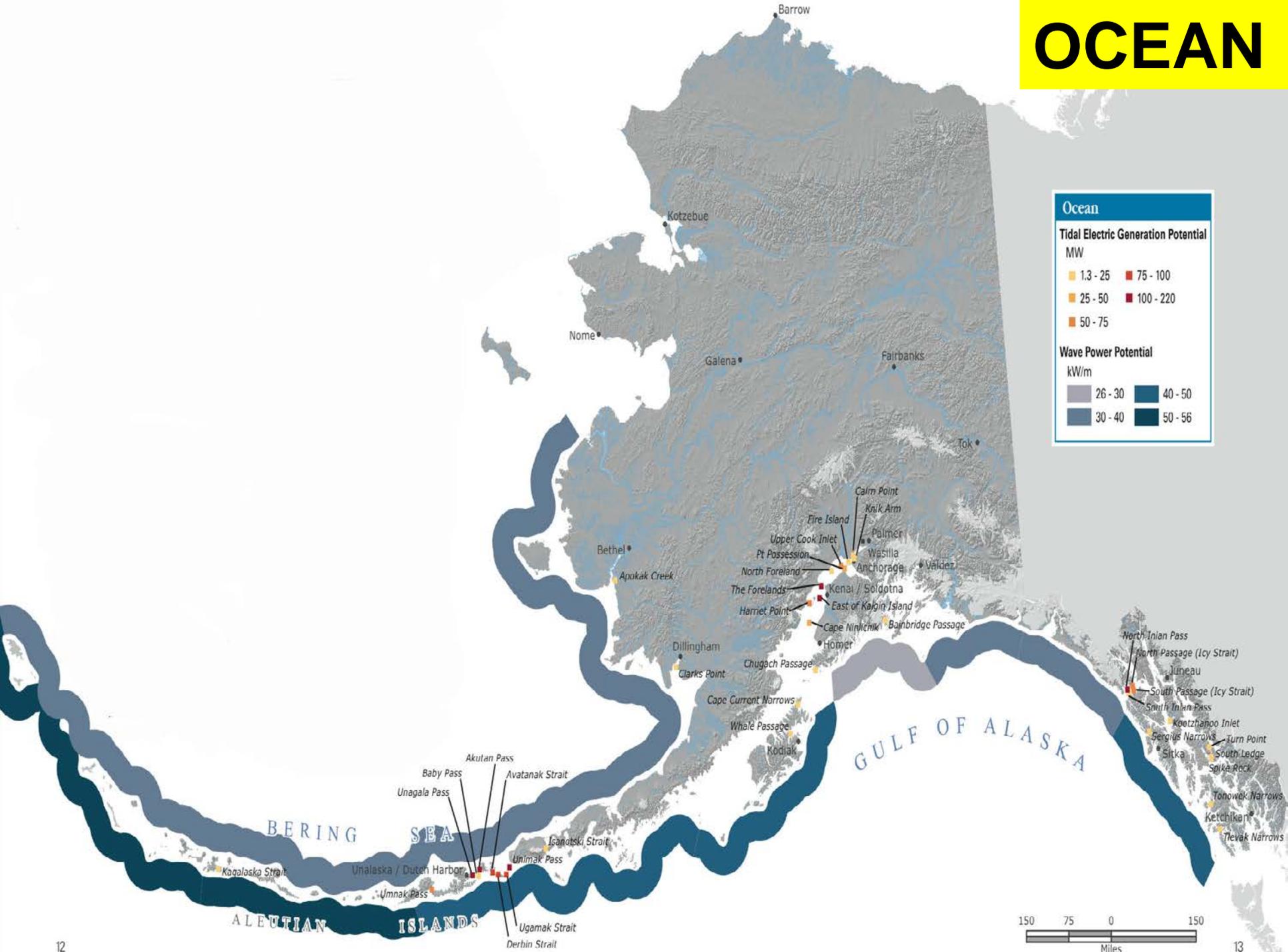
Port Lions

Wind Power Class

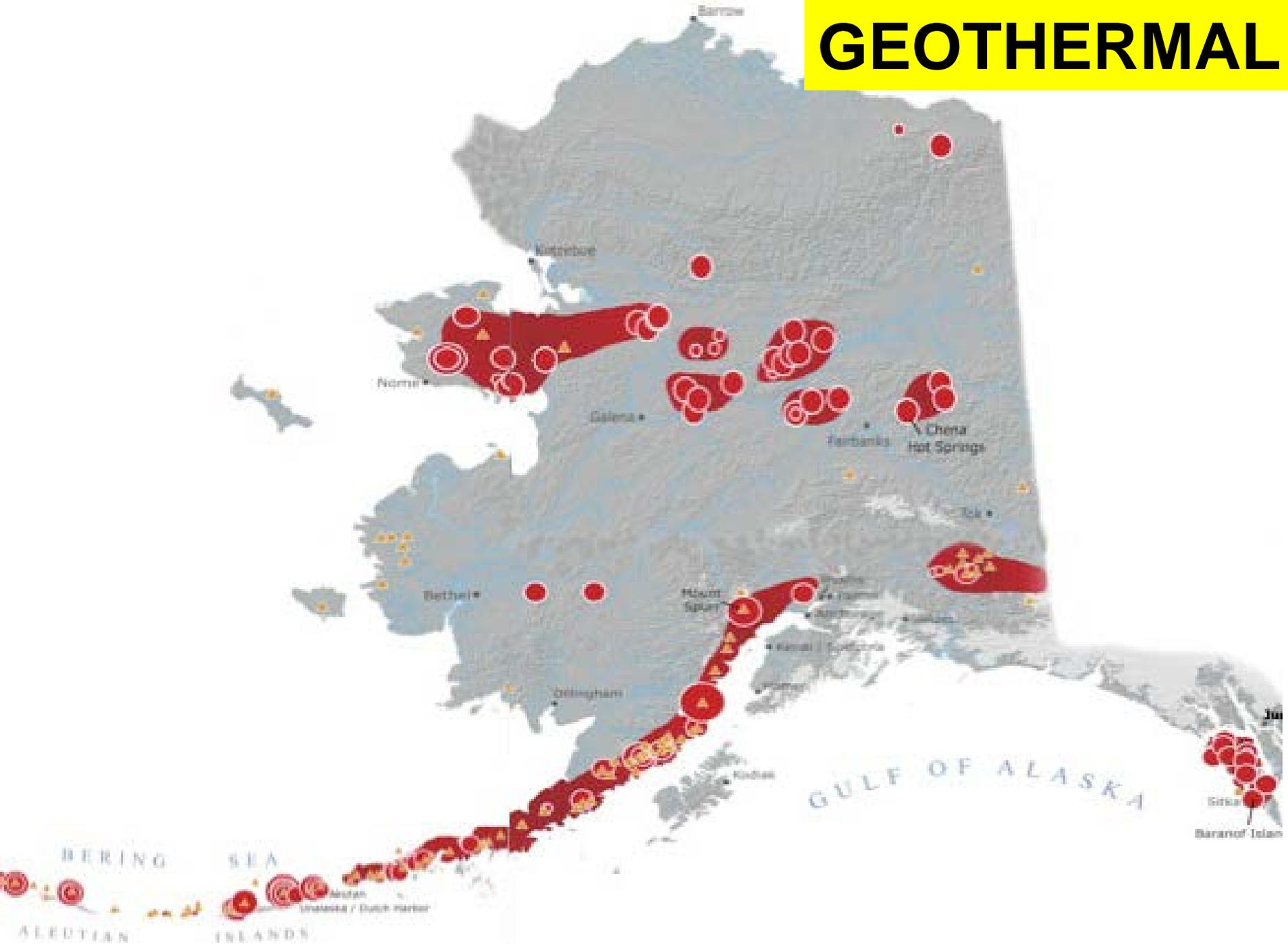


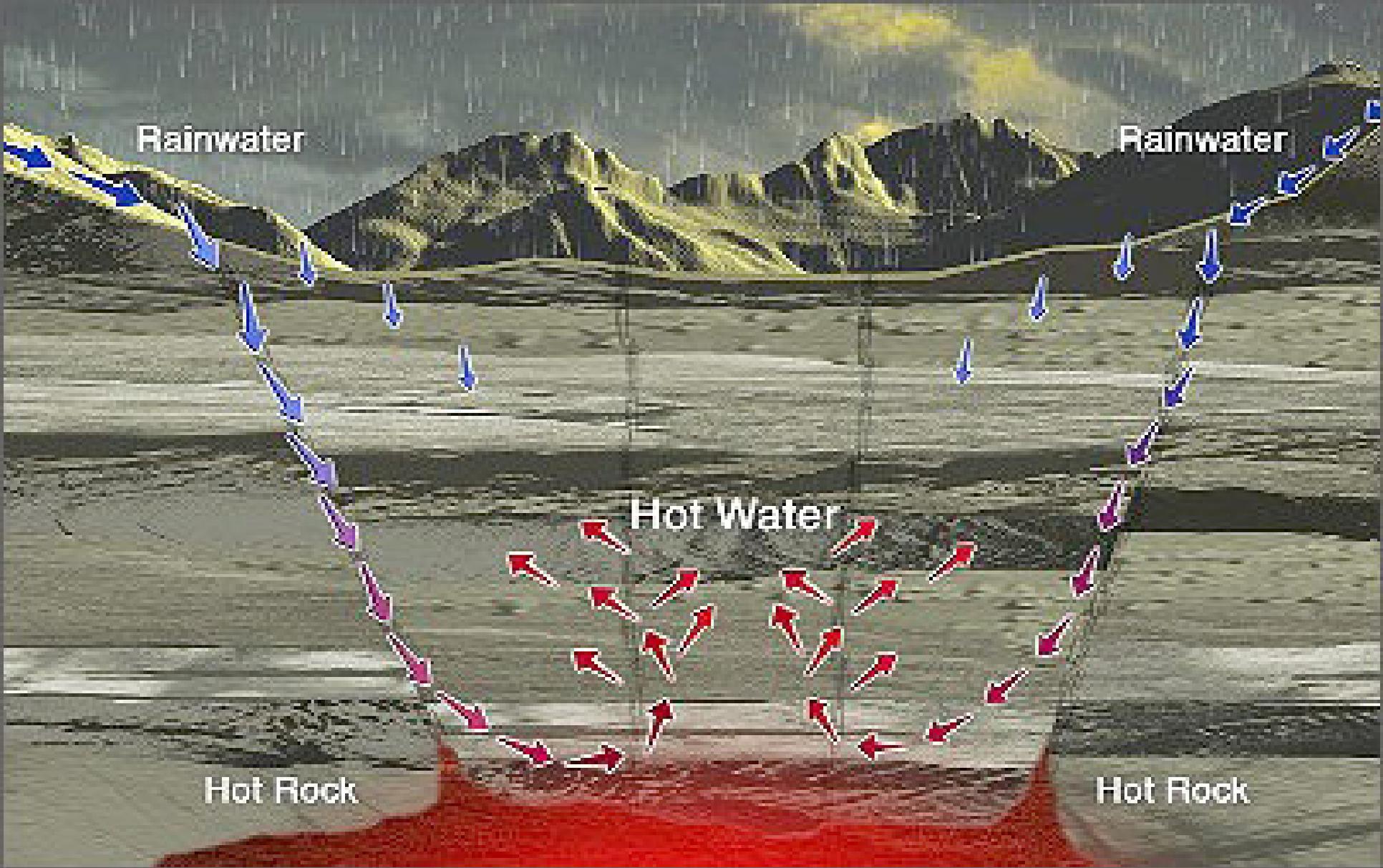
	Power Class	Speed	Power Density
	1	0.0-5.6m/s	0-200W/m ²
	2	5.6-6.4m/s	200-300W/m ²
	3	6.4-7.0m/s	300-400W/m ²
	4	7.0-7.5m/s	400-500W/m ²
	5	7.5-8.0m/s	500-600W/m ²
	6	8.0-8.8m/s	500-800W/m ²
	7	>8.8m/s	>800W/m ²

OCEAN



GEO THERMAL





Geothermal: hot water, surface recharge



Hydro

Trouble with Renewables

- **Diffuse, dispersed: gathering cost**
- **Richest are remote: “stranded”**
 - High intensity
 - Large geographic extent
- **Time-varying output:**
 - “Intermittent”
 - “Firming” integration + storage required
- **Distributed AND centralized**

Trouble with Renewables: Big Three

1. Transmission and gathering
2. Storage: Annual-scale firming
3. Integration
 - Extant energy systems
 - Electricity grid
 - Fuels: CHP, transportation

Trouble with Renewables: Electricity Transmission

- Grid nearly full: who pays?
- Integration
 - Continental energy system
 - Quality
 - Time-varying
- Costly “firming” storage: CAES, VRB, pump hydro
- Low capacity factor (CF) or curtailment
- Overhead vulnerable: God or man
- Underground: only HVDC, 6x cost
- Wide ROW
- NIMBY: delay + cost, site + ROW

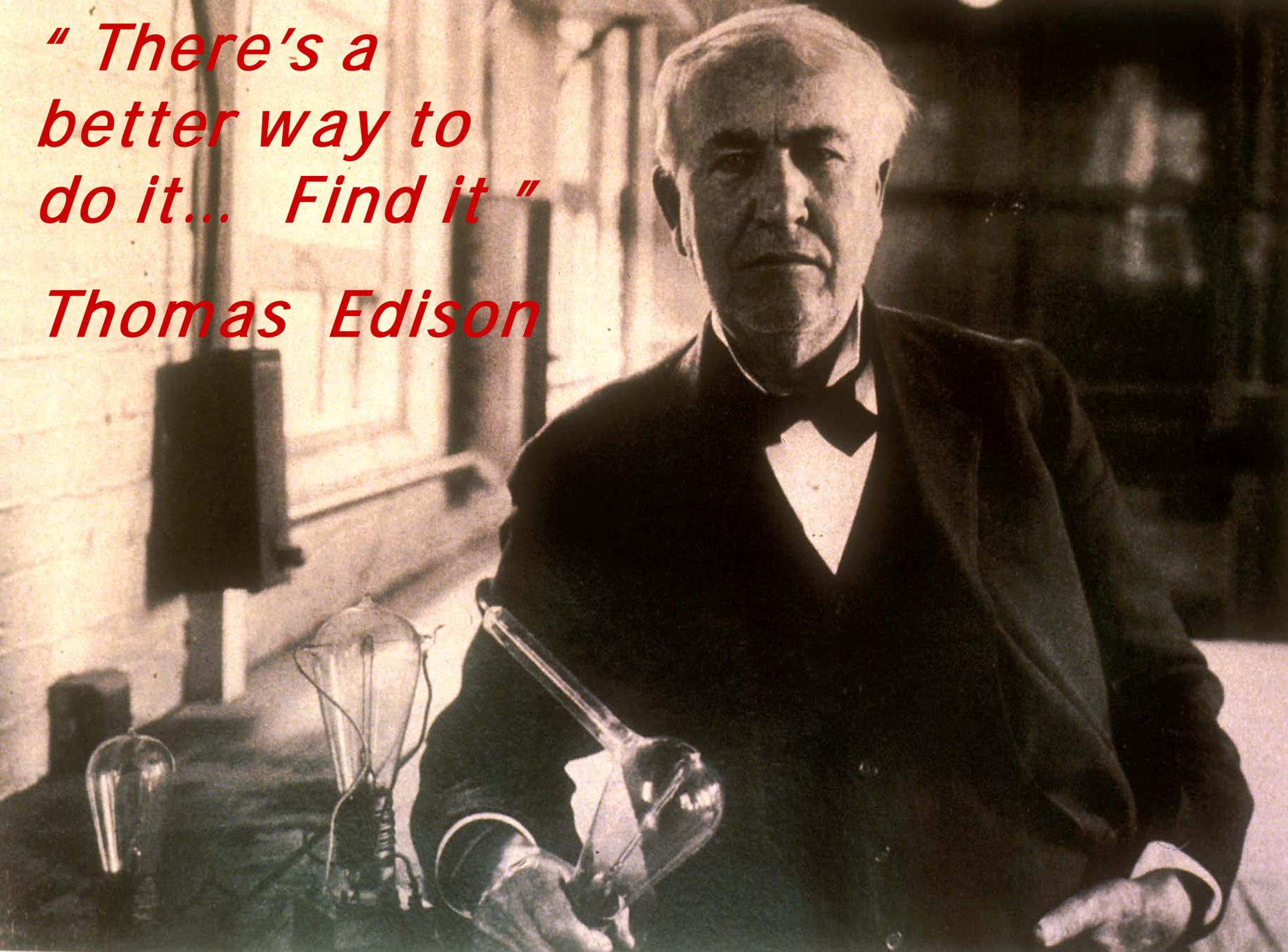
Zion, IL

Near Zion nuclear plant, Oct 02

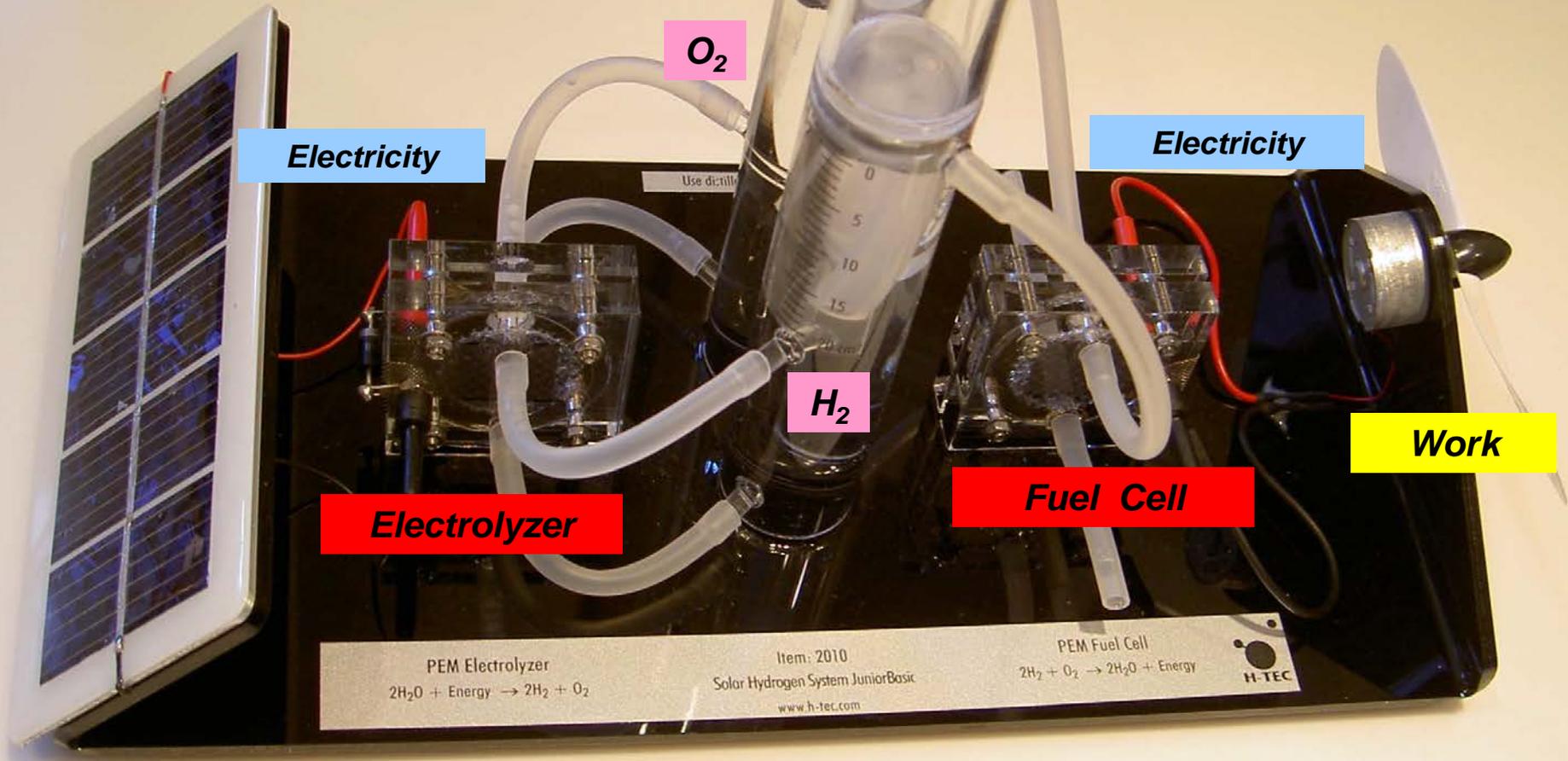


*" There's a
better way to
do it... Find it "*

Thomas Edison

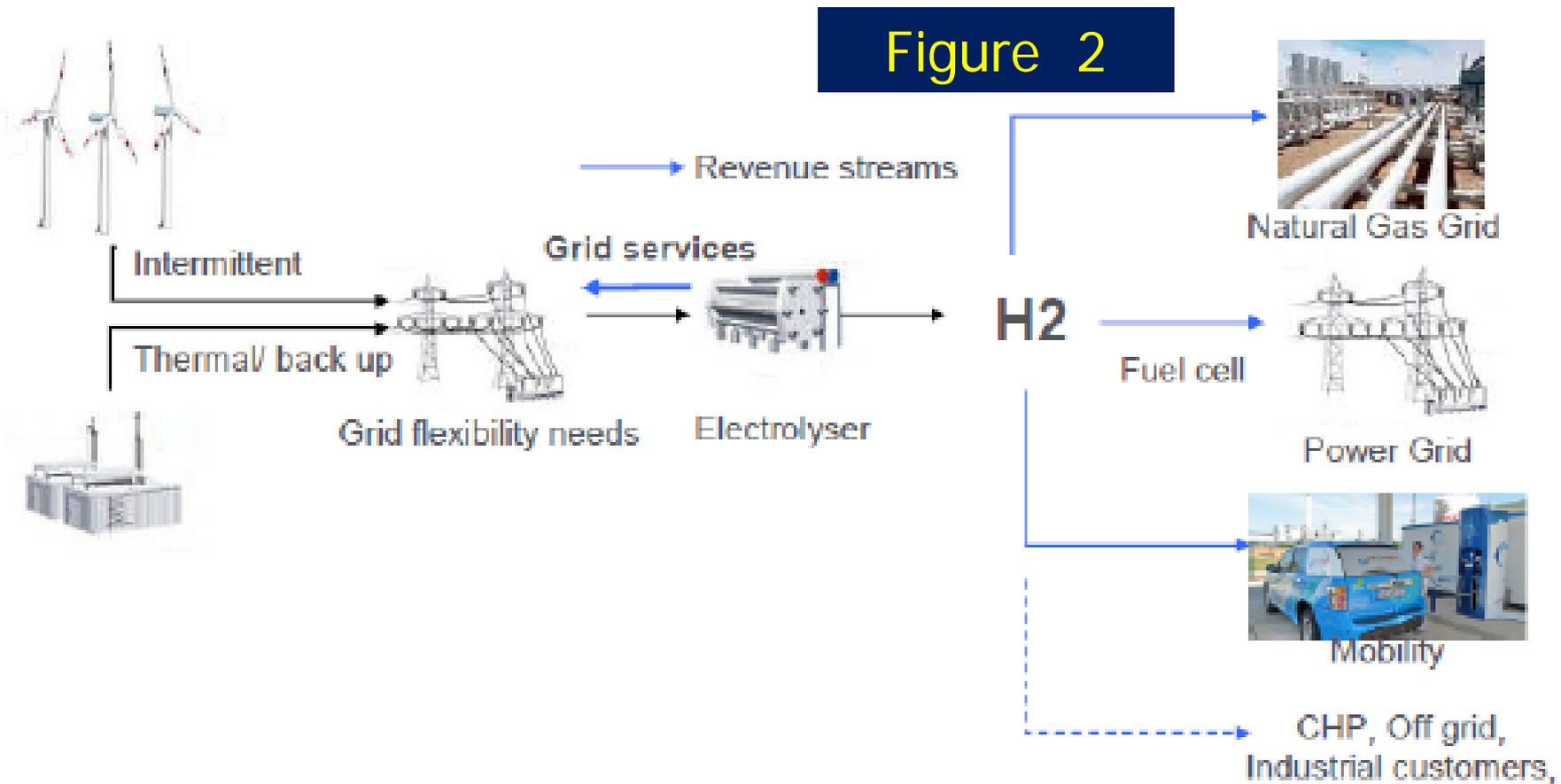


**Sunlight from
local star**



Solar Hydrogen Energy System

Versatility of Hydrogen is a key advantage for energy storage



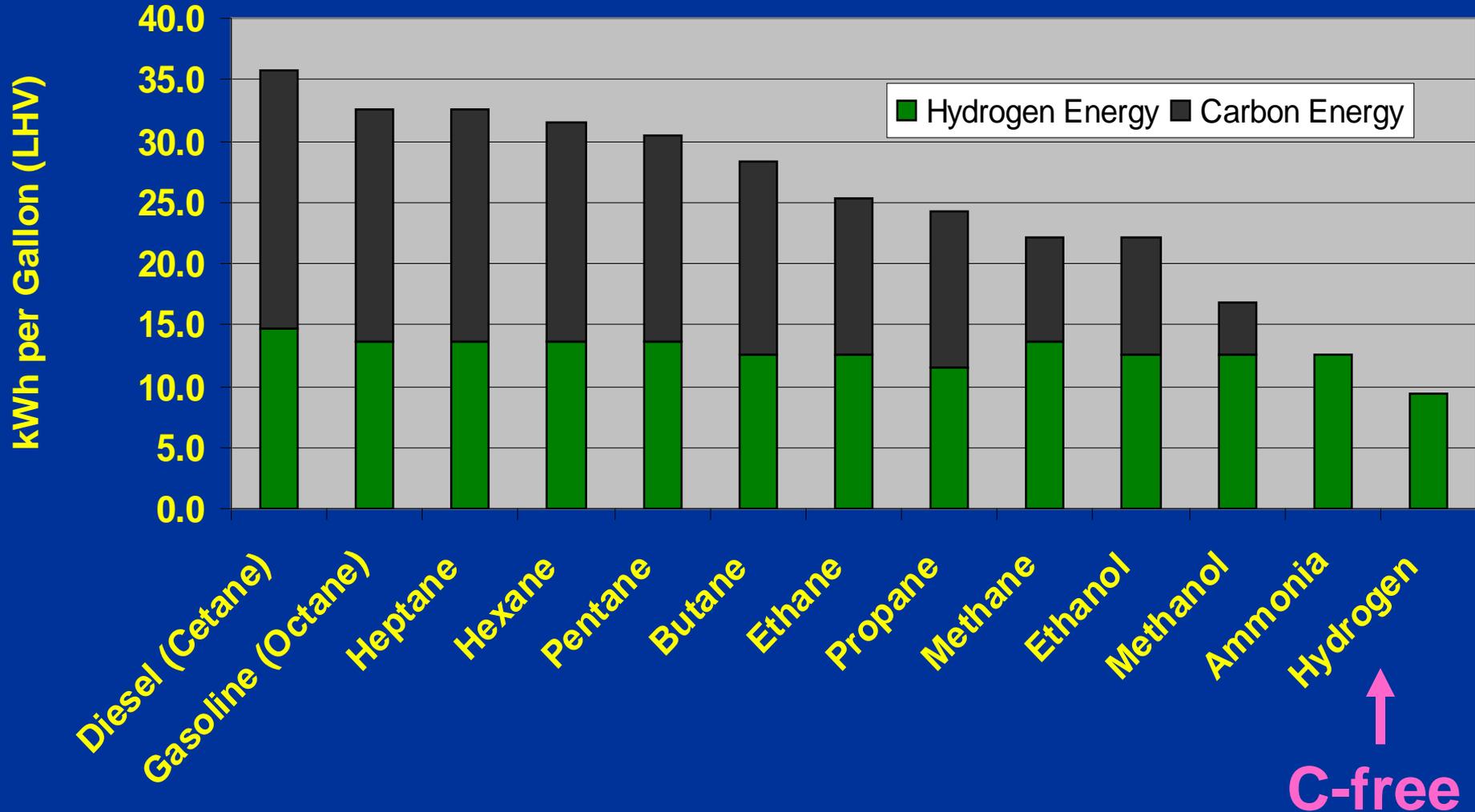
NextSTEPS White Paper: THE HYDROGEN TRANSITION

July 29, 2014 : Joan Ogden, Christopher Yang, Michael Nicholas, Lew Fulton
Institute of Transportation Studies, University of California, Davis

Hydrogen and Ammonia Fuels

- **Solve electricity's RE problems:**
 - **Transmission**
 - **Firming storage**
 - **Grid integration: time-varying output**
- **Carbon-free**
- **Underground pipelines**
- **Low-cost storage: < \$ 1.00 / kWh capital**
 - **Pipelines**
 - **GH2 salt caverns**
 - **NH3 tanks**

Volumetric Energy Density of Fuels (Fuels in their Liquid State)



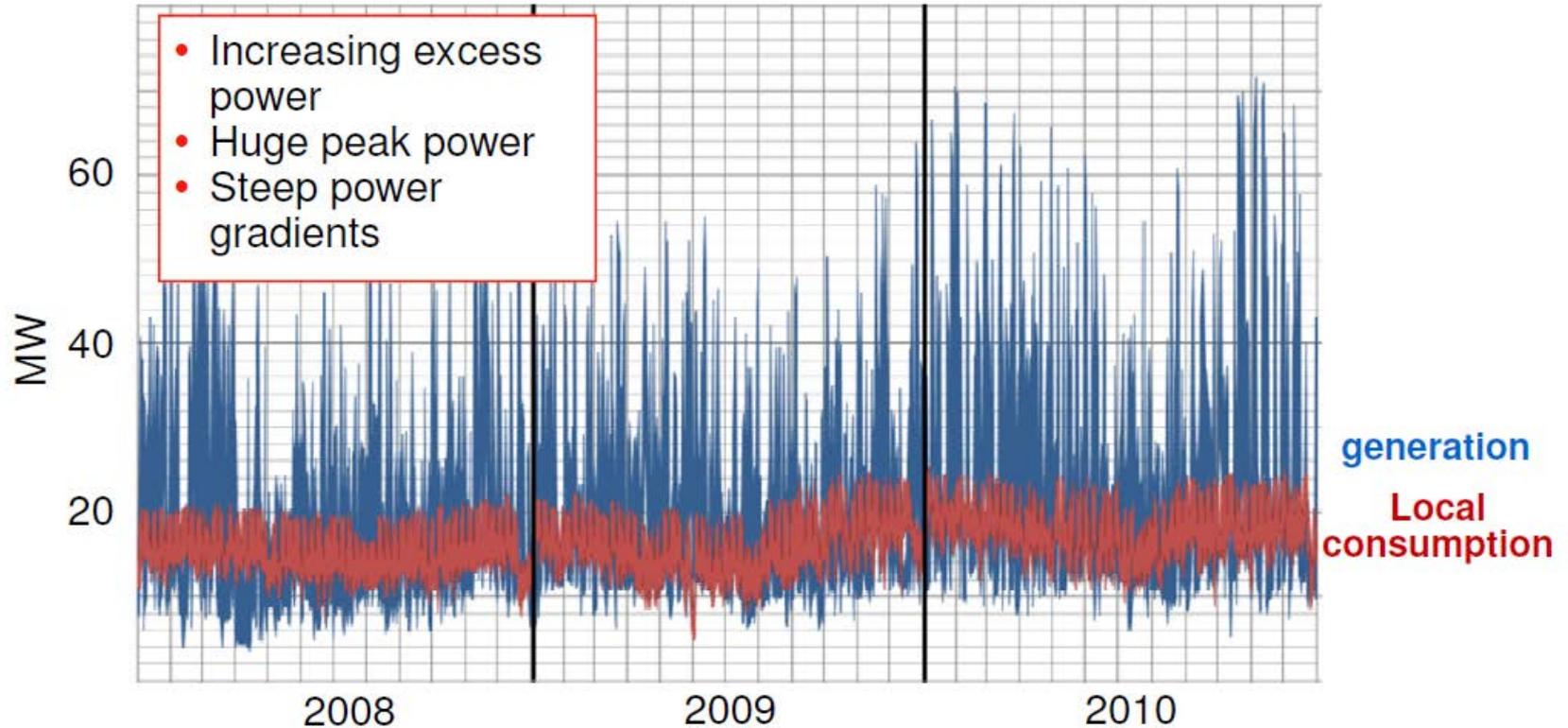
C-free

Hydrogen and Ammonia Fuels

- Delivering fuels: distribution
- ICE, CT, Fuel cell
- CHP on-site
- Utility substation wholesale
- Transportation
 - Rail
 - Truck
 - Personal
- Emissions: H_2O , N_2

Germany: window on the challenges of integrating high penetration of renewables

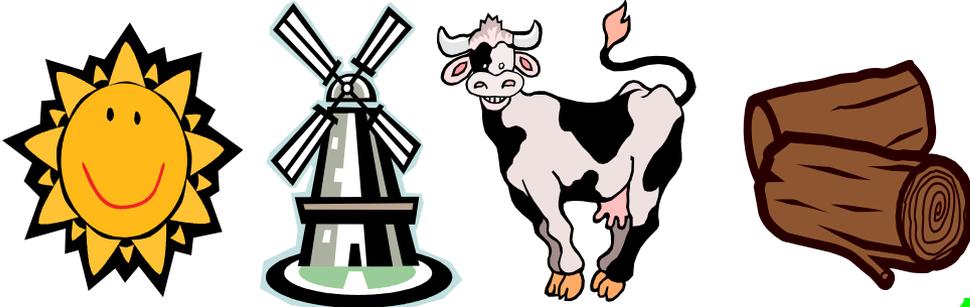
Falkenhagen Region in Northern Germany



Solution: Storage of excess wind power instead of curtailment.



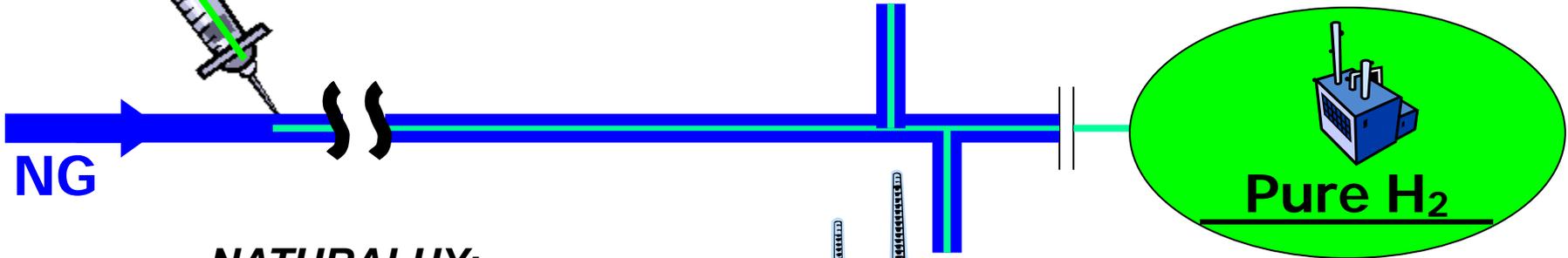
The NATURALHY approach: EC, R+D



H₂

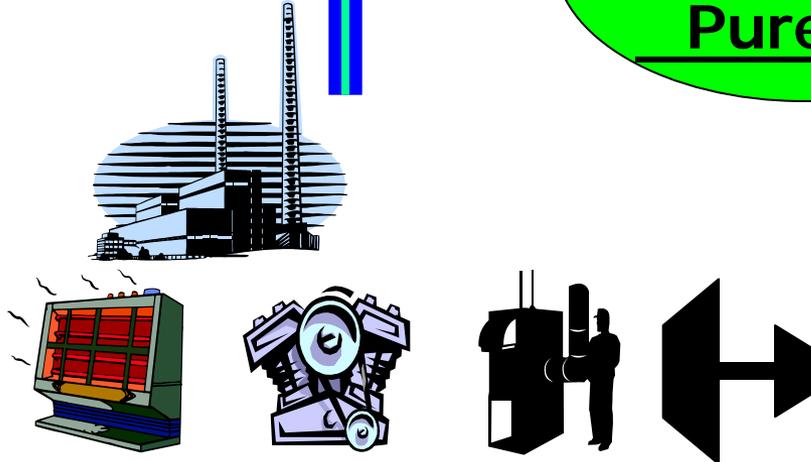


NG



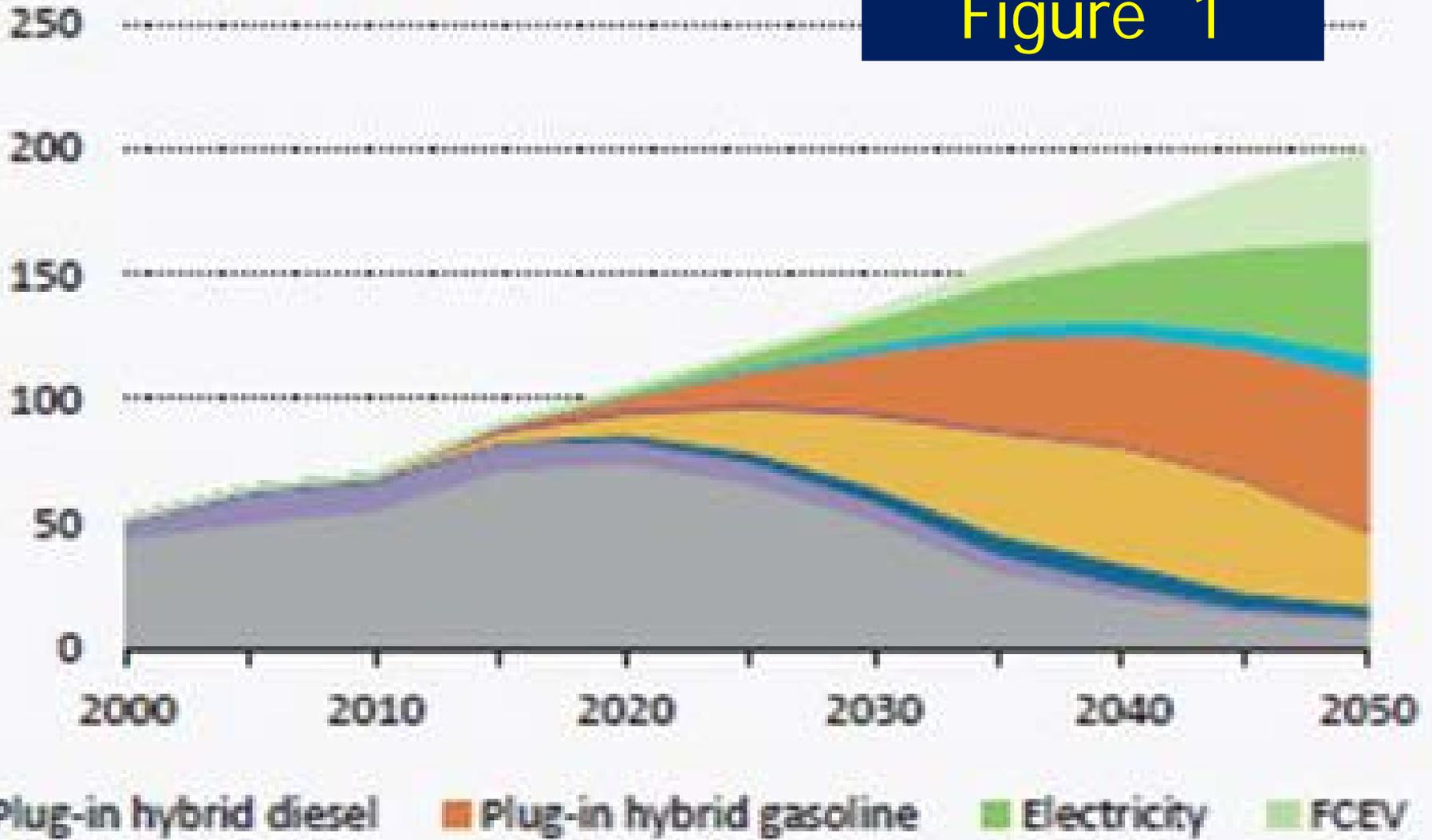
NATURALHY:

- *Breaks “chicken-egg” dilemma*
- *Bridge to sustainable future*



Improve case

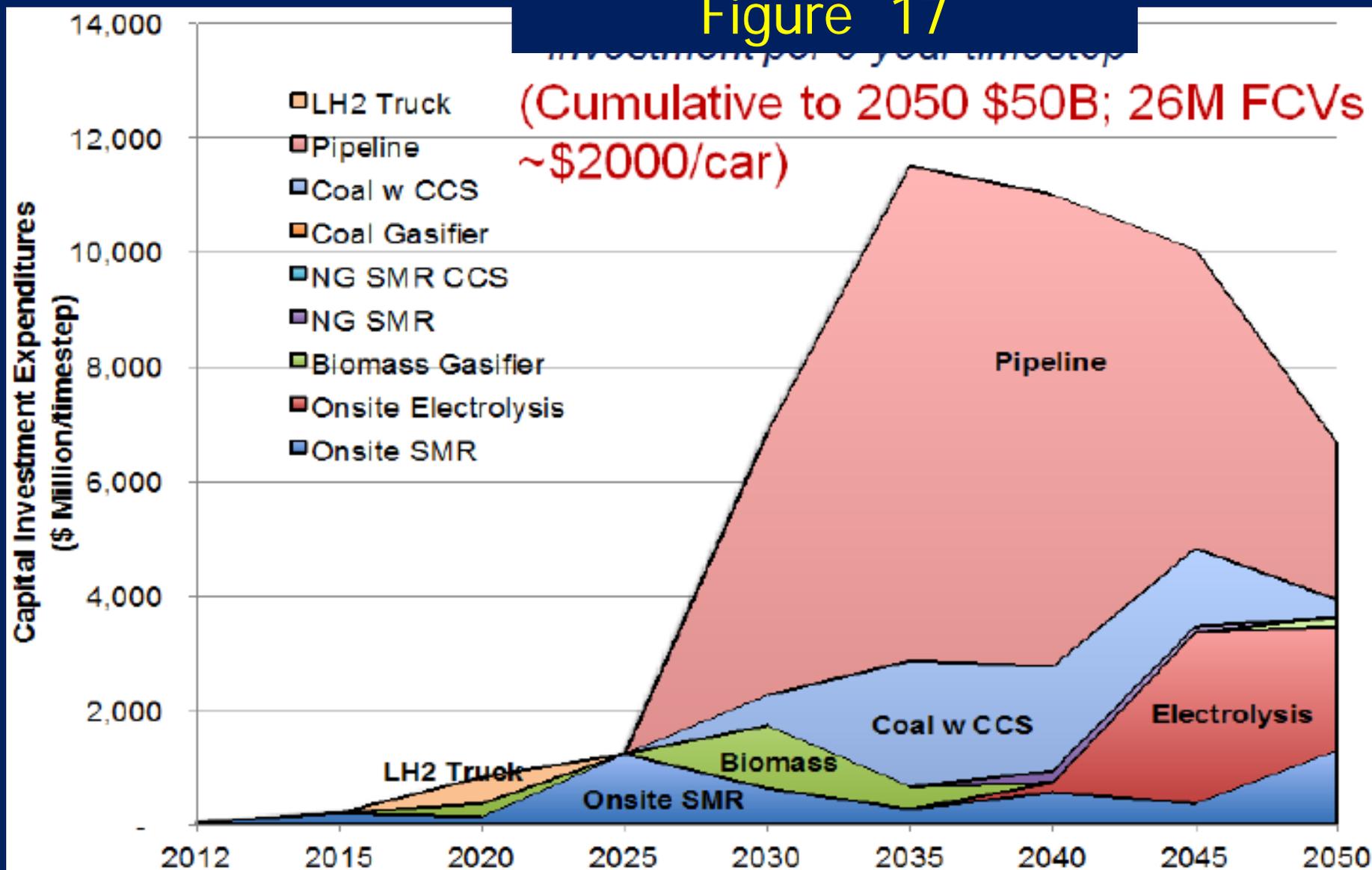
Figure 1



NextSTEPS White Paper: THE HYDROGEN TRANSITION

July 29, 2014 Joan Ogden, Christopher Yang, Michael Nicholas, Lew Fulton
Institute of Transportation Studies, University of California, Davis

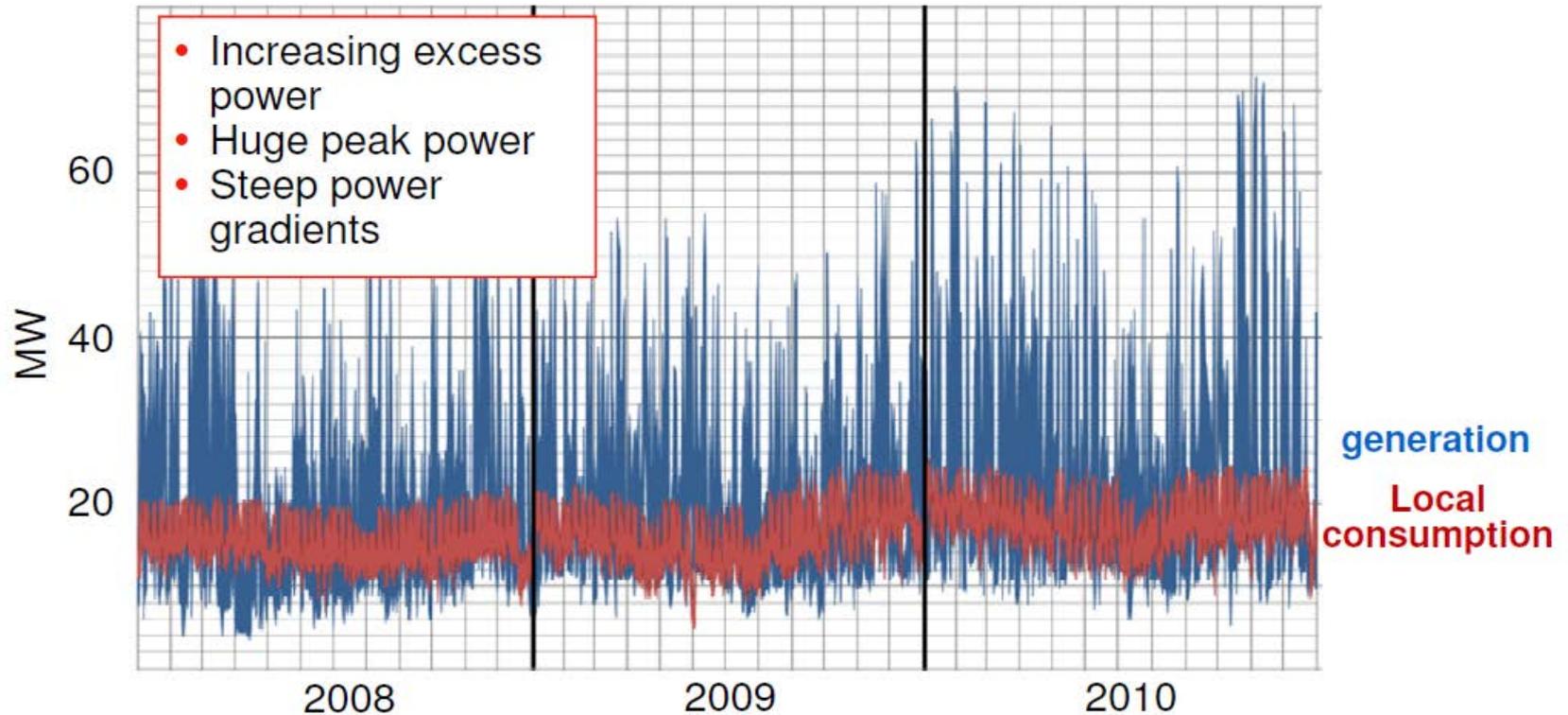
Figure 17



80% Carbon cut by 2050: CA Infrastructure Investments

Free Storage + Free Transmission in E.on Natural Gas Pipeline System

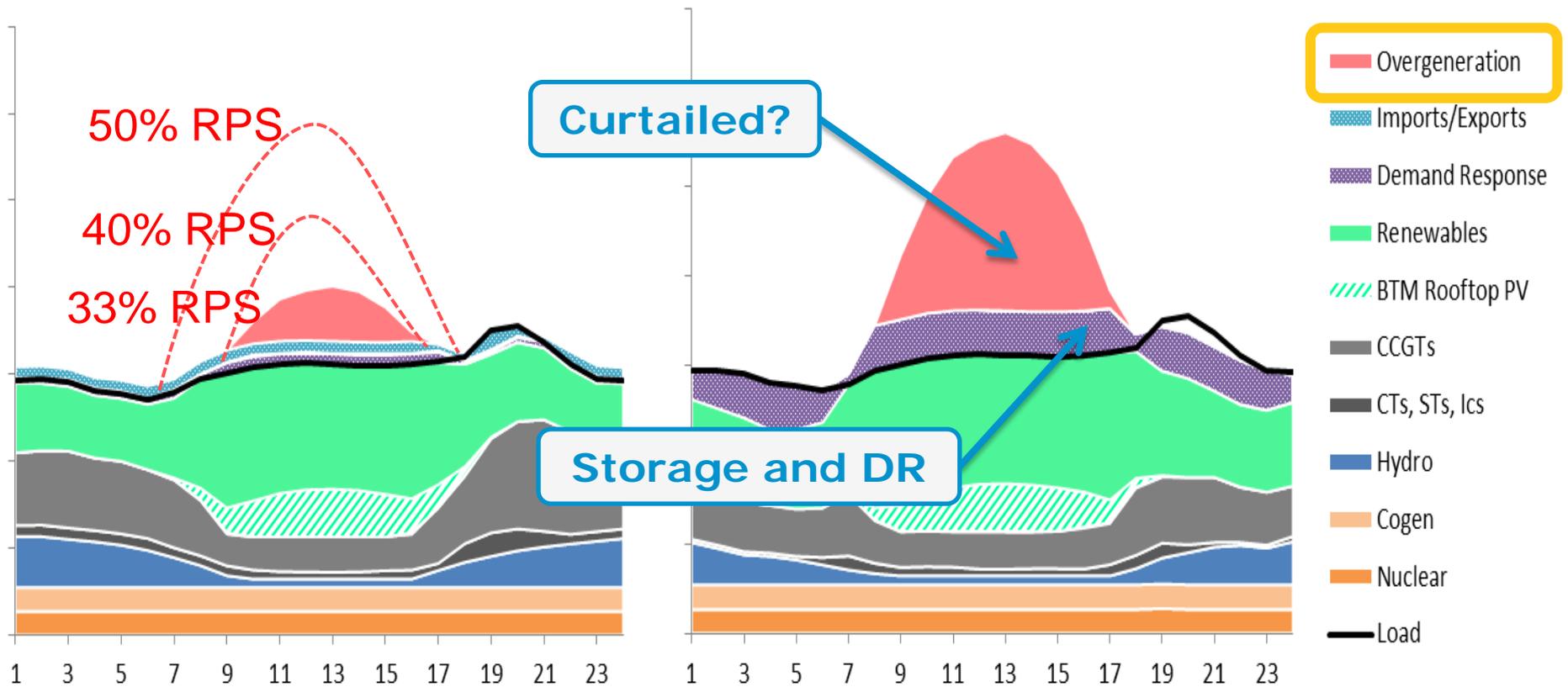
Falkenhagen Region in Northern Germany



Solution: Storage of excess wind power instead of curtailment.



California's surplus renewable generation



Do Not Cite
For Illustrative Purposes Only

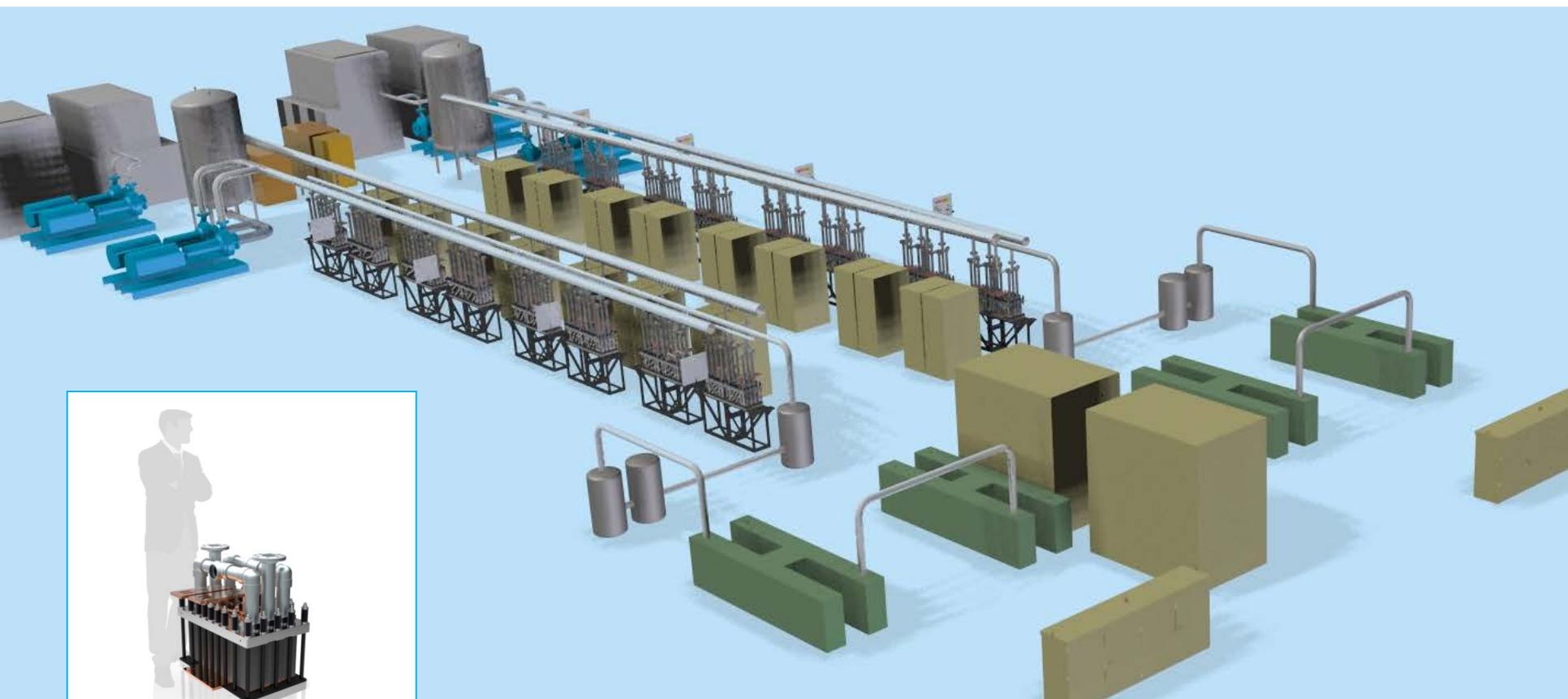
E.ON first Power-to-Gas plant Injecting hydrogen into natural gas grid

2MW Power-to-Gas Demonstration Plant in Falkenhagen, Germany

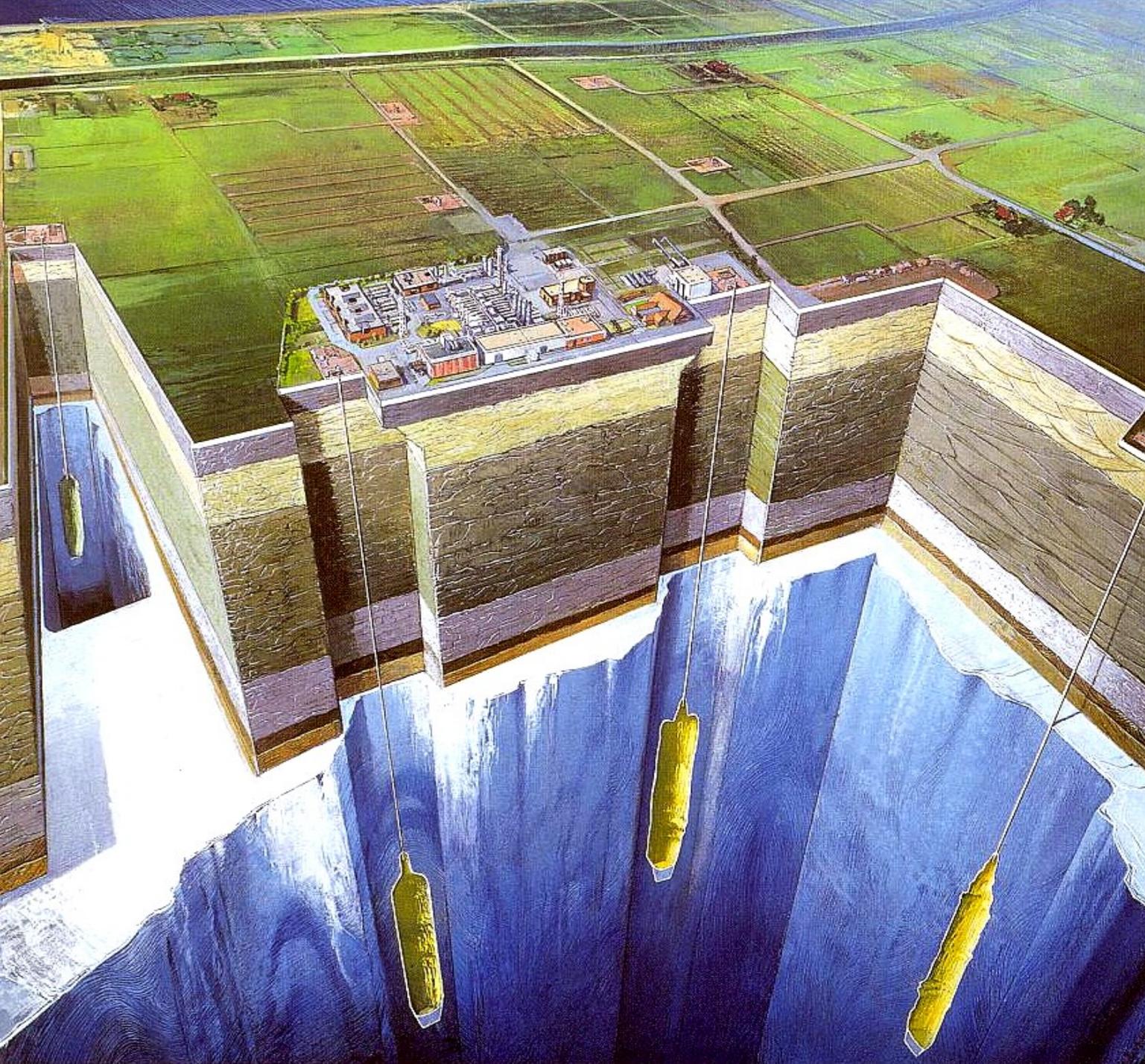


Hydrogenics' compact 1 MW PEM electrolyser Increments up to 1,500 kg/day

Future Hydrogenics' PEM Electrolyser Configuration



Domal Salt Storage Caverns



- 860,000 m³ physical
- 150 bar = 2,250 psi
- 2,500 Mt net = 92,500 MWh
- \$15M avg cap cost / cavern
- \$160 / MWh = \$0.16 / kWh
- Cavern top ~ 700m below ground

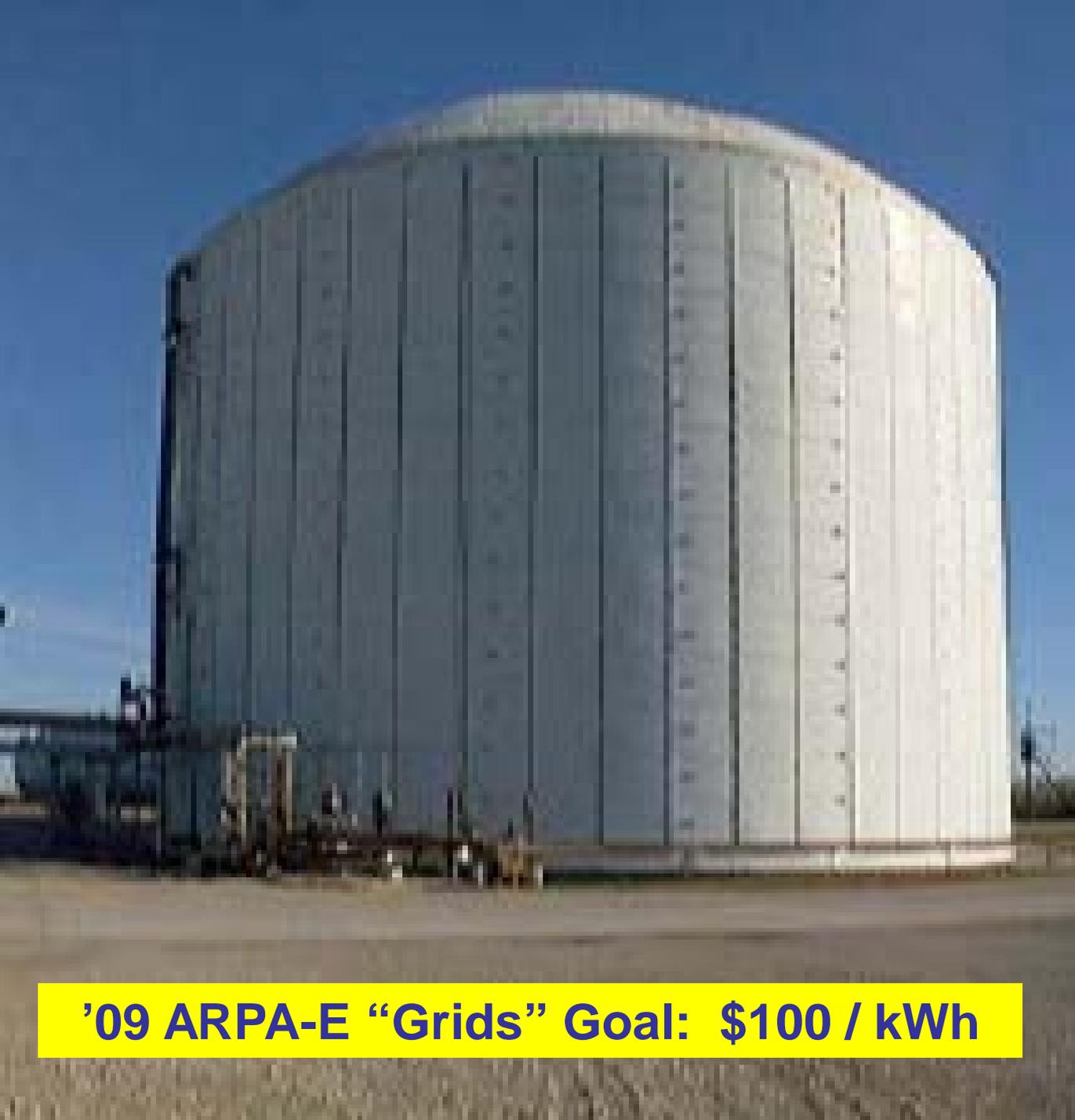
Domal Salt Storage Caverns

Texas

“Clemens
Terminal”
Conoco
Phillips
20 years

Praxair
'07

PB ESS



***“Atmospheric”
Liquid
Ammonia
Storage Tank
(corn belt)***

30,000 Tons

190 GWh

\$ 15M turnkey

\$ 80 / MWh

\$ 0.08 / kWh

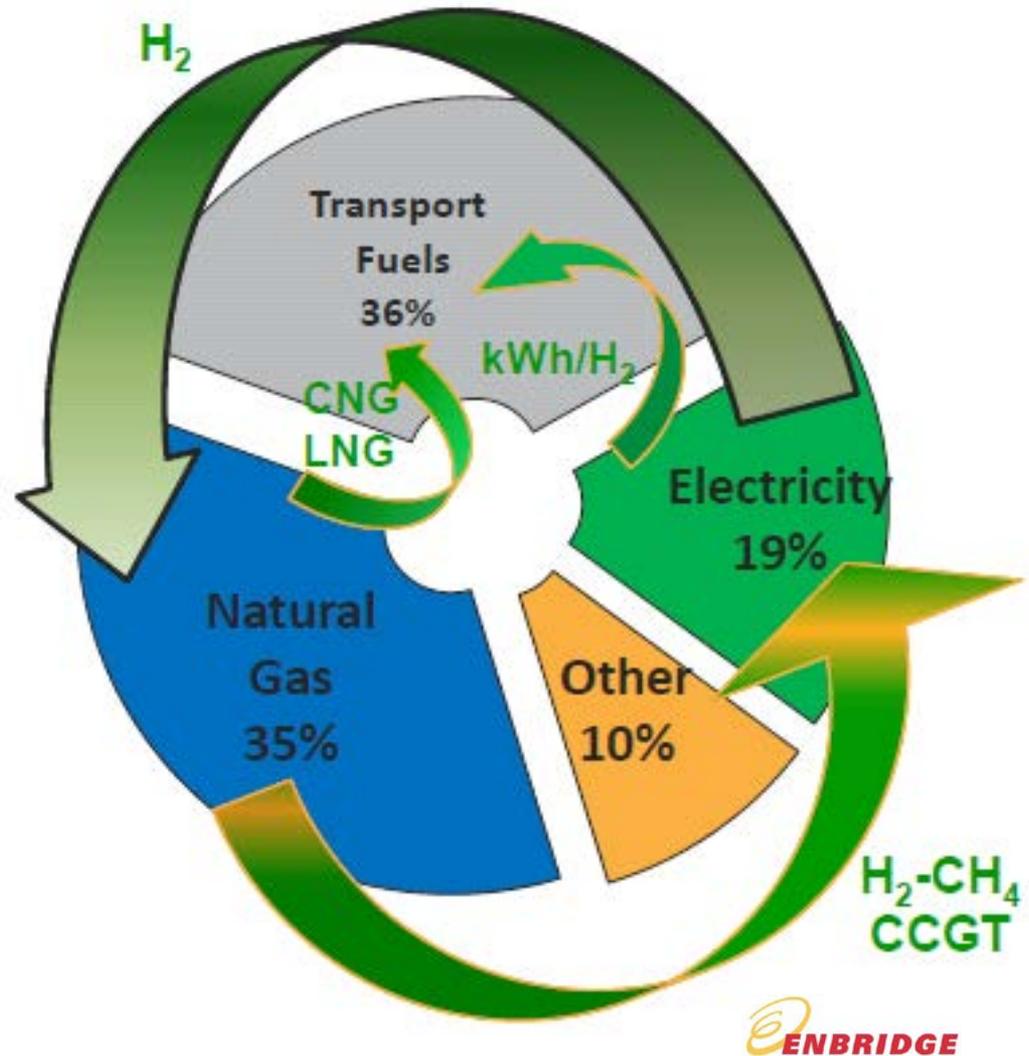
-33 C

1 Atm

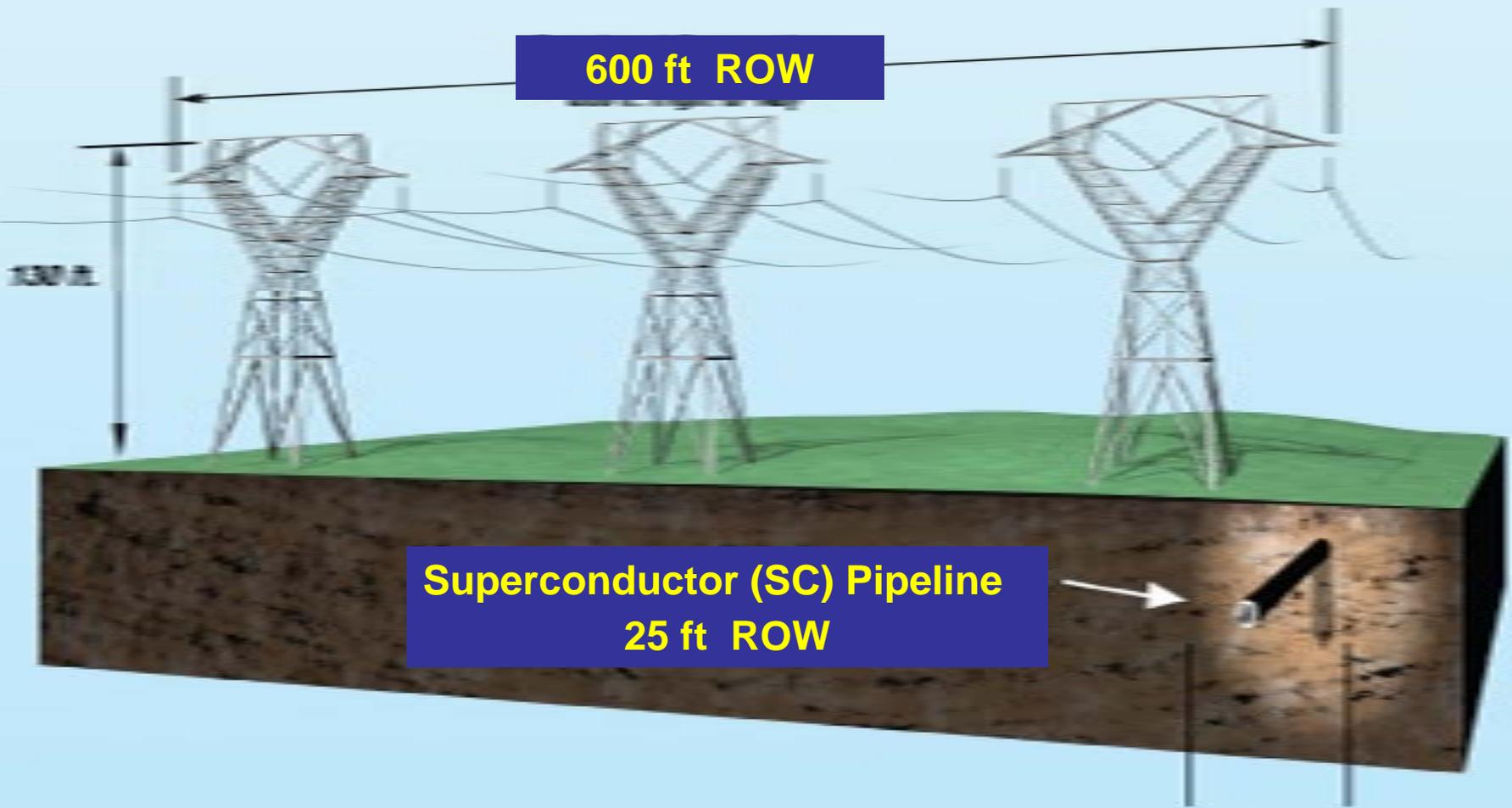
'09 ARPA-E “Grids” Goal: \$100 / kWh

What if we broke down our silos

Integrative
Thinking
About
Electricity
and
Energy



Source data: National Energy Board secondary energy demand forecast, Rethinking Energy Conservation in Ontario, May 2010 report



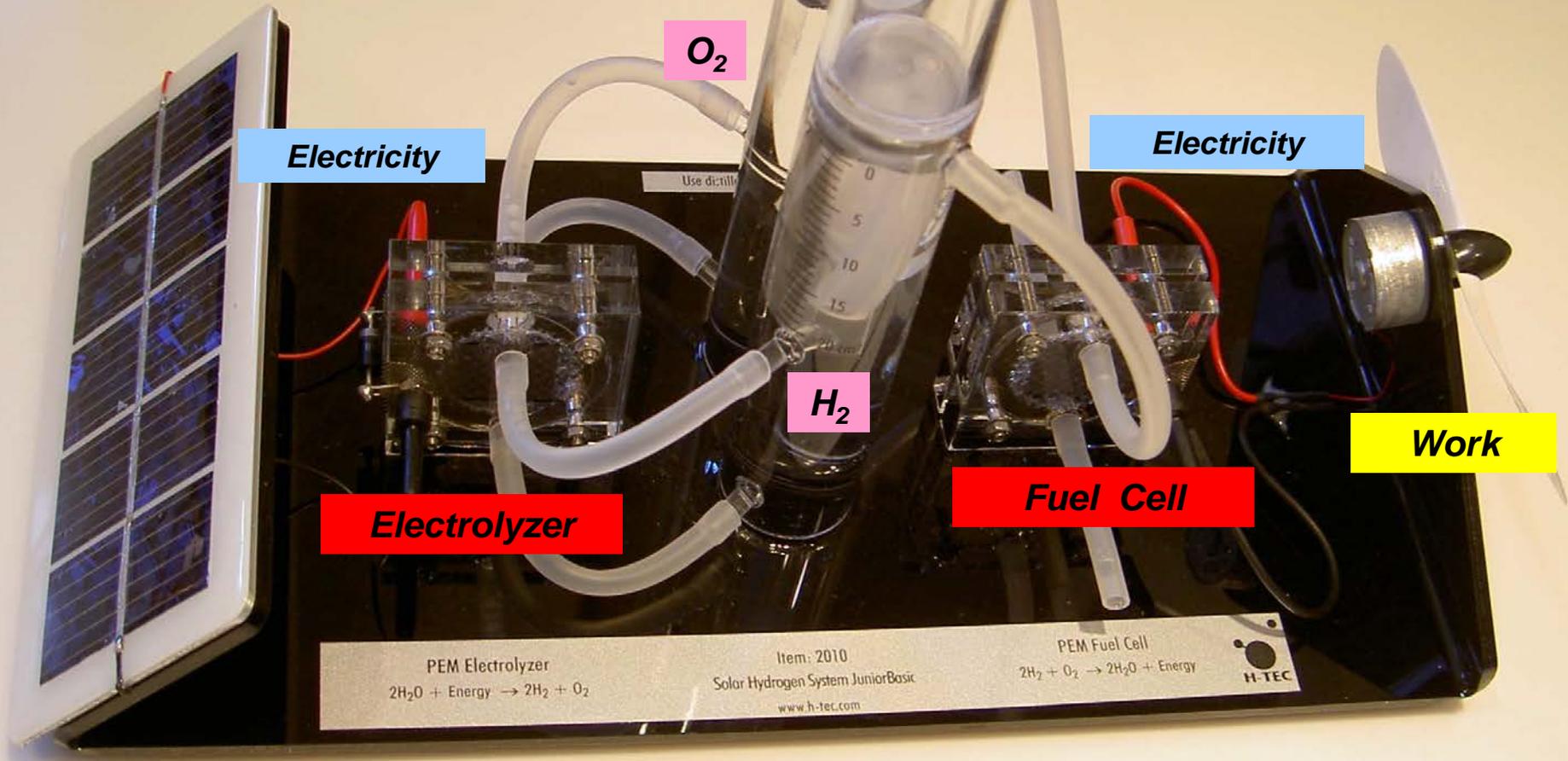
Out of Sight, Out of Harm's Way

10,000 MW alternatives: HVAC vs HVDC superconductor

“Firm” Energy Essential

- Every hour, every year
- Dispatchable
- Strategically: indigenous, secure
- Market price: worth more
- Bankable large projects
- Risk avoidance:
 - Rapid climate change
 - Economic chaos

**Sunlight from
local star**



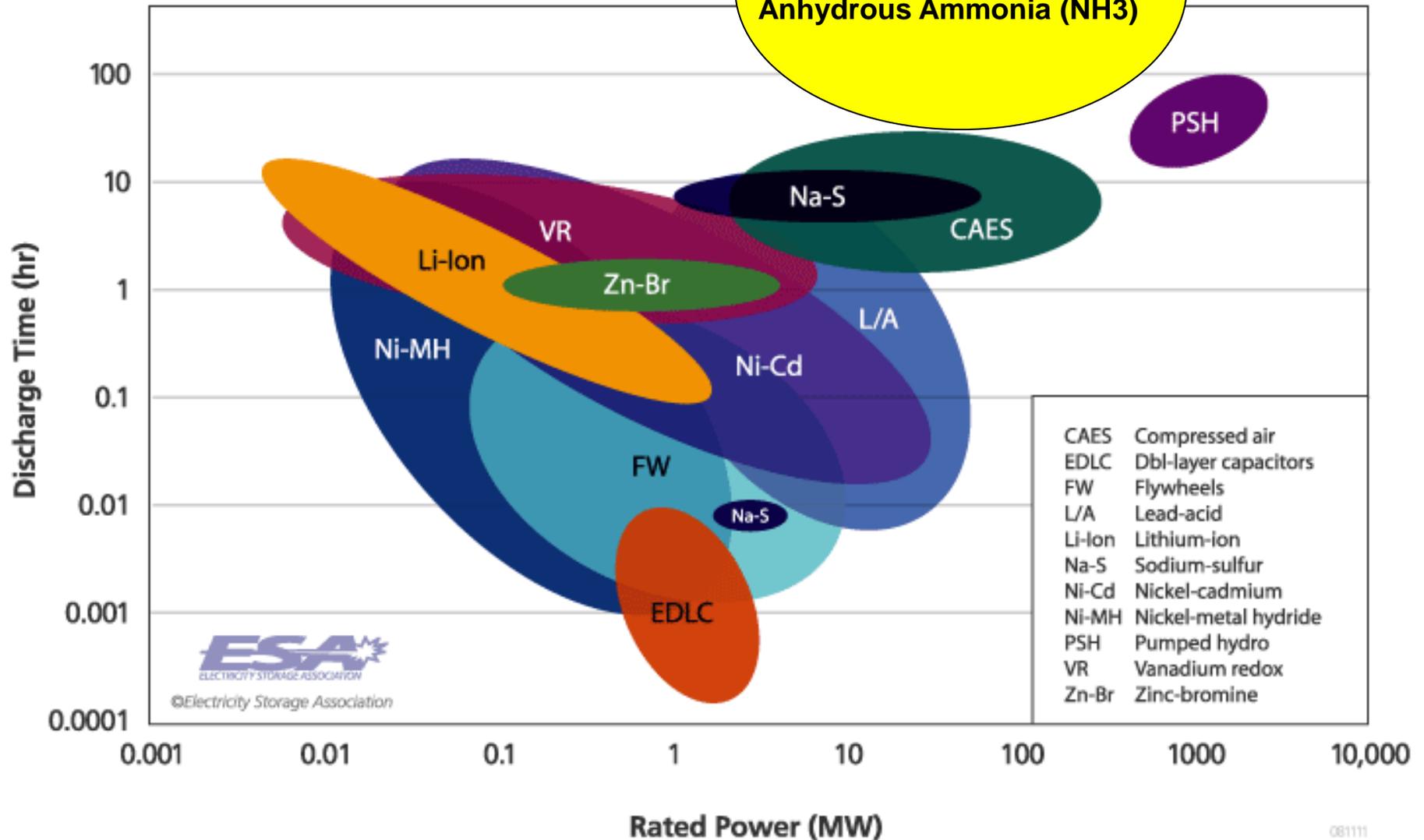
Solar Hydrogen Energy System

Energy Storage System Characteristics

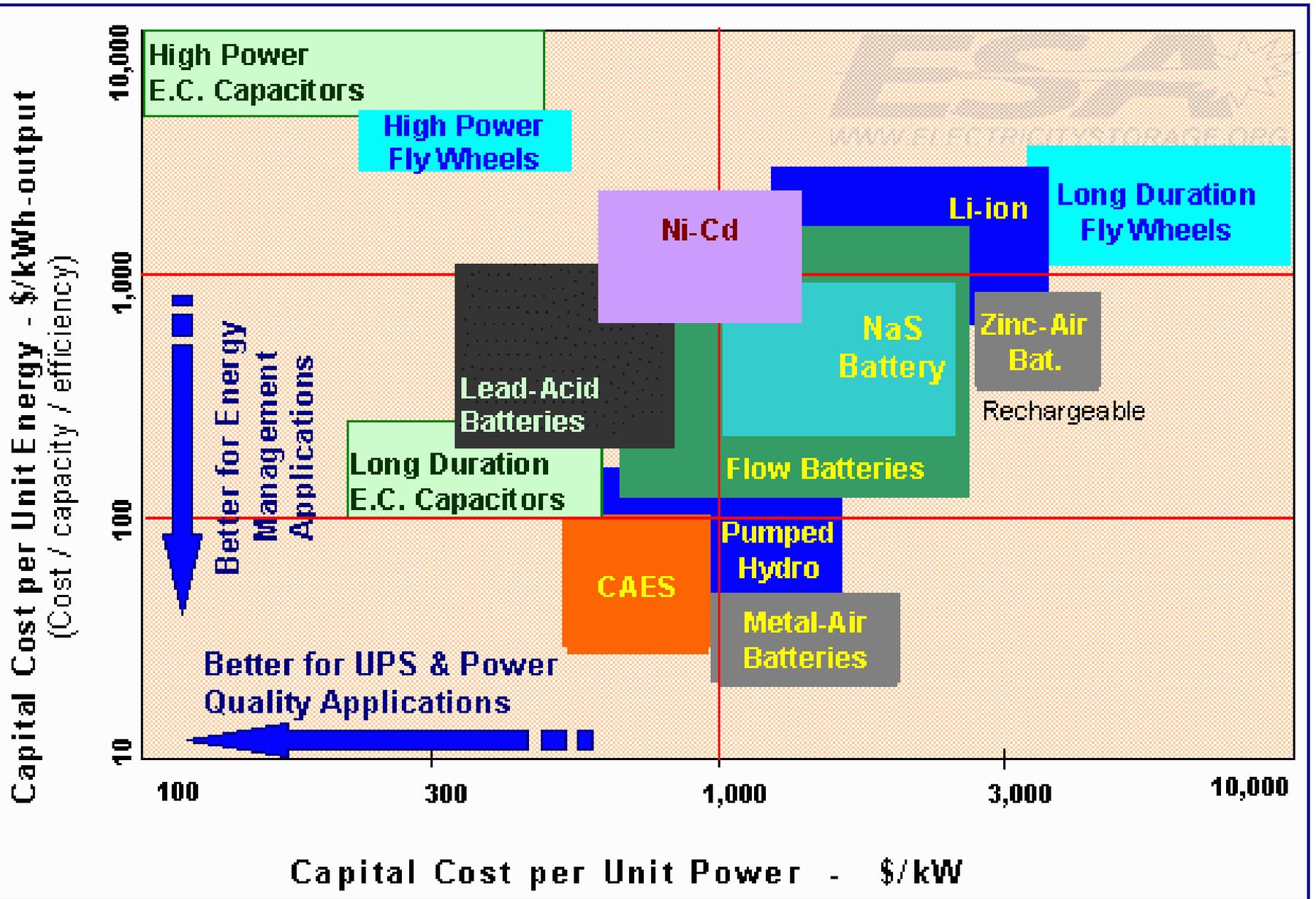
Hydrogen and Ammonia off the charts ?

- ***Storage capacity (Mwh, scf, nM3, Mt, gallons)***
- ***Power (MW, scfm) In / Out rate***
- ***Costs***
 - ***Capital***
 - ***O&M***
- **Efficiency**
- **Response time**
- **Durability (cycling capacity)**
- **Reliability**
- **Autonomy**
- **Self-discharge**
- **Depth of discharge**
- **Adaptation to the generating source**
- **Mass and volume densities of energy**
- **Monitoring and control equipment**
- **Operational constraints**
- **Feasibility**
- **Environmental**

System Ratings

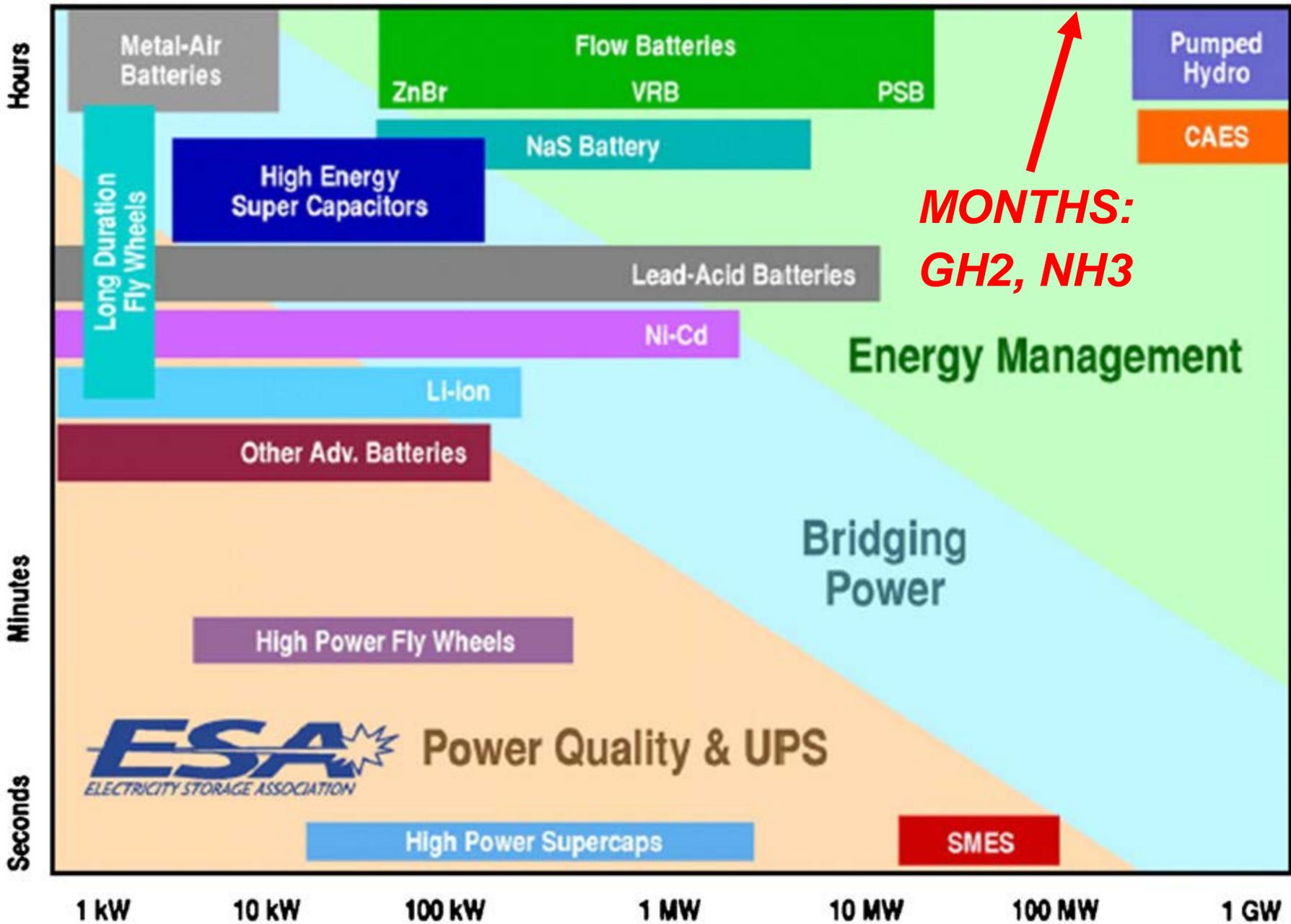


©Electricity Storage Association



GH2 and NH3

Discharge Time



Power



**“ Americans can be
counted on to
always do the right
thing –**

**but only after they
have tried
everything else ”**

Winston Churchill

The dog caught the car.

Dan Reicher

Beyond “Smart Grid”

- **Primarily DSM**
- **More vulnerable to cyberattack ?**
- **Adds no physical:**
 - **Transmission, gathering, distribution**
 - **Storage**
- **Next big thing; panacea**
- **Running the world on renewables ?**
- **Must think:**
 - **Beyond electricity**
 - **Complete energy systems**
 - **ALL energy: Hermann Scheer**

“Transmission”

- **Electrofuels**
- **Renewable-source electricity**
- **Underground pipelines**
- **Carbon-free fuels: hydrogen, ammonia**
- **Low-cost storage:**
 - **\$ 0.10 – 0.20 / kWh capital**
- **CHP, transport, industrial**
- **GW scale**

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

Capacity at 500 miles length

Capacity Factor (CF) = 30%

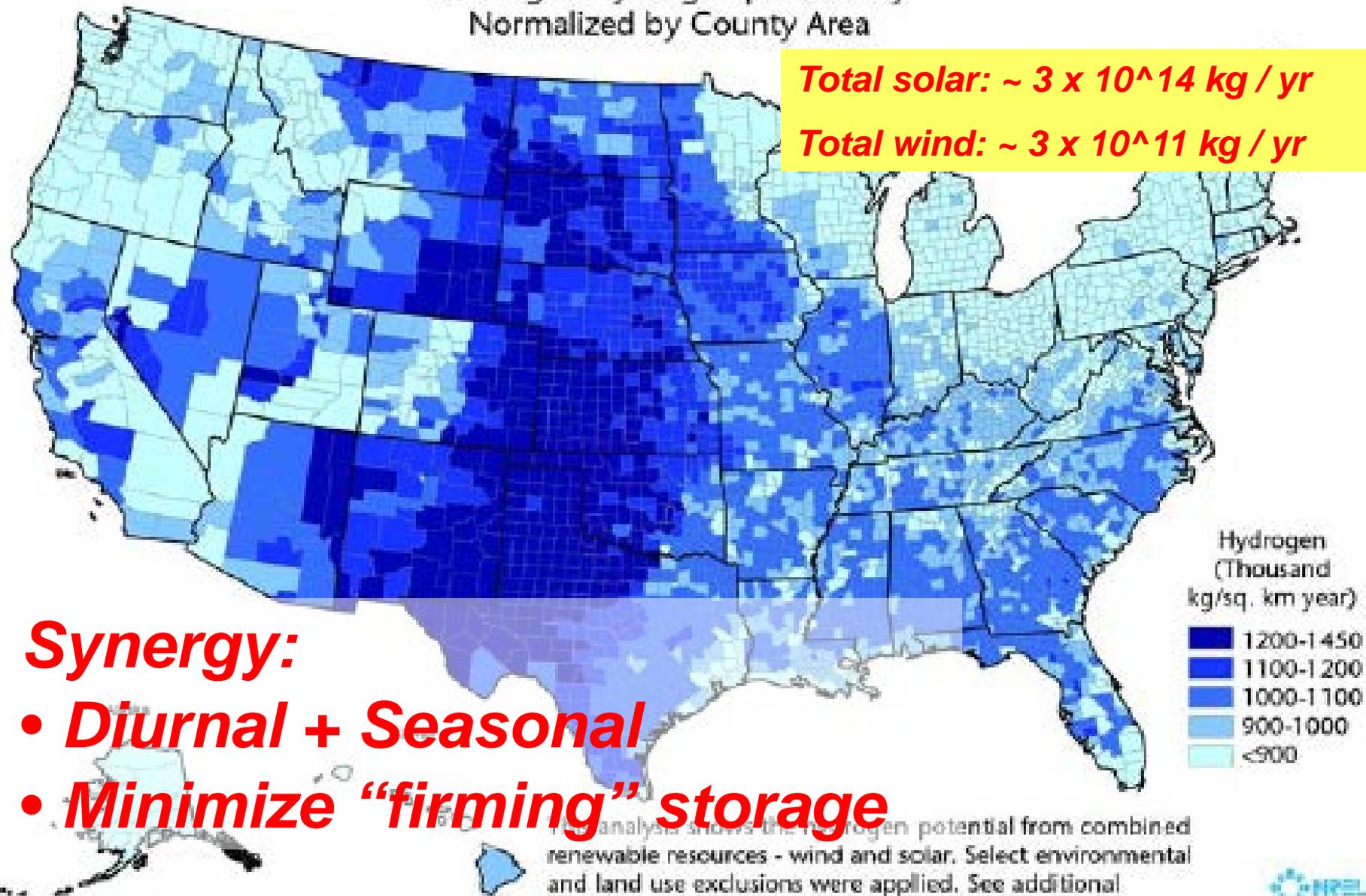
State	Annual Energy Production (TWh)	Nameplate Installed Capacity (MW)	Nameplate Installed Capacity (GW)	6 GW 36" GH2 Hydrogen Pipelines	\$ Billion Total Capital Cost	3 GW 500 KV HVDC Electric Lines	\$ Billion Total Capital Cost
Texas	6,528	1,901,530	1,902	317		634	
Kansas	3,647	952,371	952	159		317	
Nebraska	3,540	917,999	918	153		306	
South Dakota	3,412	882,412	882	147		294	
Montana	3,229	944,004	944	157		315	
North Dakota	2,984	770,196	770	128		257	
Iowa	2,026	570,714	571	95		190	
Wyoming	1,944	552,073	552	92		184	
Oklahoma	1,789	516,822	517	86		172	
Minnesota	1,679	489,271	489	82		163	
New Mexico	1,645	492,083	492	82		164	
Colorado	1,288	387,220	387	65		129	
TOTALS	33,711	9,376,694	9,377	1,563	\$1,500	3,126	\$2,000

Wind energy source: Archer, Jacobson 2003

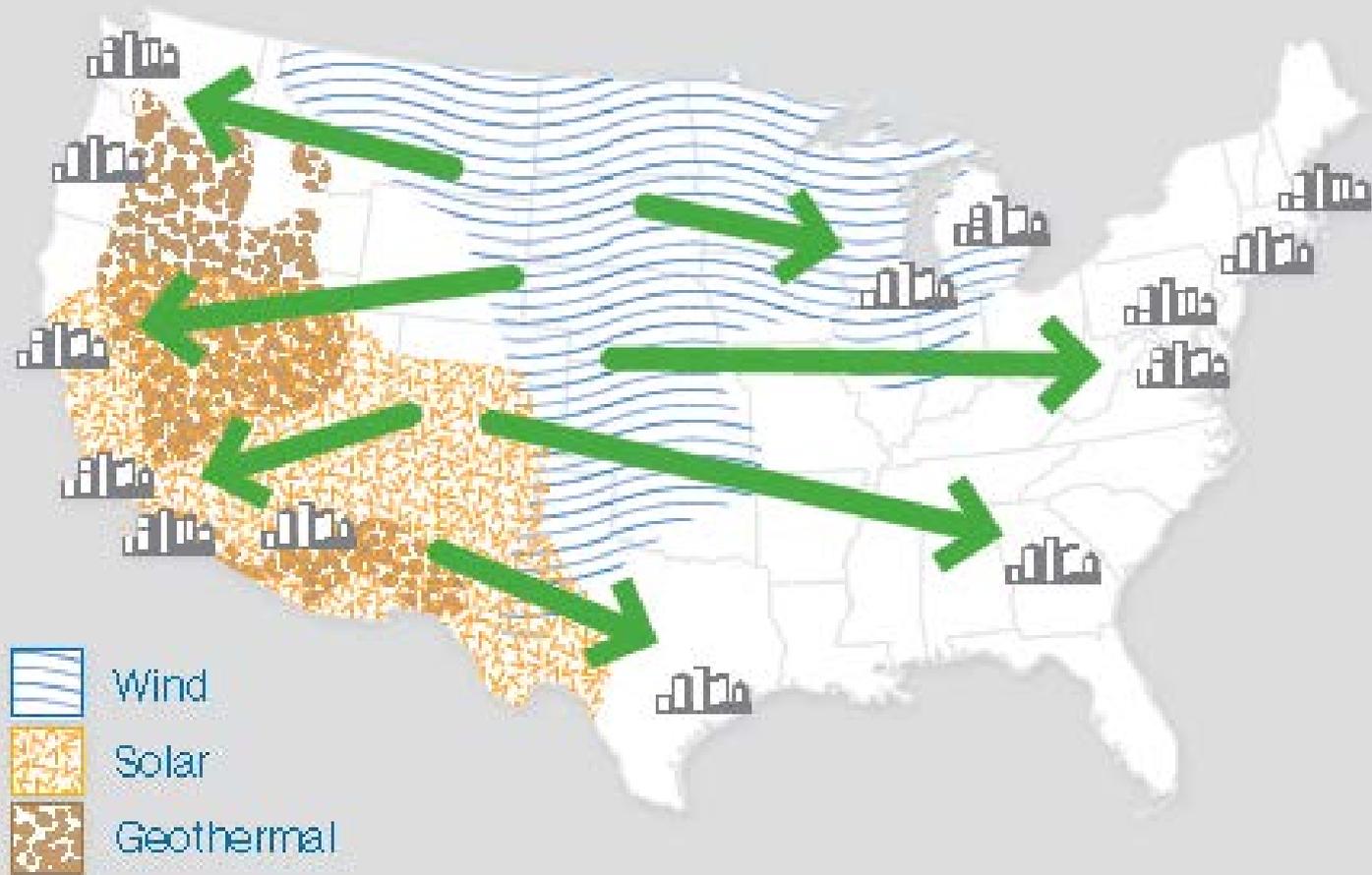
Figure 3

Hydrogen Potential from Solar and Wind Resources

Total kg of Hydrogen per County
Normalized by County Area



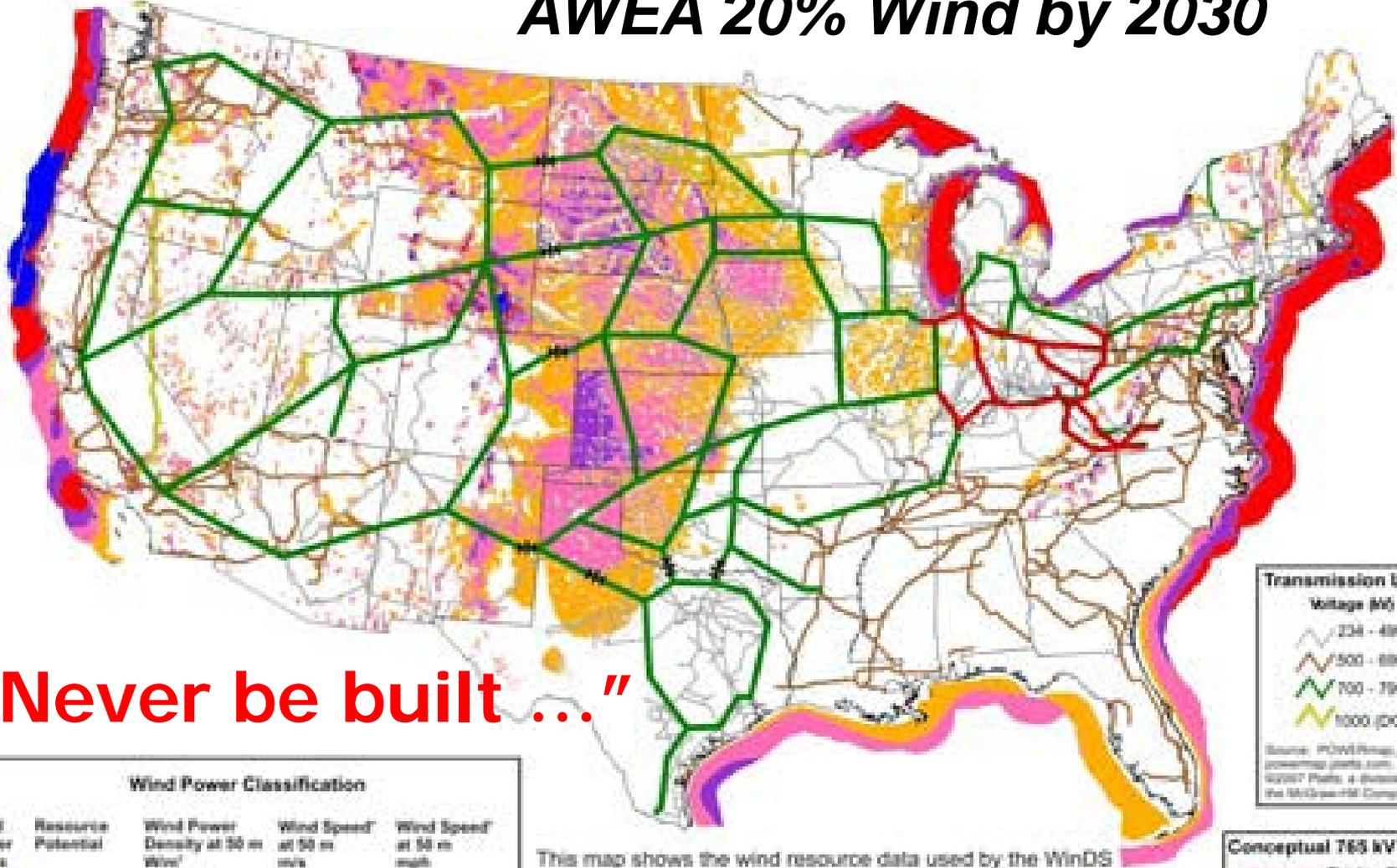
This analysis shows the hydrogen potential from combined renewable resources - wind and solar. Select environmental and land use exclusions were applied. See additional documentation for more information.



Source: AWEA and SEIA

SEIA – AWEA Feb 09
**“Green Power Superhighways:
Building a Path to America’s Clean Energy Future”**

AWEA 20% Wind by 2030



“Never be built ...”

Wind Power Classification

Wind Power Class	Resource Potential	Wind Power Density at 50 m W/m ²	Wind Speed ¹ at 50 m m/s	Wind Speed ¹ at 50 m mph
2	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

¹ Wind speeds are based on a Weibull k value of 2.0

Transmission Lines

Voltage (kV)

- 234 - 499
- 500 - 699
- 700 - 799
- 1000 (DC)

Source: FORTWIND, powermap.platts.com, ©2007 Platts, a Division of the McGraw-Hill Companies

Conceptual 765 kV Network

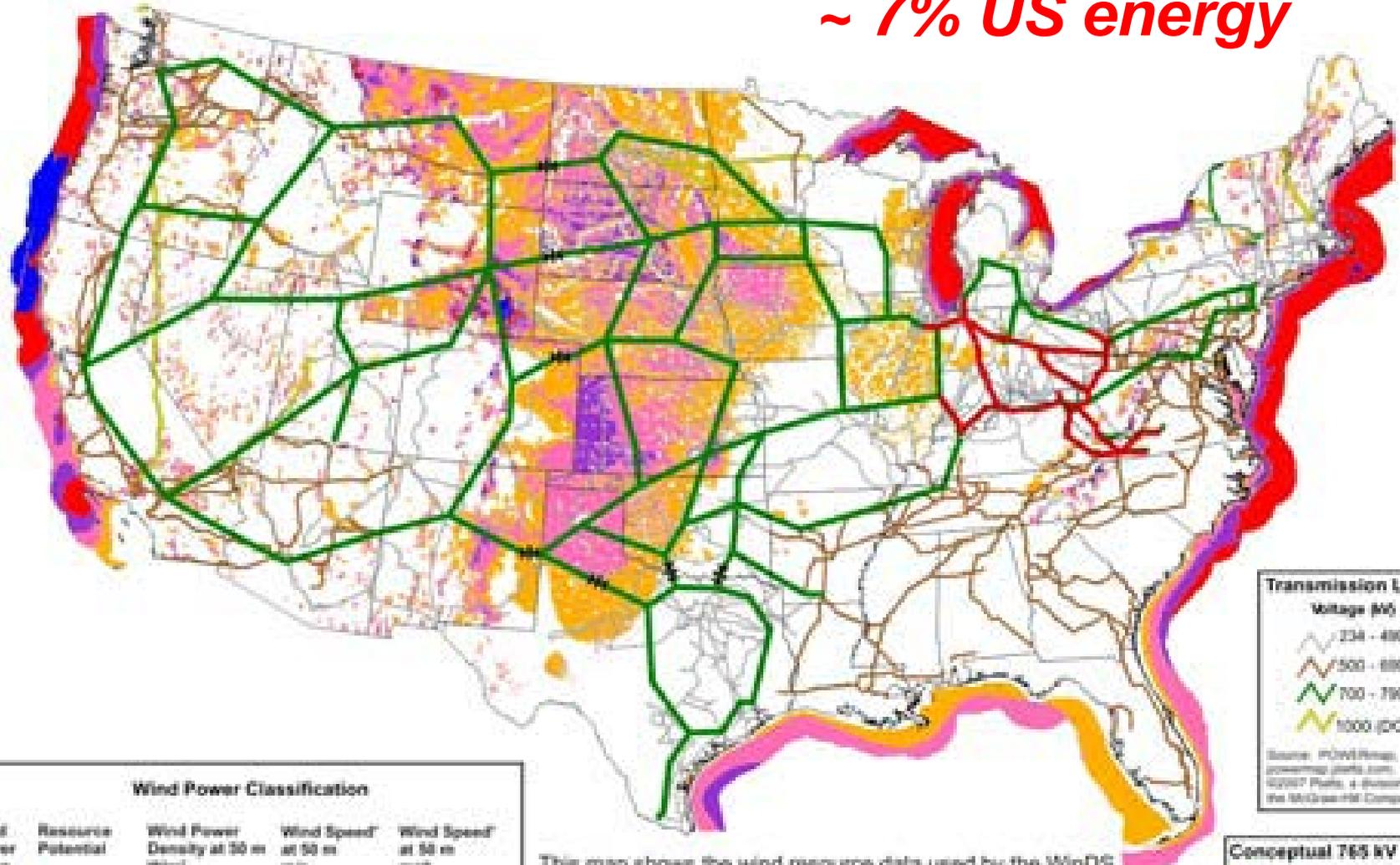
- Existing 765 kV
- New 765 kV
- AC-DC-AC Link

Source: American Electric Power (AEP)

This map shows the wind resource data used by the WinDS model for the 20% Wind Scenario. It is a combination of high resolution and low resolution datasets produced by NREL and other organizations. The data was screened to eliminate areas unlikely to be developed onshore due to land use or environmental issues. In many states, the wind resource on this map is visually enhanced to better show the distribution on ridge crests and other features.

AWEA: 20% Electricity from Wind by 2030

~ 7% US energy



Wind Power Classification

Wind Power Class	Resource Potential	Wind Power Density at 50 m W/m ²	Wind Speed ¹ at 50 m m/s	Wind Speed ¹ at 50 m mph
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

¹ Wind speeds are based on a Weibull k value of 2.0

Transmission Lines
Voltage (kV)

- 234 - 490
- 500 - 690
- 700 - 790
- 1000 (DC)

Source: POWRMap, powrmap.powr.com, ©2007 Powr, a division of the McGraw-Hill Companies

Conceptual 765 kV Network

- Existing 765 kV
- New 765 kV
- AC-DC-AC Link

Source: American Electric Power (AEP)

This map shows the wind resource data used by the WinDS model for the 20% Wind Scenario. It is a combination of high resolution and low resolution datasets produced by NREL and other organizations. The data was screened to eliminate areas unlikely to be developed onshore due to land use or environmental issues. In many states, the wind resource on this map is visually enhanced to better show the distribution on ridge crests and other features.

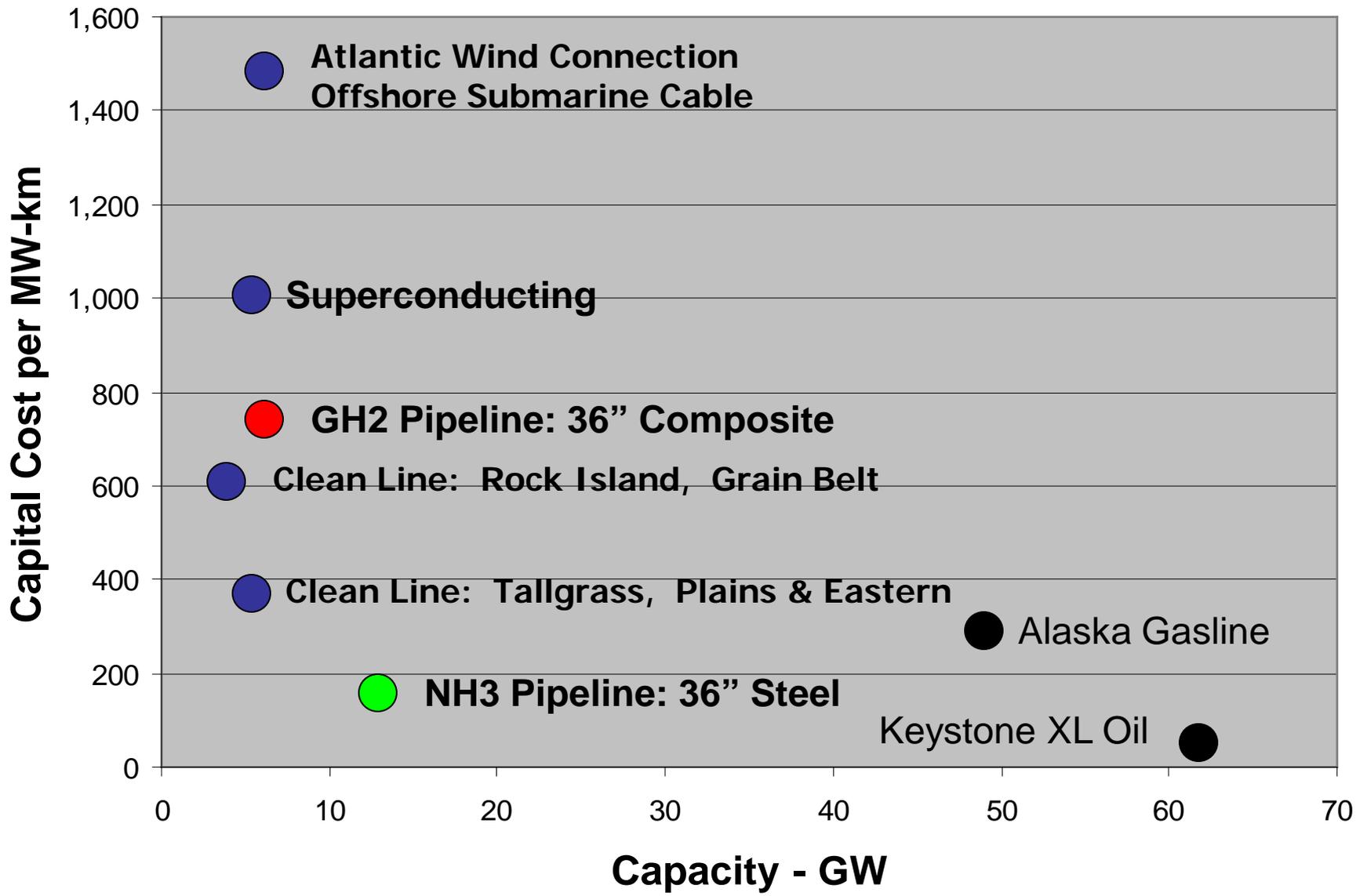
Electricity Capital Cost per GW-mile

	<u>KV</u>	<u>Capacity</u> <u>MW</u>	<u>\$M / GW-mile</u>
• SEIA:	765	5,000	1.3
	345	1,000	2.6
• AEP-AWEA	765	5,000	3.2
Consensus ?			2.5



350 miles
5 GW
\$ 5B

1,750 GW-miles @ \$5,000M =
\$2.8M / GW-mile



Wind seasonality, Great Plains

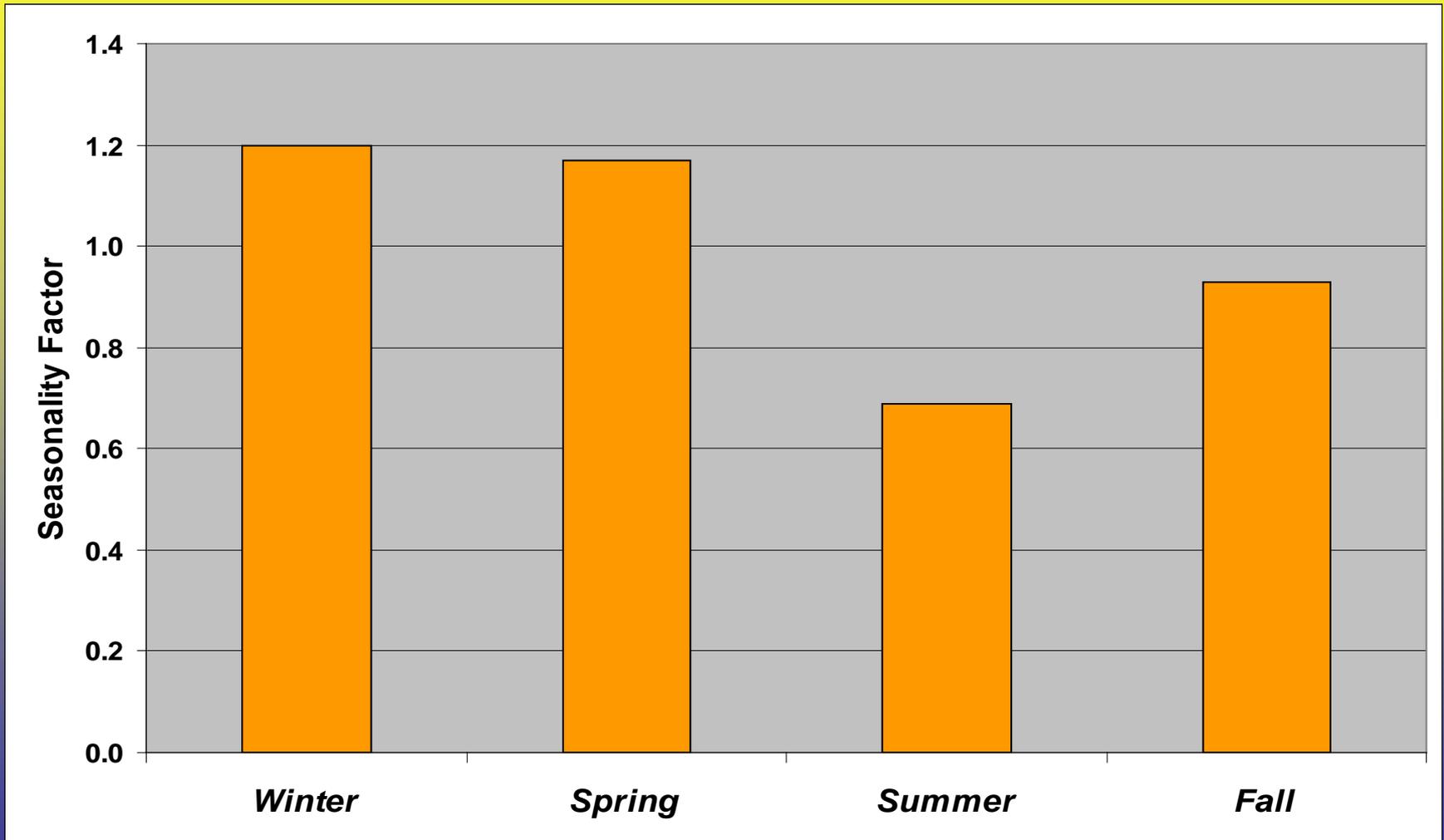
Normalized to 1.0

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

Source: D. Elliott, et al, NREL

Wind Seasonality, Northern Great Plains

Normalized to 1.0 per season



Wind Seasonality, Northern Great Plains

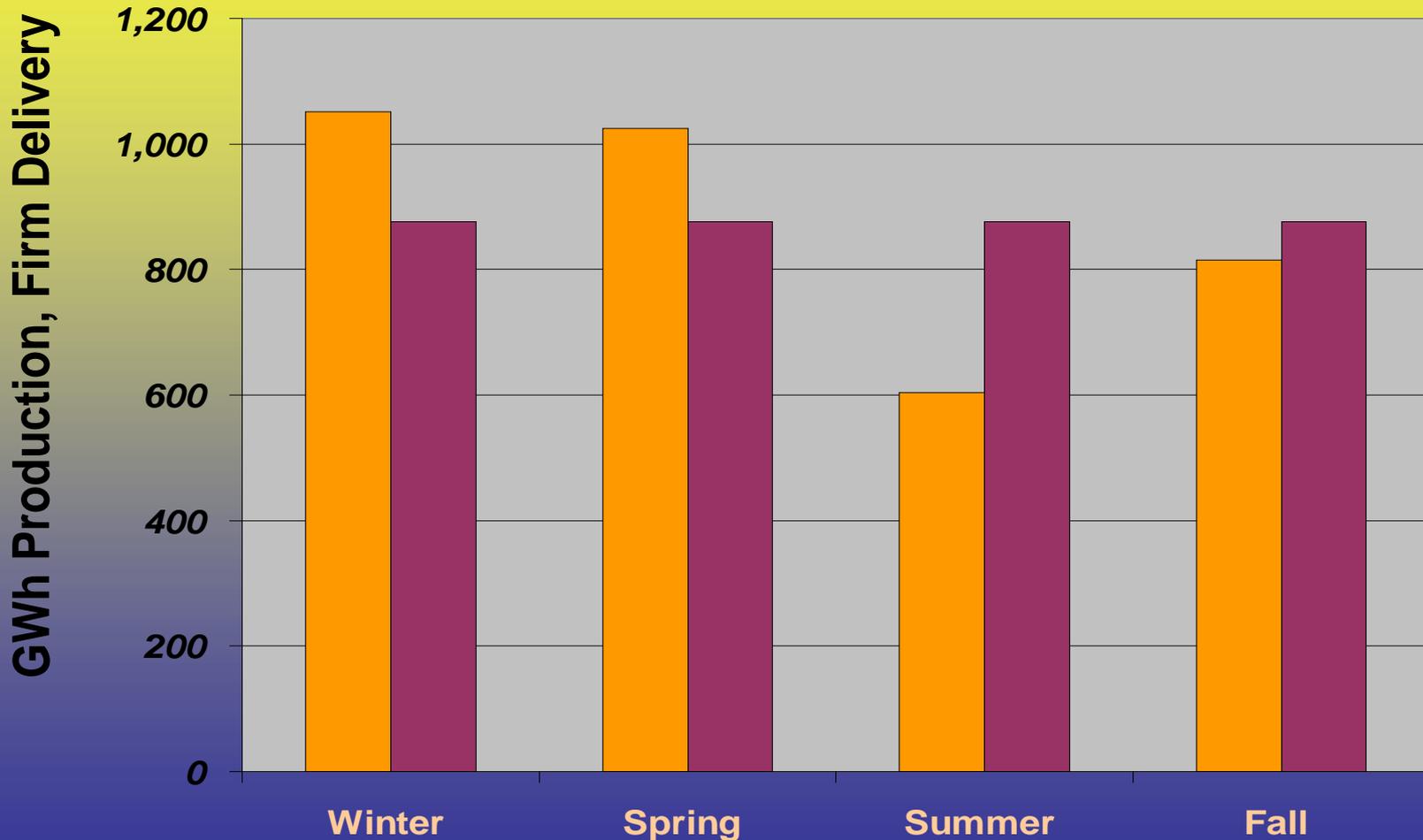
1,000 MW windplant:

AEP = 3,500 GWh / yr

“Firm” goal = 875 GWh / season

Storage: 320 GWh per 1,000 MW wind

Source: NREL, D. Elliott

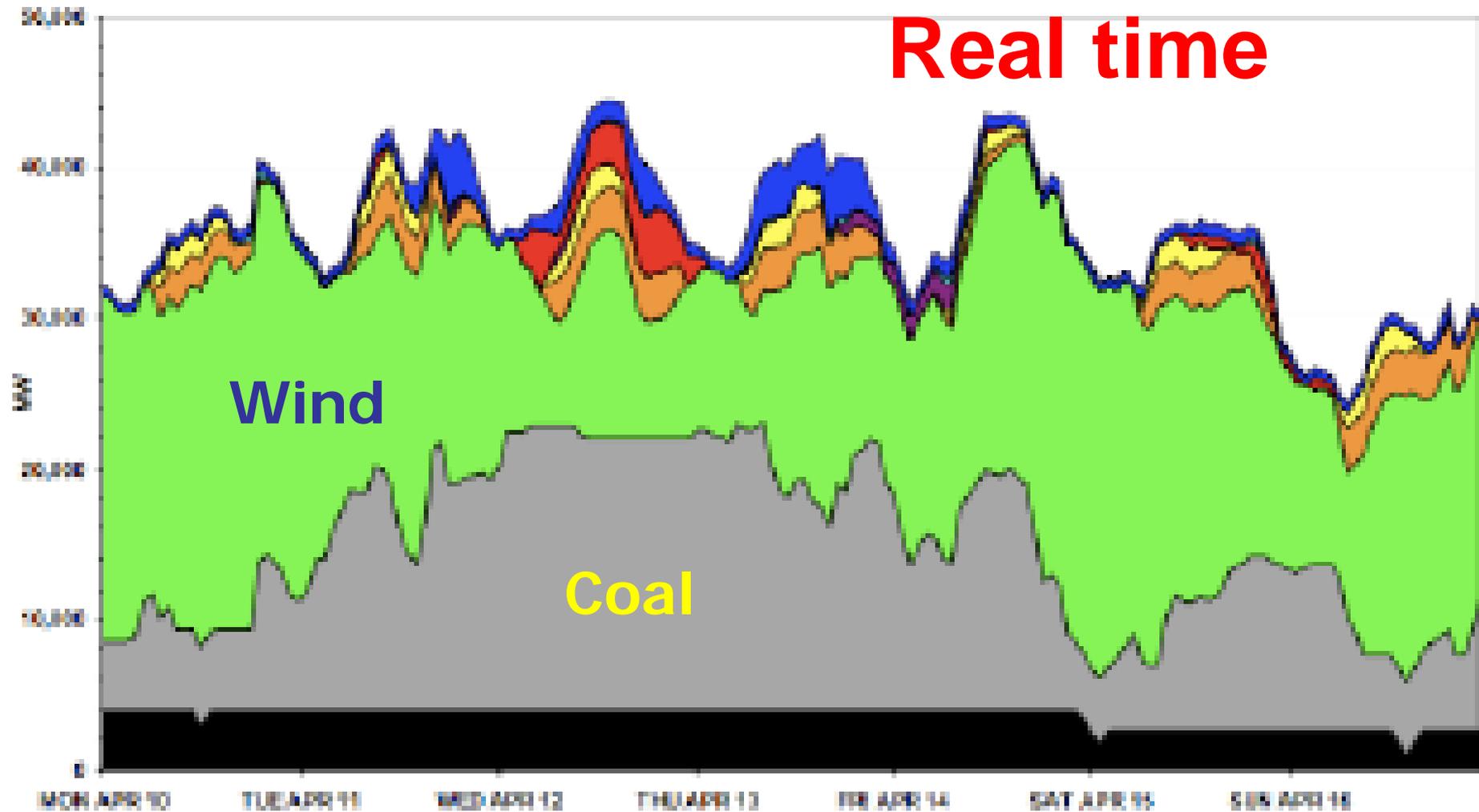


320 GWh

Annual firming, 1,000 MW wind

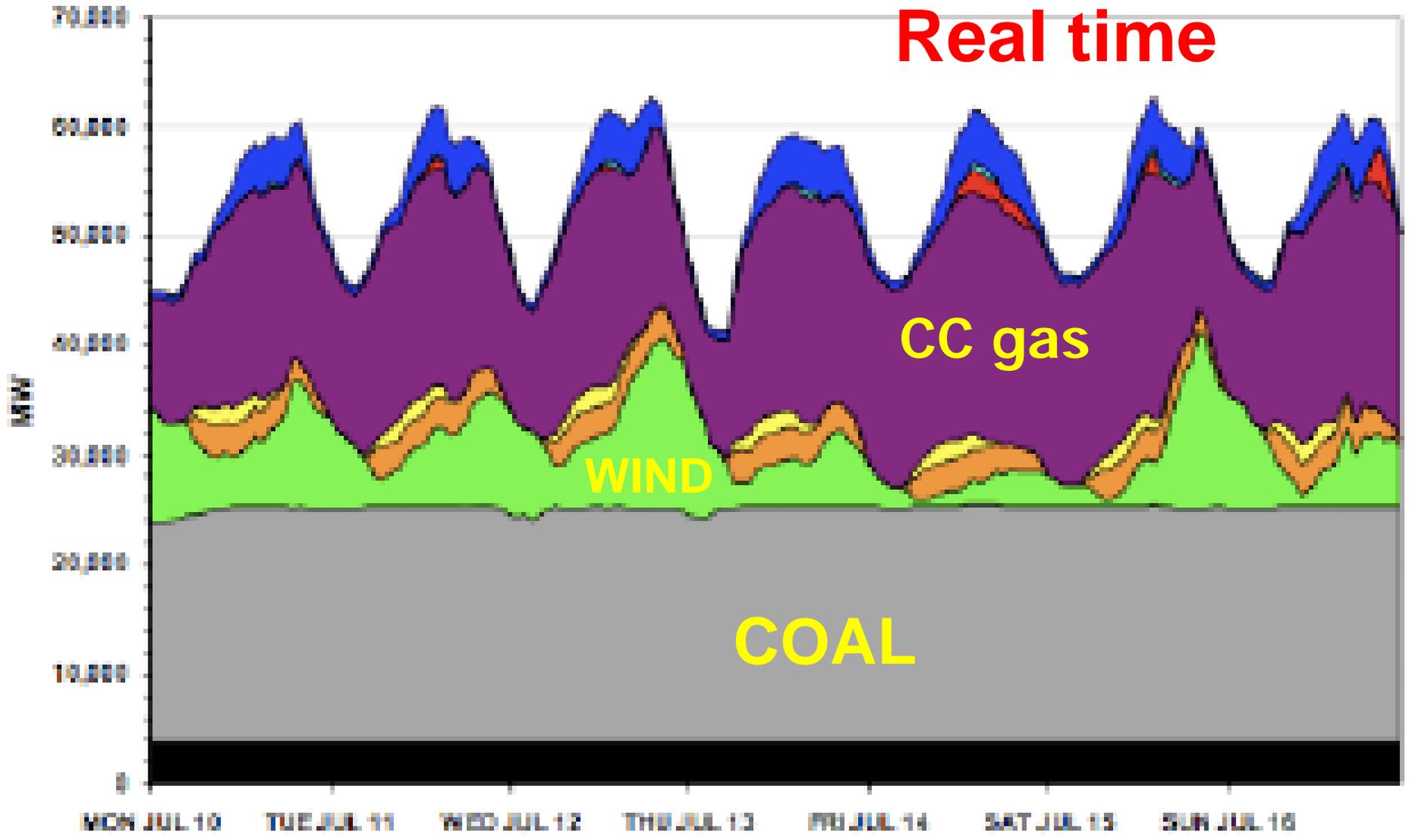
- **CAES (compressed air energy storage)**
 - **O&M: \$46 / MWh typical**
 - **Iowa: Power = 268 MW**
 - Energy capacity = 5,360 MWh**
 - Capital: 268 MW @\$800 / kW = \$214 M**
 - Storage @ \$40 / kWh = \$13 Billion**
 - Storage @ \$1 / kWh = \$325 Million**
- **VRB flow battery**
 - **O&M: 80% efficiency round-trip**
 - **Capital: \$500 / kWh = \$160 Billion**

Real time



WWSIS: April week: ~30% RE

Real time



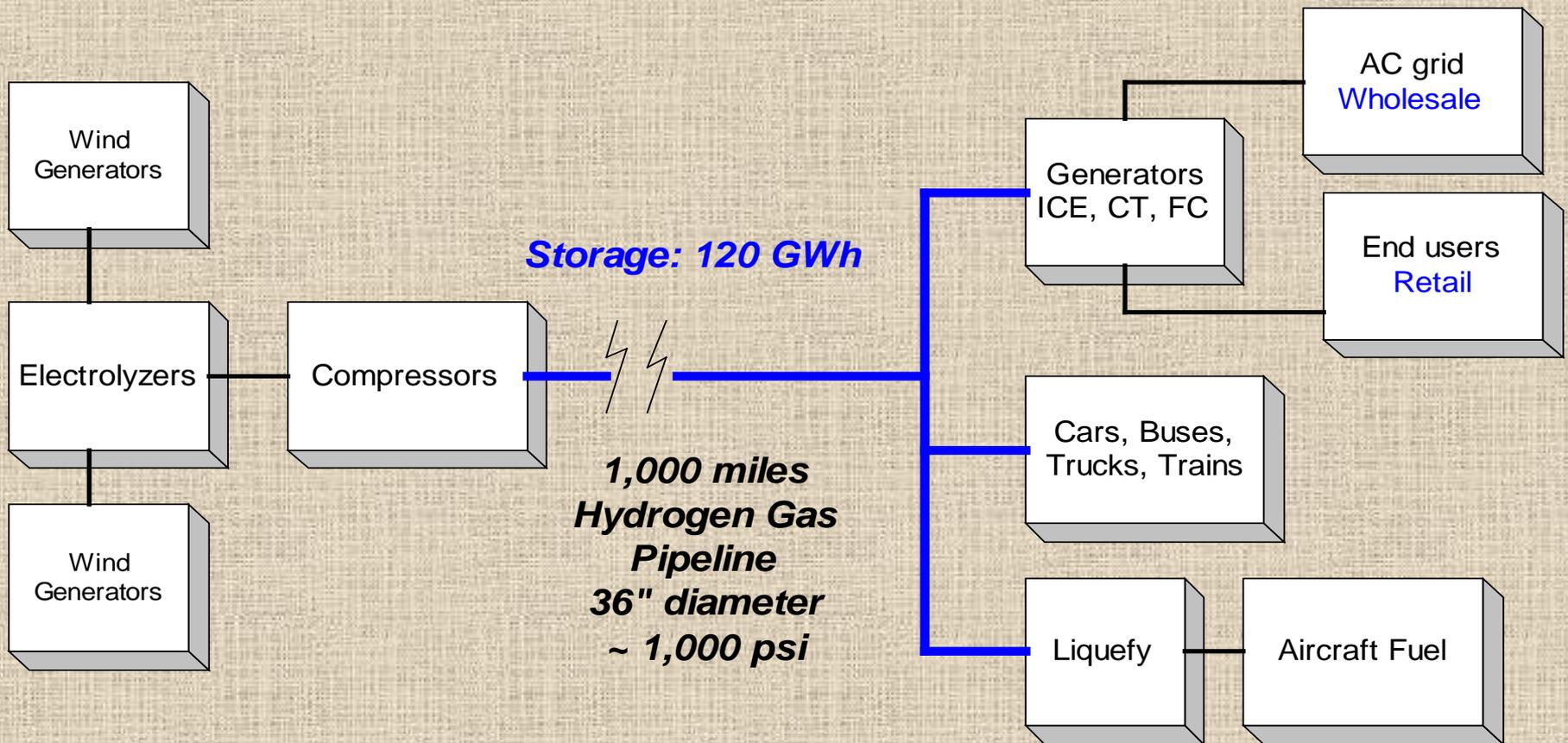
WWSIS: July week: ~10% RE

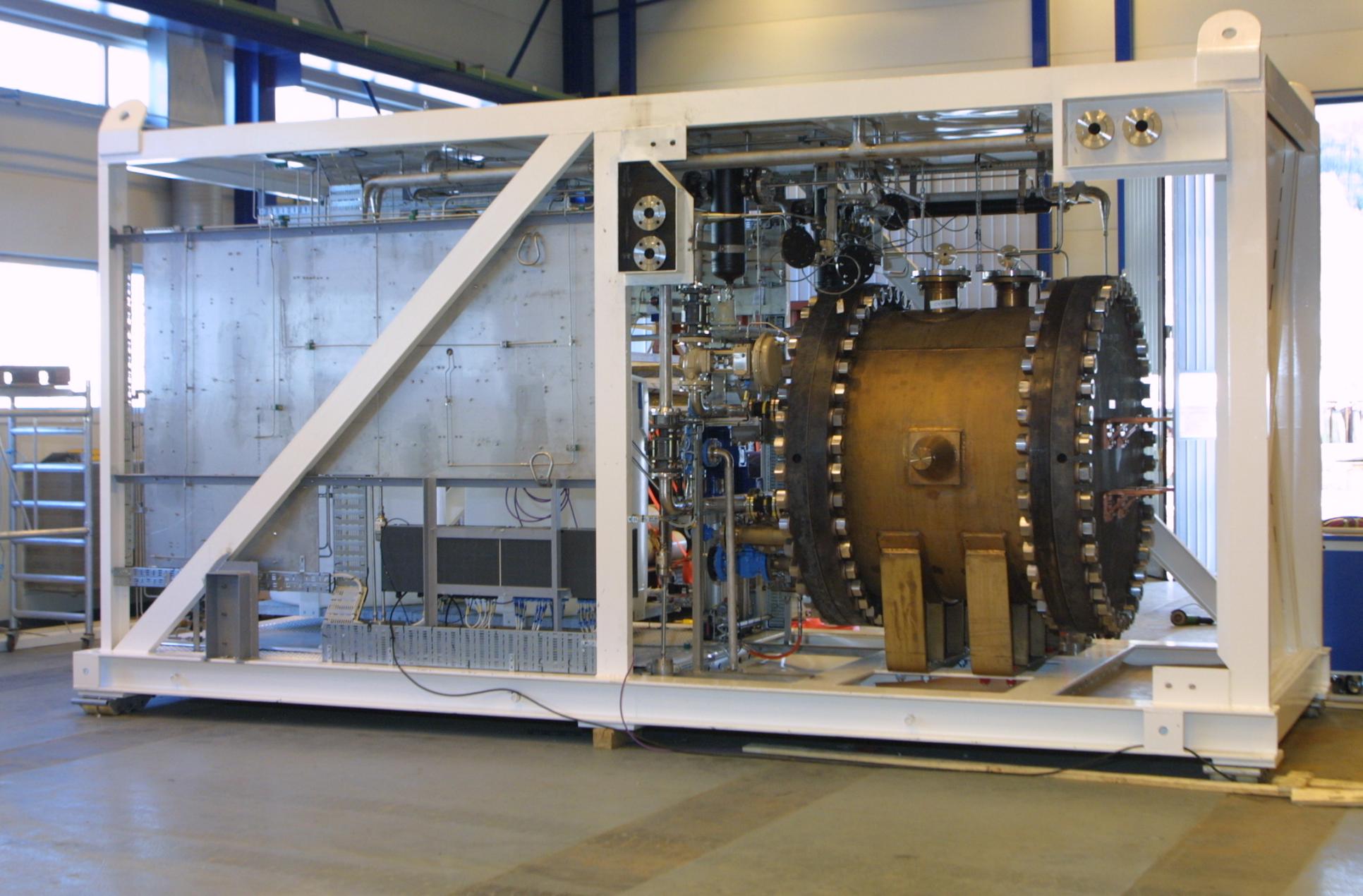
Why Hydrogen, Ammonia ?

- **Transmission via underground pipeline**
 - Easier to site, permit
 - Lower NIMBY
 - Protected: acts of God and man
 - FERC interstate jurisdiction
 - High capacity: 5 - 10 GW
 - Lower capital cost / GW - mile
- **Affordable storage:**
 - Annual-scale firming
 - Dispatchable fuel supply
- **Zero-carbon fuels: RE**
- **Nascent markets: transport fuel, other**
- **Integration**
 - Continental energy system
 - Elec grid quality

Hydrogen Transmission Scenario

- *Low-pressure electrolyzers*
- *“Pack” pipeline: ~ 120 GWh*



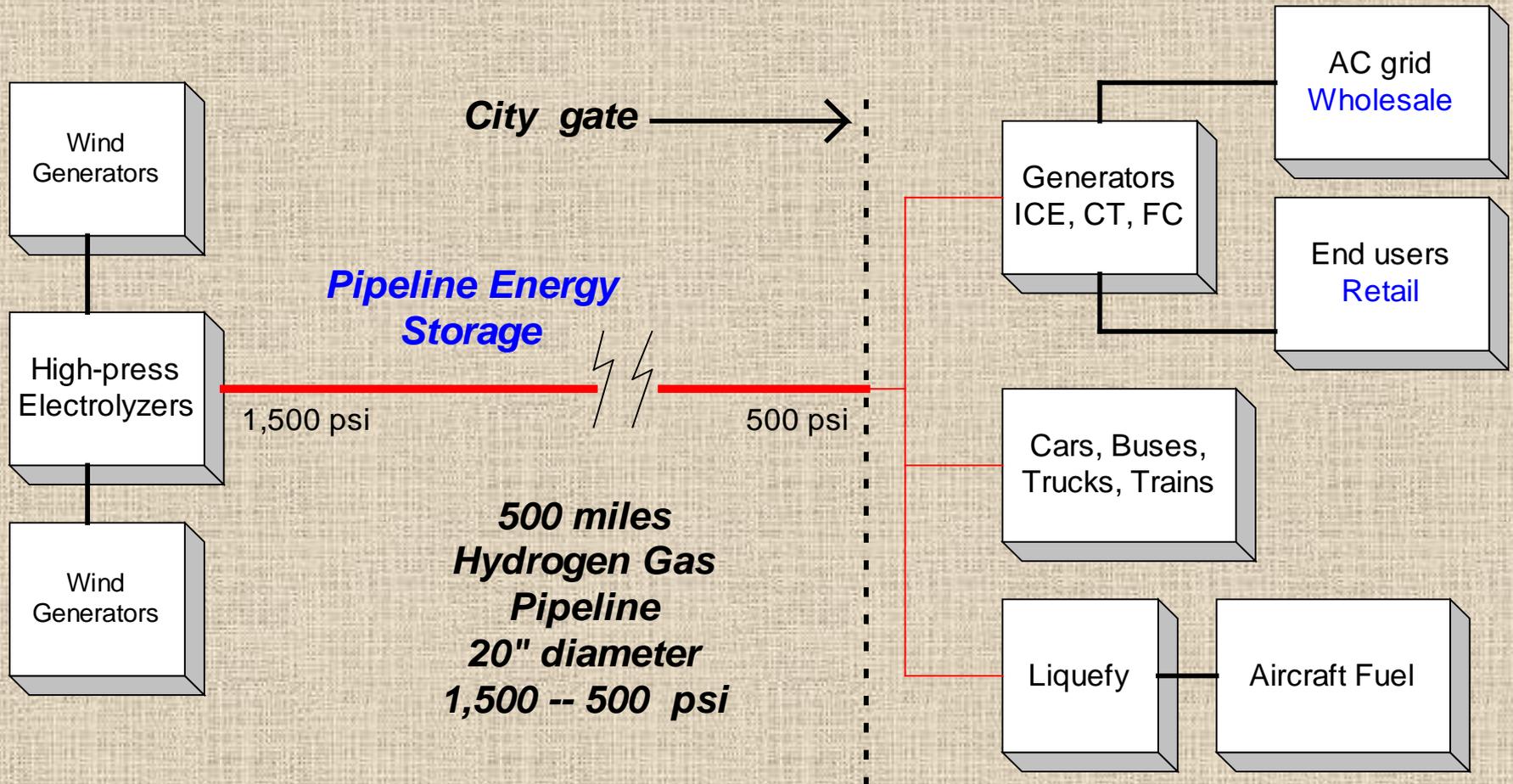


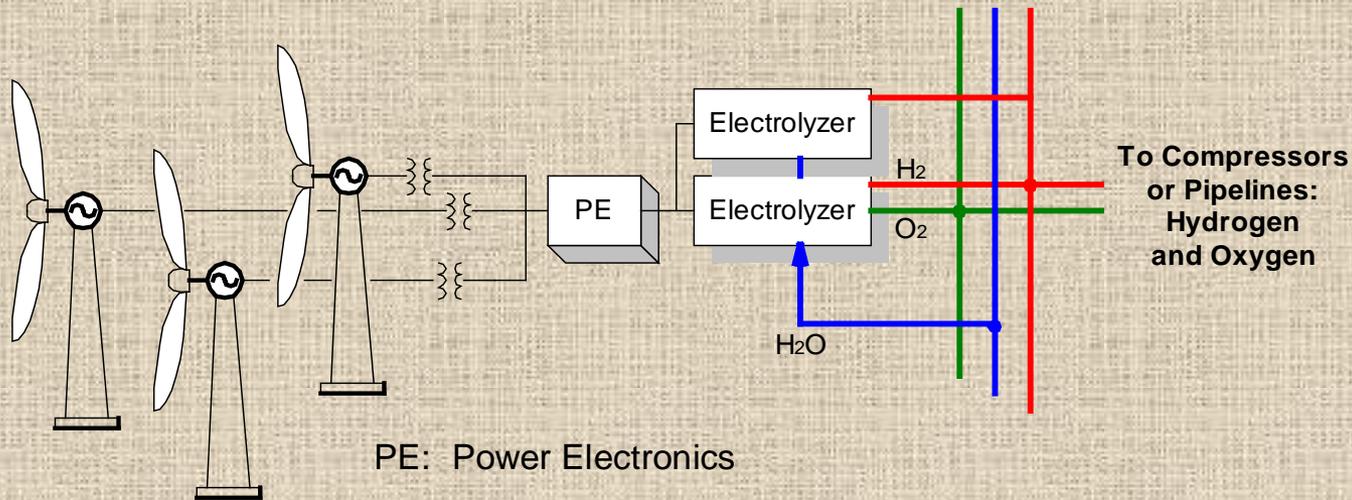
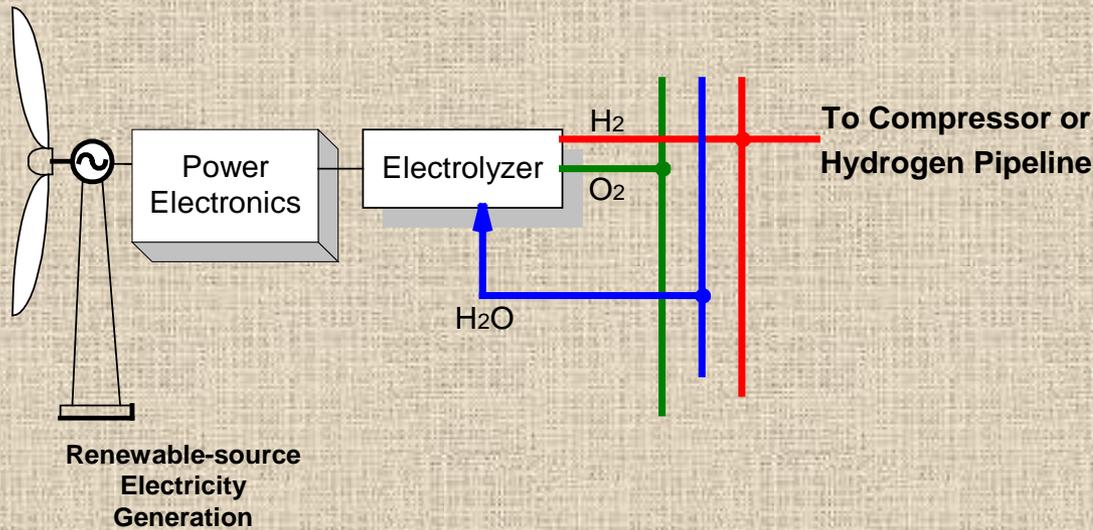
***Norsk Hydro electrolyzer, KOH type
560 kW input, 130 Nm³ / hour at 450 psi (30 bar)***

Compressorless system: No geologic storage

Transmission

Distribution



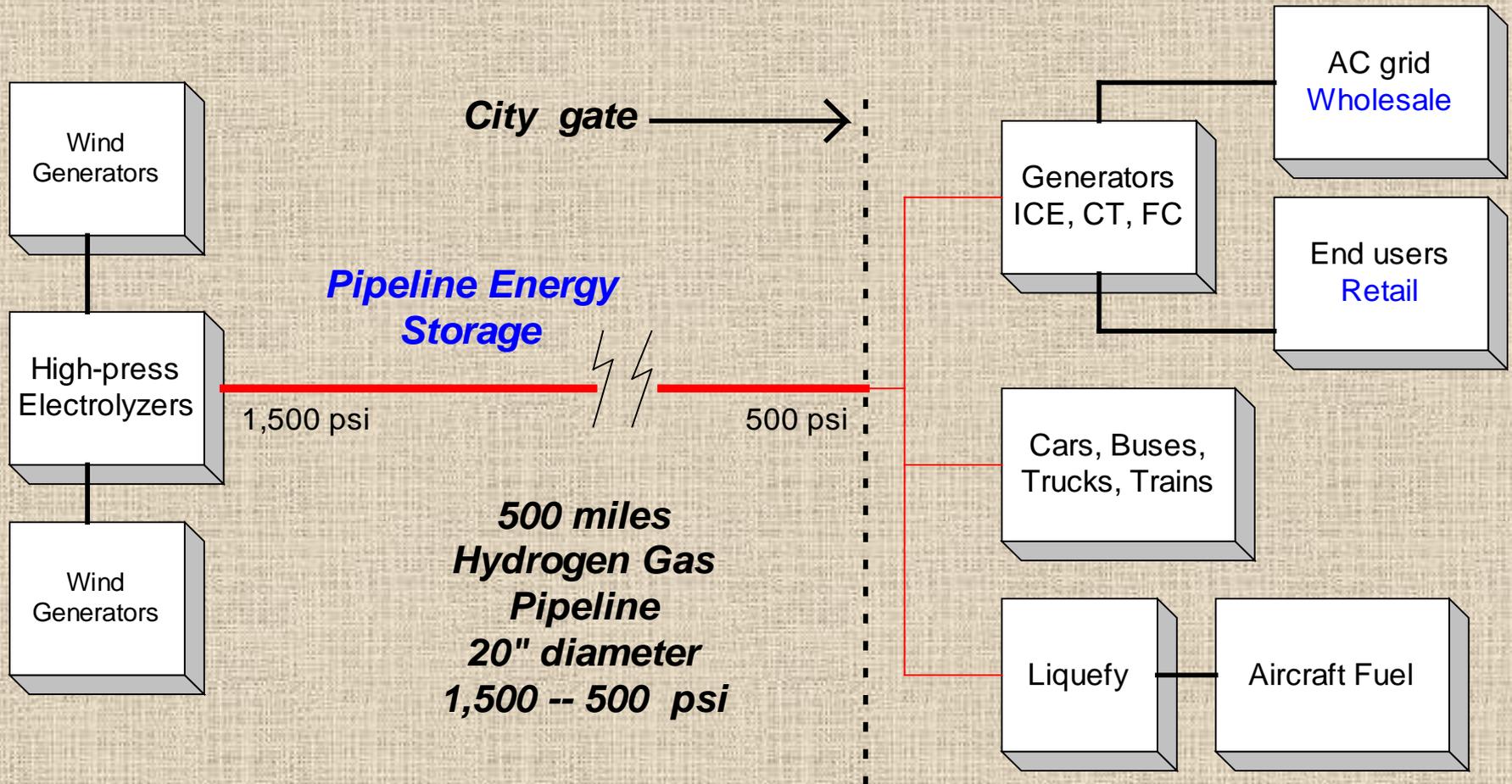


Topology Options: H₂ and O₂ Production and Gathering from Renewable Energy Generation

Compressorless system: No geologic storage

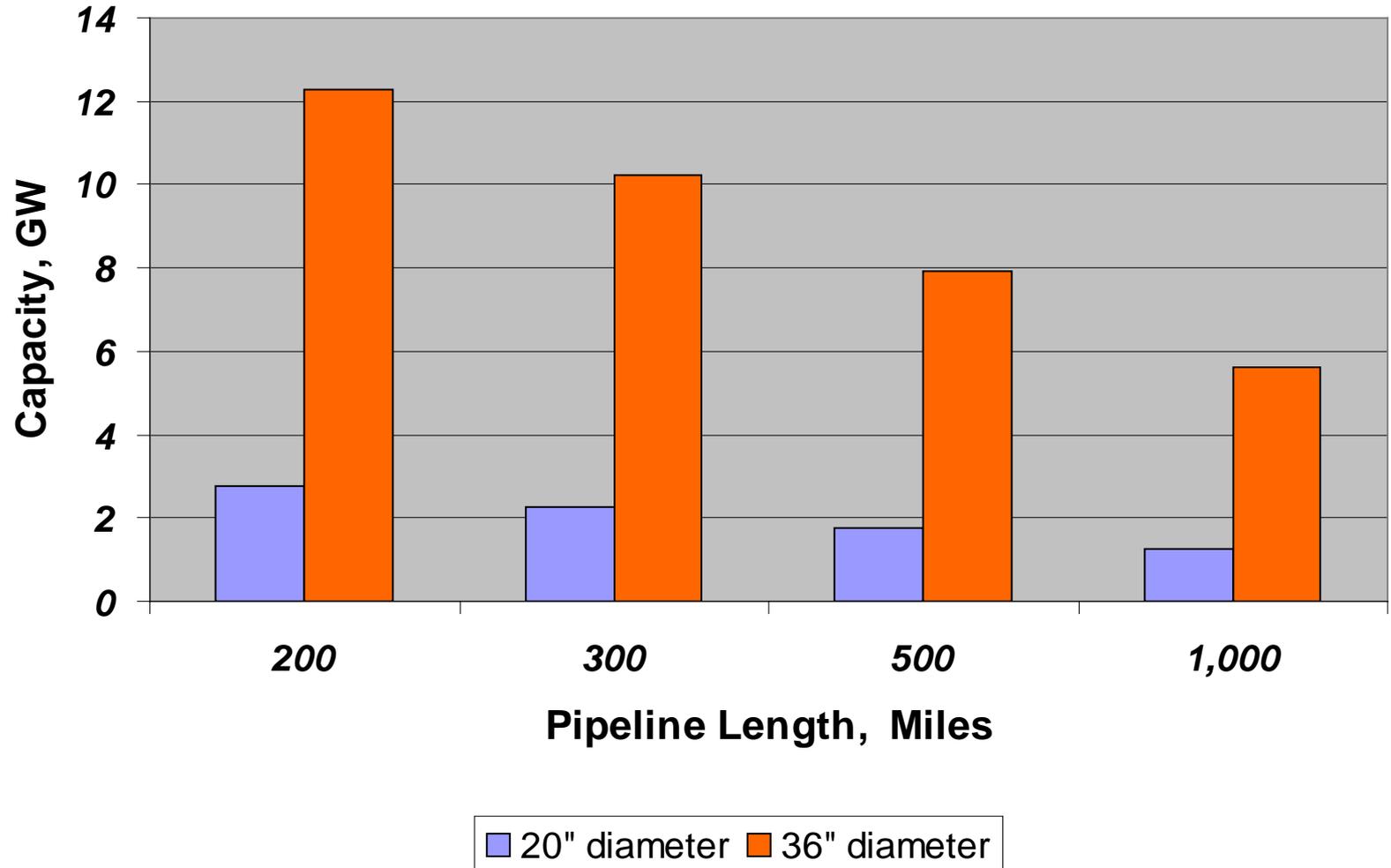
Transmission

Distribution

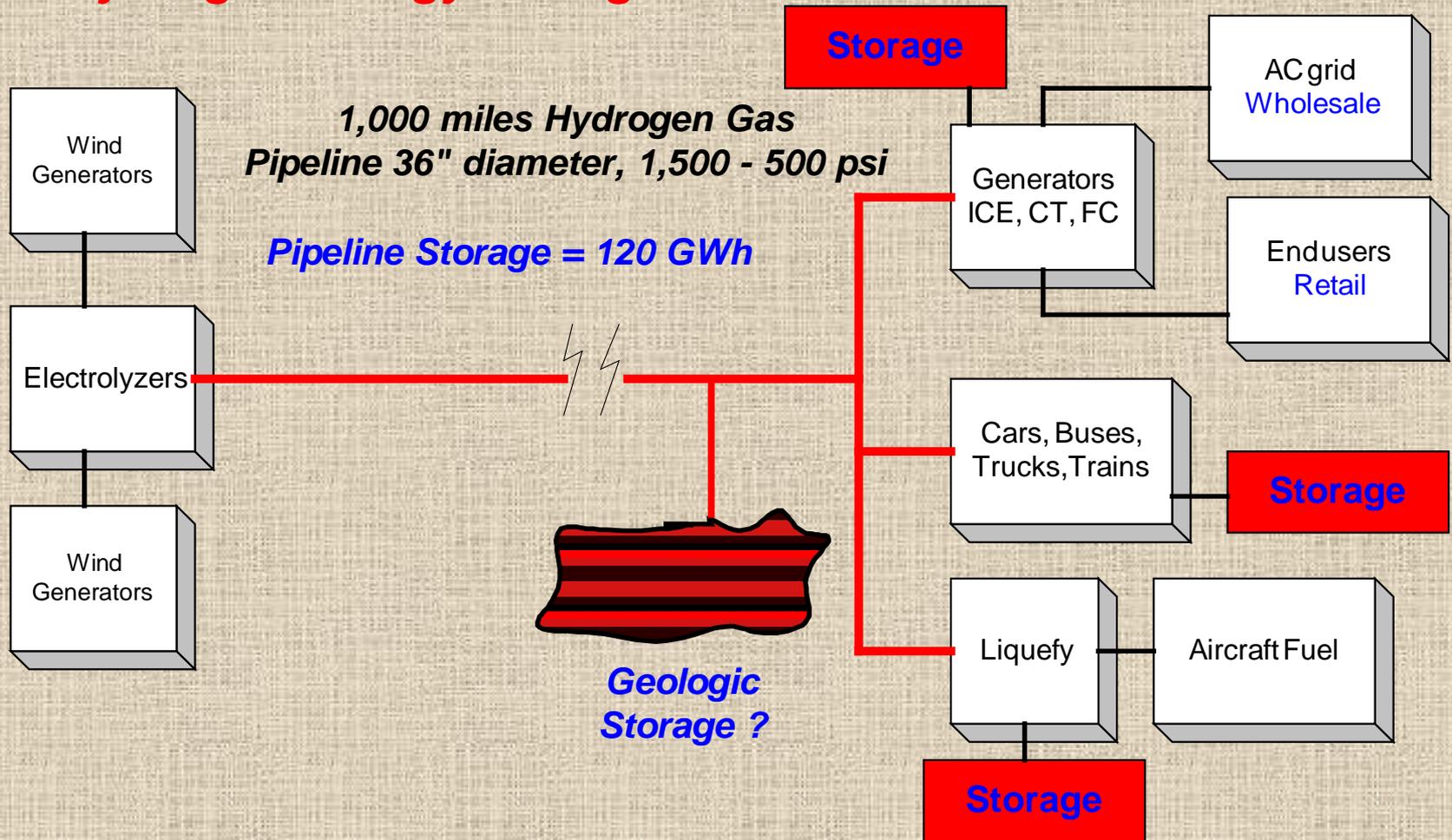


Compressorless 20", 36" GH2 Pipeline Capacity

1,500 psi IN / 500 psi OUT



Hydrogen Energy Storage



Hydrogen Caverns in Texas

- Chevron-Phillips 25 years
- Praxair 6 years

Domal
Salt
Storage
Caverns



- 860,000 m³ physical
- 150 bar = 2,250 psi
- 2,500 Mt net = 92,500 MWh
- \$15M avg cap cost / cavern
- \$160 / MWh = \$0.16 / kWh
- Cavern top ~ 700m below ground

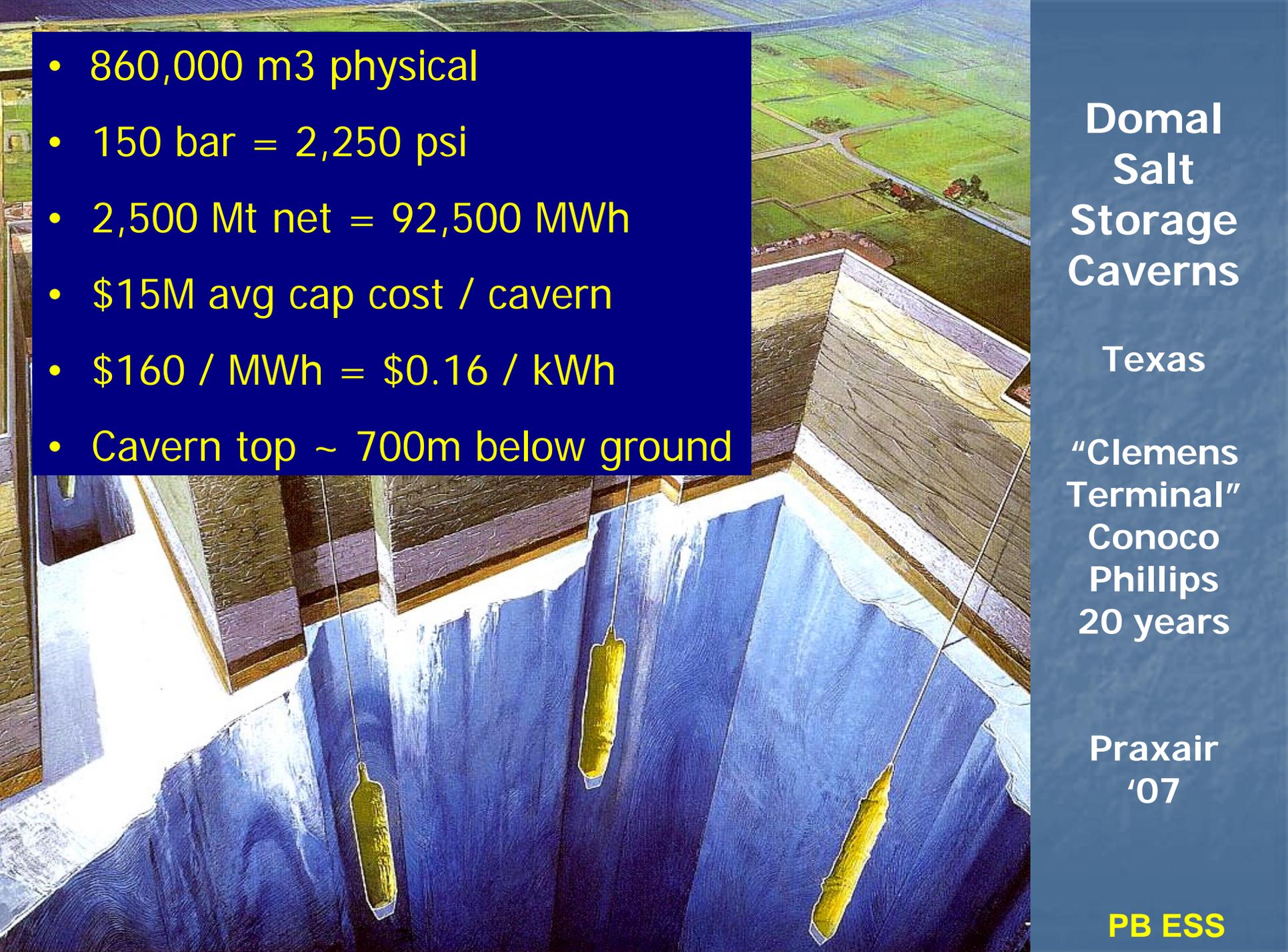
Domal Salt Storage Caverns

Texas

“Clemens
Terminal”
Conoco
Phillips
20 years

Praxair
'07

PB ESS

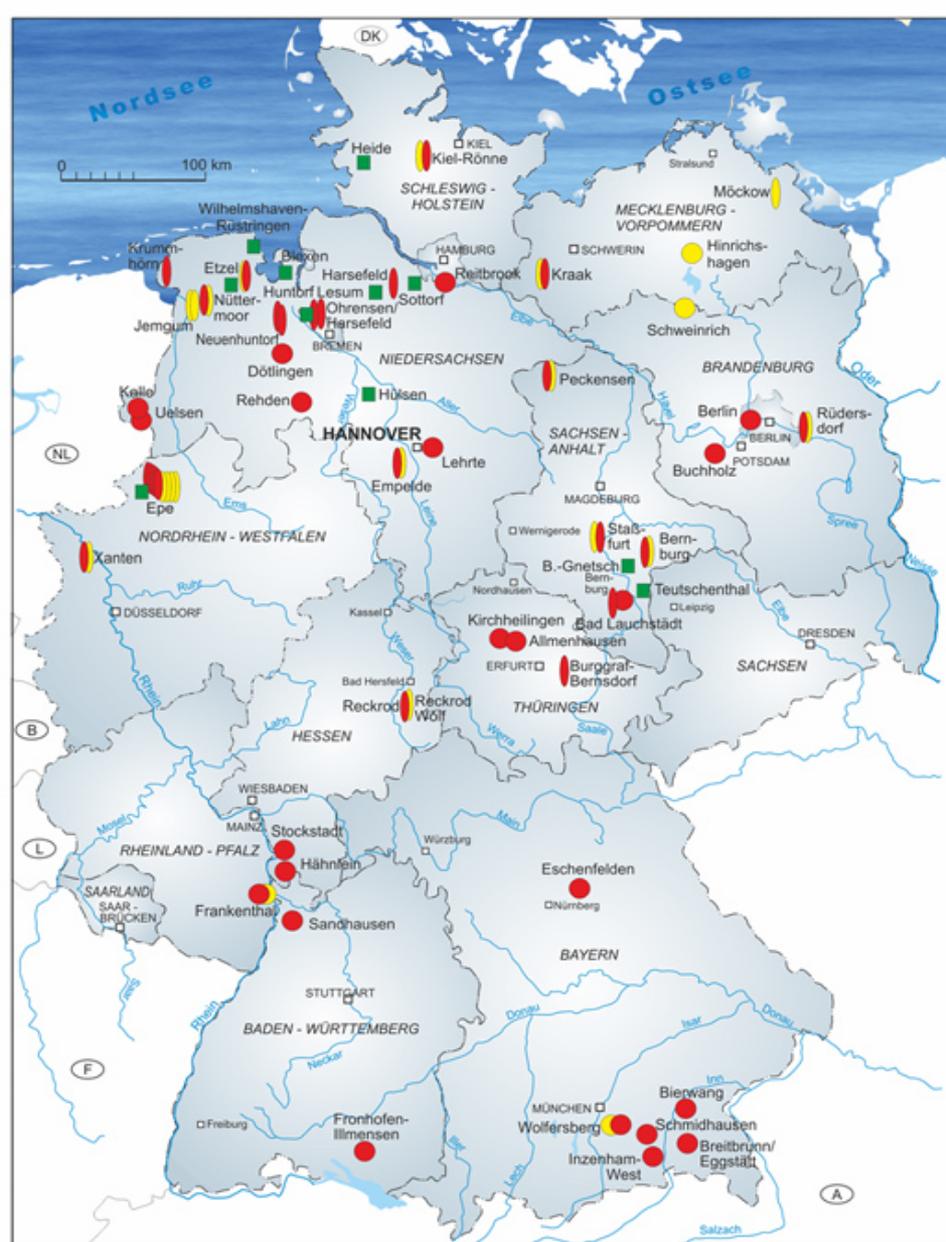
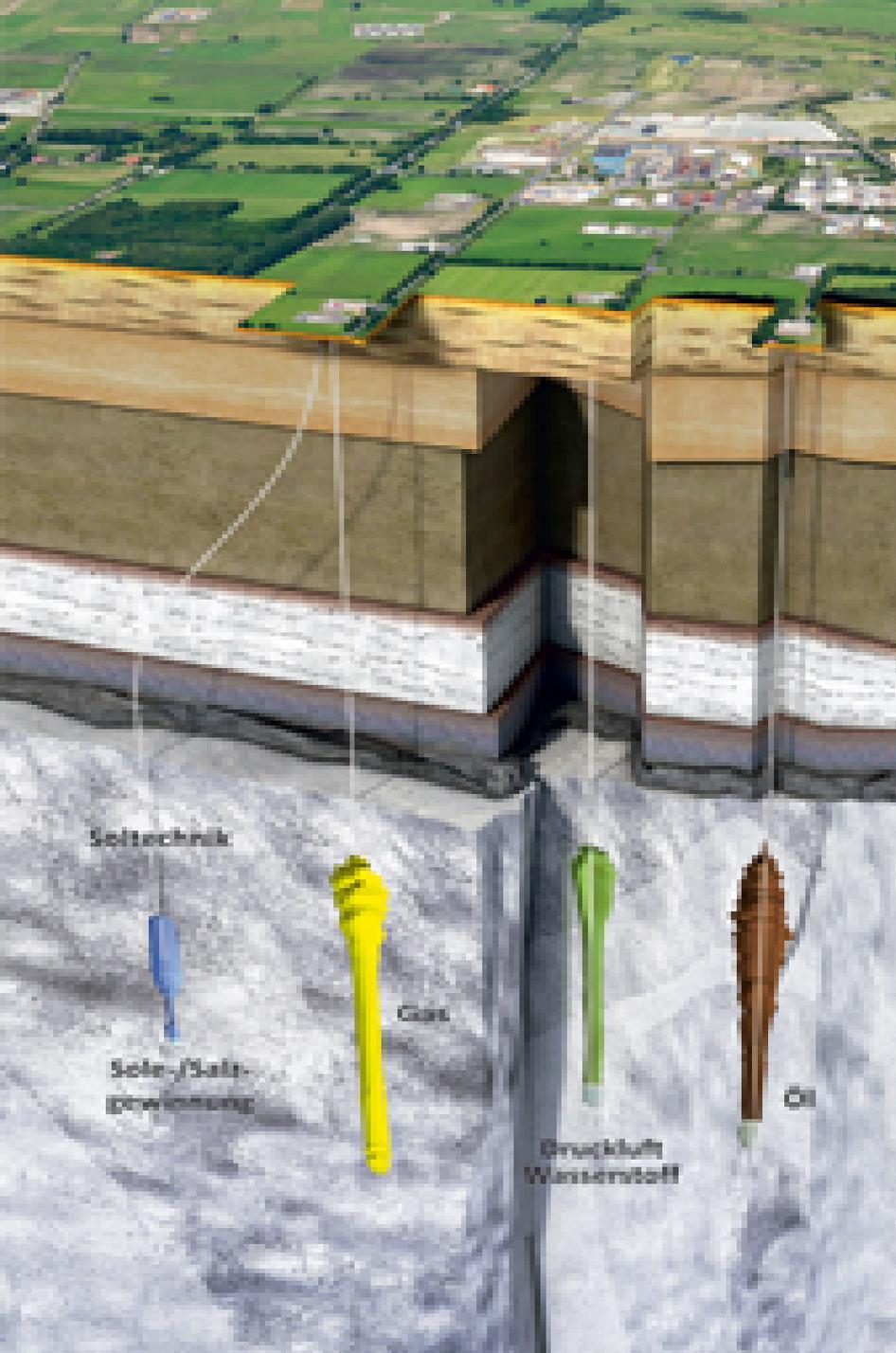




MAJOR SALT DEPOSITS AND DRY SALT PRODUCTION SITES IN NORTH AMERICA

- LEGEND**
- MAJOR SALT DEPOSITS
 - Production Sites
 - EVAPORATED
 - ROCK
 - SOLAR

Renewable-source GH2 geologic storage potential. Candidate formations for manmade, solution-mined, salt caverns



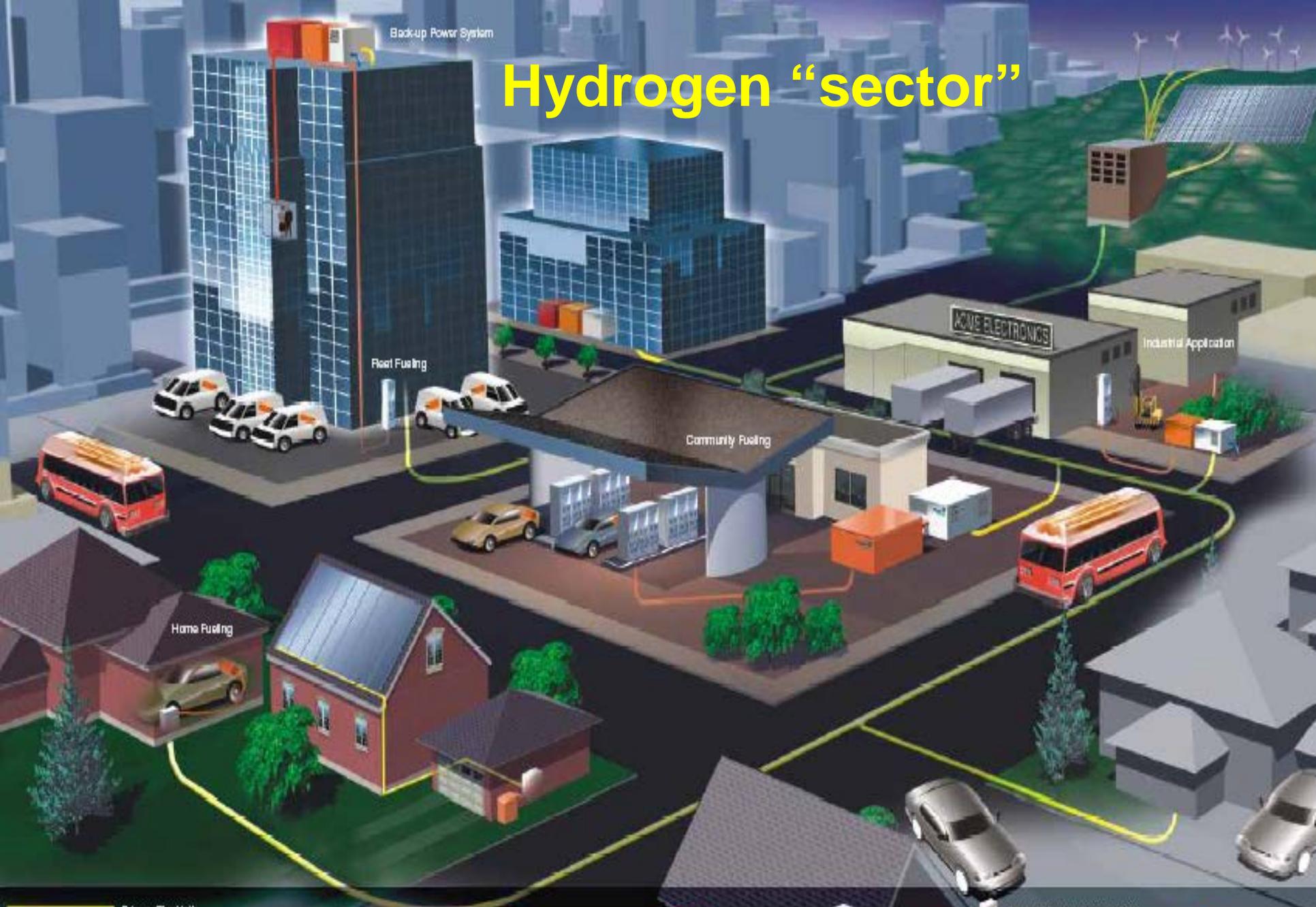
- Erdgas
- Porenspeicher
- Kavernenspeicher
- in Betrieb
- in Planung oder Bau
- in Betrieb
- in Planung oder Bau
- Rohöl, Mineralprodukte, Flüssiggas
- Kavernenspeicher
- in Betrieb

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

Windplant size	1,000 MW	
		[million]
Wind generators	\$	1,000
Electrolyzers		500
Pipeline, 20”		1,100
# storage caverns	[4]	
Caverns @ \$10M ea		40
Cushion gas @ \$5M ea		20
TOTAL	\$	2,660

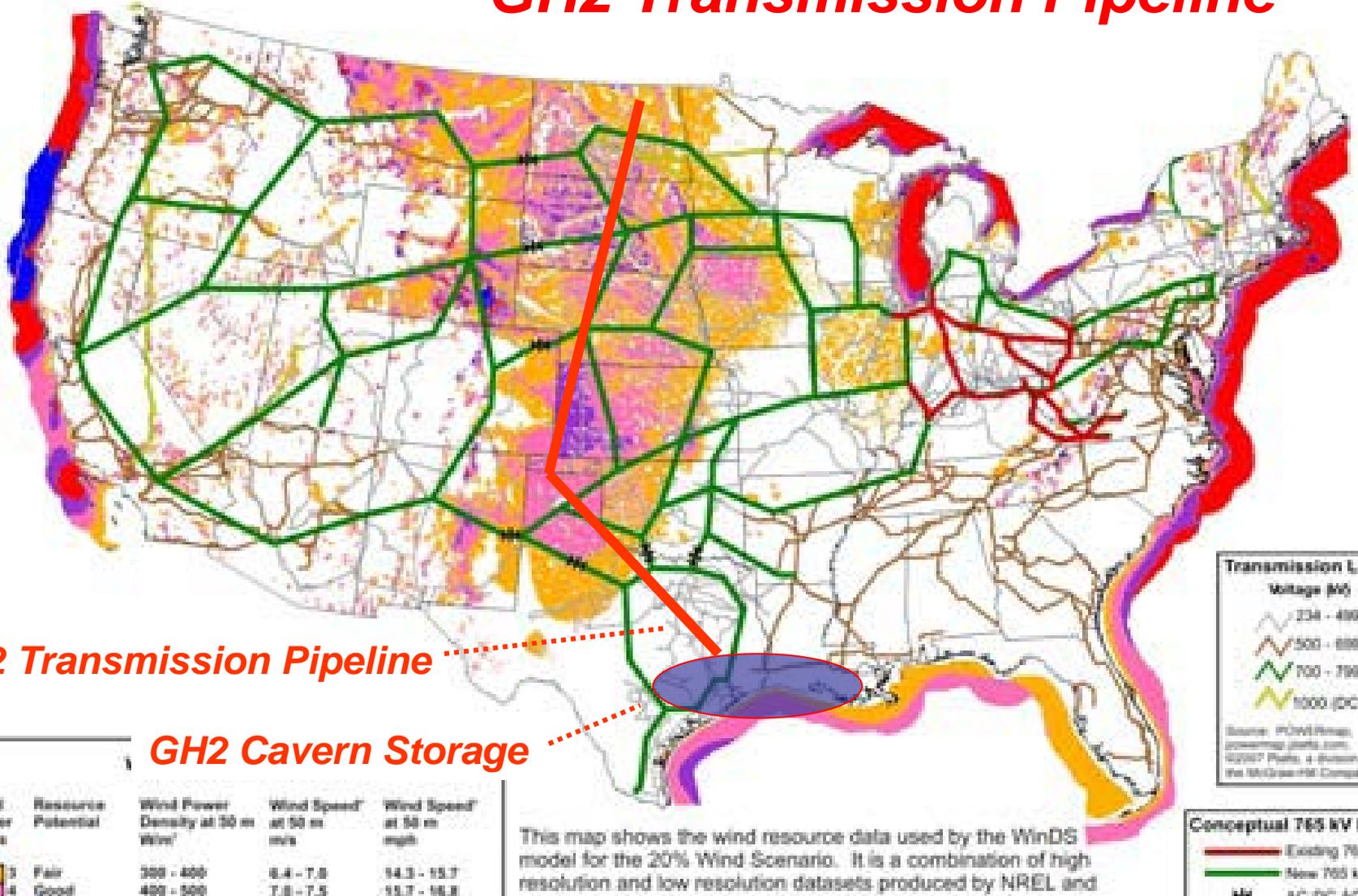
Cavern storage: ~ 3 % of total capital cost

Hydrogen “sector”



Hydrogen “sector” of a benign, sustainable, equitable, global energy economy

GH2 Transmission Pipeline



GH2 Transmission Pipeline

GH2 Cavern Storage

Wind Power Class	Resource Potential	Wind Power Density at 50 m W/m ²	Wind Speed* at 50 m m/s	Wind Speed* at 50 m mph
3	Fair	300 - 400	6.4 - 7.0	14.3 - 15.7
4	Good	400 - 500	7.0 - 7.5	15.7 - 16.8

This map shows the wind resource data used by the WinDS model for the 20% Wind Scenario. It is a combination of high resolution and low resolution datasets produced by NREL and

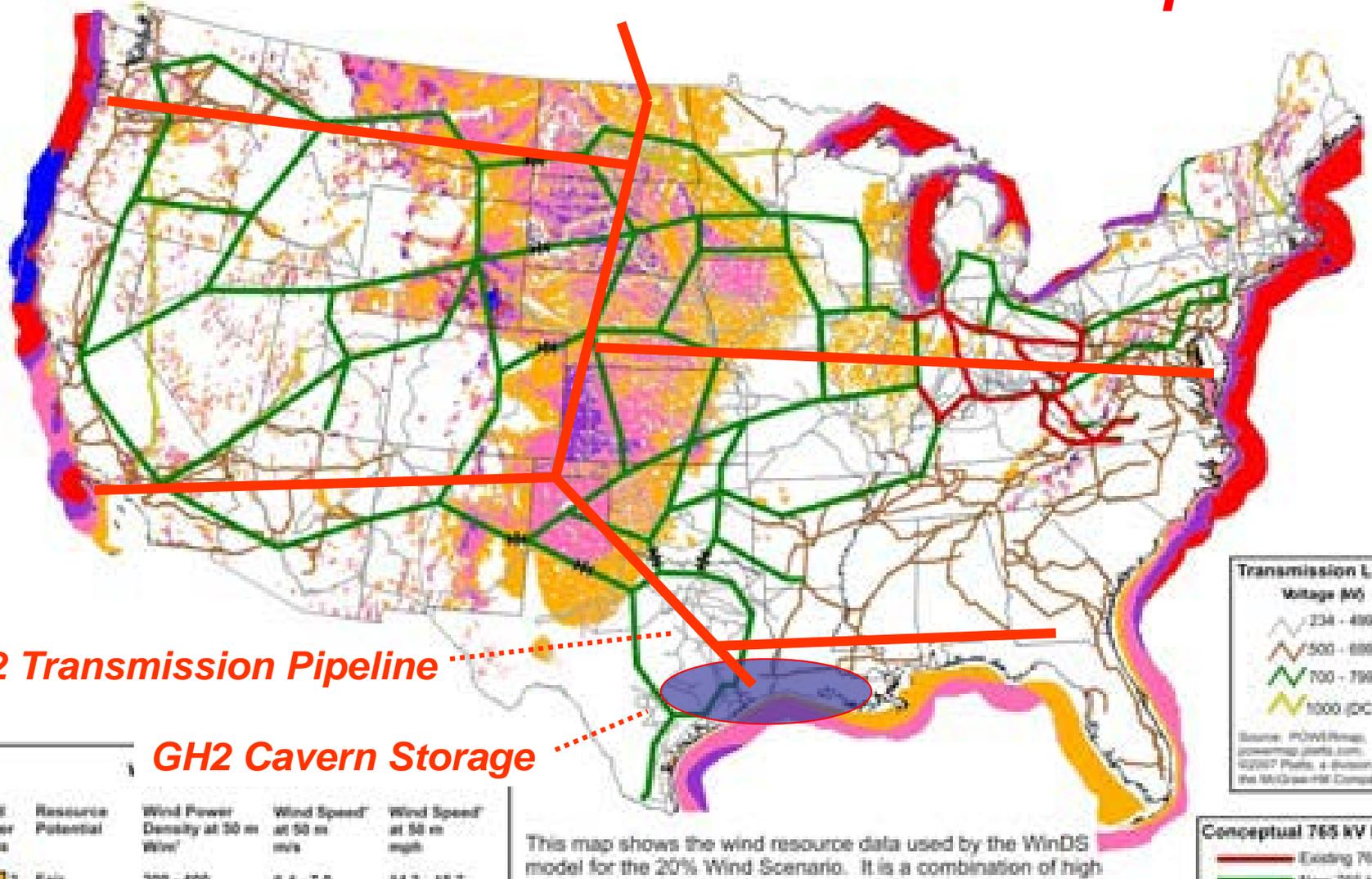
Transmission Lines	
Voltage (kV)	
	234 - 490
	500 - 690
	700 - 790
	1000 (DC)

Source: POWRMap, powermap.platts.com, ©2007 Platts, a division of the McGraw-Hill Companies

Conceptual 765 kV Network	
	Existing 765 kV
	New 765 kV

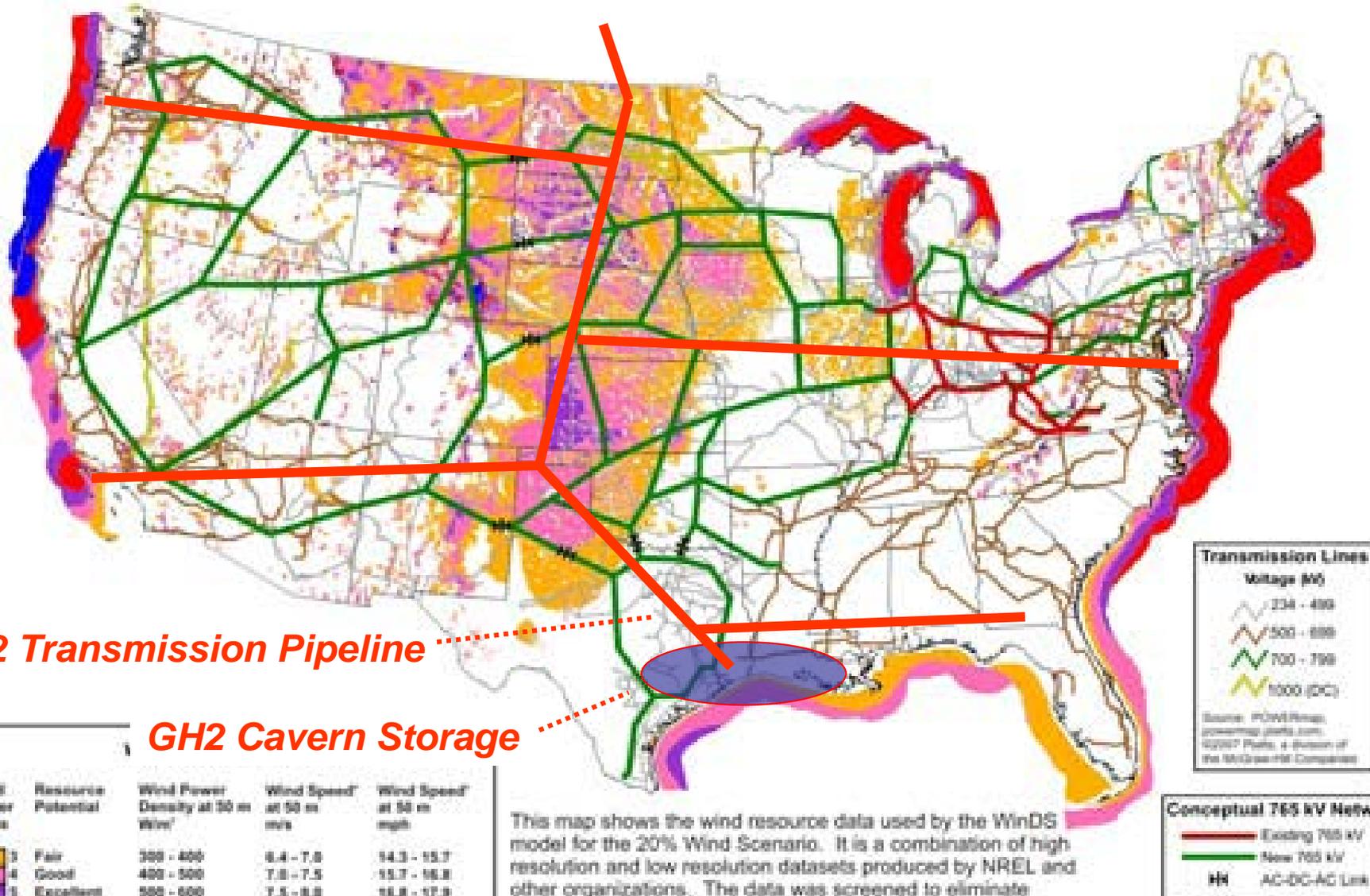
Wind Potential ~ 10,000 GW
12 Great Plains states

GH2 Transmission Pipeline



Wind Potential ~ 10,000 GW
12 Great Plains states

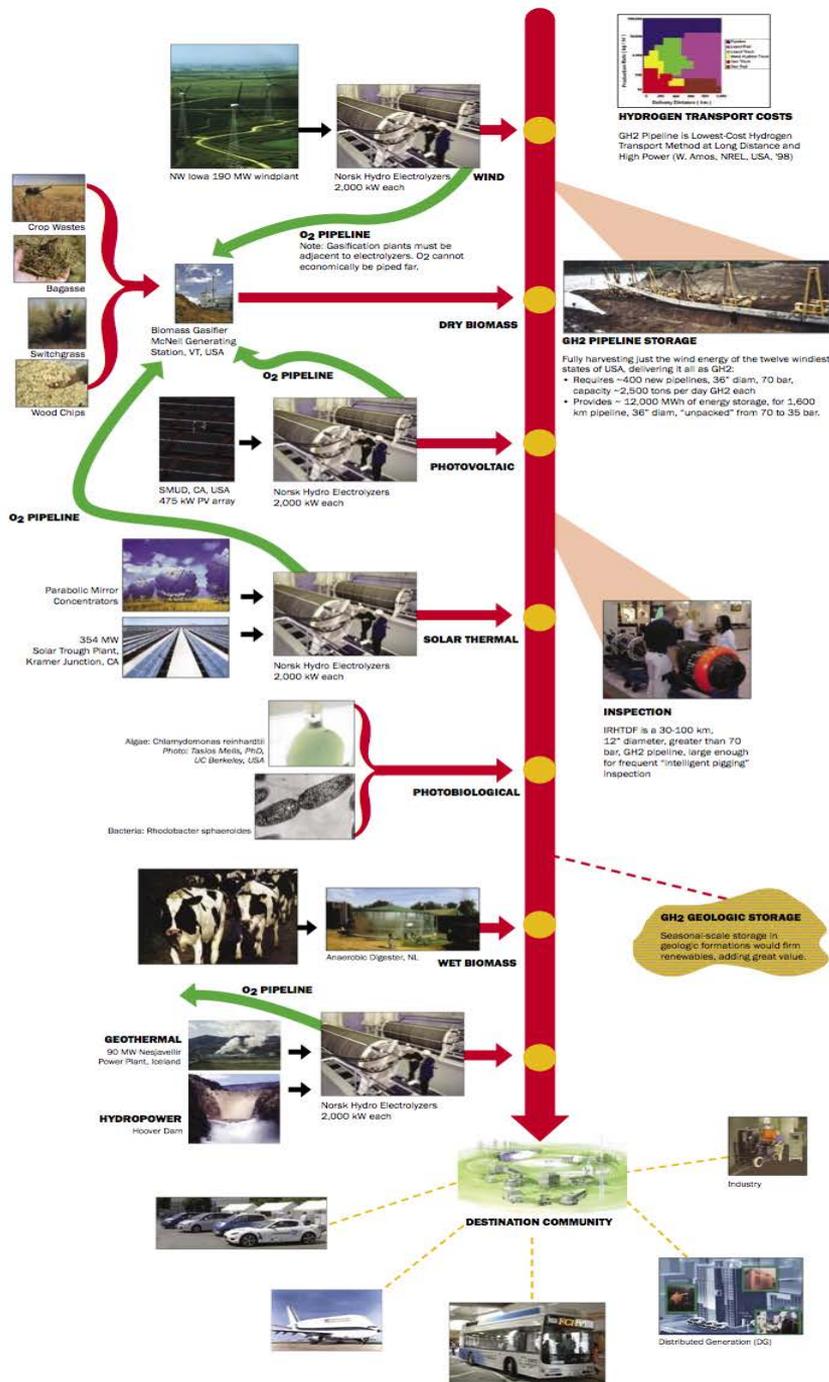
AWEA 20% Wind Electricity by 2030



Wind Potential ~ 10,000 GW

Pilot plant needed

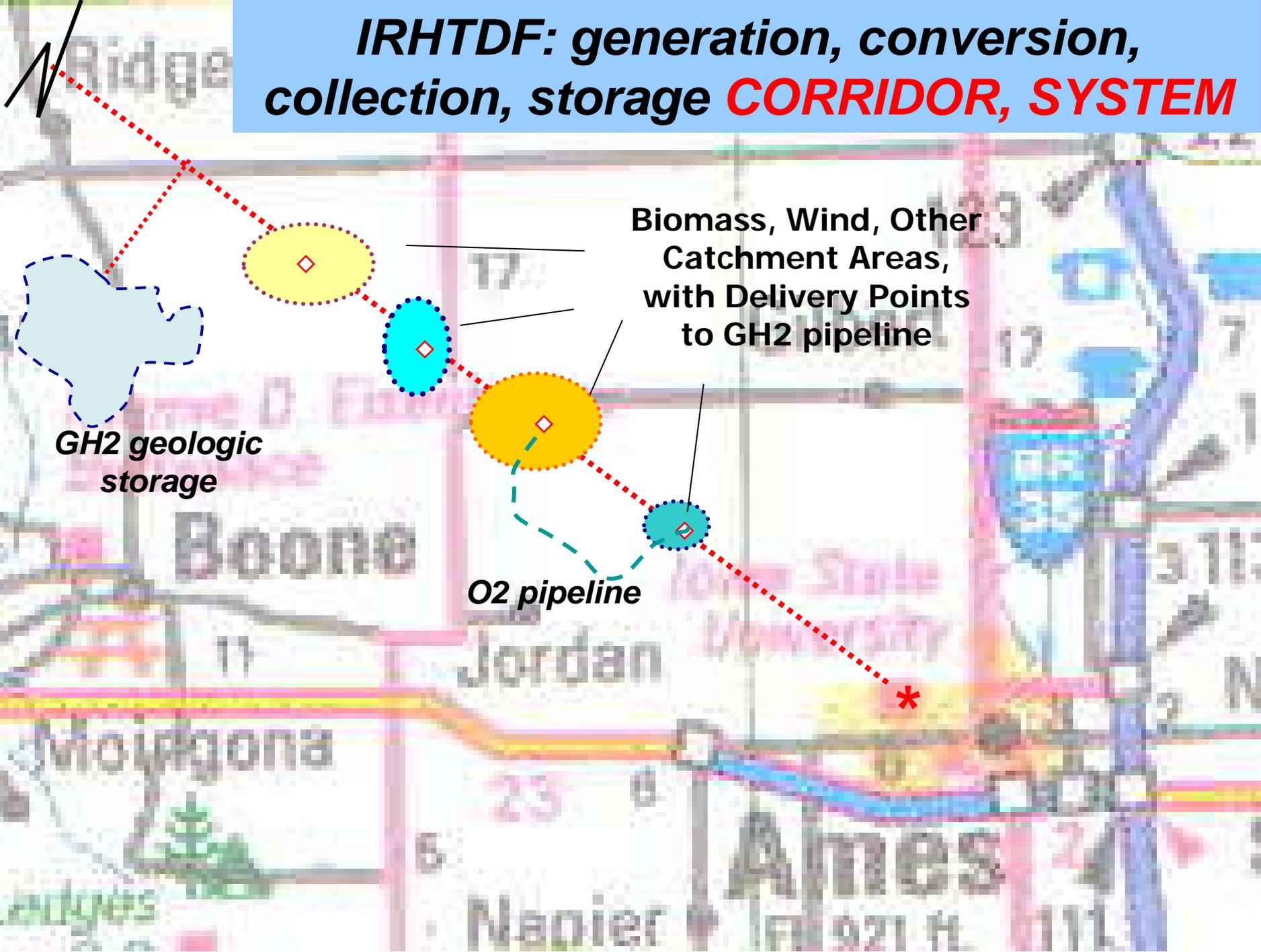
- **Every major new industrial process**
- **Renewables-source systems**
- **Diverse, large-scale, stranded**
- **US, Japan, Canada, IPHE → “ IRHTDF “**

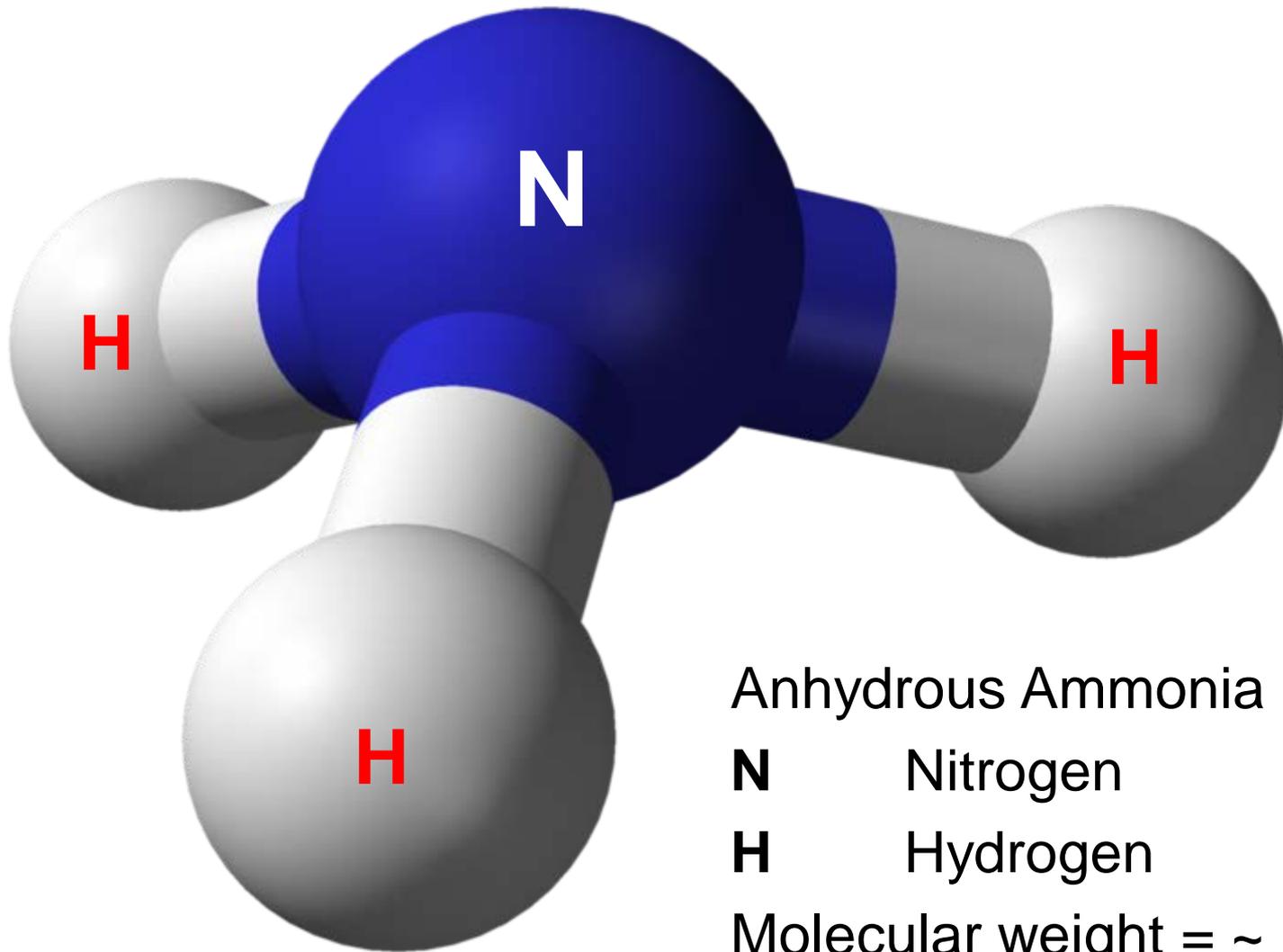


Pilot-scale Hydrogen Pipeline System: Renewables

- Diverse
- Dispersed, diffuse
- Large-scale
- Stranded
- Remote
- No transmission

IRHTDF: generation, conversion, collection, storage **CORRIDOR, SYSTEM**





Anhydrous Ammonia **NH₃**

N Nitrogen

H Hydrogen

Molecular weight = ~ 17

18% **H** by weight: “other hydrogen”



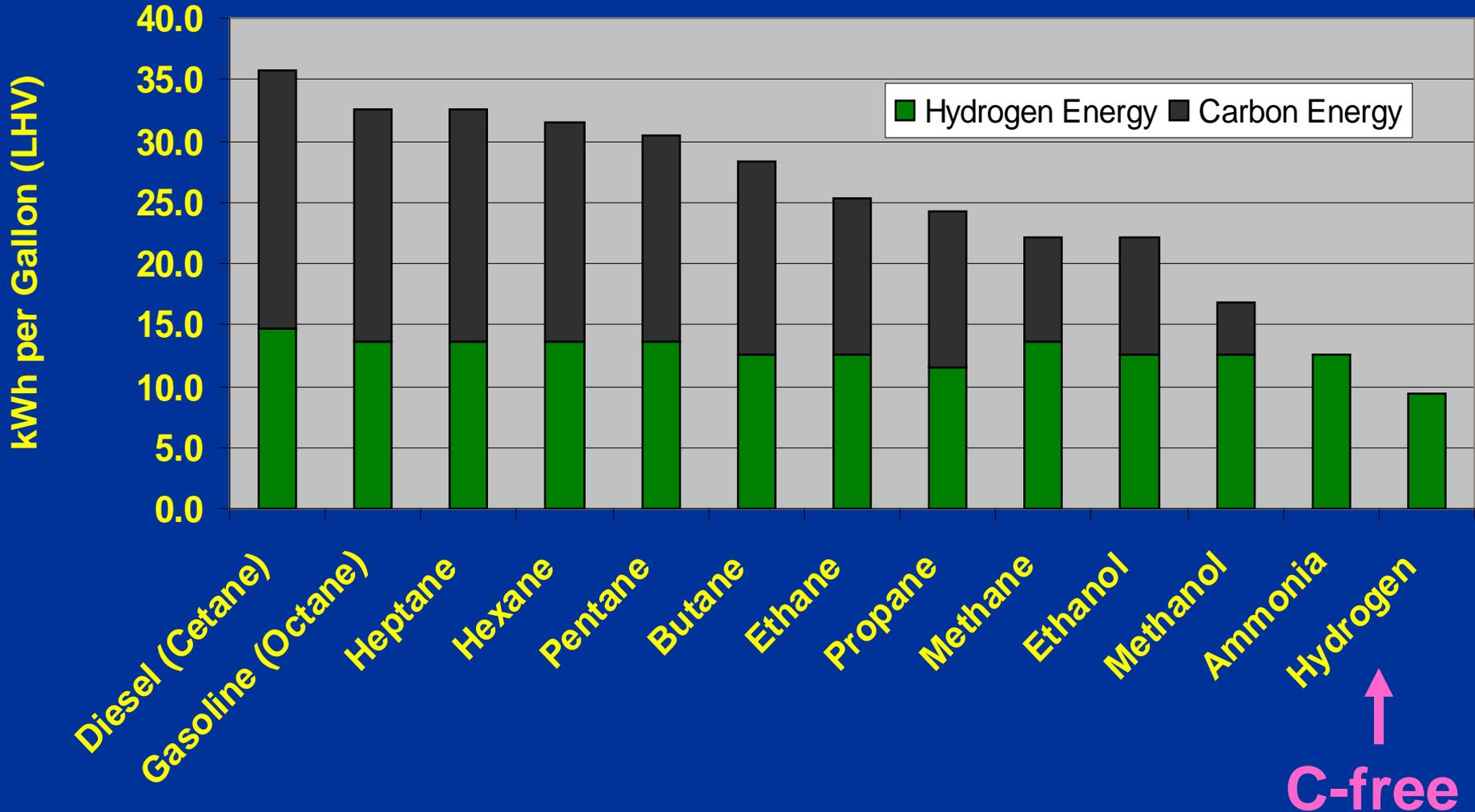
Why Ammonia ?

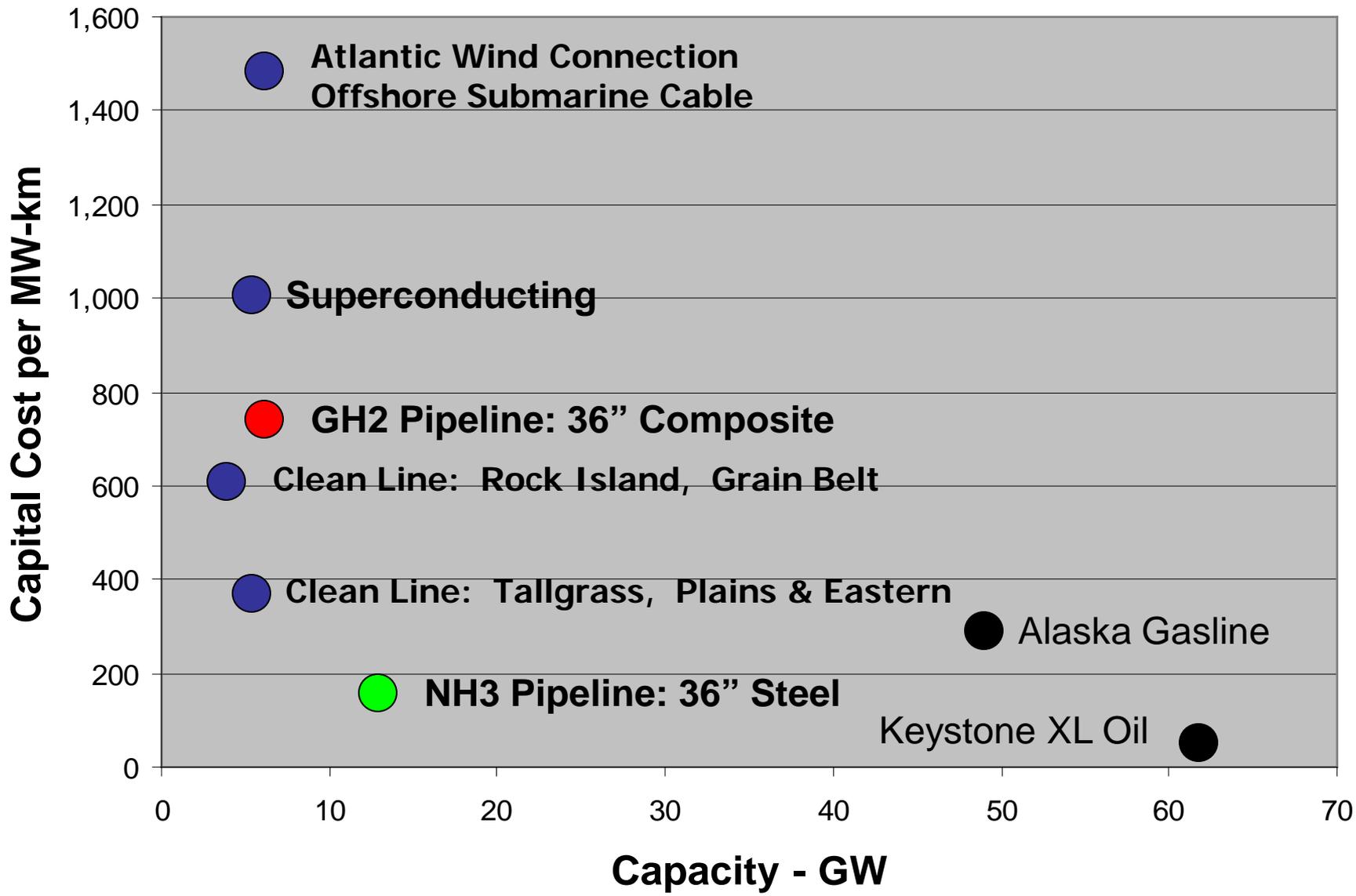
Fertilizer and Fuel

Only liquid fuel embracing:

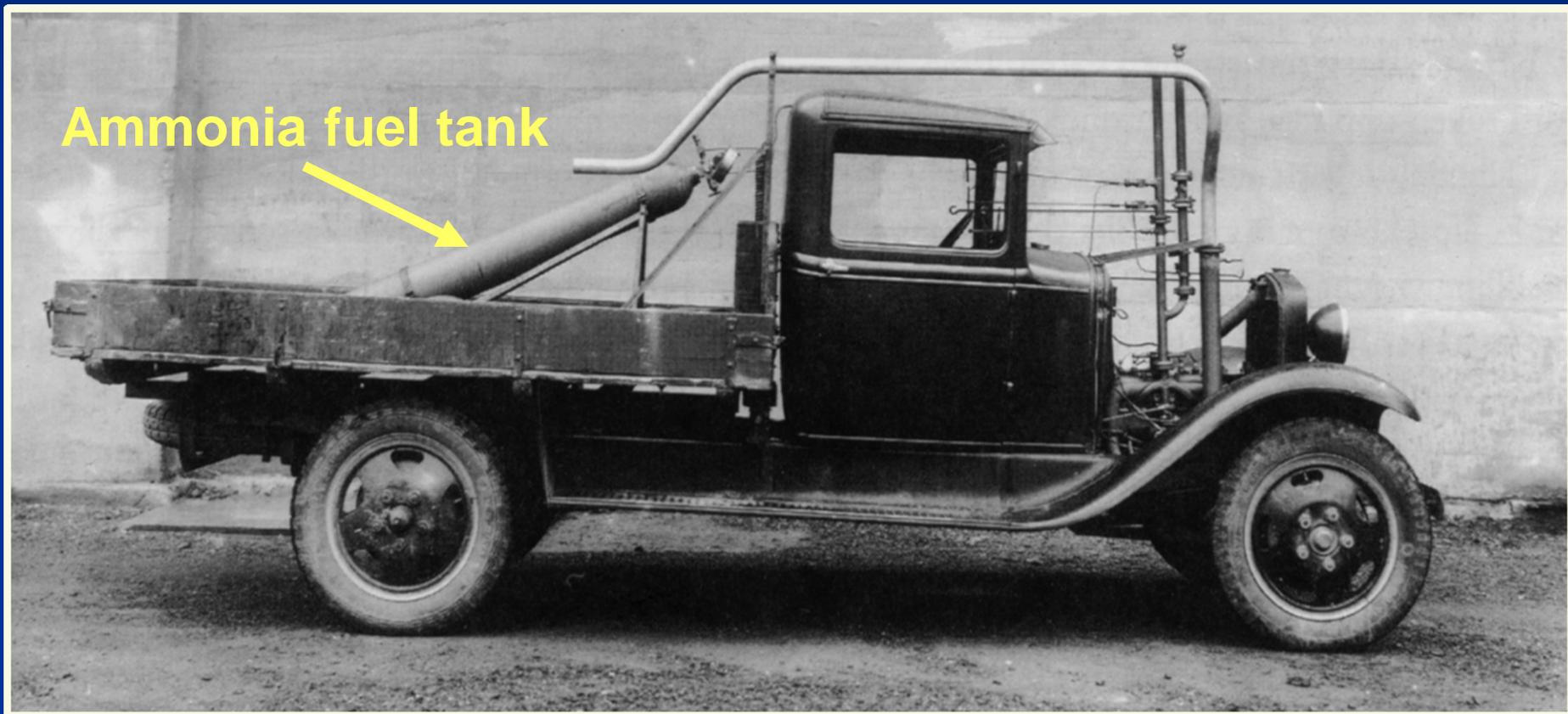
- Carbon-free: clean burn or conversion; no CO₂
 - Excellent hydrogen carrier
 - Easily "cracked" to H₂
- Reasonably high energy density
- Energy cycle inherently pollution free
 - Potentially all RE-source: elec + water + Nitrogen
 - Cost competitive with hydrocarbon fuels ?
- Decades of global use, infrastructure
 - Practical to handle, store, and transport
 - End-use in ICE, Combustion Turbine, fuel cell
 - Safety: self-odorizing; safety regs; hazard

Volumetric Energy Density of Fuels (Fuels in their Liquid State)



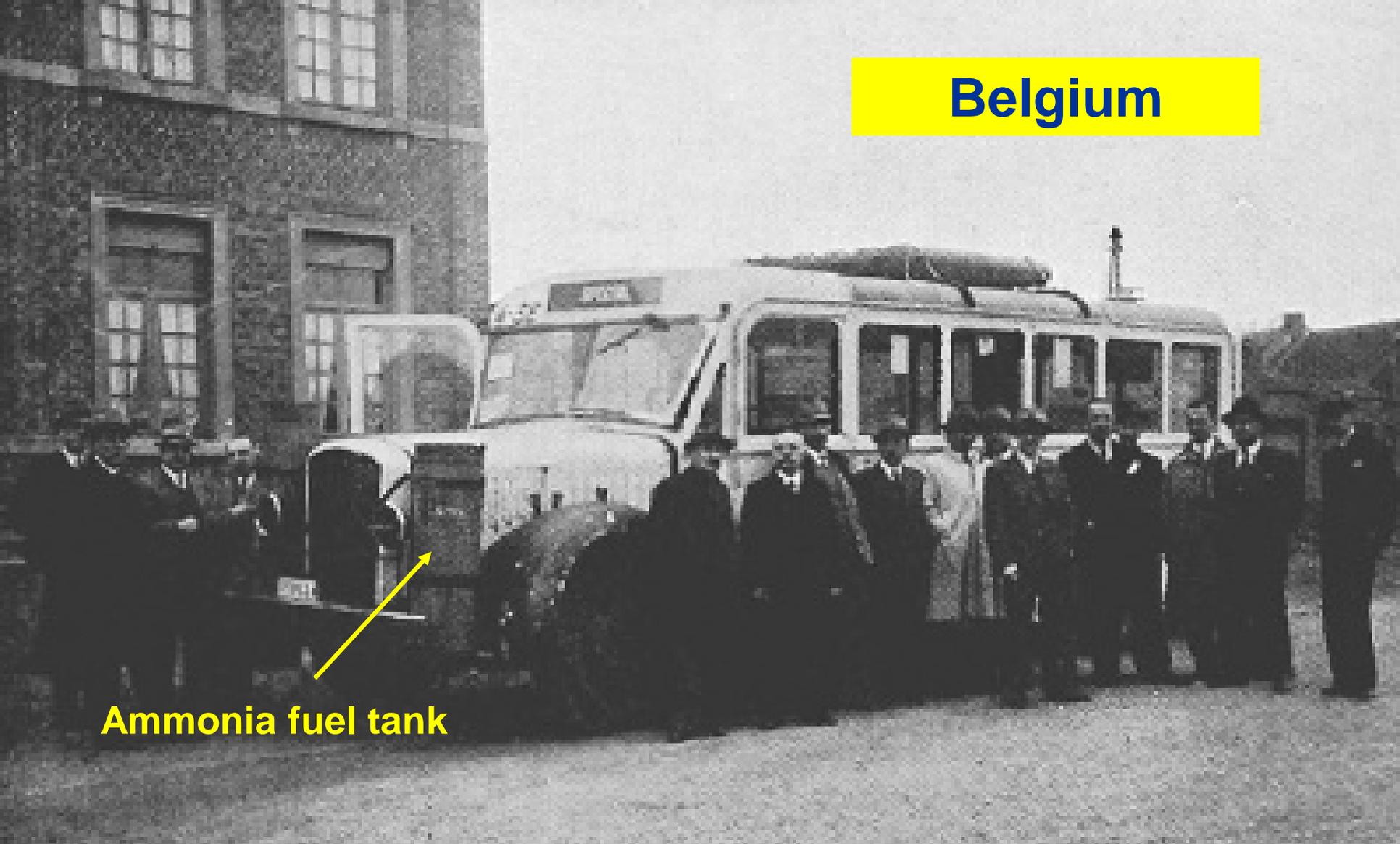


Ammonia fueled – Norway



1933

Belgium



Ammonia fuel tank

**Ammonia Fueled Bus: Thousands of Problem-free Miles
1943**



X-15 rocket plane: NH₃ + LOX fuel

Mach 6.7 on 3 Oct 67

199 missions

1959 - 68



University of Michigan

Ammonia + Gasoline Powered

- Idle: gasoline
- Full power: 80% ammonia

Summer '07 Detroit → San Francisco

2007

**1,000 hours, ICE, 6 cyl, 100 hp
75% ammonia, 25% propane**

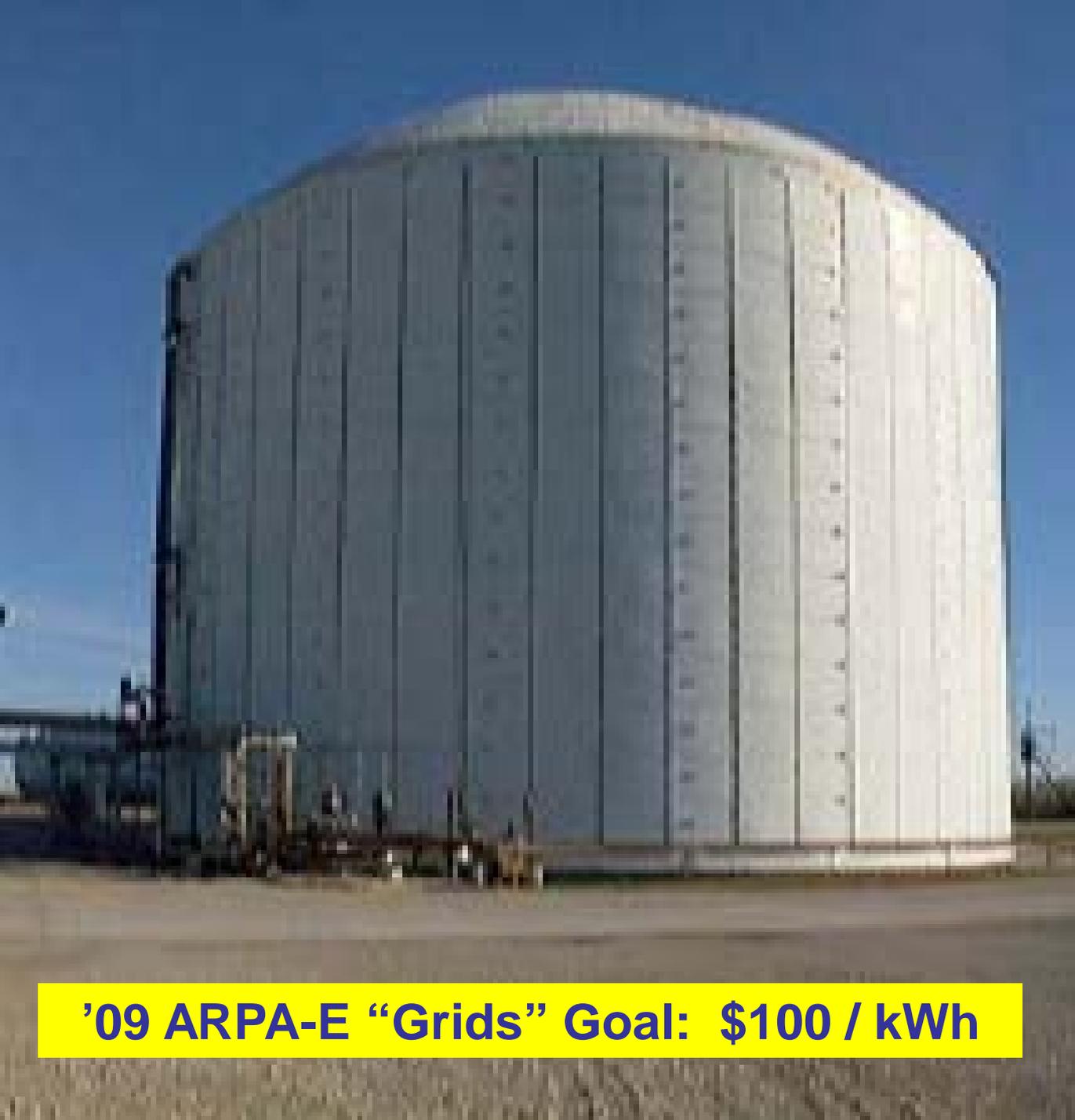
**Irrigation pump
Central Valley, CA**

2008



NH₃ Ag Fertilizer Tanks, Wind Generators, NW Iowa





***“Atmospheric”
Liquid
Ammonia
Storage Tank
(corn belt)***

30,000 Tons

190 GWh

\$ 15M turnkey

\$ 80 / MWh

\$ 0.08 / kWh

-33 C

1 Atm

'09 ARPA-E “Grids” Goal: \$100 / kWh

**Ammonia Storage Terminal
Mississippi River
Winona, MN**



The Competition

Natural gas input



80,000 Mt
liquid storage
- 33° C

To wharf

Burrup Peninsula, NW Australia, Natural Gas to Ammonia Plant
760,000 Mt / year
\$US 650 million capital cost '06



***95% Global
Ammonia***

***Synthesis
Plant***

***Natural Gas
1 – 3,000 tpd***

***Haber-Bosch
process***



Fritz Haber



Haber-Bosch Process

1909 – 1913 BASF

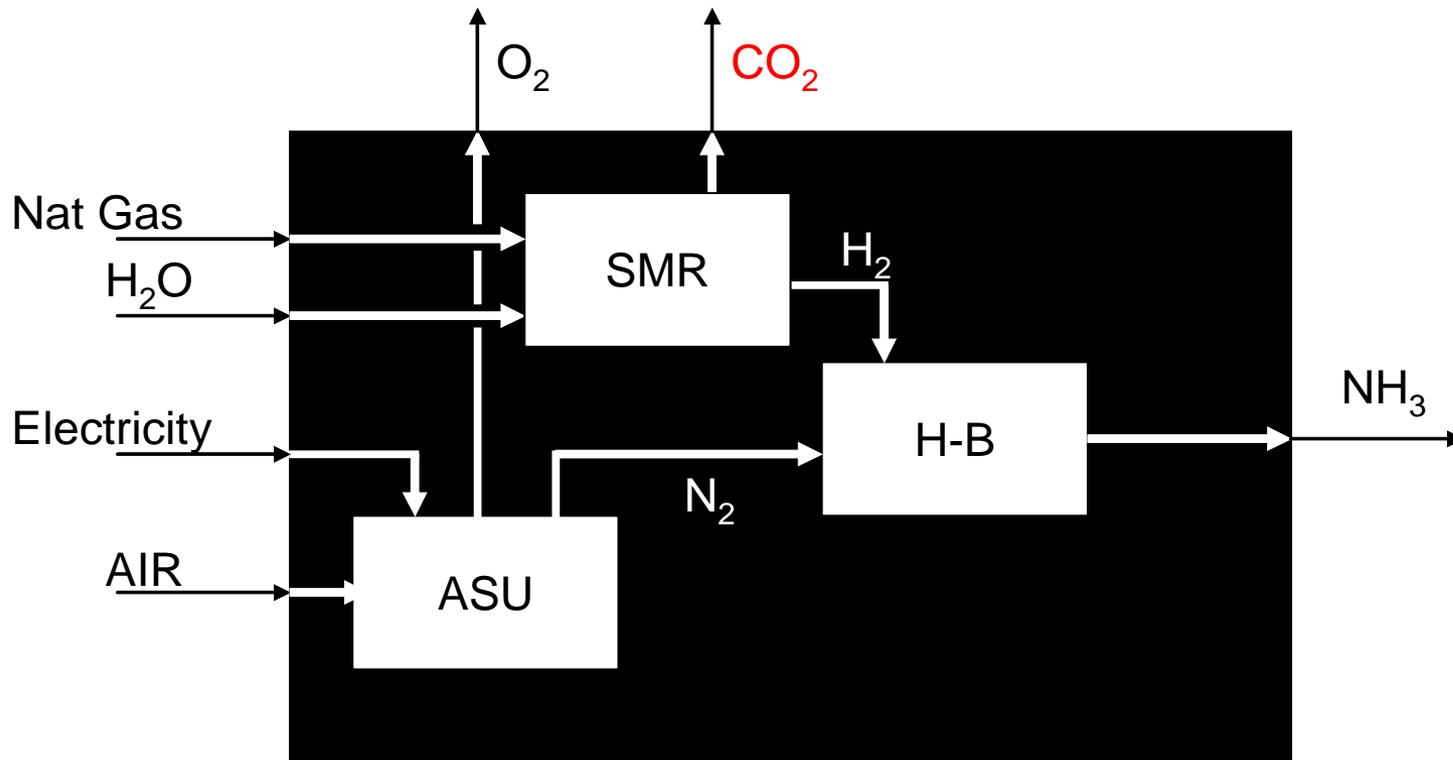
- NH_3 synthesis
- Coal gasification \rightarrow H_2
- WW I explosives
- 40% humanity: N fertilizer

Haber-Bosch Reactor

1921

Ludwigshafen, Germany

Inside the Black Box: Steam Reforming + Haber-Bosch (H-B)



Energy consumption ~33 MMBtu (9,500 kWh) per ton NH₃
Tons CO₂ per ton NH₃ = 1.8

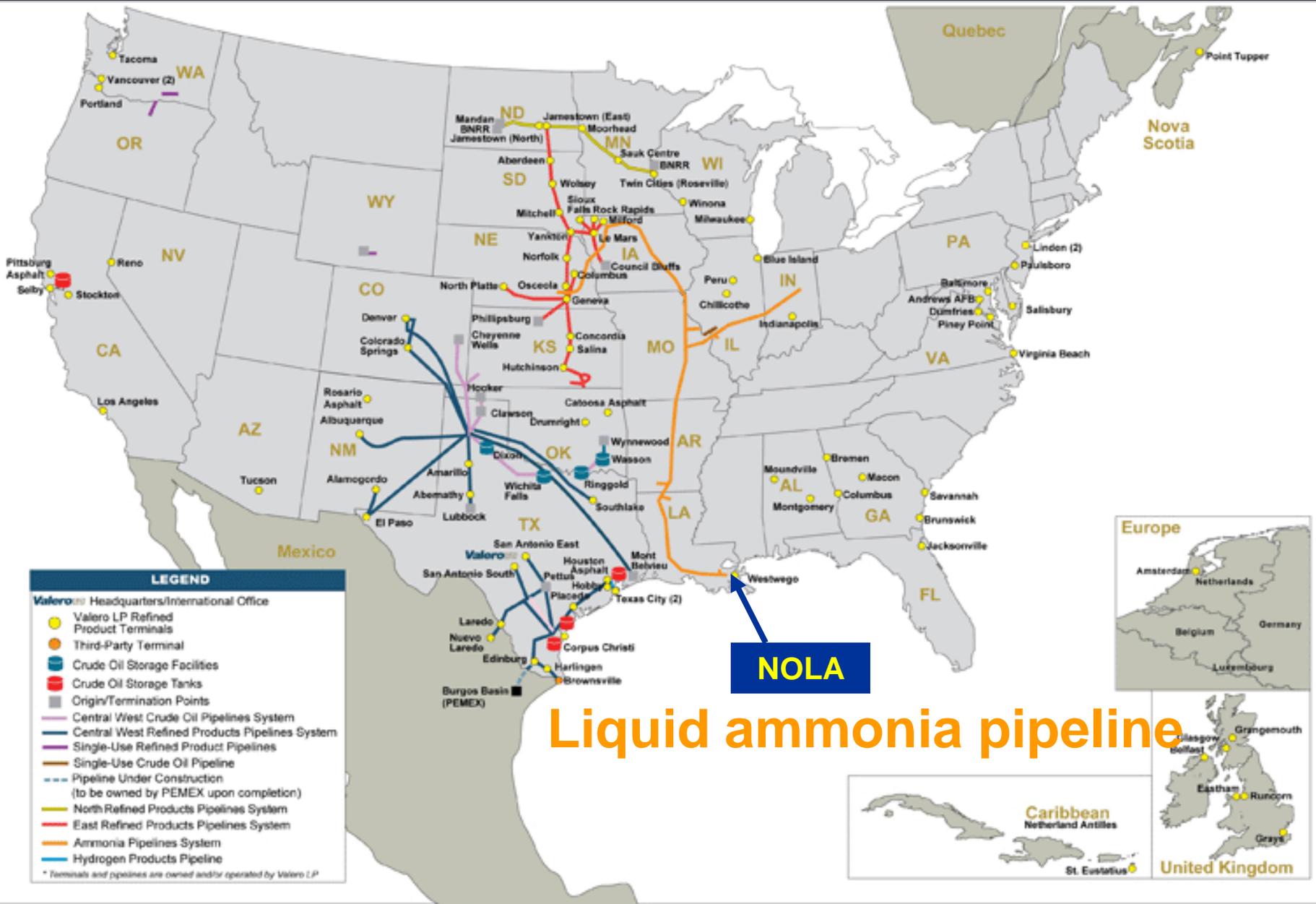


Ammonia or LPG Tanker
To 35,000 Mt
Refrigerated



USA NH3 Infrastructure

- USA imports ~60% of 14 MMt / year
- ~ 3,000 miles pipelines
 - ~ 250 psi liquid
 - Smaller diameter than NG or hydrogen
- ~ 4.5 MMt large "atmospheric" tank storage
- Mild steel construction
 - Low cost
 - No corrosion or embrittlement



Valero LP Operations

Capital Cost per GW-mile

Electricity :

	<u>KV</u>	<u>Capacity</u> <u>MW</u>	<u>\$M / GW-mile</u>
• SEIA:	765	5,000	1.3
	345	1,000	2.6
• AEP-AWEA	765	5,000	3.2
Consensus ?			2.5

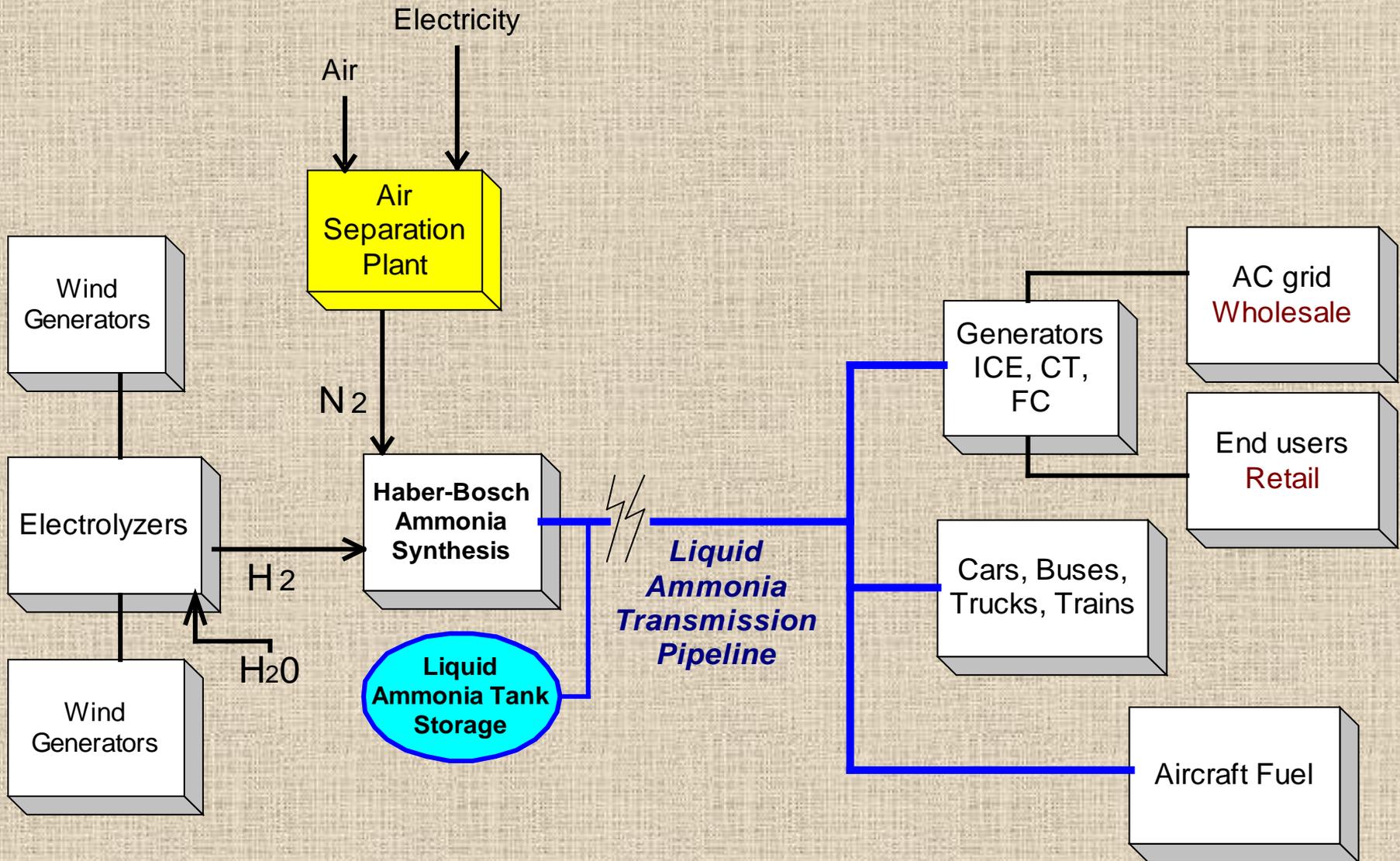
Hydrogen pipeline:

36", 100 bar, 500 miles, no compress 0.3

Ammonia pipeline:

10" , liquid, 500 miles, with pumping 0.2

RE Ammonia Transmission + Storage Scenario

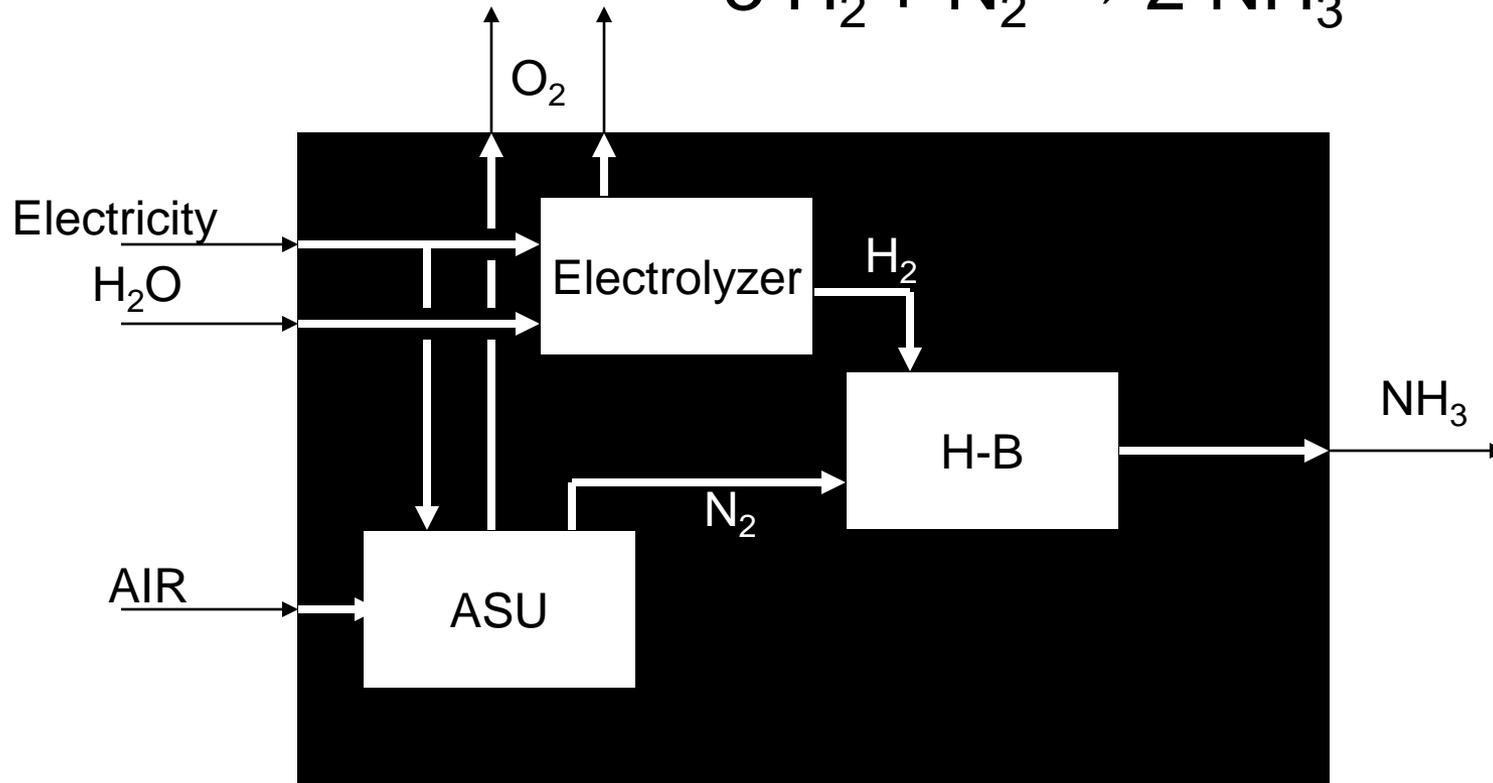
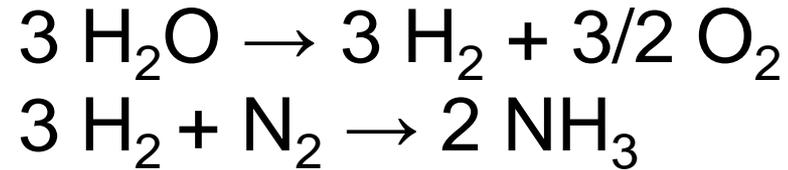


Norsk Hydro Electrolyzers 2 MW each

Ammonia from
hydrogen
from zero-cost
off-peak hydro

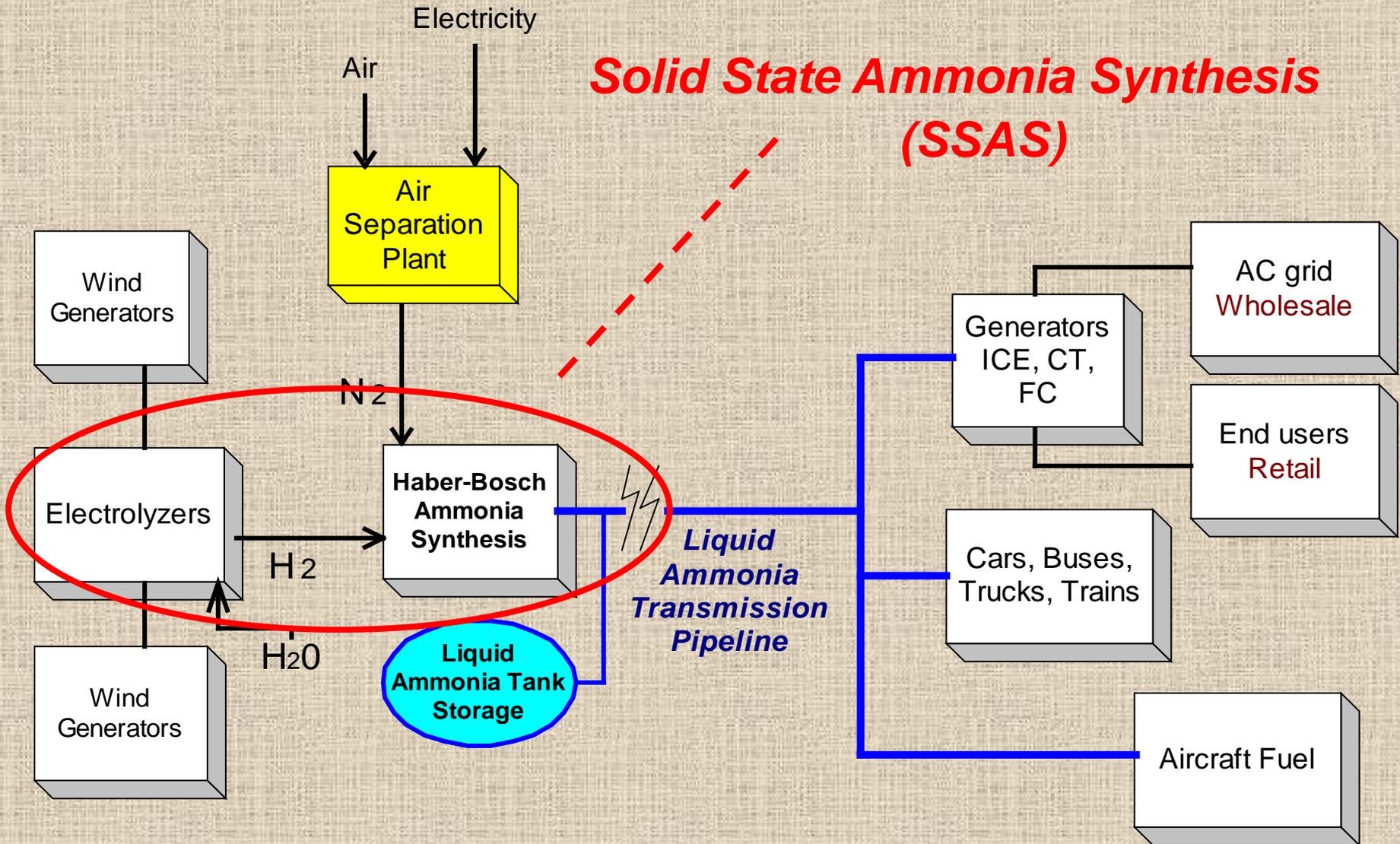


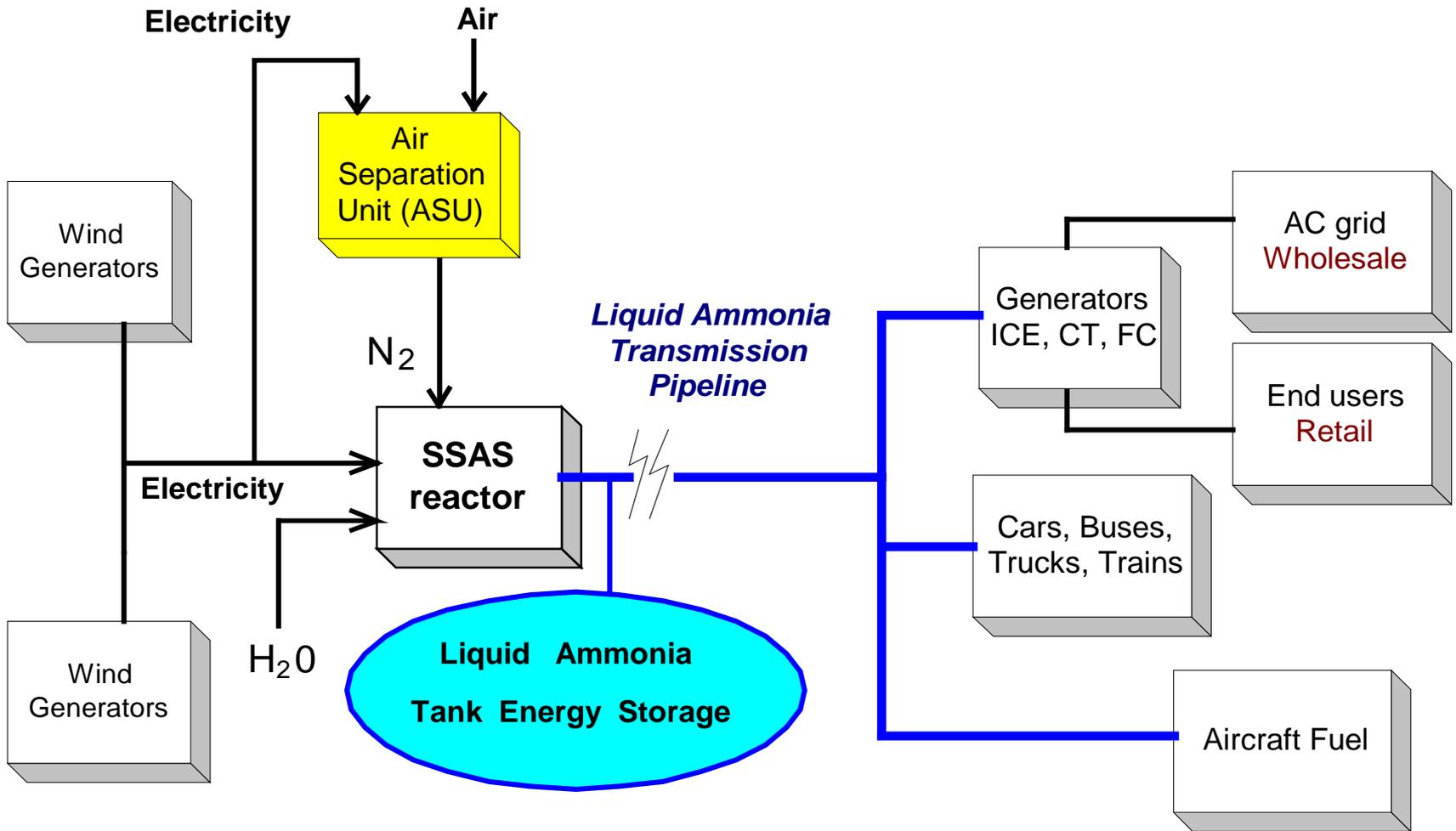
Inside the Black Box: HB Plus Electrolysis



Energy consumption ~12,000 kWh per ton NH₃

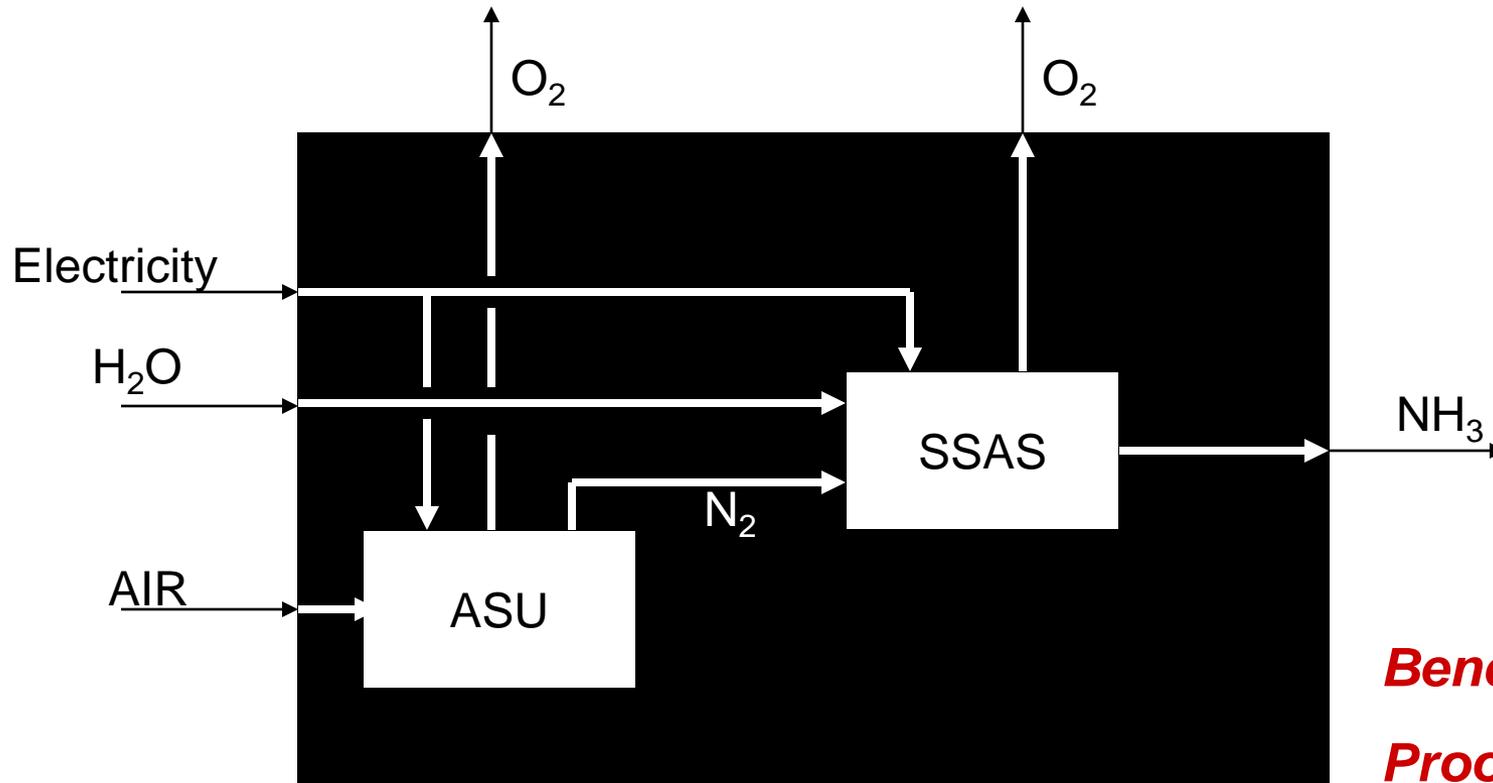
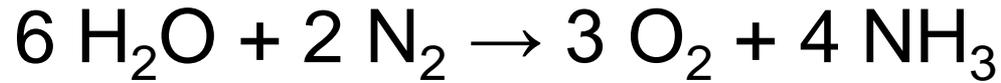
RE Ammonia Transmission + Storage Scenario





Solid State Ammonia Synthesis (SSAS)

Inside the Black Box: Solid State Ammonia Synthesis

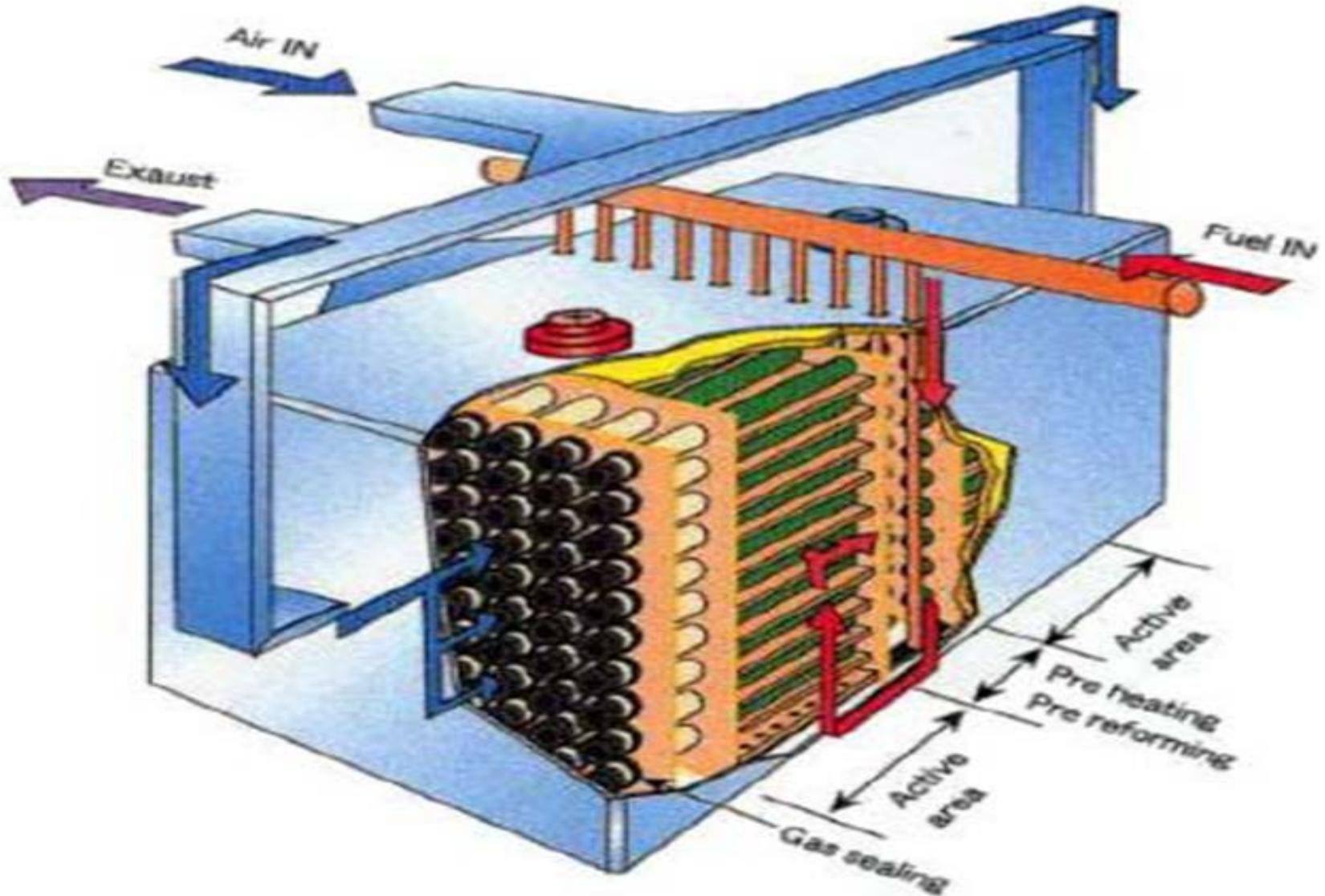


Benchtop
Proof-of-concept

Energy consumption 7,000 – 8,000 kWh per ton NH₃

Solid State Ammonia Synthesis (SSAS)

NHThree LLC patent



Wind – to – Ammonia Potential, NW Iowa



320,000 MWh storage

Annual firming 1,000 MW wind

- **Electricity**
 - **VRB (Vanadium Redox Battery)**
 - **O&M: 80% efficiency round-trip**
 - **Capital: \$500 / kWh = \$ 160 Billion**
 - **CAES (Compressed Air Energy Storage)**
 - **O&M: \$46 / MWh typical**
 - **Iowa Stored Energy Park:**
 - **Power = 268 MW**
 - **Energy capacity = 5,360 MWh**
 - **Capital: 268 MW @ \$ 1,450 / kW = \$ 390 M**
 - @ \$ 40 / kWh = \$ 13 Billion**
 - @ \$1 / kWh = \$ 325M**
 - **GH2 (3 hydrogen caverns) Capital \$70 Million**
 - **NH3 (2 ammonia tanks) Capital \$30 Million**

Renewable-Source Electricity

SSAS

Syngas Generation

Methanol

Hydrogen

GTL

Urea

Other Fertilizers

Ammonia

Liquid NH₃ Tankers

NH₃ Tanker

Loading Docks

Natural Gas

Oil

Coal

Unloading Docks
Liquid NH₃ Storage Tanks

Pipeline, railroad, barge

Farms

Crops

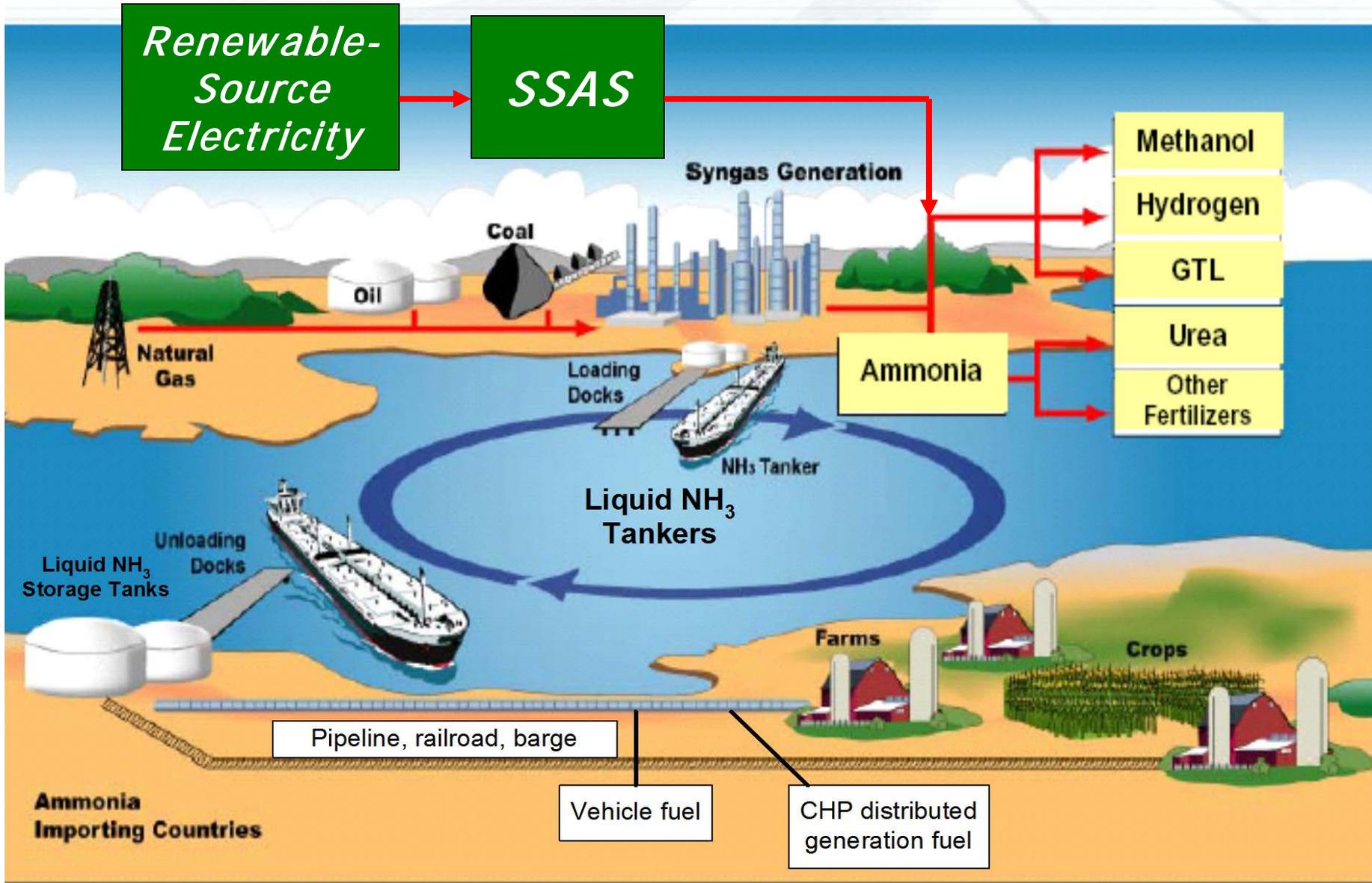
Ammonia Importing Countries

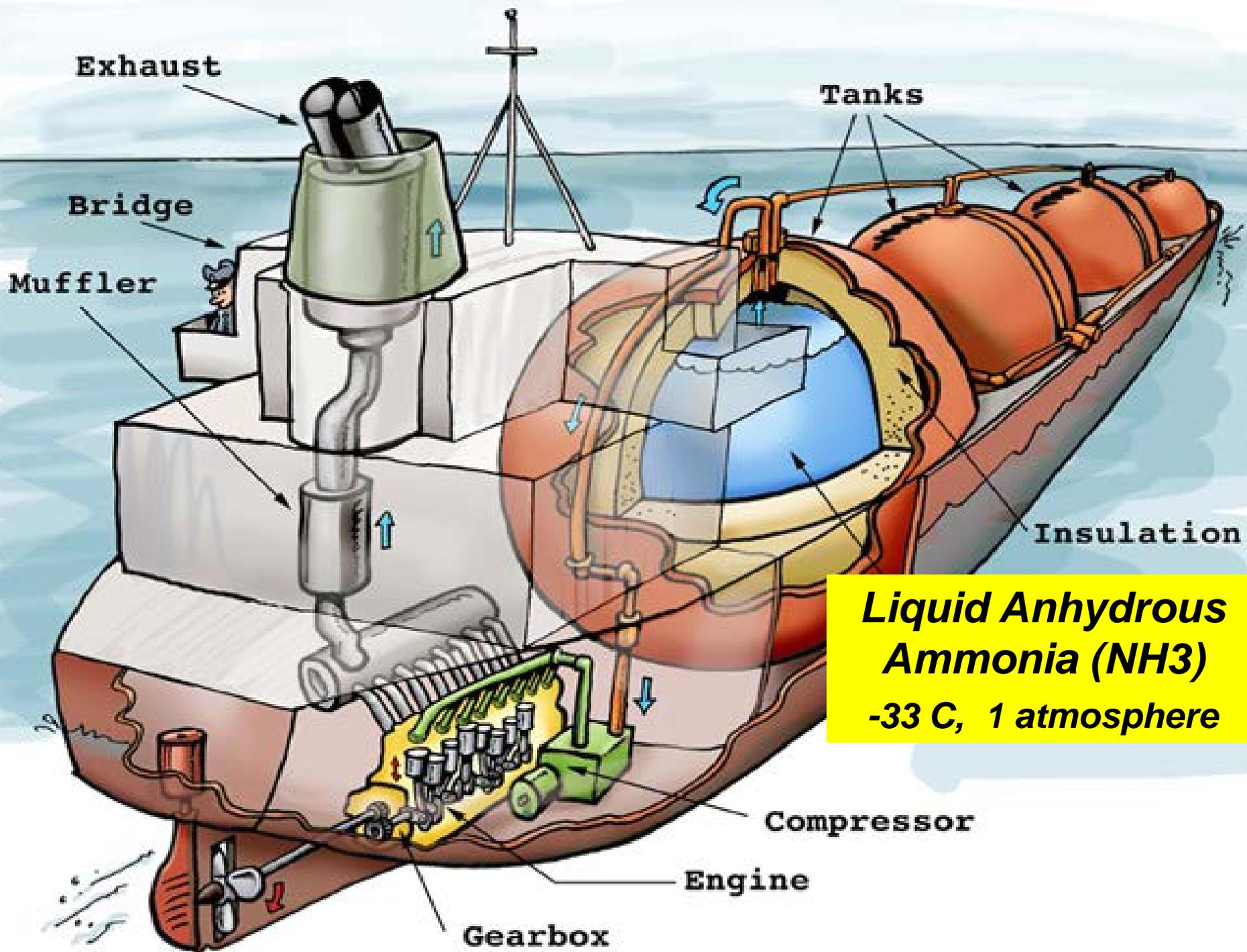
Vehicle fuel

CHP distributed generation fuel

KBR

Energy and Chemicals





Humanity's Goal: *"Run World on Renewables"*

**A global, sustainable,
benign-source, equitable,
energy economy**

- **CANNOT with only
electricity transmission**

“Transmission”

- **Beyond “Smart Grid”, GW scale**
- **Electrofuels**
- **Renewable-source electricity**
- **Underground pipelines**
- **Carbon-free fuels: hydrogen, ammonia**
- **Low-cost storage:**
 - \$ 0.10 – 0.20 / kWh capital**
- **CHP, transport, industrial**

Beyond “Smart Grid”

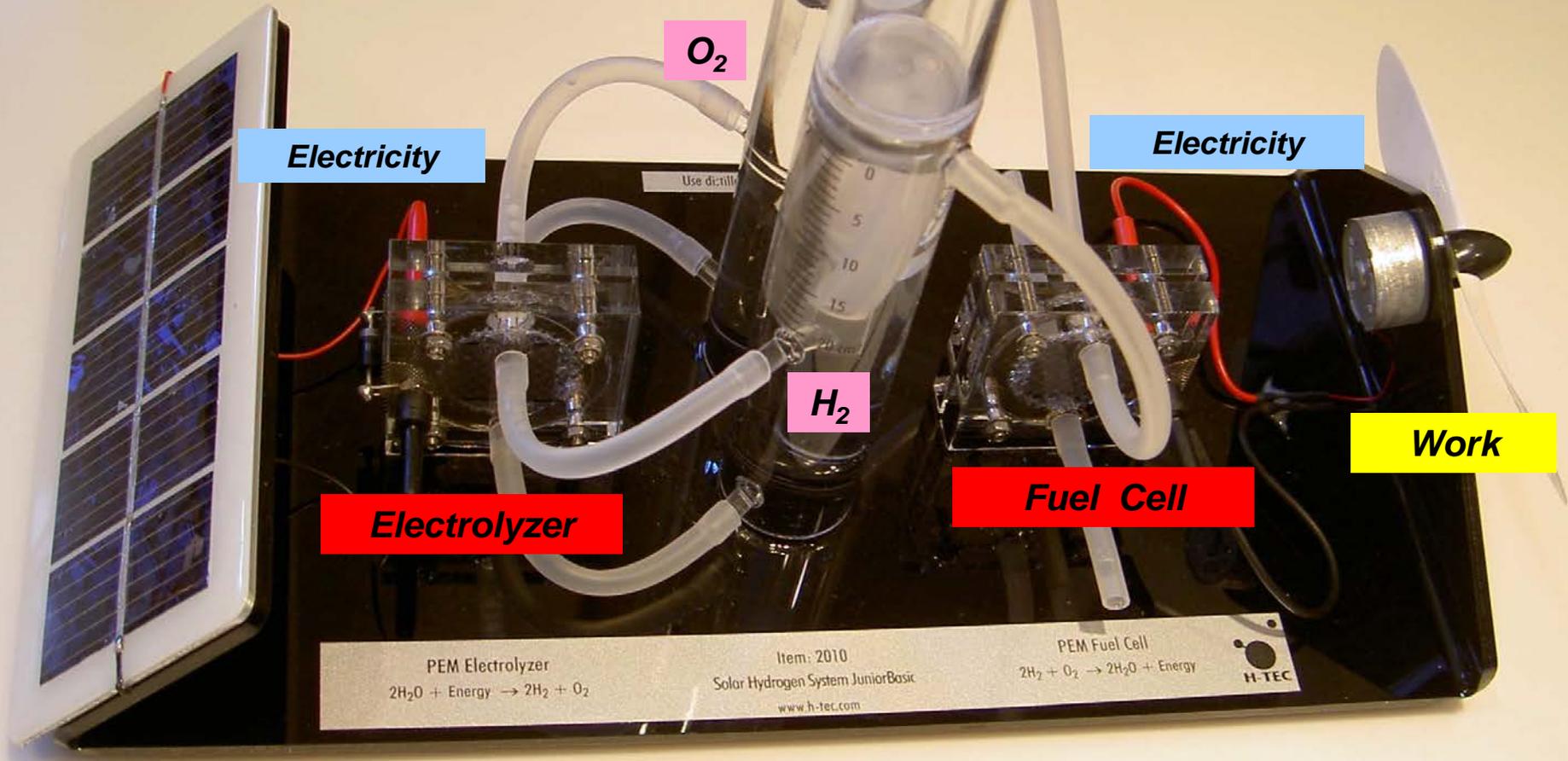
- Primarily DSM
- More vulnerable to cyberattack ?
- Adds no physical:
 - Transmission, gathering, distribution
 - Storage
- Next big thing; panacea
- Running the world on renewables ?
- Must think:
 - Beyond electricity
 - Complete energy systems

MUST Run the World on Renewables – plus Nuclear ?

- Rapid climate change
- Ocean acidification
- Sea level rise
- Species extinctions



**Sunlight from
local star**



Solar Hydrogen Energy System



***Alternatives to Electricity for Transmission,
Storage, and Integration of Stranded
Renewables: Hydrogen and Ammonia for
Transportation and CHP fuel***

***Fuel Cell and Hydrogen Energy Seminar
Fuel Cell and Hydrogen Energy Association
Los Angeles, CA 10 – 13 Nov 14***

DVD's and Handouts

***Bill Leighty, Director
The Leighty Foundation
Juneau, AK
wleighty@earthlink.net***

907-586-1426 206-719-5554 cell