Protecting the Arctic by Running the World on Renewables: Alternatives for Transmission and Low-cost Firming Storage of Stranded Renewables as Hydrogen and Ammonia Fuels

AAAS Arctic Science Conference

27 September 2013   Kodiak, AK

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Philosophers, like vegetables, are profoundly influenced by their environment.

E. A. J. Johnson

1936

Some Origins of the Modern Economic World

Bill Leighty

BSEE ’65

MBA ‘71

Mendenhall Glacier, Juneau, AK

June ‘71

Mendenhall Glacier, Juneau, AK

10 October 10

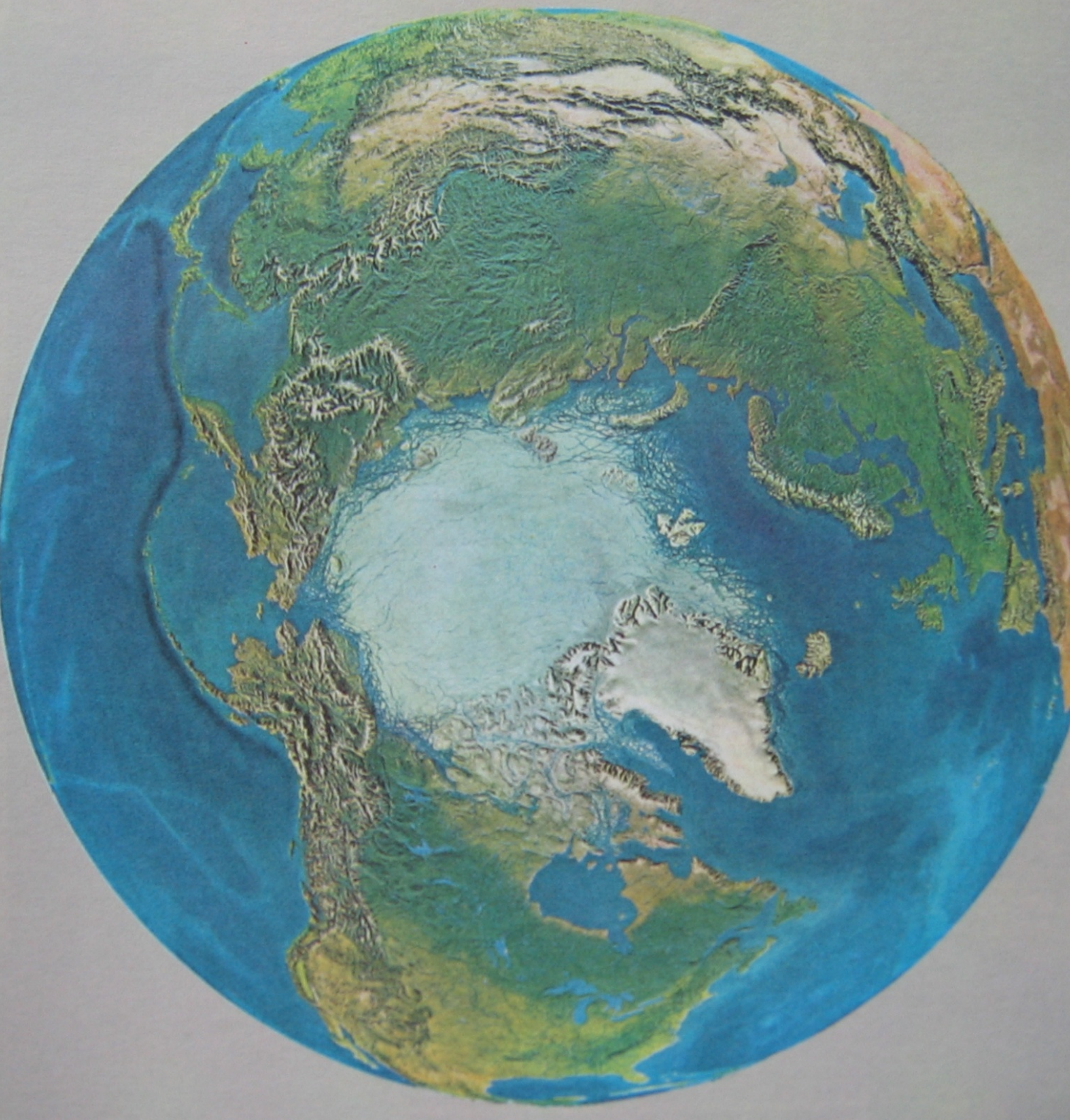
Mendenhall Glacier, Juneau, AK
10 October 10

Rapid climate change

Spruce bark beetle kill, Alaska

Spruce bark beetle kill, Alaska

“Drunken Trees” on thawing permafrost



Shishmaref, Alaska

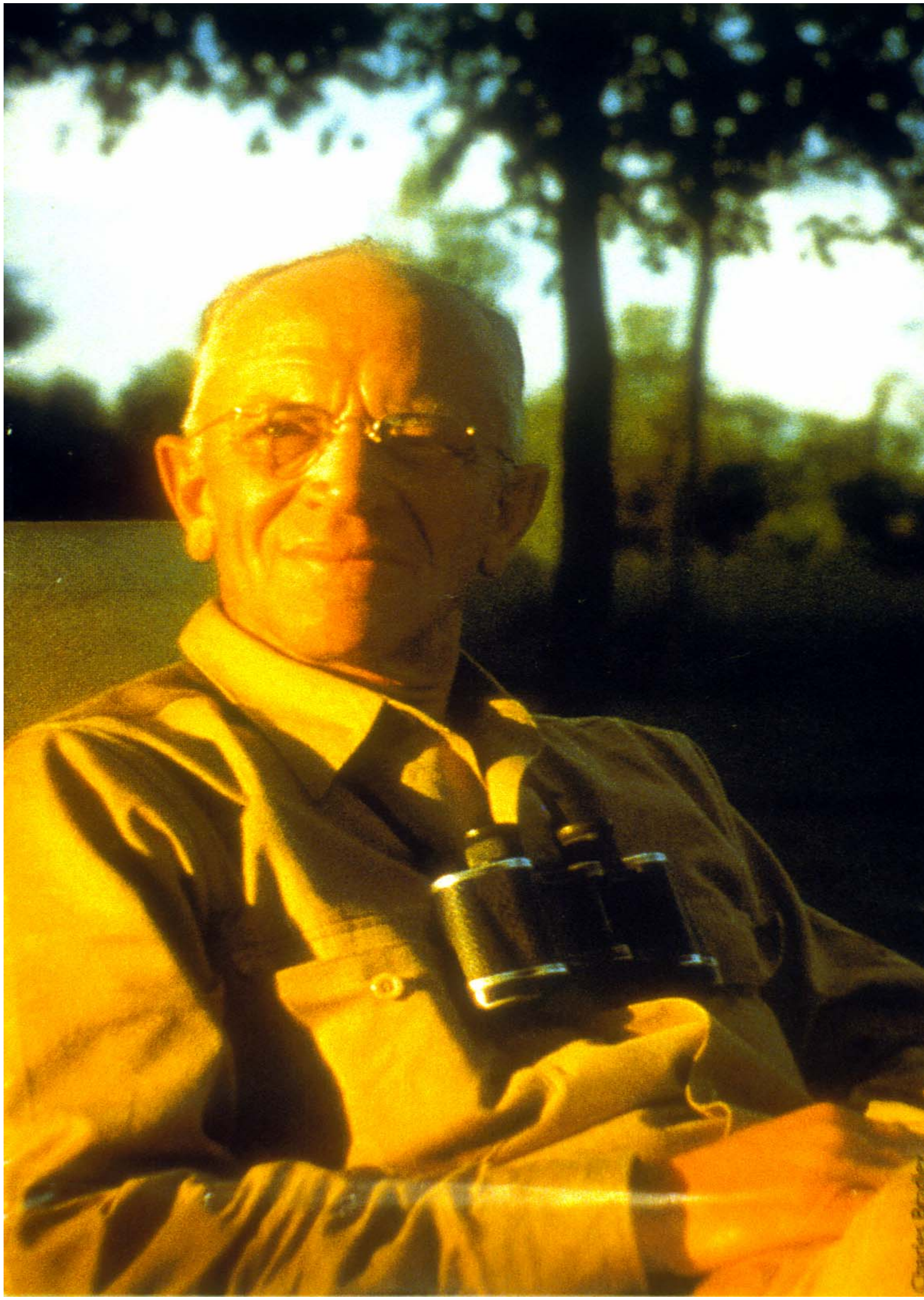
Winter storms coastal erosion

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



Aldo Leopold

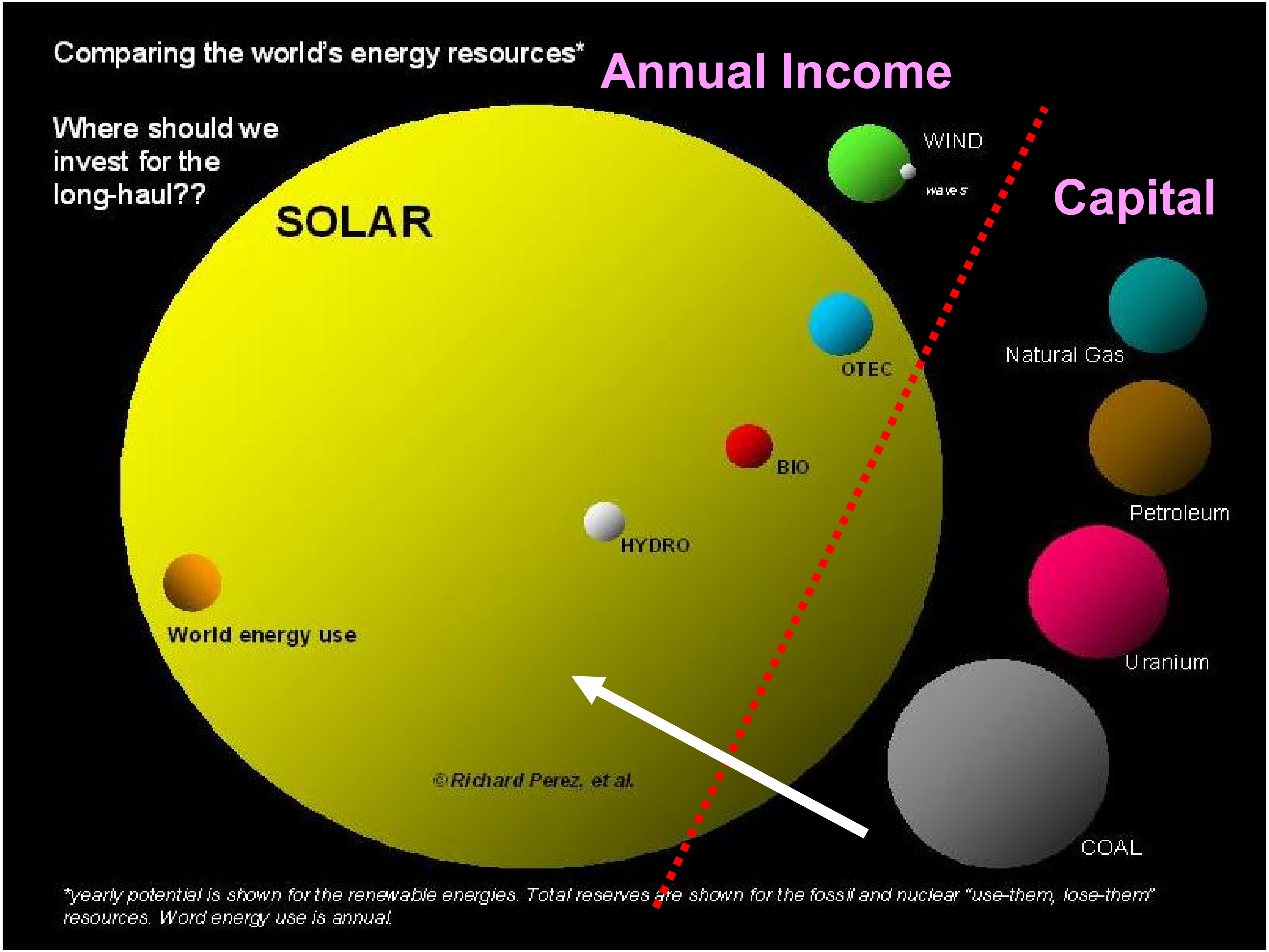
1887 - 1948

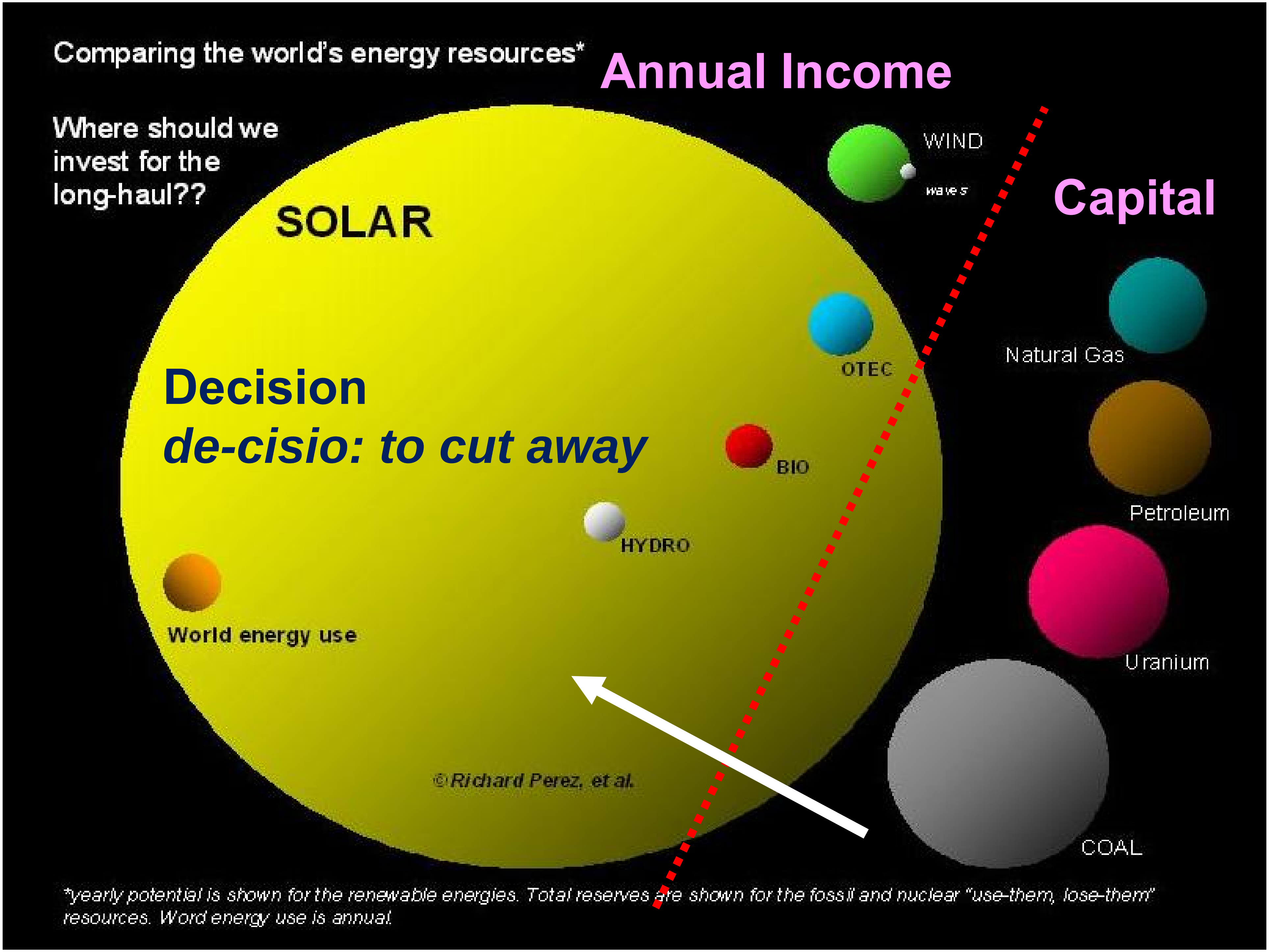
There are two spiritual dangers in not owning a farm:

One is supposing that breakfast comes from the grocery;

The other is supposing that heat comes from the furnace.

Aldo Leopold, "A Sand County Almanac"


Comparing the world's energy resources*
Annual Income
Where should we invest for the long-haul??
SOLAR
WIND
waves
Capital
Natural Gas
OTEC
BIO
Petroleum
HYDRO
World energy use
Uranium
© Richard Perez, et al.
COAL
*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.


Comparing the world's energy resources*
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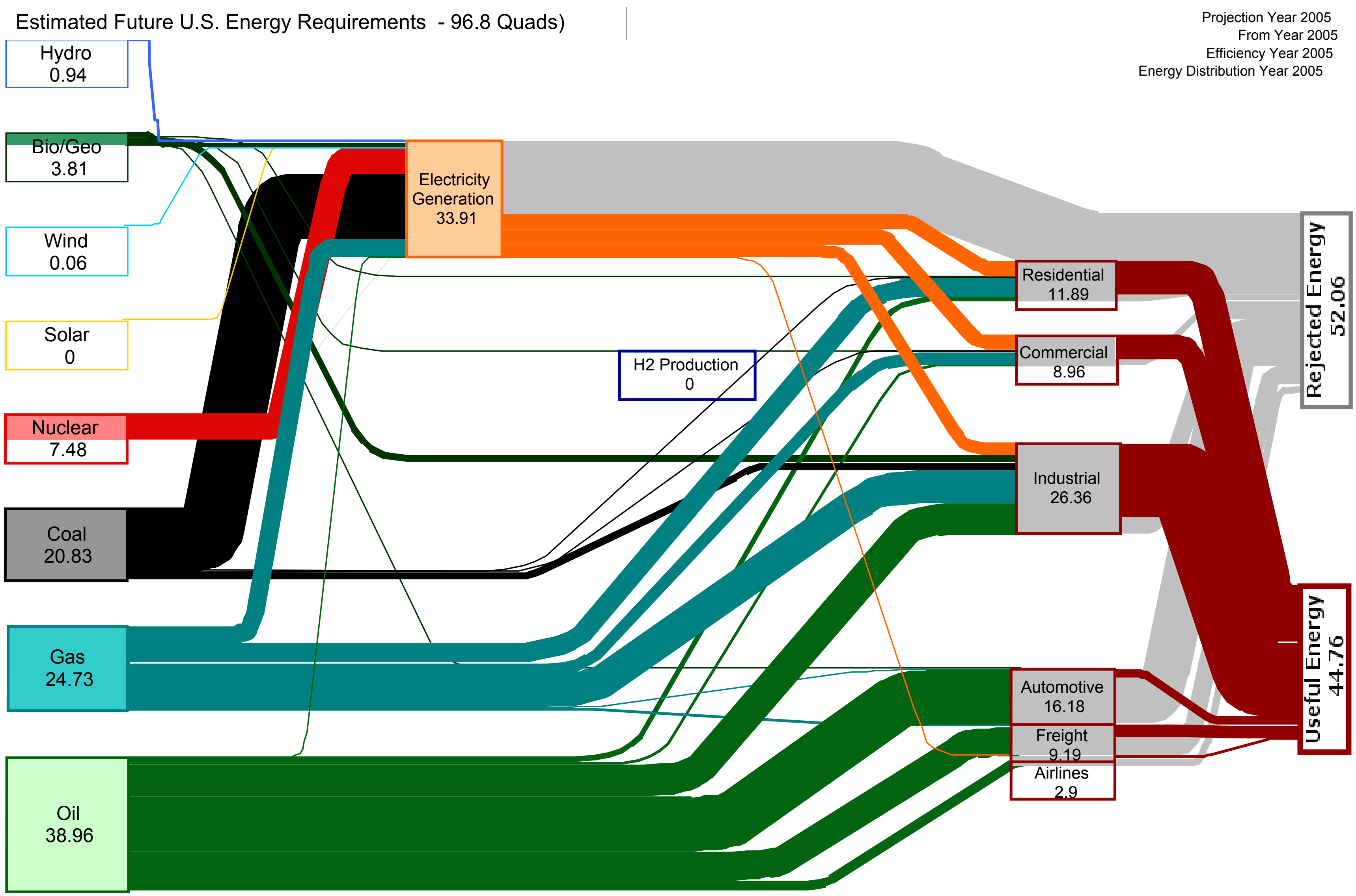
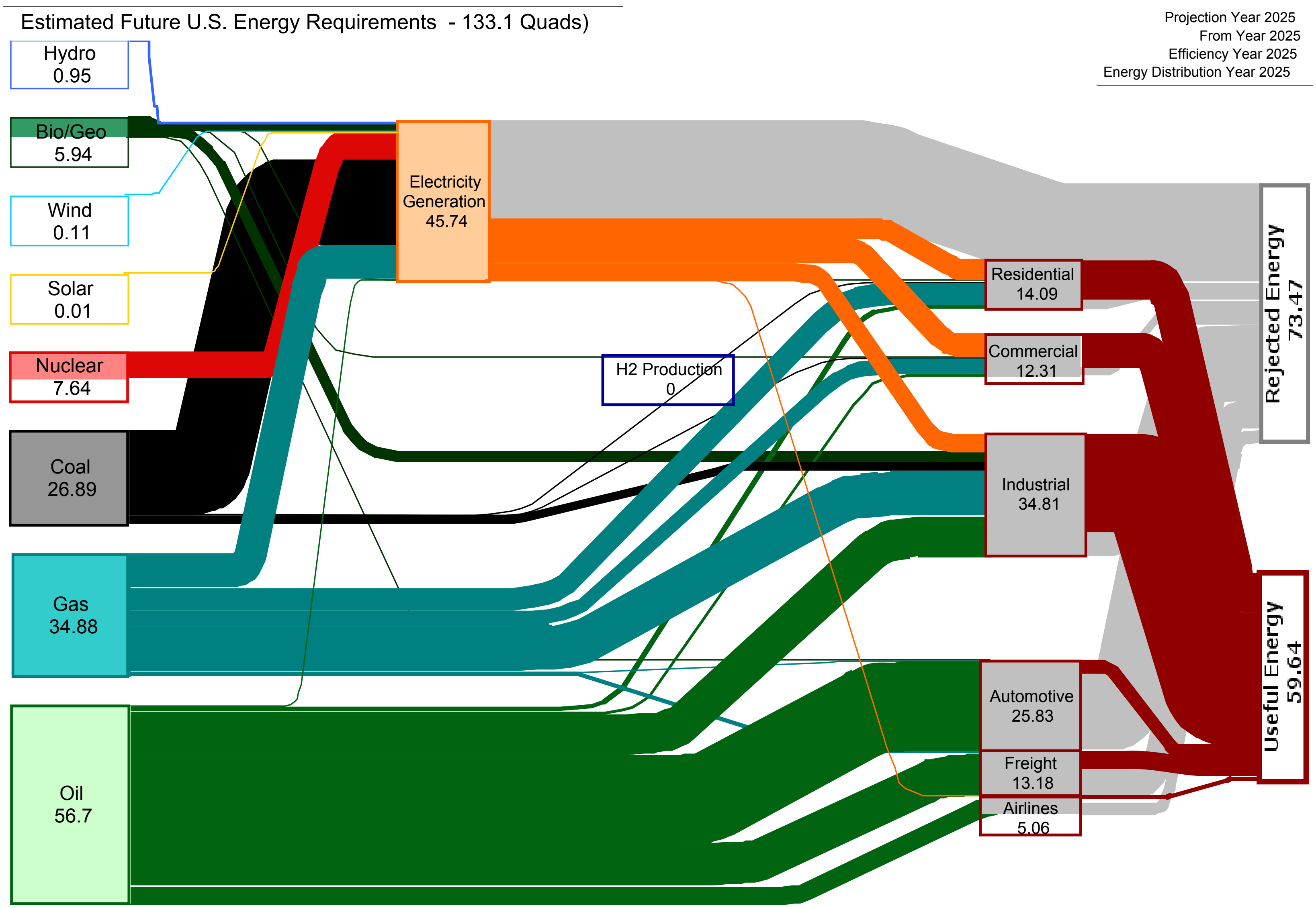
World energy use
Uranium
© Richard Perez, et al.
COAL
*yearly potential is shown for the renewable energies. Total reserves are shown for the fossil and nuclear "use-them, lose-them" resources. Word energy use is annual.

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

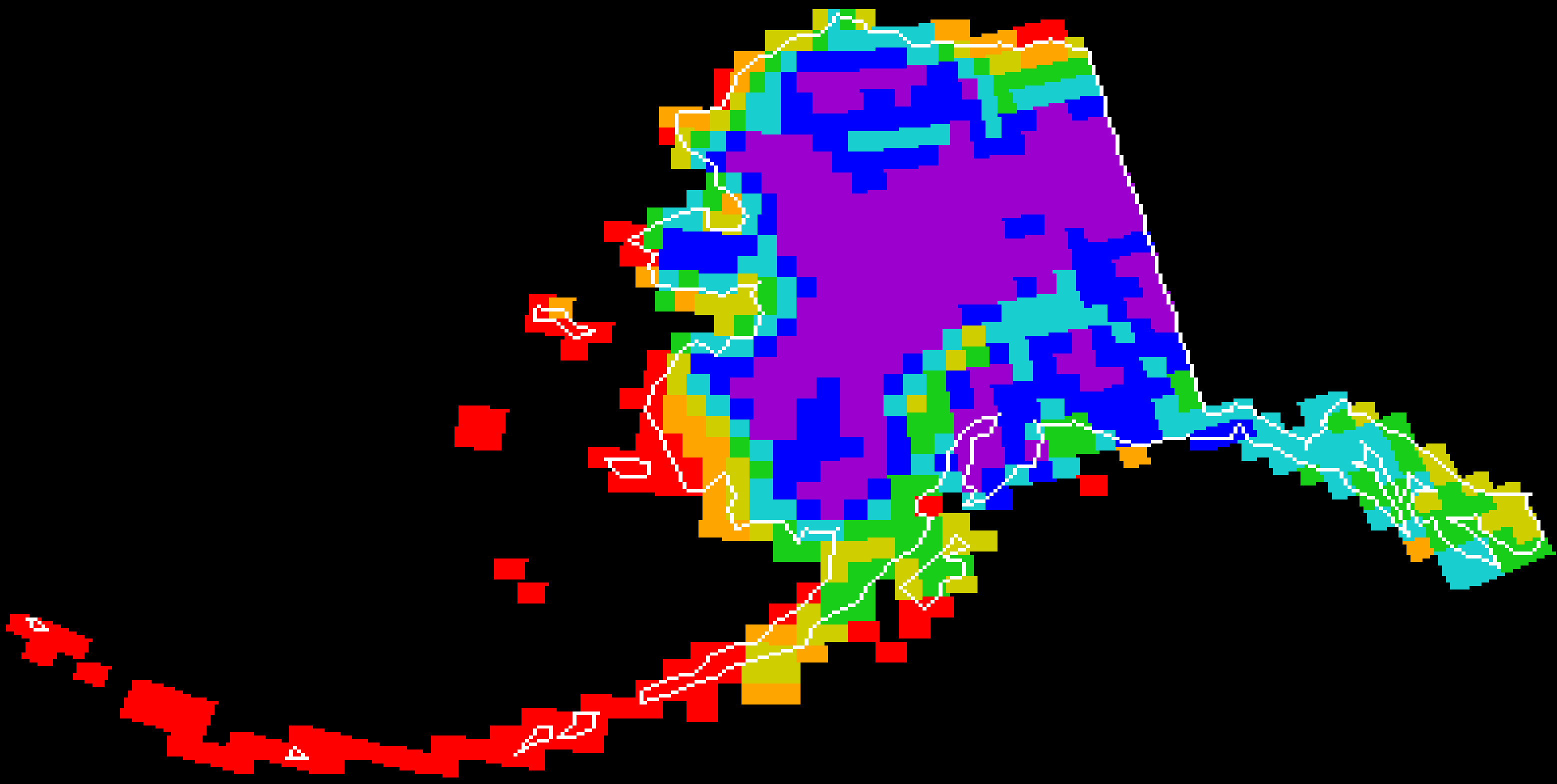


EIA estimated 2025 annual energy:
~ 130 quads = 130 TWh



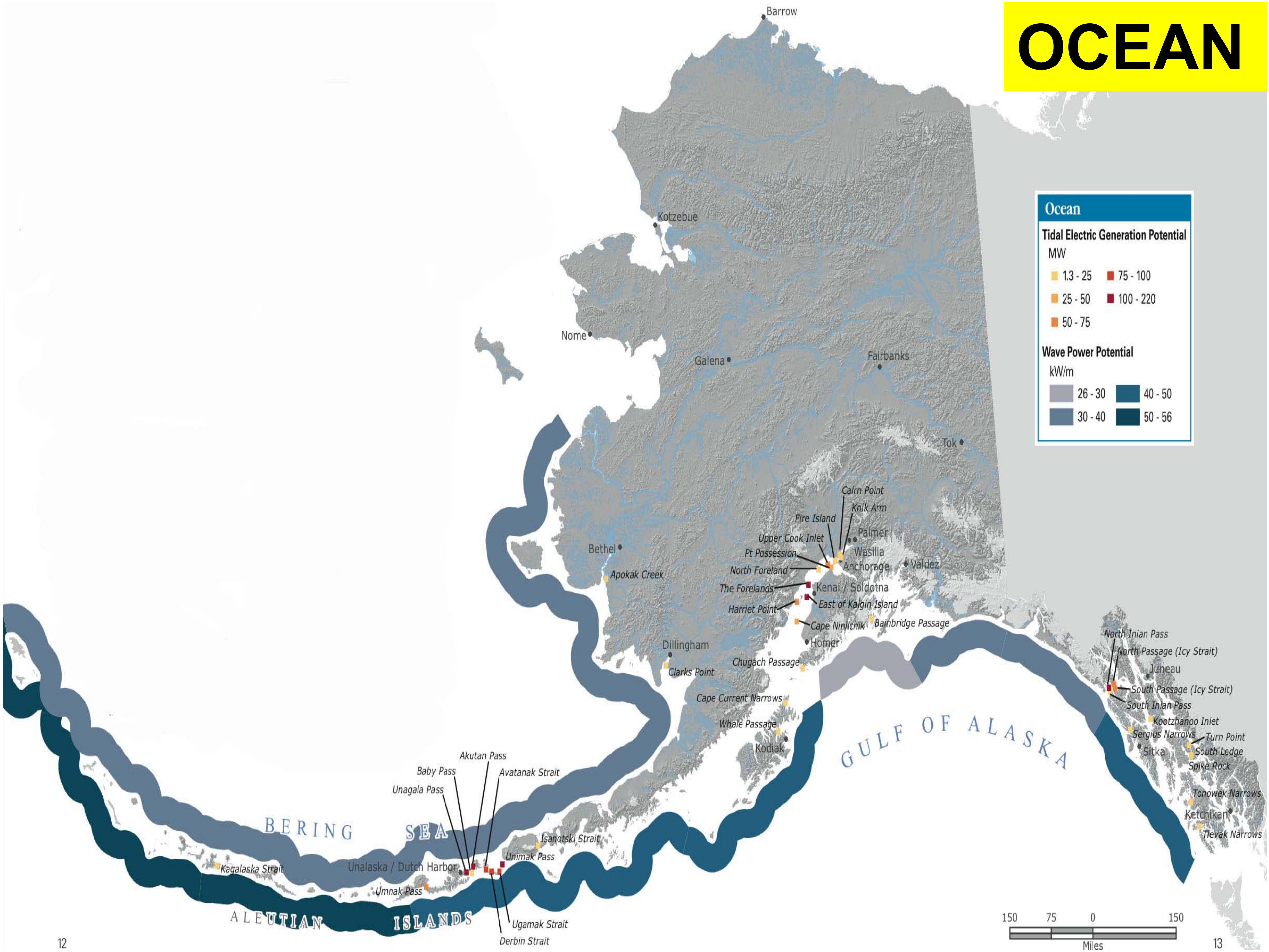
ARCTIC OCEAN
CHUKCHI SEA
BEAUFORT SEA
GULF OF ANADYR
CHUKOTK
RUSSIA
UNITED STATES
FAR NORTH
Barrow
Wainwright
Point Hope
Prudhoe Bay
Deadhorse
Umiat
Colville River
Noatak
Noatak River
Kotzebue
Noorvik
Selawik
Shishmaref
Wales
Little Diomede
Uelen
Lavrentiya
Provideniya
GATES OF THE ARCTIC NAT'L PARK & PRESERVE
Anaktuvuk Pass
ARCTIC NATIONAL WILDLIFE REFUGE
BROOKS RANGE
Arctic Village
Coldfoot
Bettles
ARCTIC CIRCLE
U.S.A. ALASKA
CANADA YUKON
Gambell
Savoonga
ST. LAWRENCE ISLAND
Teller
Taylor
Pilgrim Springs
Nome
Council
White Mountain
Huslia
Nulato
Unalakleet
St. Michael
Emmonak
ST. MATTHEW ISLAND
Galena
Yukon R.
Tanana
Rampart
Stevens Village
Fort Yukon
Manley Hot Springs
INTERIOR
Central
Circle
Chena Hot Springs
Fairbanks
North Pole
Nenana
YUKON-CHARLEY RIVERS NAT'L PRESERVE
DENALI NAT'L PARK & PRESERVE
Kantishna
MT. McKINLEY
Healy
Cantwell
Delta Jct.
Eagle
Chicken
Boundary
Dawson City
Scammon Bay
Hooper Bay
Saint Marys
Holy Cross
KUSKOKWIM MTNS
McGrath
Mekoryuk
NUNIVAK ISLAND
Bethel
Aniak
Kuskokwim River
BERING SEA
ALASKA RANGE
Paxson
Tok
Northway
Talkeetna
Willow
Houston
Big Lake
Wasilla
Sutton
Lake Louise
Gakona Jct.
Glennallen
Nabesna
Beaver Creek
PRIBILOF ISLANDS
ST. PAUL ISLAND
ST. GEORGE ISLAND
KISKA ISLAND
SOUTHWEST
Quinhagak
Wood-Tikchik System
Goodnews Bay
TOGIAK NAT'L WILDLIFE REFUGE
LK. CLARK NAT'L PARK & PRESERVE
Lake Clark
Anchorage
Palmer
Copper Center
CHUGACH MTNS.
Chitina
Kennicott
McCarthy
Dillingham
Nushagak River
Iliamna
Iliamna Lake
Kenai
Soldotna
Whittier
Valdez
PRINCE WILLIAM SOUND
Cordova
Ninilchik
Anchor Pt.
Homer
Seward
Seldovia
COOK INLET
KENAI FJORDS NAT'L PARK
Naknek
King Salmon
KATMAI NAT'L PARK & PRESERVE
WRANGELL-ST. ELIAS NAT'L PARK & PRESERVE
Carmacks
Ross River
N.W. TERRITORY
YUKON
Kluane Lake
Destruction Bay
KLUANE NAT'L PARK
Haines Junction
Lake Laberge
Whitehorse
ALEUTIAN ISLANDS
Dutch Harbor
Unalaska
Akutan
False Pass
Cold Bay
King Cove
Sand Point
Chignik
ANIAKCHAK NAT'L MONUMENT & PRESERVE
Port Lions
Kodiak
KODIAK ISLAND
Old Harbor
KODIAK NATIONAL WILDLIFE REFUGE
SOUTHCENTRAL
GULF OF ALASKA
Yakutat
White Pass Summit
Carcross
Watson Lake
BRITISH COLUMBIA
Haines
Skagway
GLACIER BAY NAT'L PARK & PRESERVE
Auke Bay
Juneau
Gustavus
Elfin Cove
Pelican
Hoonah
Tracy Arm
Tenakee
Angoon
Stikine River
Sitka
Kake
Petersburg
Wrangell
PACIFIC OCEAN
INSIDE PASSAGE
MISTY FIORDS NAT'L MONUMENT WILDERNESS
Hyder
Stewart
Hollis
Ketchikan
Metlakatla
Prince Rupert

Wind Power Class



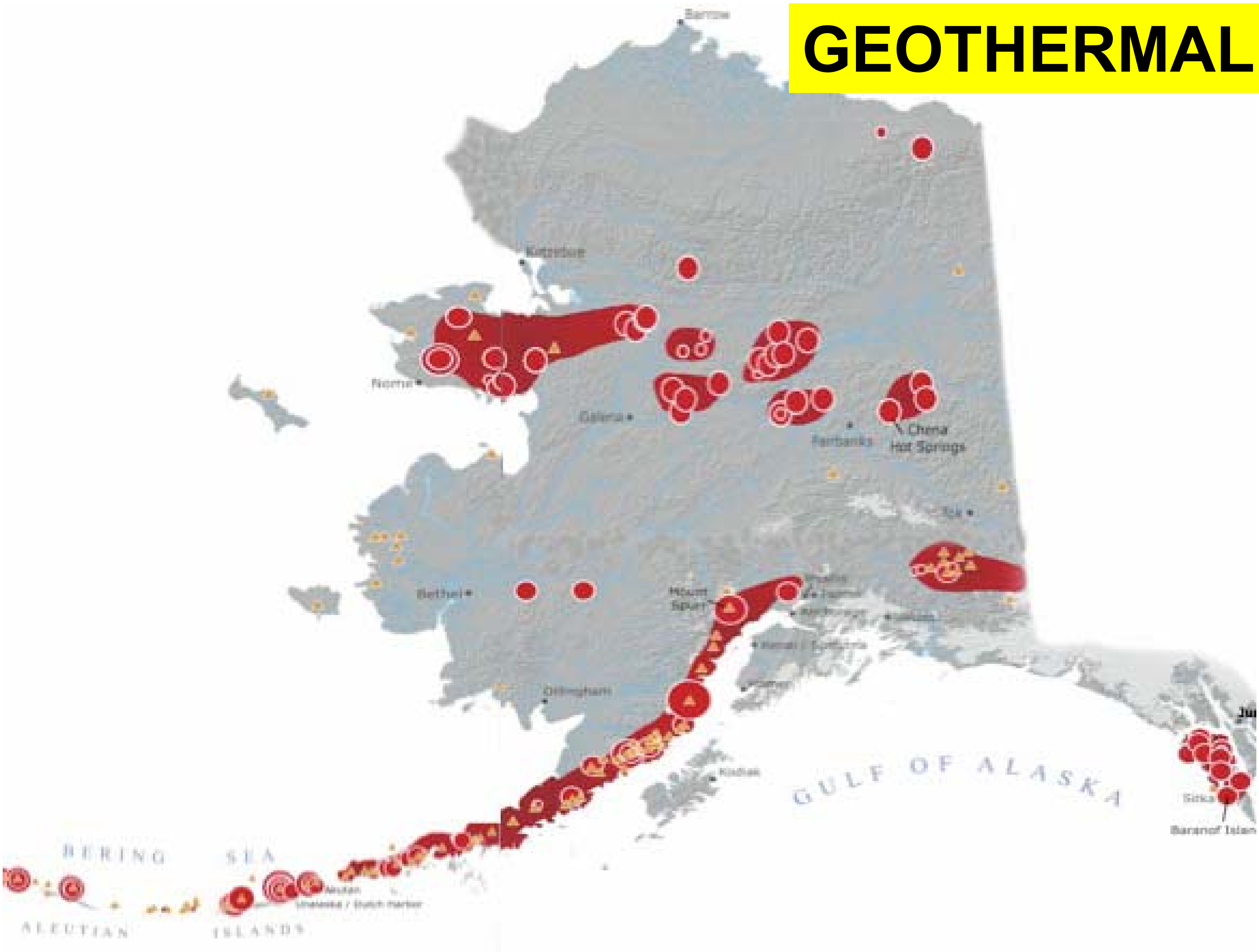
Power Class	Speed	Power Density
1	0.0-5.6m/s	0-200W/m2
2	5.6-6.4m/s	200-300W/m2
3	6.4-7.0m/s	300-400W/m2
4	7.0-7.5m/s	400-500W/m2
5	7.5-8.0m/s	500-600W/m2
6	8.0-8.8m/s	500-800W/m2
7	>8.8m/s	>800W/m2

OCEAN



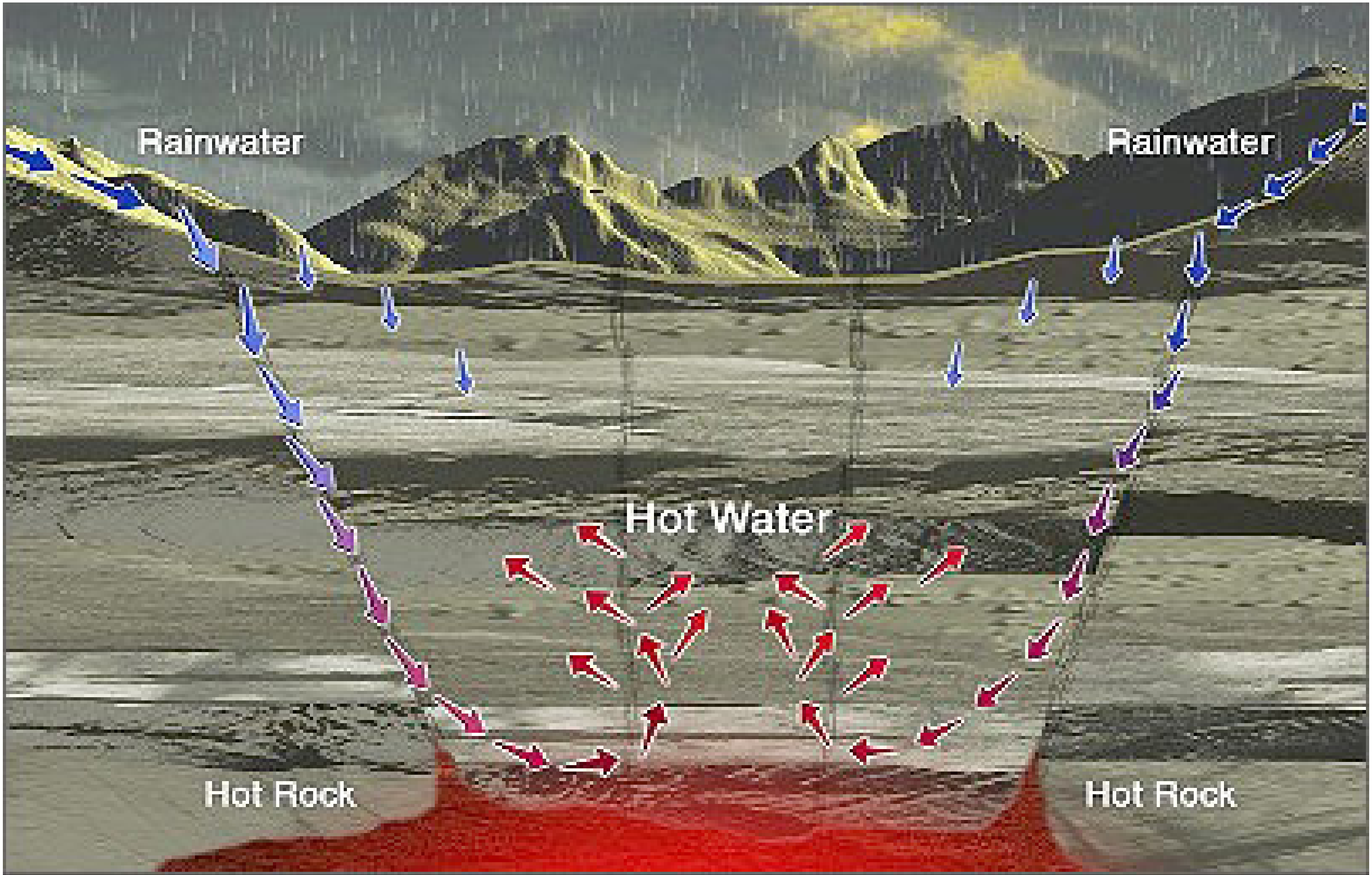
Ocean
Tidal Electric Generation Potential
MW
1.3 - 25
25 - 50
50 - 75
75 - 100
100 - 220
Wave Power Potential
kW/m
26 - 30
30 - 40
40 - 50
50 - 56
Barrow
Kotzebue
Nome
Galena
Fairbanks
Tok
Bethel
Apokak Creek
Dillingham
Clarks Point
Cairn Point
Knik Arm
Fire Island
Upper Cook Inlet
Pt Possession
North Foreland
The Forelands
Harriet Point
Palmer
Wasilla
Anchorage
Valdez
Kenai / Soldotna
East of Kalgin Island
Cape Ninilchik
Bainbridge Passage
Homer
Chugach Passage
Cape Current Narrows
Whale Passage
Kodiak
GULF OF ALASKA
BERING SEA
ALEUTIAN ISLANDS
Akutan Pass
Baby Pass
Avatanak Strait
Unagala Pass
Isanotski Strait
Unimak Pass
Unalaska / Dutch Harbor
Kagalaska Strait
Umnak Pass
Ugamak Strait
Derbin Strait
North Inian Pass
North Passage (Icy Strait)
Juneau
South Passage (Icy Strait)
South Inian Pass
Kootznahoo Inlet
Sergius Narrows
Turn Point
Sitka
South Ledge
Spike Rock
Tonowek Narrows
Ketchikan
Tlevak Narrows
150 75 0 150
Miles

GEOTHERMAL

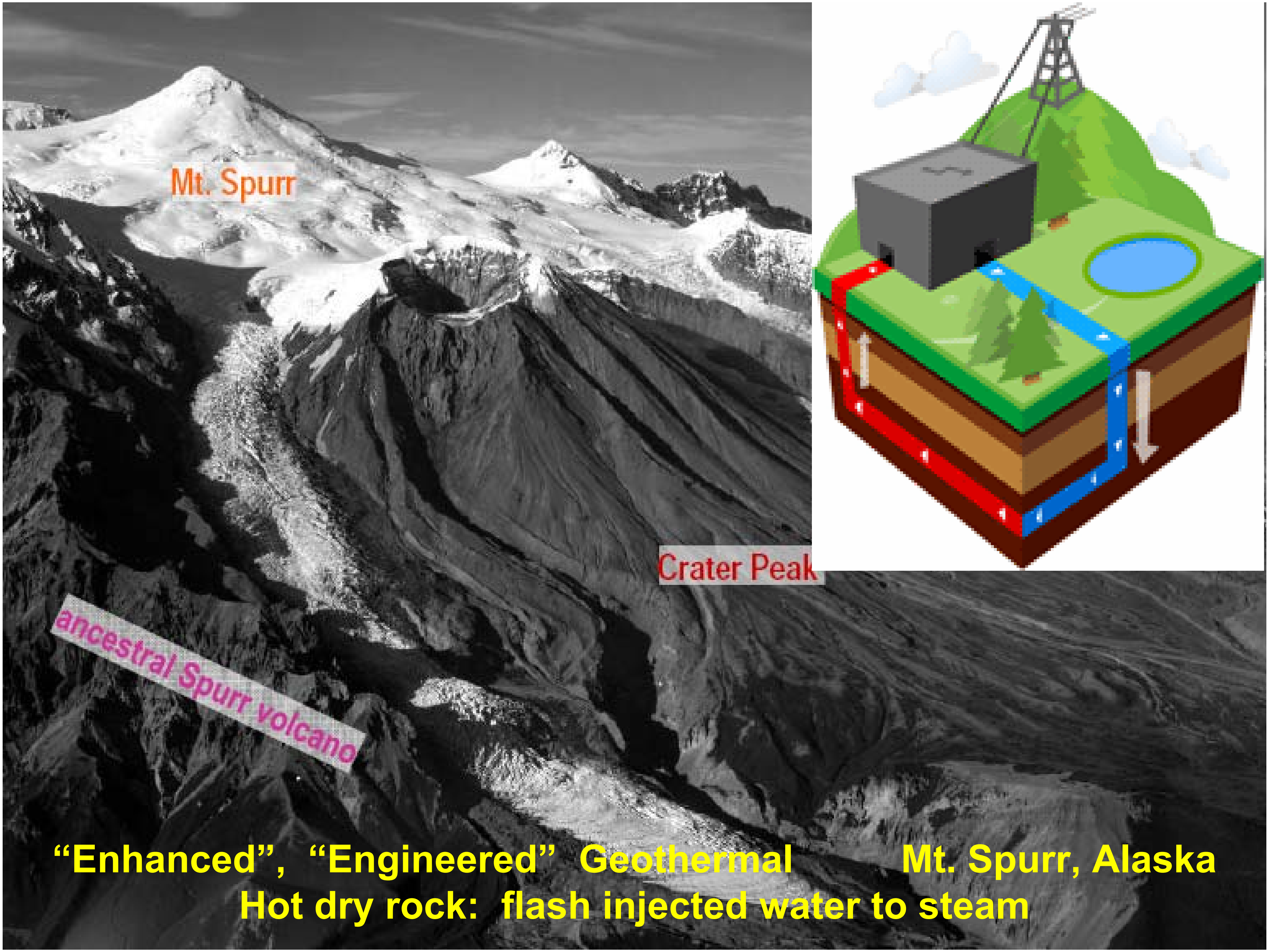


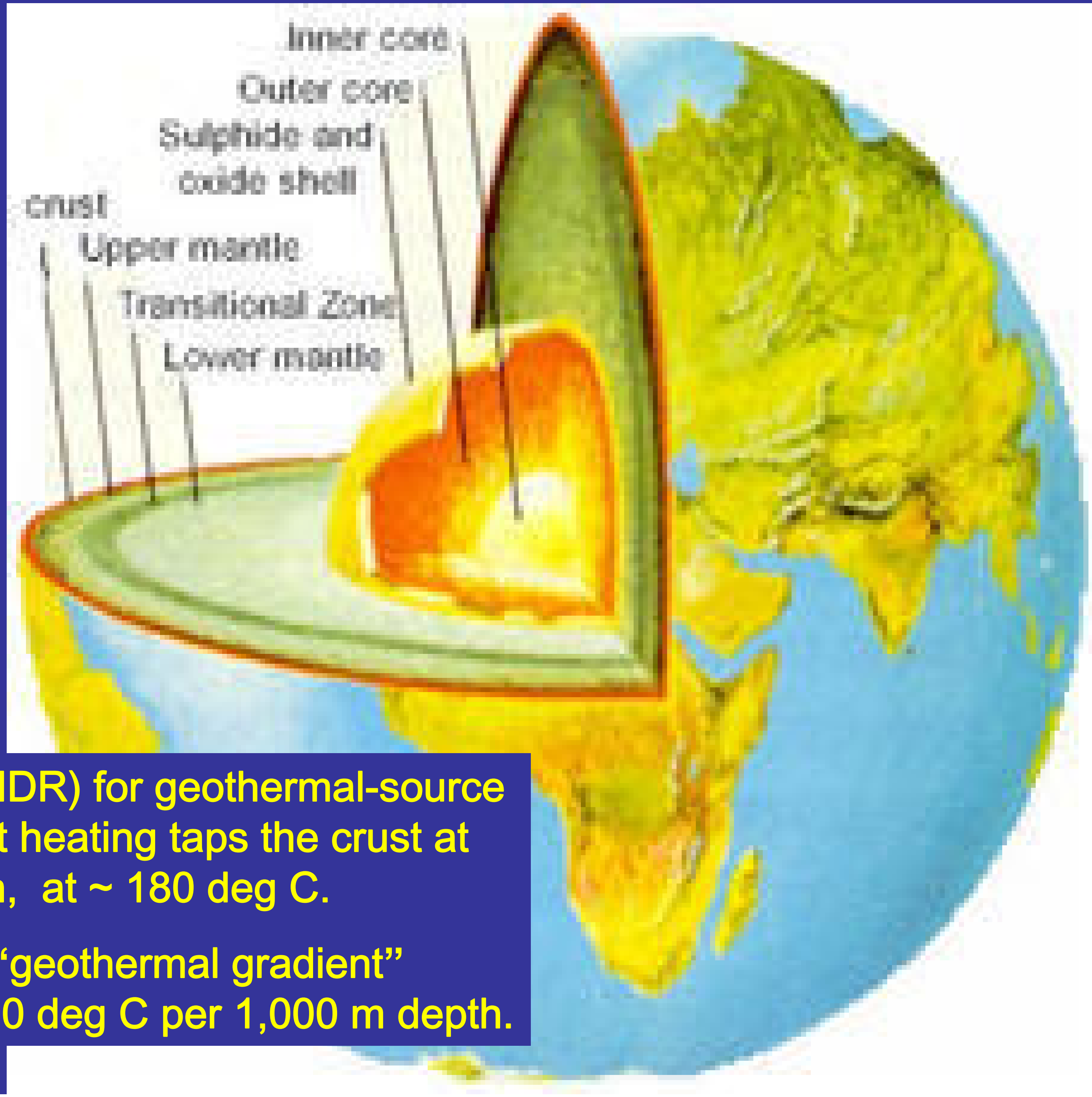
Barrow
Kotzebue
Nome
Galena
Chena
Hot Springs
Fairbanks
Tok
Bethel
Mount
Spurr
Dillingham
Kodiak
GULF OF ALASKA
Sitka
Baranof Islan
BERING SEA
Akutan
Unalaska / Dutch Harbor
ALEUTIAN ISLANDS

Hydro



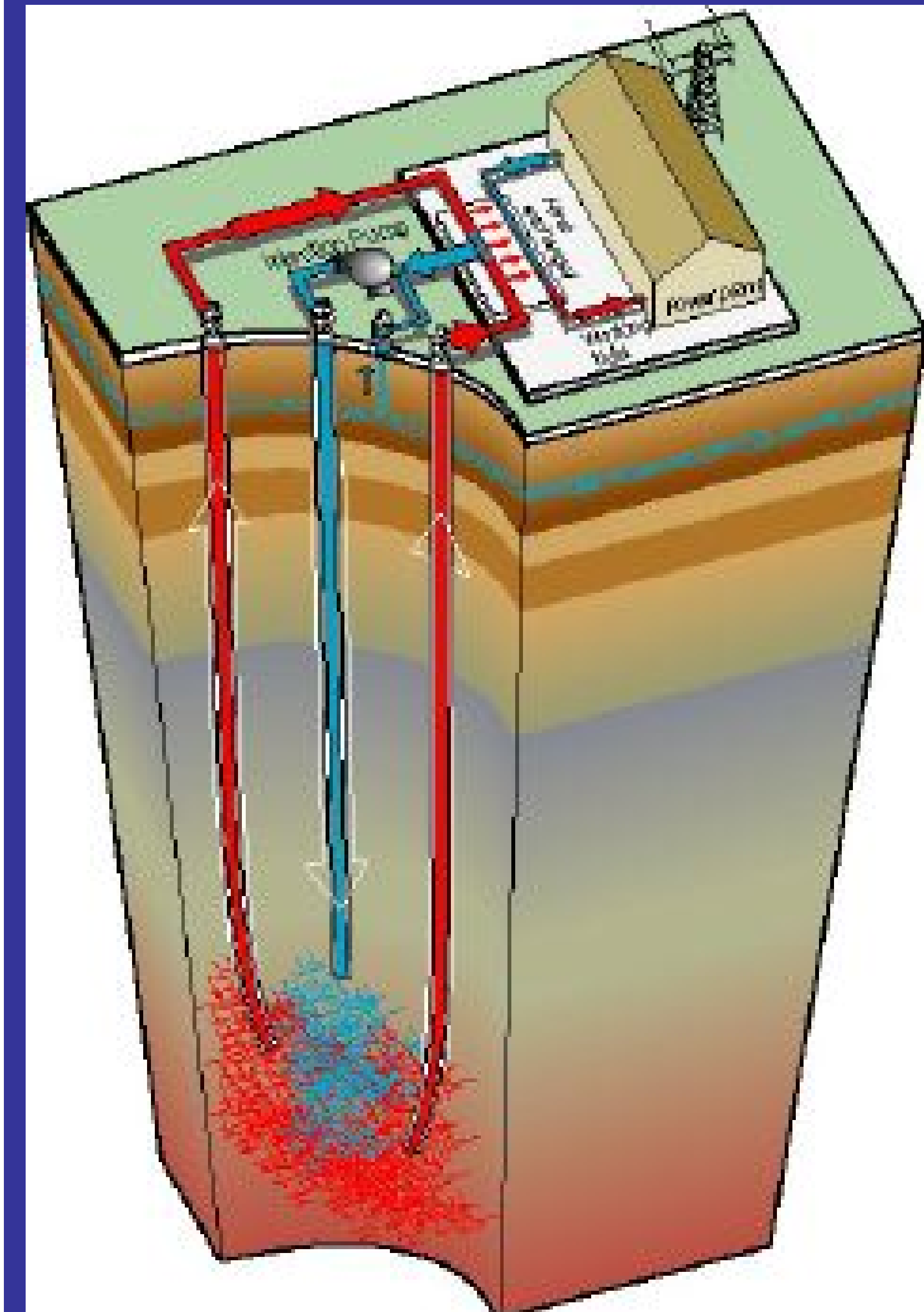
Geothermal: hot water, surface recharge


Mt. Spurr
Crater Peak
ancestral Spurr volcano
"Enhanced", "Engineered" Geothermal
Mt. Spurr, Alaska
Hot dry rock: flash injected water to steam

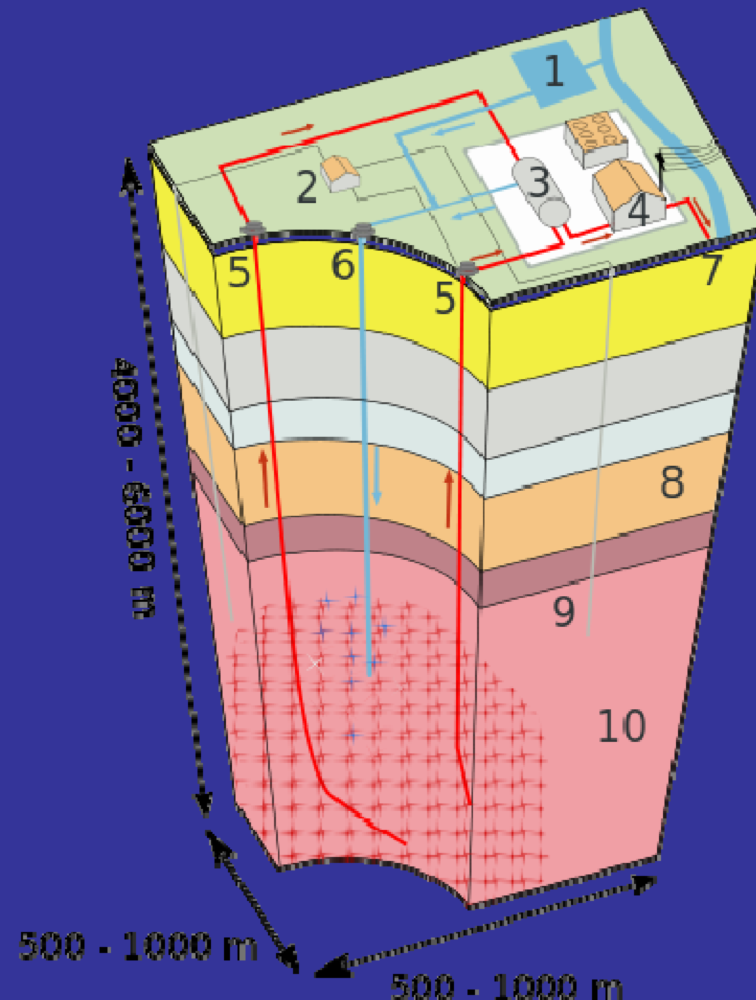


Hot Dry Rock (HDR) for geothermal-source hot water district heating taps the crust at ~ 6,000 m depth, at ~ 180 deg C.

The ubiquitous “geothermal gradient” worldwide is ~ 30 deg C per 1,000 m depth.

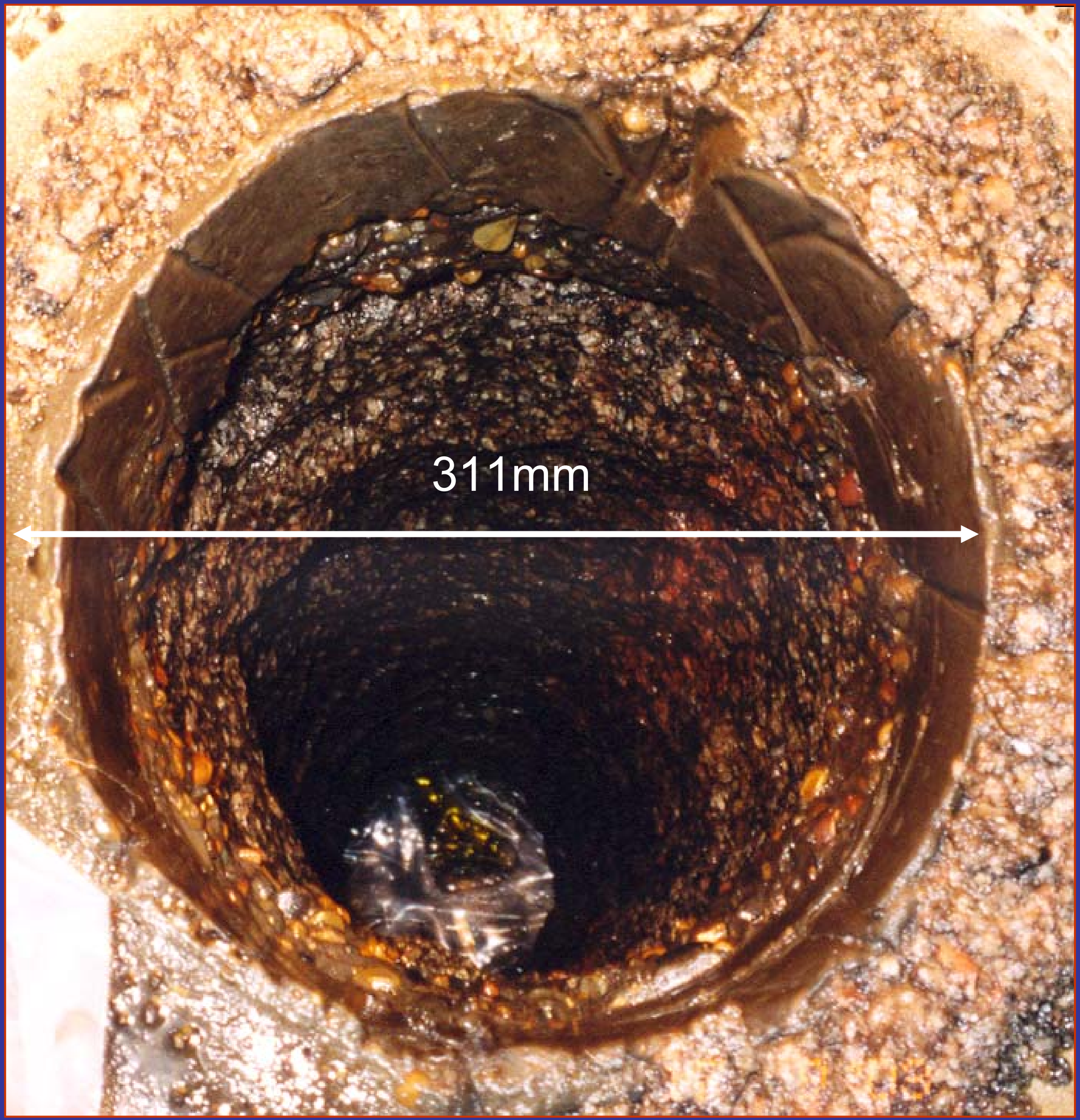


"Engineered Geothermal Systems"



EPB might be used for this, at deep rock temp < 200 deg C, but is probably most economical as a single borehole HDR "well".

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



2006 BIT DESIGN

Cost Of Energy (COE) for EPB HDR hot water community DHS

The following DRAFT calculations slides assume:

1. Single "simple" or "enhanced" geothermal well 6,000 m deep, 20" diam via EPB,
2. Well reaches HDR at 180 deg C, per geothermal gradient of 30 deg C per 1,000 m depth
3. Well boring costs $150 / m x 6,000 m = $ 900,000
4. Cuttings (produced gravel) from EPB = 1,200 cubic meters = 3,300 tons
5. 1 kWh = 3,410 Btu
6. 1 gallon of heating oil = 135,000 Btu gross = 39.6 kWh / gallon "equivalent" (at 100% energy content)
7. Oil-fired heaters (Toyo, Monitor) average 90% efficiency
8. SINTEF study for NTNU estimates for one EPB well of above size:
    a. Net 25,000 MWht / year produced as hot water per "simple" HDR well
    b. Net 50,000 MWht / year produced as hot water per "enhanced" 4-leg branched HDR well
    c. Well output / input temps modeled at 70 / 30 and 90 / 20 degrees C


ORC = Organic Rankine Cycle, for lower-temp hot water sources
Chena Hot Springs, Alaska: Two 225 kW ORC generation sets
By: UTC – Carrier PurePower 225.
Input 165 F = 74 C, 480 gpm
Cold = 40-45 F = 7 C, 1,500 gpm

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

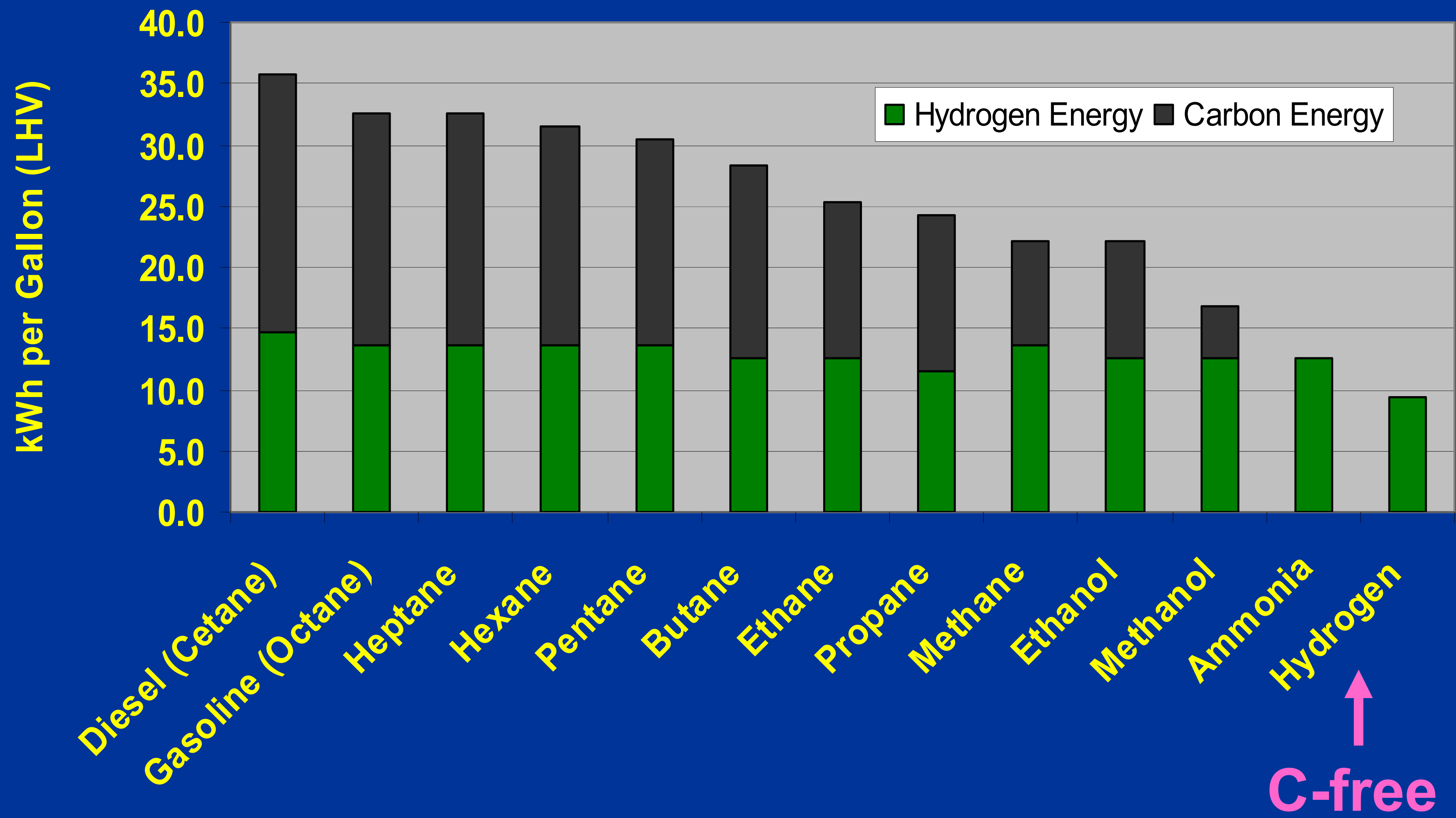
- Grid nearly full: who pays?
- Integration
  - Continental energy system
  - Quality
  - Time-varying
- Costly "firming" storage: CAES, VRB, pump hydro
- Low capacity factor (CF) or curtailment
- Overhead vulnerable: God or man
- Underground: only HVDC, 6x cost
- FERC no interstate jurisdiction
- Wide ROW
- NIMBY: delay + cost, site + ROW


Zion, IL
Near Zion nuclear plant, Oct 02

Hydrogen and Ammonia Fuels

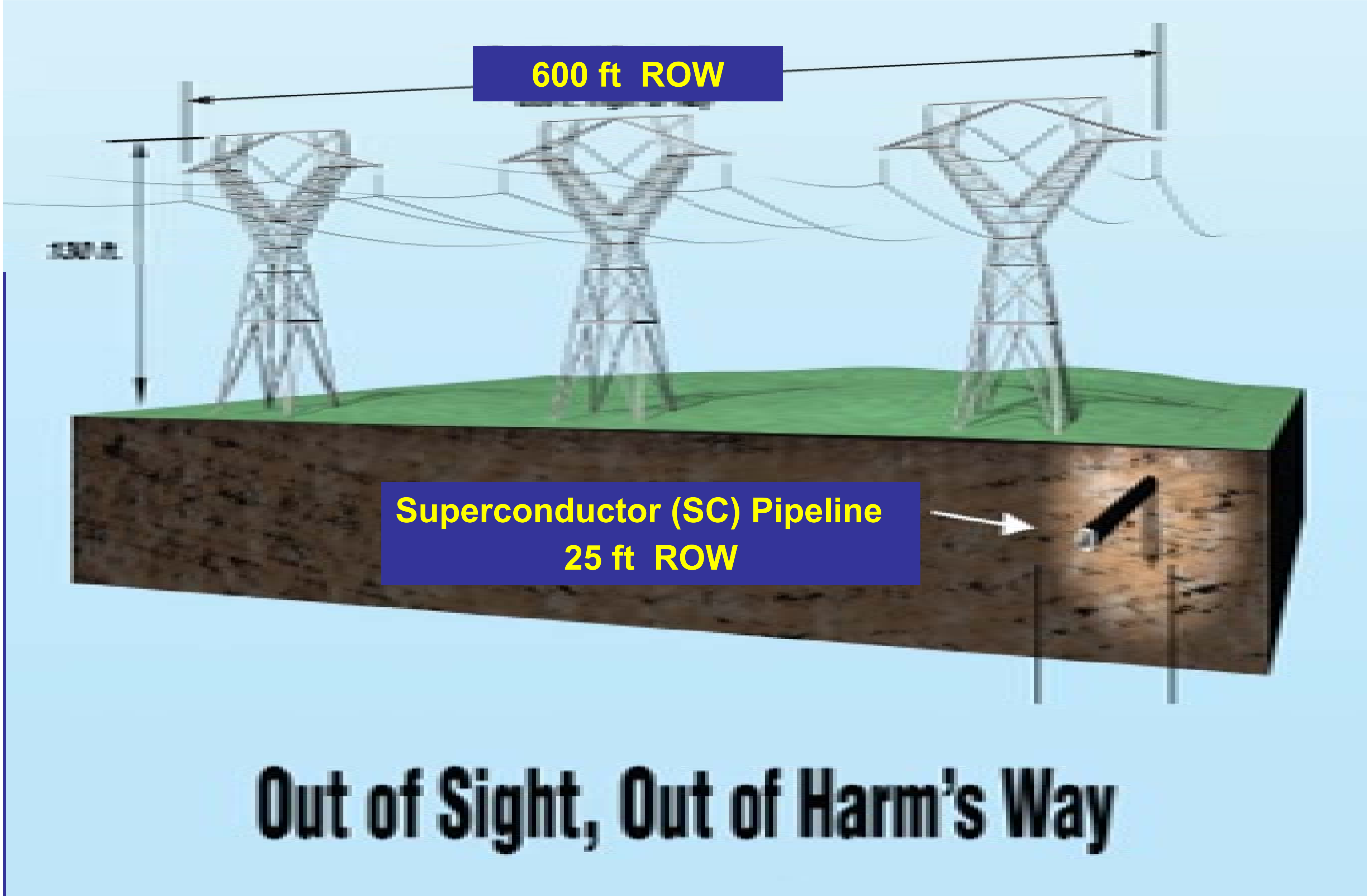
- **Solve electricity's RE problems:**
  - **Transmission**
  - **Firming storage**
  - **Grid integration: time-varying output**
- **Carbon-free**
- **Underground pipelines**
- **Low-cost storage: < $ 1.00 / kWh capital**
  - **Pipelines**
  - **GH2 salt caverns**
  - **NH3 tanks**

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



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**



10,000 MW alternatives: HVAC vs HVDC superconductor

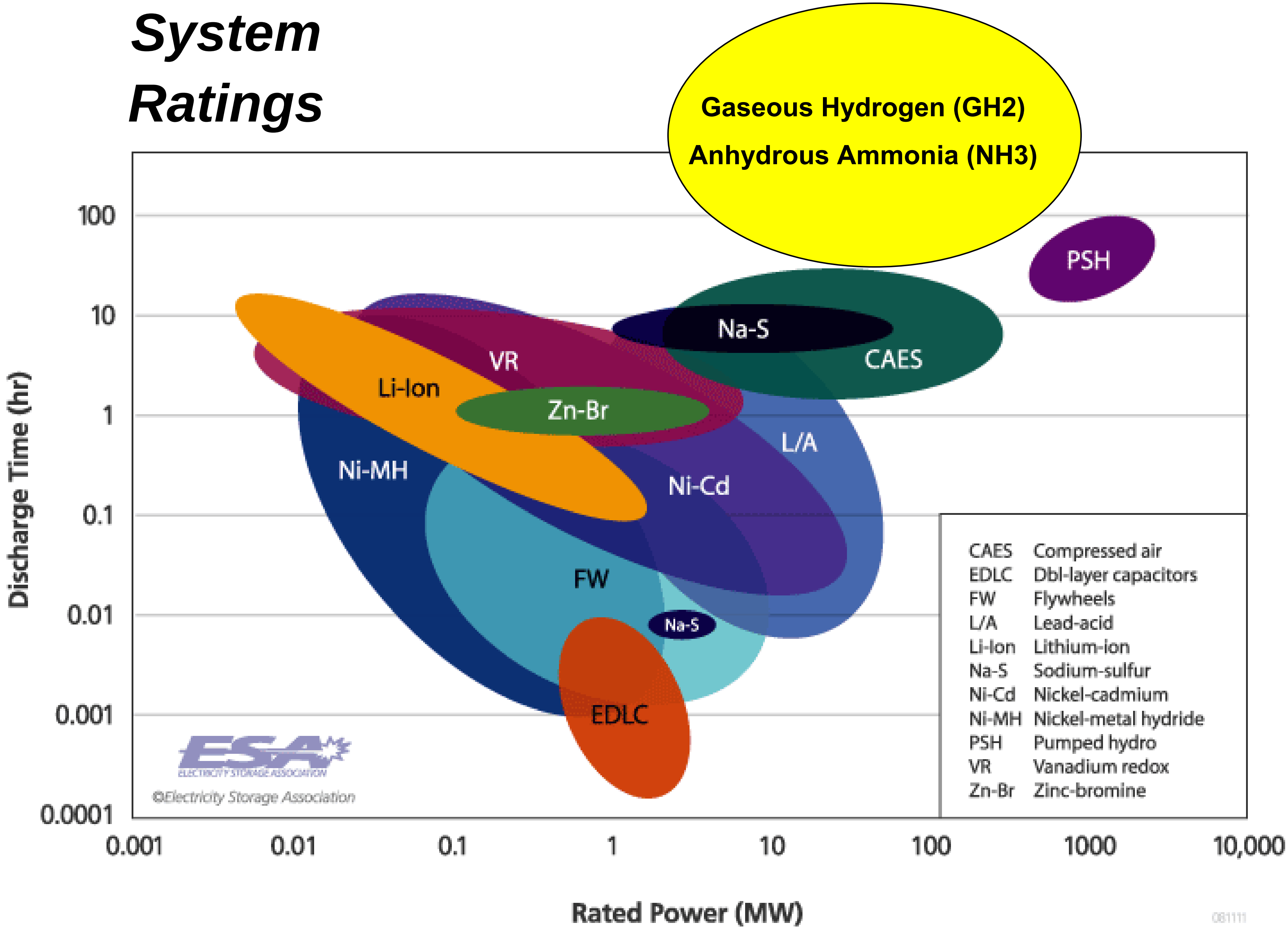
"Firm" Energy Essential

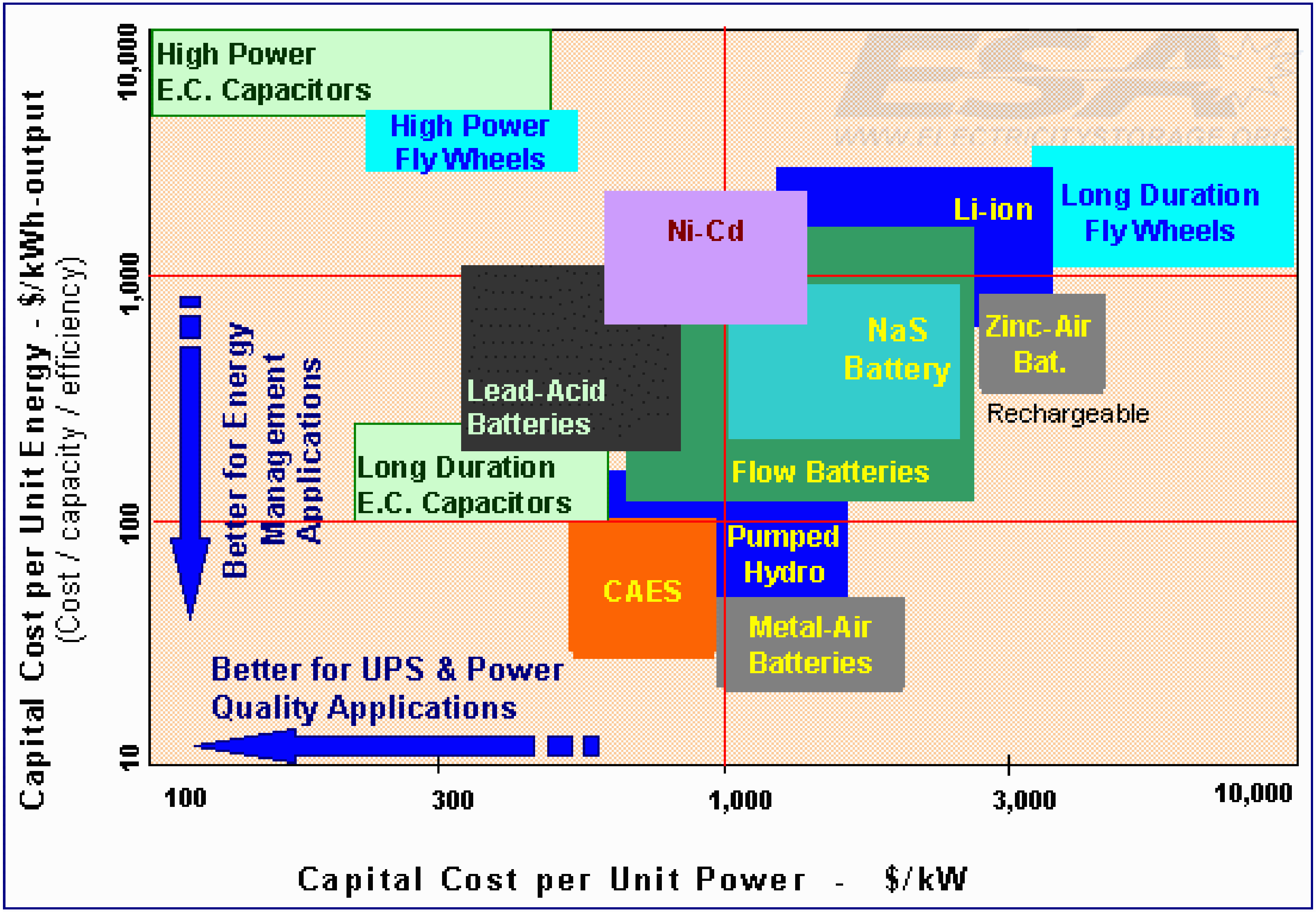
- Every hour, every year
- Dispatchable
- Strategically: indigenous, secure
- Market price: worth more
- Bankable large projects
- Risk avoidance:
  - Rapid climate change
  - Economic chaos

Energy Storage System Characteristics
Hydrogen and Ammonia off the charts ?

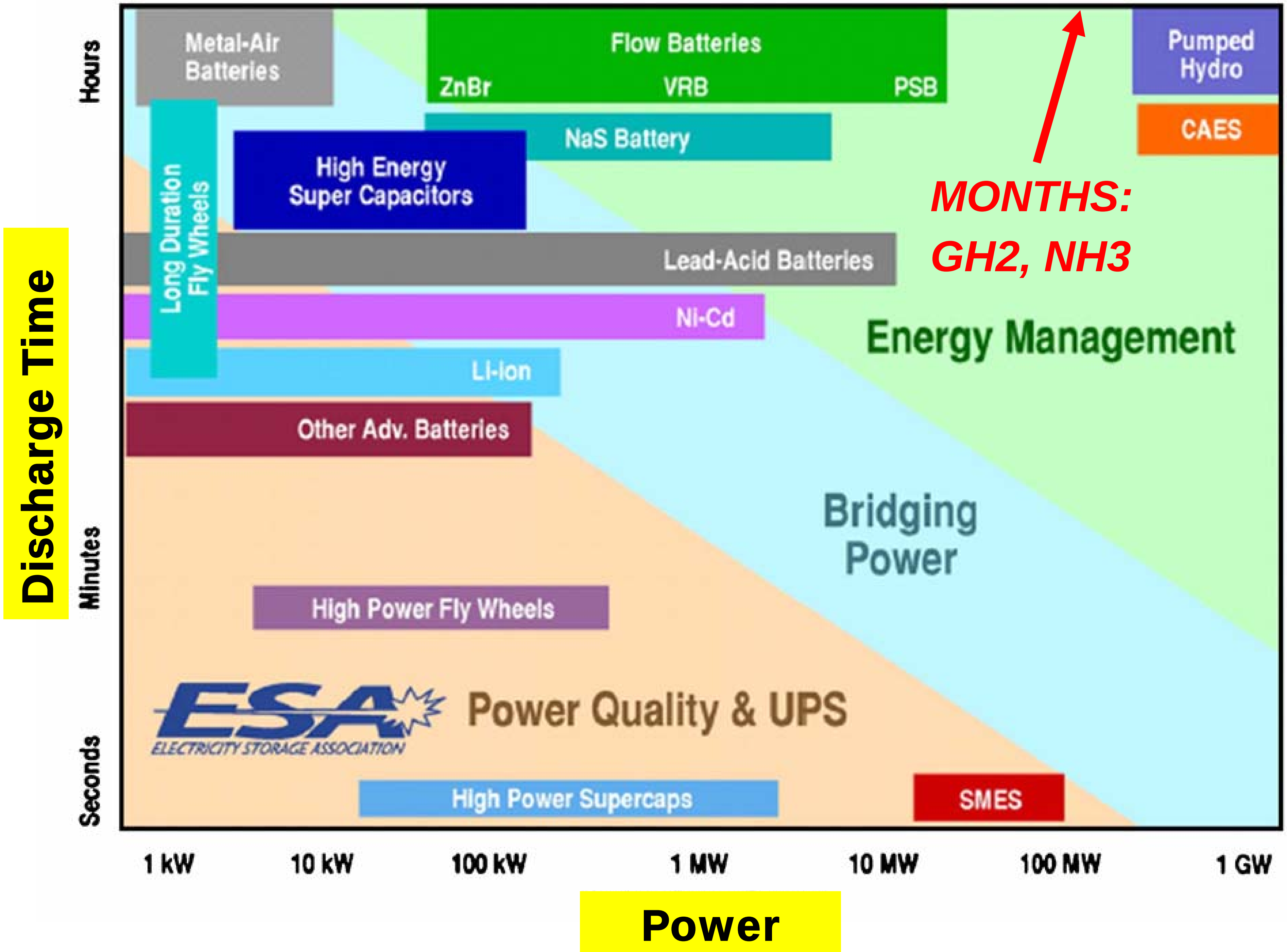
- *Storage capacity (Mwh, scf, nM3, Mt, gallons ….)*
- *Power (MW, scfm ….)   In / Out rate*
- *Costs*
  - *Capital*
  - *O&M*
- **Efficiency**
- **Response time**
- **Durability (cycling capacity)**
- **Reliability**
- **Autonomy**
- **Self-discharge**
- **Depth of discharge**
- **Adaptation to the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

System Ratings




High Power
E.C. Capacitors
High Power
Fly Wheels
Li-ion
Long Duration
Fly Wheels
Ni-Cd
NaS
Battery
Zinc-Air
Bat.
Rechargeable
Lead-Acid
Batteries
Long Duration
E.C. Capacitors
Flow Batteries
Pumped
Hydro
CAES
Metal-Air
Batteries
Better for Energy
Management
Applications
Better for UPS & Power
Quality Applications
Capital Cost per Unit Energy - $/kWh-output
(Cost / capacity / efficiency)
10,000
1,000
100
10
100
300
1,000
3,000
10,000
Capital Cost per Unit Power - $/kW

GH2 and NH3



Discharge Time
Hours
Minutes
Seconds
Metal-Air Batteries
Flow Batteries
ZnBr
VRB
PSB
Pumped Hydro
CAES
NaS Battery
Long Duration Fly Wheels
High Energy Super Capacitors
MONTHS: GH2, NH3
Lead-Acid Batteries
Ni-Cd
Energy Management
Li-Ion
Other Adv. Batteries
Bridging Power
High Power Fly Wheels
ESA
ELECTRICITY STORAGE ASSOCIATION
Power Quality & UPS
High Power Supercaps
SMES
1 kW
10 kW
100 kW
1 MW
10 MW
100 MW
1 GW
Power

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**

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

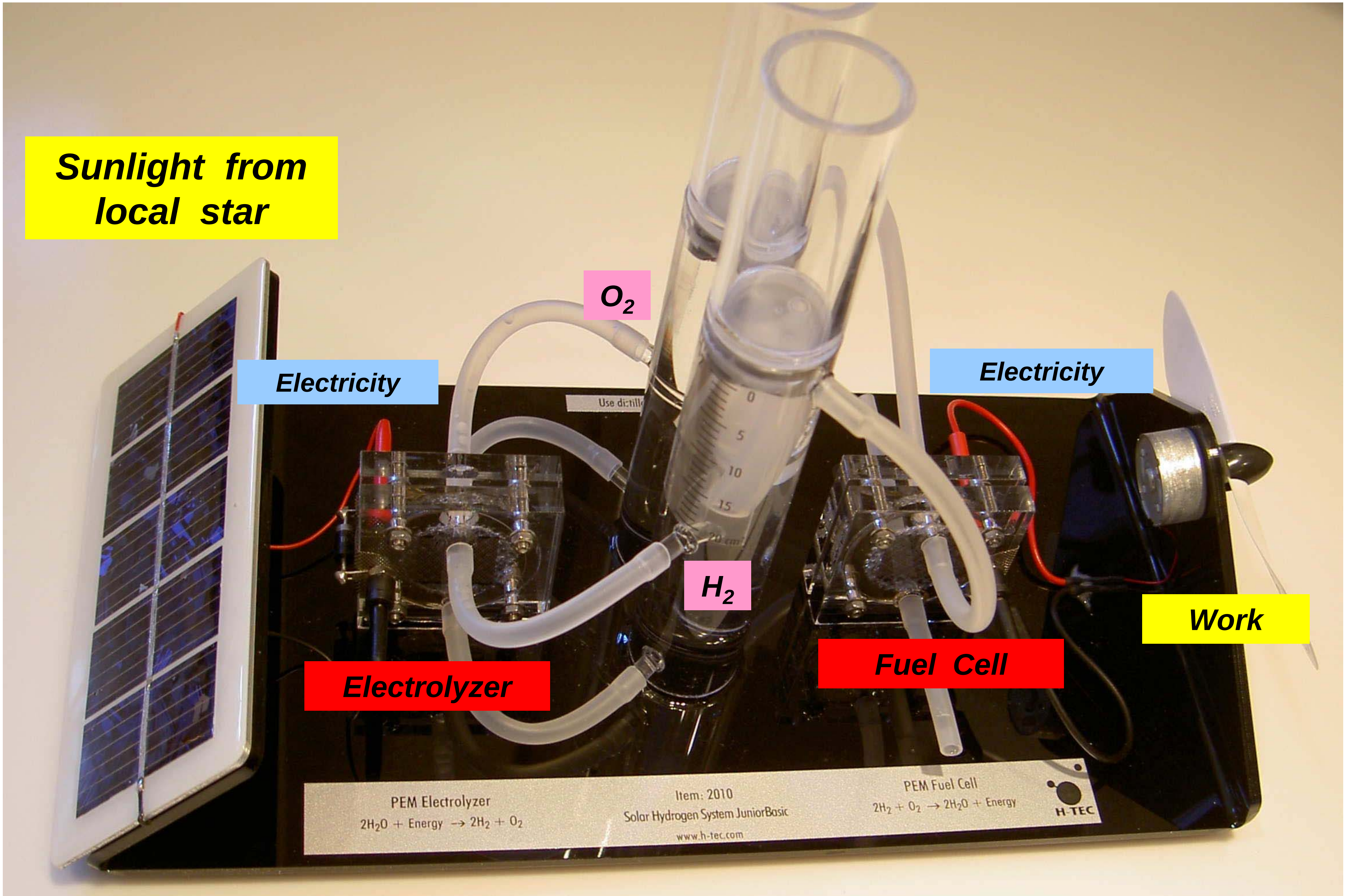
but only after they have tried everything else ”

Winston Churchill

The dog caught the car.

Dan Reicher

Solar Hydrogen Energy System



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

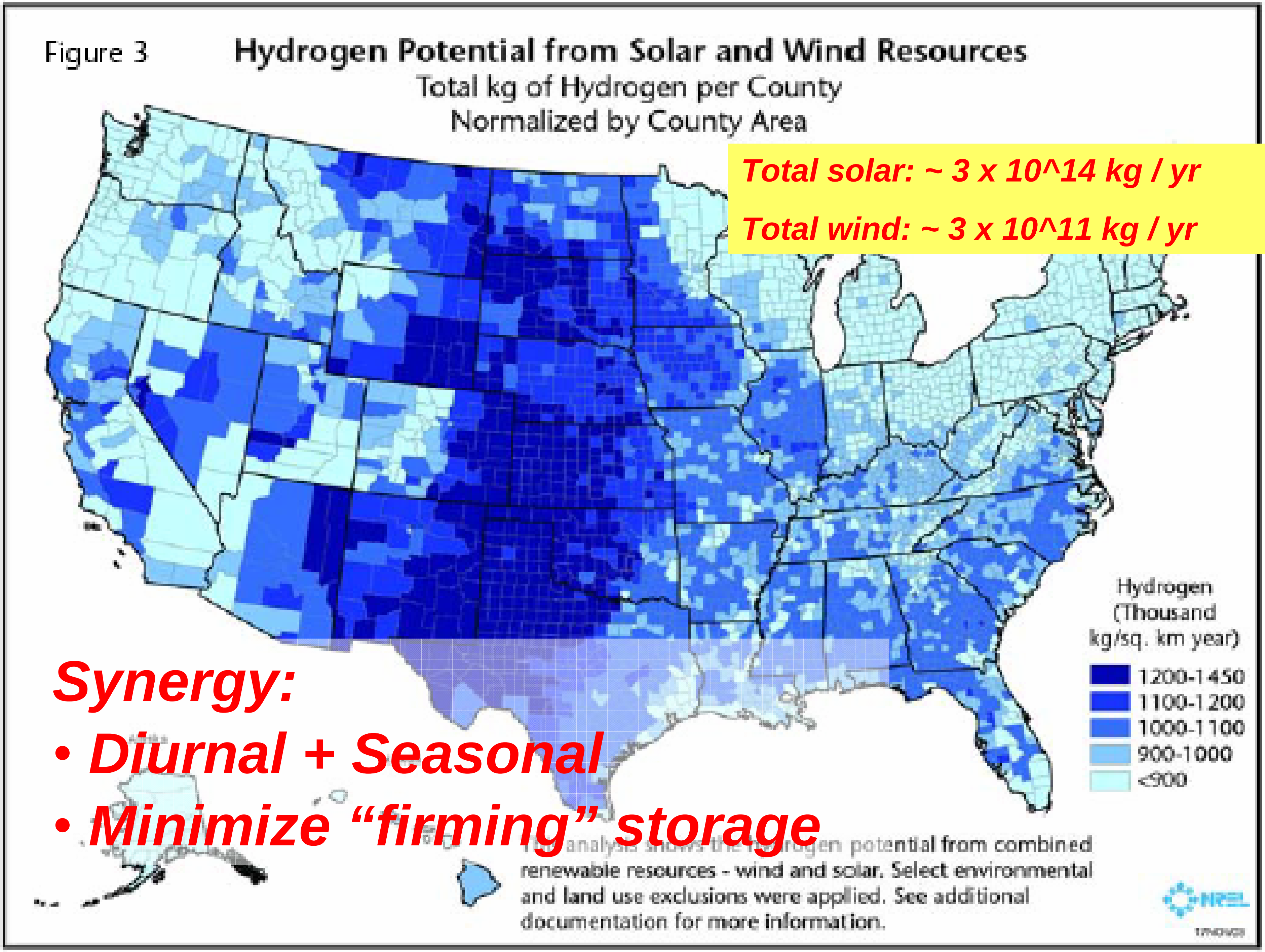
Capacity Factor (CF) = 30%

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

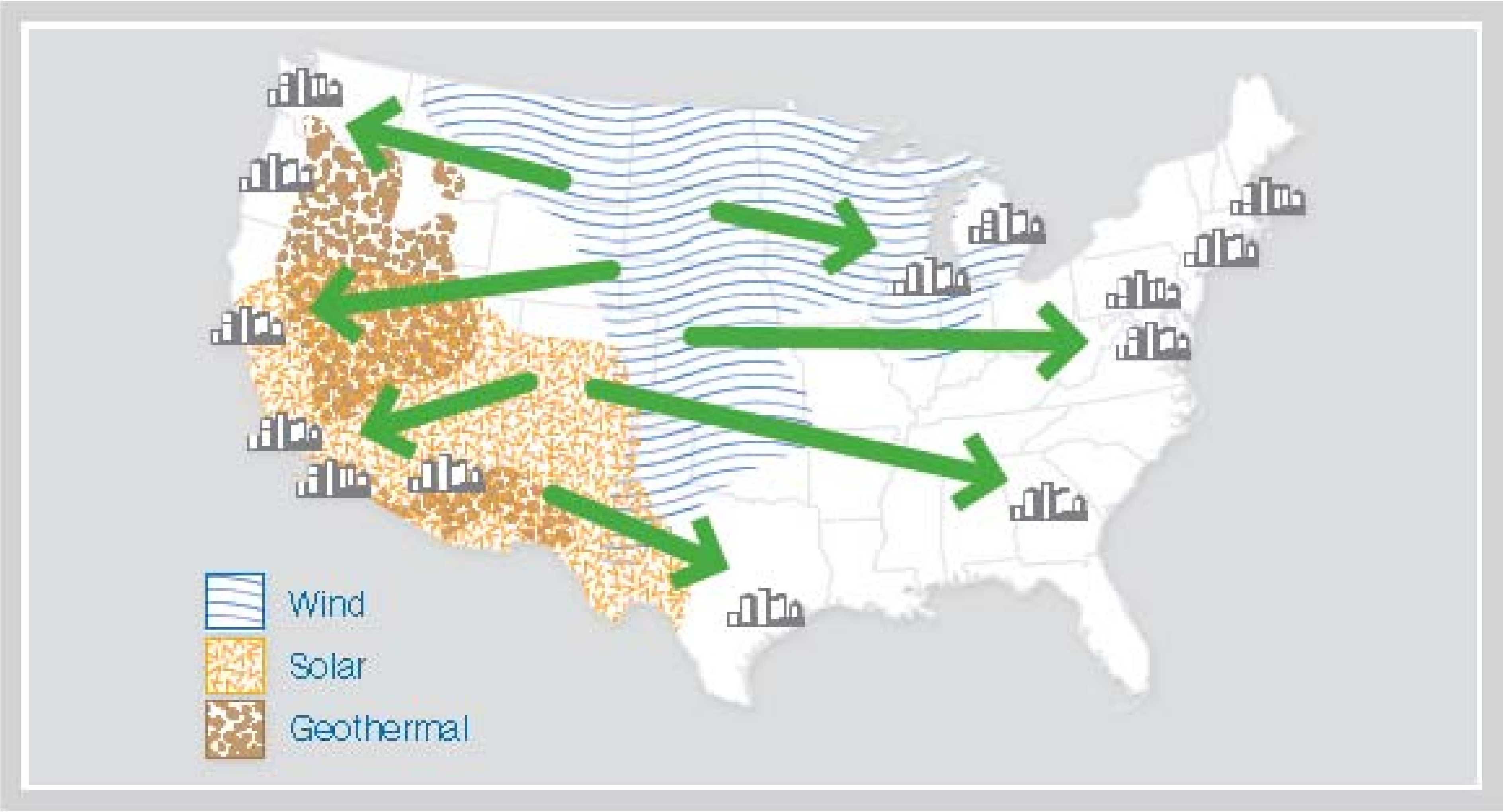
Total solar: ~ 3 x 10^14 kg / yr

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



Synergy:

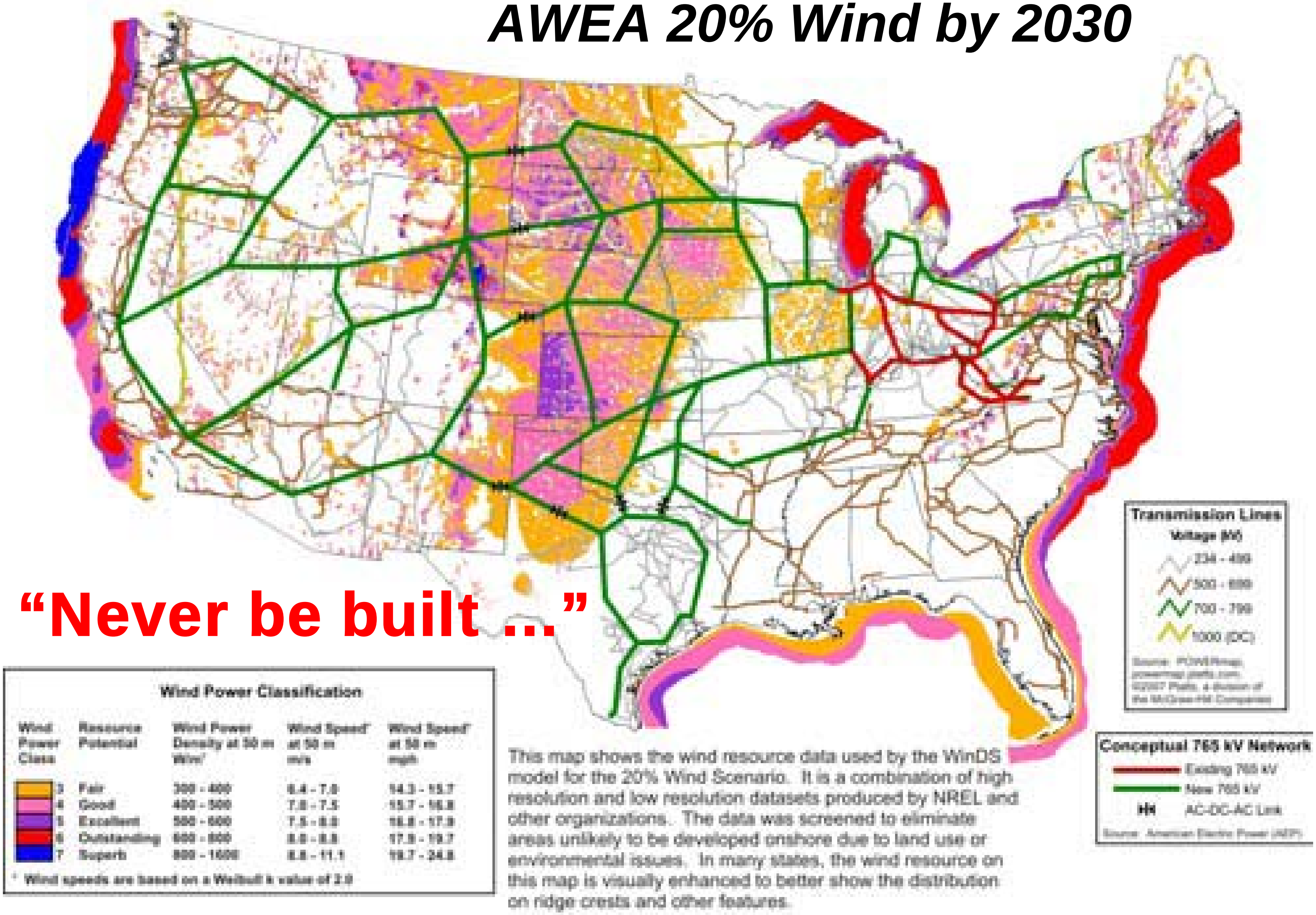
- **Diurnal + Seasonal**
- **Minimize "firming" storage**



Source: AWEA and SEIA

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

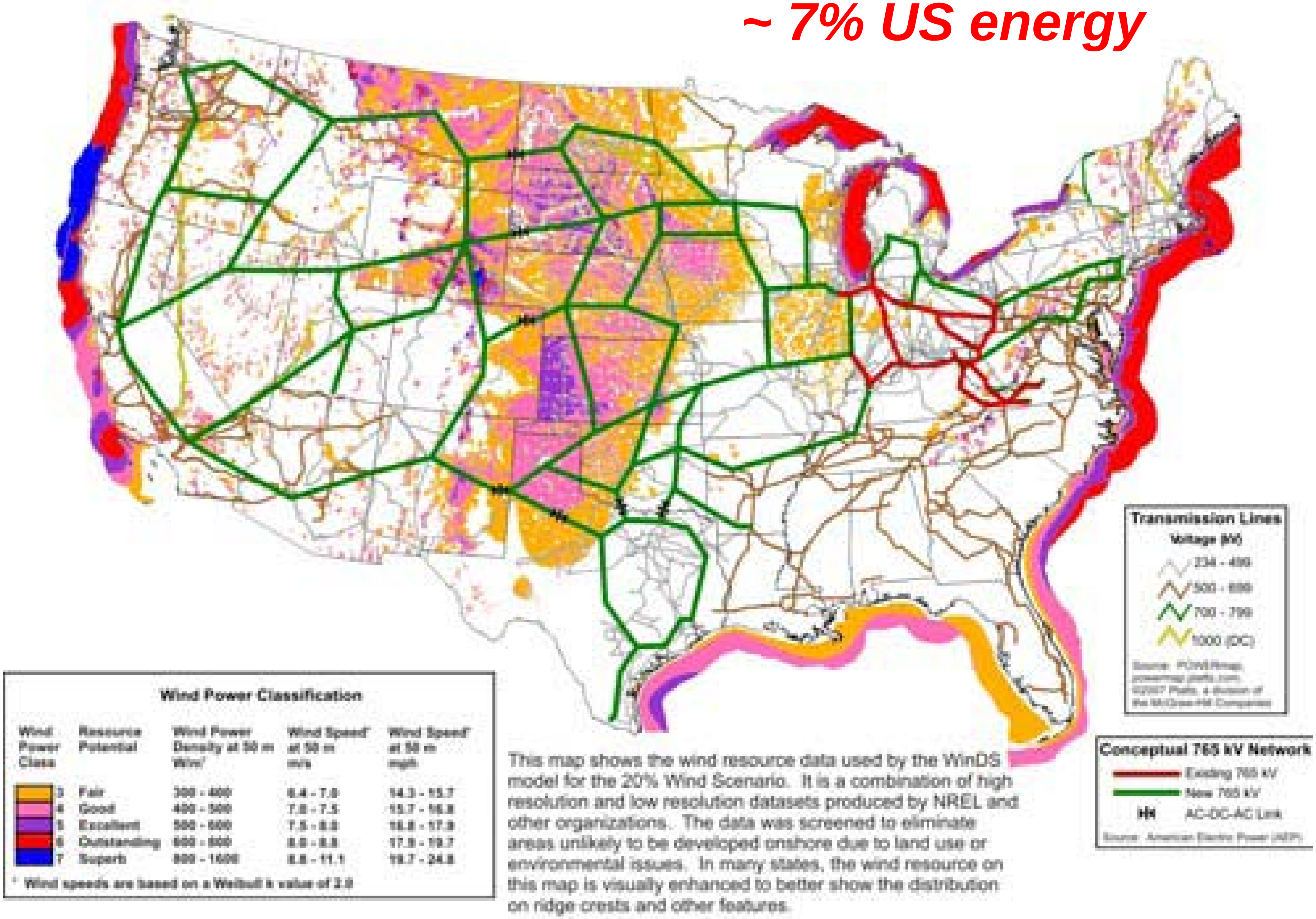
AWEA 20% Wind by 2030



"Never be built ..."

AWEA: 20% Electricity from Wind by 2030

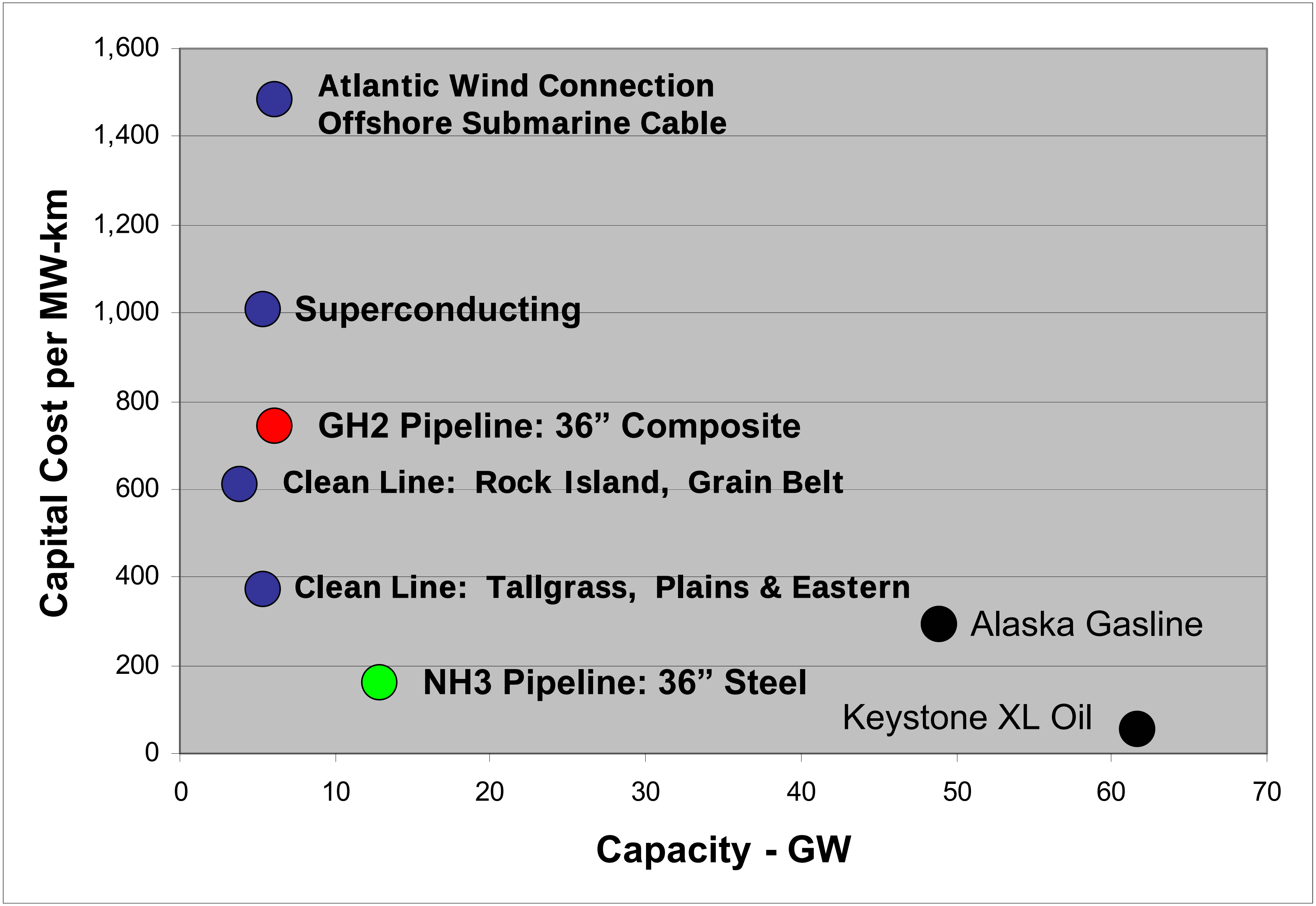
~ 7% US energy



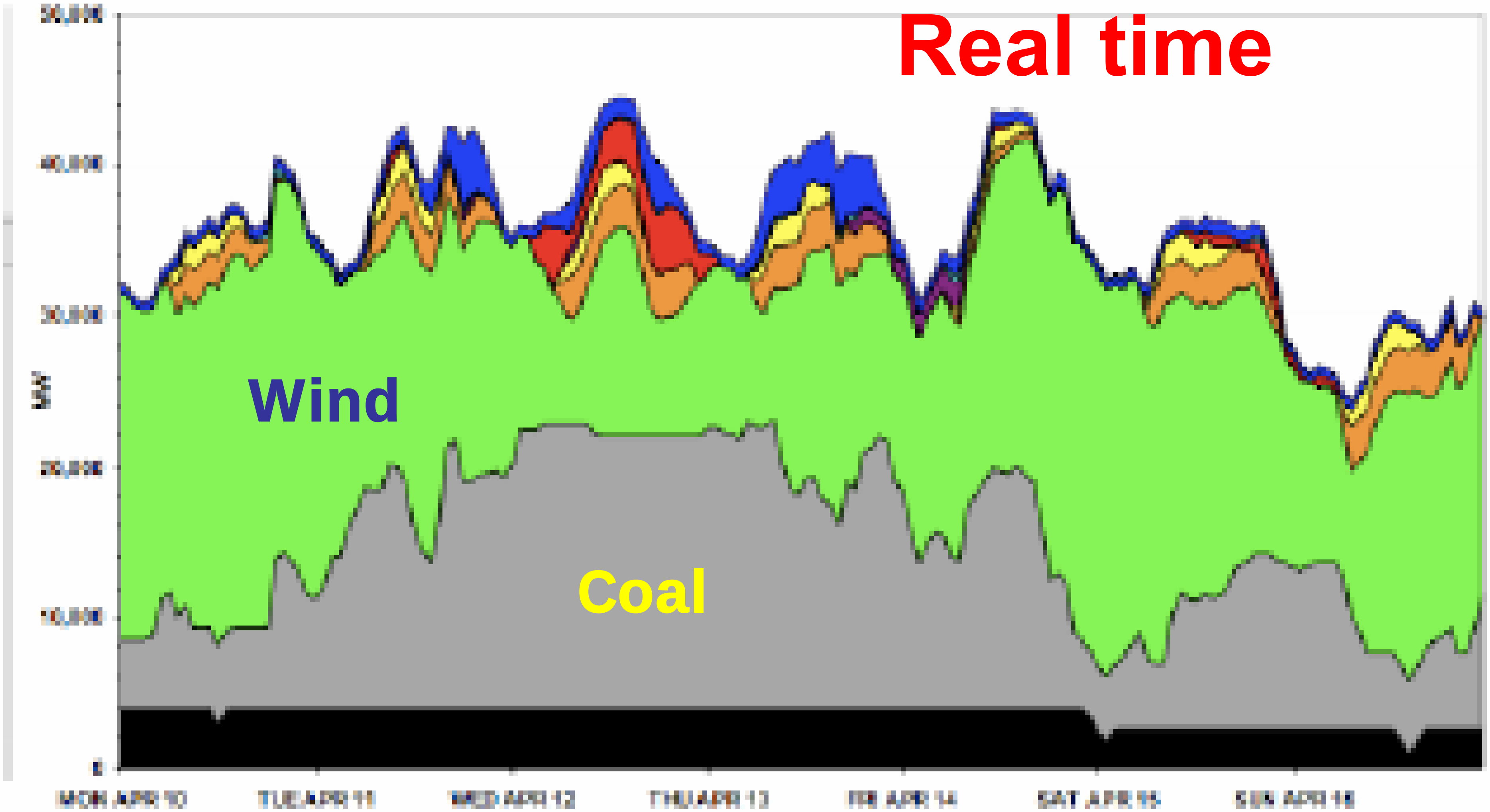
Electricity Capital Cost per GW-mile

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

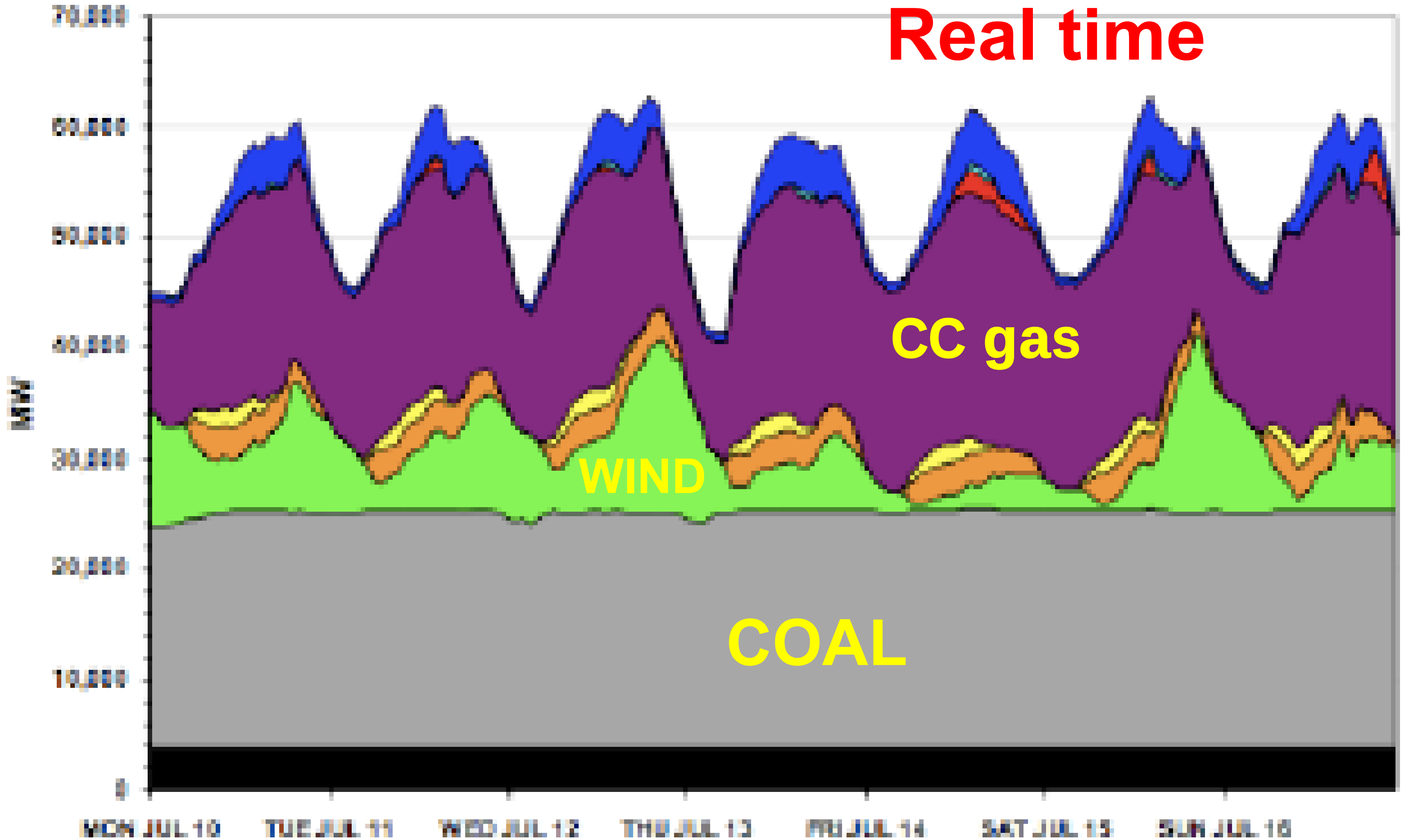

Atlantic
Wind Connection
350 miles
5 GW
$ 5B
1,750 GW-miles @ $5,000M =
$2.8M / GW-mile
Google



Capital Cost per MW-km
1,600
1,400
1,200
1,000
800
600
400
200
0
Atlantic Wind Connection
Offshore Submarine Cable
Superconducting
GH2 Pipeline: 36” Composite
Clean Line: Rock Island, Grain Belt
Clean Line: Tallgrass, Plains & Eastern
Alaska Gasline
NH3 Pipeline: 36” Steel
Keystone XL Oil
0
10
20
30
40
50
60
70
Capacity - GW



WWSIS: April week: ~30% RE



WWSIS: July week: ~10% RE

Wind seasonality, Great Plains

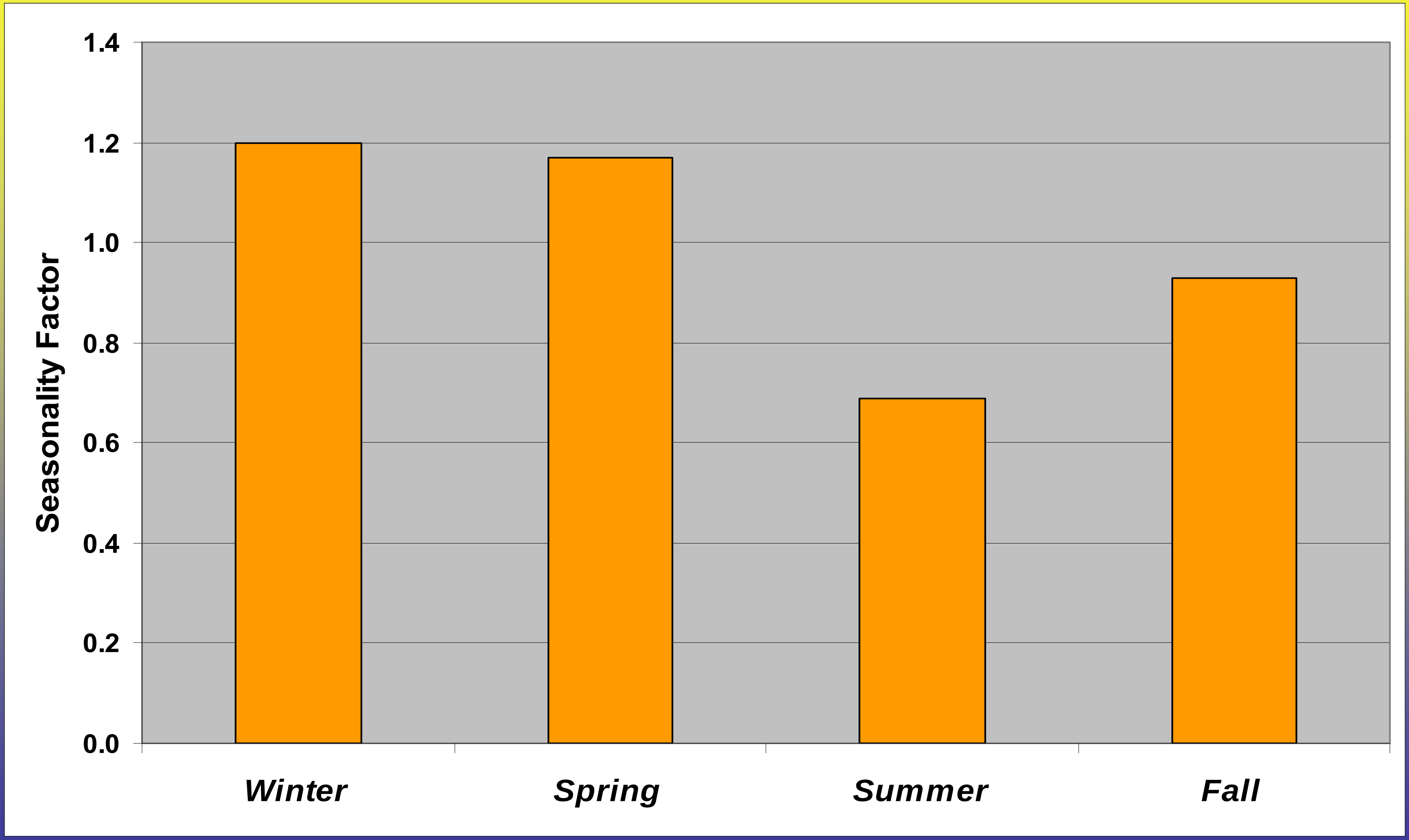
Normalized to 1.0

• 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



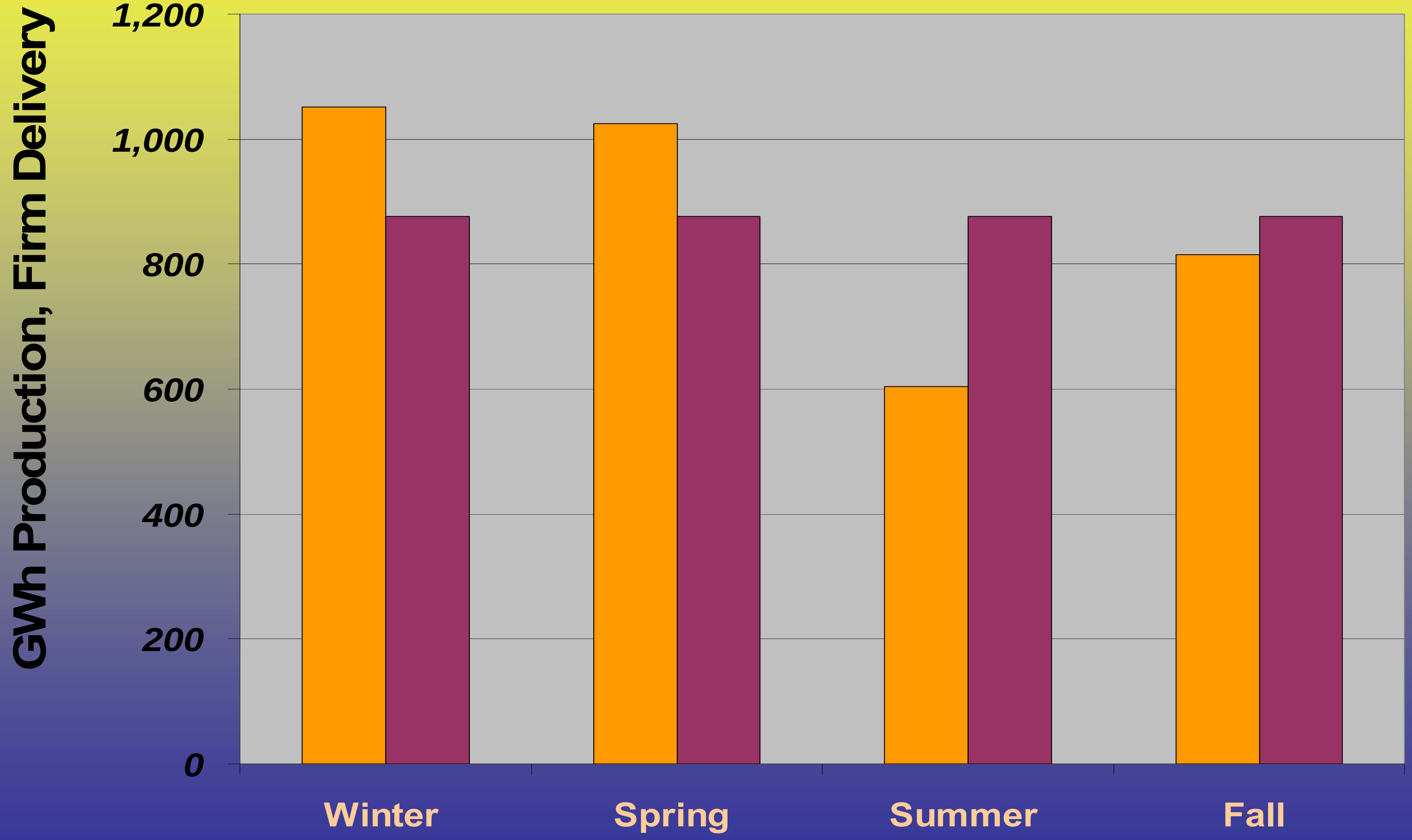
Wind Seasonality, Northern Great Plains

1,000 MW windplant: AEP = 3,500 GWh / yr

"Firm" goal = 875 GWh / season

Storage: 320 GWh per 1,000 MW wind

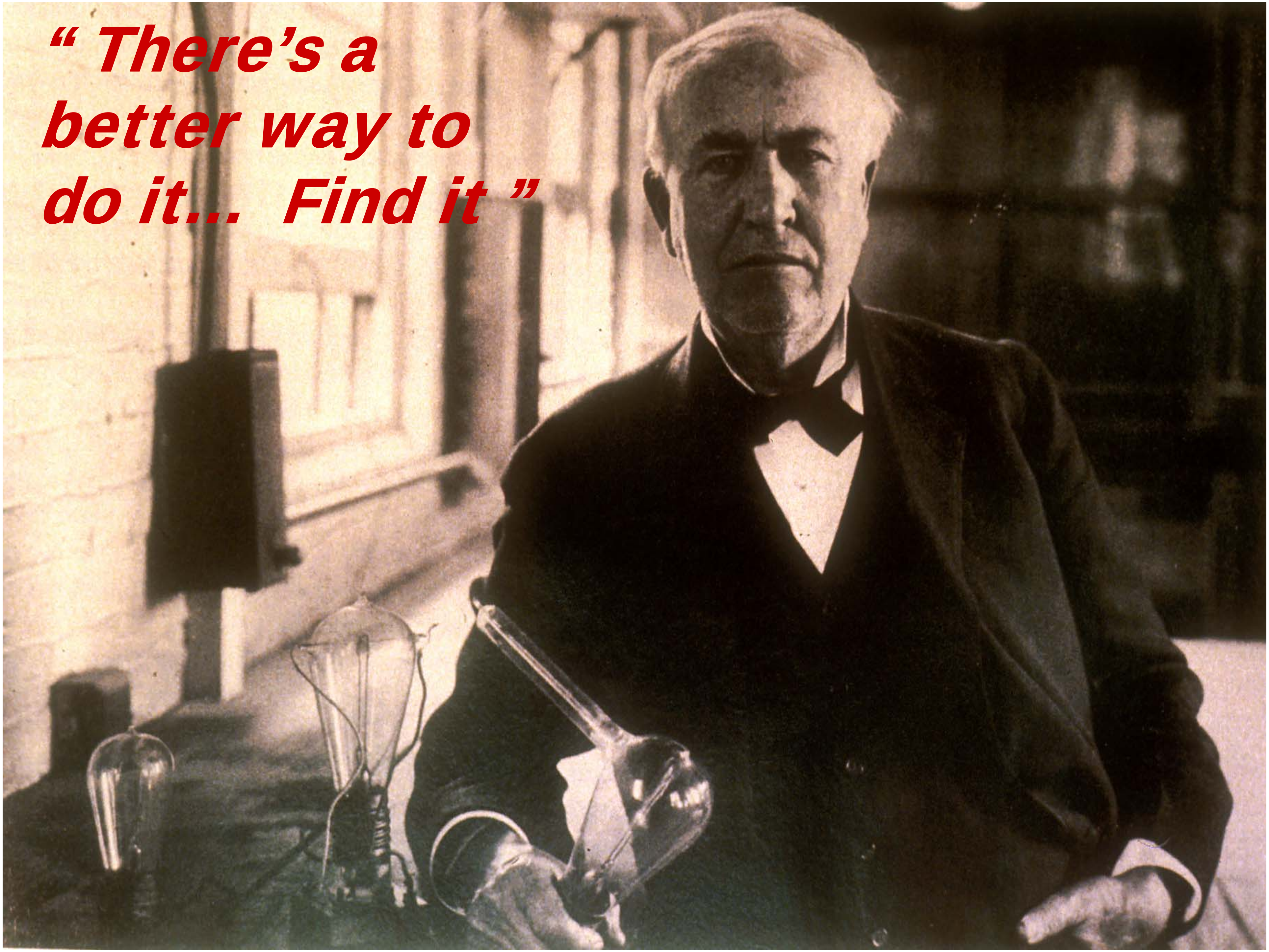
Source: NREL, D. Elliott



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**


" There's a
better way to
do it… Find it "

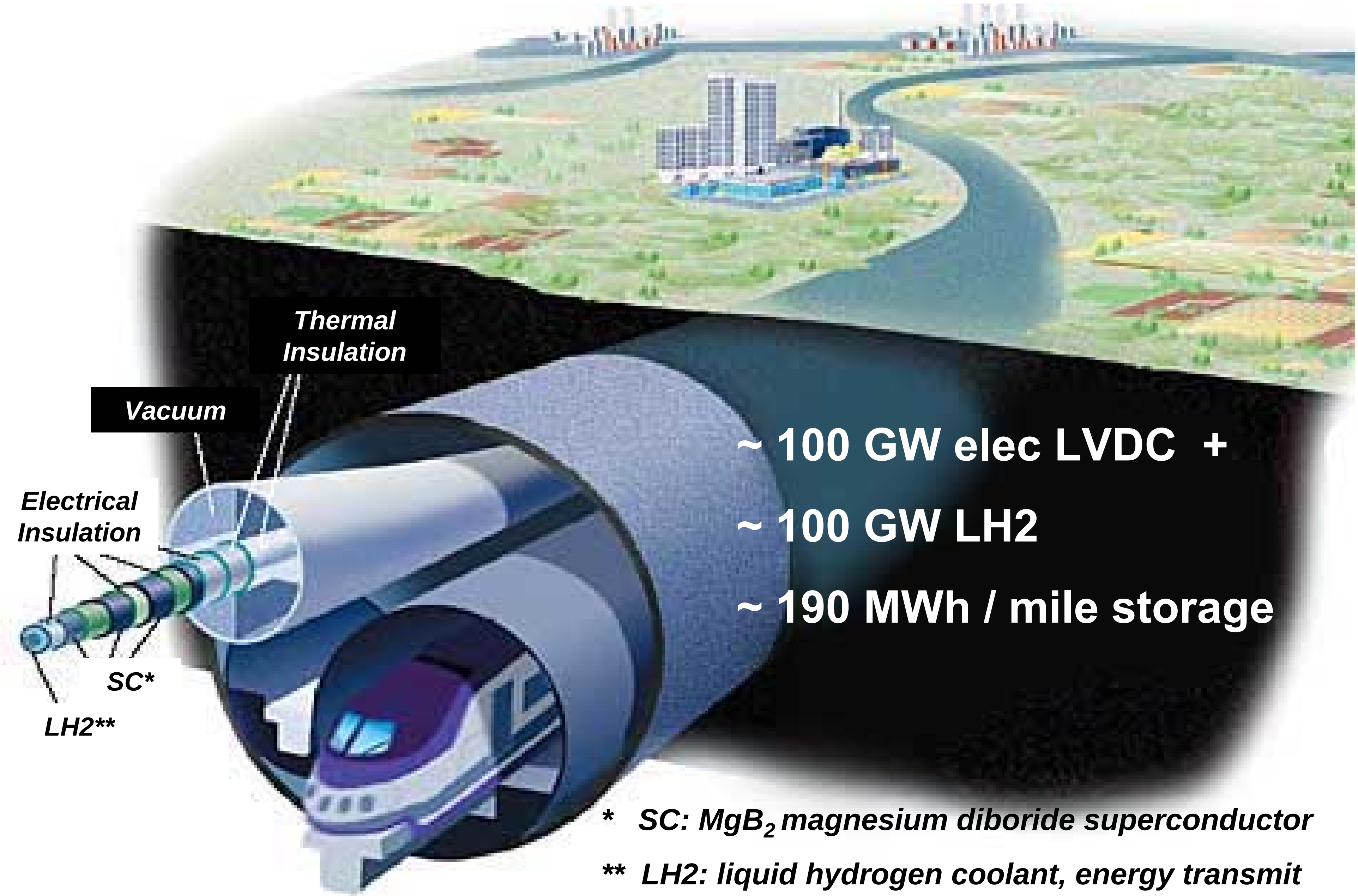
Why Hydrogen, Ammonia ?

- **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 f**uel, other
- Integration
  - Continental energy system
  - Elec grid quality

Annual Fresh Water for Energy

- ***USA today***
- ***All energy***

- **17,000 billion liters**
  - **"Withdrawn"**
  - **"Consumed"**
  - **Include all NG "fracking" ?**
- **If all via GH2 + NH3 fuels, required feedstock:**
  - **Dissociated, disintegrated: $H_2O \rightarrow H_2 + O_2$**
  - **900 billion liters**

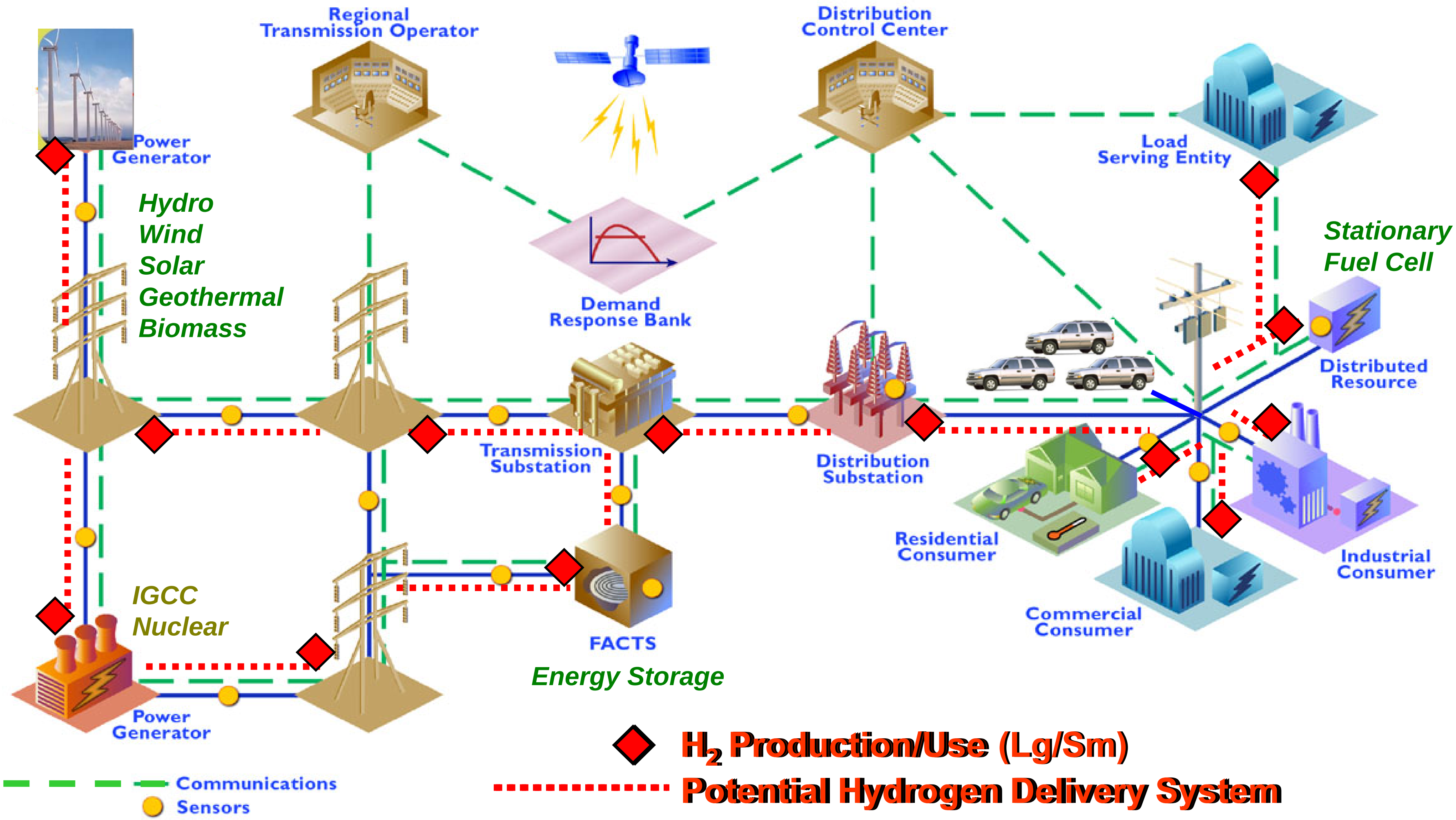


* *SC: MgB_2 magnesium diboride superconductor*

** *LH2: liquid hydrogen coolant, energy transmit*

Continental Supergrid – EPRI concept "Energy Pipeline"

Energy System *of the Future*



Frank Novachek, Director Corporate Planning

Xcel Energy

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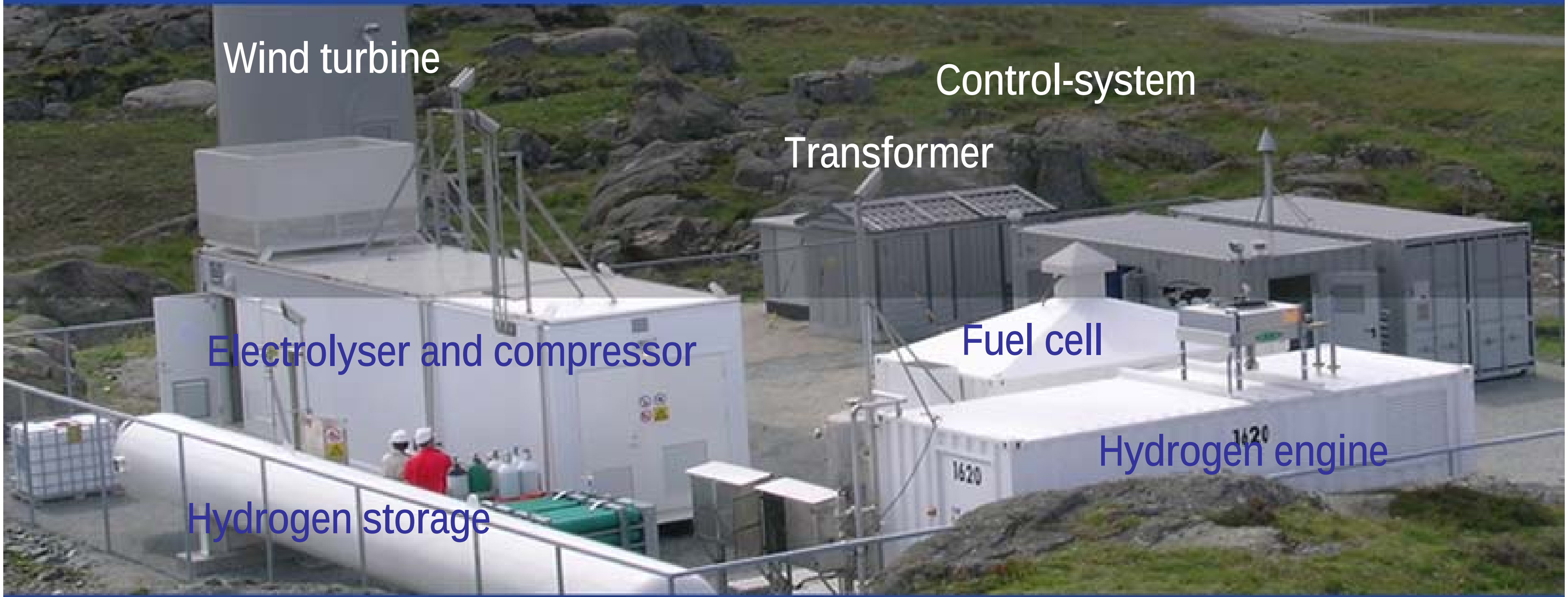
EPRI

Utsira Island, Norway

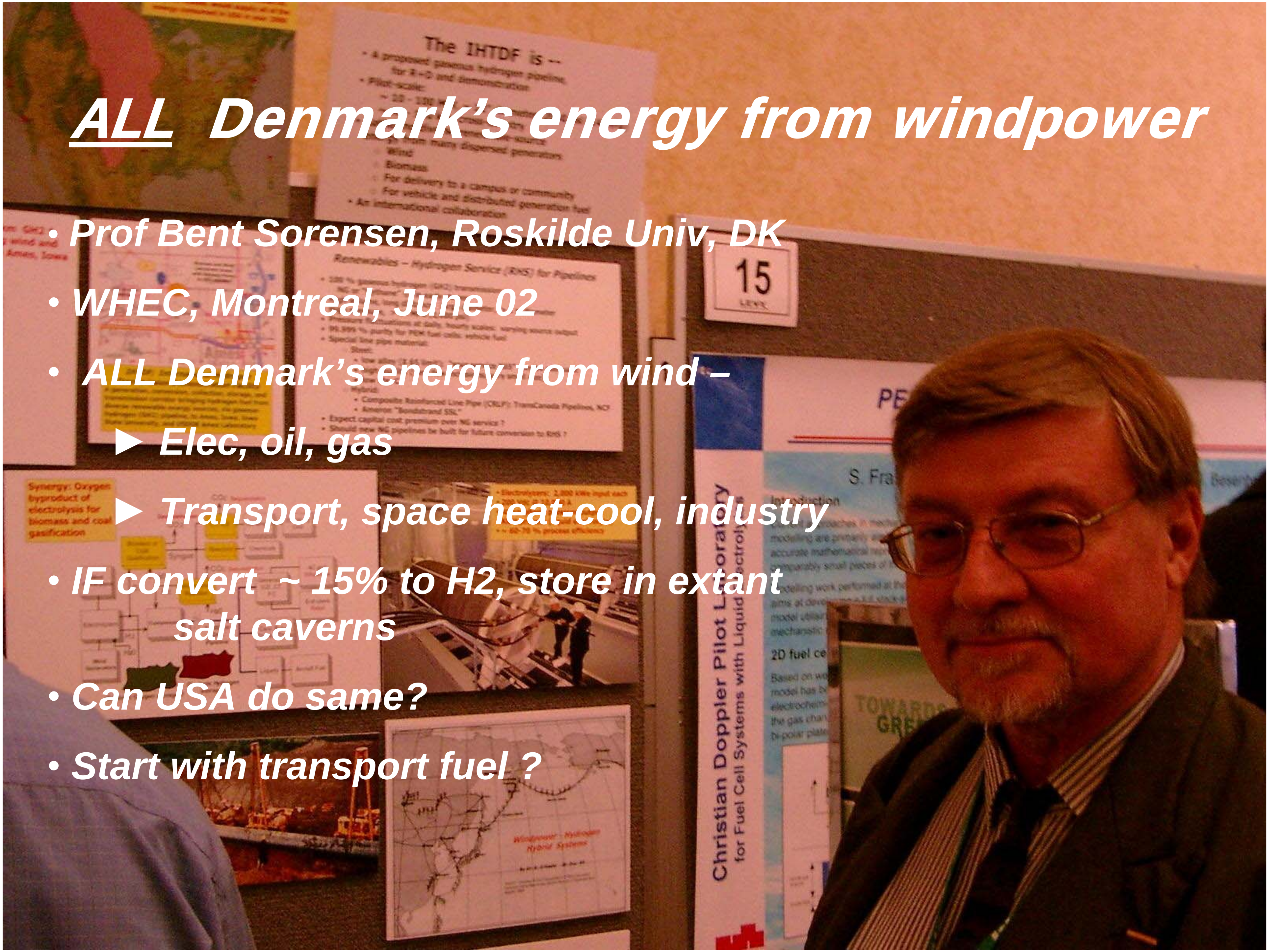
The wind – hydrogen plant at Utsira

A vision becoming reality



HYDRO

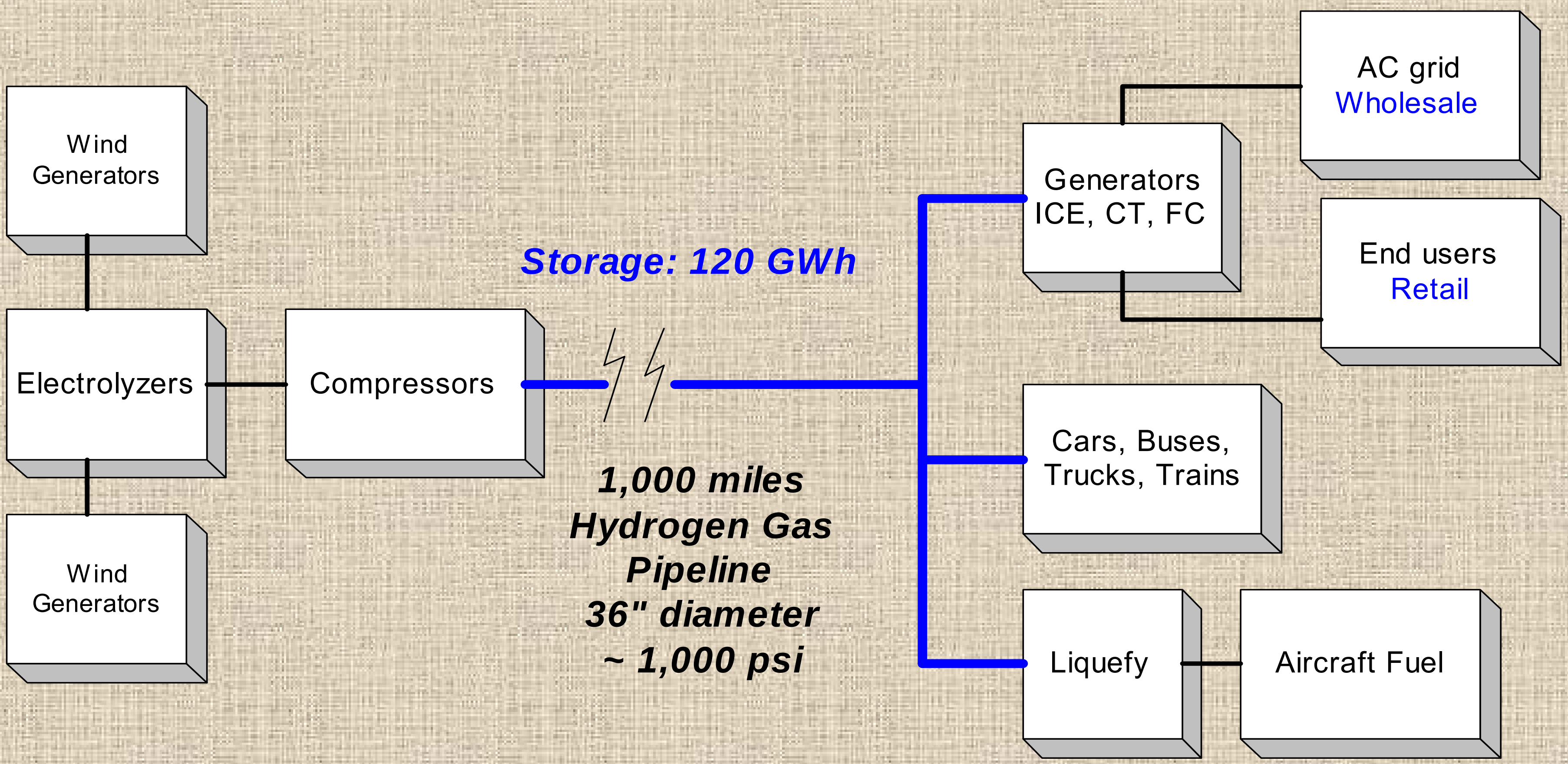
<u>ALL</u> Denmark's energy from windpower

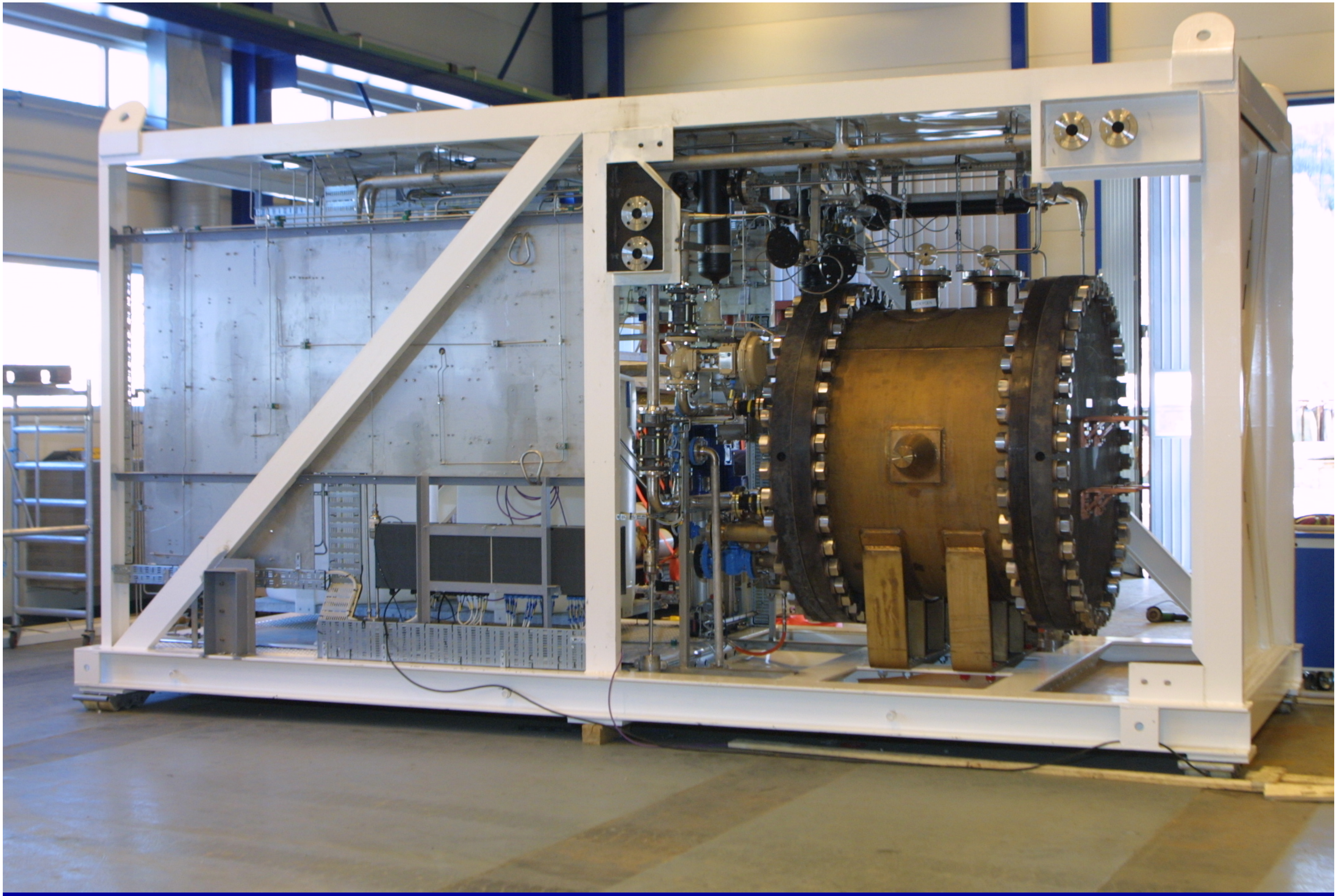


- *Prof Bent Sorensen, Roskilde Univ, DK*
- *WHEC, Montreal, June 02*
- *ALL Denmark's energy from wind –*
  - ► *Elec, oil, gas*
  - ► *Transport, space heat-cool, industry*
- *IF convert ~ 15% to H2, store in extant salt caverns*
- *Can USA do same?*
- *Start with transport fuel ?*

Hydrogen Transmission Scenario

- *Low-pressure electrolyzers*
- *"Pack" pipeline: ~ 120 GWh*

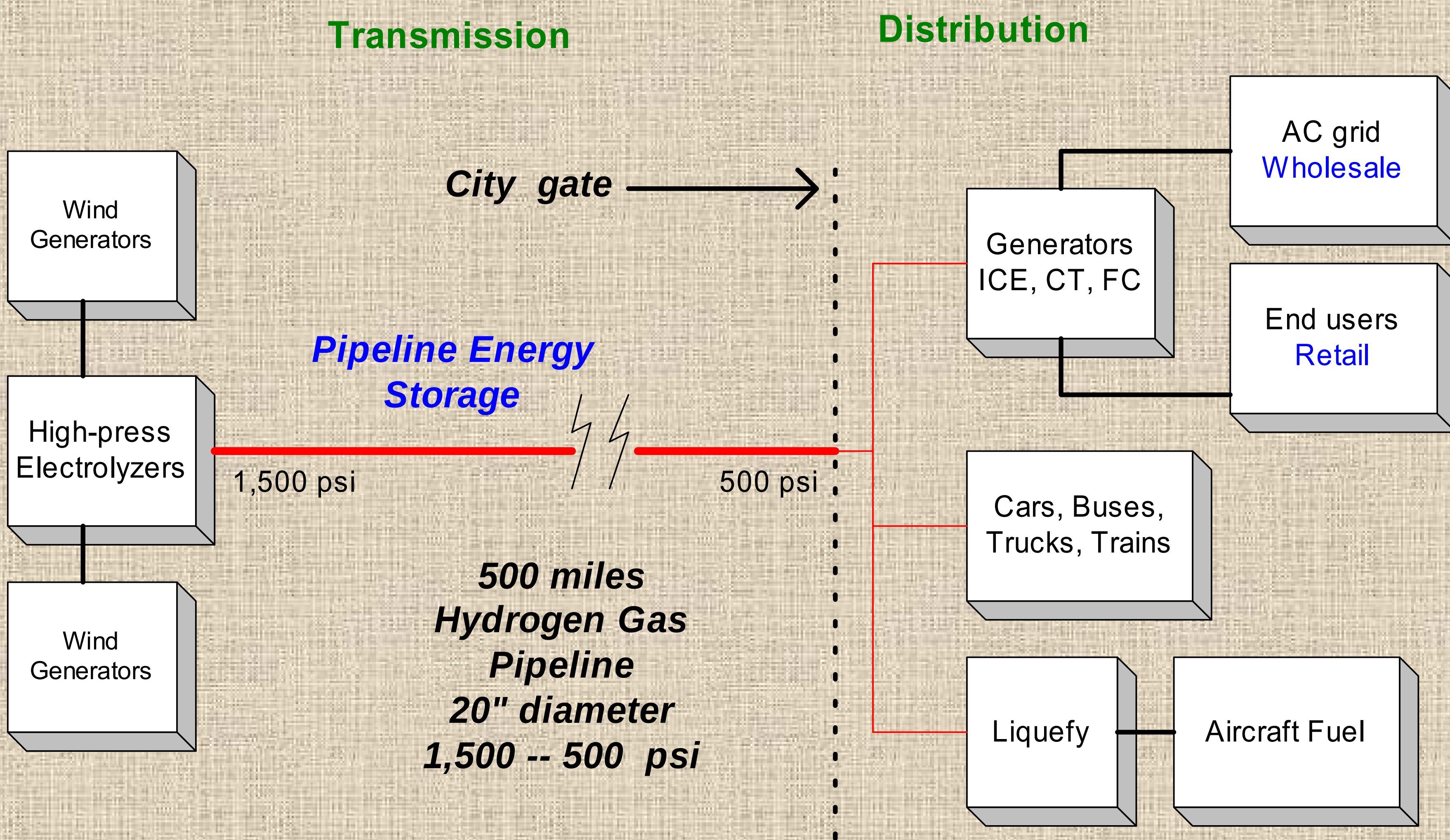


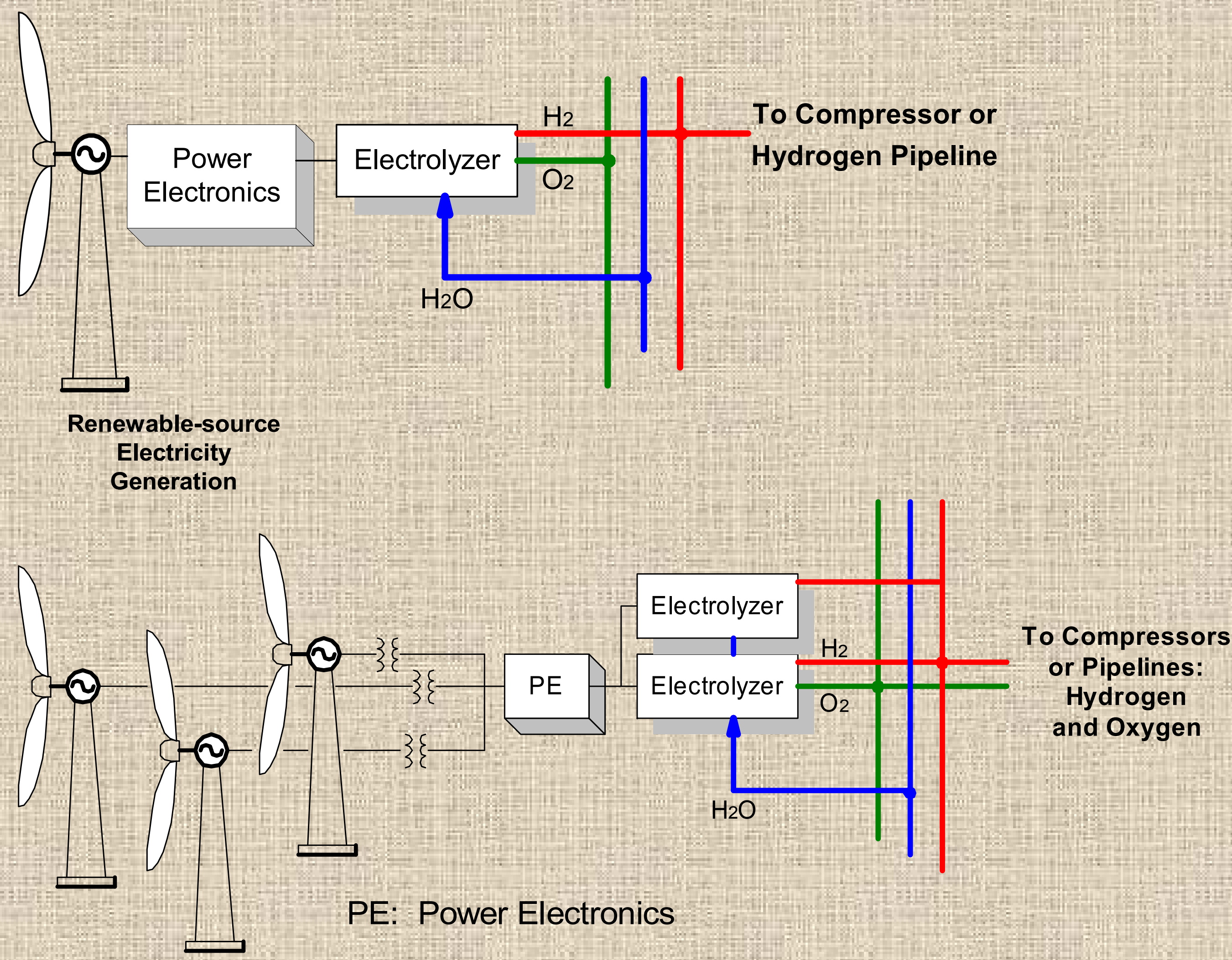


Norsk Hydro electrolyzer, KOH type

560 kW input, 130 Nm3 / hour at 450 psi (30 bar)

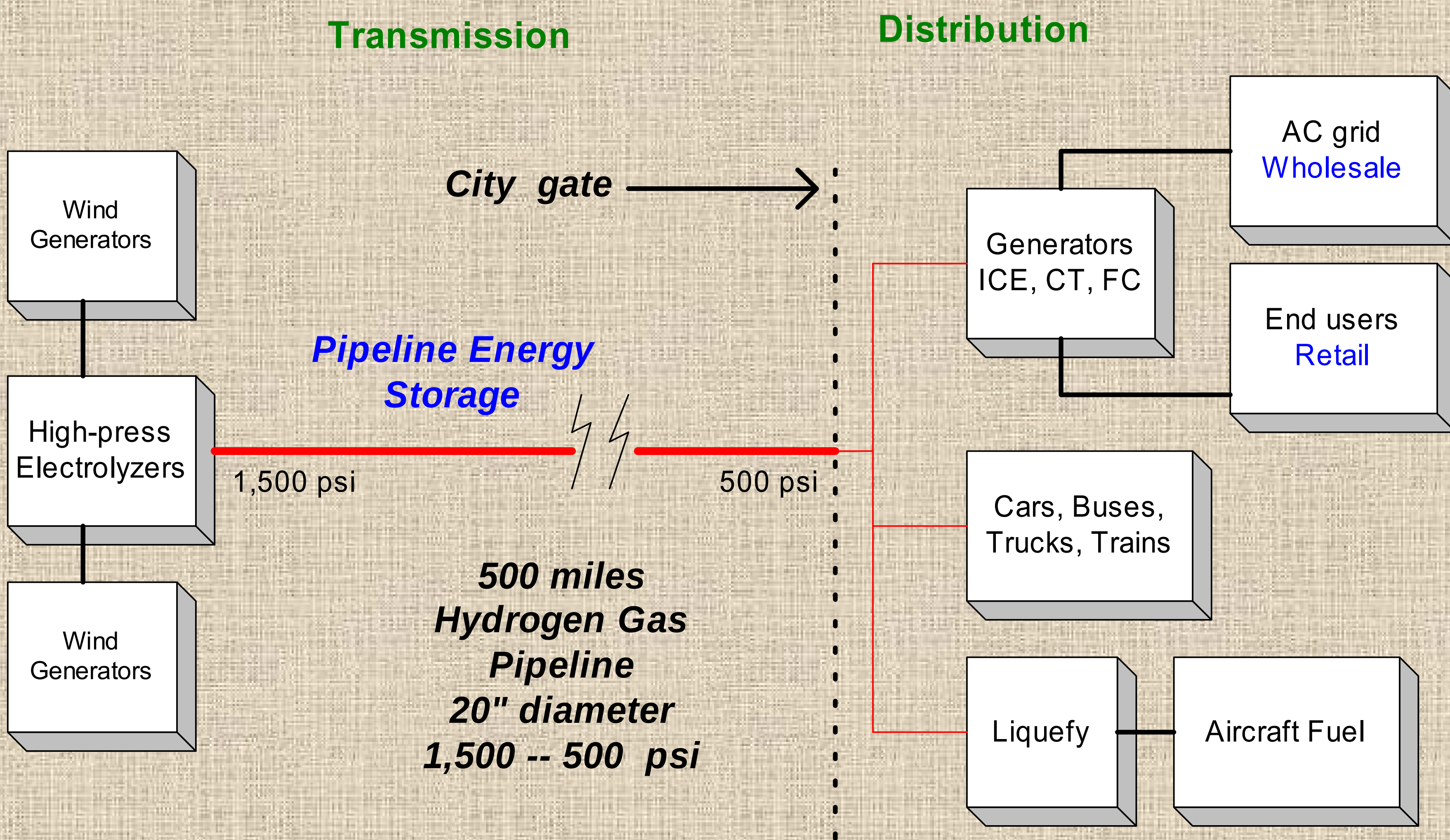
Compressorless system: No geologic storage





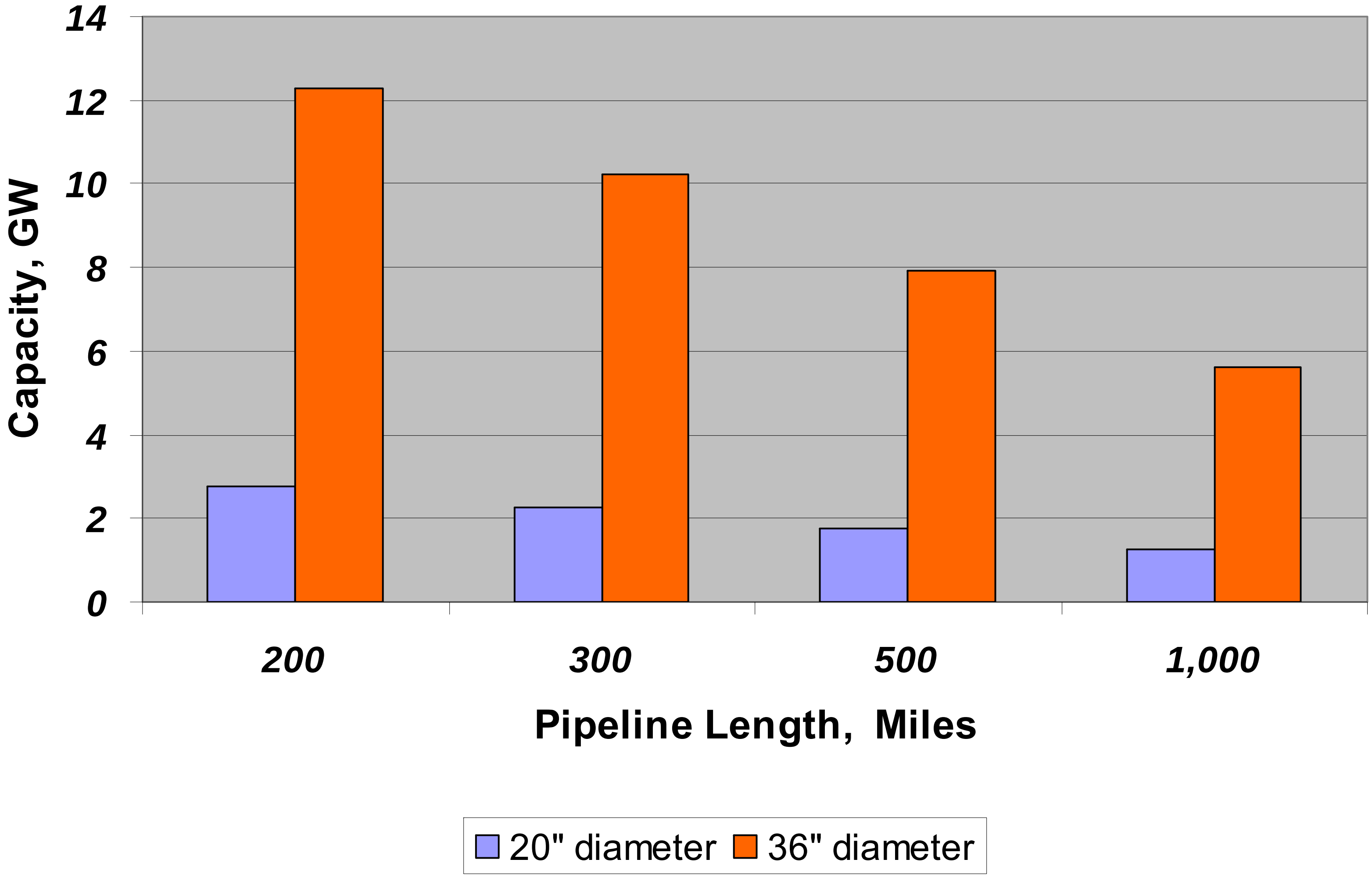
Topology Options: H_2 and O_2 Production and Gathering from Renewable Energy Generation

Compressorless system: No geologic storage

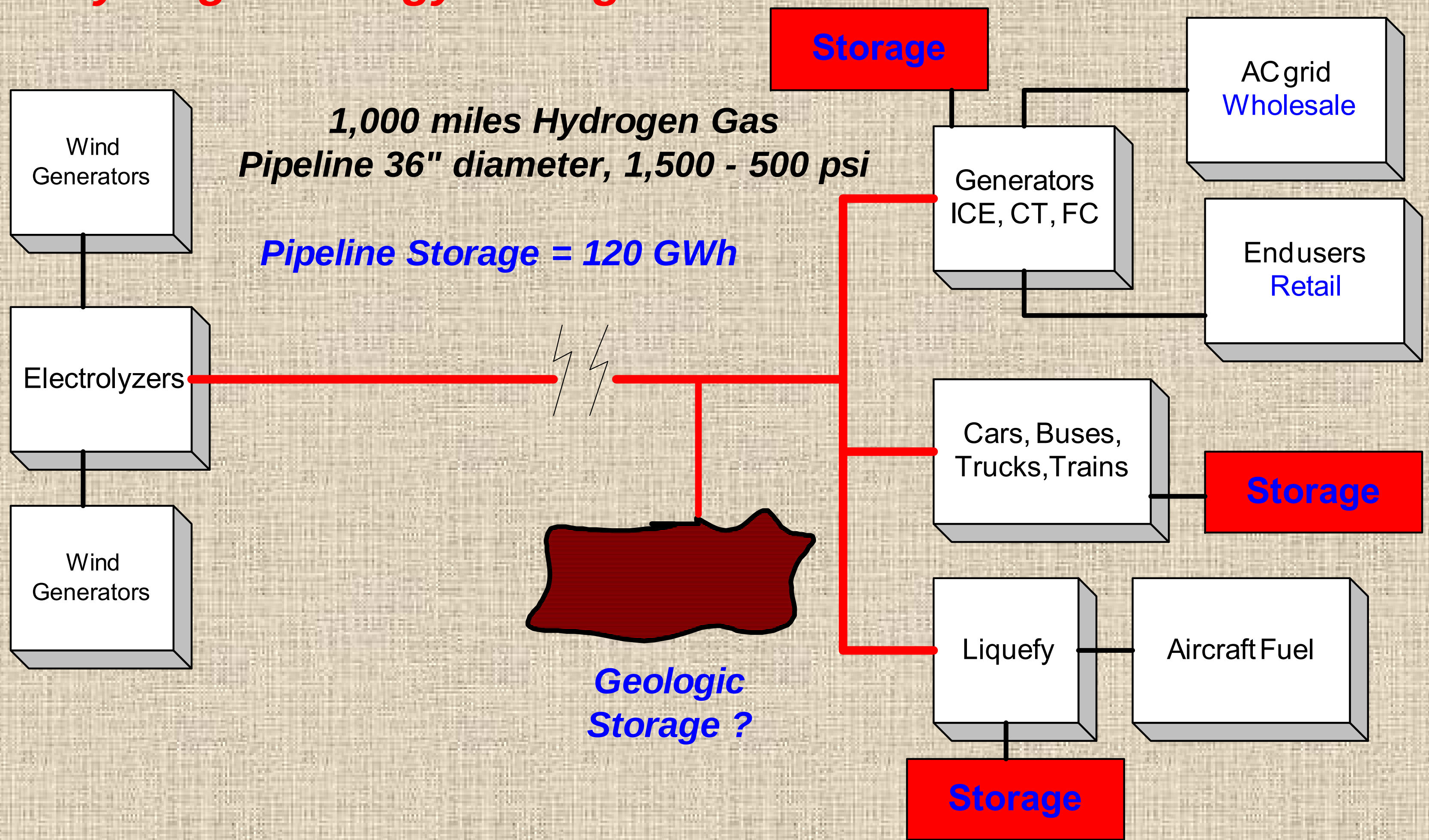


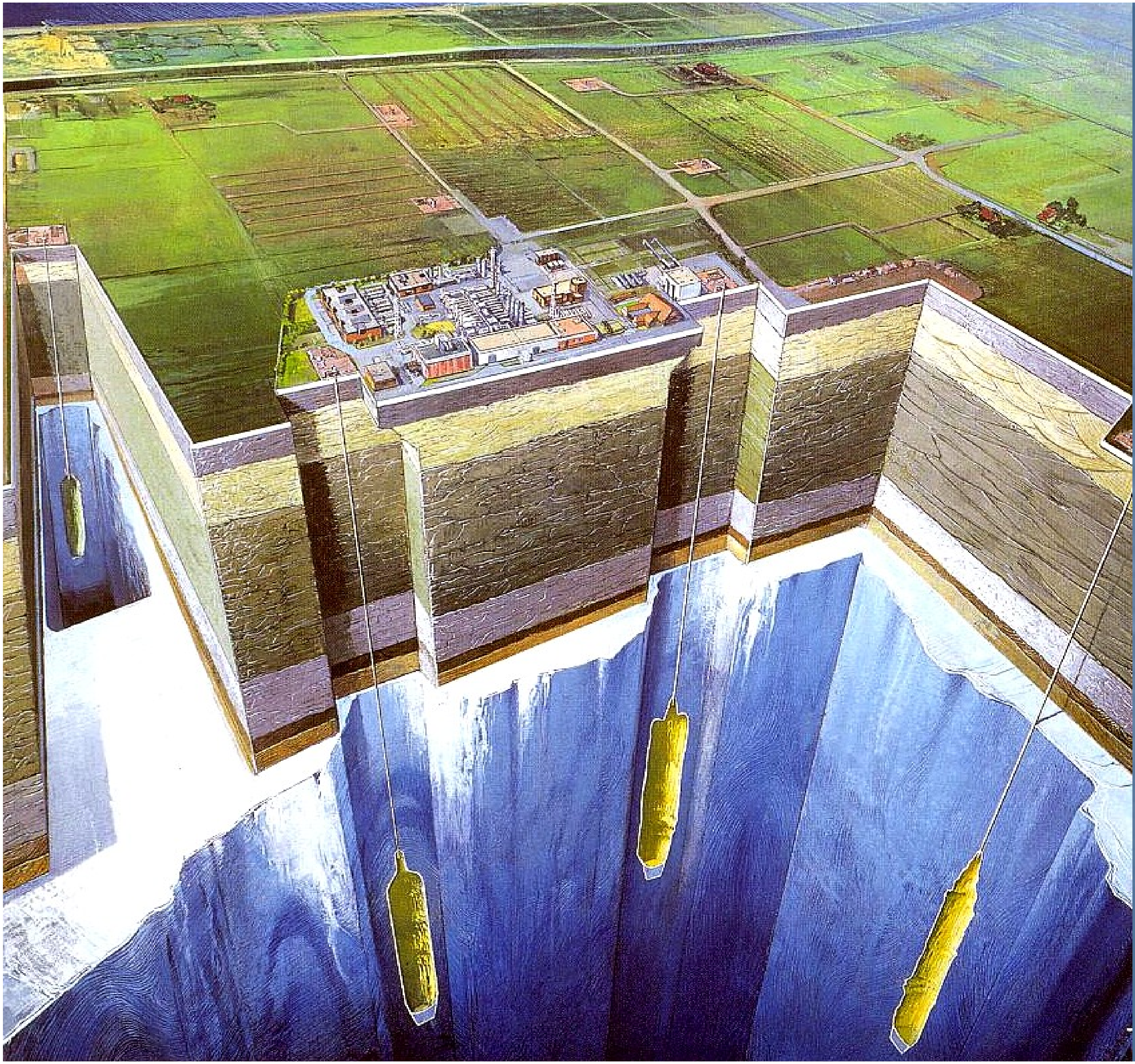
Compressorless 20”, 36” GH2 Pipeline Capacity

1,500 psi IN / 500 psi OUT



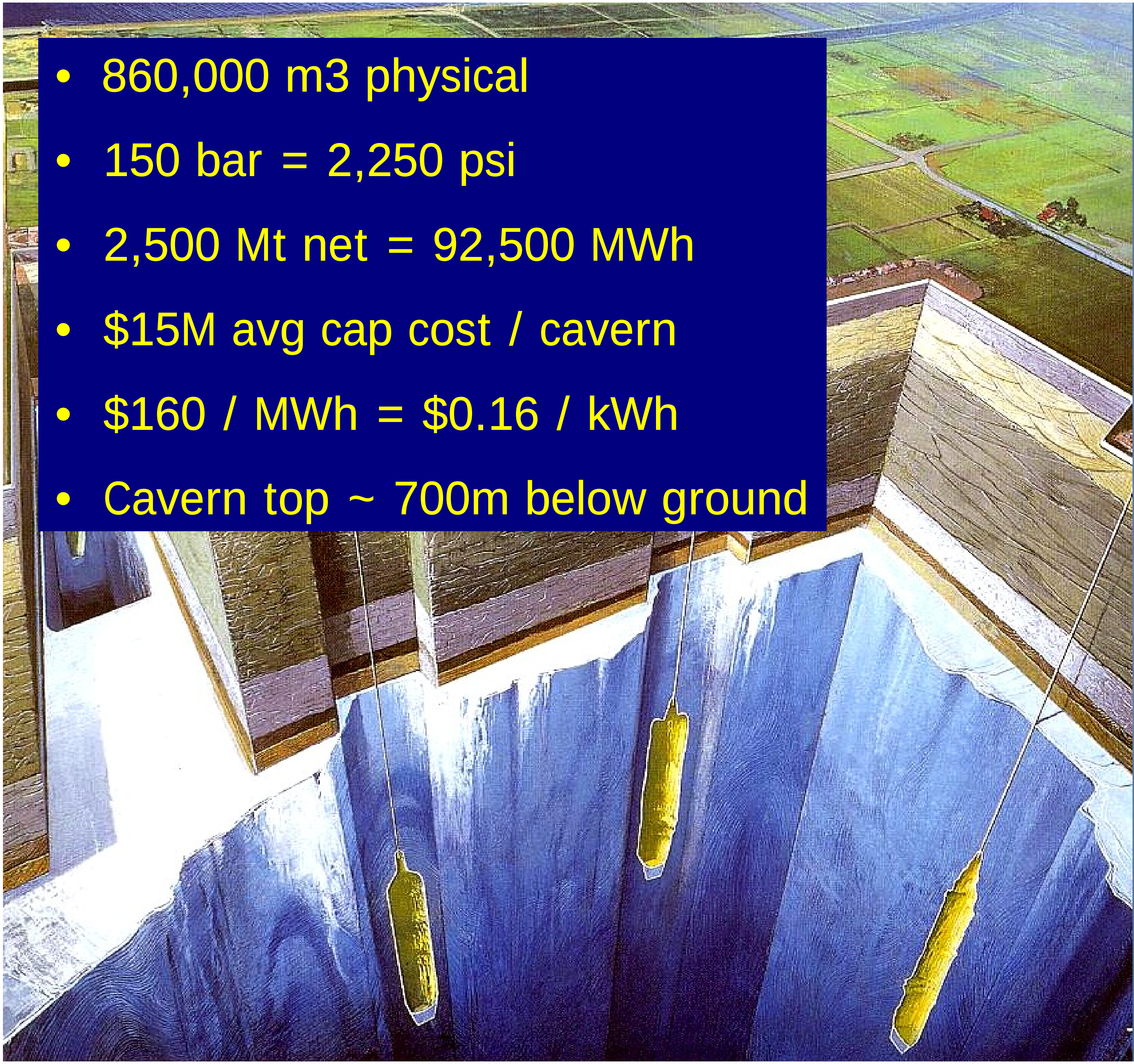
Hydrogen Energy Storage





Domal Salt Storage Caverns

PB ESS



- 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

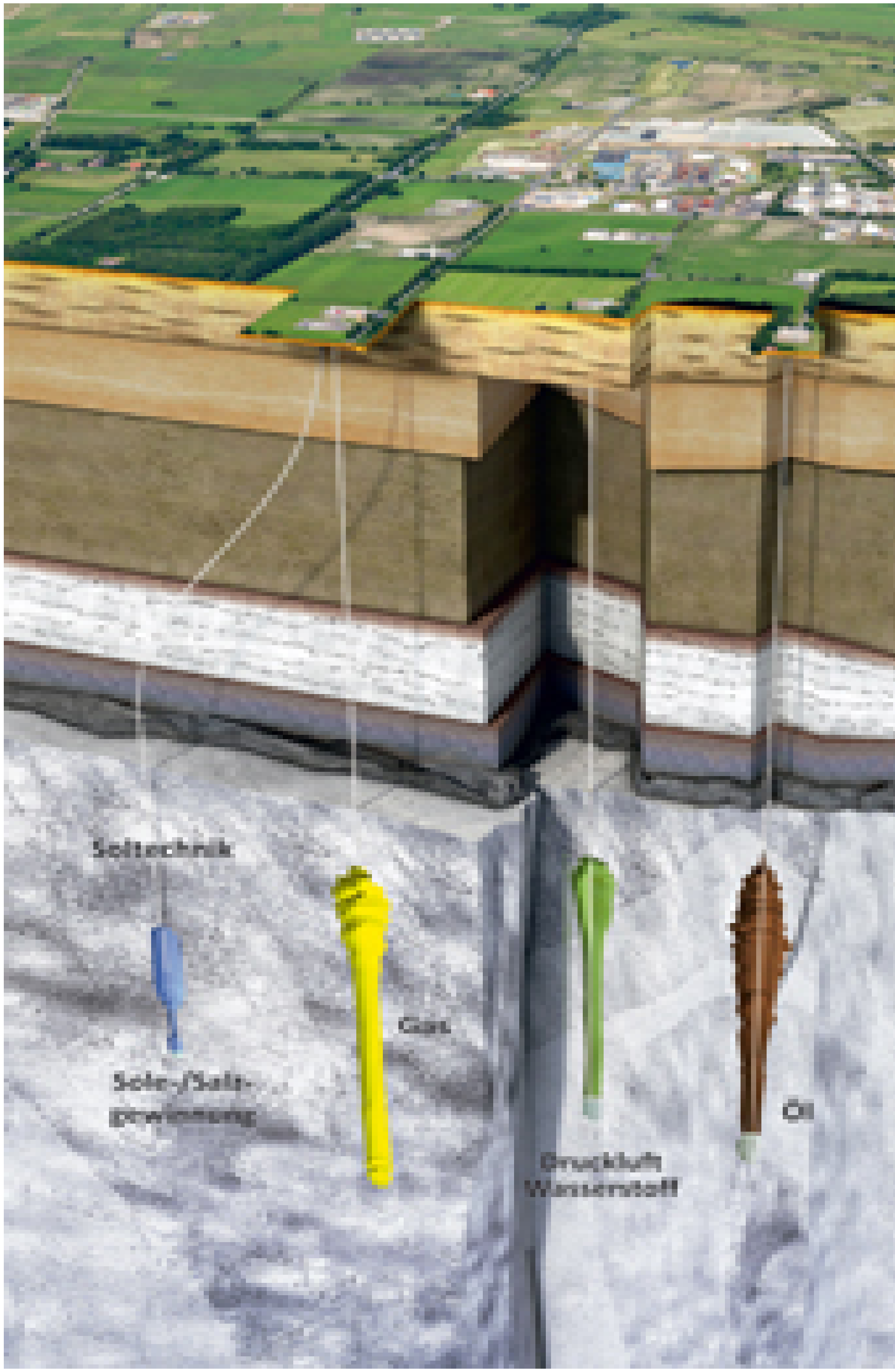
Domal Salt Storage Caverns

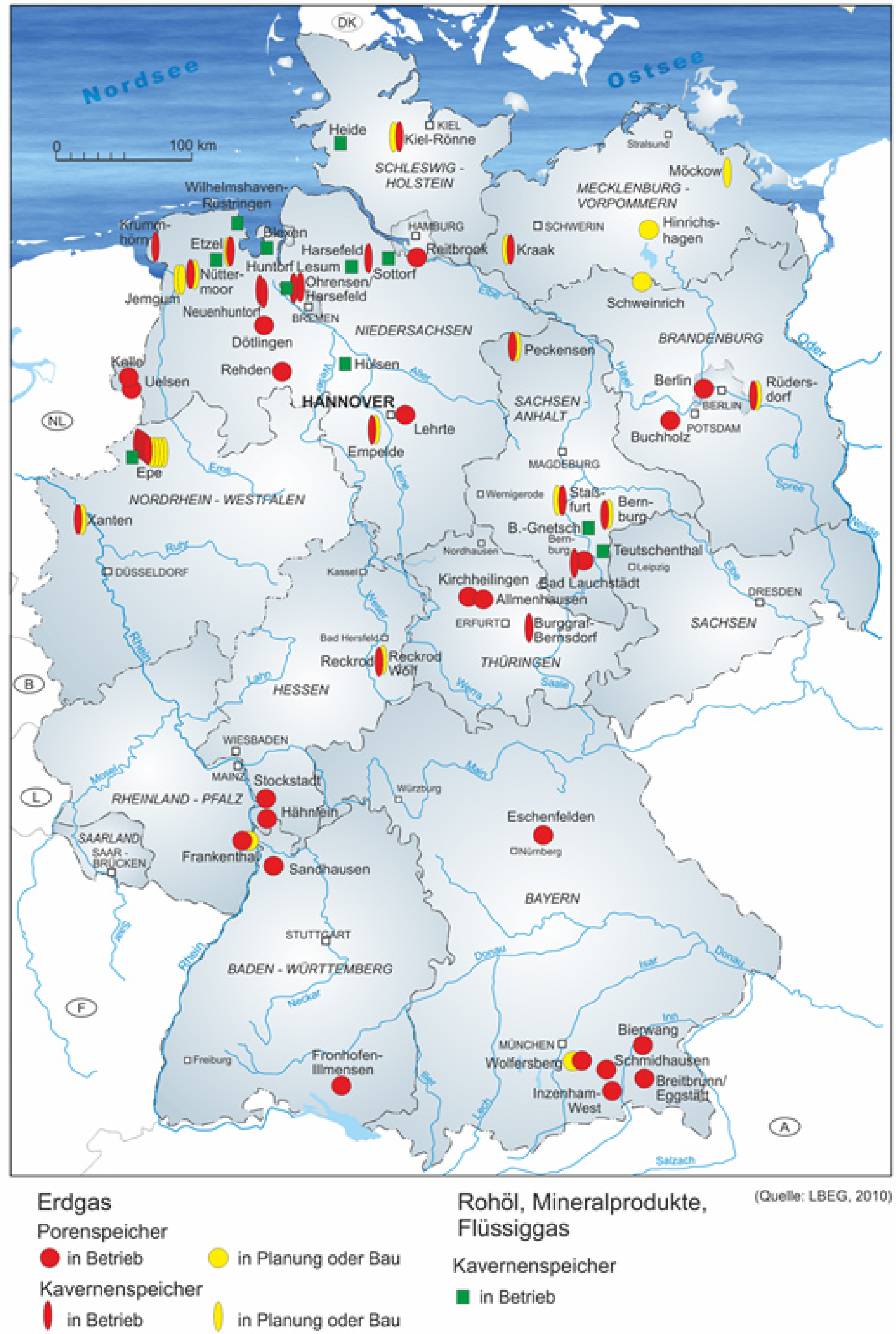
Texas

“Clemens Terminal” Conoco Phillips 20 years

Praxair ‘07

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


Soltechnik
Gas
Druckluft
Wasserstoff
Öl


Nordsee
Ostsee
DK
NL
B
L
F
A
0
100 km
SCHLESWIG - HOLSTEIN
MECKLENBURG - VORPOMMERN
NIEDERSACHSEN
BRANDENBURG
SACHSEN - ANHALT
NORDRHEIN - WESTFALEN
THÜRINGEN
SACHSEN
HESSEN
RHEINLAND - PFALZ
SAARLAND
BADEN - WÜRTTEMBERG
BAYERN
HANNOVER
Heide
Kiel-Rönne
KIEL
Stralsund
Möckow
Wilhelmshaven-Rüstringen
Krummhörn
Etzel
Blexen
Nüttermoor
Huntorf
Lesum
Harsefeld
Sottorf
Reitbrook
HAMBURG
SCHWERIN
Kraak
Hinrichshagen
Schweinrich
Jemgum
Neuenhuntorf
Ohrensen/Harsefeld
BREMEN
Dötlingen
Peckensen
Kalle
Uelsen
Rehden
Hülsen
Berlin
BERLIN
Rüdersdorf
Lehrte
Empelde
Buchholz
POTSDAM
Epe
MAGDEBURG
Wernigerode
Staßfurt
Bernburg
B.-Gnetsch
Teutschenthal
Xanten
Nordhausen
Leipzig
DÜSSELDORF
Kassel
Kirchheilingen
Bad Lauchstädt
Allmenhausen
DRESDEN
ERFURT
Burggraf-Bernsdorf
Bad Hersfeld
Reckrod
Reckrod Wolf
WIESBADEN
MAINZ
Stockstadt
Würzburg
Hähnlein
Eschenfelden
Frankenthal
Nürnberg
SAARBRÜCKEN
Sandhausen
STUTTGART
MÜNCHEN
Bierwang
Wolfersberg
Schmidhausen
Breitbrunn/Eggstätt
Inzenham-West
Freiburg
Fronhofen-Illmensen
Elbe
Oder
Weser
Aller
Havel
Ems
Leine
Ruhr
Rhein
Lahn
Werra
Saale
Spree
Neiße
Mosel
Main
Neckar
Donau
Isar
Inn
Iller
Lech
Salzach
(Quelle: LBEG, 2010)
Erdgas
Porenspeicher
in Betrieb
in Planung oder Bau
Kavernenspeicher
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

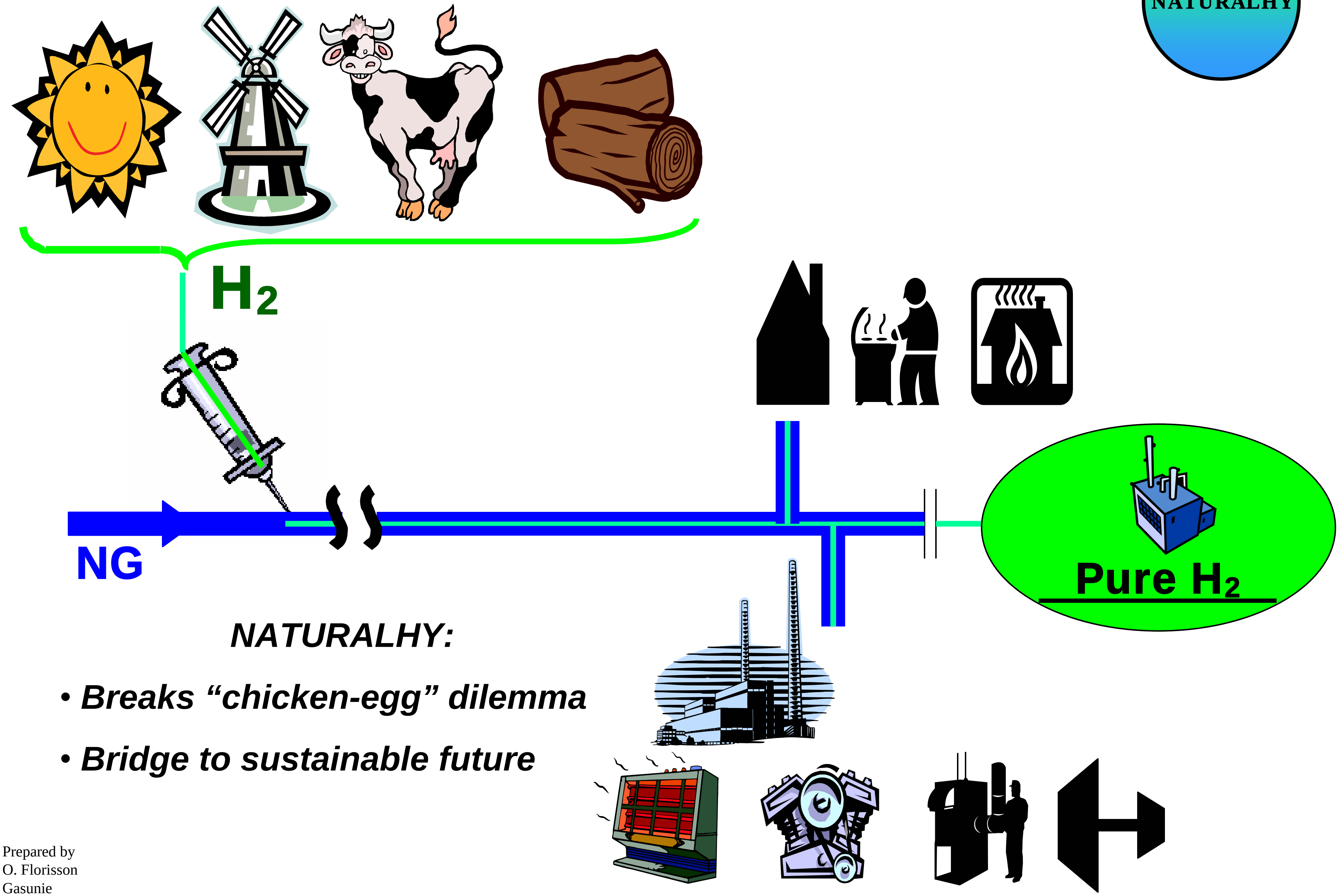
Hydrogen “sector”

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

Hydrogen - fueled
2005 Prius
ICE Hybrid

The NATURALHY approach: EC, R+D

NATURALHY



NATURALHY:

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

Prepared by
O. Florisson
Gasunie

Carmakers Commit to Hydrogen Fuel Cell Cars ?

- **9 Sept 09** "Letter of Understanding"
- Carmakers:

Daimler	Ford
GM/Opel	Honda
Hyundai/Kia	Renault
Nissan	Toyota

- Serial production **~ 2015**: "… quite significant number" of electric vehicles powered by fuel cells
- Vague; lobbying for fed FCV funds restore ?
- Will need H2 fuel: "… hydrogen infrastructure has to be built up with sufficient density …"

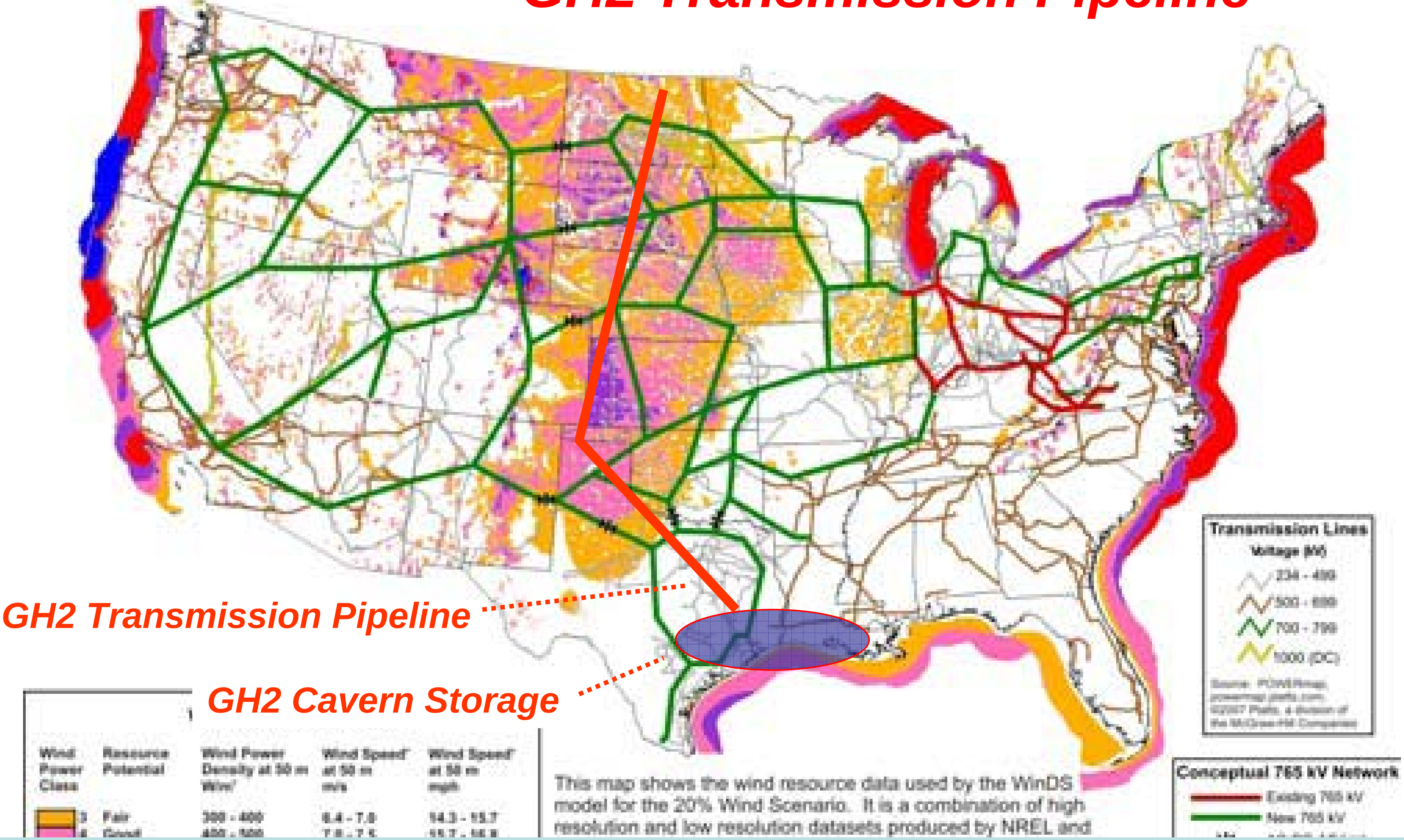
CA: 20% of "cars" hydrogen fueled by 2030

- **20% of 45M vehicles = 9M**
- **@ 78 mpg = 78 miles / kg H2**

- **12,000 miles / year = 150 kg H2 / year**

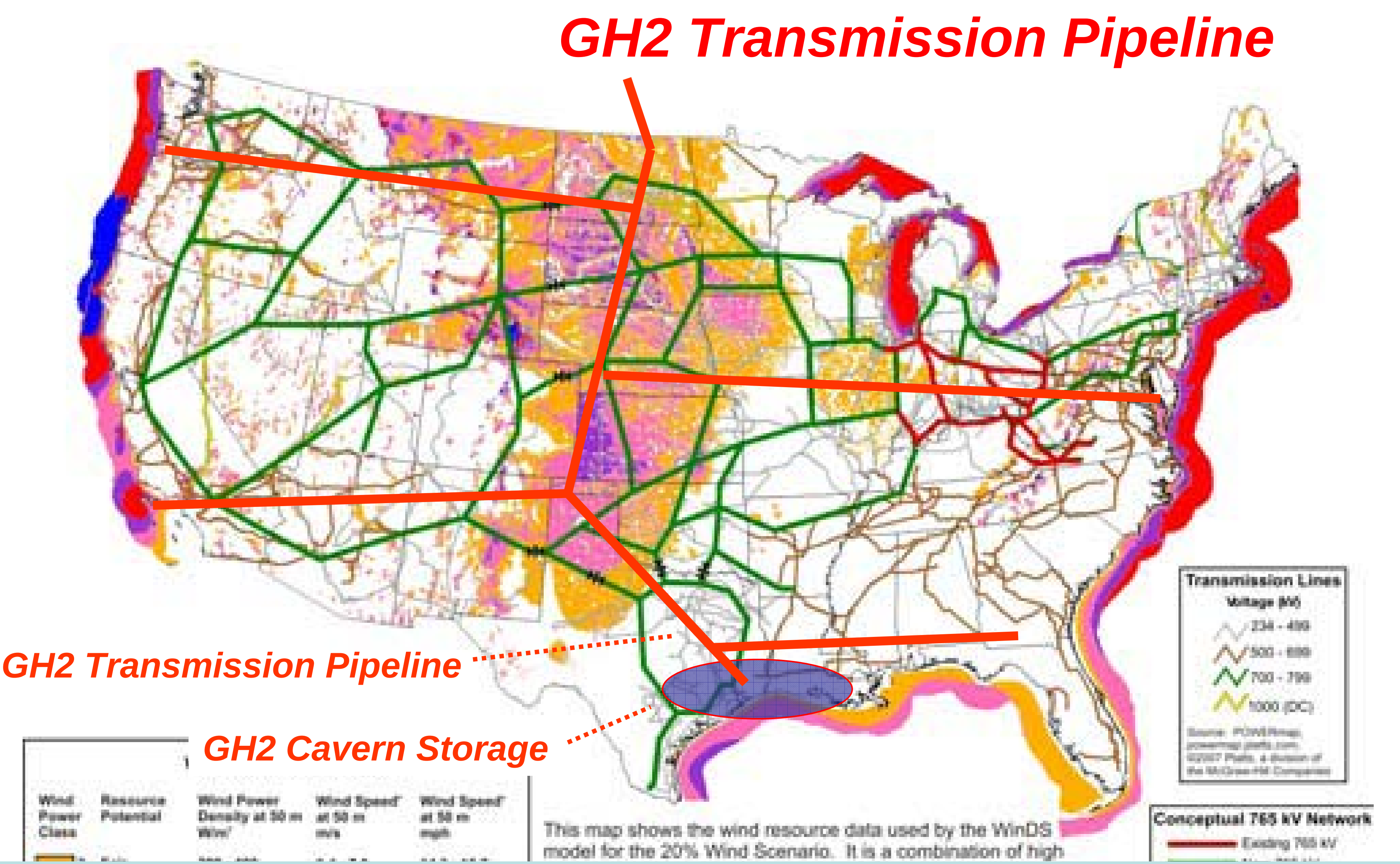
- **1,800 M kg H2 / year = 1.65 MMt H2 fuel**
- **@ 50 kWh / kg at windplant gate:**
  - **82,500 GWh / year**
  - **@ 40% CF = 23,000 MW nameplate wind**
  - **Requires 3 GH2 pipelines, 36", 500 miles long**
  - **PLUS @ 4 caverns / GW = 92 storage caverns, to firm the supply at annual scale**

GH2 Transmission Pipeline



Wind Potential ~ 10,000 GW

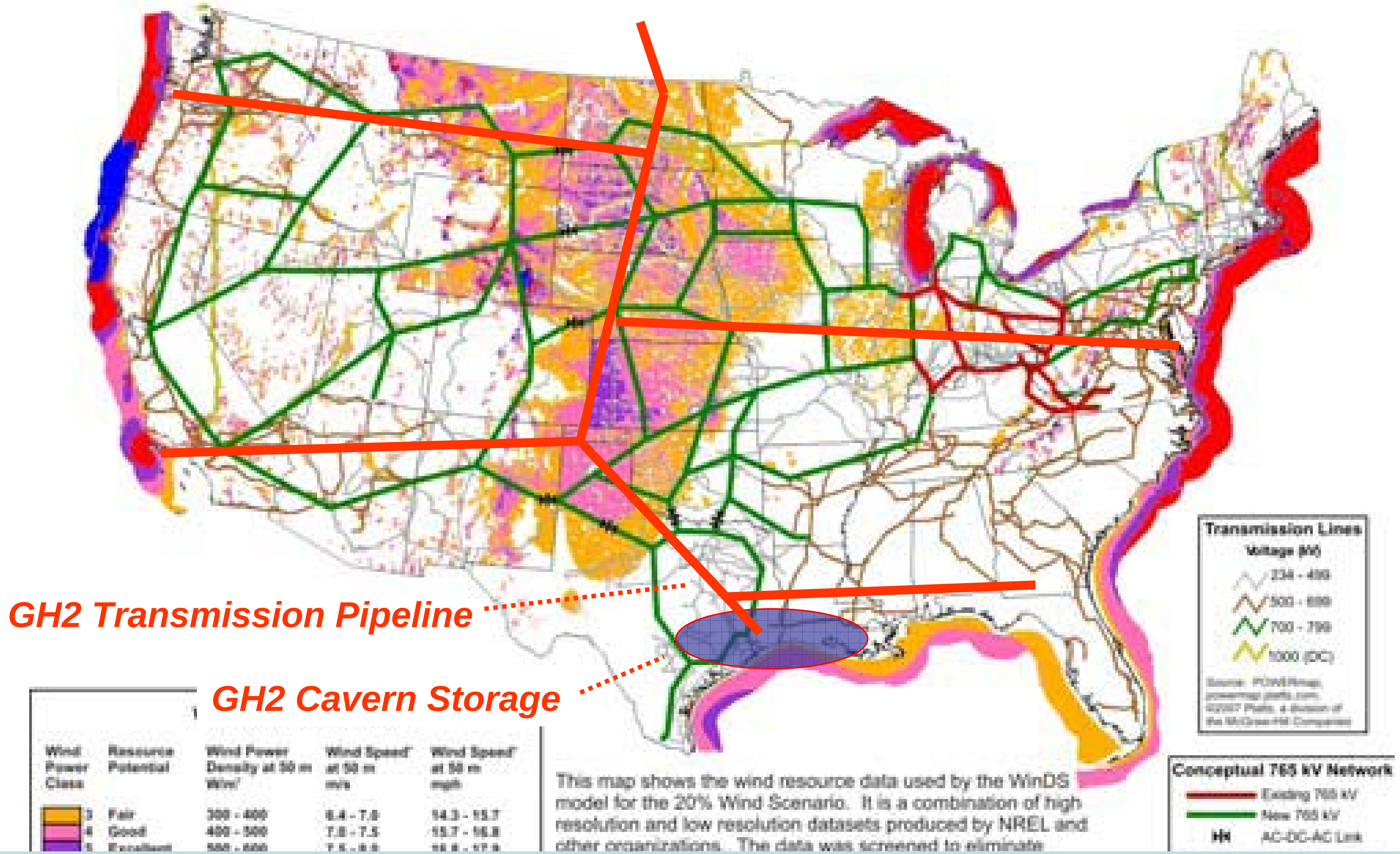
12 Great Plains states



Wind Potential ~ 10,000 GW

12 Great Plains states

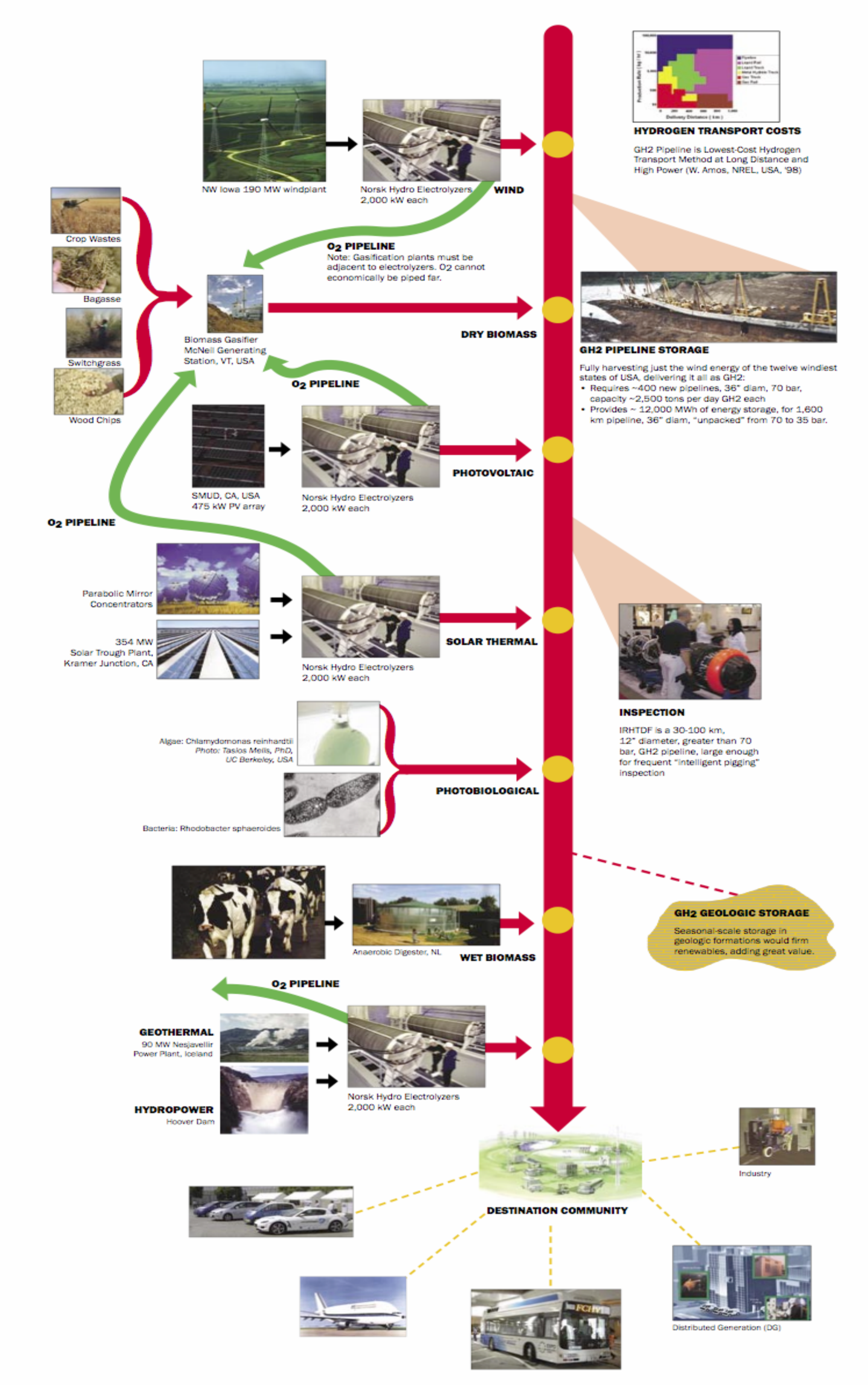
AWEA 20% Wind Electricity by 2030



Wind Potential ~ 10,000 GW

Pilot plant needed

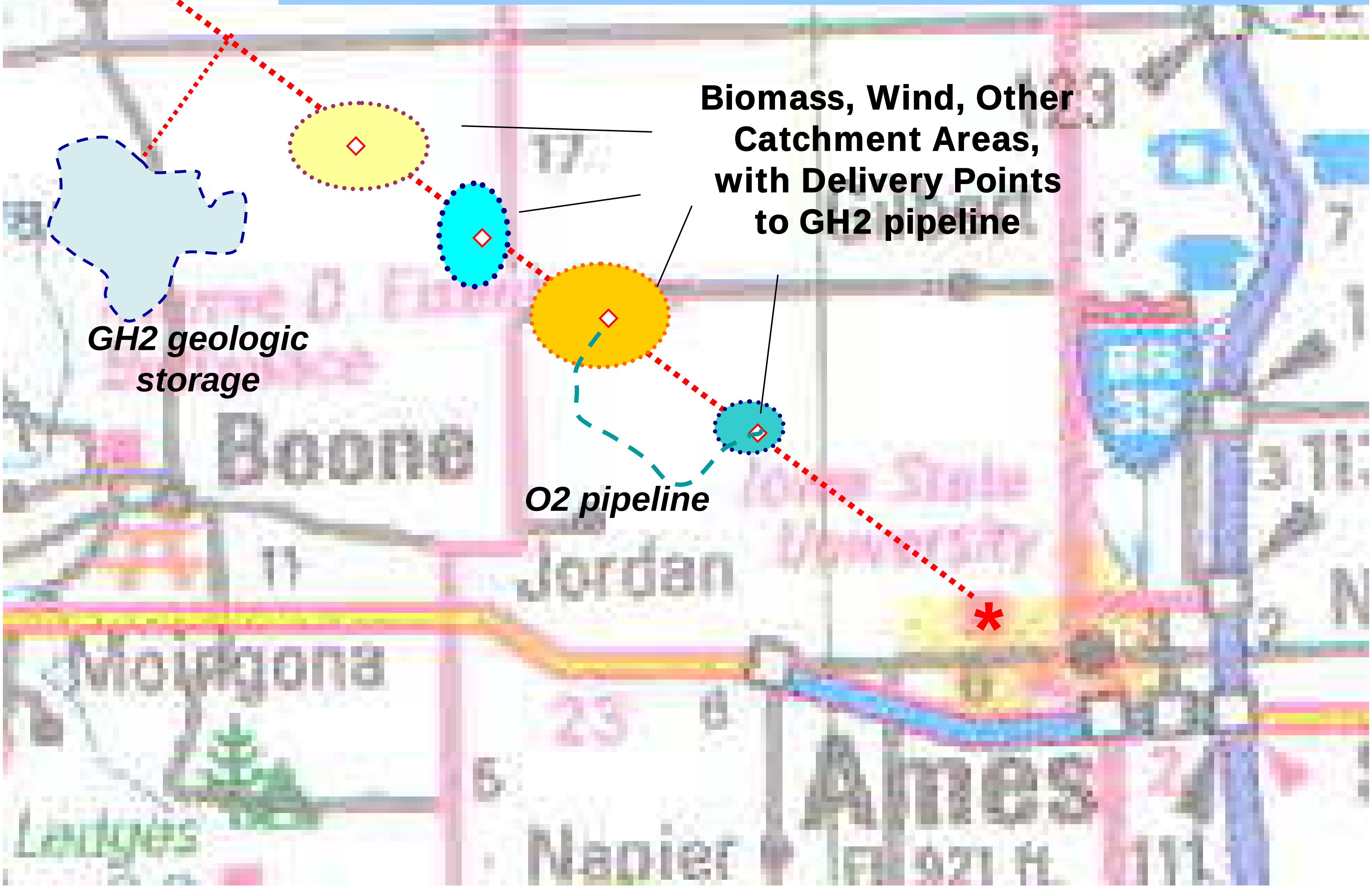
- Every major new industrial process
- Renewables-source systems
- Diverse, large-scale, stranded
- US, Japan, Canada, IPHE → " IRHTDF "

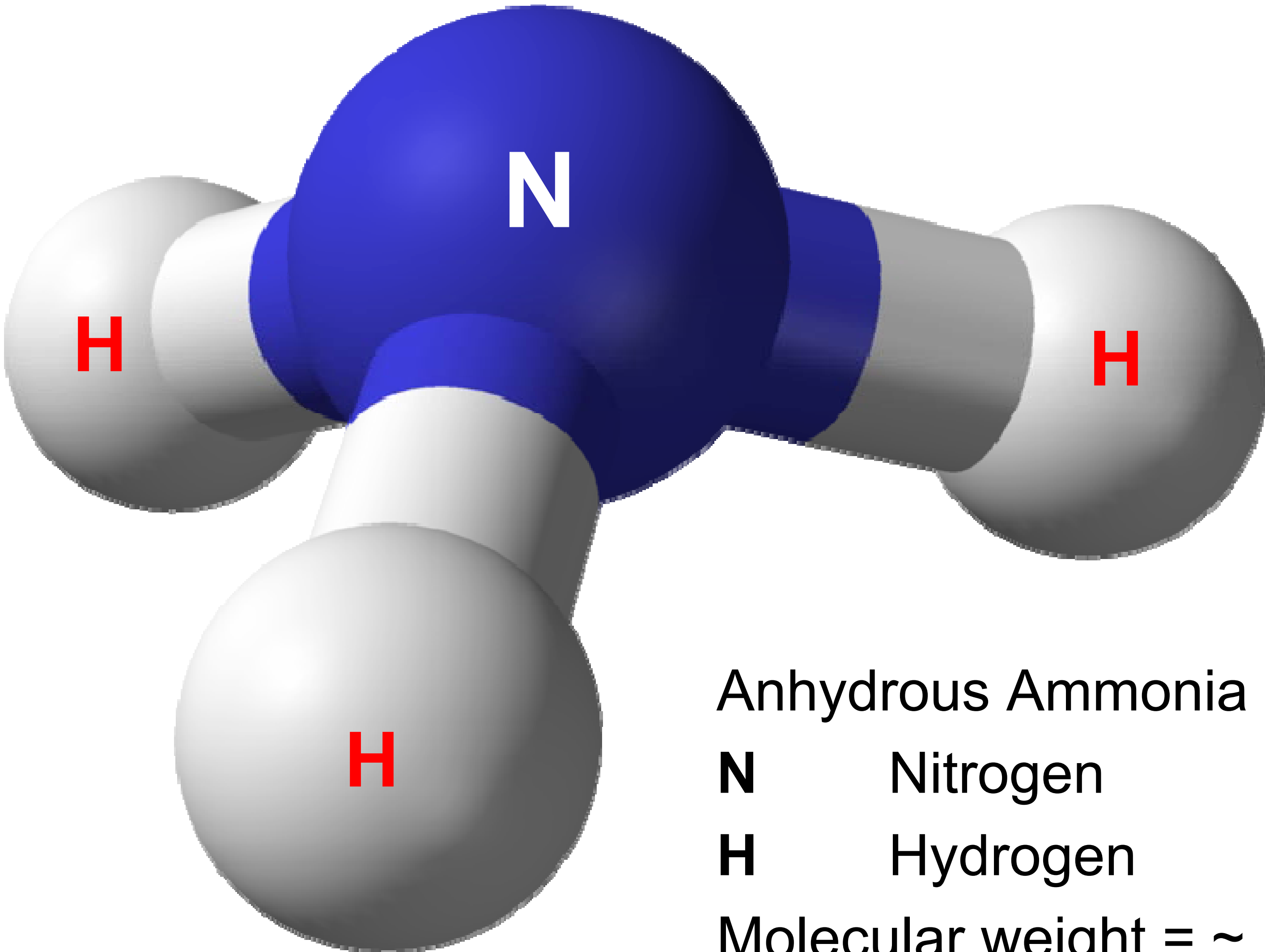


Pilot-scale Hydrogen Pipeline System: Renewables

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

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





Anhydrous Ammonia **NH_3**

N Nitrogen

H Hydrogen

Molecular weight = ~ 17

18% **H** by weight: “other hydrogen”

$NH_3 + O_2 = N_2 + H_2O$

Why Ammonia ?

Fertilizer <u>and</u> Fuel

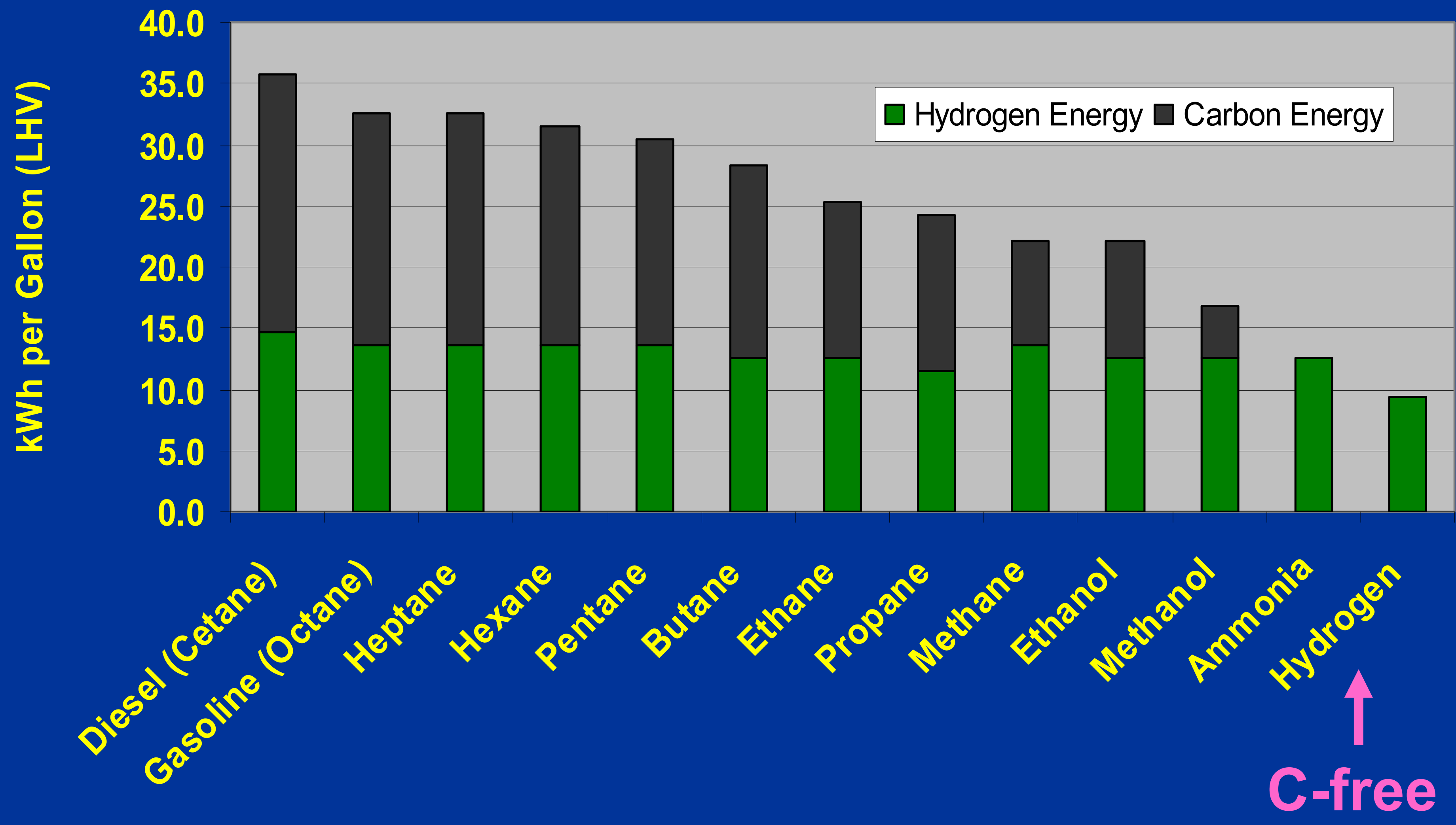
Only liquid fuel embracing:

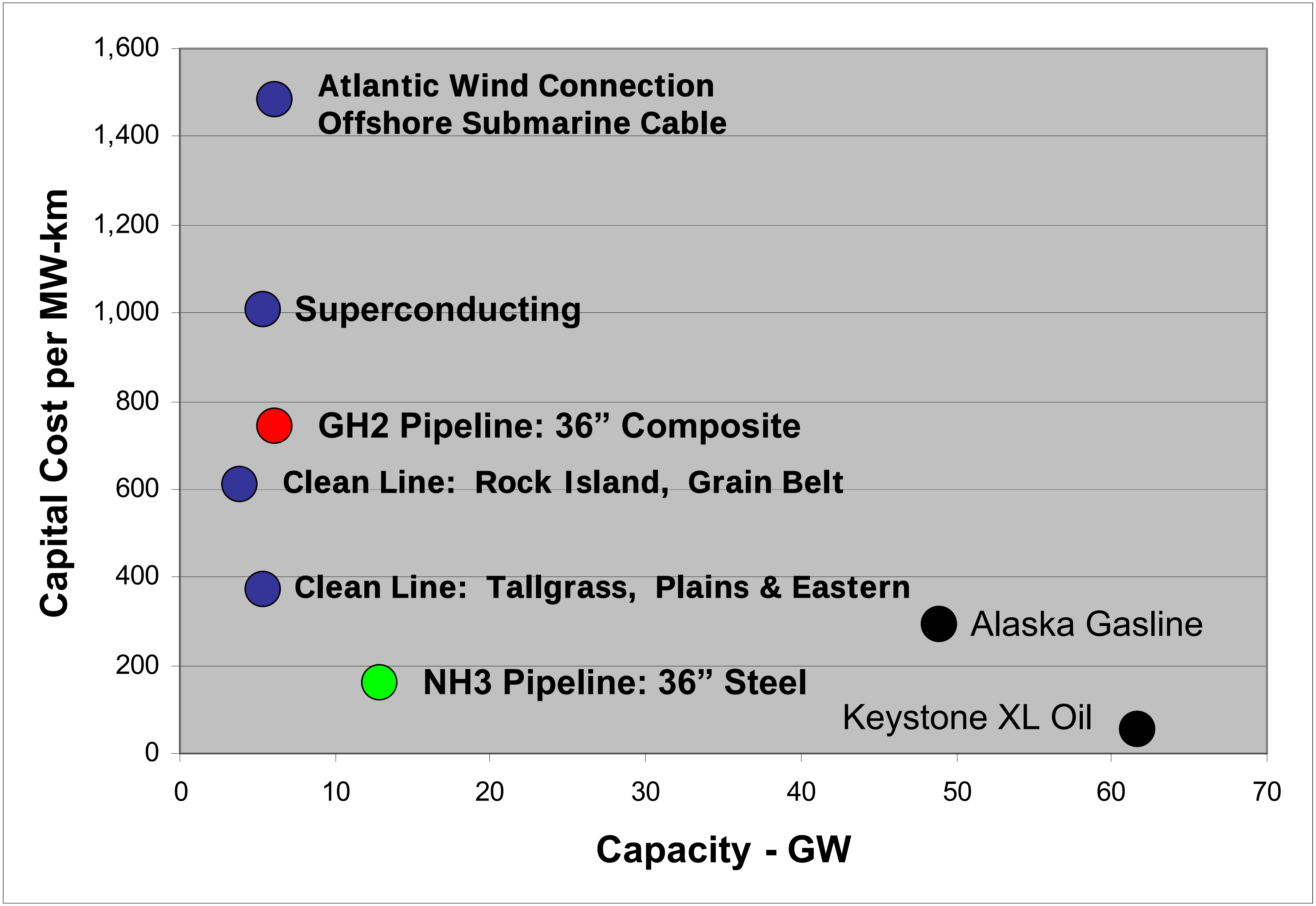
- Carbon-free: clean burn or conversion; no CO_2
  - Excellent hydrogen carrier
  - Easily “cracked” to H_2
- Reasonably high energy density
- Energy cycle inherently pollution free
  - Potentially all RE-source: elec + water + Nitrogen
  - Cost competitive with hydrocarbon fuels ?
- Decades of global use, infrastructure
  - Practical to handle, store, and transport
  - End-use in ICE, Combustion Turbine, fuel cell
  - Safety: self-odorizing; safety regs; hazard

Ammonia Fuel Uses

1. Internal Combustion Engine (ICE)
   - Diesel: NH_3 gas mixed with intake air
   - Spark-ignition: 70%+ NH_3 plus gasoline, ethanol, propane, NG, hydrogen
   - NOx ~ ¼ gasoline engines
2. Combustion Turbines
3. Direct Ammonia Fuel Cells:
   - Combined heat + power (CHP)
   - No NOx
4. Reform ("crack") to liberate hydrogen for fuel cells: $2NH_3 \rightarrow 3H_2 + N_2$

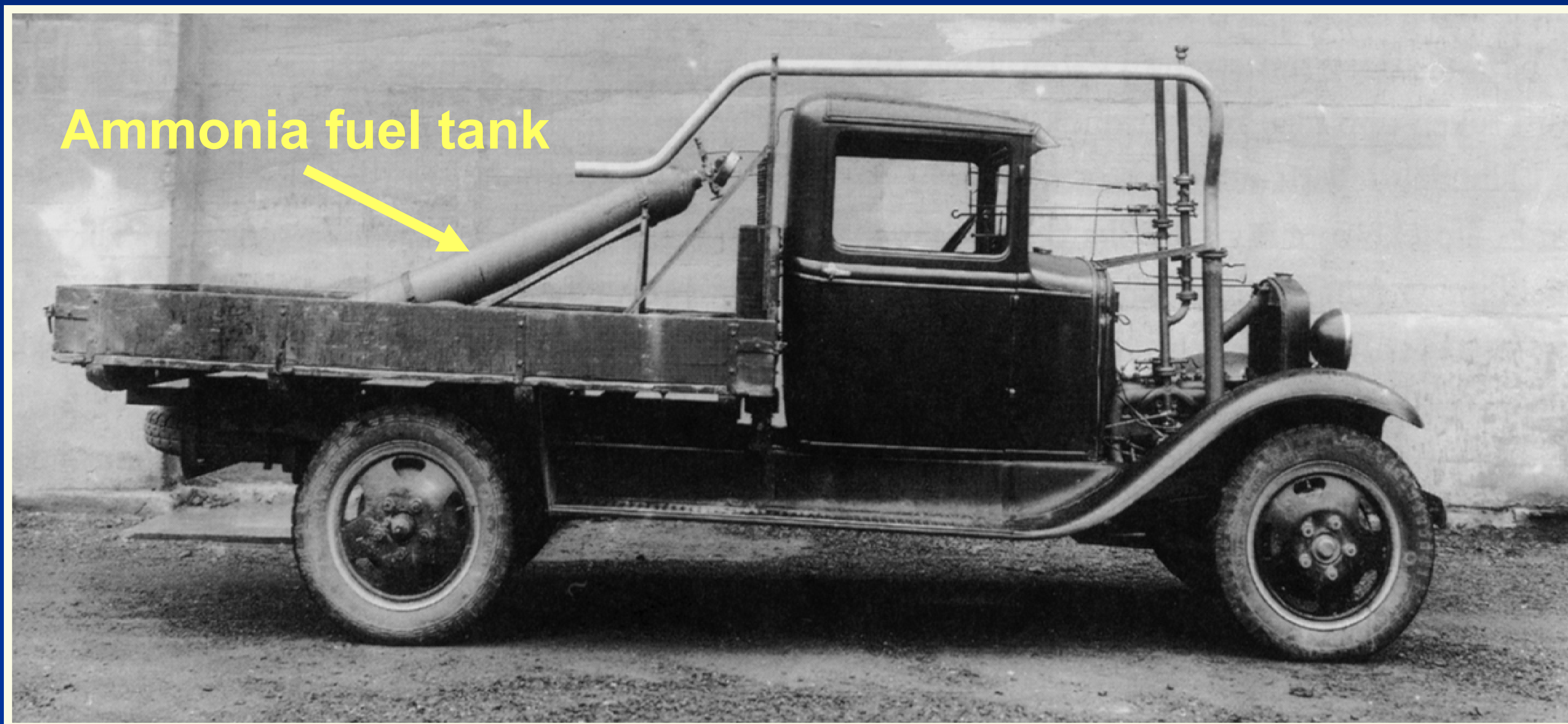
Volumetric Energy Density of Fuels
(Fuels in their Liquid State)



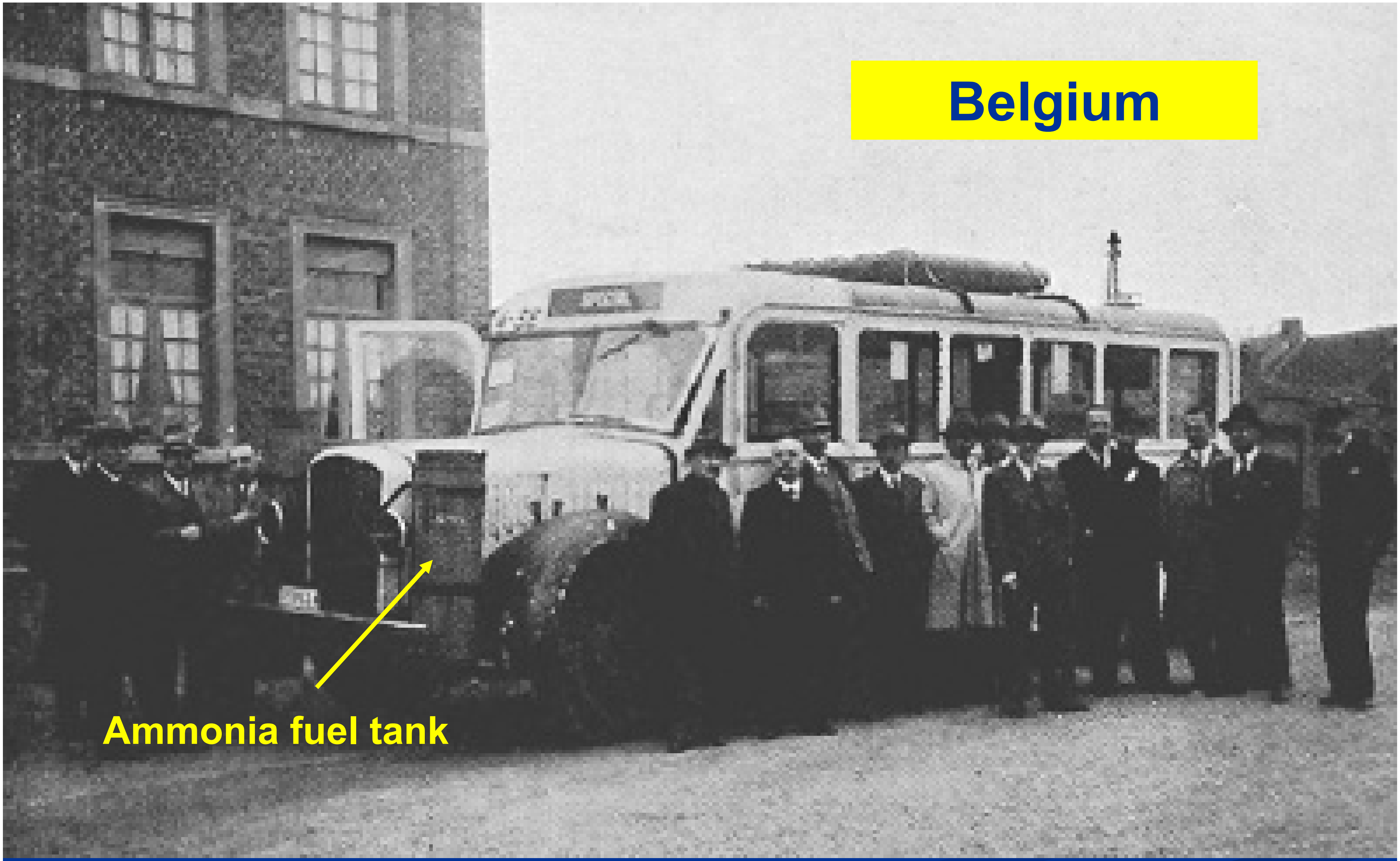


Capital Cost per MW-km
1,600
1,400
1,200
1,000
800
600
400
200
0
0
10
20
30
40
50
60
70
Capacity - GW
Atlantic Wind Connection
Offshore Submarine Cable
Superconducting
GH2 Pipeline: 36” Composite
Clean Line: Rock Island, Grain Belt
Clean Line: Tallgrass, Plains & Eastern
Alaska Gasline
NH3 Pipeline: 36” Steel
Keystone XL Oil

Ammonia fueled – Norway



1933



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

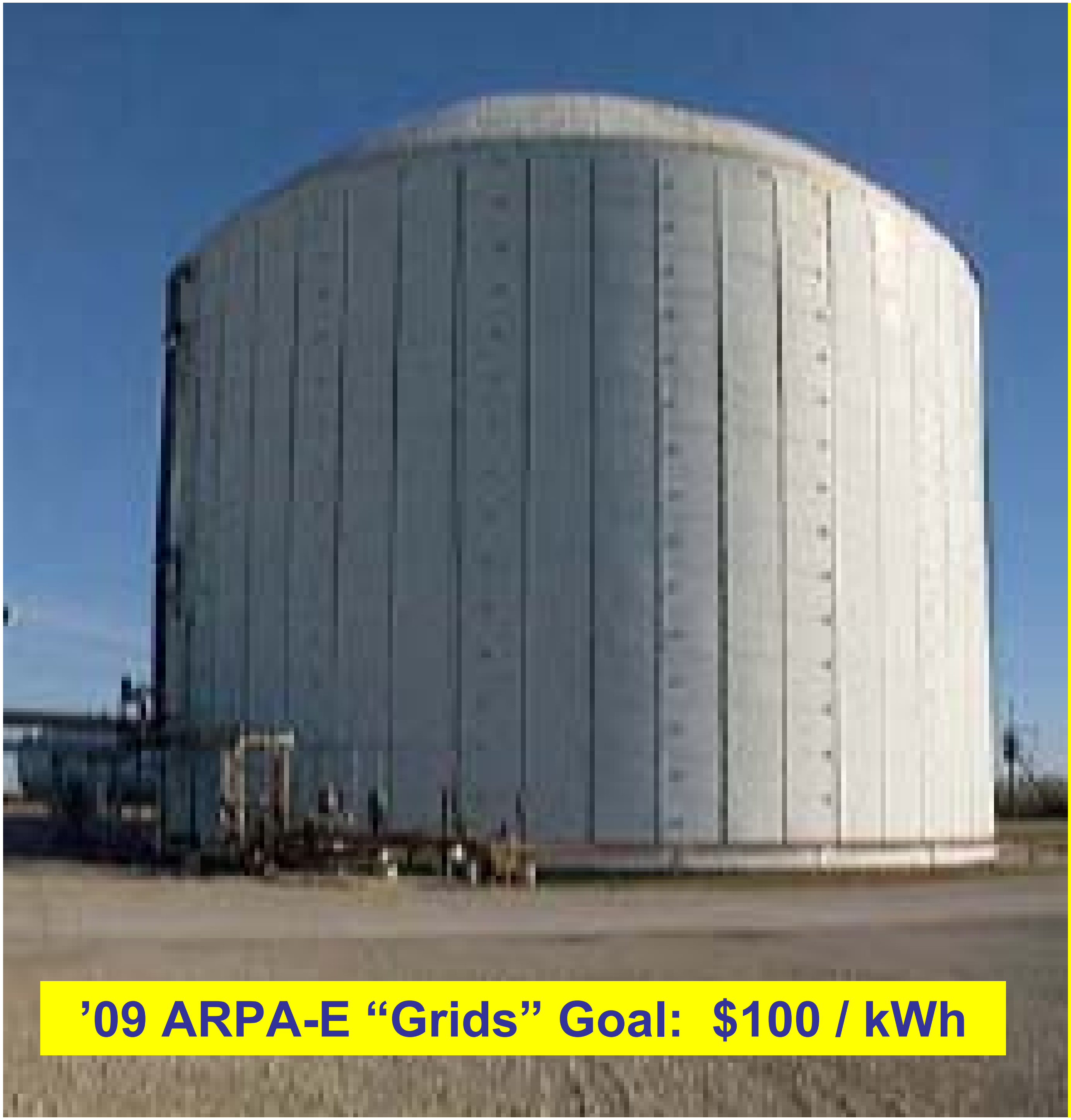
- **Idle: gasoline**
- **Full power: 80% ammonia**

Summer ’07 Detroit → San Francisco

2007

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

NH_3 Ag Fertilizer Tanks, Wind Generators, NW Iowa



“Atmospheric” Liquid Ammonia Storage Tank (corn belt)

30,000 Tons

190 GWh

$ 15M turnkey

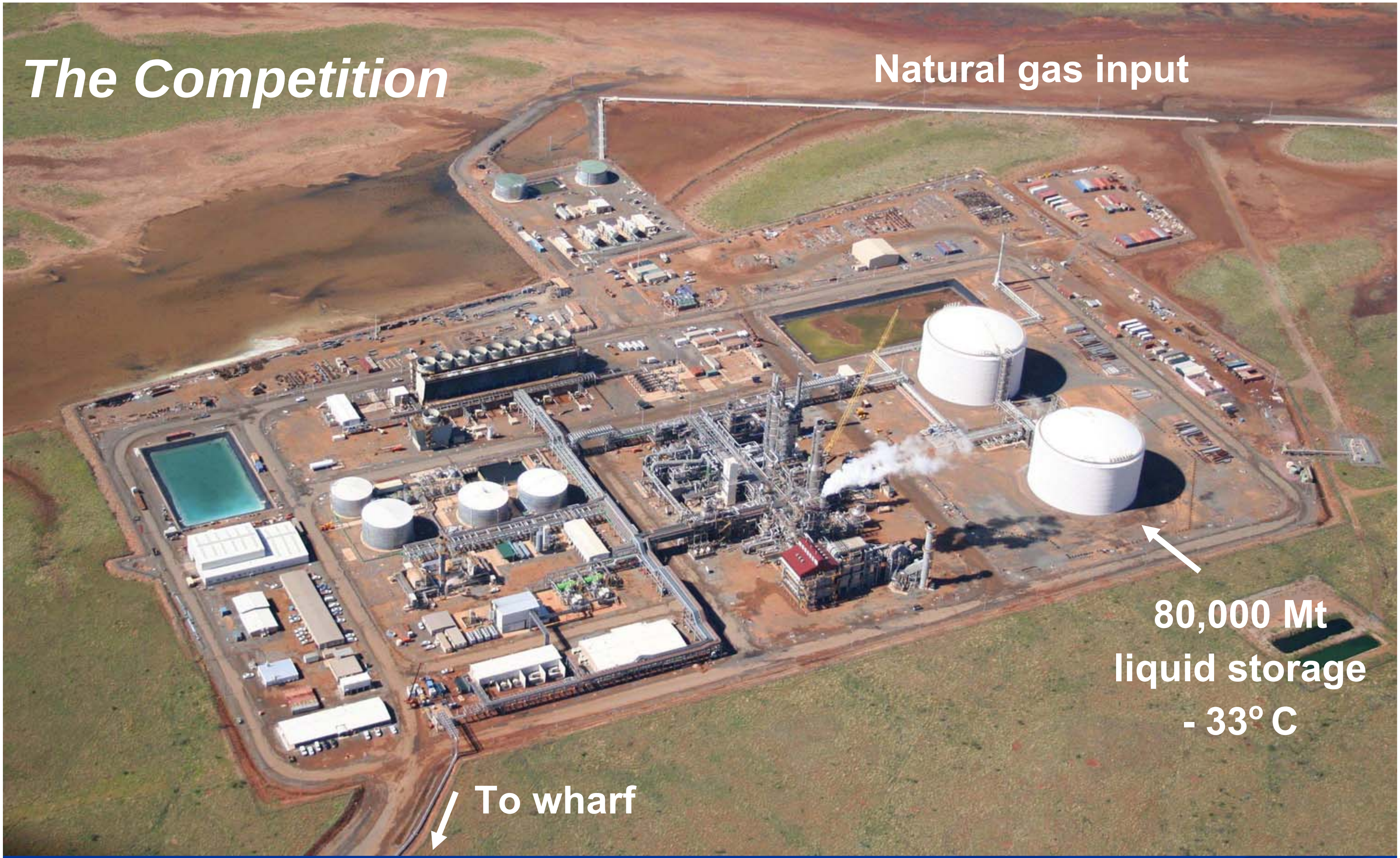
$ 80 / MWh

$ 0.08 / kWh

-33 C

1 Atm

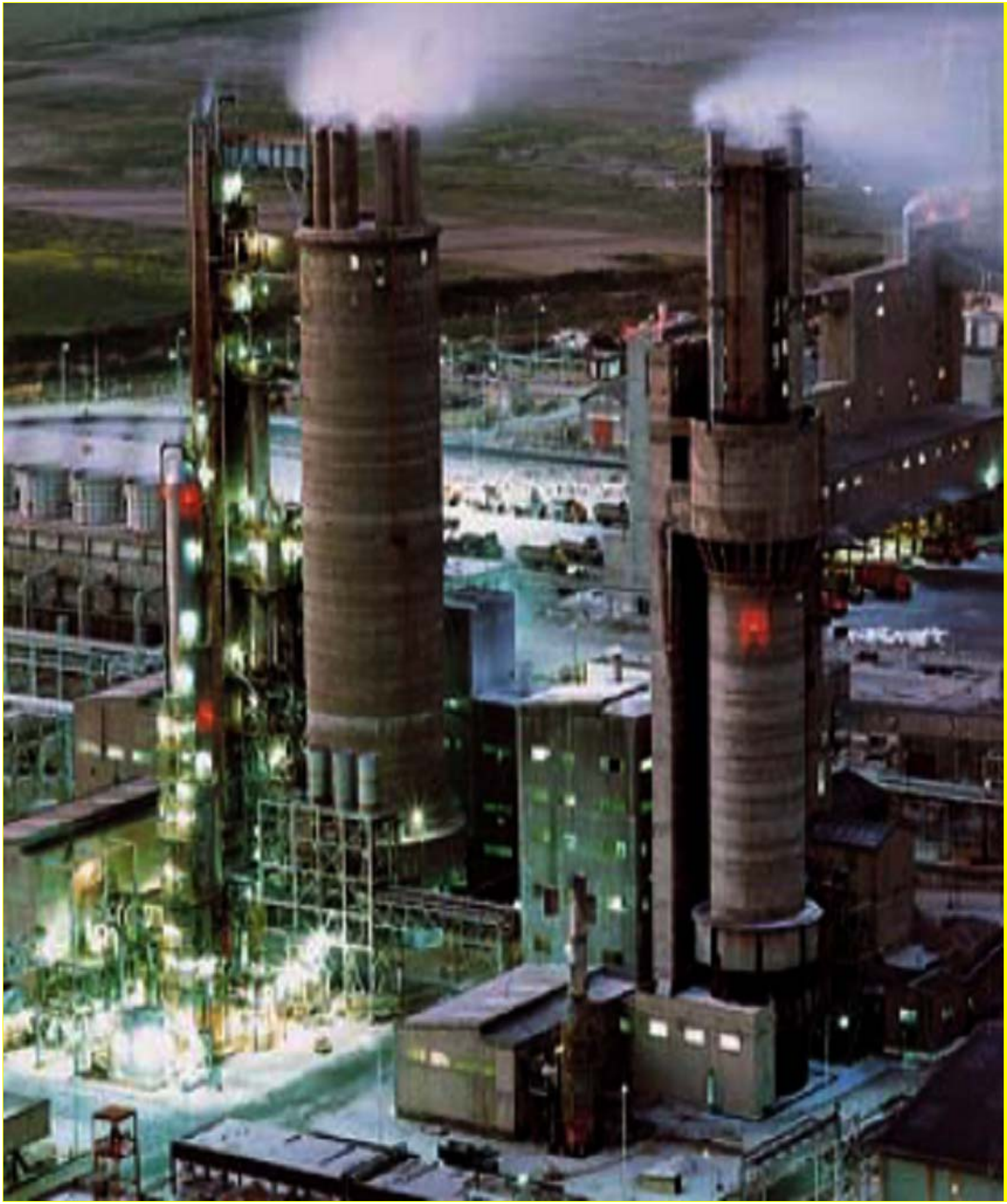

Ammonia Storage Terminal
Mississippi River
Winona, MN



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 → H2
- WW I explosives
- 40% humanity: N fertilizer

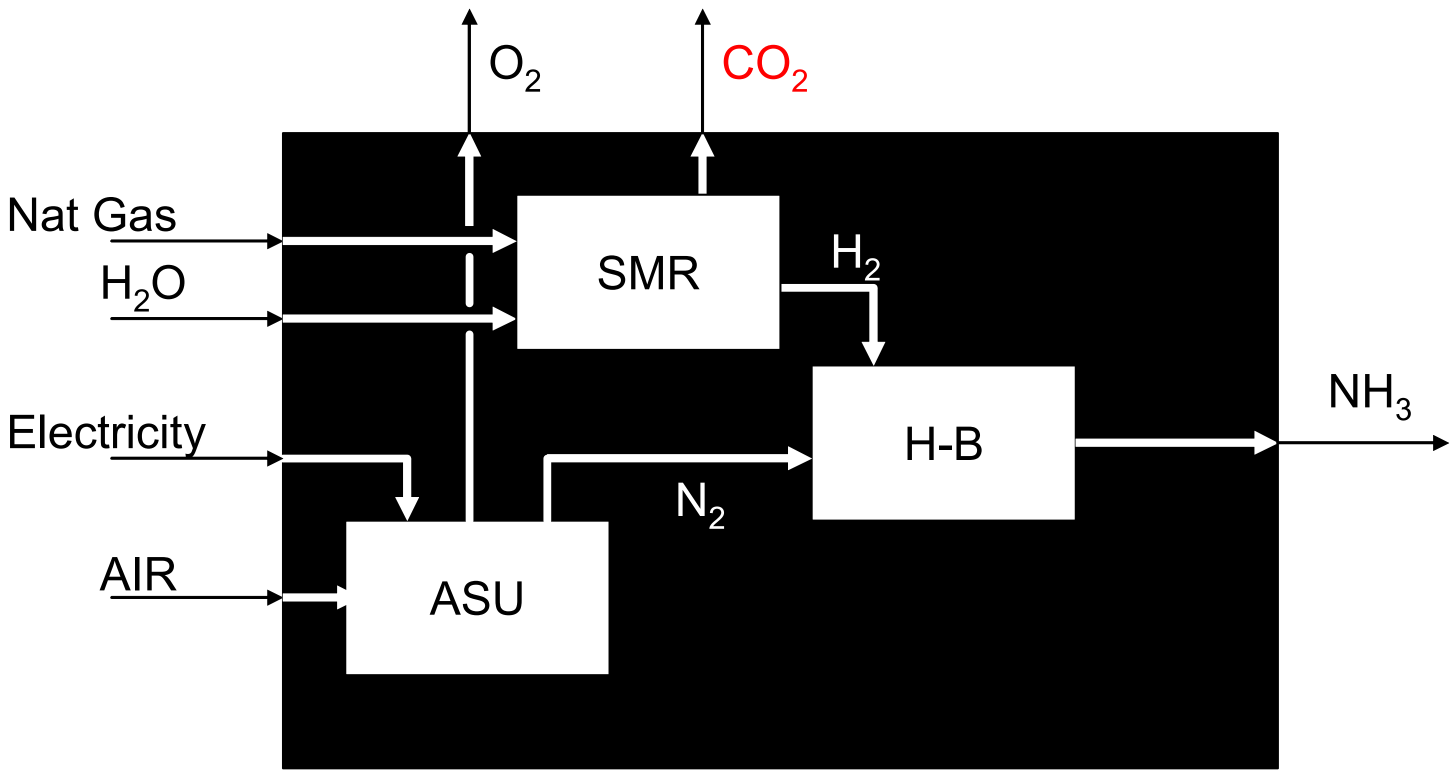
Haber-Bosch Reactor

1921

Ludwigshafen, Germany

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

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



Energy consumption ~33 MMBtu (9,500 kWh) per ton NH_3

Tons CO_2 per ton NH_3 = 1.8

Ammonia Tanker Burrup Peninsula Western Australia

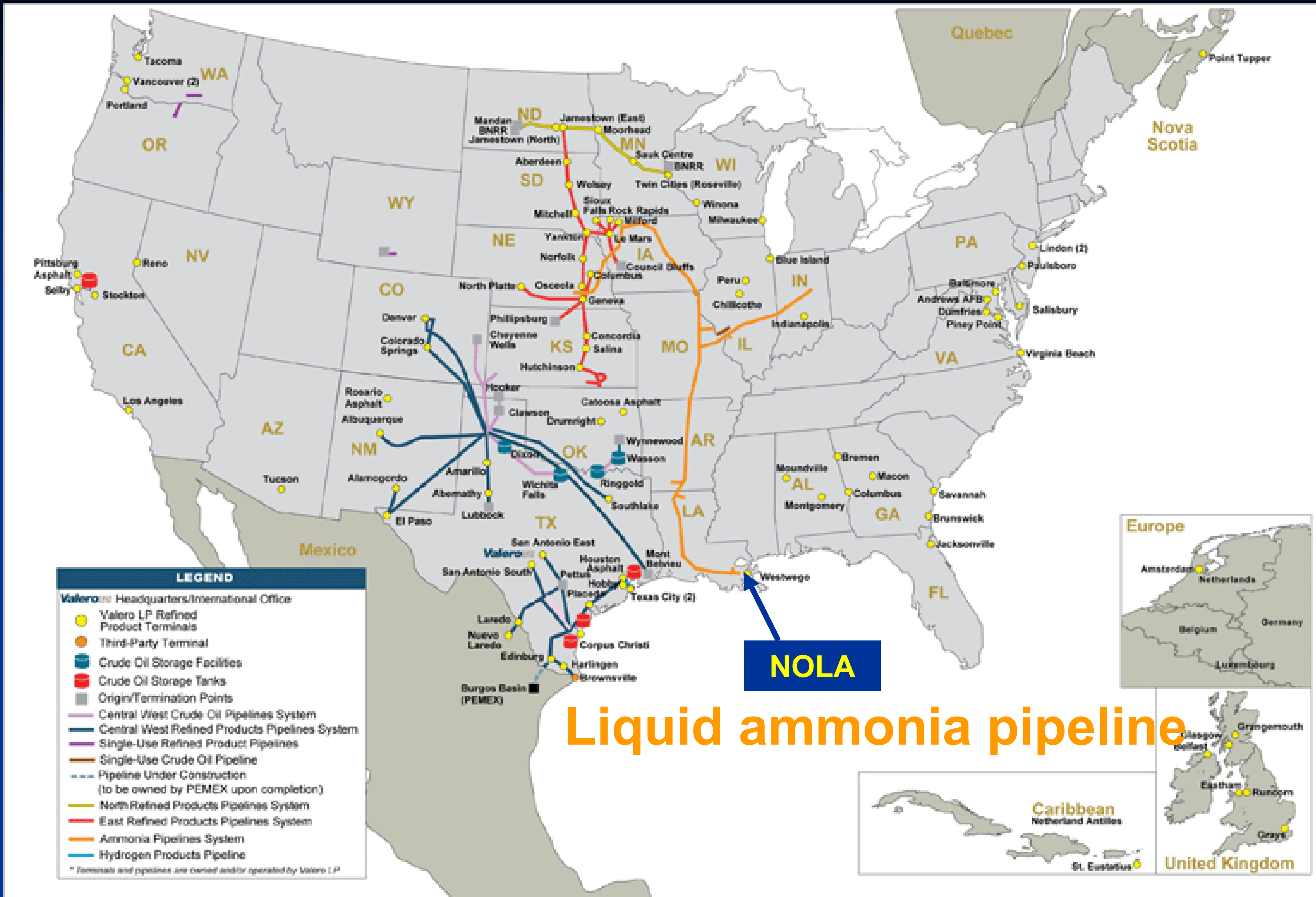
Ammonia or LPG Tanker

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

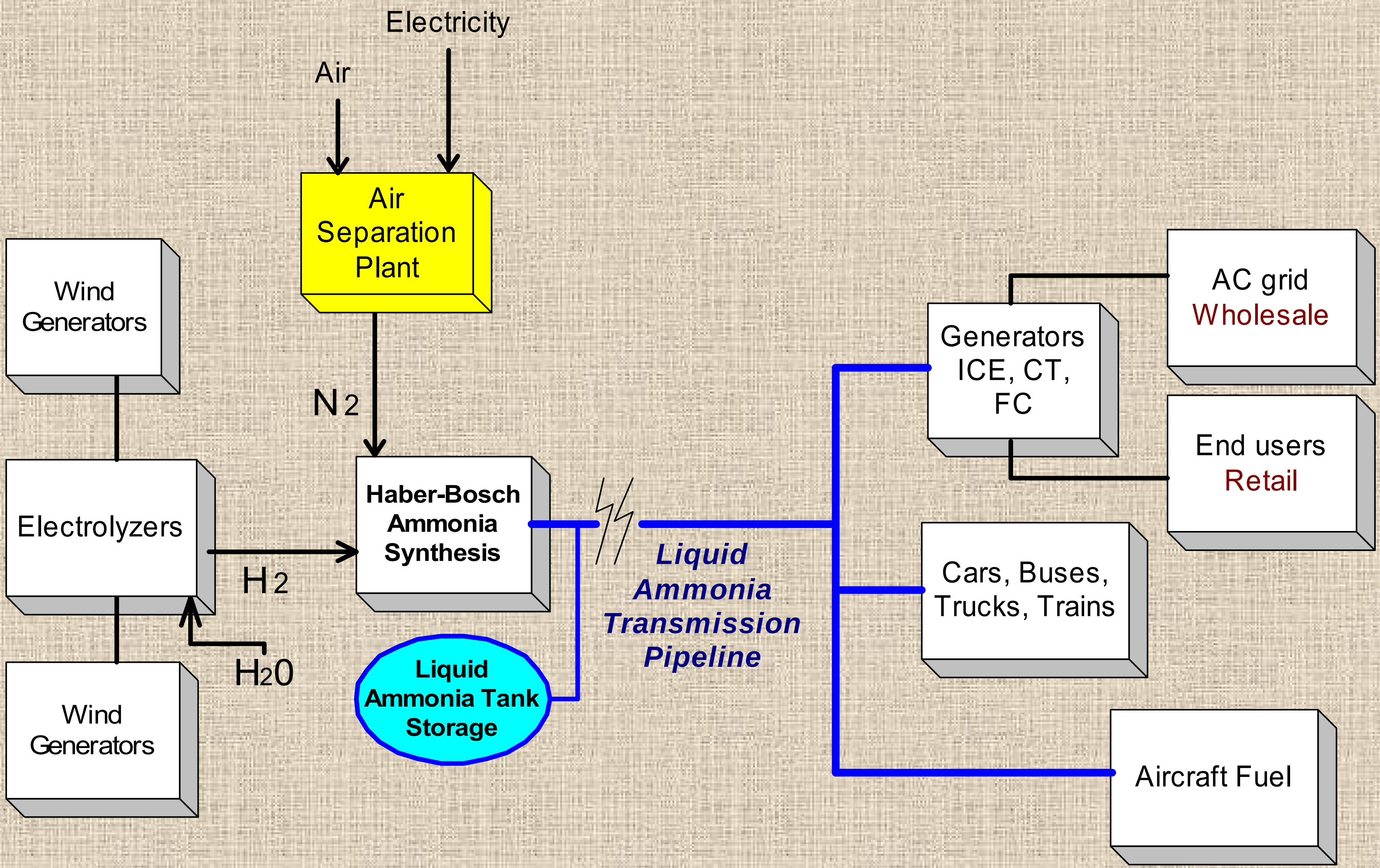
Hydrogen pipeline:

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

Ammonia pipeline:

10" , liquid, 500 miles, with pumping 0.2

RE Ammonia Transmission + Storage Scenario

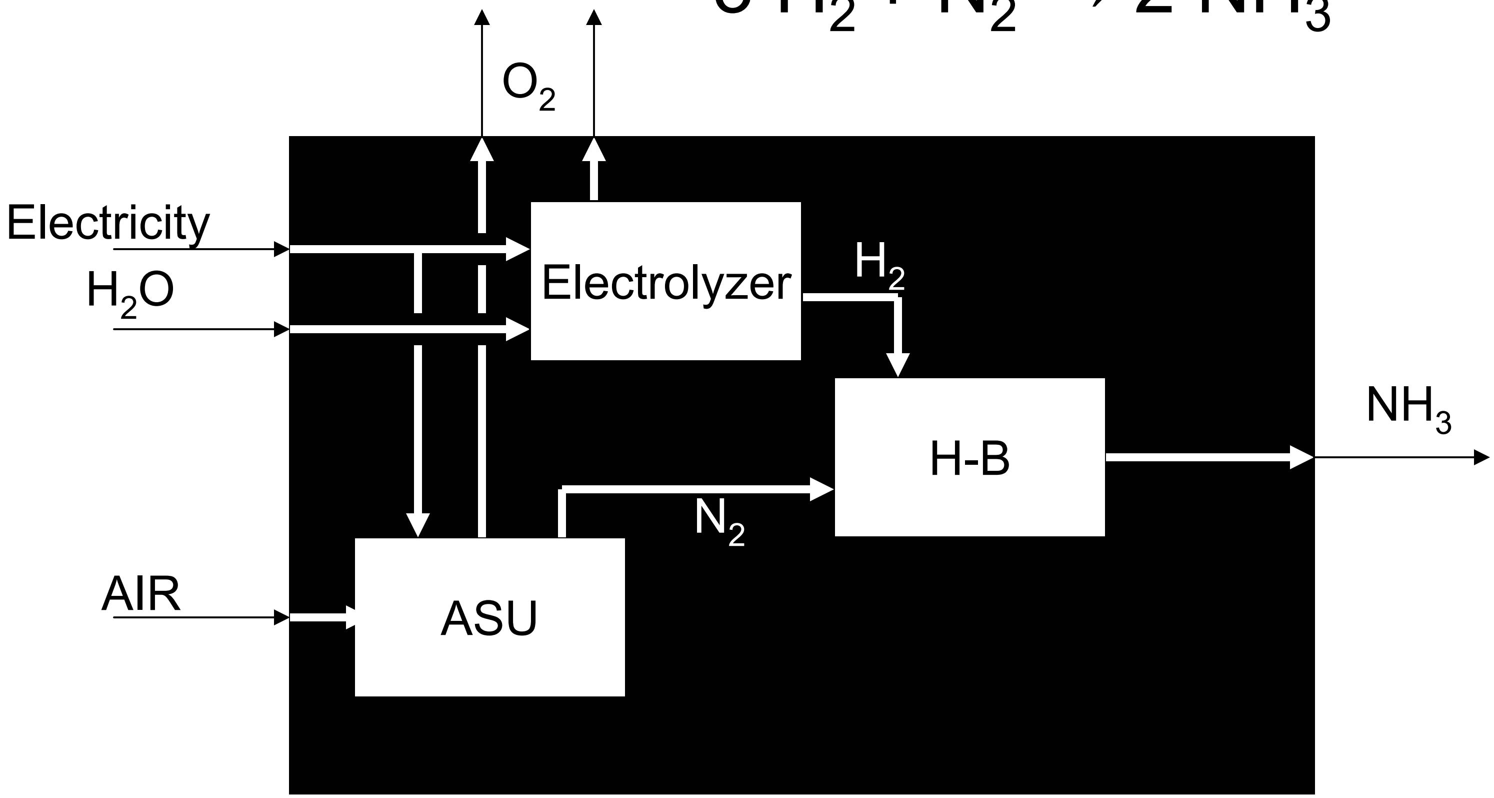


Norsk Hydro Electrolyzers 2 MW each

Ammonia from hydrogen from zero-cost off-peak hydro

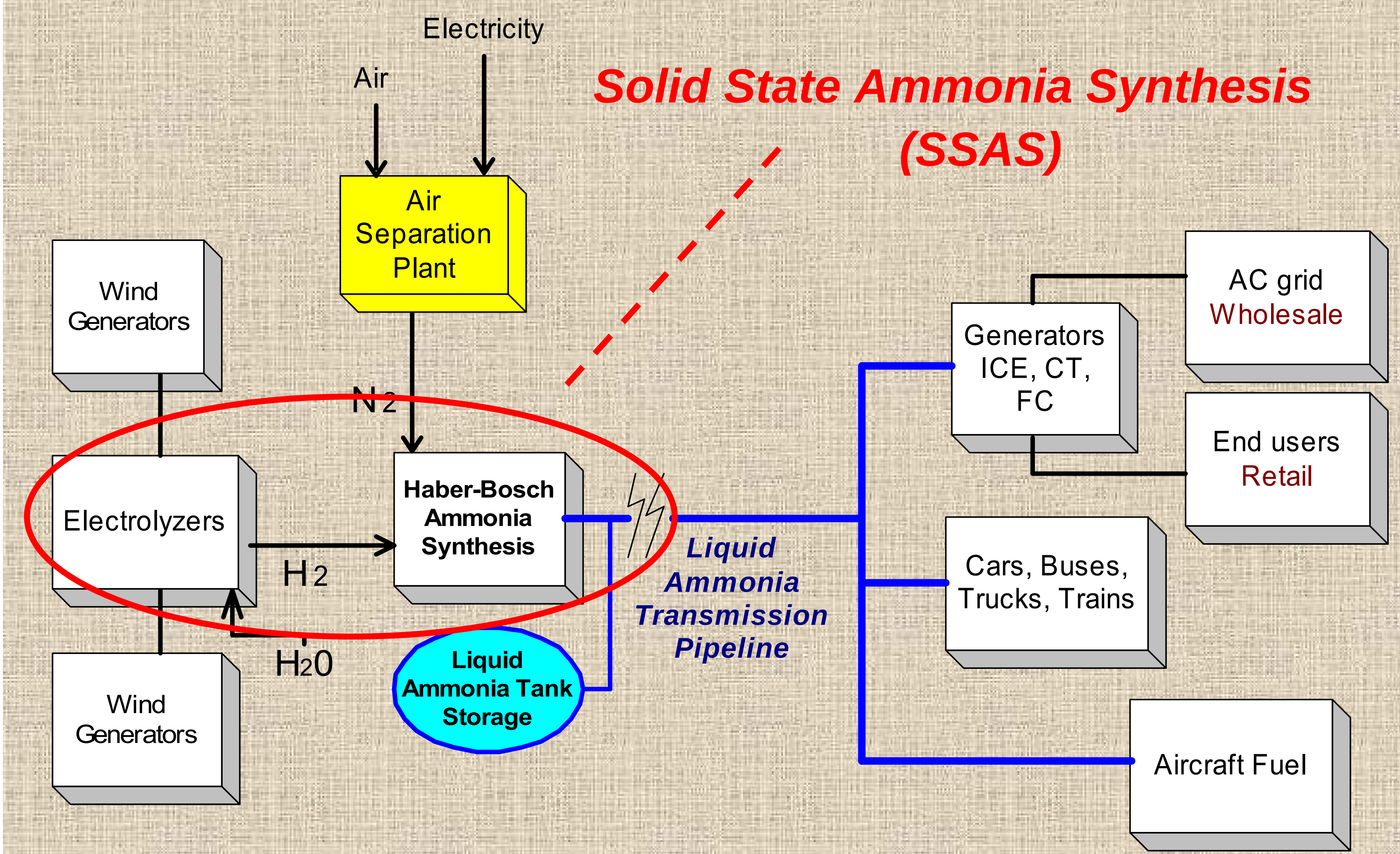
Inside the Black Box: HB Plus Electrolysis

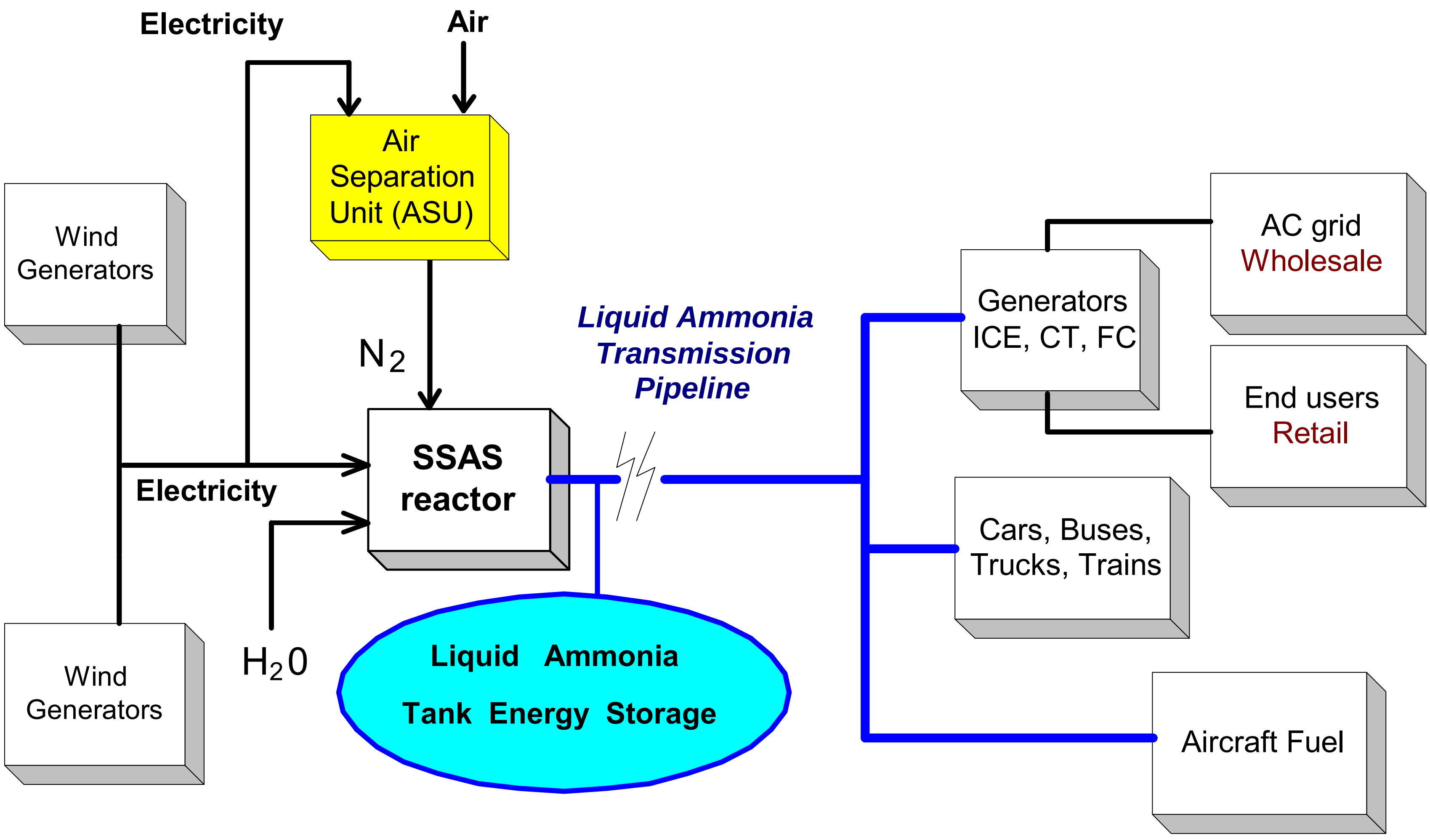
$$3\ H_2O \rightarrow 3\ H_2 + 3/2\ O_2$$
$$3\ H_2 + N_2 \rightarrow 2\ NH_3$$



Energy consumption ~12,000 kWh per ton NH_3

RE Ammonia Transmission + Storage Scenario

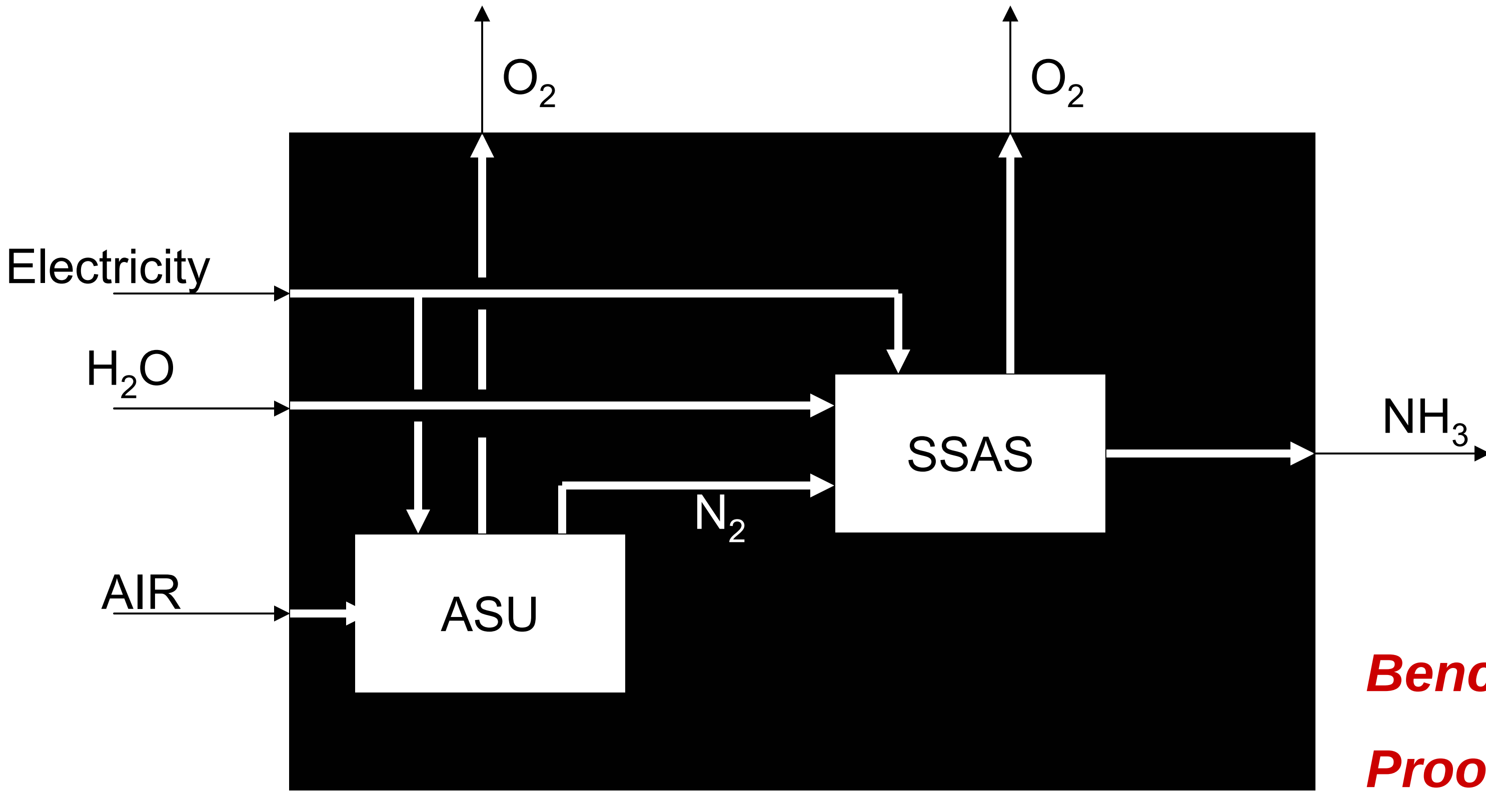




Solid State Ammonia Synthesis (SSAS)

Inside the Black Box: Solid State Ammonia Synthesis

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

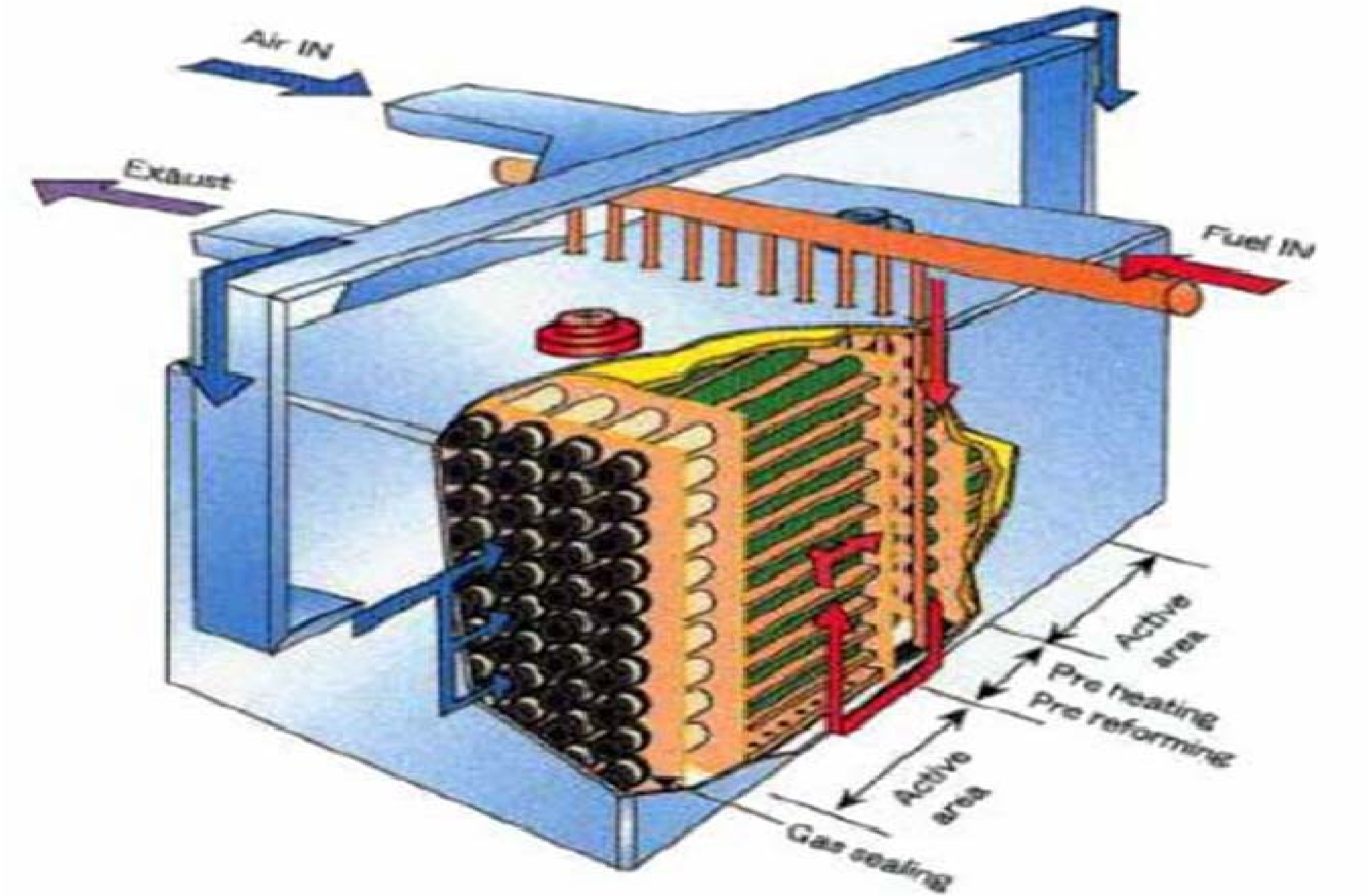


Benchtop

Proof-of-concept

Energy consumption 7,000 – 8,000 kWh per ton NH_3

Solid State Ammonia Synthesis (SSAS)
NHThree LLC patent



Why SSAS ?

- Electrolysis + Haber-Bosch too costly
  - From RE electricity
  - Capital components at low capacity factor (CF)
  - Energy conversion losses
- Proton conducting ceramics (PCC) now
- Solid oxide fuel cell (SOFC) success
- Need stranded RE transmission
- Need RE storage

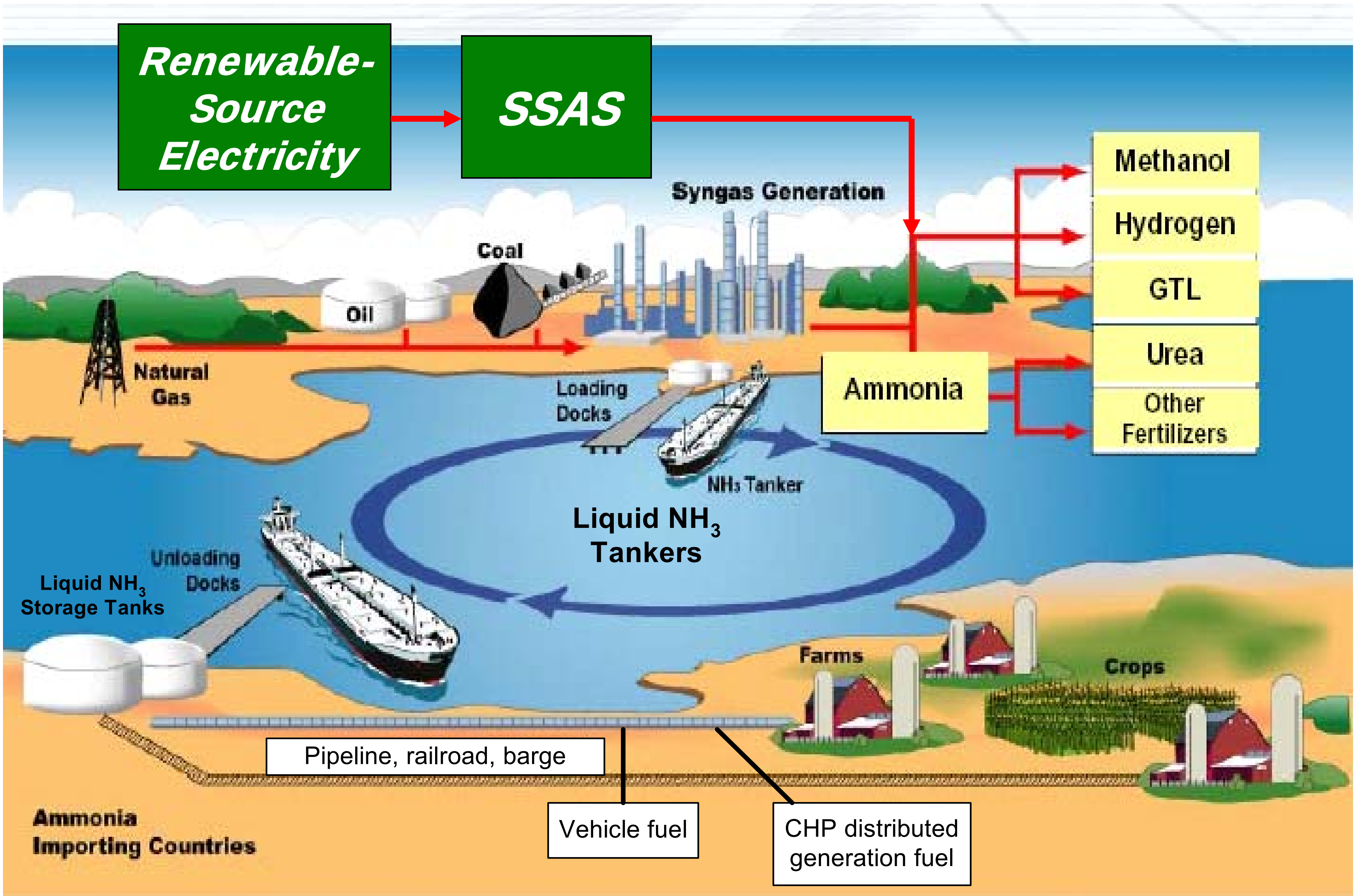
Wind – to – Ammonia Potential, NW Iowa

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

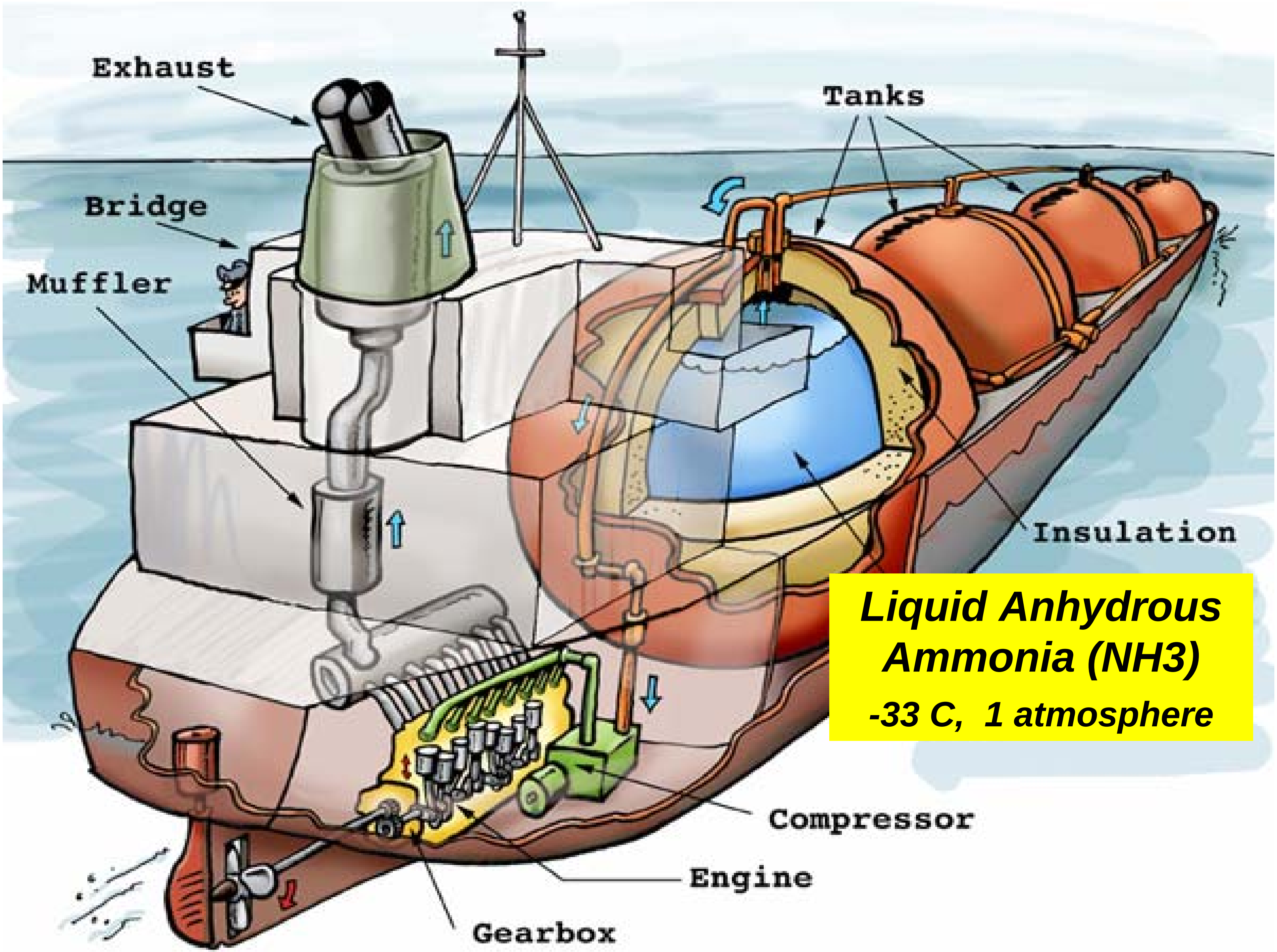
- **Electricity**
  - **VRB (Vanadium Redox Battery)**
    - **O&M: 80% efficiency round-trip**
    - **Capital: $500 / kWh = $ 160 Billion**
  - **CAES (Compressed Air Energy Storage)**
    - **O&M: $46 / MWh typical**
    - **Iowa Stored Energy Park:**
      - **Power = 268 MW**
      - **Energy capacity = 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**

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



KBR
Energy and Chemicals



Liquid Anhydrous Ammonia (NH3)

-33 C, 1 atmosphere

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:**

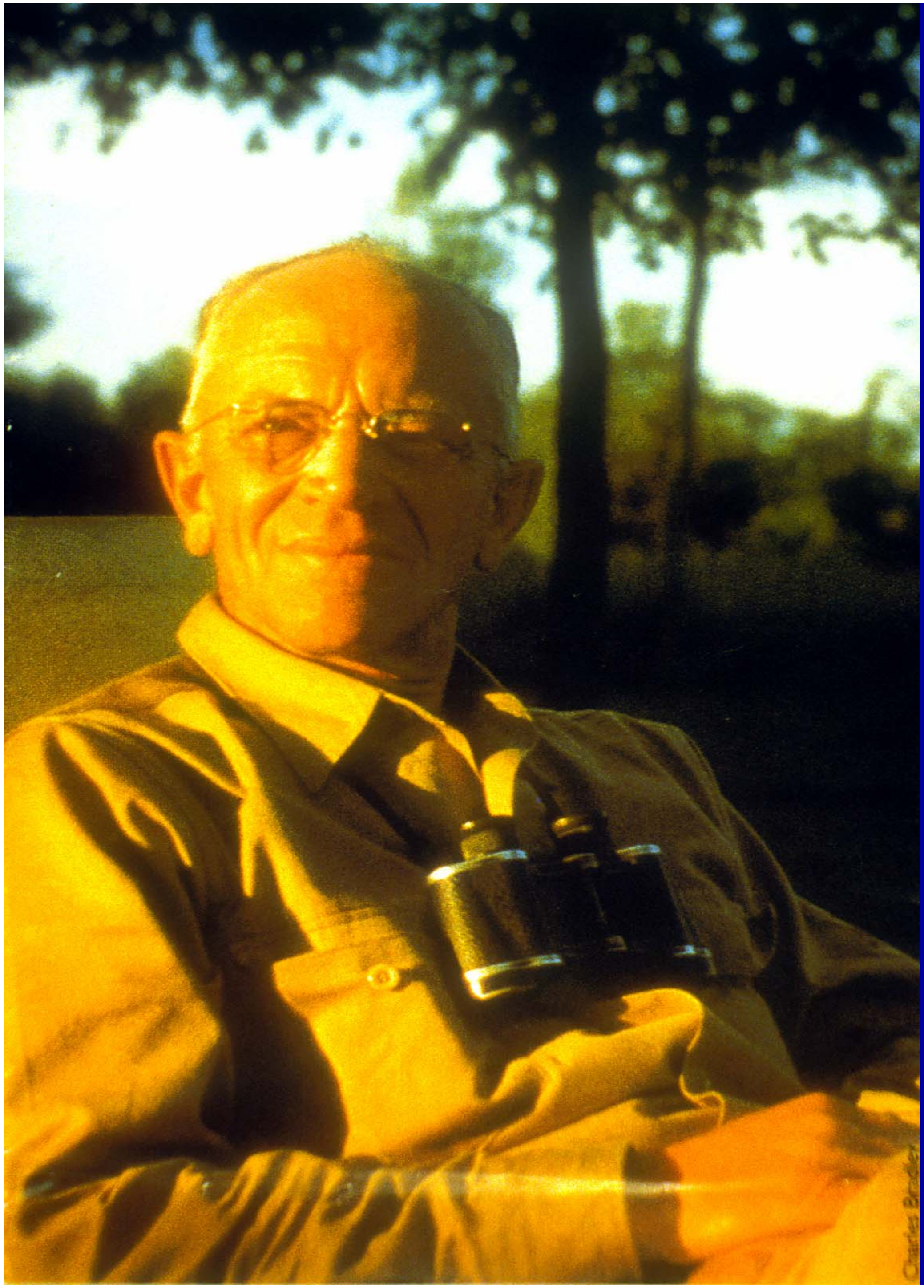
  $ 0.10 – 0.20 / kWh capital
- **CHP, transport, industrial**

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



Aldo Leopold

1887 - 1948

Protecting the Arctic by Running the World on Renewables: Alternatives for Transmission and Low-cost Firming Storage of Stranded Renewables as Hydrogen and Ammonia Fuels

DVD' s available

AAAS Arctic Science Conference

27 September 2013 Kodiak, AK

Bill Leighty, Director
The Leighty Foundation
Juneau, AK
wleighty@earthlink.net
907-586-1426 206-719-5554 cell

End of 27 Sep 13 presentation

Following slides are supplemental

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.

Alaska Energy Authority Emerging Energy Technology Fund $750K grant to Alaska Applied Sciences, Inc.

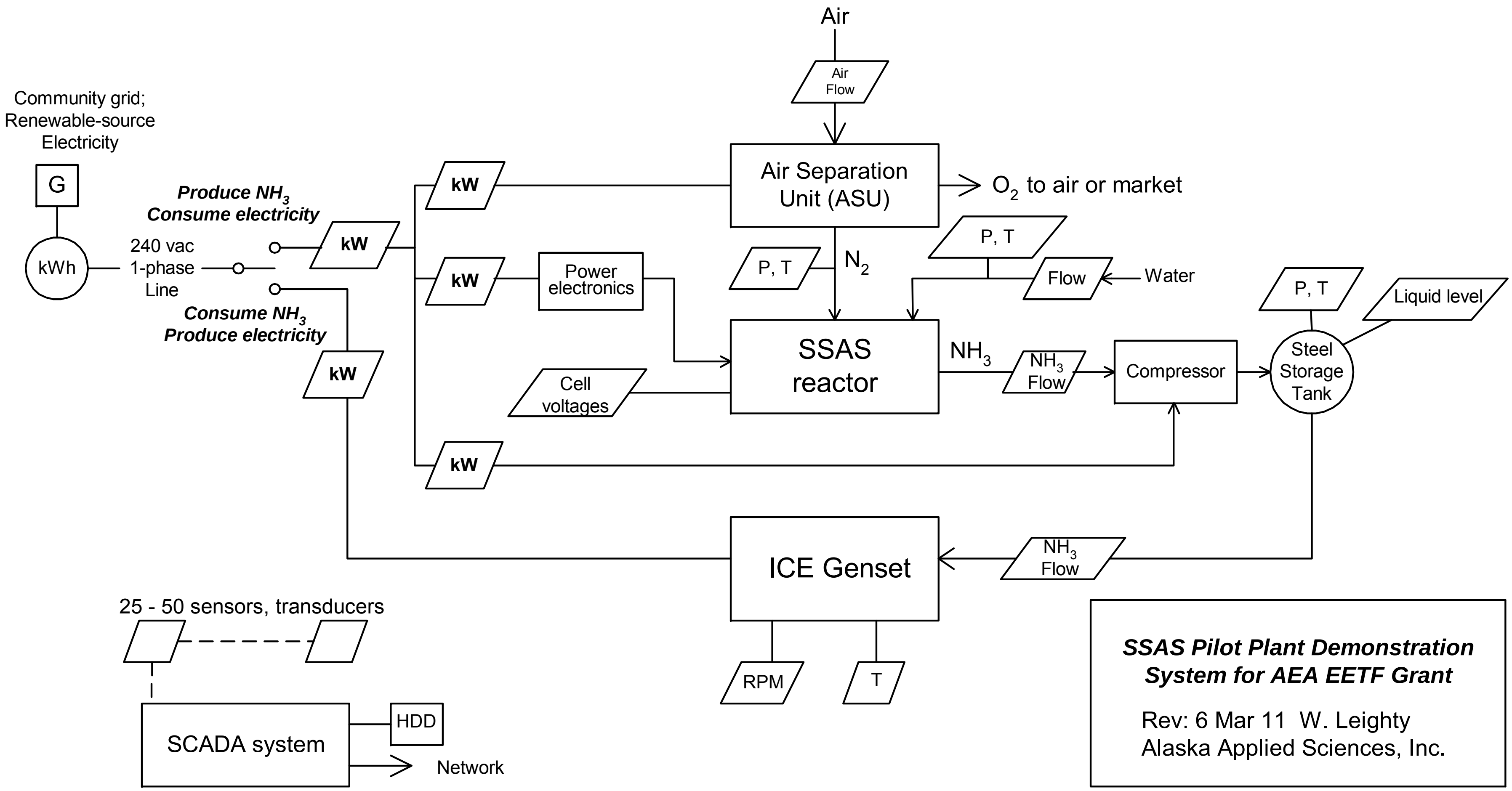
- SSAS Proof-of-concept pilot plant
- Alaska applications
  - Village energy independence
  - RE export as NH3 fuel
  - Hydro firming, annual-scale
- 2-year project

Project Fundamentals

1. Anhydrous ammonia (NH3) is a fuel and transmission and low-cost energy storage medium
2. NH3 made from renewable energy (RE) electricity, water, and air (Nitrogen, N2) by:
   a. Electrolysis + Haber-Bosch (EHB)
   b. Solid State Ammonia Synthesis (SSAS)
3. SSAS should best EHB in:
   a. Capital cost per kWe in, kg NH3 out
   b. Energy conversion efficiency
   c. System simplicity, low O&M cost
   d. AK value

Project Fundamentals

4. SSAS unproven: needs proof-of-concept, small pilot plant
5. Design and build pilot plant:
   a. Complete
   b. SCADA instrumented
   c. Containerized & transportable
   d. Upgradeable
6. Success:
   a. Great value to AK, beyond
   b. Next steps to commercial
   c. SA AK “RE Cluster Industry” via USFS, JEDC



PROJECT: Complete RE – NH_3 SSAS Storage System

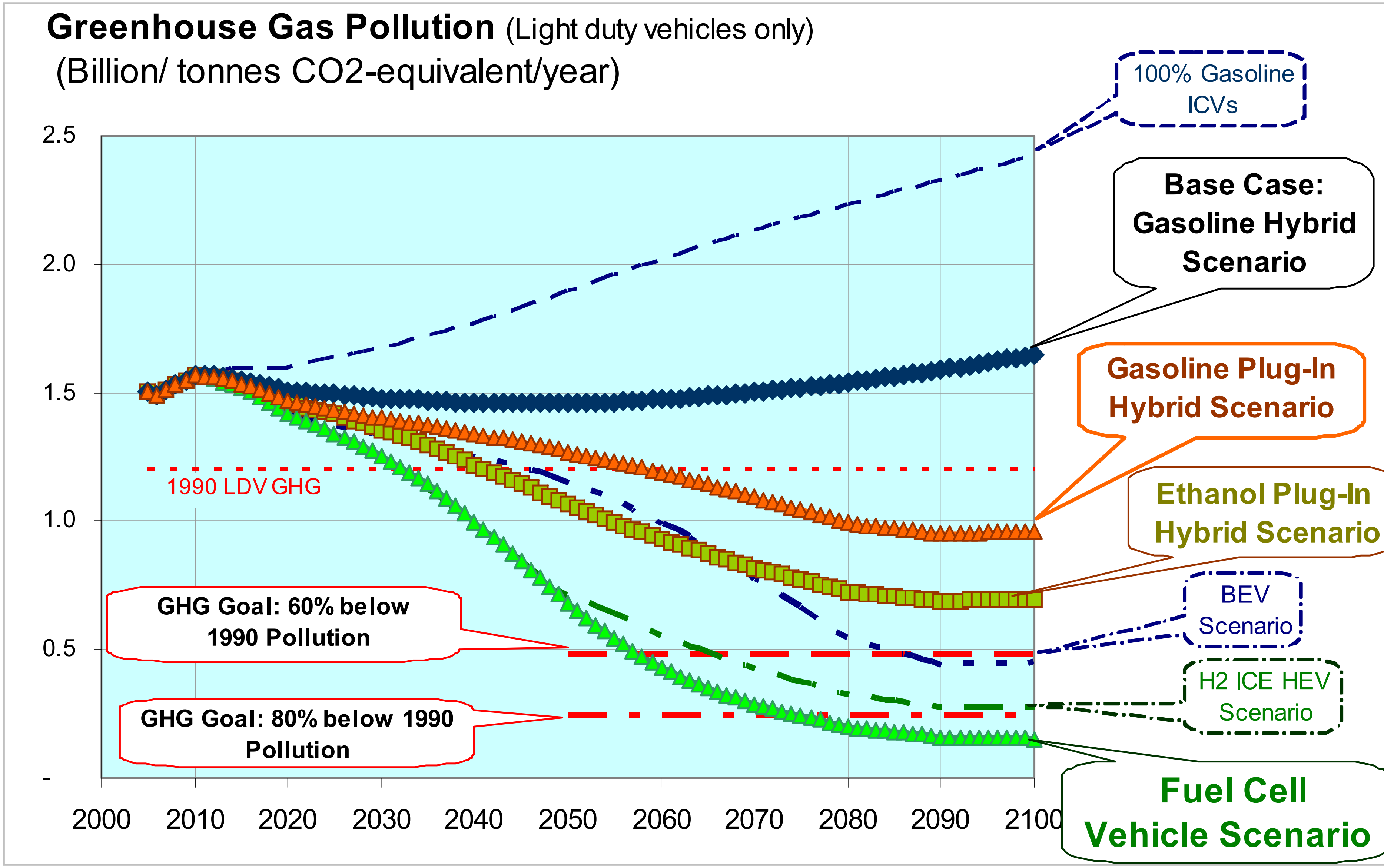
- **> NH_3 synthesis from RE electricity, water, air (N_2)**
- **> Liquid NH_3 tank storage**
- **> Regeneration + grid feedback**
- **> SCADA instrumentation → UAF - ACEP**

Alaska Applied Sciences, Inc.

560 kW windplant

Palm Springs, CA

Juneau: Thin shell concrete scale model, ~ 1 cm thick


Greenhouse Gas Pollution (Light duty vehicles only)
(Billion/ tonnes CO2-equivalent/year)
2.5
2.0
1.5
1.0
0.5
-
2000
2010
2020
2030
2040
2050
2060
2070
2080
2090
2100
100% Gasoline ICVs
Base Case: Gasoline Hybrid Scenario
Gasoline Plug-In Hybrid Scenario
Ethanol Plug-In Hybrid Scenario
BEV Scenario
H2 ICE HEV Scenario
Fuel Cell Vehicle Scenario
1990 LDV GHG
GHG Goal: 60% below 1990 Pollution
GHG Goal: 80% below 1990 Pollution

Capital Cost per GW-mile

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

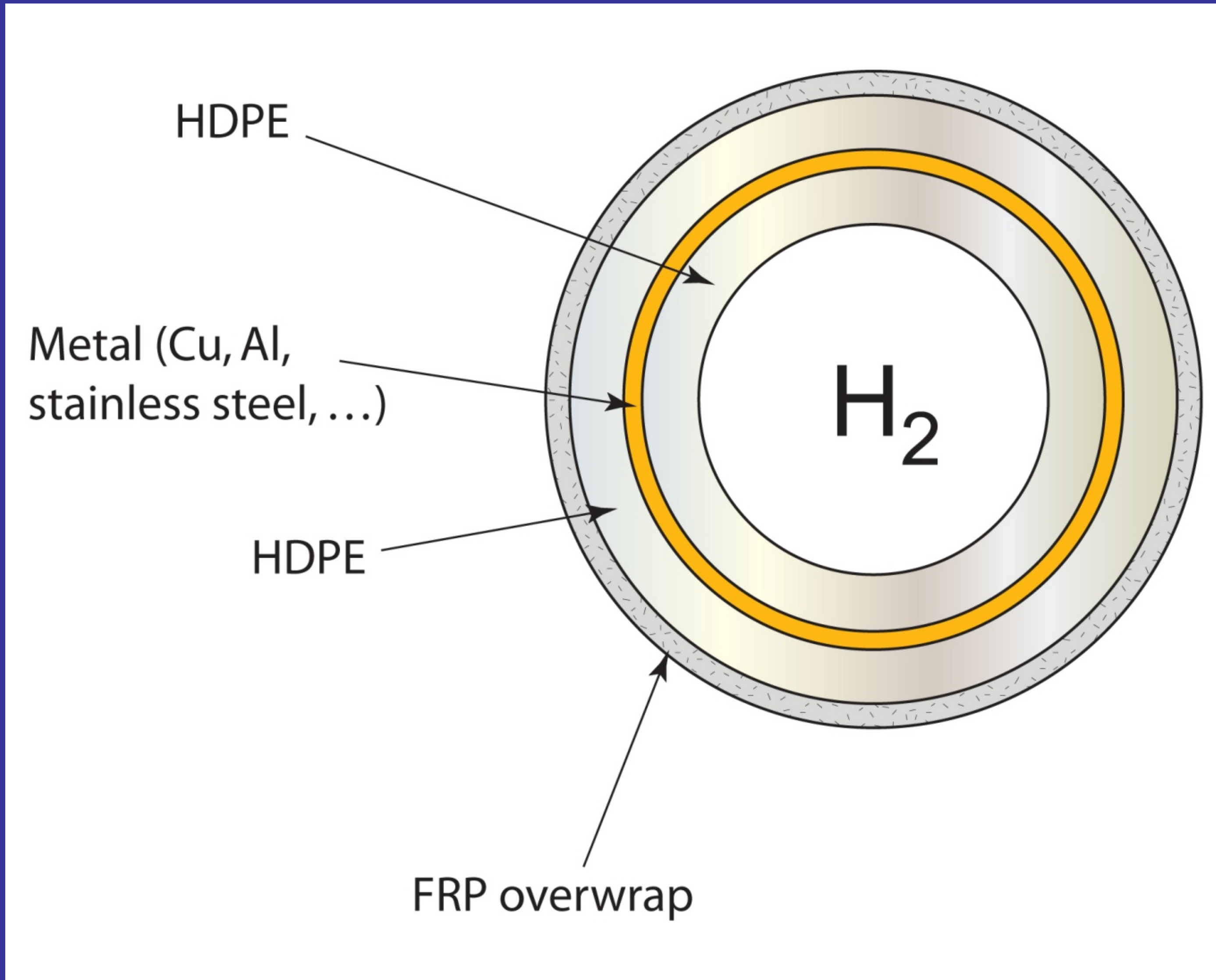
Hydrogen pipeline:

36”, 100 bar, 500 mi, no compress 0.3

(100 bar = 1,500 psi)

10” NH3 liquid pipeline cost

- Industry sources, all costs:
  - $750 – 900 K per mile, 10”, “uncongested area”
  - $250K per mile “small diameter”
- 1,000 mile pipeline @ 10” = $ 400M
- Capacity 2 GW
- **Capital cost = $200K / GW-mile**



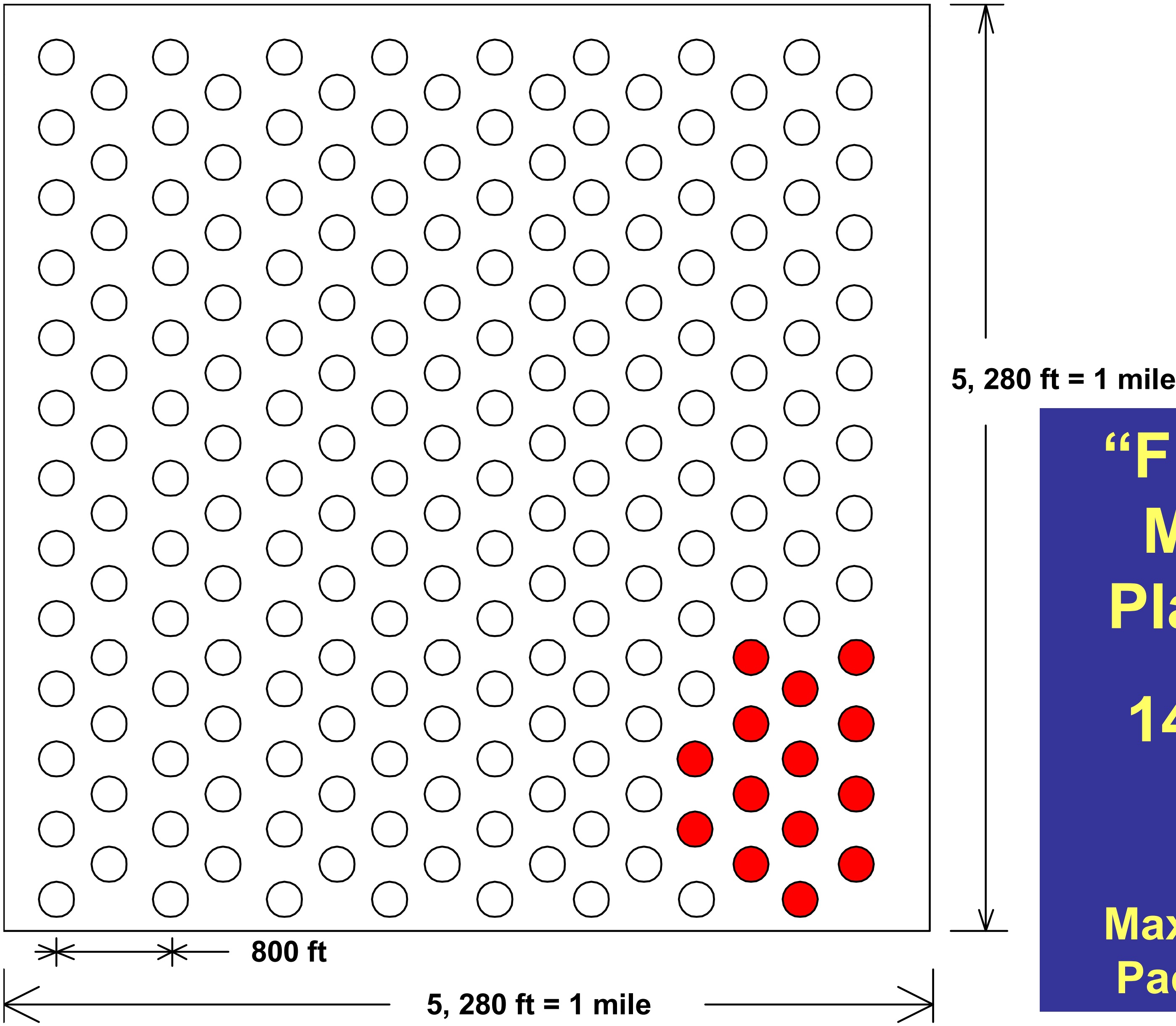
Polymer-metal linepipe avoids hydrogen embrittlement

Gaseous Hydrogen (GH2)

36” diam,
800 km
No compression

8,000 MW

CRLP™ is a trademark of NCF Industries, Inc.

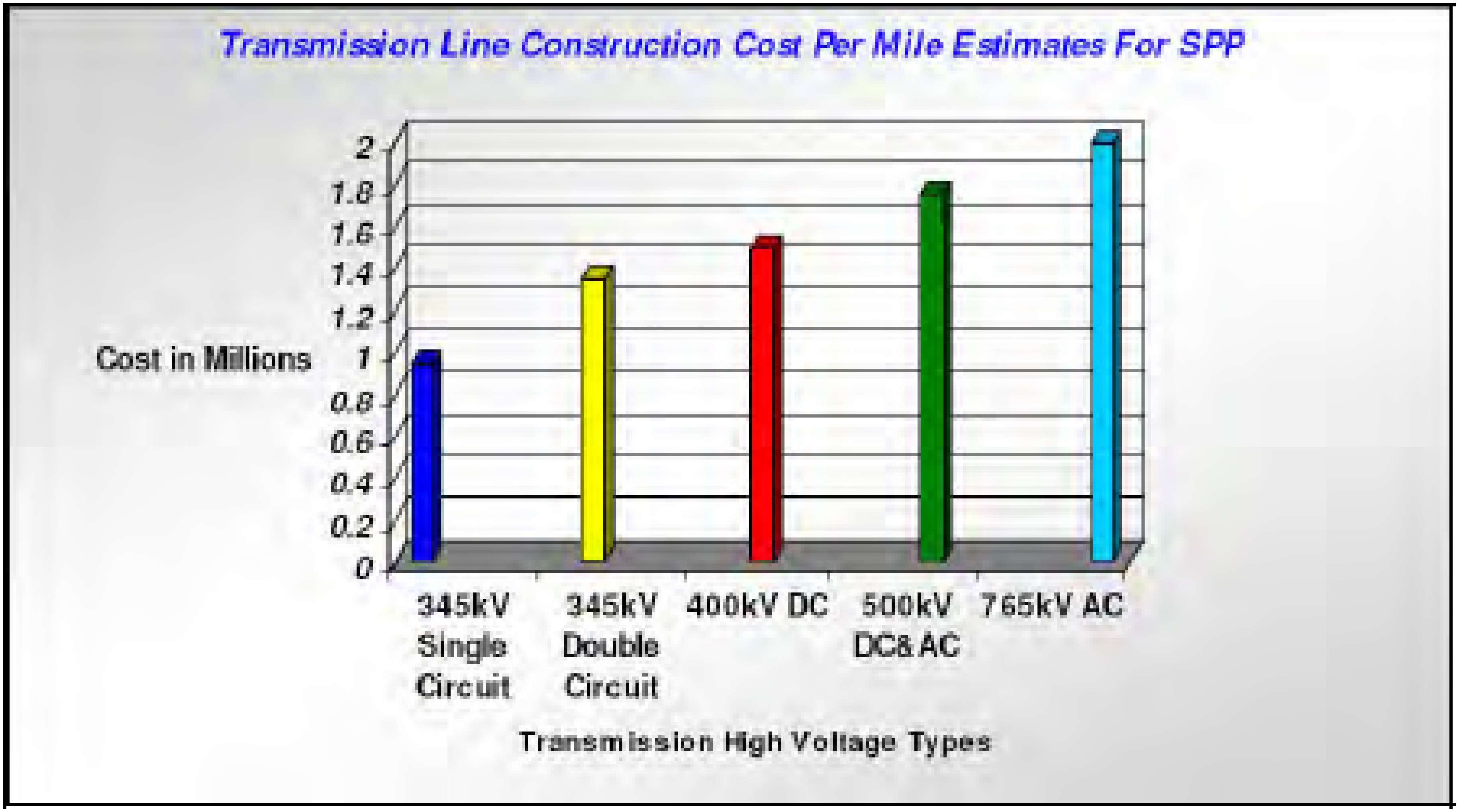


“Firm” 4,000 MW Great Plains wind

14 caverns

Maximum Cavern Packing Density

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



Transmission Line Construction Cost

$ million per Mile

Southwest Power Pool '07

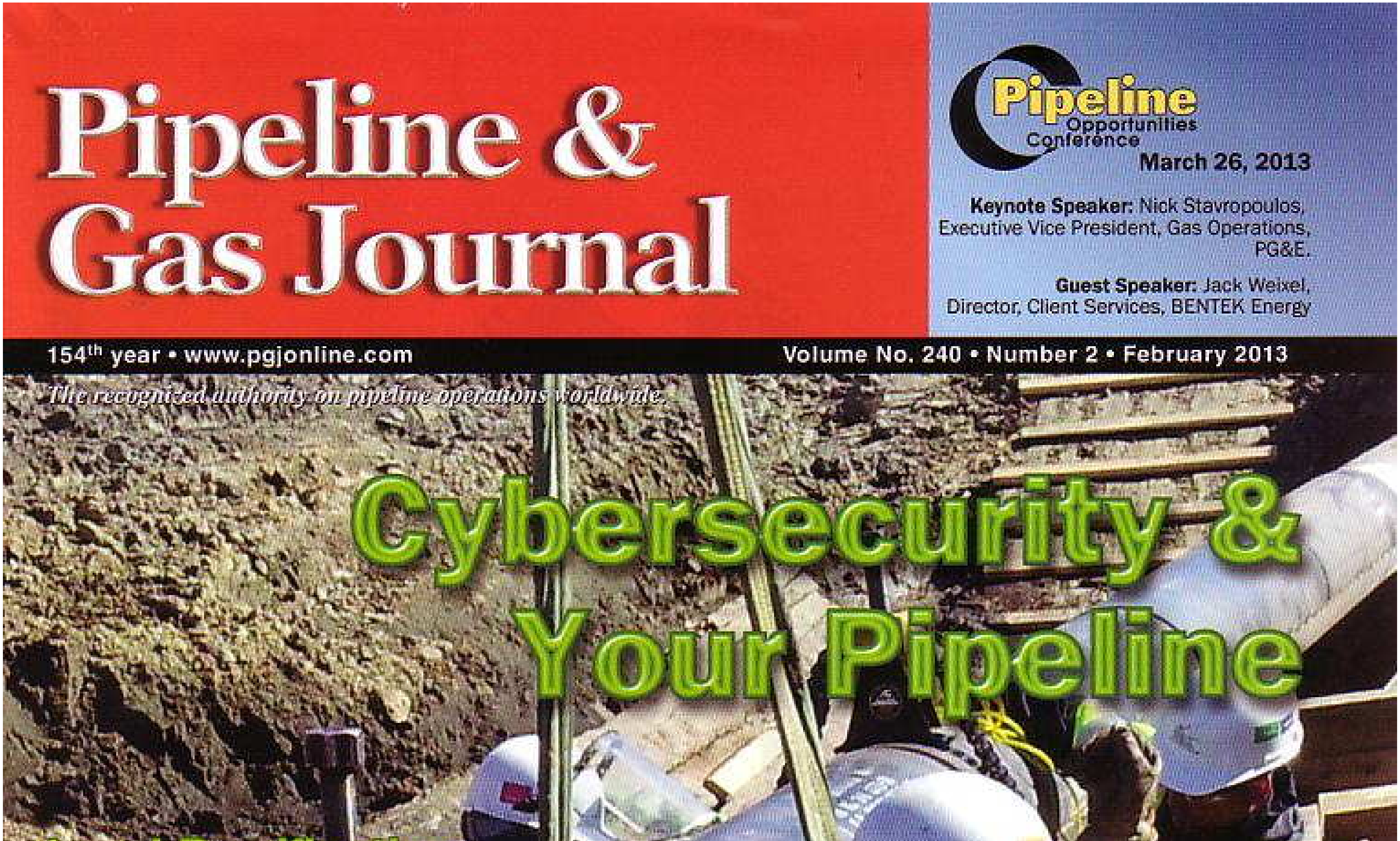
NOTE: Approximate relationship based on Surge Impedance Loading (i.e. reactive power balance point) 345 kV single circuit tower lines with two conductors per phase compared to 765 kV single circuit lines with six conductors per phase.

Transmission Voltage (kV)	Cost per Mile ($/mile)	Capacity (MW)	Cost per Unit of Capacity ($/MW-mile)
230	$2.077 million	500	$5,460
345	$2.539 million	967	$2,850
500	$4.328 million	2040	$1,450
765	$6.578 million	5000	$1,320

(Sources: Edison Foundation[12], AEP[13])

SEIA – AWEA Feb 09

"Green Power Superhighways: Building a Path to America's Clean Energy Future"


Pipeline & Gas Journal
Pipeline Opportunities Conference
March 26, 2013
Keynote Speaker: Nick Stavropoulos, Executive Vice President, Gas Operations, PG&E.
Guest Speaker: Jack Weixel, Director, Client Services, BENTEK Energy
154th year • www.pgjonline.com
Volume No. 240 • Number 2 • February 2013
The recognized authority on pipeline operations worldwide.
Cybersecurity & Your Pipeline

2012 AIChE Ammonia Safety Committee

Front: Danny Franceus (Yara), Jim Richardson (Sud-Chemie), John Mason (Agrium), Venkat Pattabathula (Incitec Pivot), AK Singh (IFFCO), Dorothy Shaffer (Baker Risk), Ali Jama (QAFCO)

Back: Ruben Wagek (Vale Fertilizers), John Brightling (Johnson Matthey), Neal Barkley (Coffeyville Resources), Robert Collins (KBR), David Pierce (Southern Ionics), Harrie Duisters (OCI Nitrogen), Svend-Erik Nielsen (Haldor Topsøe), Reinhard Michel (Uhde GmbH), Ian Welch (PCS Nitrogen)

Annual Fresh Water for Energy

- ***USA today***
- ***All energy***

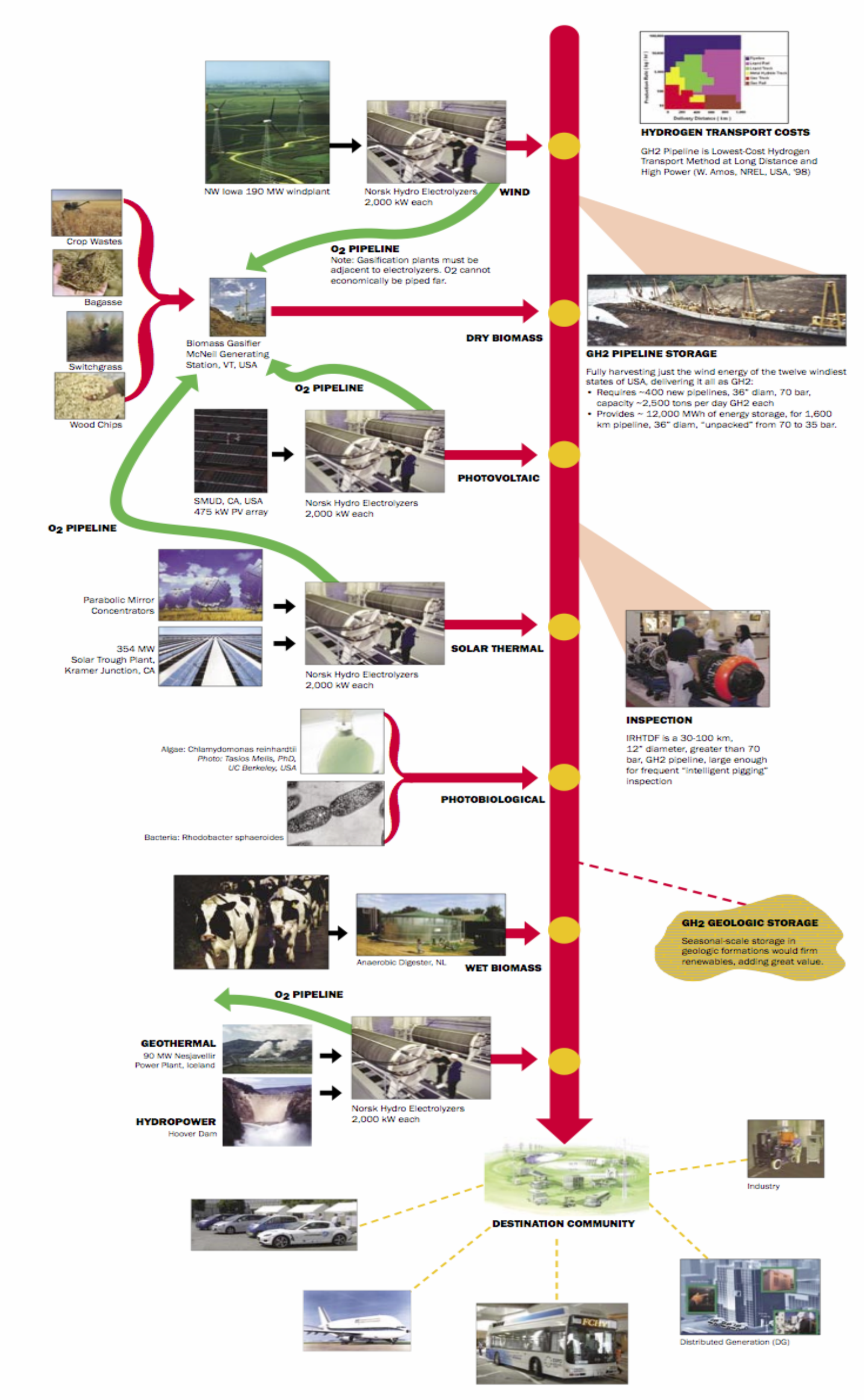
- **17,000 billion liters in today's "energy" system**
  - **"Withdrawn"**
  - **"Consumed"**
  - **Include all oil & gas "fracking" ?**
- **If all via GH2 + NH3 fuels, required feedstock:**
  - **Dissociated, disintegrated: $H_2O \rightarrow H_2 + O_2$**
  - **7,650 billion liters "consumed"**

Hydrogen Utility Group (HUG)

- Southern Company — Energy to Serve Your World
- Sempra Energy
- Southern California Edison — An Edison International Company
- BC hydro
- DTE Energy
- KEPCO — Korea Electric Power Corporation
- Entergy — Entergy Nuclear
- SMUD — Sacramento Municipal Utility District — The Power To Do More.®
- APS®
- New York Power Authority
- City of Fort Collins Utilities
- Connexus® Energy — Your Community Energy Partner
- Xcel Energy®
- Nebraska Public Power District — Always there when you need us

Frank Novachek, Director Corporate Planning

Xcel Energy®



International Renewable Hydrogen Transmission Demonstration Facility

(IRHTDF)

Pilot plant

Global opportunity: IPHE project

Humanity's Goal

- International Collaboration
- Alternatives to electricity
- R & D
- Pilot plant demonstrations

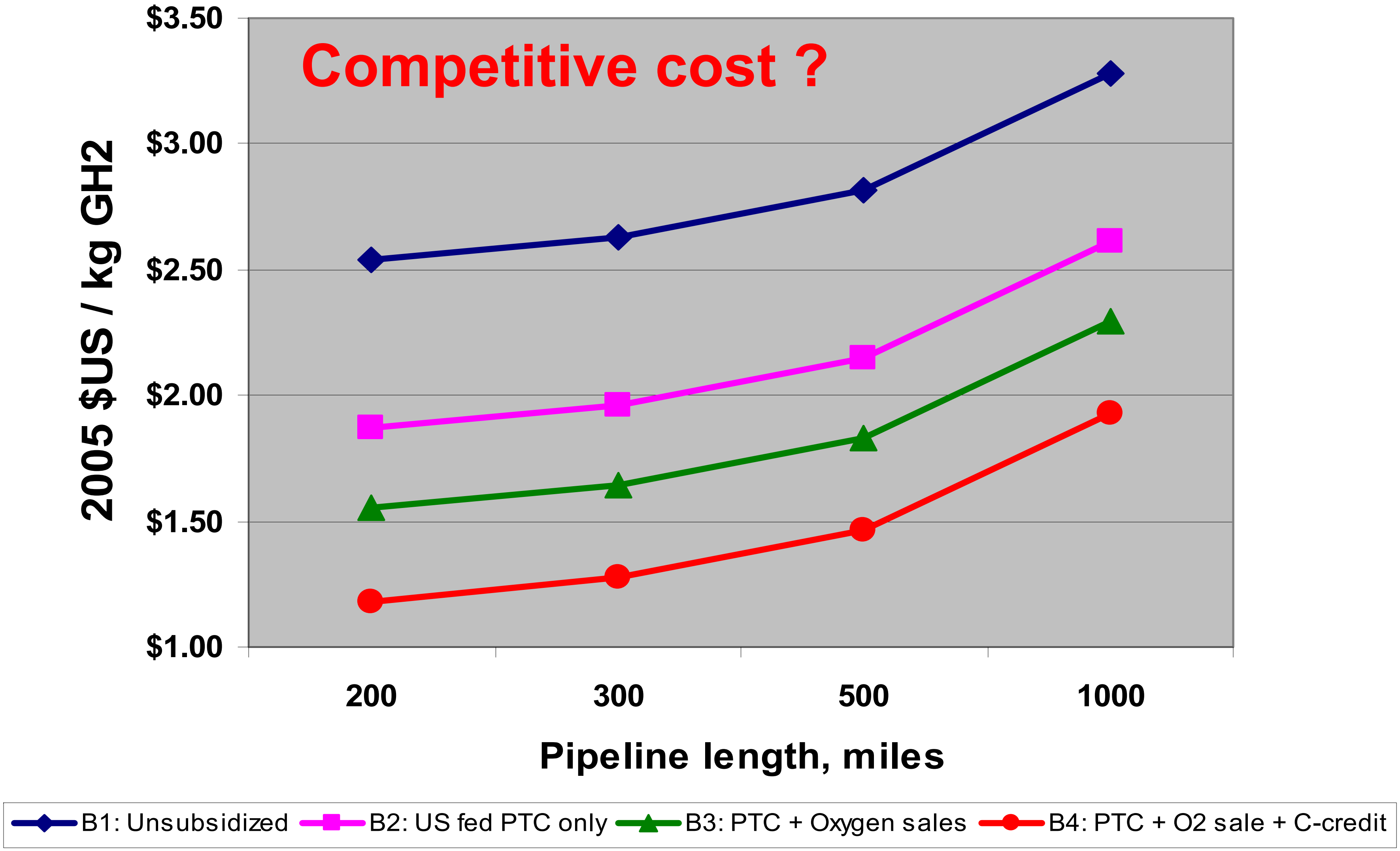
Funding?

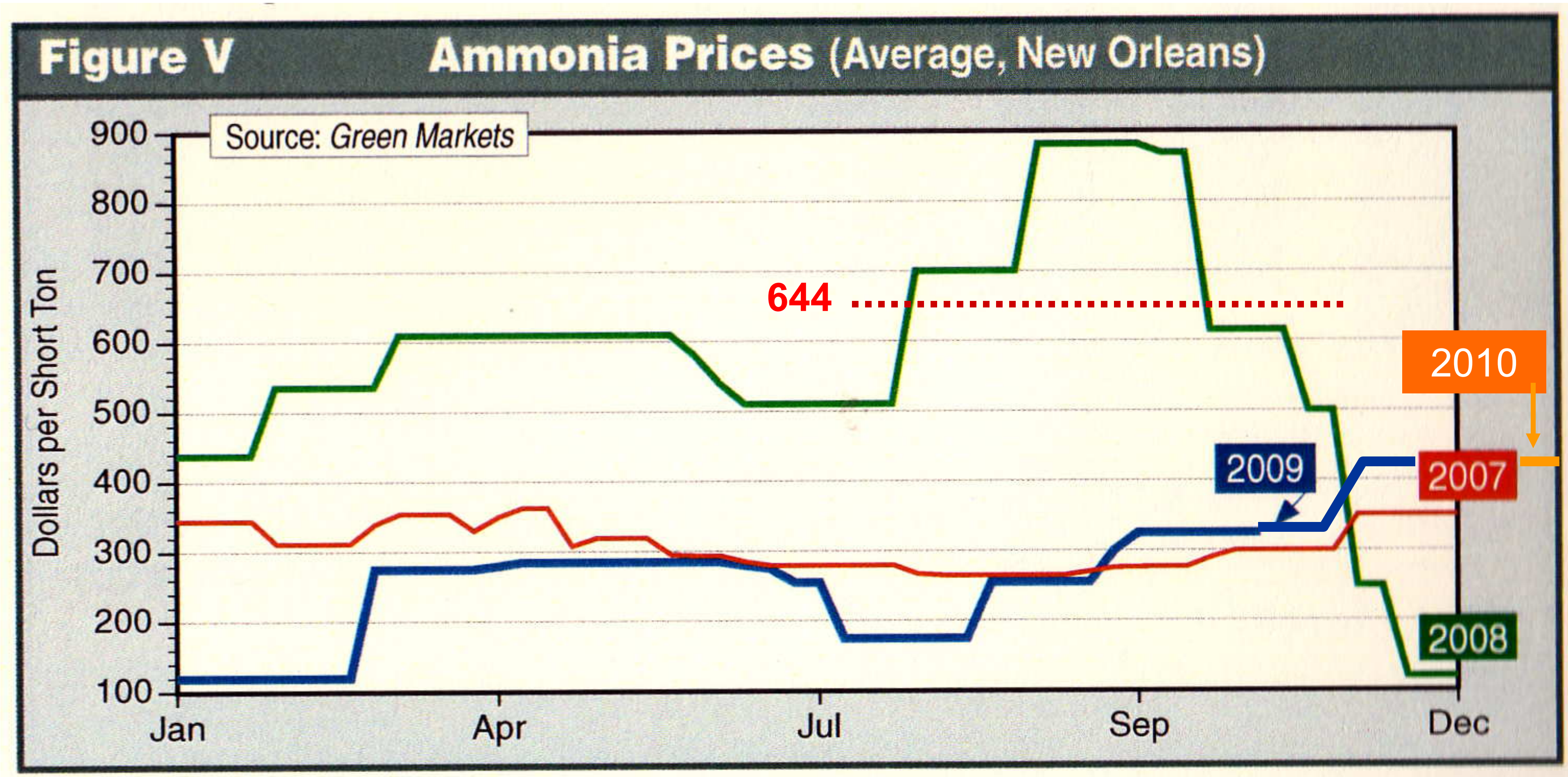
- China, Korea, others
- Big oil
- Military spending
- Global C-tax
- Capital markets

GW-scale Transmission + Storage Options

- **Electricity: HVAC, HVDC**
  - **CAES compressed air energy storage**
  - **Vanadium Redox battery (VRB Power Systems)**
  - **Sodium-sulfur battery**
  - **PHEV, BEV (distributed)**
- **Gaseous Hydrogen (GH2)**
  - **Pipeline**
  - **Geologic: salt caverns (man-made)**
  - **Geologic: natural formations ? *Terra incognita***
- **Liquid Hydrogen (LH2)**
  - **Pipeline, truck, rail car, ship**
  - **1/3 energy to liquefy Ammonia (NH3) liquid**
  - **Tank, refrigerated, 10K – 60K ton**
  - **Truck, rail car, ship**
- **Liquid anhydrous ammonia (NH3)**
  - **Pipelines**
  - **Tanks**
- **Liquid synthetic HC's – zero net C**
  - **Pipeline**
  - **Tank, truck, rail car, ship**
  - **Geologic: salt caverns (man made)**
- **"Energy Pipeline", EPRI: LH2 in pipeline, SC LVDC electric**
- **Chemicals**
  - **Hydrides**
  - **Al – Ga ← → Alumina**

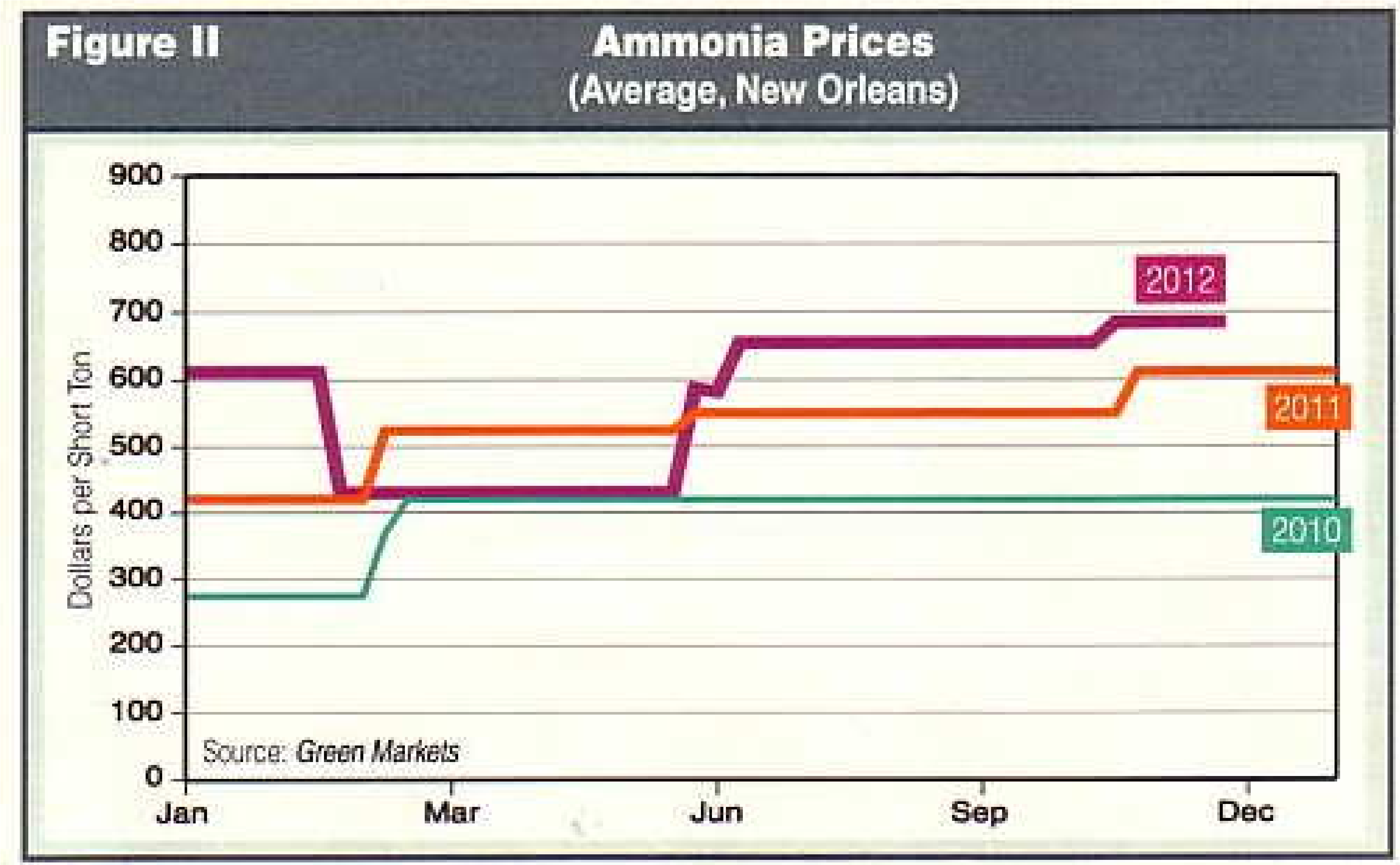
OPTIMISTIC
City-gate GH2 cost @ 15% CRF, 20" pipeline, from 2,000 MW Great Plains windplant





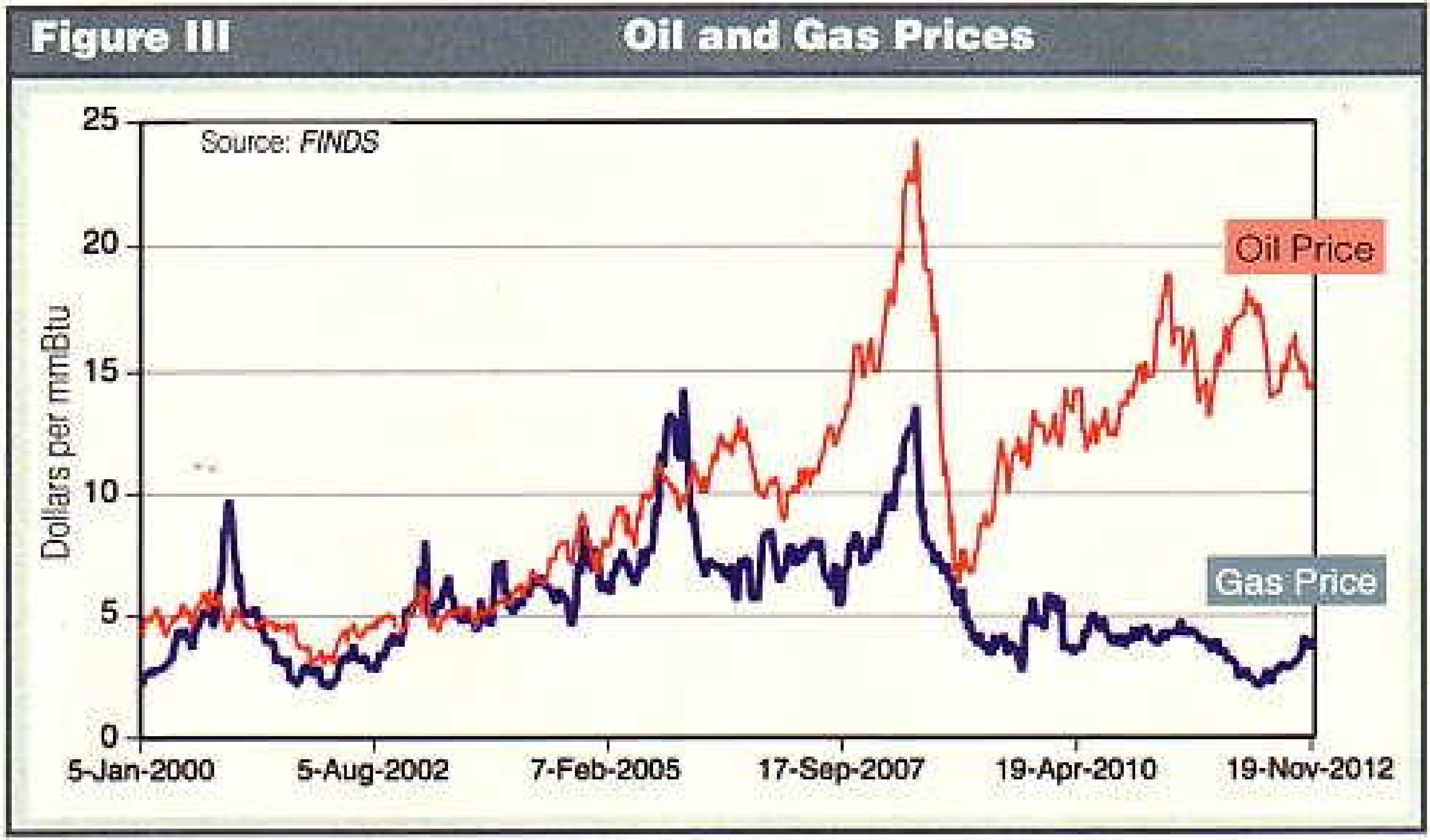
Anhydrous Ammonia (NH3) wholesale price,

NOLA (New Orleans, LA)



Anhydrous Ammonia (NH3) wholesale price,

NOLA (New Orleans, LA)



Oil and Natural Gas Prices, late 2012

1. Decrease Cash OUT: Village "Energy Independence" via RE Generation + Storage

- **What's Annual Average RE Cost of Energy (COE) ?**
- **Competitive ?**
- **What degree of "energy independence" ?**
- **Is SSAS required ?**

2. Increase Cash IN: Export AK GW-scale RE as "Green" Ammonia

- **Can RE compete with "brown" ?**
- **What would C-tax need to be ?**
- **What would global NG price need to be?**

Humanity's Goal

A global, sustainable, benign, equitable, energy economy

Humanity's Goal

- International Collaboration
- Alternatives to electricity
- R & D
- Pilot plant demonstrations

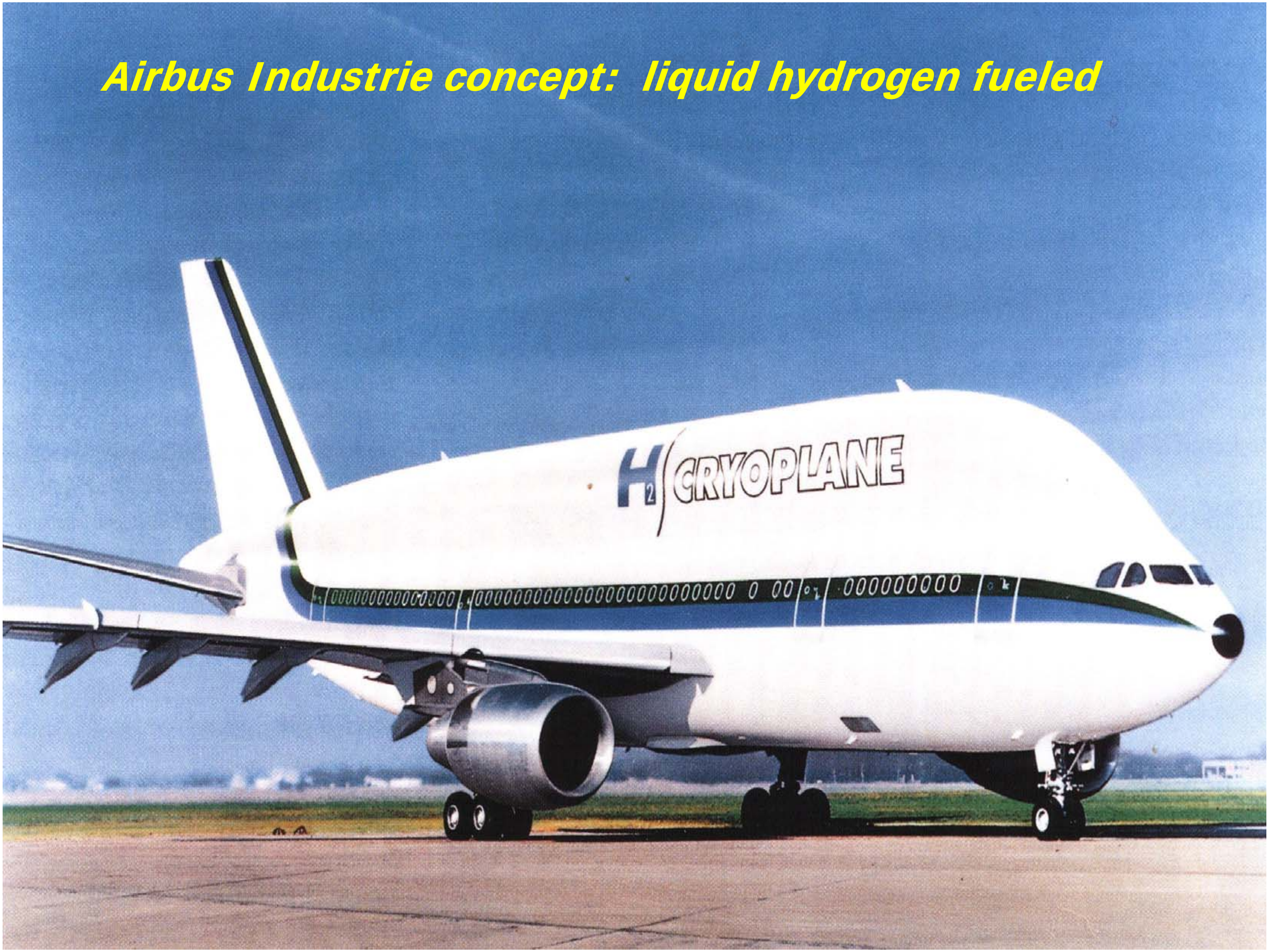
Funding?

- – China, Korea, others
- – Big oil
- – Military spending
- – Global C-tax
- – Capital markets: Mike Eckhart, 19 Oct

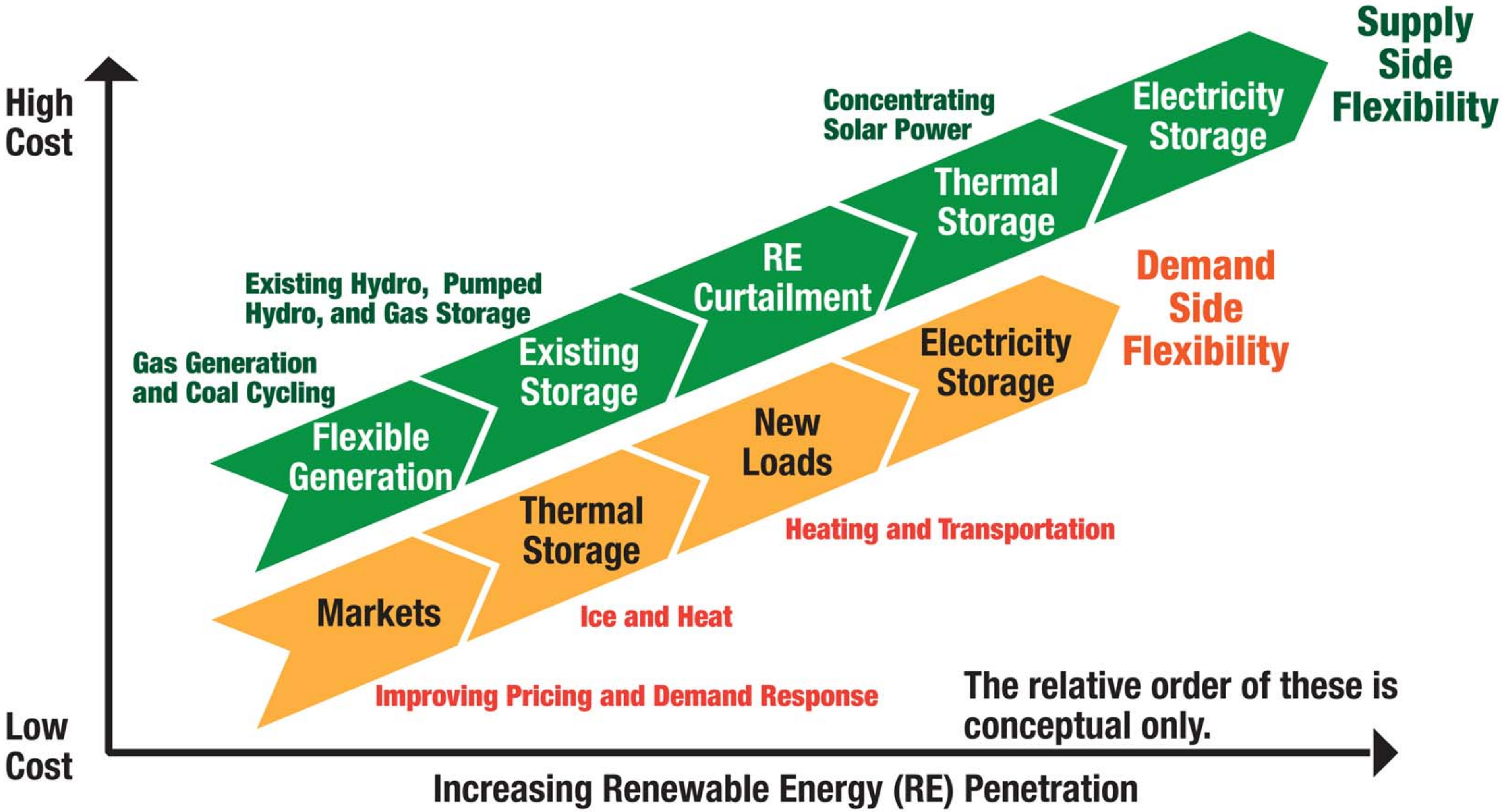
Trouble with Renewables: Electricity Transmission

- Grid nearly full
  - New must pay for transmission
  - Costly: AC or DC
- Integration
  - Continental energy system
  - Quality
  - Generation O+M: fatigue, wear, low efficiency
- Low capacity factor (CF) or curtailment
- Costly “firming” storage: CAES, VRB
- Overhead vulnerable: God or man
- Underground: Only HVDC, 6x cost
- FERC no interstate jurisdiction
- Wide ROW
- NIMBY: site, ROW delay + cost

Airbus Industrie concept: liquid hydrogen fueled



Flexibility Supply Curve



NREL: Systems Integration

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

Stanford wind energy study: 2003

- Underestimated: PNNL, NREL
- 80 m hub height
- 1.3 – 1.7 m / s faster windspeed
- IF transmission network:

  steady, reliable, abundant supply

"Spatial and temporal distributions of U.S. winds and wind power at 80 m derived from measurements"

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 108, NO. D9, 4289, 2003

Jan '09 Transmission Backlog

• California:	13 GW wind
	30 GW solar
• Upper Midwest	70 GW wind
• Lower Midwest	40 GW wind
• Great Lakes + Mid Atlantic	40 GW wind
• Texas	50 GW wind
Total	**243 GW**
Potential Great Plains Wind	**3,000 GW**

SSAS Pilot Plant Budget

EETF via AEA	**$ 750 K**
NHThree LLC in-kind	**$ 100 K**
Wind2Green (W2G) in-kind	**$ 100 K**
AASI in-kind	**$ 50 K**
TOTAL	**$ 1 M**

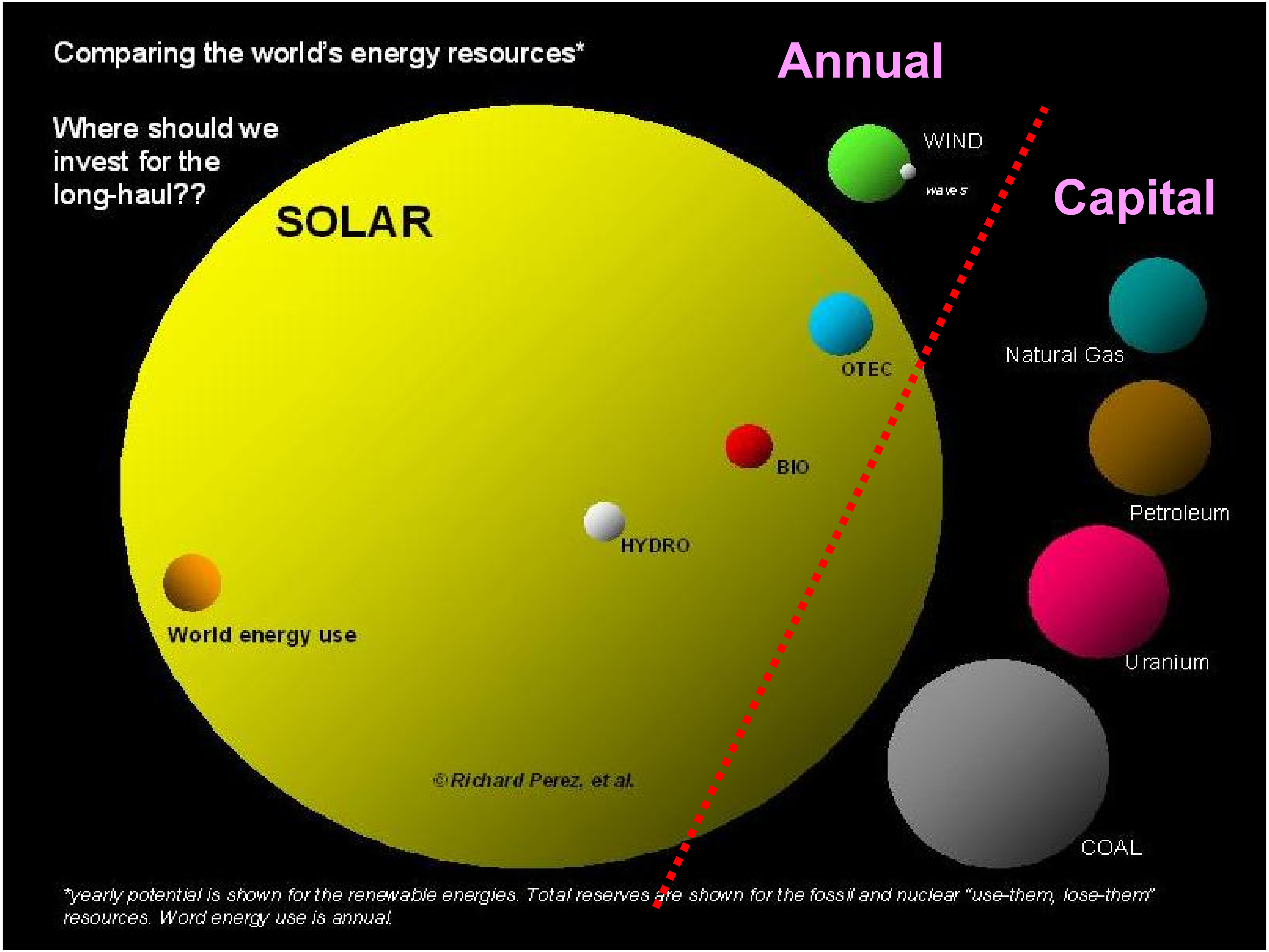
EETF Emerging Energy Technology Fund, State of Alaska

AEA Alaska Energy Authority, State of Alaska

AASI Alaska Applied Sciences, Inc.

SSAS Pilot Plant Schedule: 24 months from ~ Dec '12

1. Test PCC tubes; accept
2. Build and test multi-tube reactor
3. Build and test BOS
4. Instrument with SCADA, remote read at UAF
5. Add regeneration: NH_3 → electricity to grid
6. Package in insulated CONEX
7. Acceptance test
8. Transport to Juneau, AK for demo
9. Demo at other AK sites as budget allows
10. Upgrade as budget allows

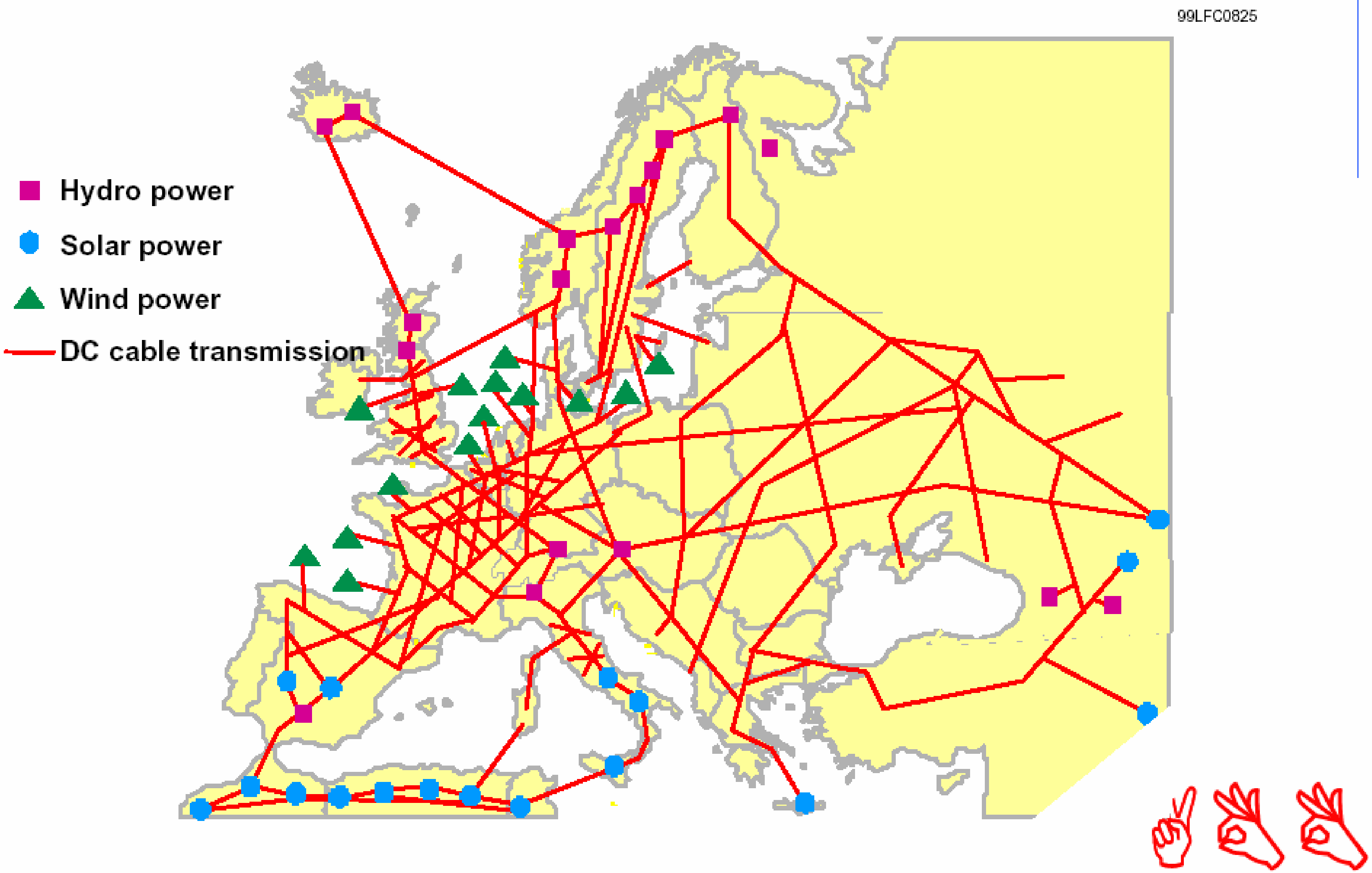


Comparing the world's energy resources*
Annual
Where should we invest for the long-haul??
SOLAR
WIND
waves
Capital
Natural Gas
OTEC
BIO
Petroleum
HYDRO
World energy use
Uranium
© Richard Perez, et al.
COAL
*yearly potential is shown for the renewable energies. Total reserves are shown for the fossil and nuclear "use-them, lose-them" resources. Word energy use is annual.

Gaseous Hydrogen (GH2)
36" diam, 500 miles
No compression
8,000 MW

Vision: Remote renewable energy sources

connected to loads by DC grid



© ABB Ltd - Page 15
IEEE July 2001

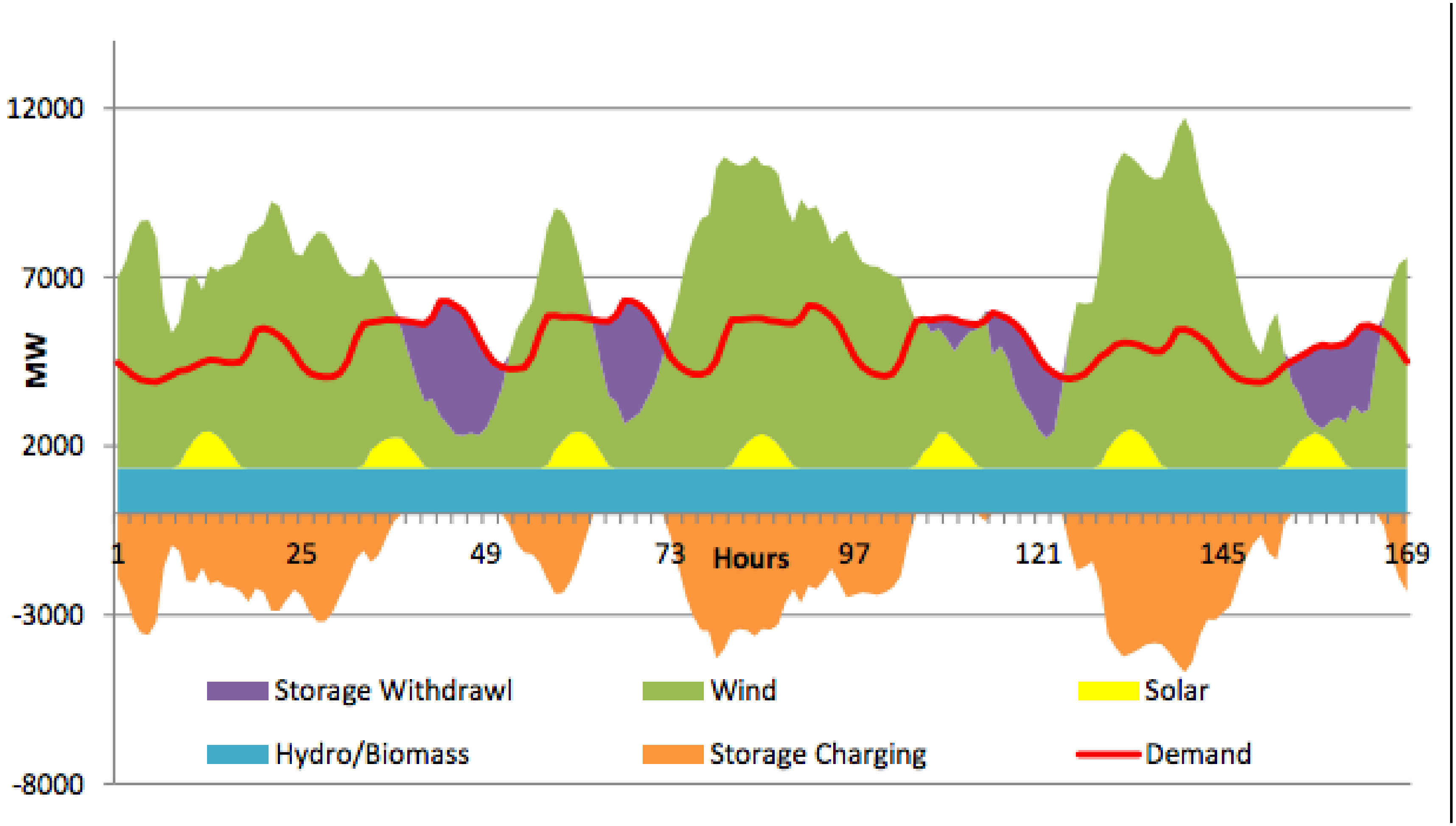
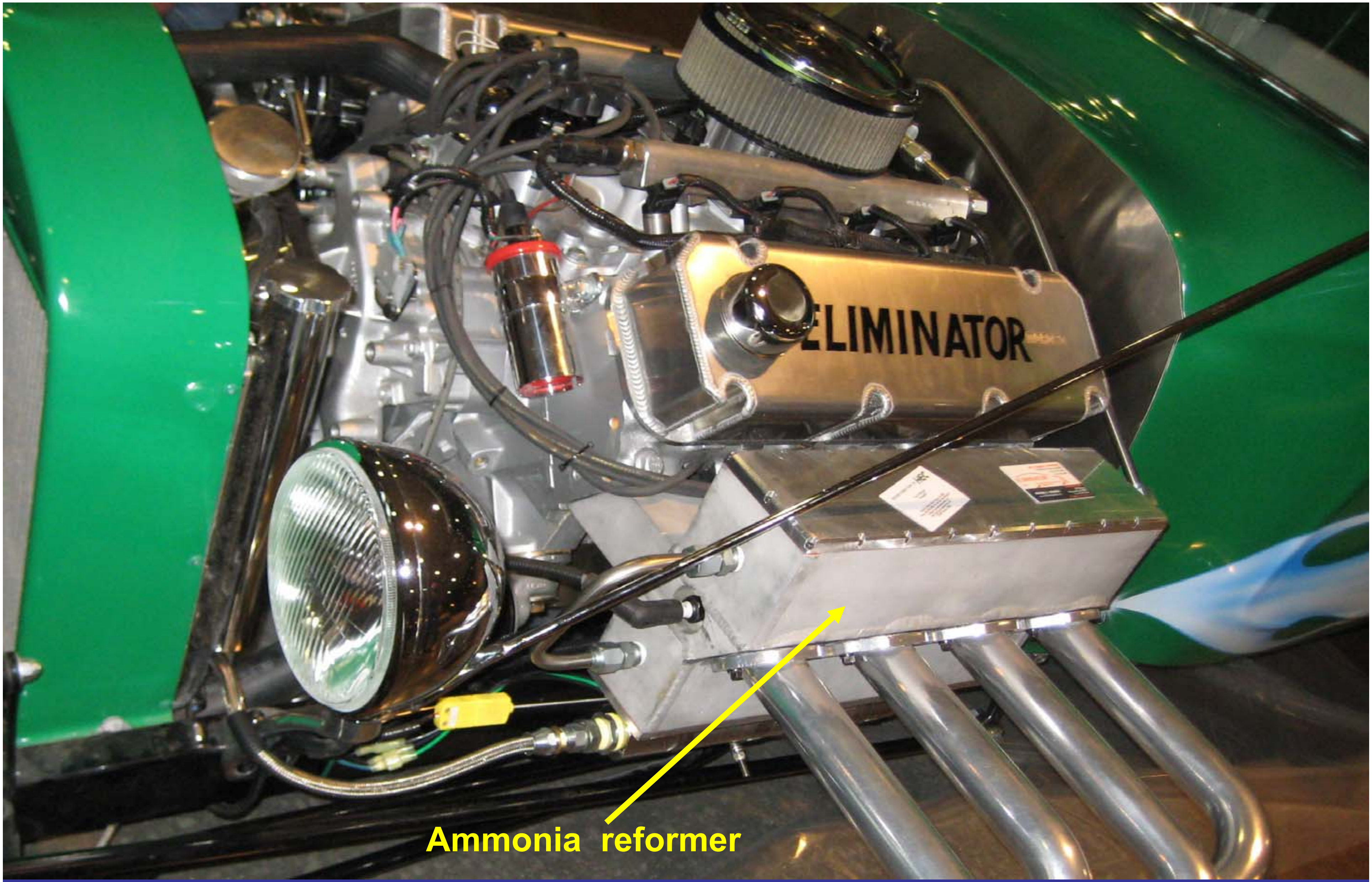


Figure III-6: Hourly supply and demand with storage, January 1-7, 2007. *Source: IEER.*



Oct ’09 Ammonia Fueled V-8 with Hydrogen Injection: Reformed from NH_3

Hydrogen Engine Center, Algona, IA

2009

MUST Run the World on Renewables – plus Nuclear ?

- Global
- Indigenous
- Firm: available
- C-free
- Benign
- Abundant
- Affordable
- Equitable
- Perpetual:
  - solar
  - geothermal
  - tidal