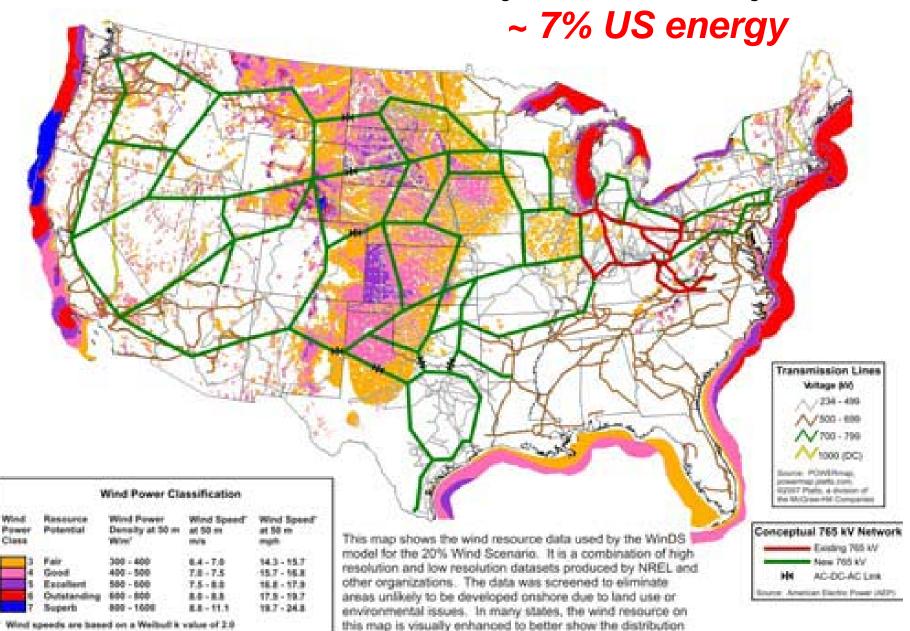


on ridge crests and other features.

AWEA: 20% Electricity from Wind by 2030



on ridge crests and other features.

Wind seasonality, Great Plains

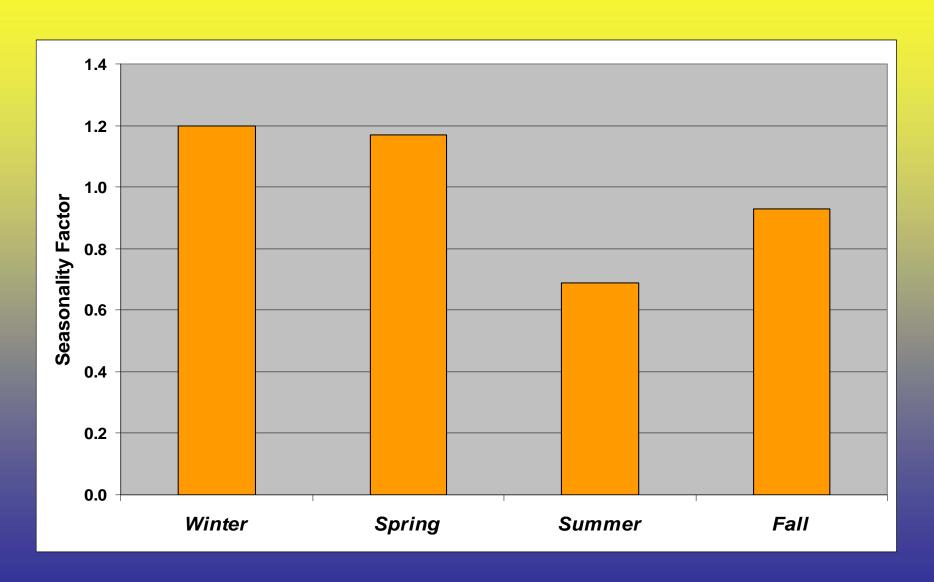
Normalized to 1.0

• V	Vinter	1.20
• \$	pring	1.17
· S	ummer	0.69
. ^	utumn	0.03

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

- Pumped hydro: available capacity?
- CAES (compressed air energy storage)
 - O&M: \$46 / MWh typical
 - Iowa: Power = 268 MW

Energy capacity = 5,360 MWh

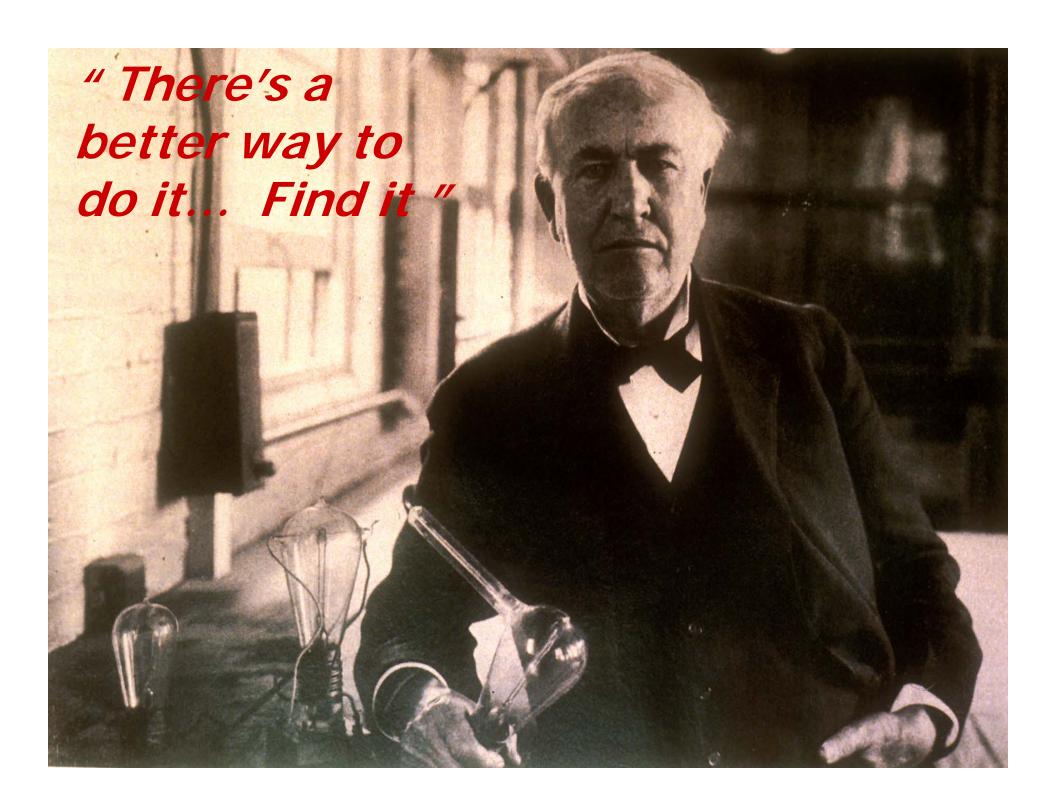
Capital: 268 MW @\$800 / kW = \$214 M

Storage @ \$40 / kWh = \$13 Billion

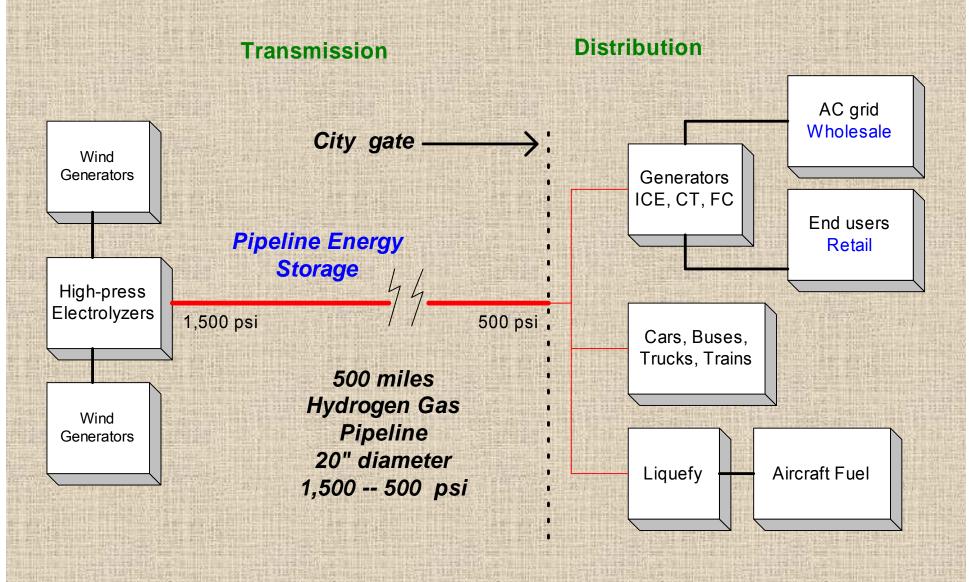
Storage @ \$1 / kWh = \$325 Million

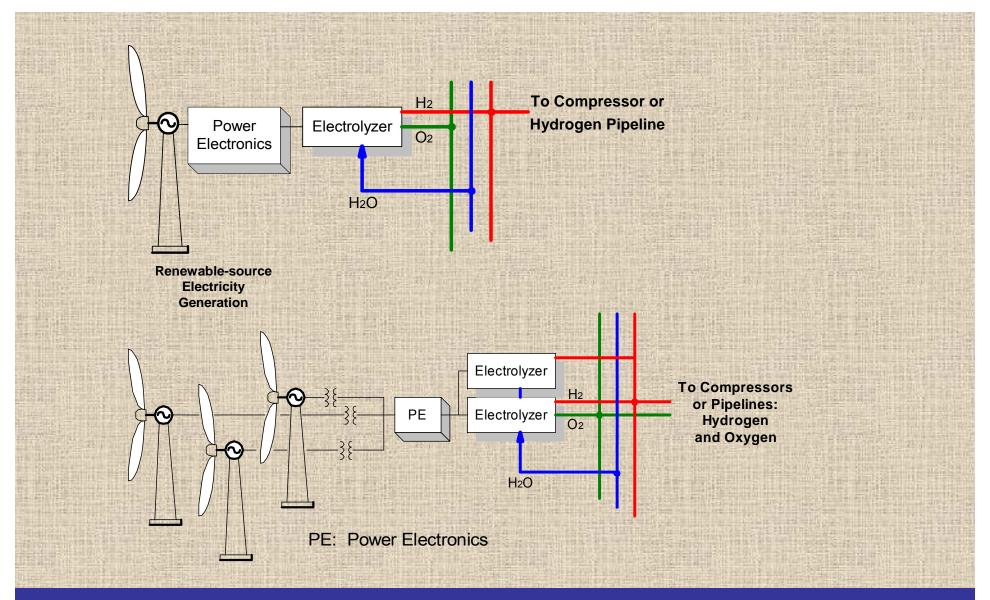
- VRB flow battery
 - O&M: 80% efficiency round-trip
 - Capital: \$500 / kWh = \$160 Billion



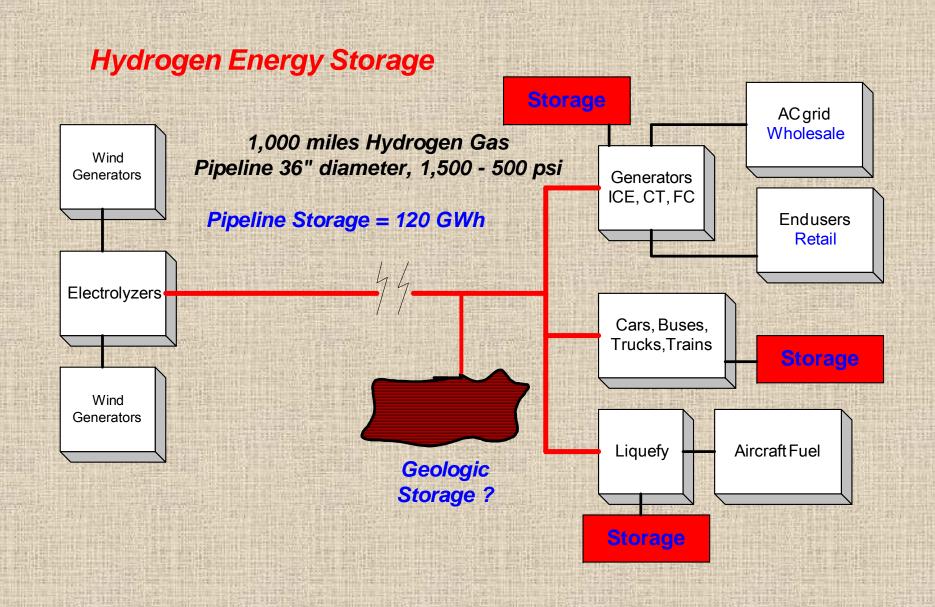


Compressorless system: No geologic storage

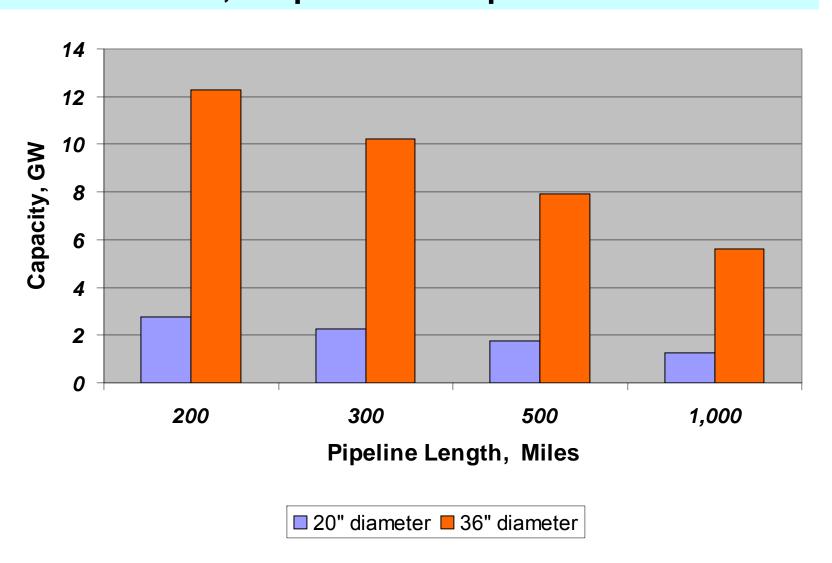


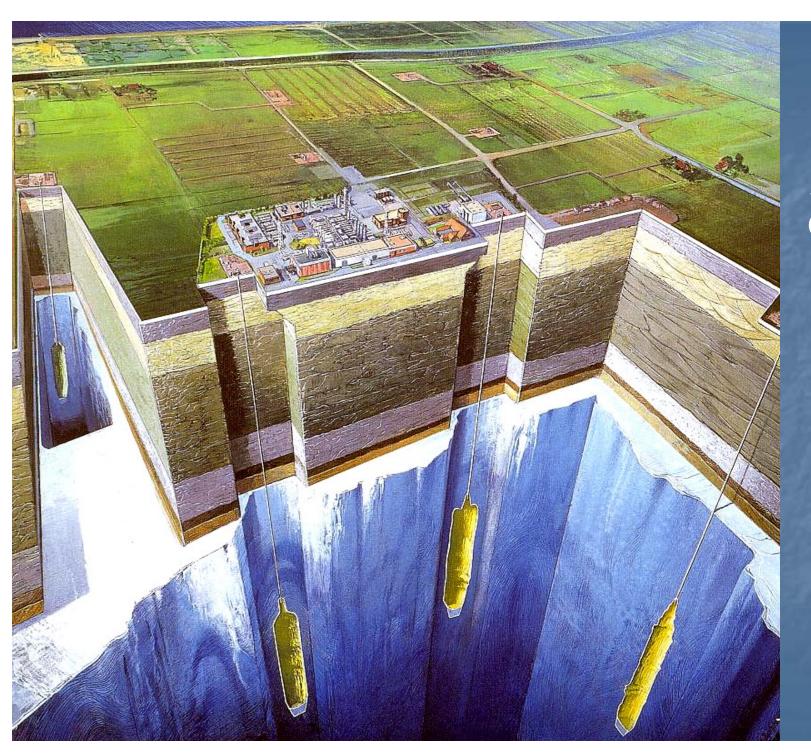


Topology Options: H₂ and O₂ Production and Gathering from Renewable Energy Generation



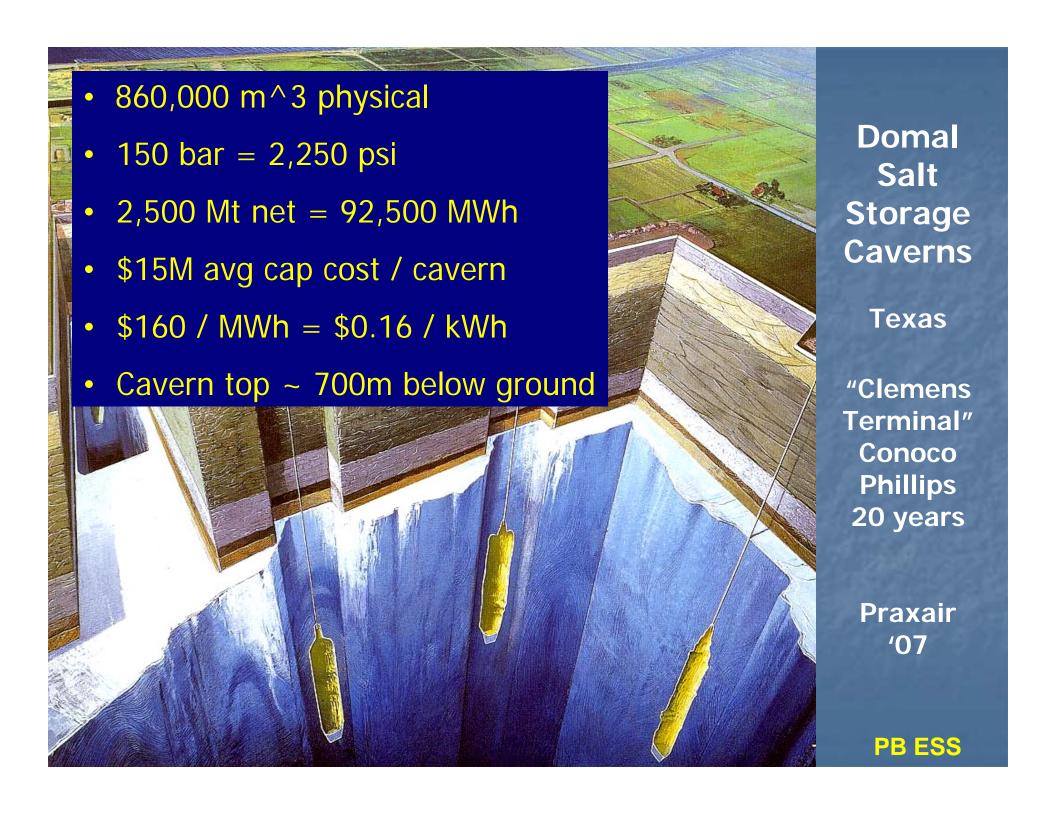
Compressorless 20", 36" GH2 Pipeline Capacity 1,500 psi IN / 500 psi OUT





Domal Salt Storage Caverns

PB ESS



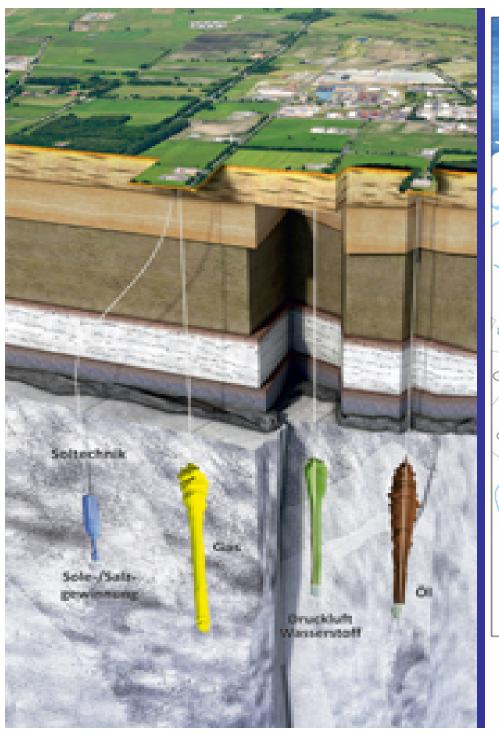


Renewable-source GH2 geologic storage potential.

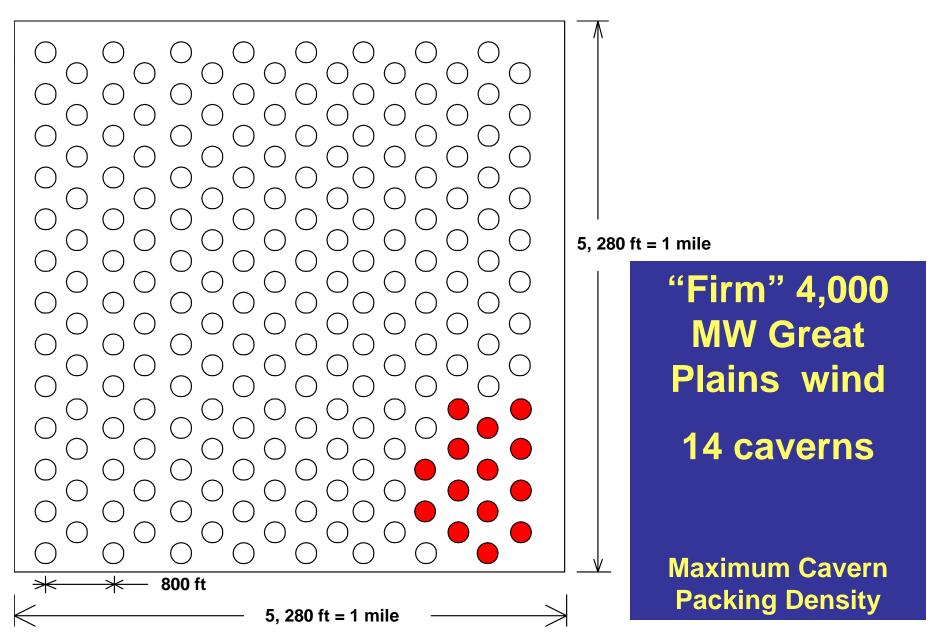
Candidate formations for manmade, solution-mined, salt caverns

Two Hydrogen Storage Caverns near Moss Bluff, Texas

- ConocoPhillips "Clemens Terminal"
 - SMR buffer → Sweeny Refinery
 - 2,500 tons net GH2
 - 25 years
 - Low leakage, O&M cost
- Praxair
 - Commissioned '07
 - Proprietary specs
 - About same size







 $(8 \times 13) = 104 + (8 \times 12) = 96$ Total = 200 caverns per square mile Each cavern is 200 ft diam, with minimum 200 ft web separation.

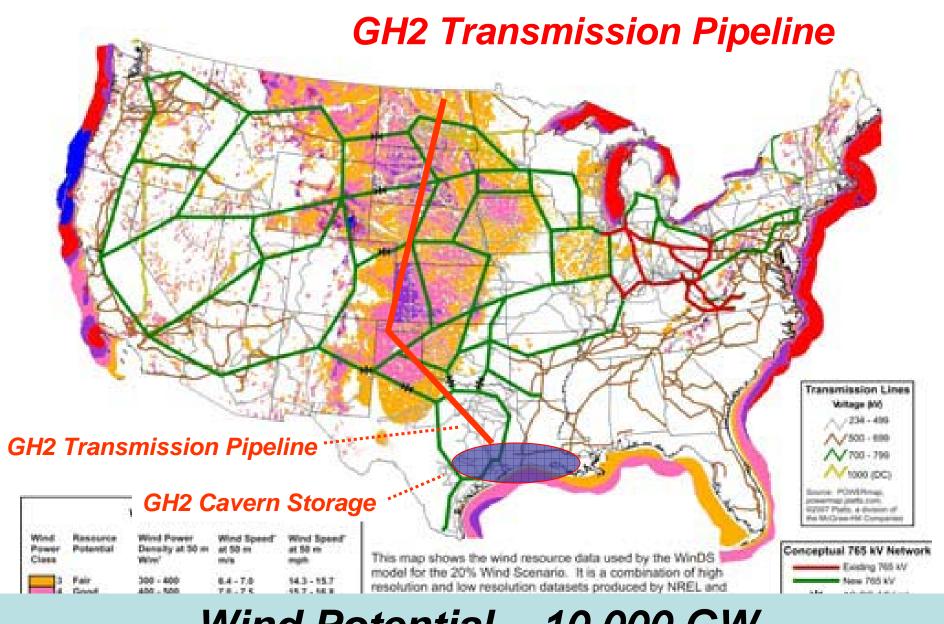


Hydrogen "sector" of a benign, sustainable, equitable, global energy economy

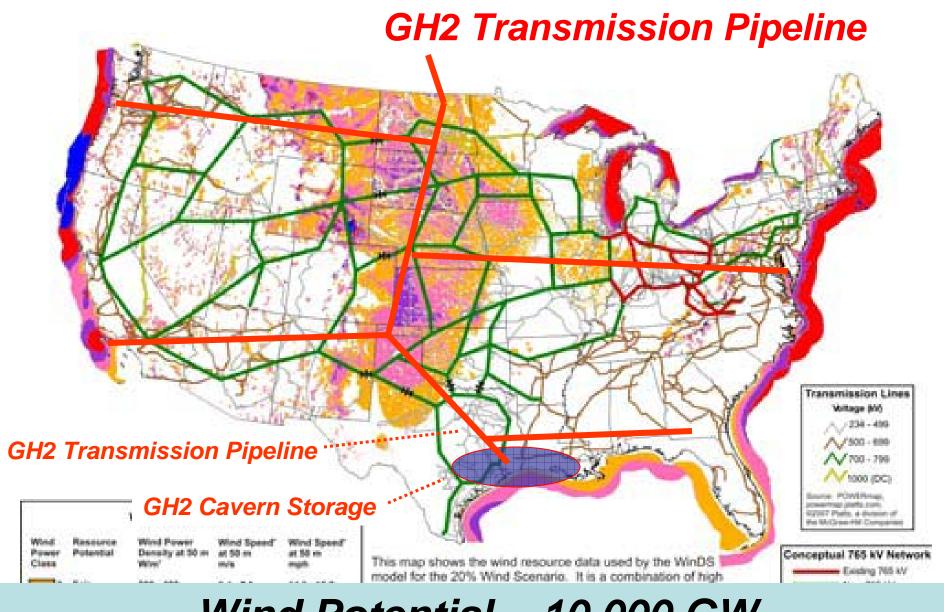
Optimistic: Total Installed Capital Cost 1,000 mile Pipeline "Firming" GH2 cavern storage

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

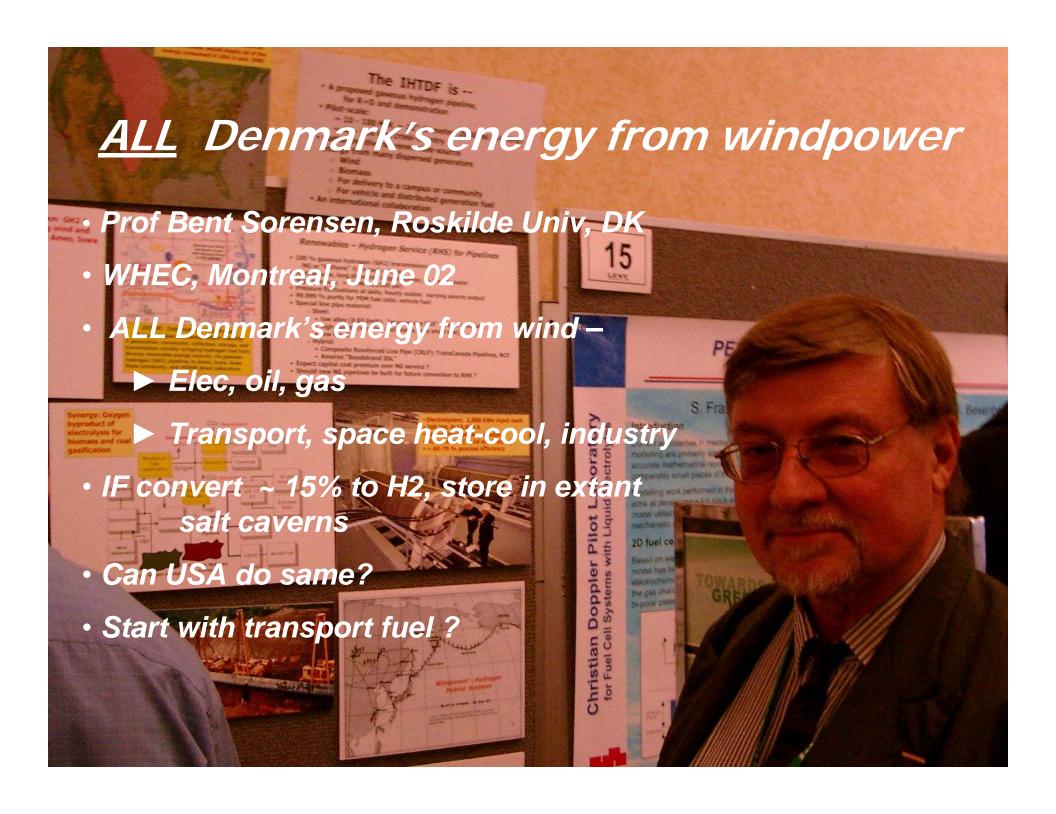
Cavern storage: ~ 3 % of total capital cost

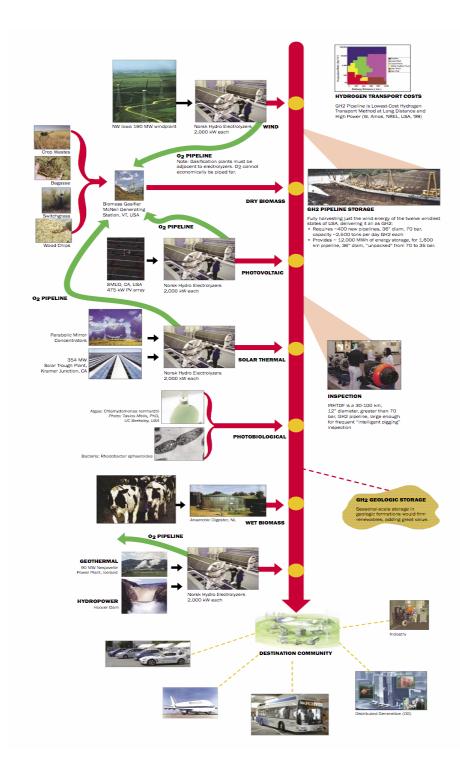


Wind Potential ~ 10,000 GW 12 Great Plains states



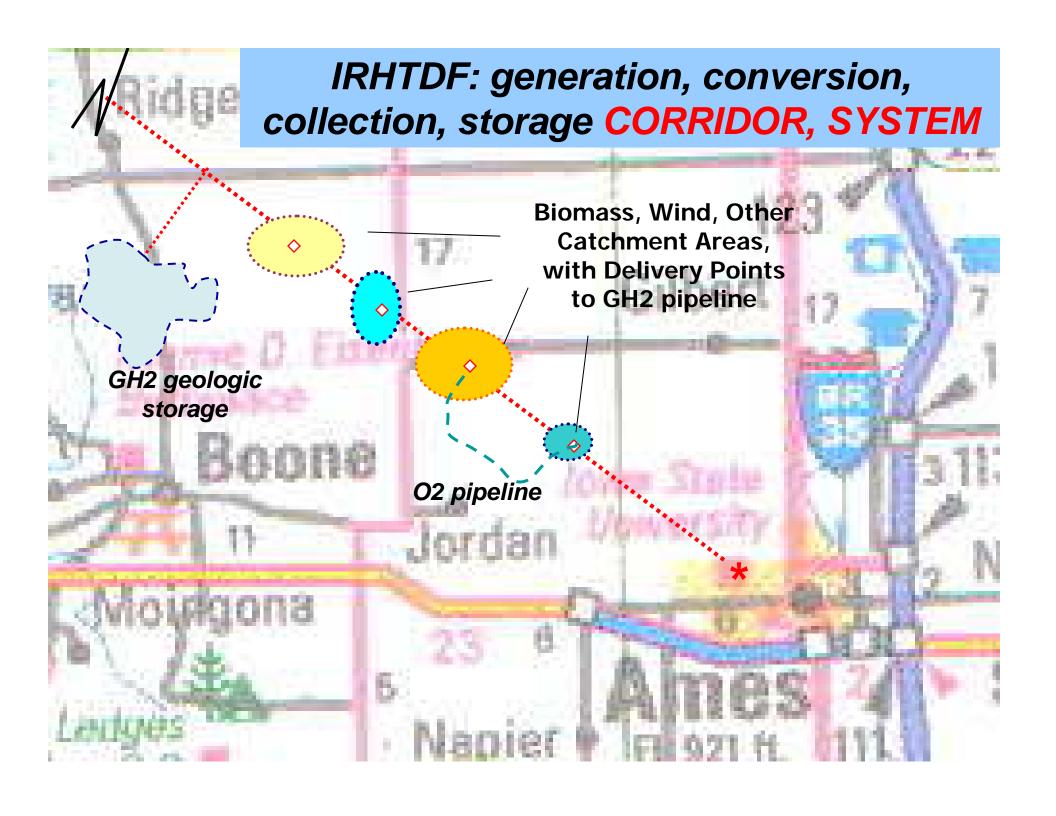
Wind Potential ~ 10,000 GW 12 Great Plains states





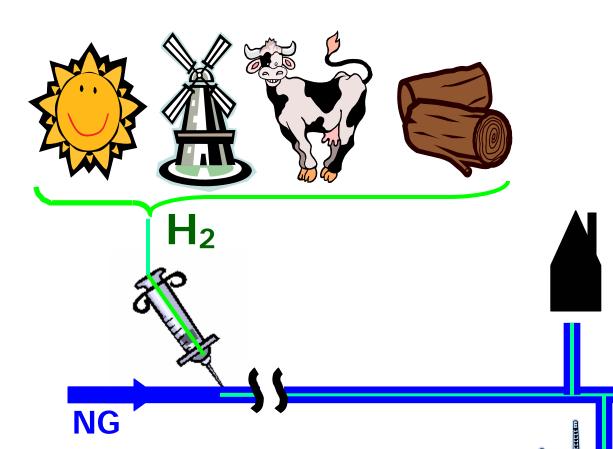
Pilot-scale Hydrogen Pipeline System: Renewables

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



The NATURALHY approach: EC, R+D







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







Pure H₂

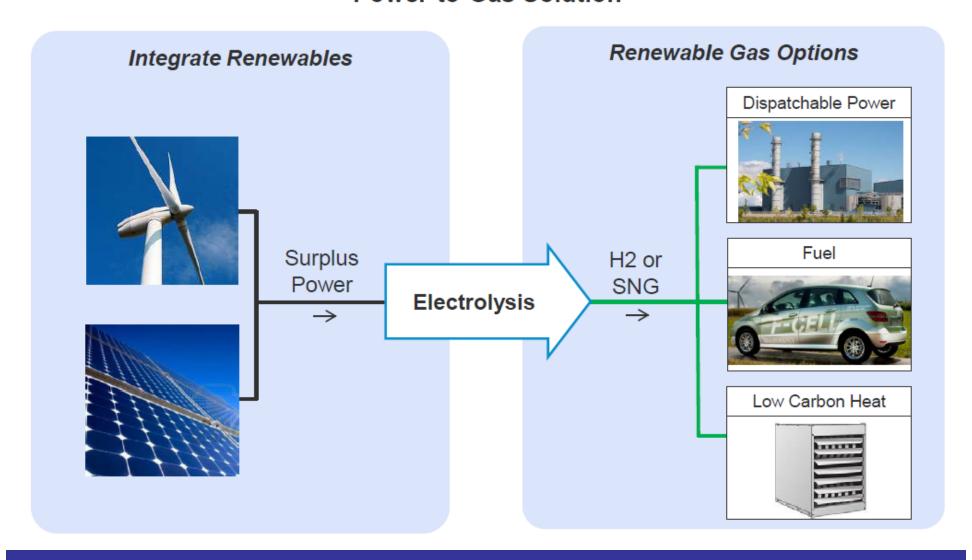
"Power - to - Gas"

- RE-source electricity → hydrogen → NG pipeline
- Otherwise-curtailed wind, solar
- WHEC, Toronto, 2010: two sessions
- FREE storage
- FREE transmission
- Earns only NG price: champagne → beer
- Recover "five nines" H2 fuel?
- E.ON utility, Falkenhagen, Germany
 - World's largest
 - 2 MW electrolysis plant
 - Hydrogenics
 - Wind generated. Solar?
- Enbridge Pipelines, Ontario: next?

"Power - to - Gas"

- EU: "NaturalHY" project 2003 5
- Concentration limits:
 - Energy content, metering
 - Hydrogen Embrittlement
 - Germany: 5 % H2 in NG pipelines, now
- EU: "HY Under" project: salt caverns

Power-to-Gas Solution



Hydrogenics, Toronto



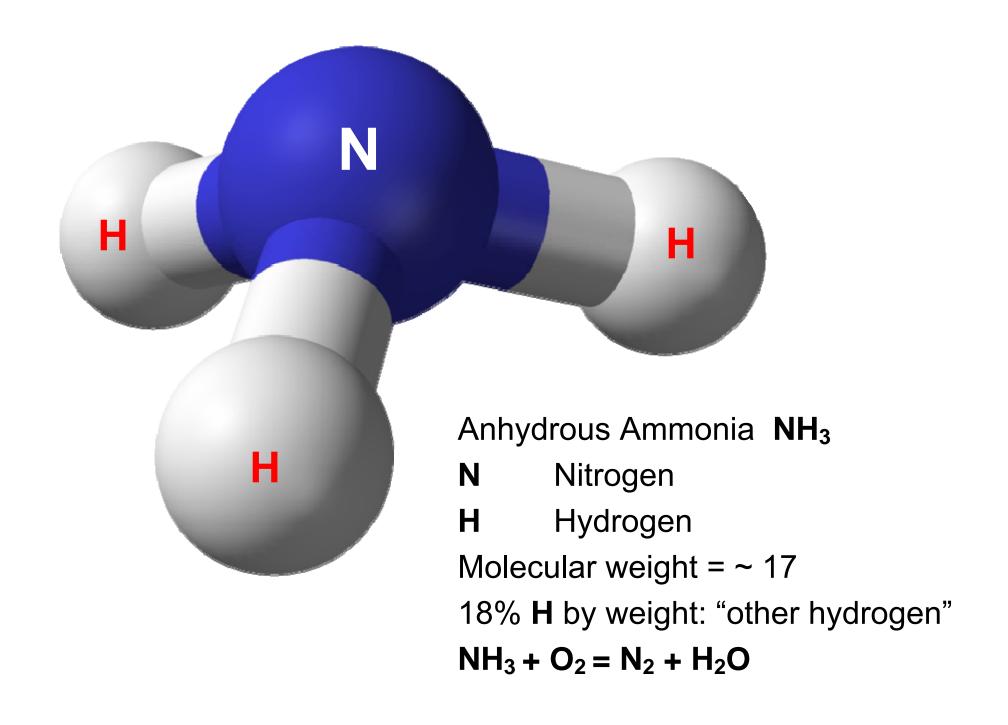
Hydrogenics 1 MW PEM Electrolyzer, June 2013

POWER TO GAS

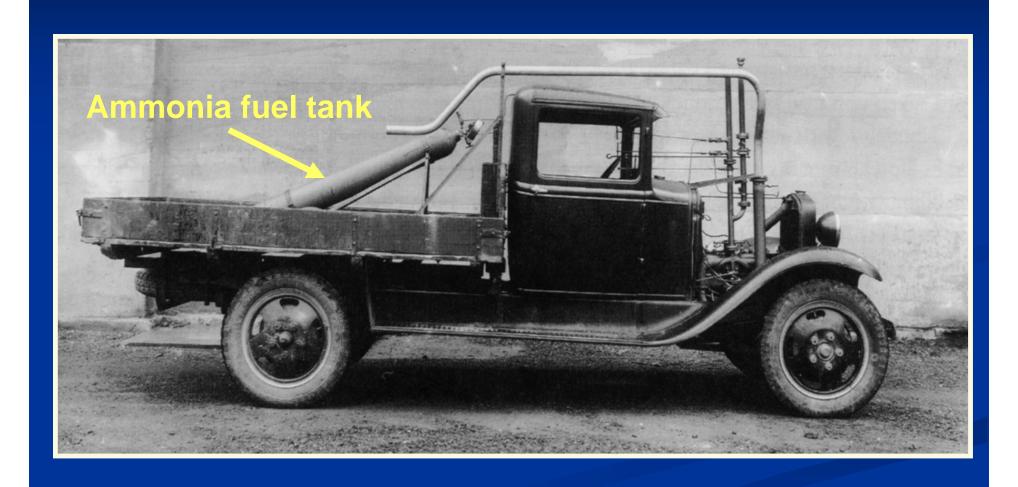


POWER TO FUEL | MOVE | PROTECT





Ammonia fueled - Norway





Ammonia Fueled Bus: Thousands of Problem-free Miles 1943





Ammonia + Gasoline Powered

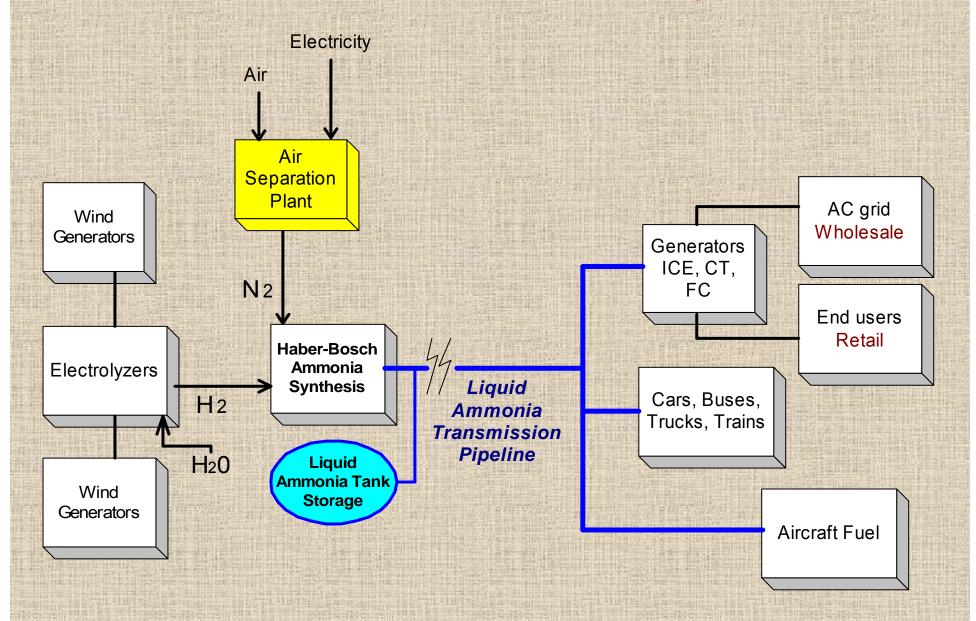
Idle: gasoline

• Full power: 80% ammonia

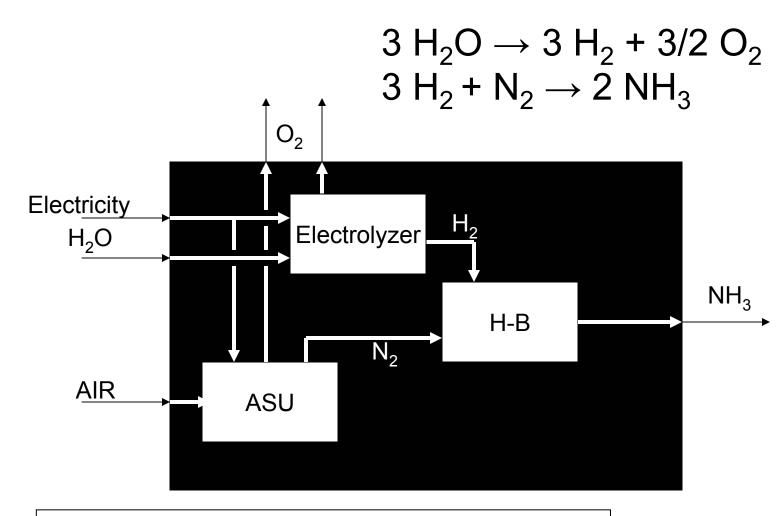
Summer '07 Detroit → San Francisco

2007

RE Ammonia Transmission + Storage Scenario

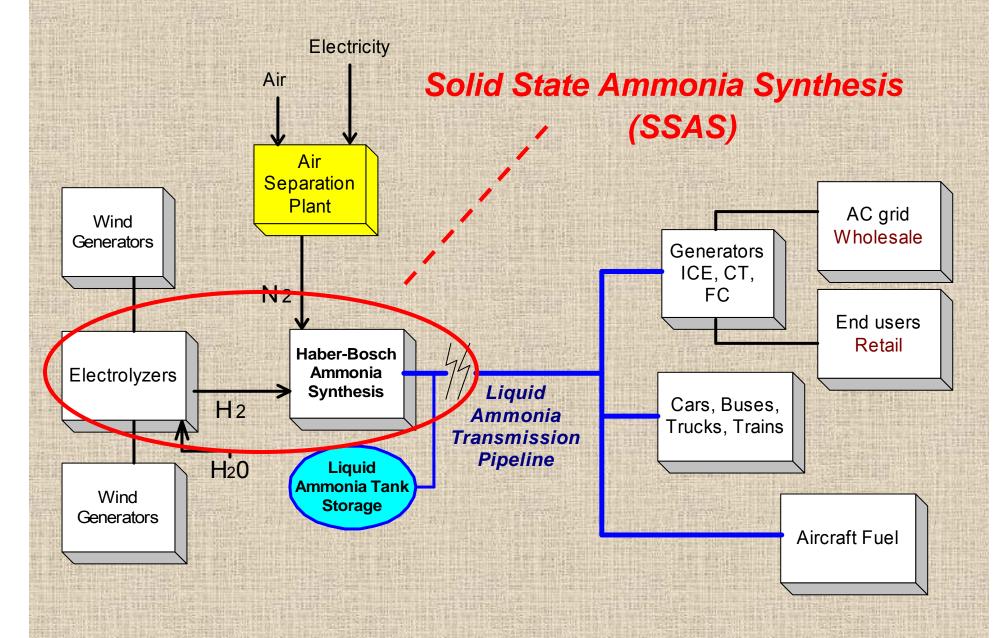


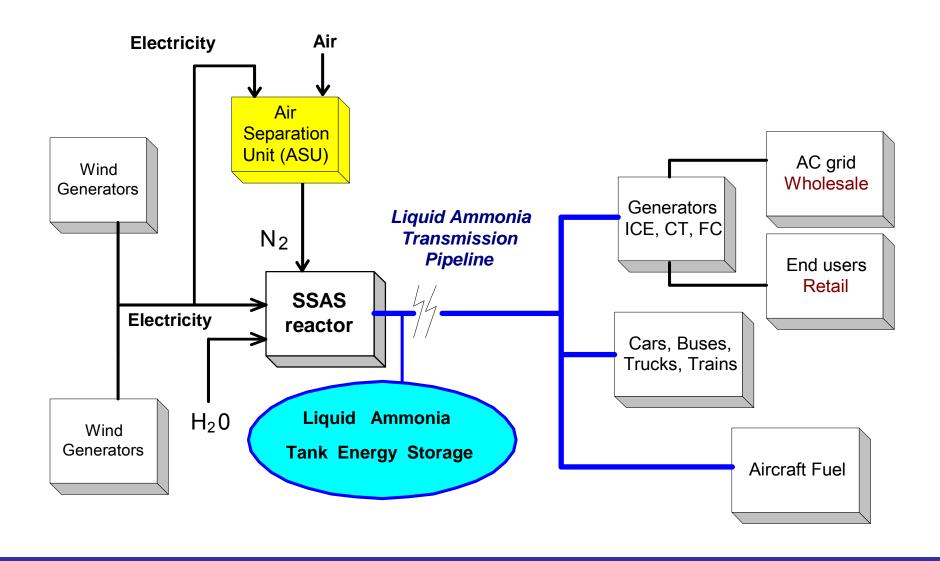
Inside the Black Box: HB Plus Electrolysis



Energy consumption ~12,000 kWh per ton NH₃

RE Ammonia Transmission + Storage Scenario





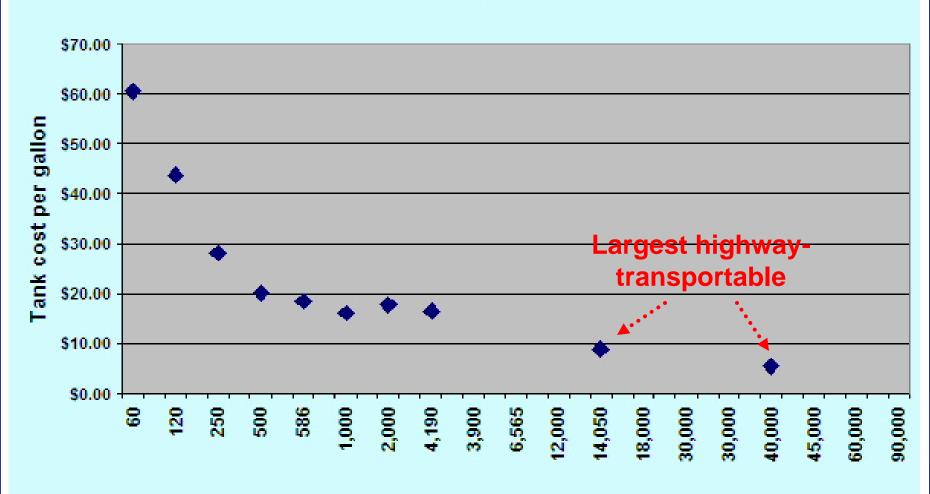
Solid State Ammonia Synthesis (SSAS)

NH₃ Ag Fertilizer Tanks, Wind Generators, NW Iowa



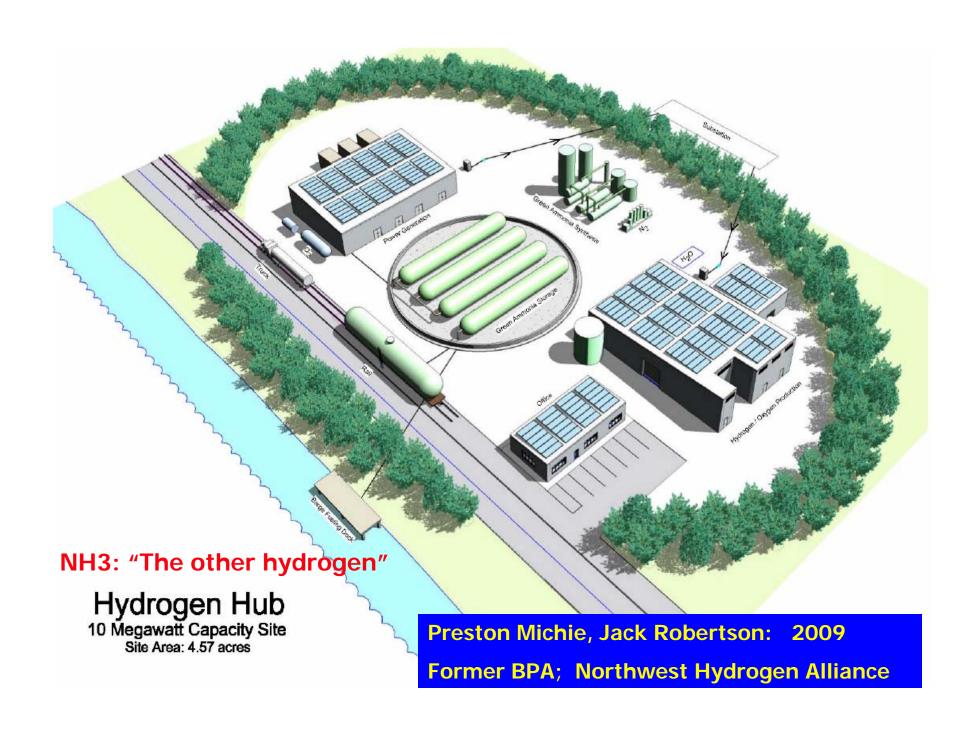
Liquid Ammonia Tank Storage



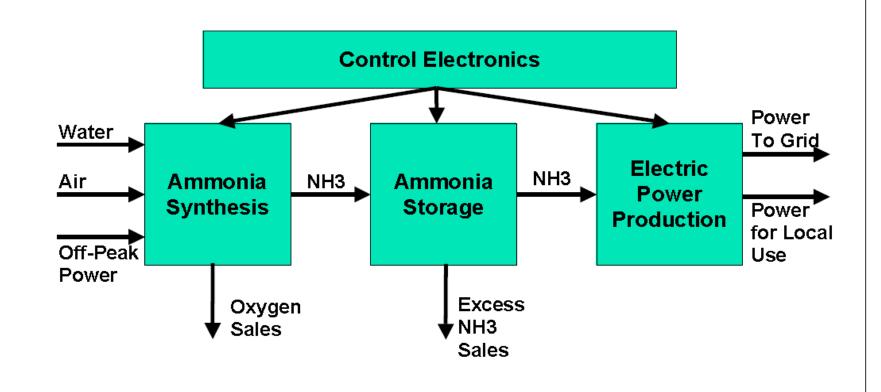


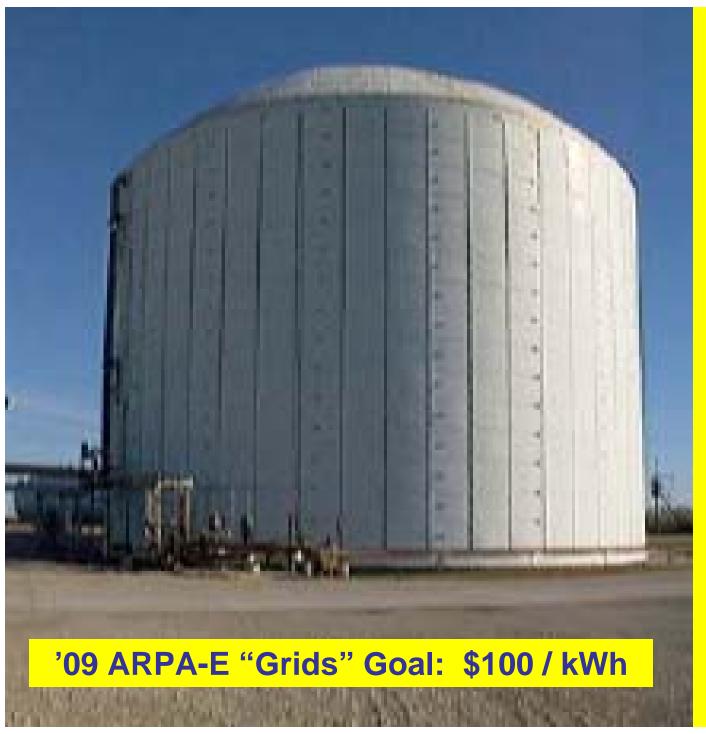
Tank capacity, gallons





Hydrogen Hub Concept





"Atmospheric"
Liquid
Ammonia
Storage Tank
(corn belt)

30,000 Tons 190 GWh

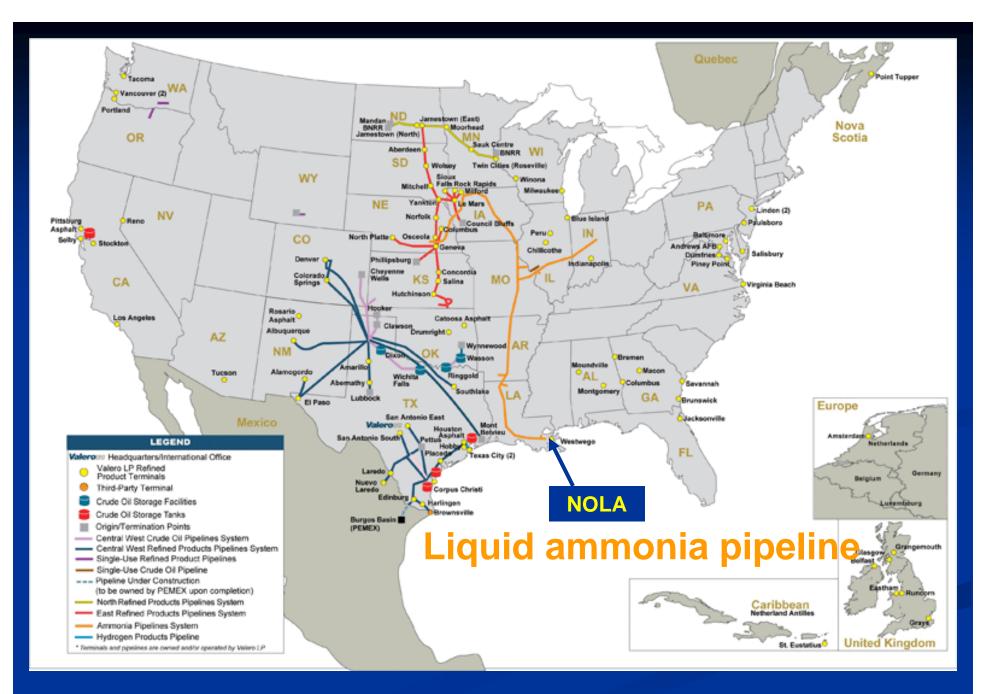
\$ 15M turnkey

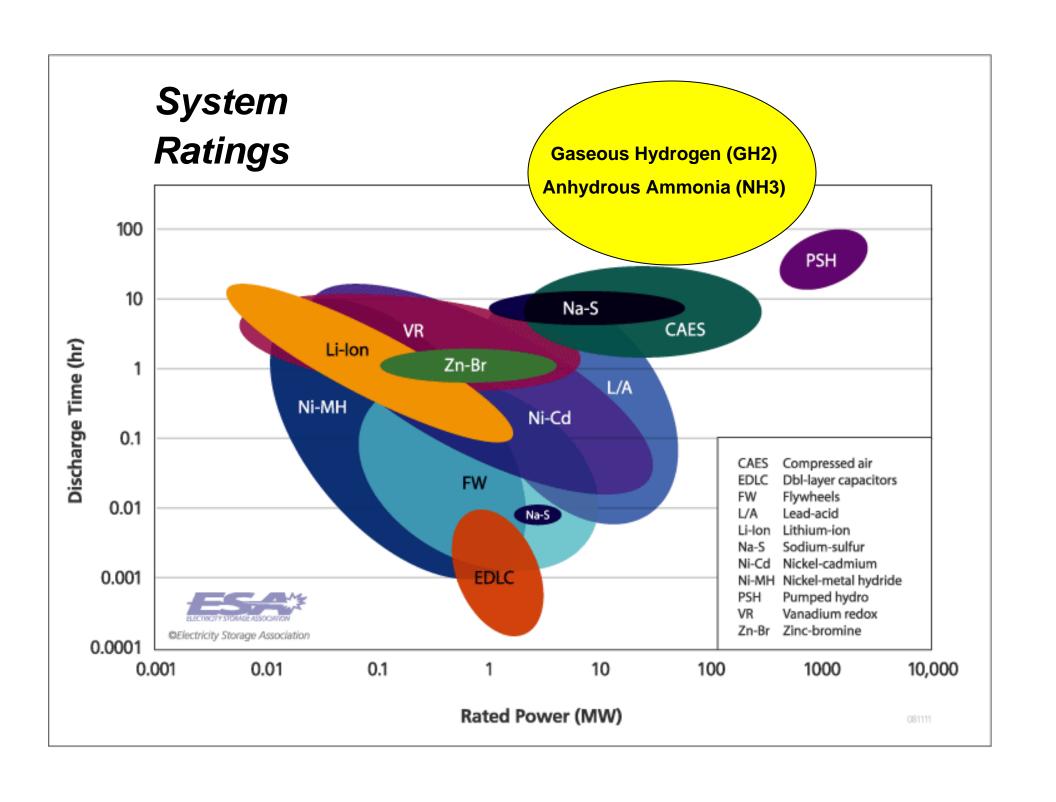
\$ 80 / MWh

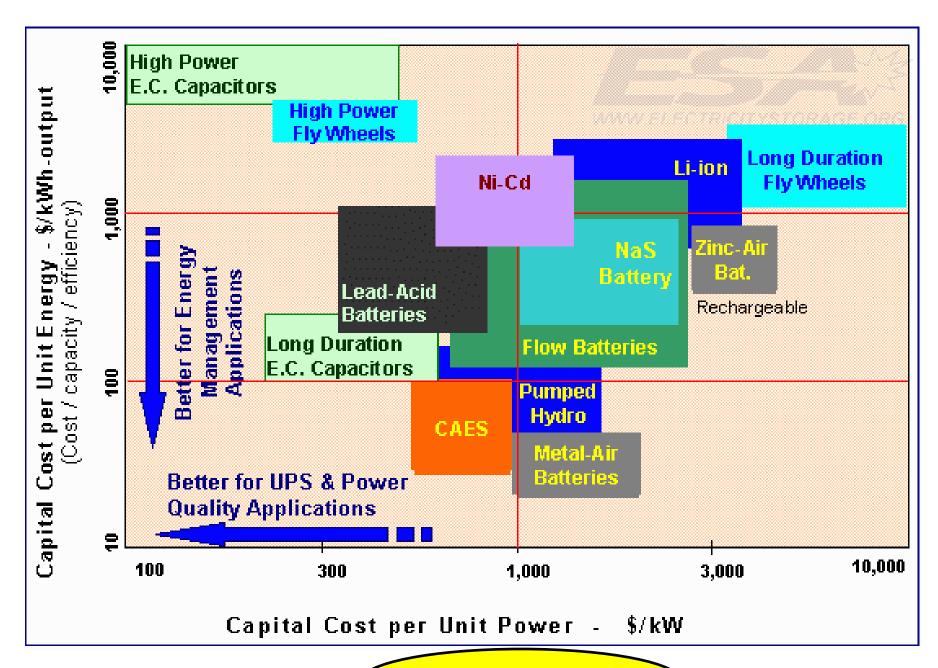
\$ 0.08 / kWh

-33 C

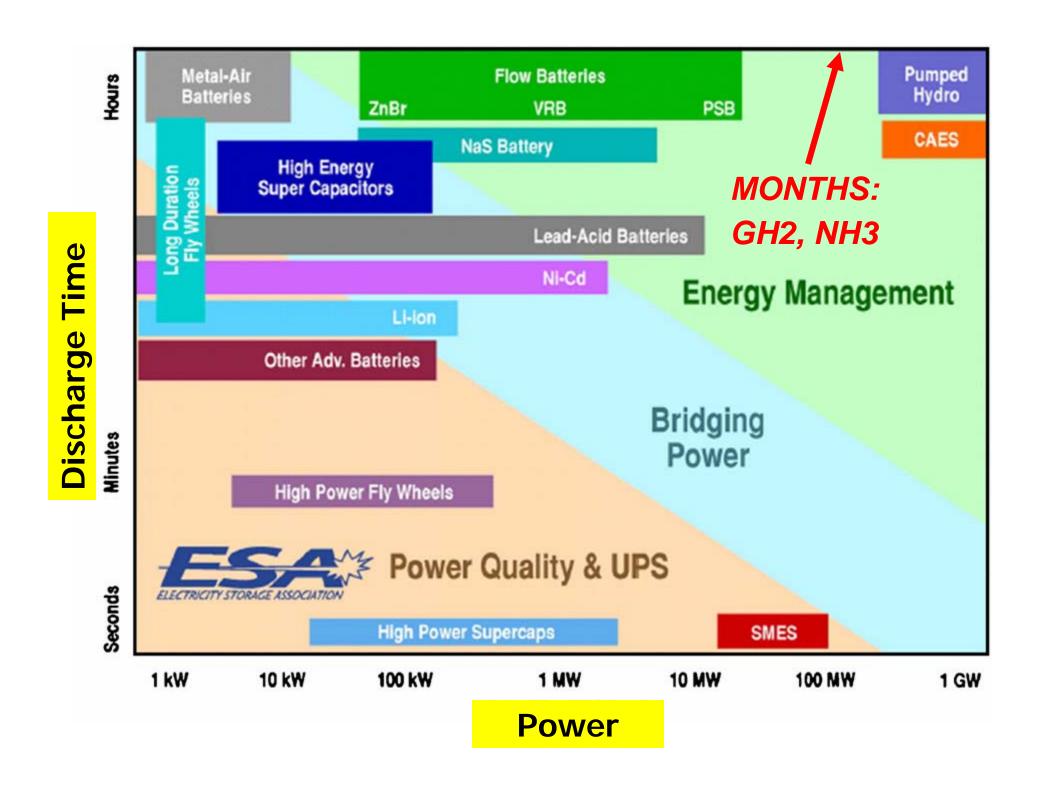
1 Atm







GH2 and NH3



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 energy densities
- Monitoring and control equipment
- Operational constraints
- Feasibility
- Environmental
- Fresh water use

Annual Fresh Water for Energy

- USA today
- All energy = 100 Quads = 10^20 J
- 17,000 billion liters
 - "Withdrawn"
 - "Consumed"
 - Include all NG + oil "fracking" ?
- If all via GH2 + NH3 feedstock:
 - Dissociated, disintegrated: H₂O → H₂ + O₂
 - 7,000 billion liters H2O
 - System efficiency vis-à-vis today's ?

Annual Fresh Water for Energy

- USA today
- All energy = 100 Quads = 10^20 J

If all via GH2 + NH3, feedstock water:

- Dissociated, disintegrated: H₂O → H₂ + O₂
- 7,000 billion liters fresh H₂O
- Gal / MWh = 63
- Liters / kWh = 0.24
- System efficiency vis-à-vis today's ?

Handout: GM 2014 panel

"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

Trouble with Renewables

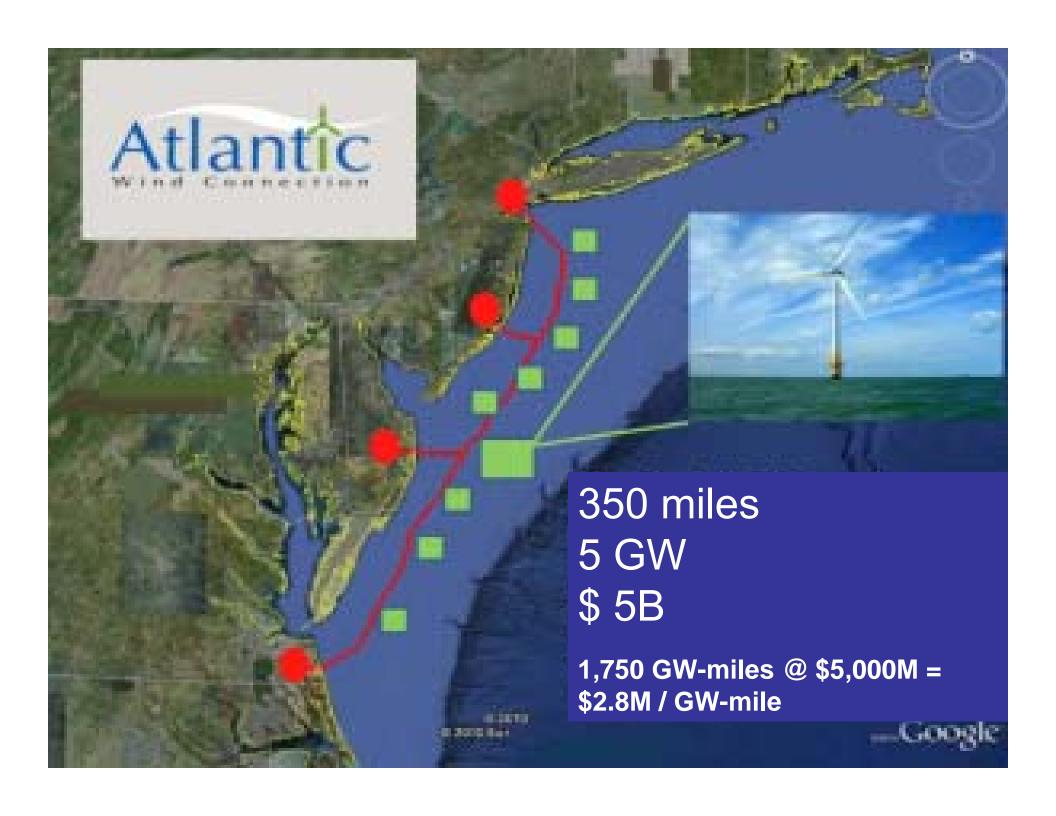
- Diffuse, dispersed: gathering cost
- Richest are remote: "stranded"
 - High intensity
 - Large geographic extent
- Time-varying output:
 - "Intermittent"
 - "Firming" integration + storage required
- Distributed AND centralized

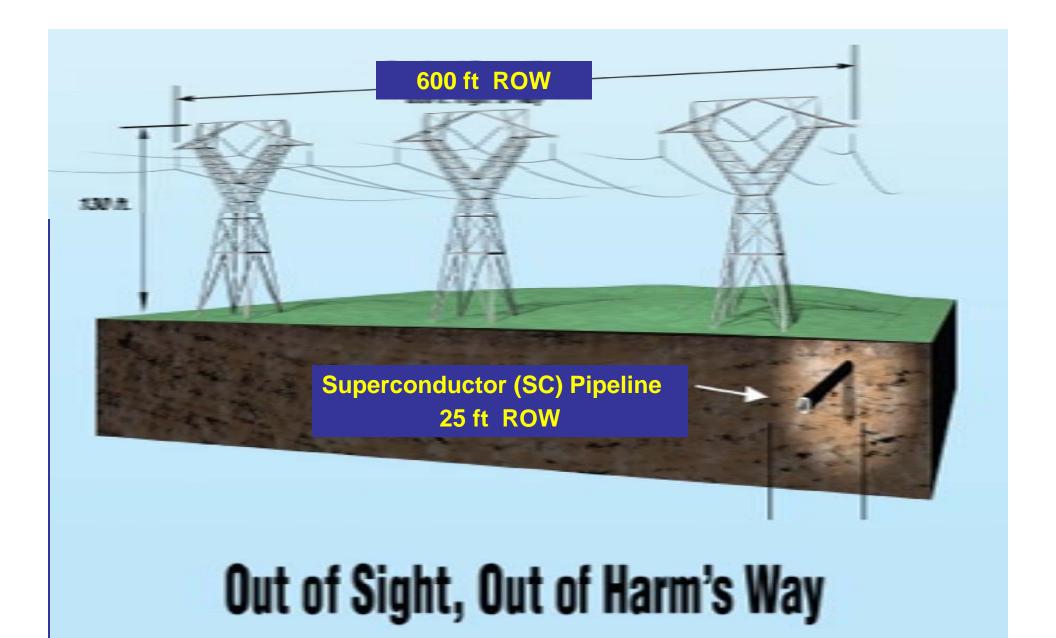
Trouble with Renewables: Big Three

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

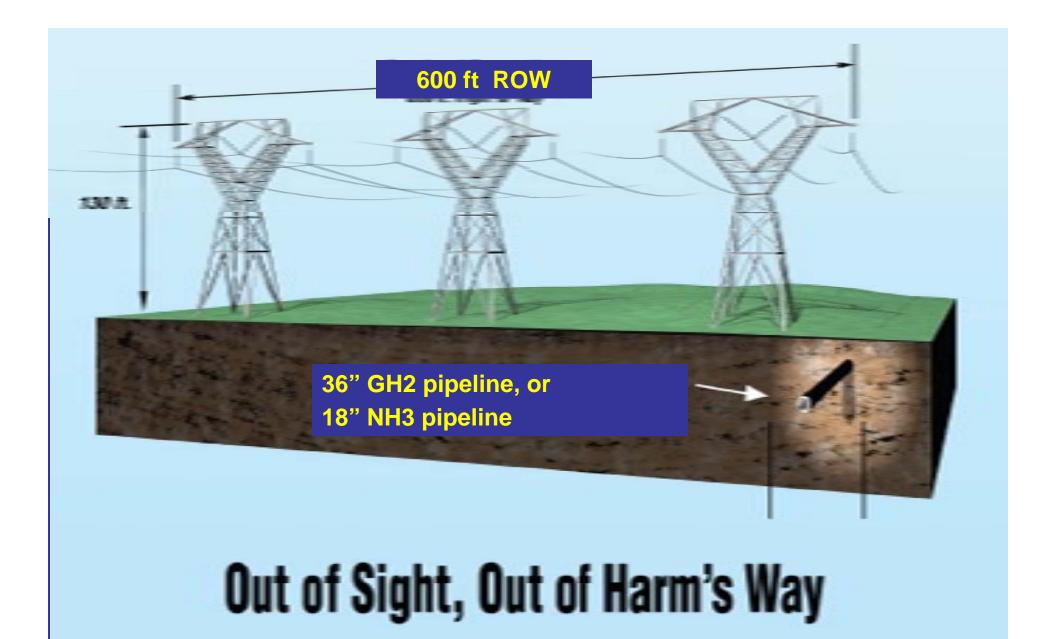
Trouble with Renewables: Electricity Transmission

- Grid nearly full: who pays?
- Integration
 - Continental energy system
 - Quality, stability
 - 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
- FERC no interstate jurisdiction
- Wide ROW
- NIMBY: delay + cost, site + ROW

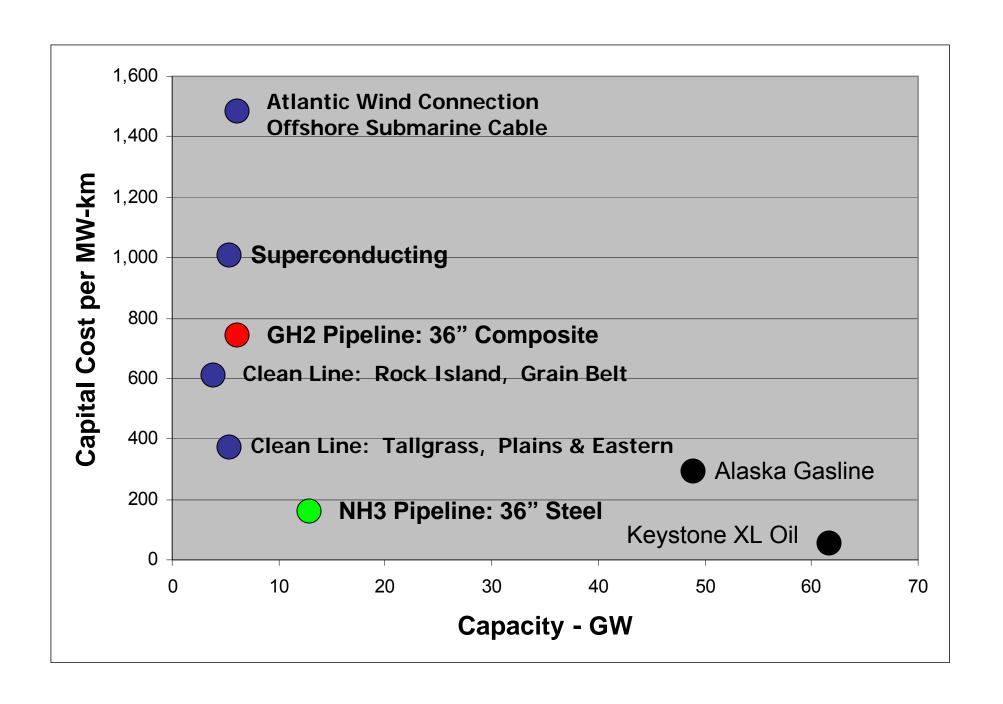




10,000 MW alternatives: HVAC vs HVDC superconductor



10,000 MW alternatives: HVAC vs Hydrogen, Ammonia

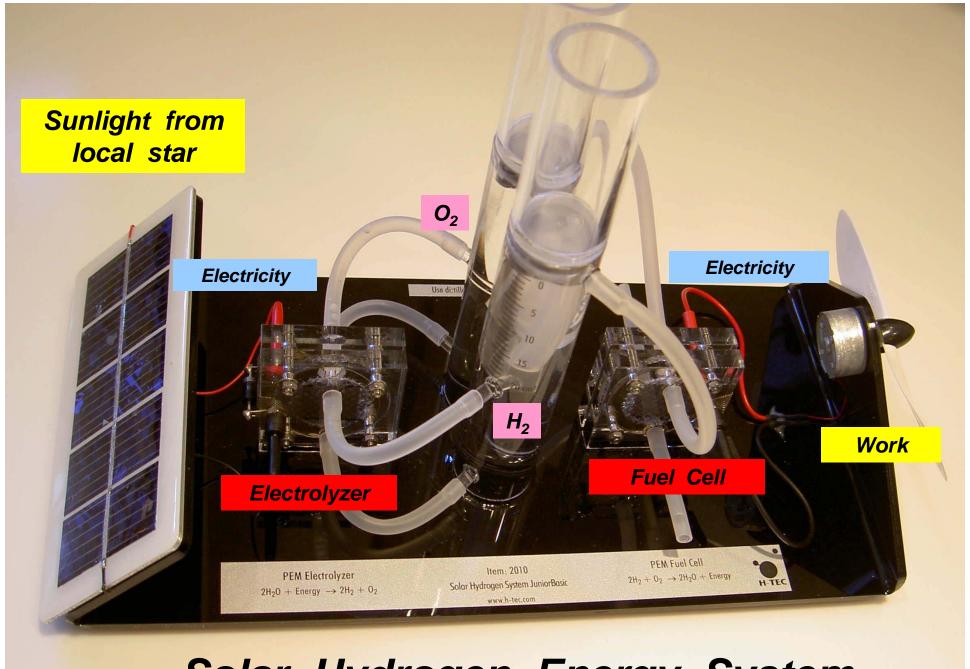


Beyond "Smart Grid"

- 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, Bundestag

"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



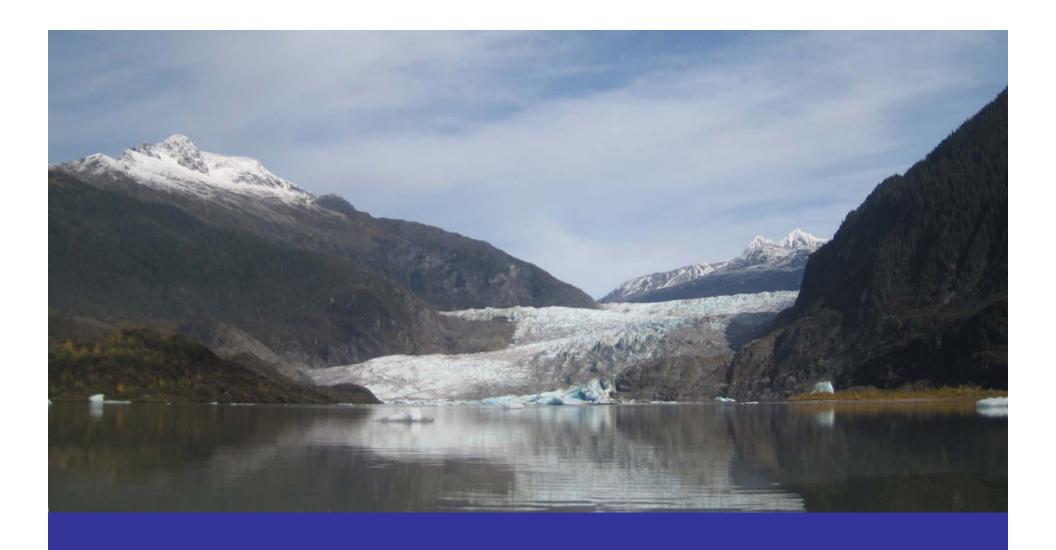
Solar Hydrogen Energy System



Mendenhall Glacier, Juneau, AK June '71



Mendenhall Glacier, Juneau, AK 10 October 10



Mendenhall Glacier, Juneau, AK 10 October 10

Rapid climate change



Spruce bark beetle kill, Alaska



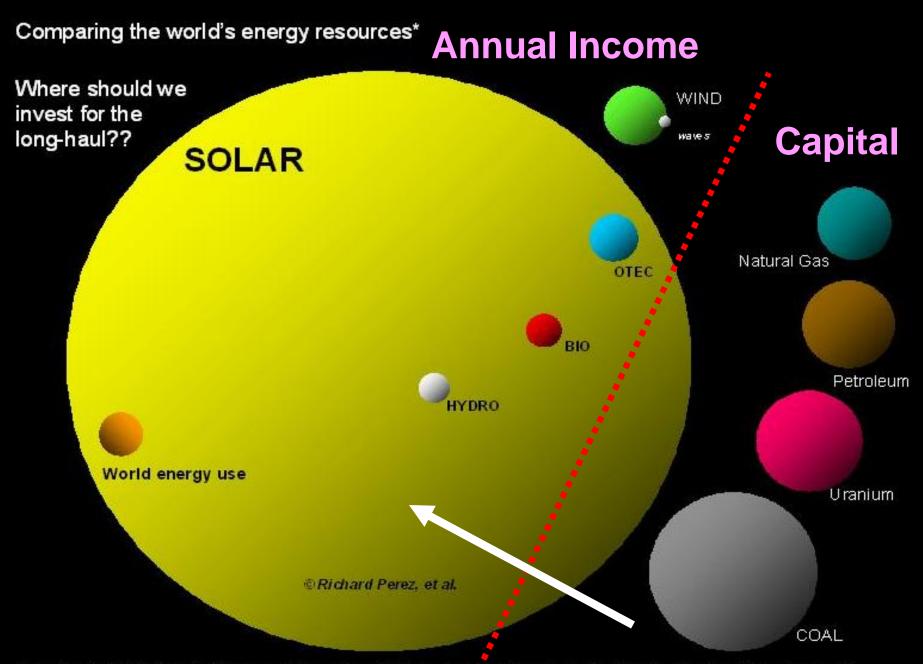


Shishmaref, Alaska Winter storms coastal erosion

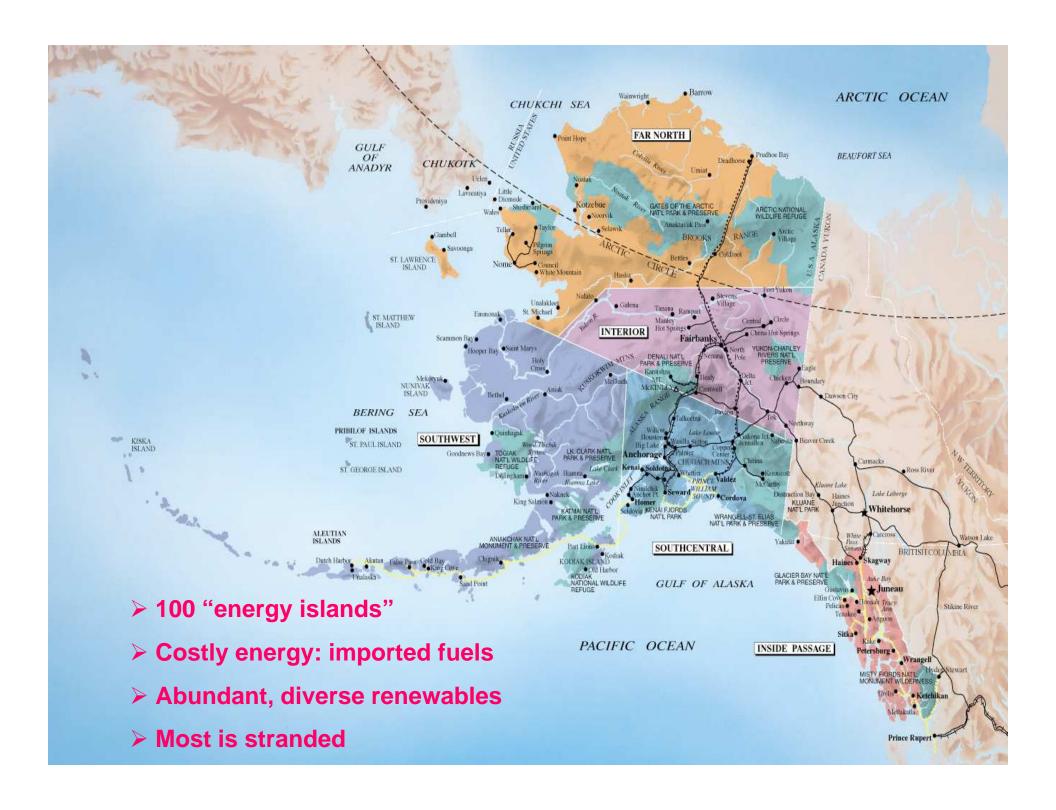
MUST Run the World on Renewables – plus Nuclear?

- Climate Change
- Ocean acidification
- Sea level rise
- 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

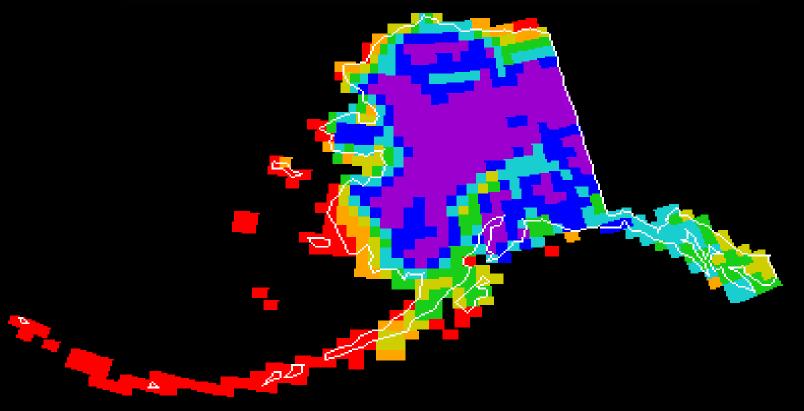




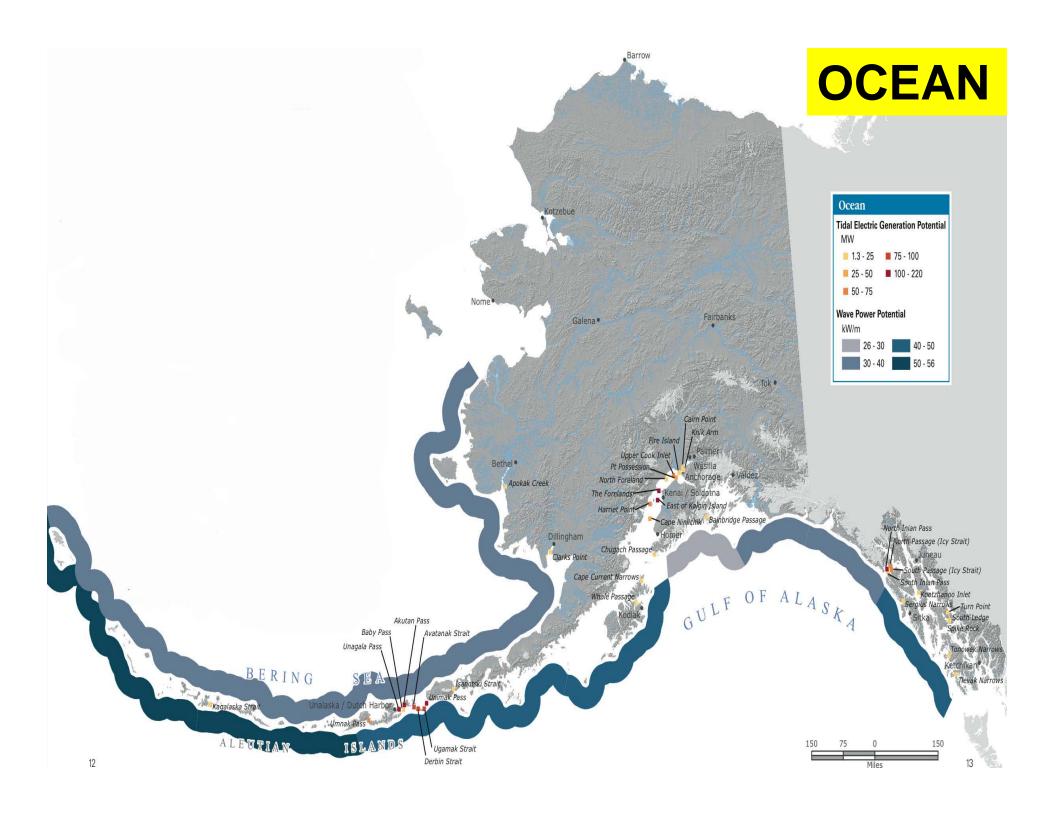
*yearly potential is shown for the renewable energies. Total reserves are shown for the fossil and nuclear "use-them, lose-them" resources. Word energy use is annual.

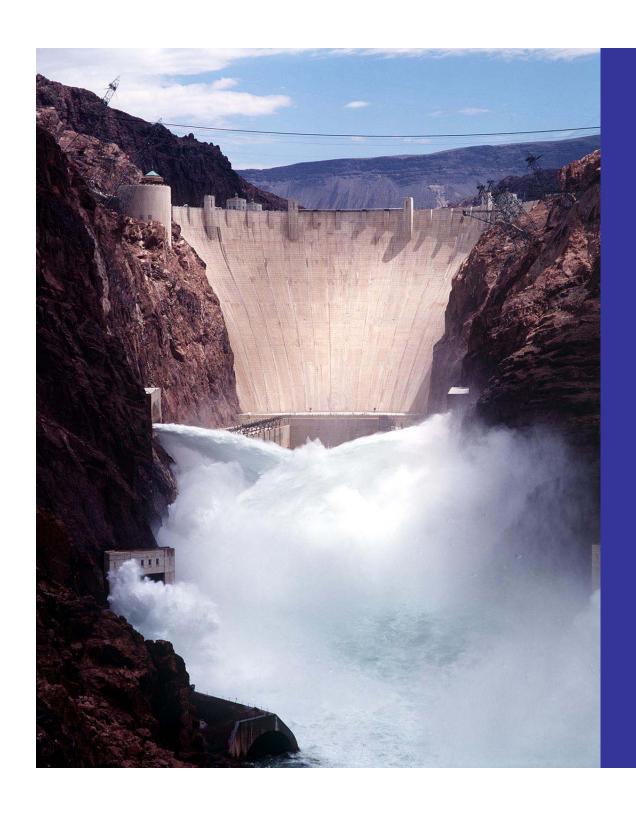


Wind Power Class

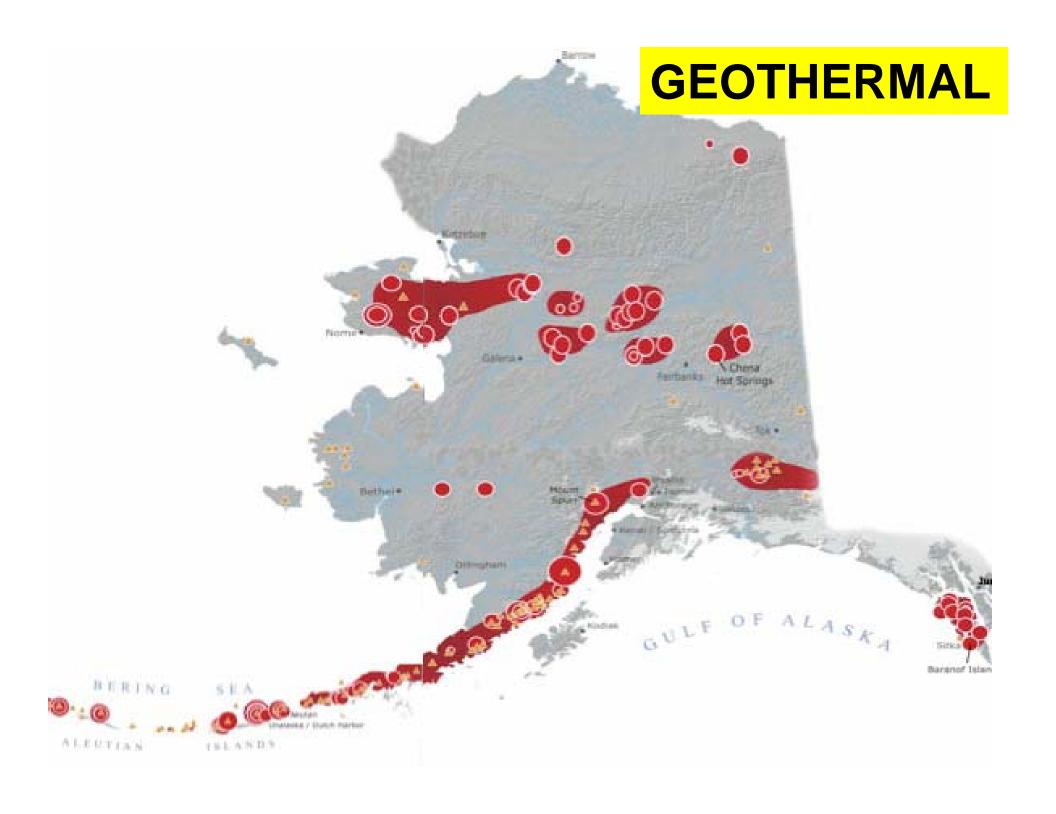


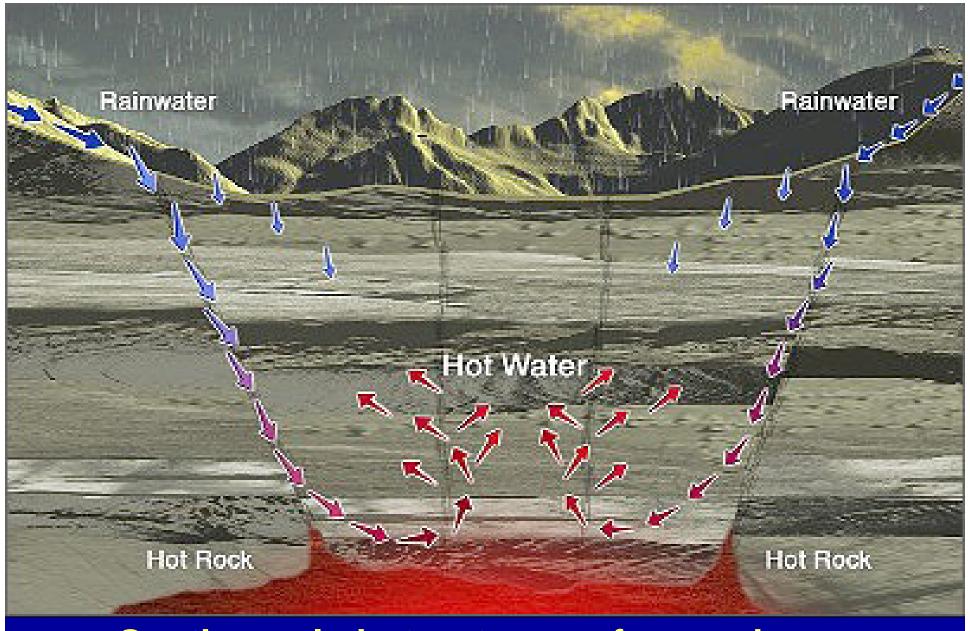
Power	Class	Speed	Power Density
	1	0.0-5.6m/s	0-200W/m2
	2	5.6-6.4m/s	200-300W/m2
	3		300-400W/m2
	4	7.0-7.5m/s	400-500W/m2
	5	7.5-8.0m/s	500-600W/m2
	6	8.0-8.8m/s	500-800W/m2
	7	>8.8m/s	>800W/m2



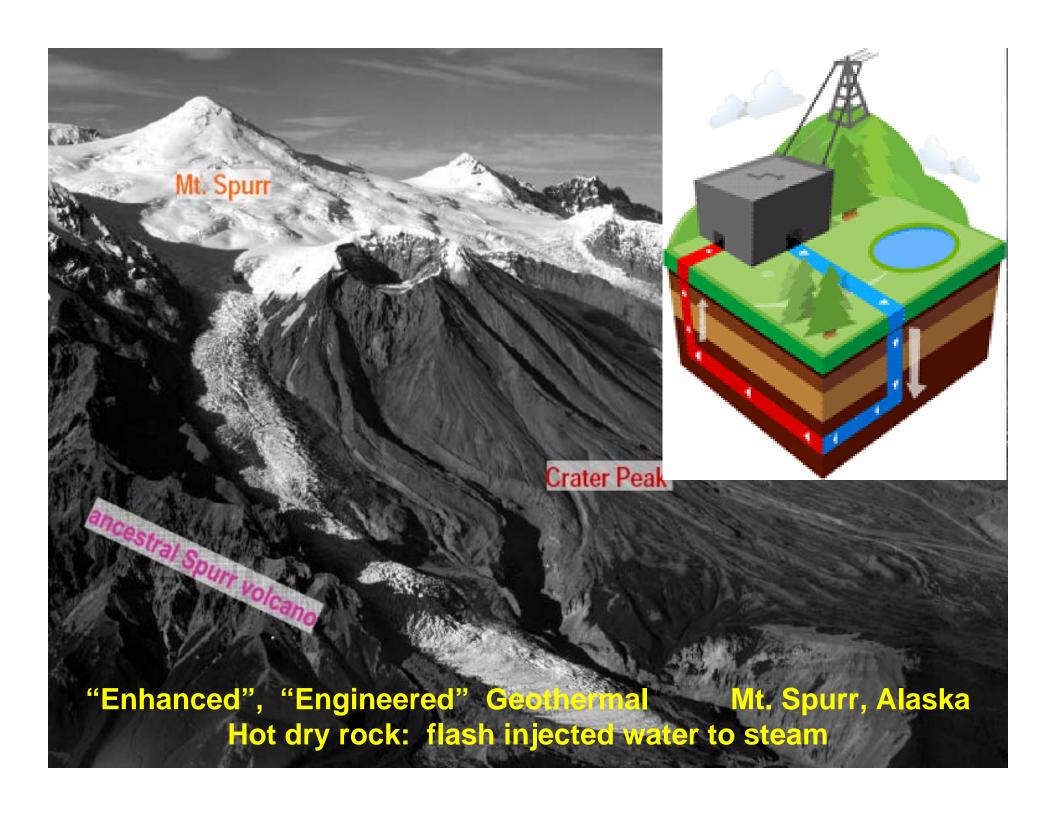


Hydro



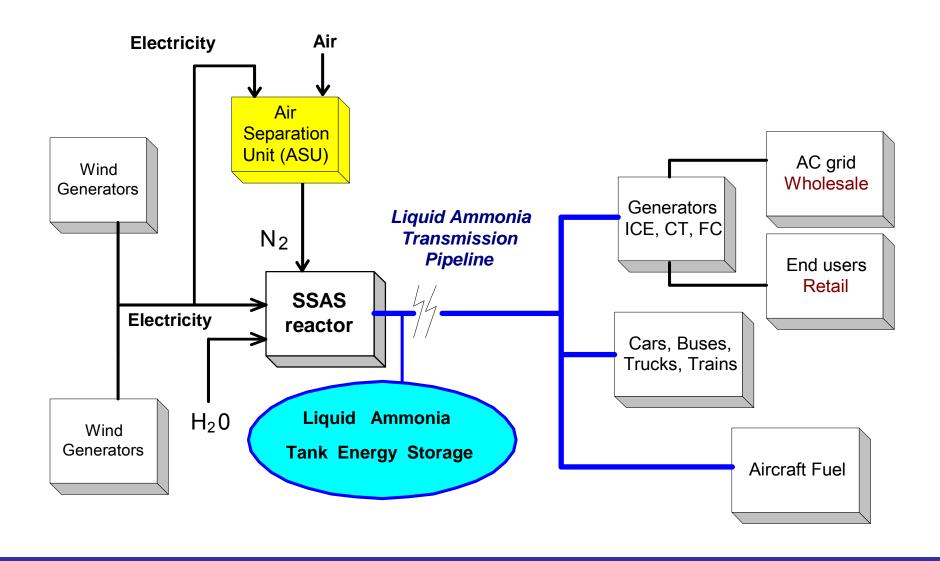


Geothermal: hot water, surface recharge



Opportunity: Alaska Applications

- 1. Village energy "independence": degree
 - a. Internal, external energy economies
 - b. Diverse renewable sources
 - c. Low-cost tank storage
 - d. CHP, transportation fuels
- 2. Firming storage: annual scale
 - a. Susitna hydro
 - b. Other
- 3. Export large, diverse, stranded renewables
 - a. Cryo tankers: global trade
 - b. "Green" NH3 premium? C-tax required?
 - c. SE AK "Cluster Industry"
 - d. Aleutians cargo ship fueling
- 4. Military fuel: ground, marine
 - a. USCG, Navy
 - b. Other services
 - c. DOD Assistant Secretary Sharon Burke visit 3-7 Aug 12

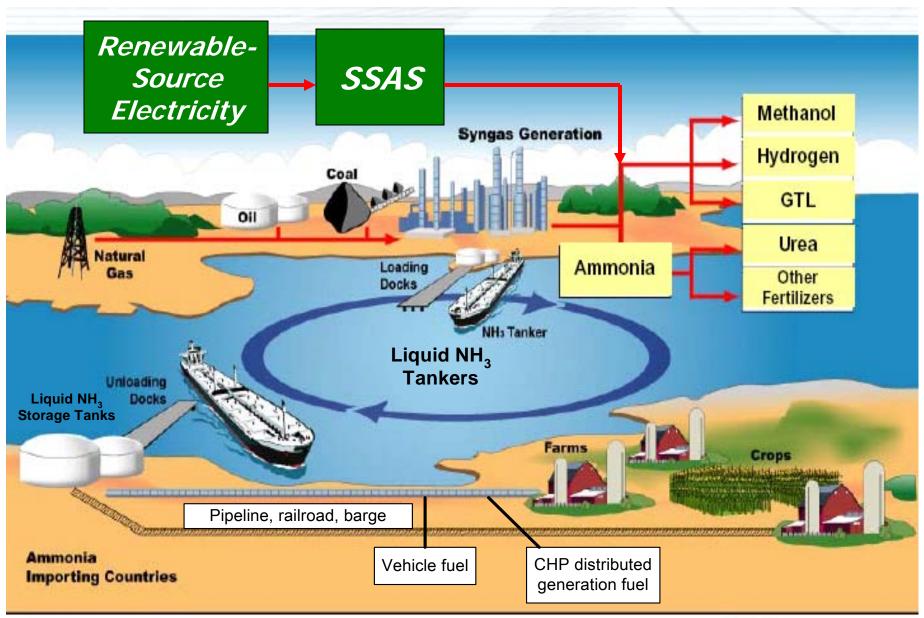


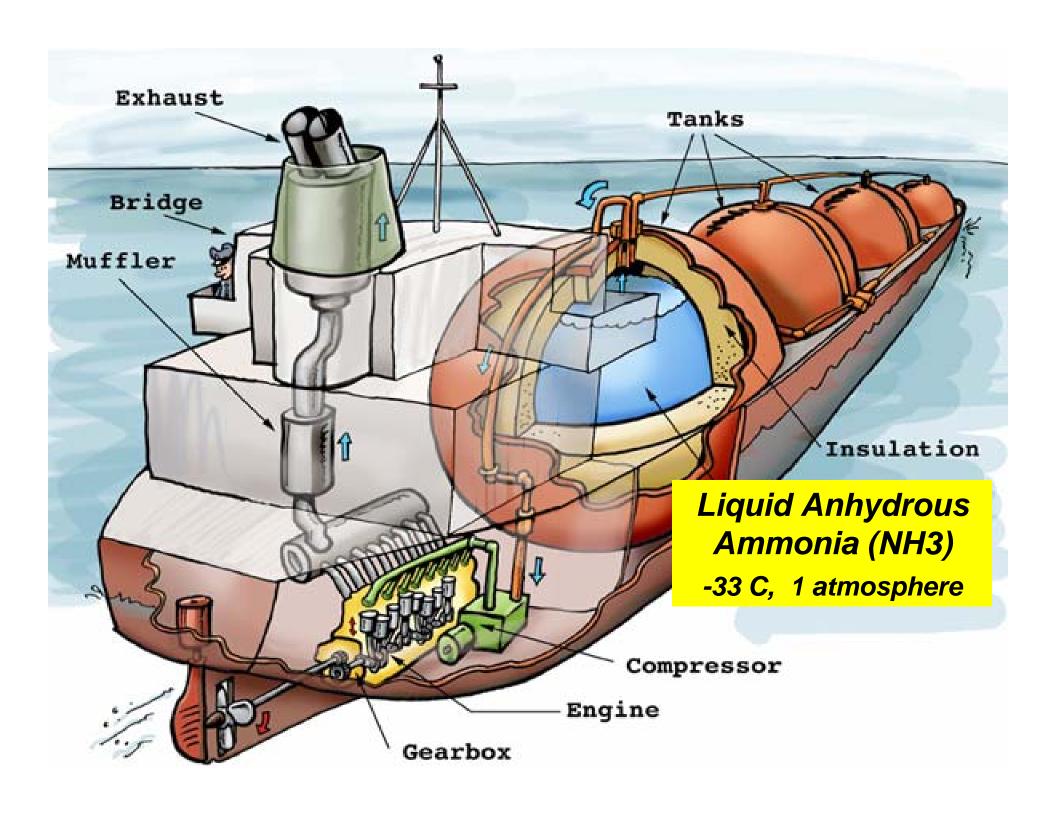
Solid State Ammonia Synthesis (SSAS)

Alaska Energy Authority Emerging Energy Technology Fund Project Fundamentals

- 1. Does SSAS system "work"?
- 2. Competitive with EHB?
- 3. Useful in Alaska?

SSAS Proof-of-concept pilot plant Two-year project Alaska Applied Sciences, Inc.

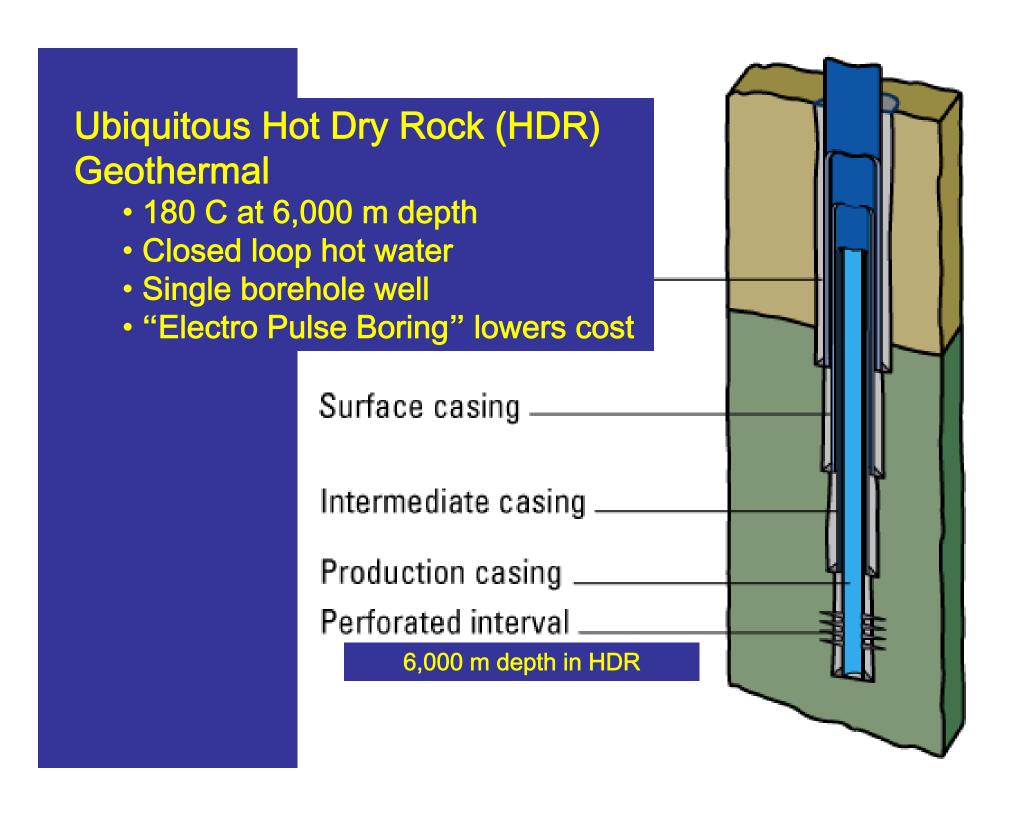


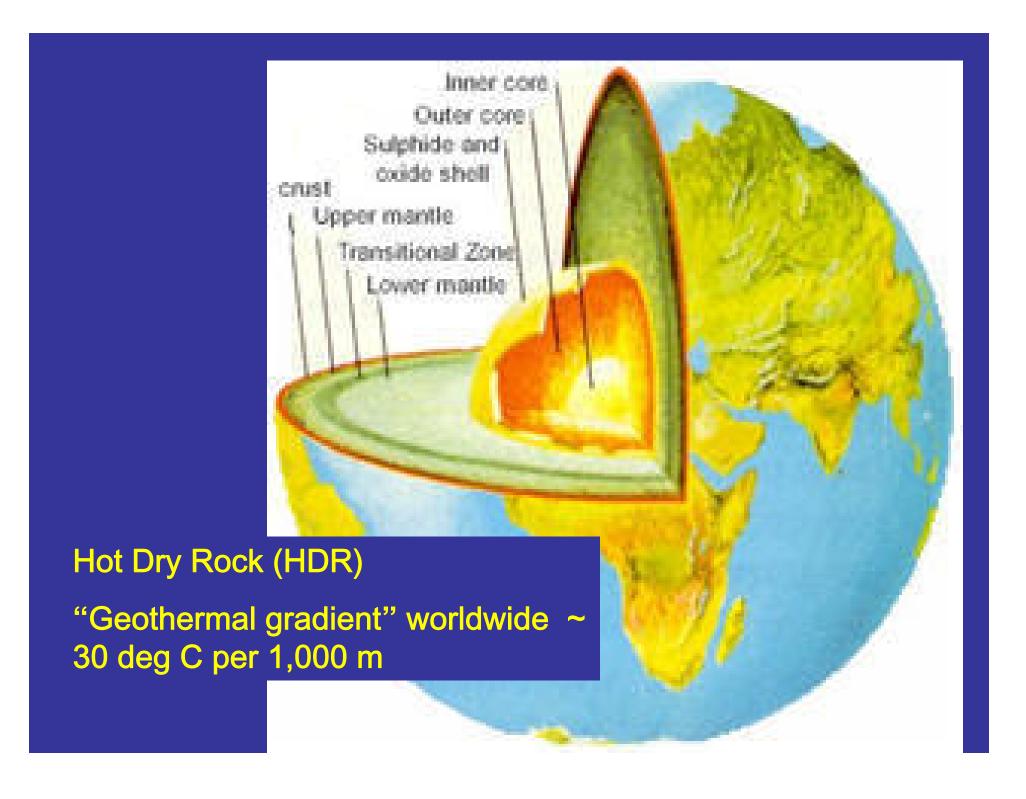


Military: Land + sea fuel

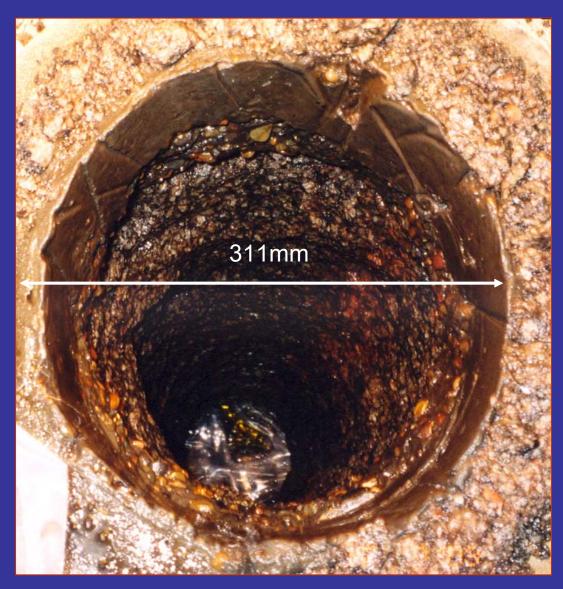
- USCG, Navy ships
- Land vehicles: road, rail
- Recip engines modify: multifuel, Sturman
- Mini + micro app's







2003 : EPB Drilling Full Scale in Granite 311 mm = 12.25 "



2006 BIT DESIGN





Exporting From 12 Windiest Great Plains States

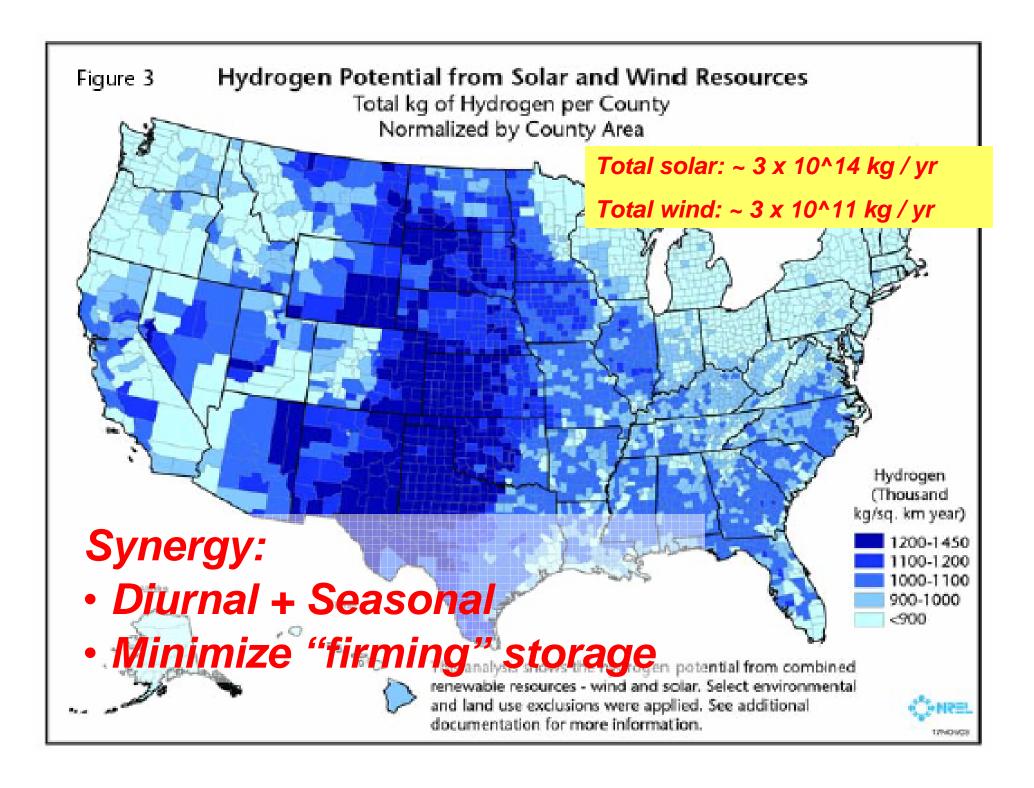
Number of GH2 pipelines or HVDC electric lines necessary to export total wind resource

Capacity at 500 miles length

Capacity Factor (CF) = 30%

						3 GW	
	Annual	Nameplate	Nameplate	6 GW	\$ Billion	500 KV	\$ Billion
	Energy	Installed	Installed	36" GH2	Total	HVDC	Total
	Production	Capacity	Capacity	Hydrogen	Capital	Electric	Capital
State	(TWh)	(MW)	(GW)	Pipelines	Cost	Lines	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

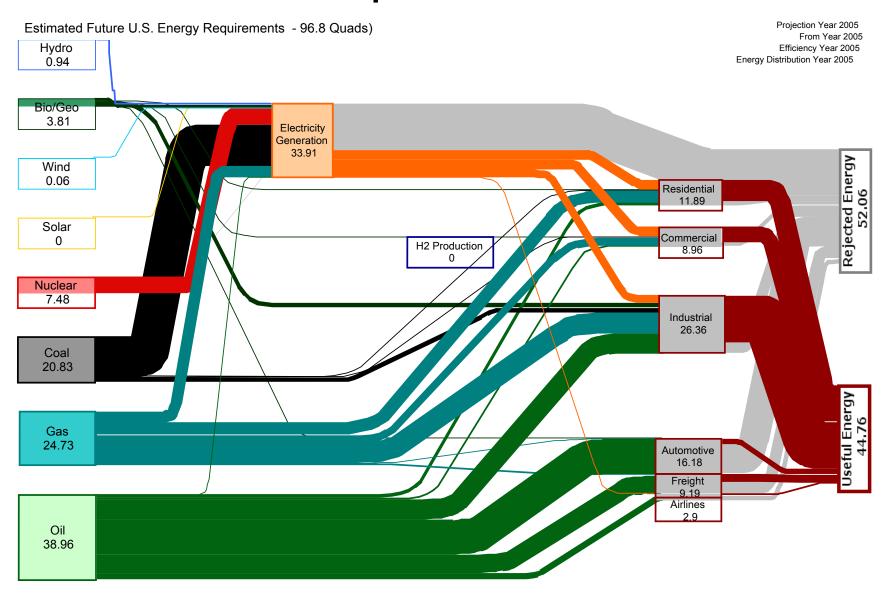
Wind energy source: Archer, Jacobson 2003



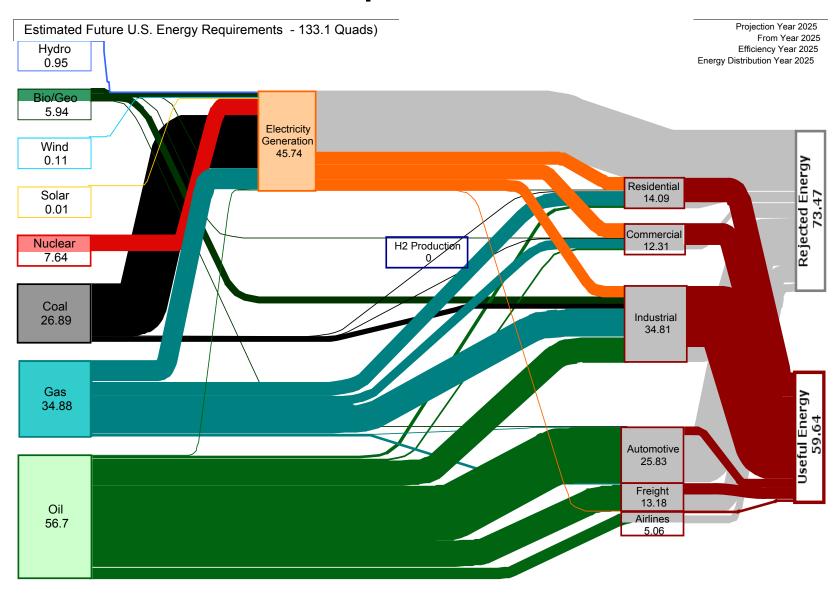
320,000 MWh storage Annual firming 1,000 MW wind

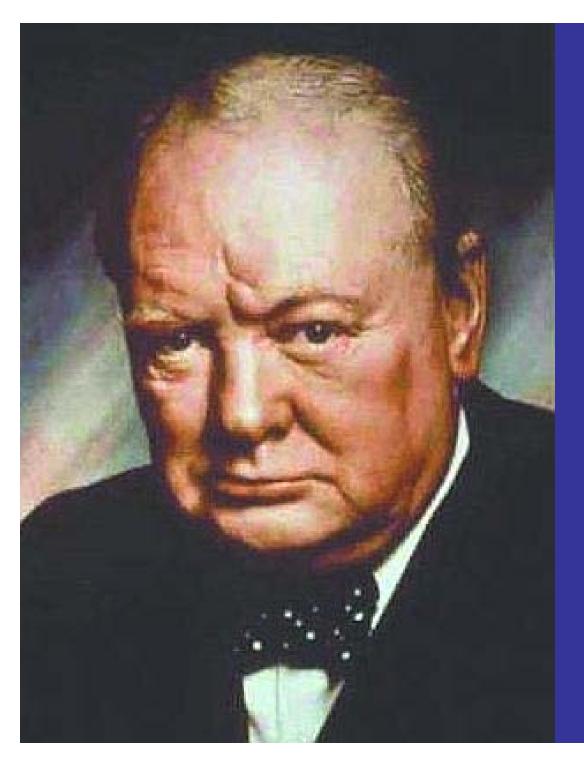
- Electricity
 - VRB (Vanadium Redox Battery)
 - O&M: 80% efficiency round-trip
 - Capital: \$500 / kWh = \$ 160 Billion
 - CAES (Compressed Air Energy Storage)
 - O&M: \$46 / MWh typical
 - Iowa Stored Energy Park:
 - Power = 268 MW
 - Energy capacity = 5,360 MWh
 - Capital: 268 MW @ \$ 1,450 / kW =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

DOE-EIA: 2005 estimated US annual energy: ~ 100 quads = 100 TWh



EIA estimated 2025 annual energy: ~ 130 quads = 130 TWh





" 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

Humanity's Goal

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

- CANNOT with only electricity transmission
- Alternative RE systems: complete

