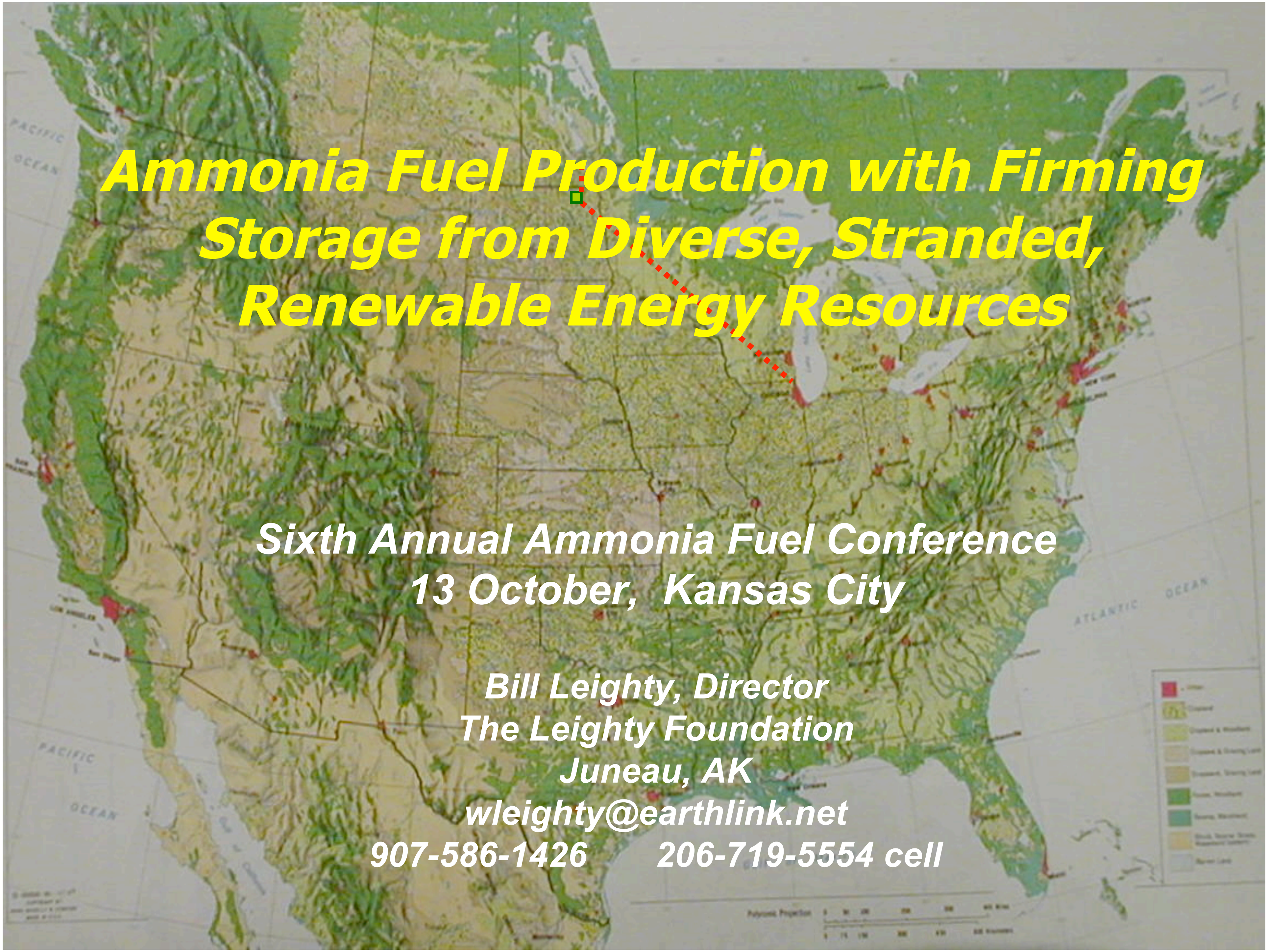


Ammonia Fuel Production with Firming Storage from Diverse, Stranded, Renewable Energy Resources

Sixth Annual Ammonia Fuel Conference
13 October, Kansas City

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

MUST Run the World on Renewables – plus Nuclear ?

Earth's only source of income: Solar radiation, lunar tides

MUST Run the World on Renewables – plus Nuclear ?

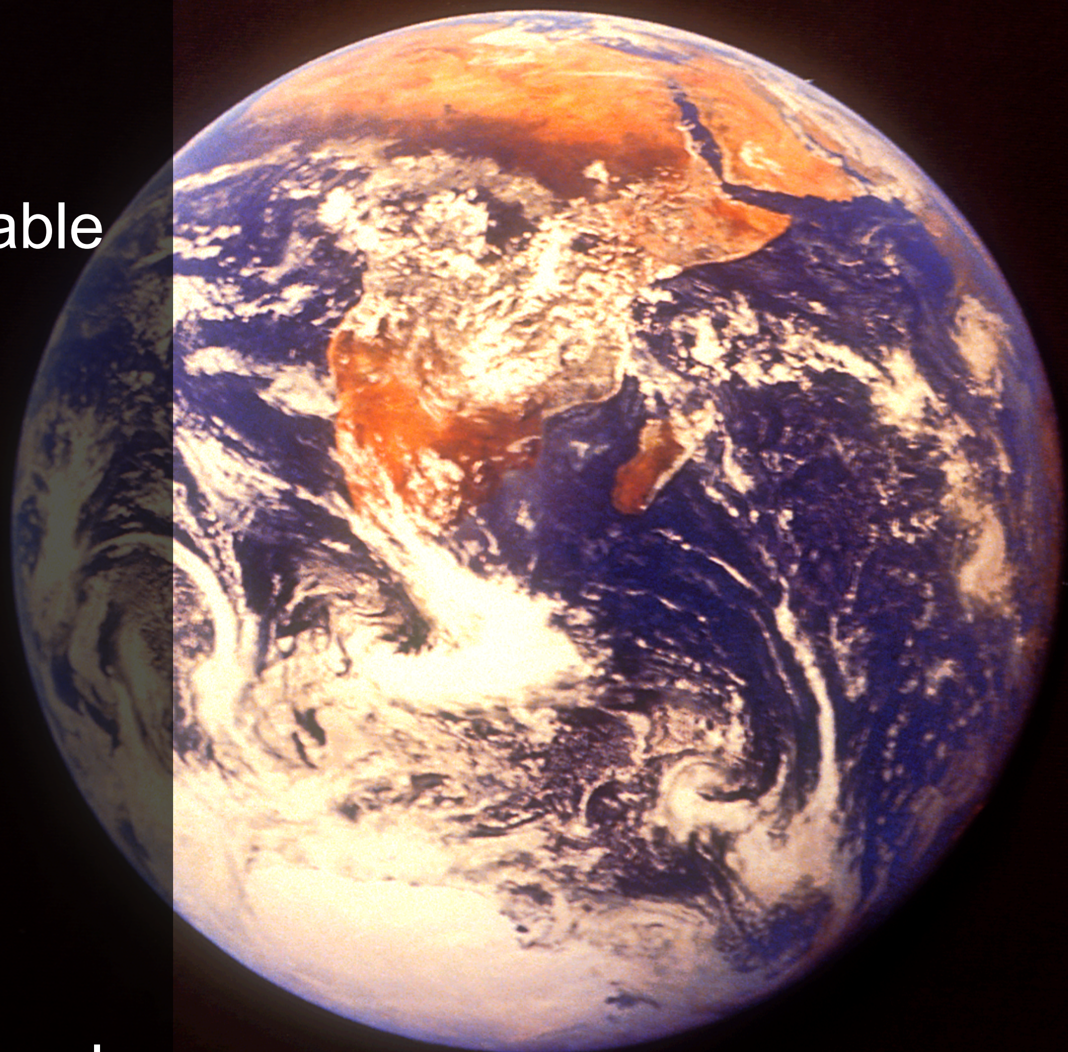
- Climate Change
- Demand growth
- Depletion of Oil and Gas
- Only 200 years of Coal left
- Only Source of Income:
    - Sunshine
    - Tides
    - Meteors and dust
    - Spend our capital ?

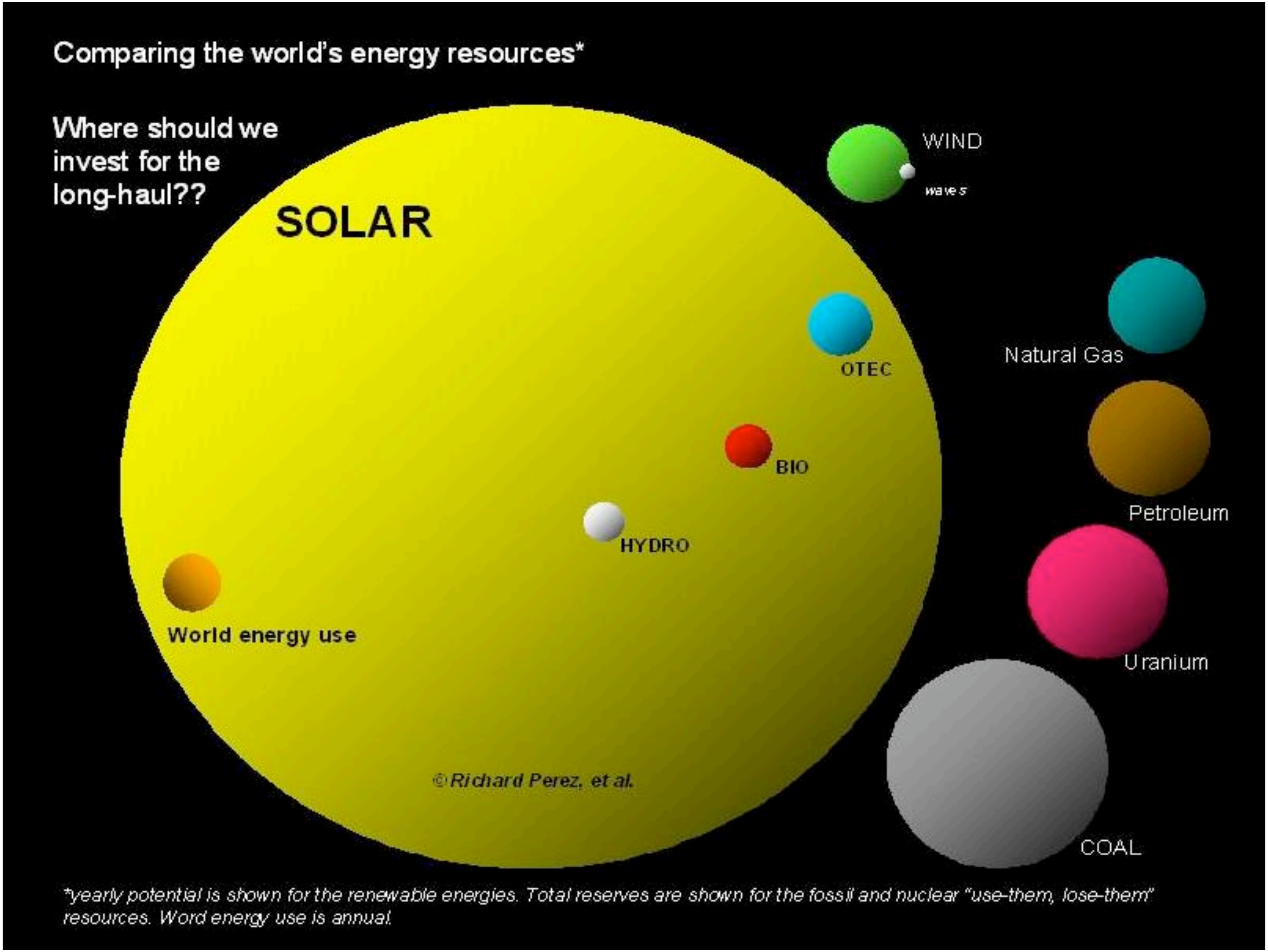
MUST Run the World on Renewables – plus Nuclear ?

- Emergencies:
  - Climate change
  - Energy prices
  - Energy security
- Conservation + efficiency
- GW scale renewables
- Beyond Electricity Grid
- Energy: beyond electricity
- Hydrogen , ammonia, ?

MUST Run the World on Renewables – plus Nuclear ?

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




Comparing the world's energy resources*
Where should we invest for the long-haul??
SOLAR
WIND
waves
OTEC
Natural Gas
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.

WE'RE HERE:
385.92 ppm
WE NEED TO GET BELOW:
350 ppm
www.350.org
CO_2 in the Atmosphere

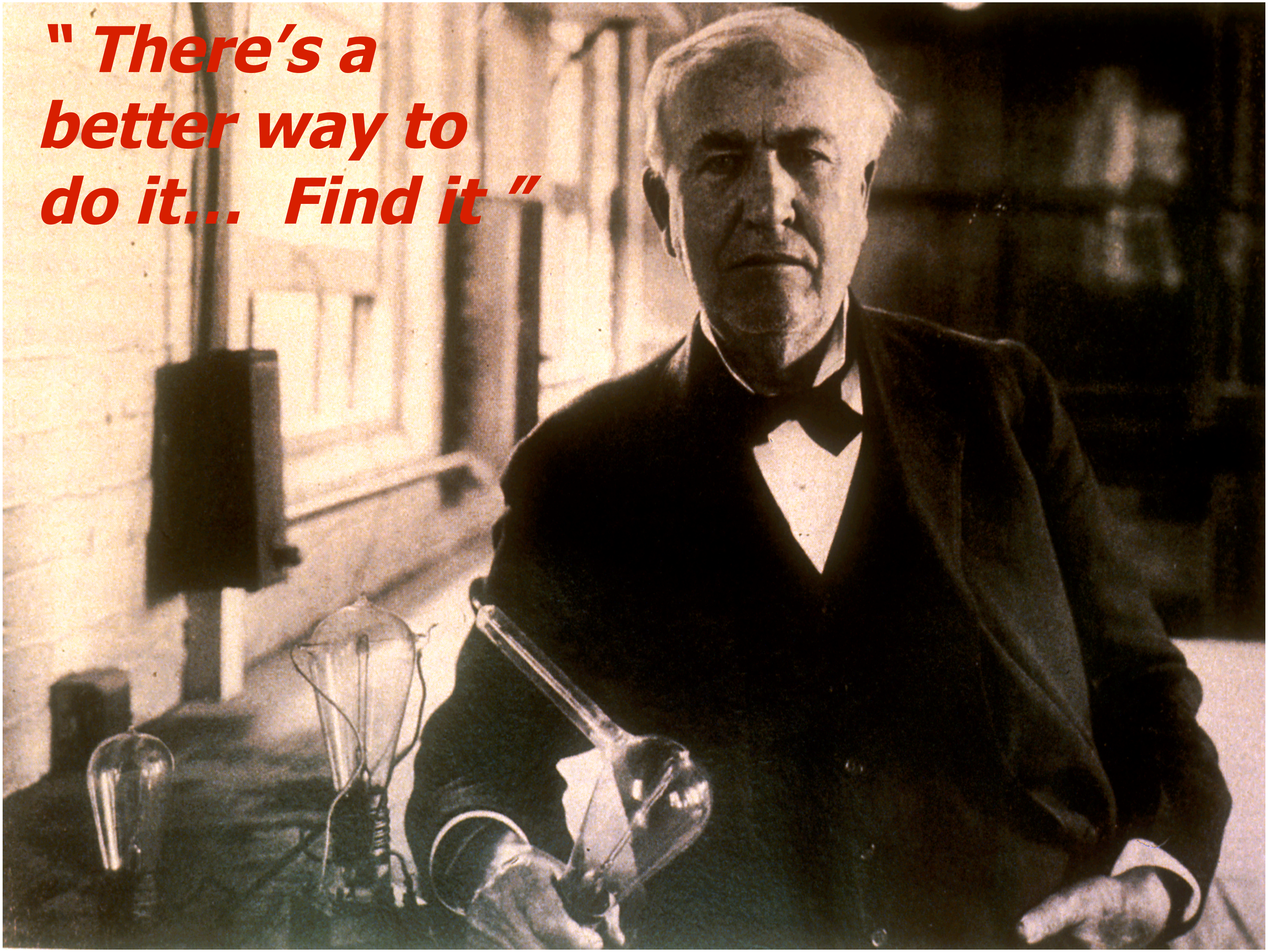
“ Americans can be counted on to always do the right thing –

but only after they have tried everything else ”

Winston Churchill

The dog caught the car.

Dan Reicher

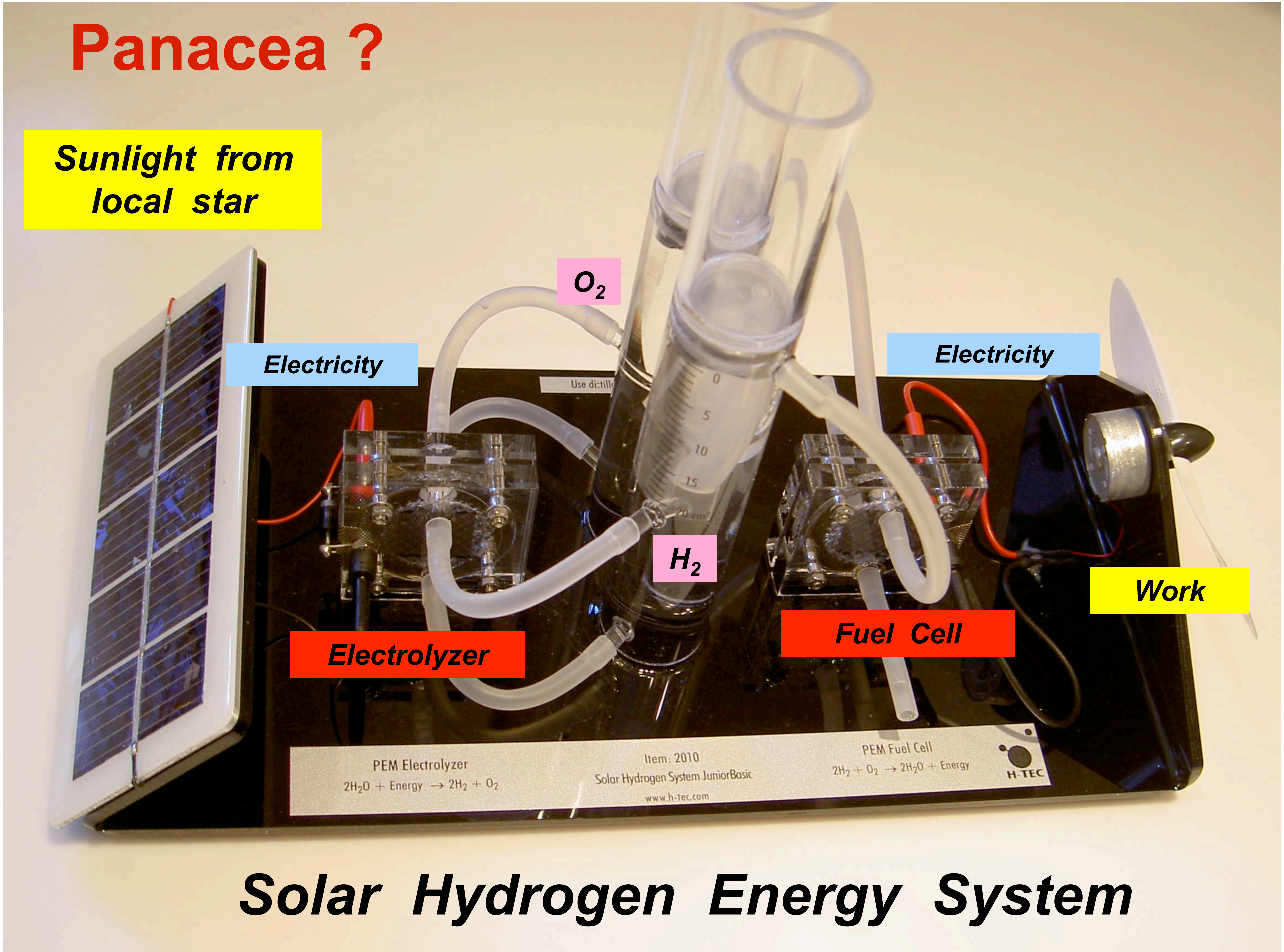

" There's a better way to do it... Find it "

Pickens Plan

- Bold, large-scale, motivates thinking
- Rally public: “Army”
- Disappoint ? Disillusion ?
- GW scale: economies
- Underestimates
  - Transmission
  - Grid integration, thermal plant abuse
  - Firming storage needed
- Disregards Hydrogen demand
  - Gulf Coast refineries
  - Transport fuel
- Out of gas ?

Benefit / Cost Perspective

- **Analytical framework: Not all answers**
- **Long-term**
- **Benefits**
- **Costs**
- **Systems thinking → tech, econ analysis**

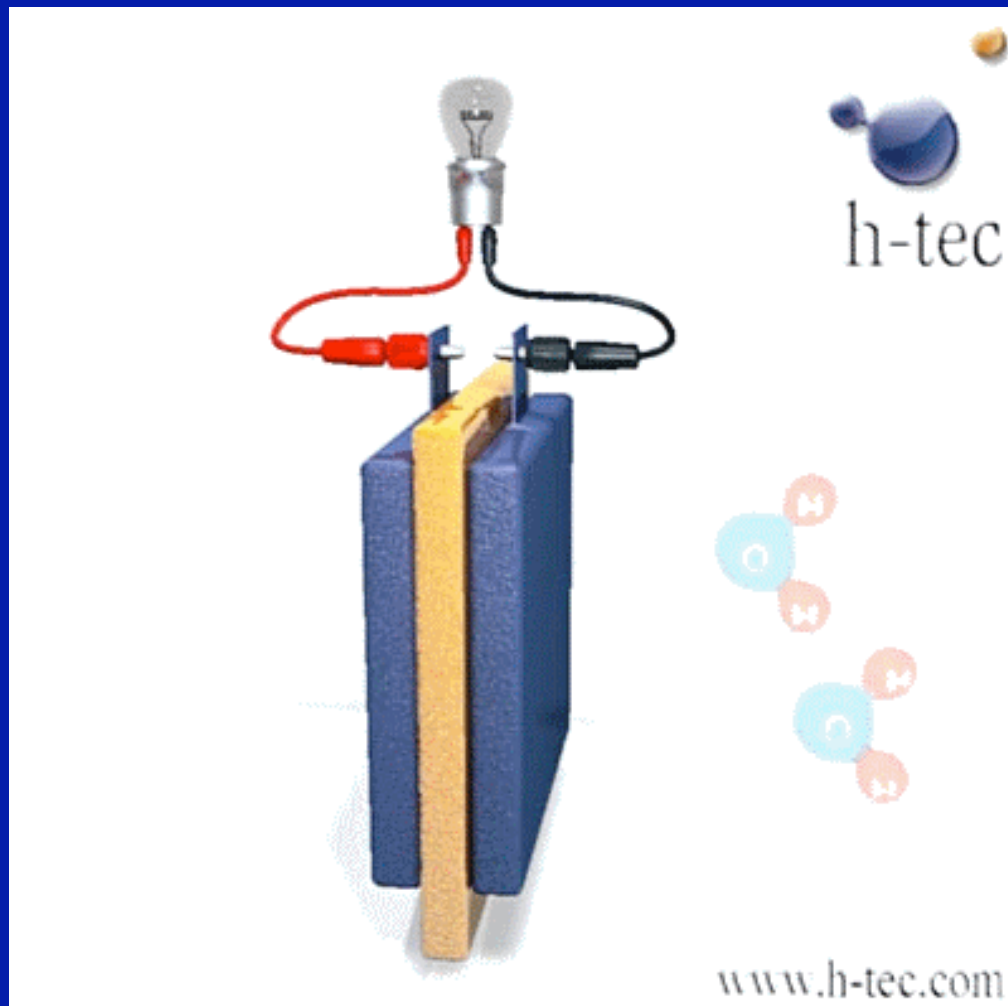


Panacea ?
Sunlight from local star
Electricity
O_2
H_2
Electricity
Work
Electrolyzer
Fuel Cell
PEM Electrolyzer
$2H_2O$ + Energy → $2H_2 + O_2$
Item: 2010
Solar Hydrogen System JuniorBasic
www.h-tec.com
PEM Fuel Cell
$2H_2 + O_2$ → $2H_2O$ + Energy
H-TEC
Solar Hydrogen Energy System

Hydrogen Fuel Cell

Proton Exchange Membrane (PEM) type

Hydrogen (H_2) combines with Oxygen (O_2) to make electricity + heat + water (H_2O)

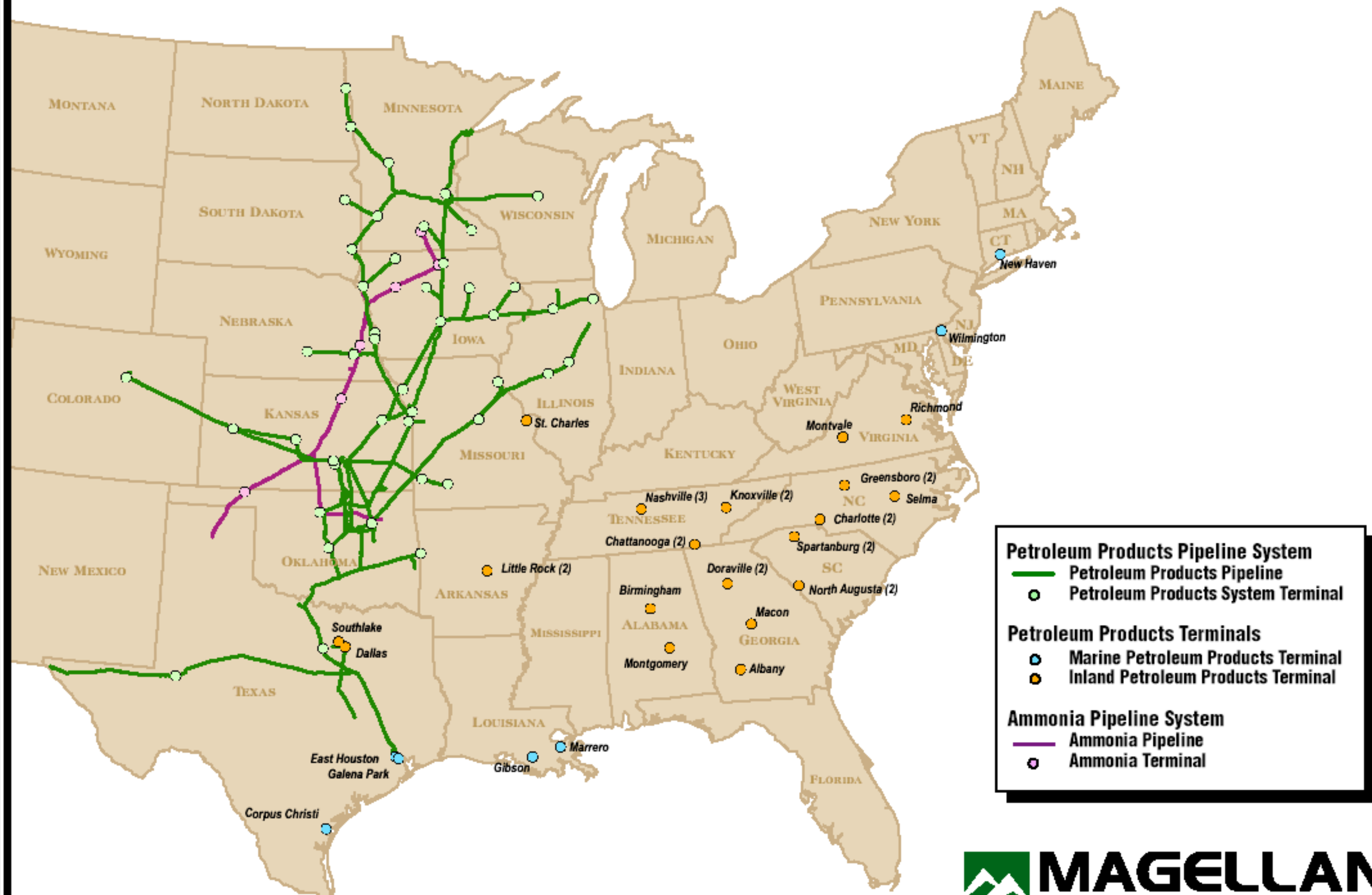


“Ammonia Nation ?”

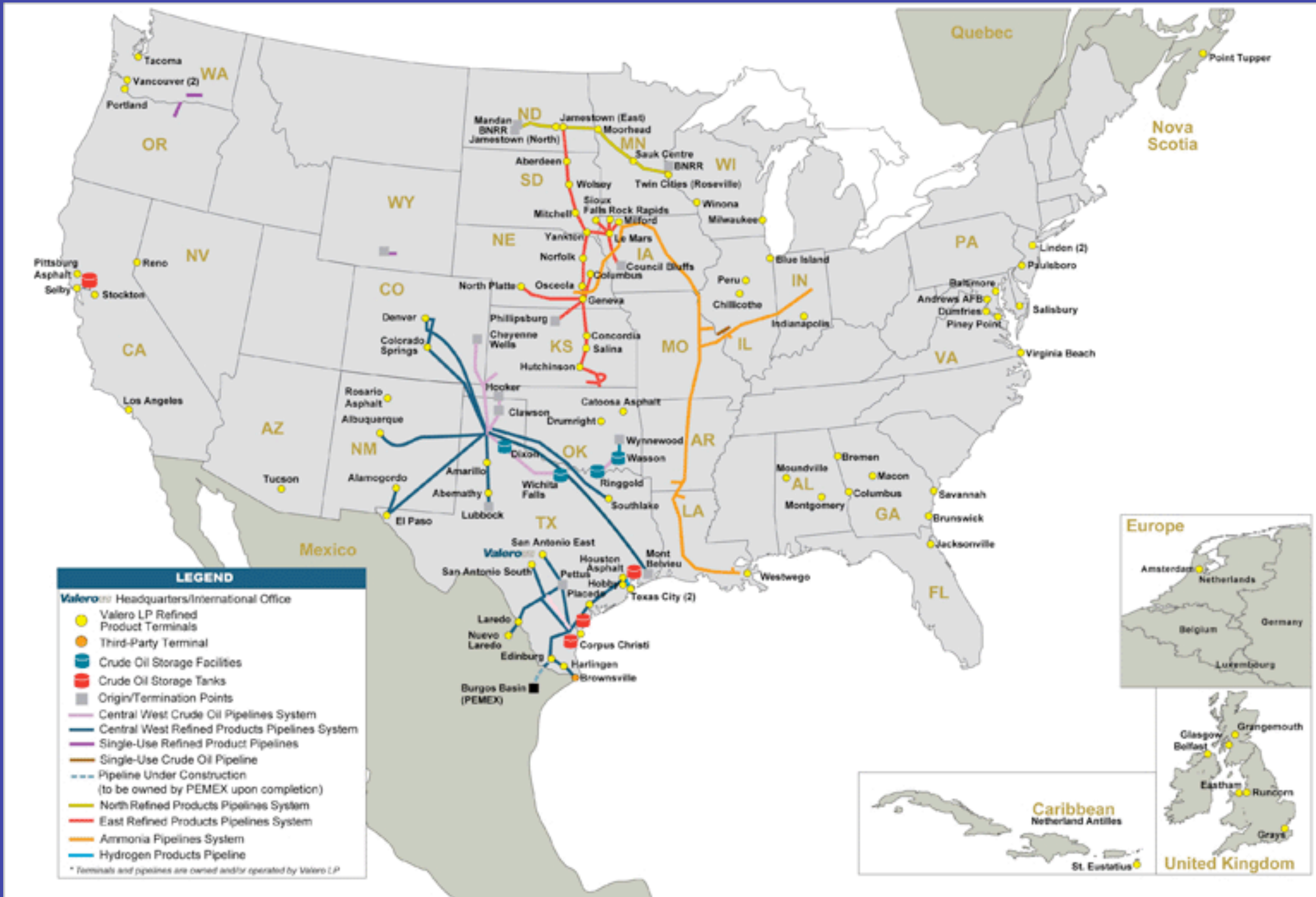
Anhydrous ammonia (NH3)

- Low-cost transmission, storage: liquid
- Transportation fuel
- Stationary generation, CHP
- Total USA annual energy ’02 - 06
    - 100 quads
    - 10,000 TWh
- More renewables than coal
- Coal limits:
    - Only 200 year supply ?
    - CCS limits: where to put the CO2 ?

Asset Portfolio



MAGELLAN®
MIDSTREAM PARTNERS, L.P.

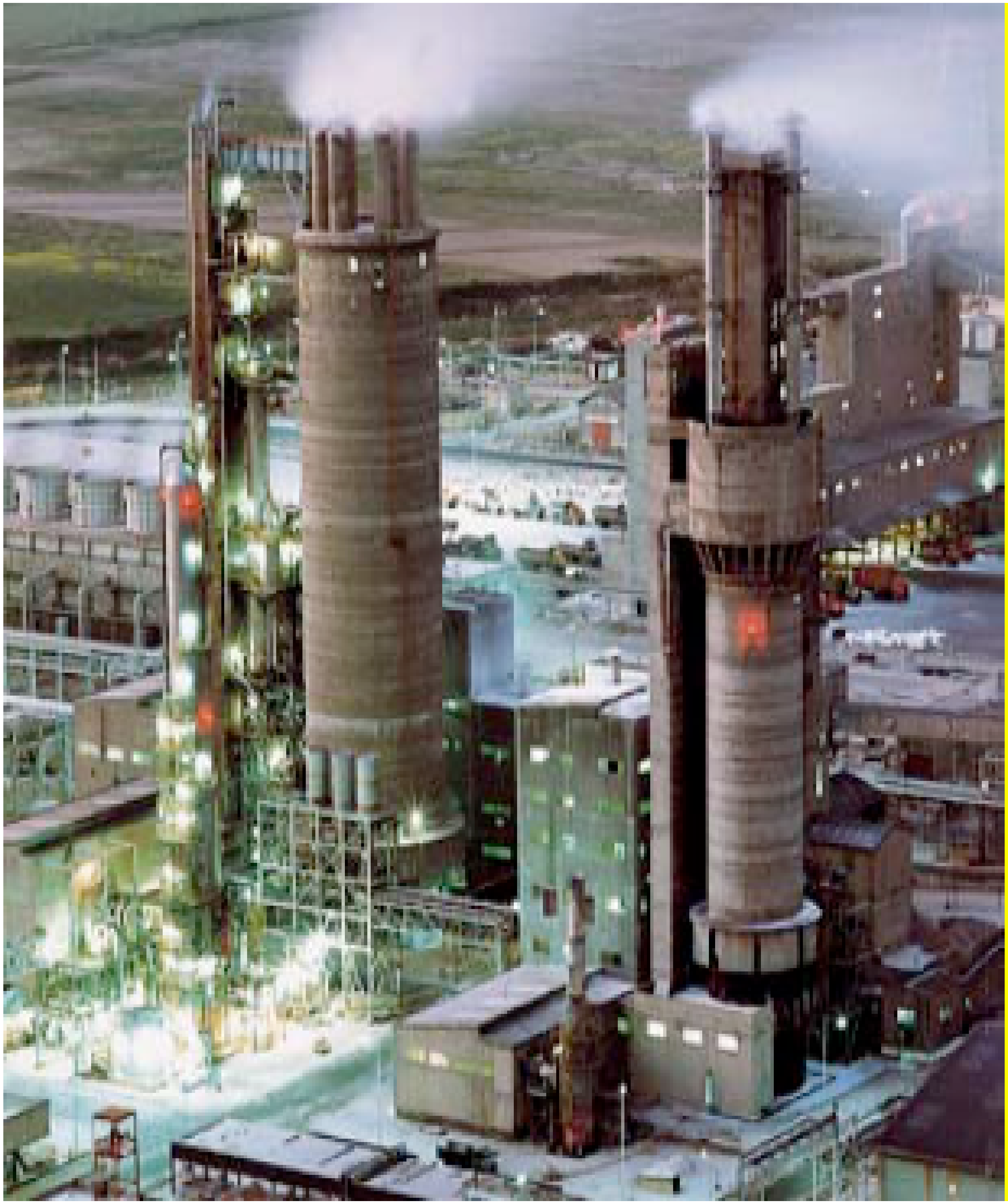


Valero LP Operations

Why Ammonia ?

Only liquid fuel embracing:

- Potentially all RE-source
- Cost competitive with HC fuels
- Carbon-free
- Energy cycle inherently pollution free
- Reasonably high energy density
- Practical to handle, store, and transport
- End-use in ICE, CT, fuel cell
- Self-odorizing safety
- "The other hydrogen"



Ammonia
(NH_3)
Synthesis
Plant

Natural Gas

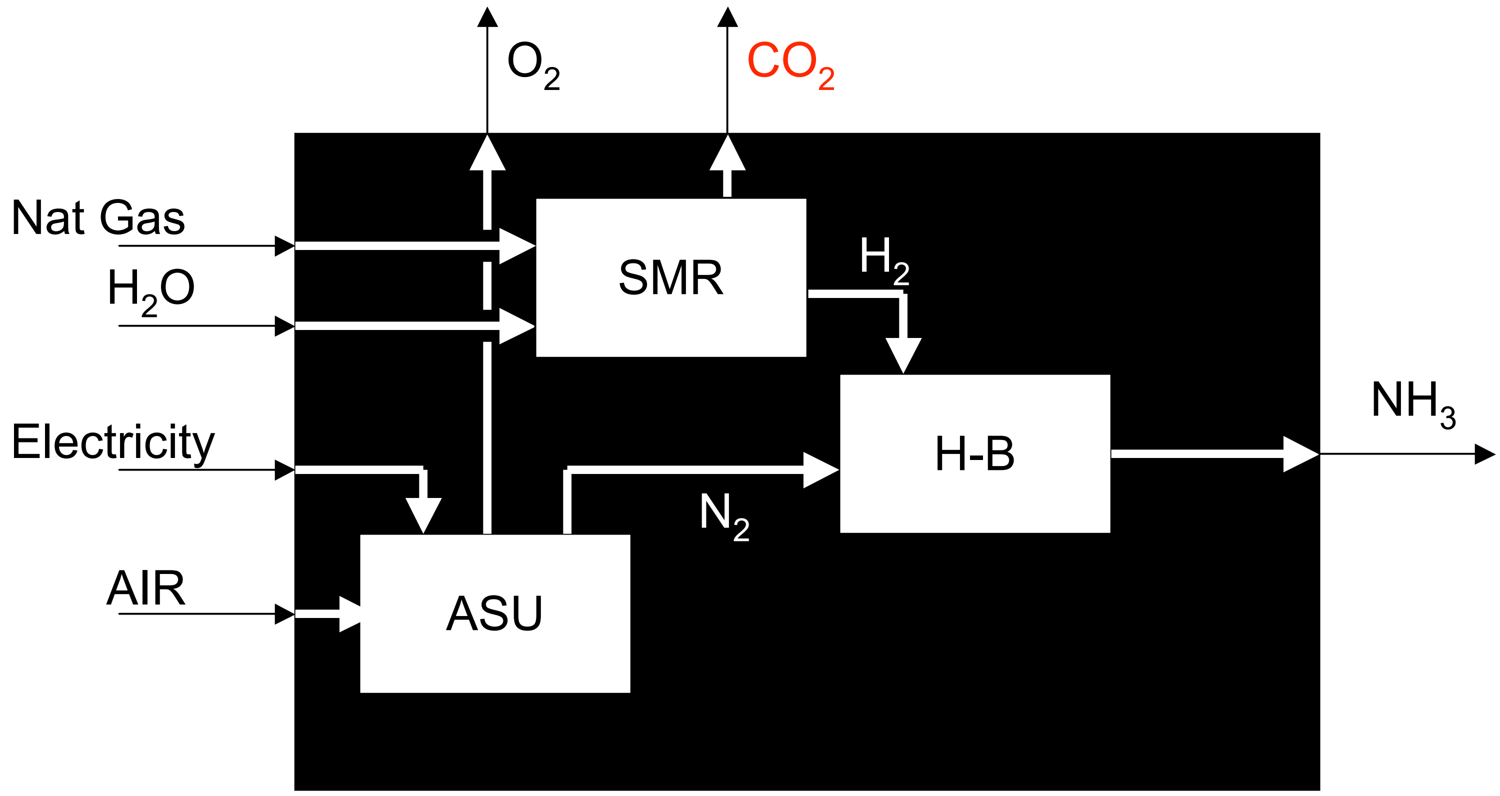
Feed

1 – 3,000 tpd

Haber-Bosch
“Synloop”

Inside the Black Box: Steam Reforming + Haber-Bosch

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



Energy consumption ~33 MBtu (9500 kWh) per ton NH_3

The Great Plains Wind Resource
PACIFIC OCEAN
ATLANTIC OCEAN
Gulf of Mexico
LOS ANGELES
NEW YORK
Polyconic Projection

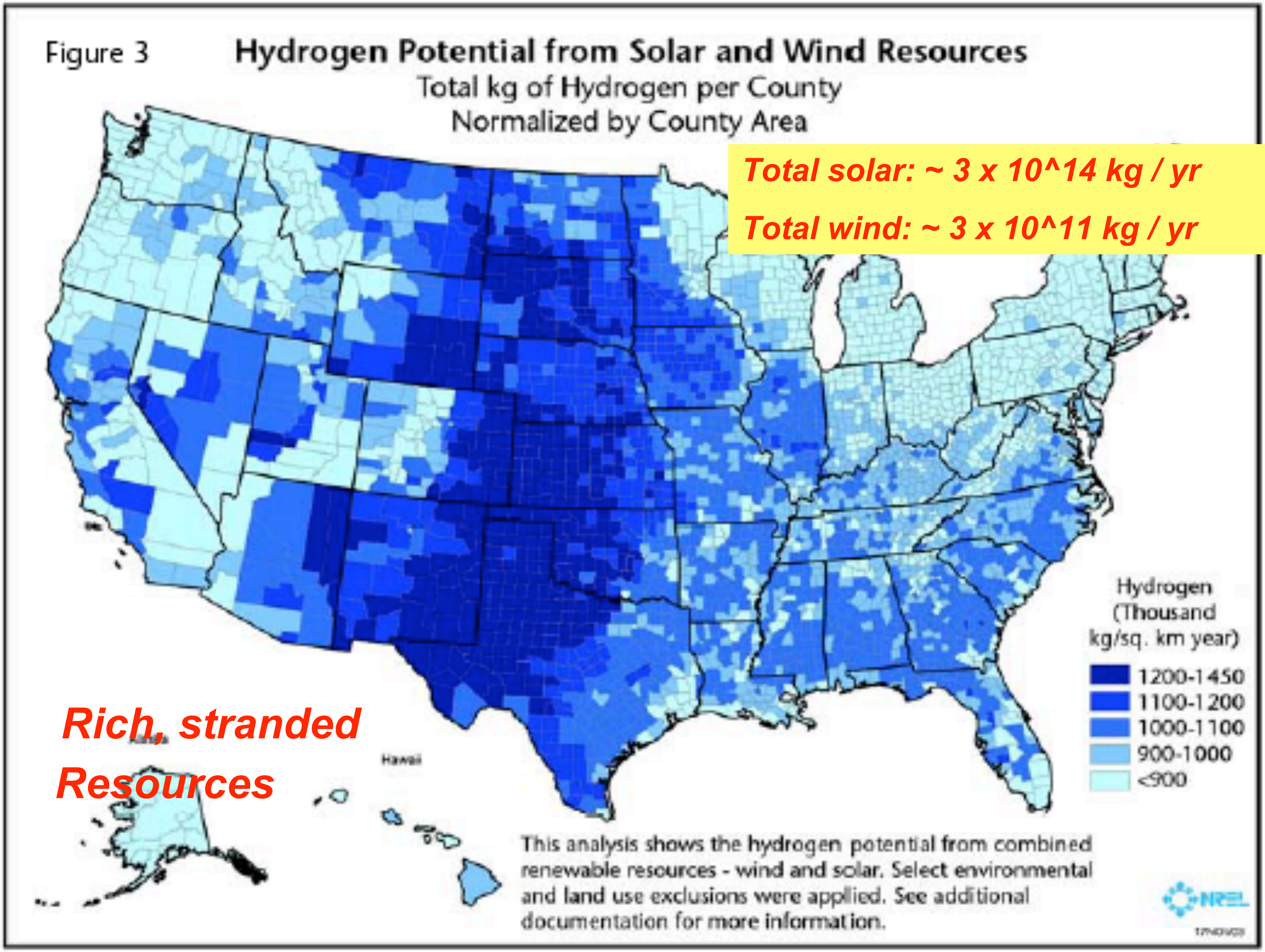


Figure 3
Hydrogen Potential from Solar and Wind Resources
Total kg of Hydrogen per County
Normalized by County Area
Total solar: ~ 3 x 10^14 kg / yr
Total wind: ~ 3 x 10^11 kg / yr
Rich, stranded
Resources
Hawaii
Hydrogen
(Thousand
kg/sq. km year)
1200-1450
1100-1200
1000-1100
900-1000
<900
This analysis 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.
NREL


The Great Plains Wind Resource
How shall we bring the large, stranded, Great Plains renewables to market ?
PACIFIC OCEAN
ATLANTIC OCEAN
Gulf of Mexico

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

Trouble with Renewables

- Diffuse, dispersed: gathering cost
- Richest are remote: “stranded”
- Time-varying output:
  - “intermittent”
  - “firming” storage required
- Transmission:
  - low capacity factor (CF) or curtailment
  - NIMBY
- Distributed or centralized ?

Trouble with Renewables - Electricity Transmission

- **Grid nearly full**
  - **New wind must pay for transmission**
  - **Costly: AC or DC**
- **NIMBY**
- **Low capacity factor or curtailment**
- **No storage: smoothing or firming**
- **Overhead towers vulnerable: God or man**
- **Underground: Only HVDC**

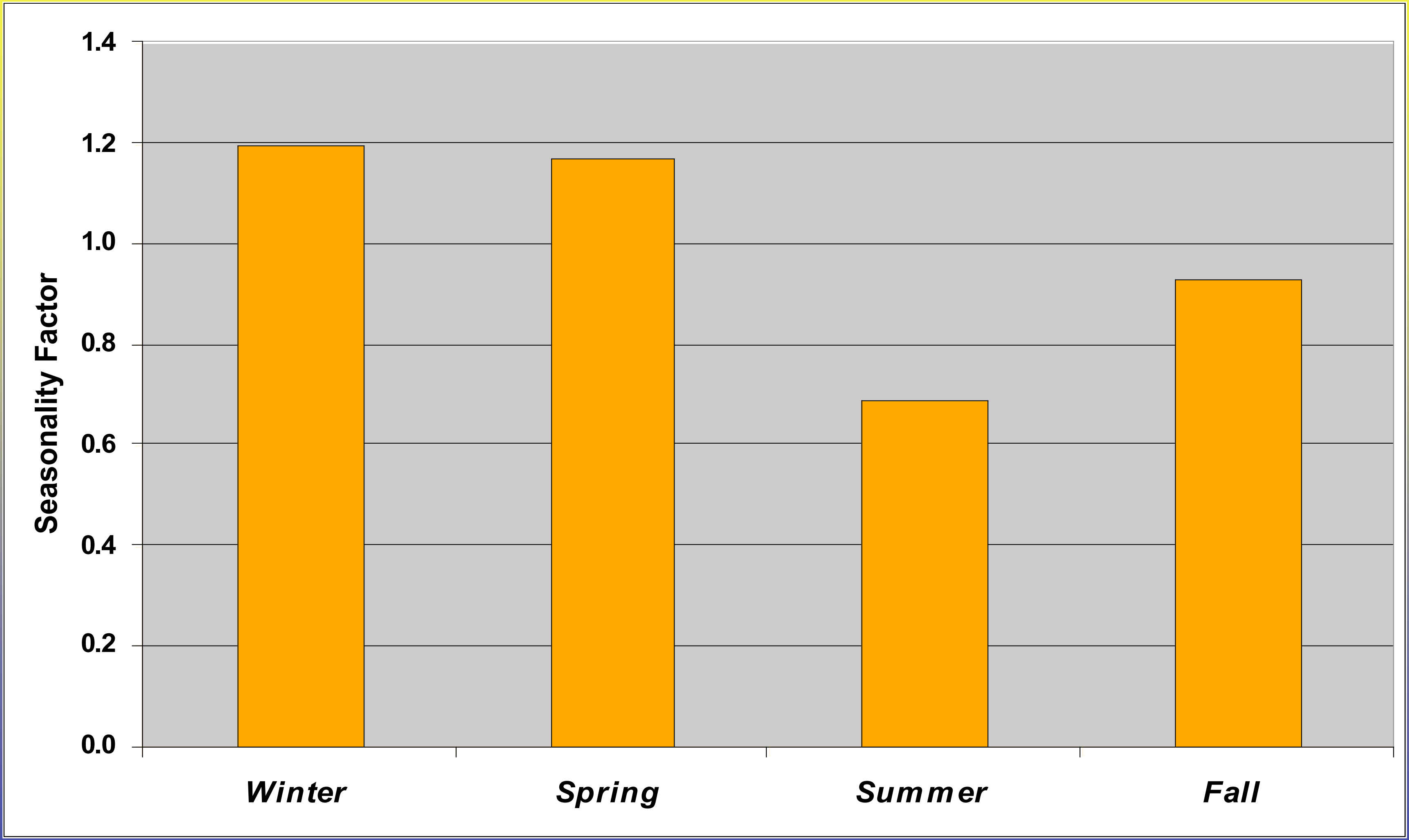
Wind seasonality, Great Plains

- 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



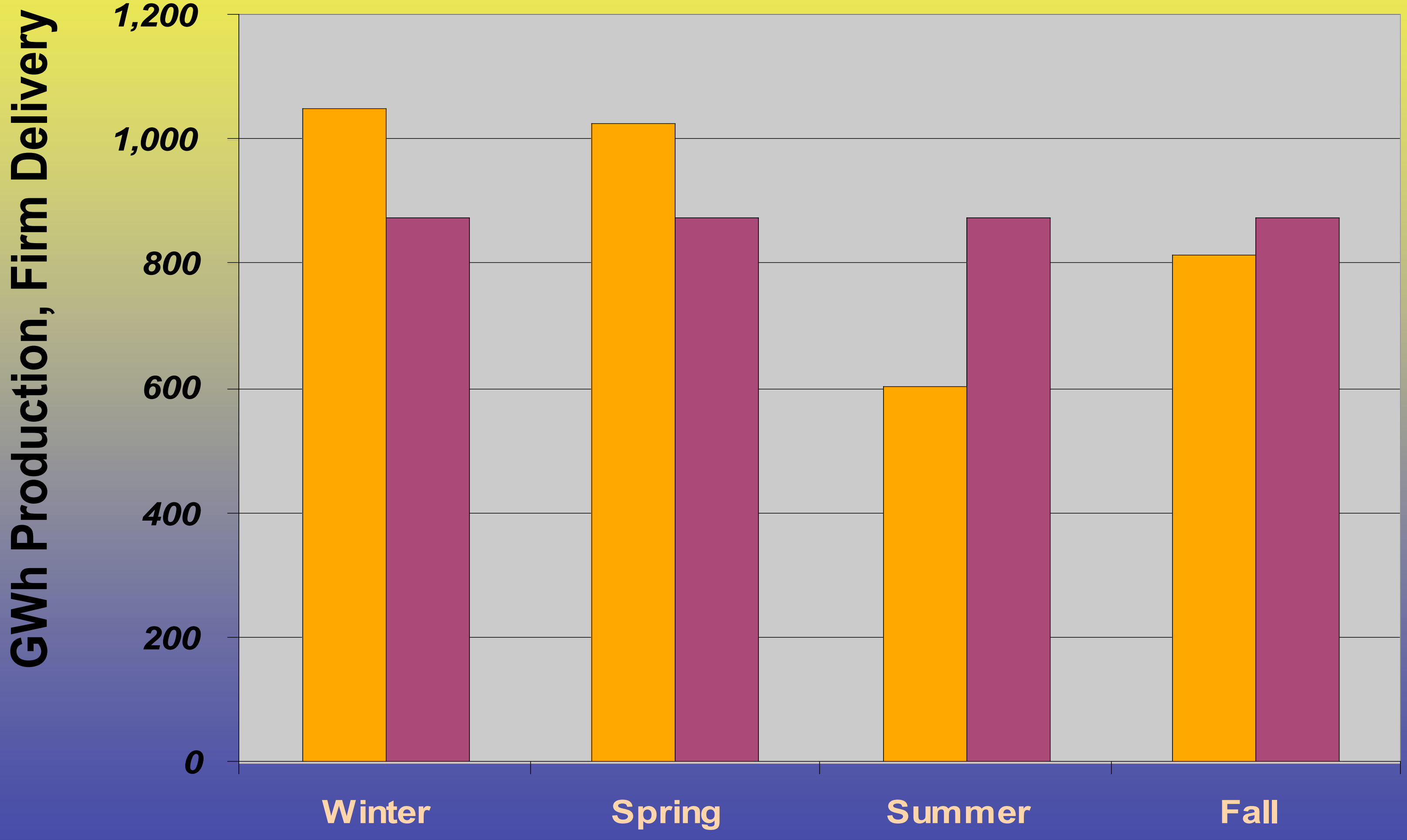
Wind Seasonality, Northern Great Plains

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



Annual – scale "Firming"
Great Plains Wind

- **Potential, 12 states, ~50% land area:**
  - **10,000 TWh = 100 quads = entire USA energy**
  - **2,800,000 MW nameplate**
- **Seasonality:**
  - **Summer minimum**
  - **Spring – Summer maximum storage**
  - **"Firming" energy storage, per 1,000 MW wind:**
    - **As electricity = 320 GWh**
    - **As GH2 = 15,712 tons, metric @ 2,500 tons / cavern = 6 caverns**
    - **As NH3 = 87,291 tons, metric @ 60,000 tons / tank = 1.4 tanks**
  - **"Firming" energy storage, all great Plains wind:**
    - **As GH2 = 17,000 caverns @ $15M each = $264 billion**
    - **As NH3 = 5,000 tanks @ $25M each = $127 billion**

"Firm" energy worth more

- **Every hour, every year**
- **Strategic: indigenous, secure, essential**
- **Dispatchable**
- **Market price**
- **Bankable large projects**
- **Risk avoidance: rapid climate change**
- **RE C-taxes acceptable**

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**
        @$ 30 / kWh = $ 10 Billion
- **GH2 (3 hydrogen caverns) Capital $70 Million**
- **NH3 (2 ammonia tanks) Capital $30 Million**

Focus: Energy Storage Alternatives

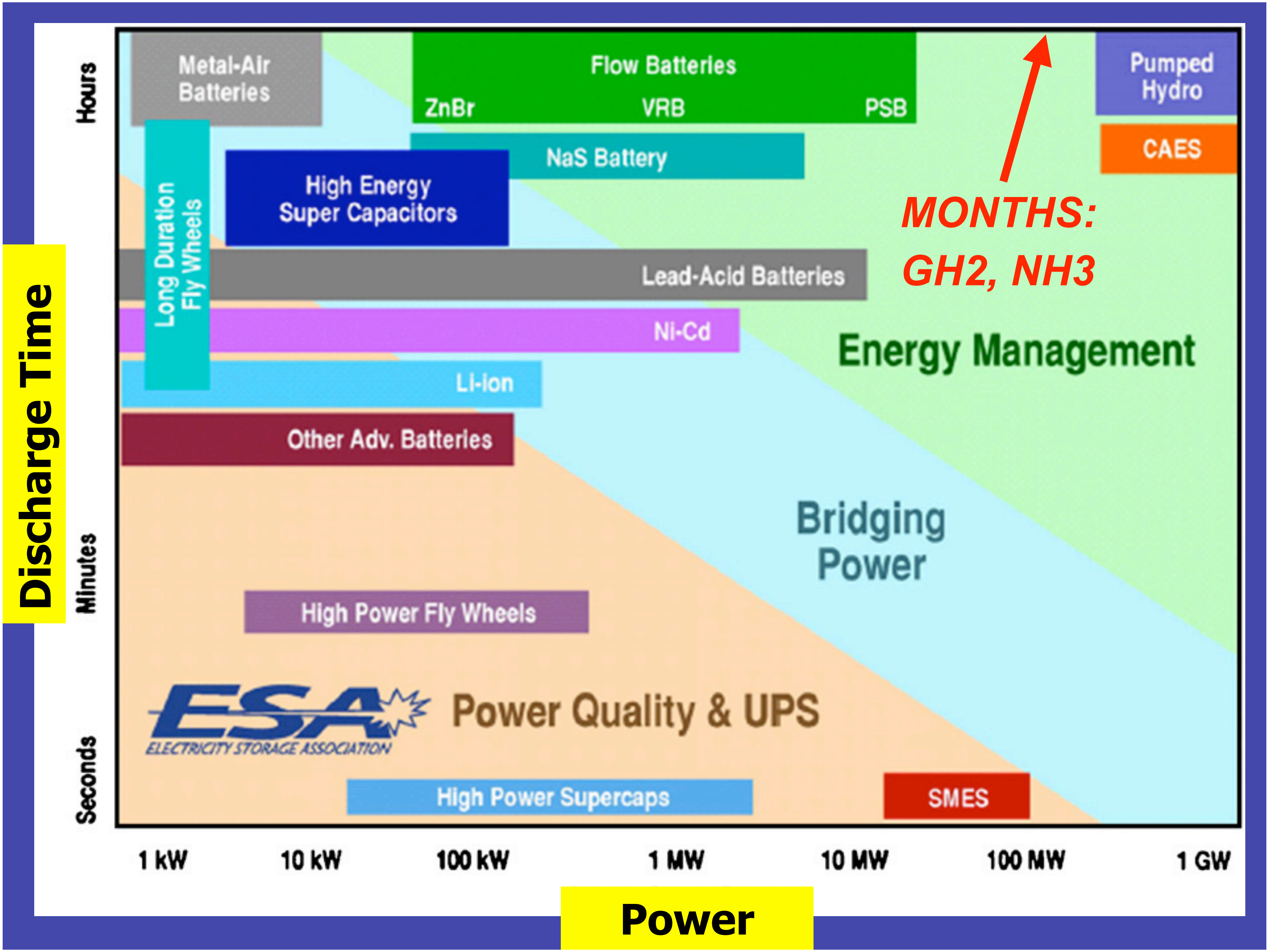
– **Gaseous Hydrogen (GH2)**
  - **Pipelines**
  - **Caverns**
  - **End-users**
  - **"Hydricity"**
– **Ammonia (NH3), liquid in tanks**
  - **Small, 150 psi**
  - **Large, "atmospheric", refrigerated**
  - **"Energy Islands": Alaska villages**
– **Electricity**

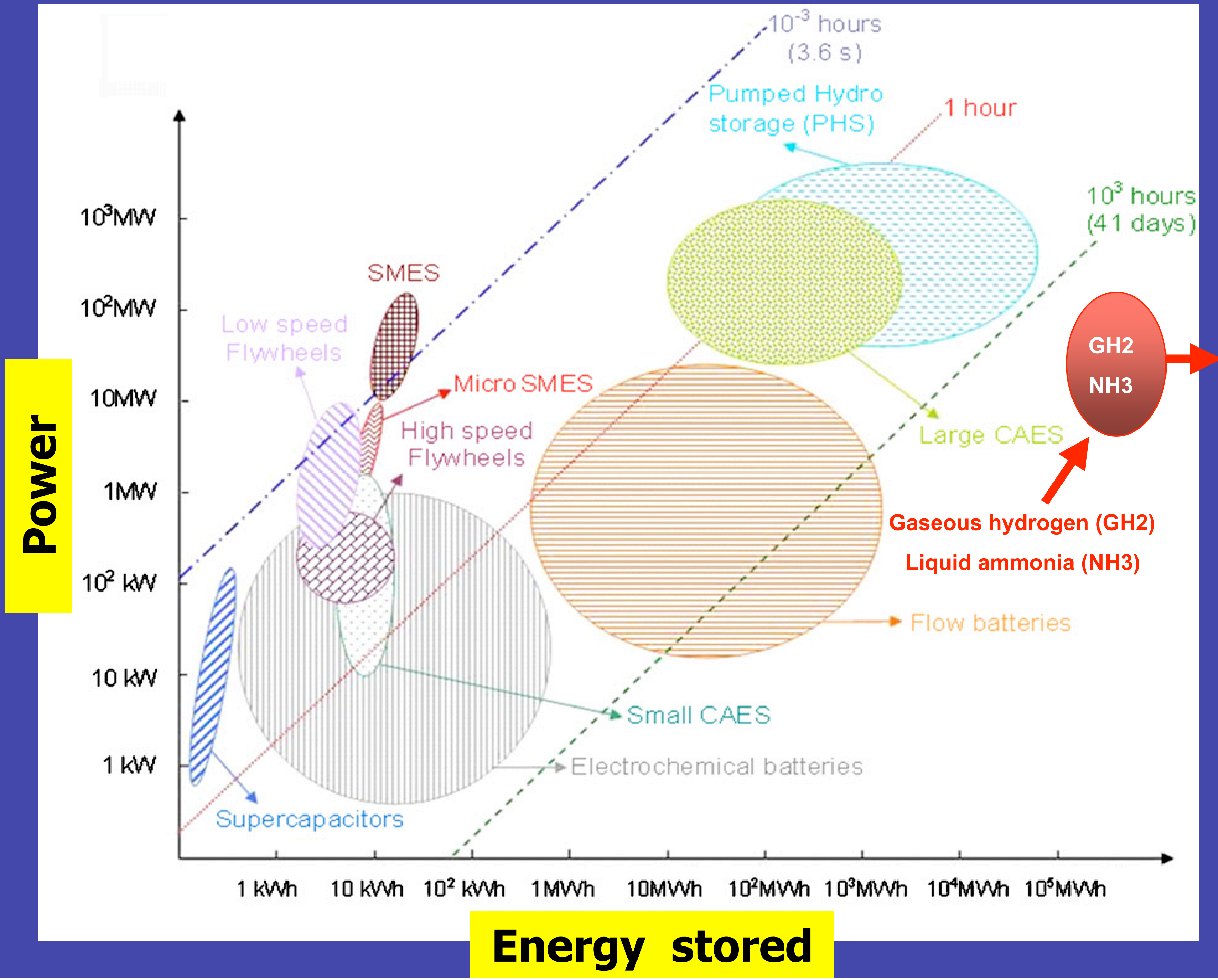
Energy Storage System Characteristics

- 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

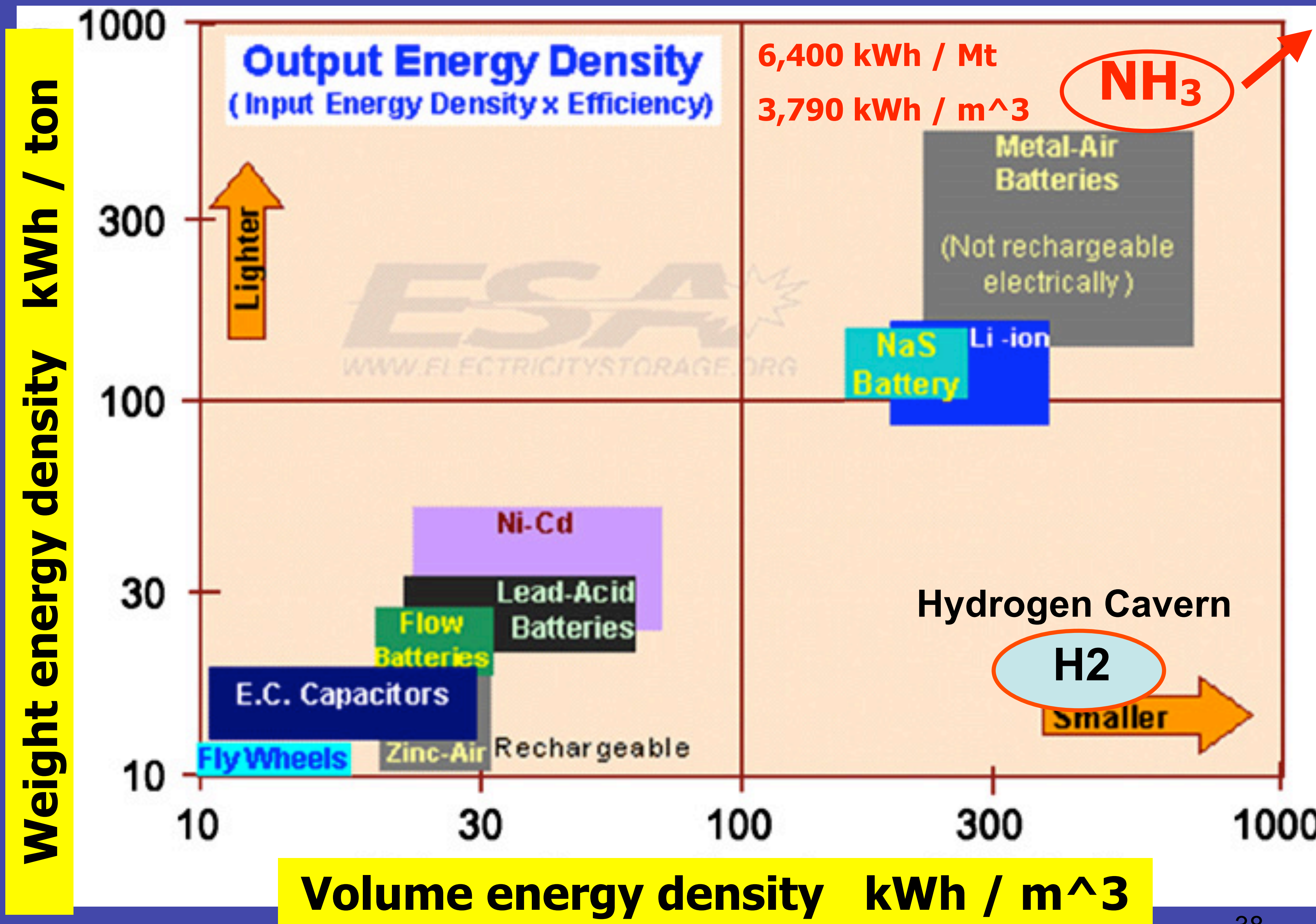
Energy Storage System Characteristics --
Ammonia off the charts ?

- *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**

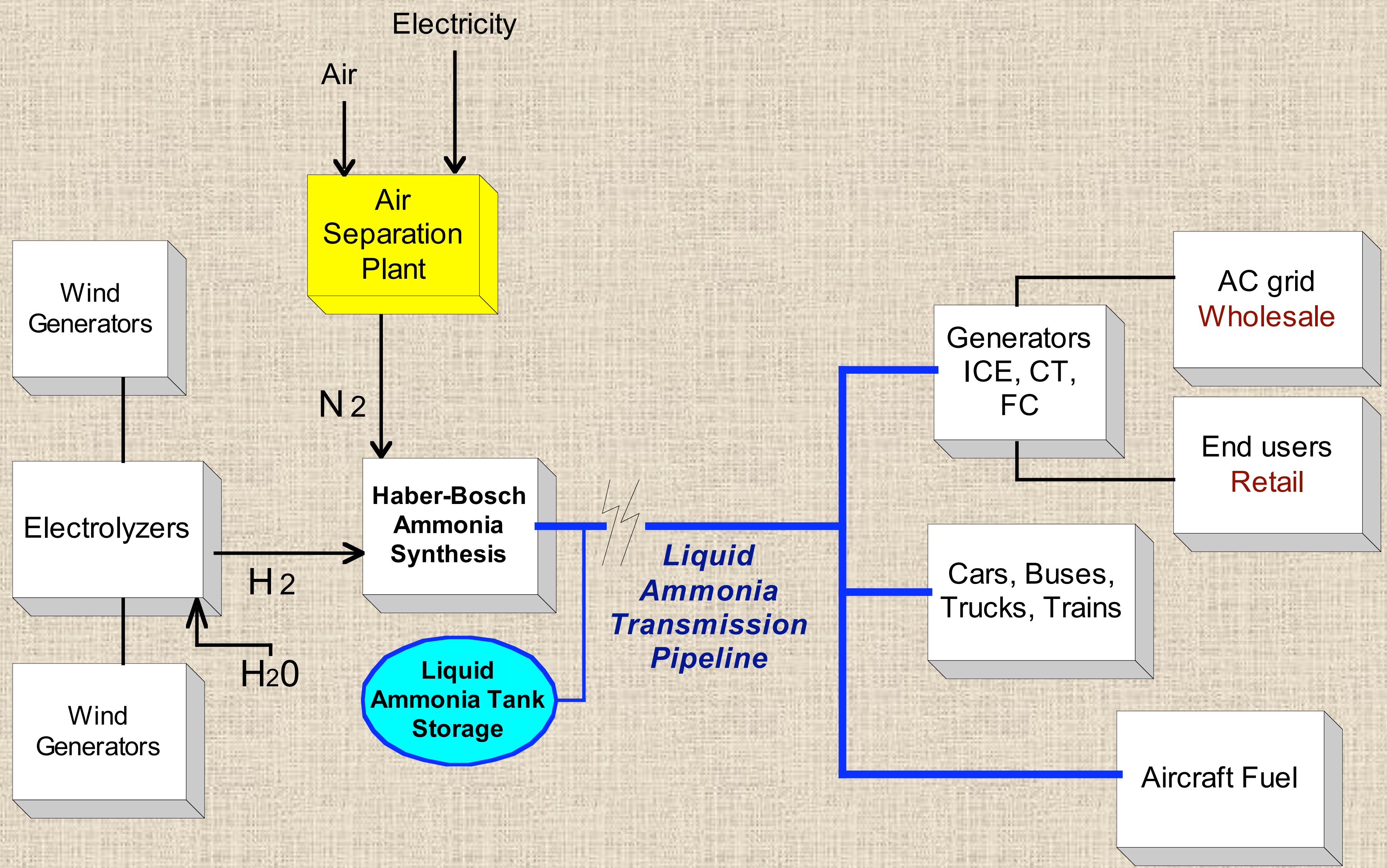

Discharge Time
Hours
Minutes
Seconds
Metal-Air Batteries
Flow Batteries
ZnBr
VRB
PSB
Pumped Hydro
CAES
NaS Battery
High Energy Super Capacitors
Long Duration Fly Wheels
Lead-Acid Batteries
Ni-Cd
Li-ion
Other Adv. Batteries
MONTHS: GH2, NH3
Energy Management
Bridging Power
High Power Fly Wheels
ESA ELECTRICITY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



10^{-3} hours
(3.6 s)
Pumped Hydro storage (PHS)
1 hour
10^3 hours
(41 days)
SMES
Low speed Flywheels
Micro SMES
High speed Flywheels
Large CAES
GH2
NH3
Gaseous hydrogen (GH2)
Liquid ammonia (NH3)
Flow batteries
Small CAES
Electrochemical batteries
Supercapacitors
Power
10^3MW
10^2MW
10MW
1MW
10^2 kW
10 kW
1 kW
1 kWh
10 kWh
10^2 kWh
1 MWh
10MWh
10^2MWh
10^3MWh
10^4MWh
10^5MWh
Energy stored

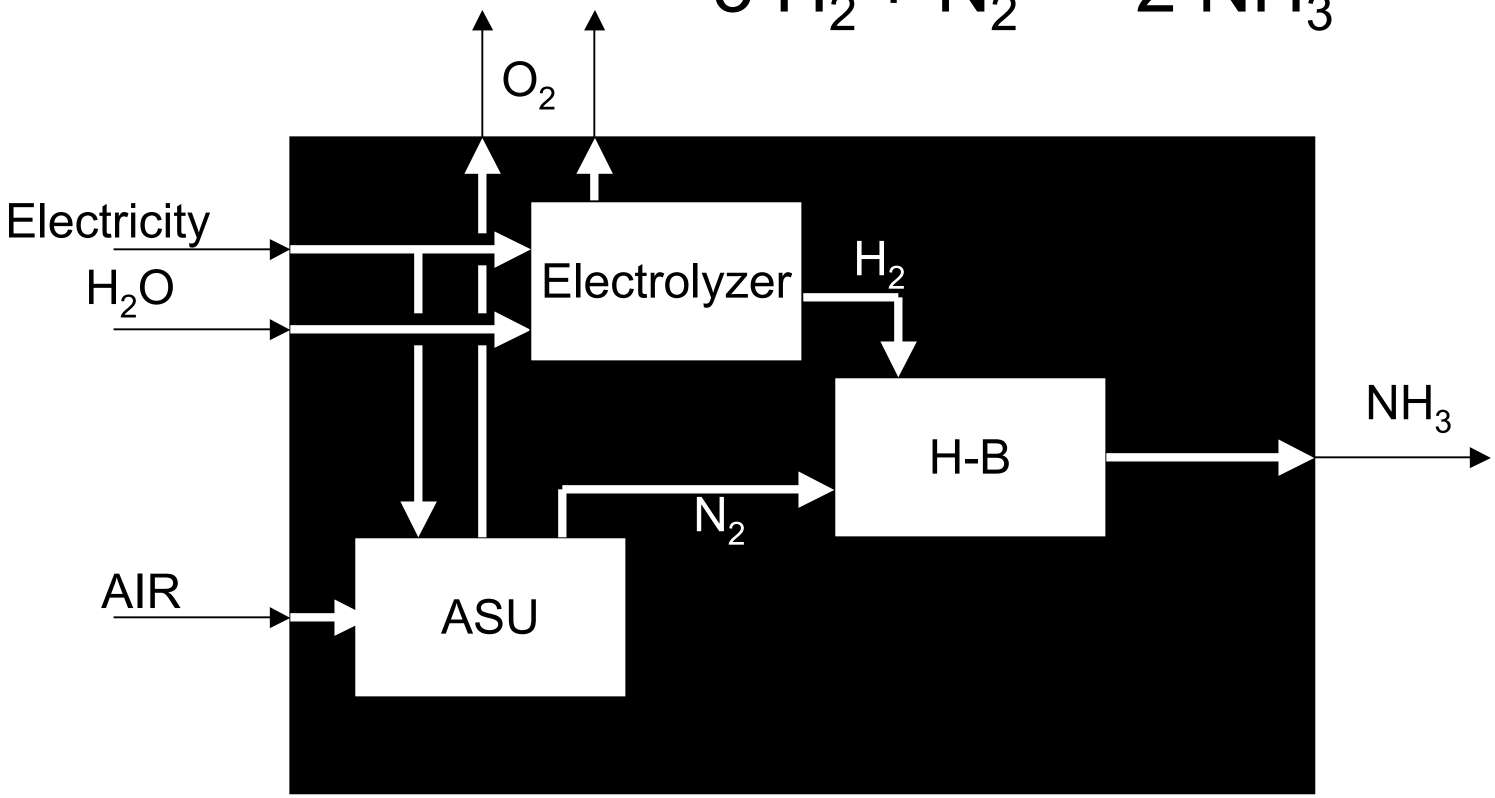


Output Energy Density
(Input Energy Density x Efficiency)
6,400 kWh / Mt
3,790 kWh / m^3
NH3
Lighter
Metal-Air Batteries
(Not rechargeable electrically)
NaS Battery
Li -ion
Ni-Cd
Lead-Acid Batteries
Flow Batteries
E.C. Capacitors
Fly Wheels
Zinc-Air
Rechargeable
Hydrogen Cavern
H2
Smaller
1000
300
100
30
10
10
30
100
300
1000
Weight energy density kWh / ton
Volume energy density kWh / m^3


Electricity
Air
Air Separation Plant
Wind Generators
N2
Electrolyzers
H2
Haber-Bosch Ammonia Synthesis
H20
Wind Generators
Liquid Ammonia Tank Storage
Liquid Ammonia Transmission Pipeline
Generators ICE, CT, FC
AC grid Wholesale
End users Retail
Cars, Buses, Trucks, Trains
Aircraft Fuel

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

2,000 MW (nameplate) Great Plains Windplant Output

Energy production at windplant 40 % Capacity Factor:

As electricity: **19,200 MWh / day**
7,000,000 MWh / year

	tons/hr	tons/day	tons/yr
As H_2 @ 80% electrolysis efficiency	16	390	142,350
As NH_3 @ 70% conversion efficiency	97	2,321	847,321
10” NH_3 pipeline capacity as H_2	11	264	96,360
10” NH_3 pipeline capacity as NH_3	60	1,440	525,600

Case 4a: Capital costs, no firming
2,000 MW Great Plains windplant

Elec → GH2 → NH3 → Liquid Pipeline → "Terminal" or "City gate"

Capital costs:

– Wind generators, 1.5 MW @ $1,500 / kW	$ 3,000 M
– Electrolyzers, 450 psi out @ $350 / kWe	$ 700 M
– Electrolyzer power electronics saving	$ 0 M
– H2 compressors	$ 10 M
– NH3 synthesis plants (2), with ASU	$ 750 M
– Pipeline: 1,000 miles	$ 800 M
– Pipeline pumping	$ 8 M
– Pipeline infrastructure	$ 2 M
Total, without firming storage	**$ 5,270 M**

Case 4a: Annual costs, no firming

Elec → GH2 → NH3 → Liquid Pipeline → "Terminal" or "City gate"

Unsubsidized [1]

Production capital costs @ 15% CRF @ $ 5,270 M	**$ 790 M**
Conversion and transmission losses	
– Electrolyzer conversion loss @ 20% AEP [2]	$ 80 M
– Compression energy	$ 1 M
– NH3 synthesis plant, with ASU	$ 80 M
– Pipeline pumping energy	$ 2 M
– Pipeline misc O&M	$ 1 M
Total annual costs	**$ 954 M**

Total cost per mt NH3 = $ 1,126

Total cost per kg NH3 = $ 1.13

[1] Subsidies, value-adders: PTC, O_2 sales, REC

[2] Annual Energy Production @ $US 0.057 / kWh

Case 4b: Capital costs, Firming storage tanks

2,000 MW Great Plains windplant

Elec → GH2 → NH3 → Liquid Pipeline → Firming tanks → "Terminal" or "City gate"

Capital costs

–	Wind generators, 1.5 MW @ $1,500 / kW	$ 3,000 M
–	Electrolyzers, 450 psi out @ $350 / kWe	$ 700 M
–	Electrolyzer power electronics saving	$ 0 M
–	H2 compressors	$ 10 M
–	NH3 synthesis plant, with ASU	$ 750 M
–	Pipeline: 1,000 miles	$ 800 M
–	Pipeline pumping	$ 8 M
–	Pipeline infrastructure	$ 2 M
–	Tanks: 4 tanks @ $ 25 M	$ 100 M
	Total, with firming storage	$ 5,370 M

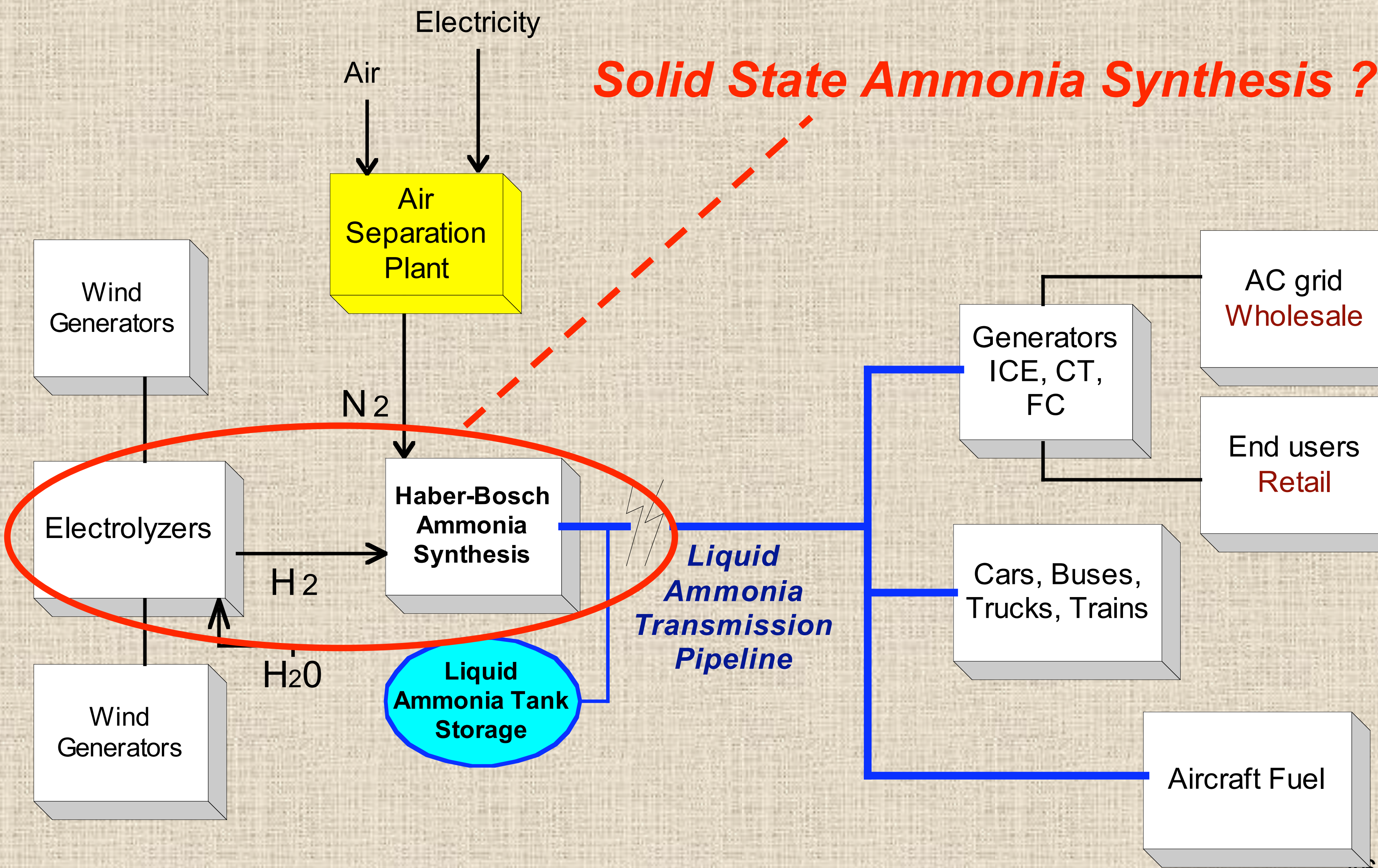
Incremental capital cost of NH3 tanks = $ 100 / 5,370 = ~ 0.2 %

Case 4b: Annual costs, Firming storage tanks
2,000 MW Great Plains windplant
Elec → GH2 → NH3 → Liquid Pipeline + tanks → City gate

• Capital costs @ 15% CRF @ $ 5,370	$ 805 M
• Conversion and transmission losses	
– Electrolyzer conversion loss @ 20% AEP	$ 80 M
– Compression	$ 1 M
– NH3 synthesis plants (2), with ASU	$ 80 M
– Pipeline pumping energy	$ 2 M
– Pipeline misc O&M	$ 1 M
– Tank in / out	$ 0 M
Total annual costs	$ 969 M

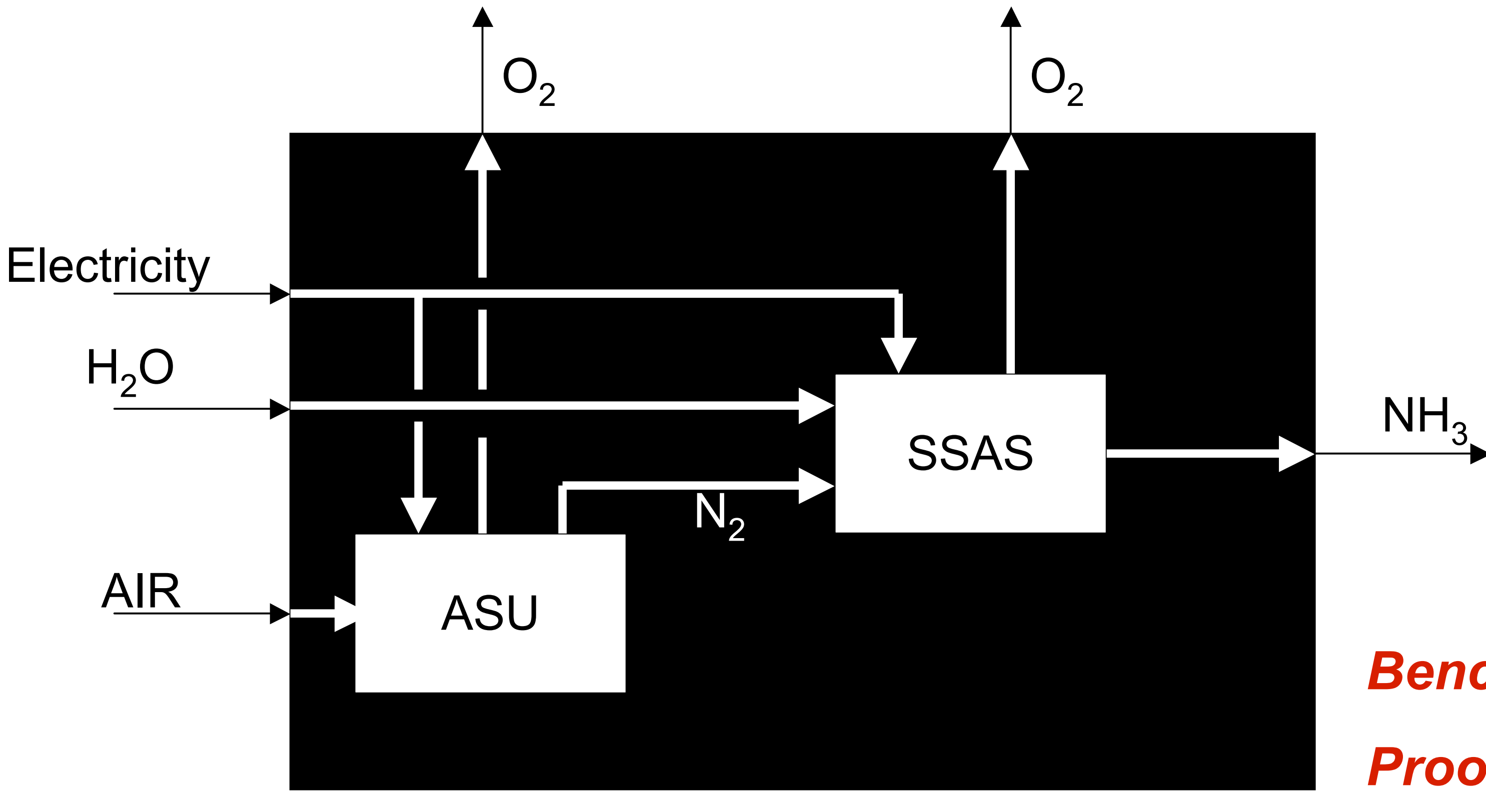
Total cost per Mt NH3 = $ 1,144

Ammonia Transmission + Storage Scenario



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

SSAS vs H-B NH3 Synthesis

(Solid State Ammonia Synthesis vs Haber – Bosch)

- **H-B (Haber-Bosch)**
  - **\$1.5 M per MWe input**
  - **2 tons / day output per MWe input**
  - **O&M cost / ton: ??**

- **SSAS (Solid State Ammonia Synthesis)**
  - **\$650 K per MWe input**
  - **3.2 tons / day output per MWe input**
  - **O&M cost / ton: lower ?**

Denali Commission EETG

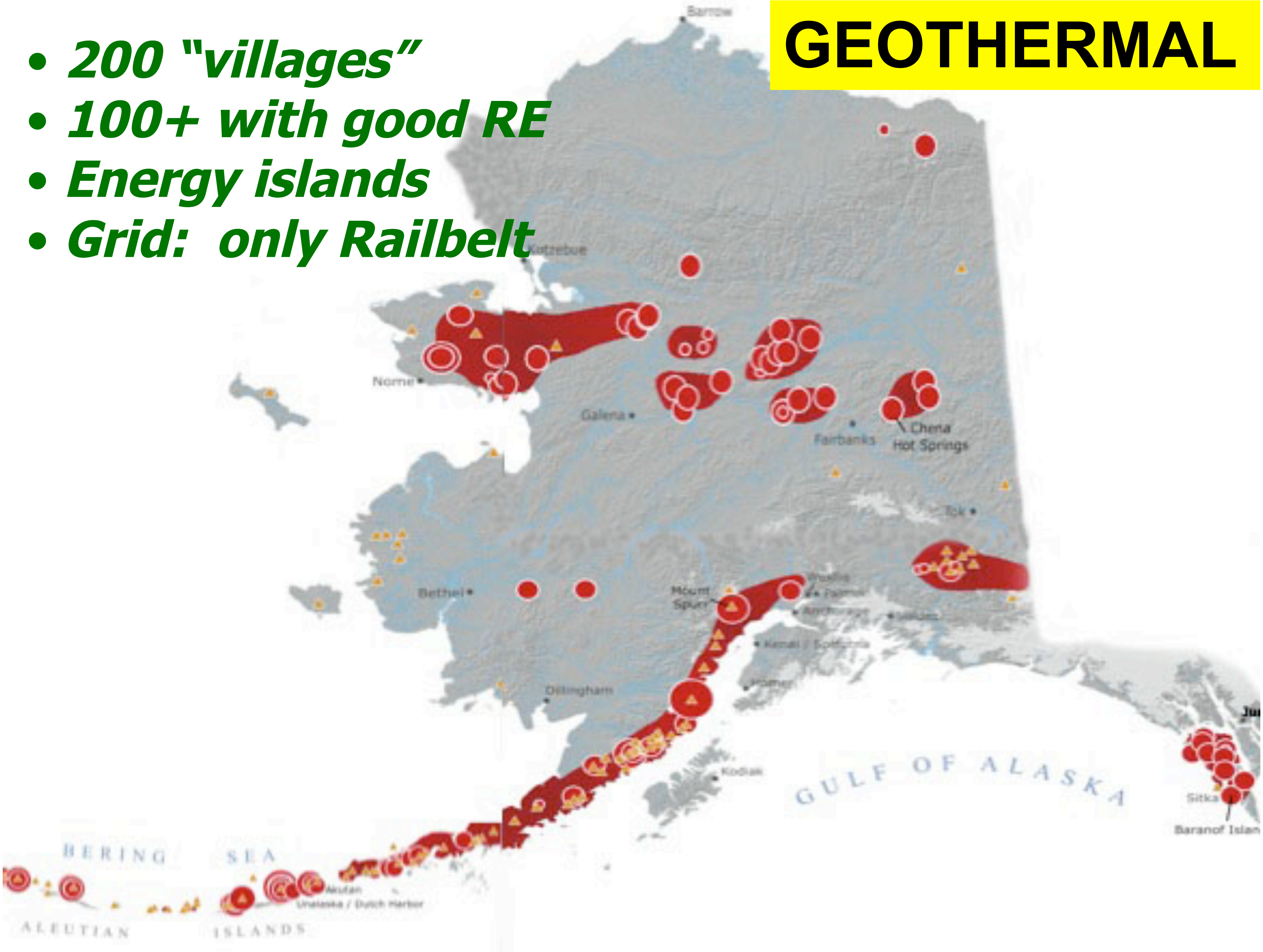
Solid State Ammonia Synthesis (SSAS) Pilot Plant for Renewable Energy (RE) Firming Storage

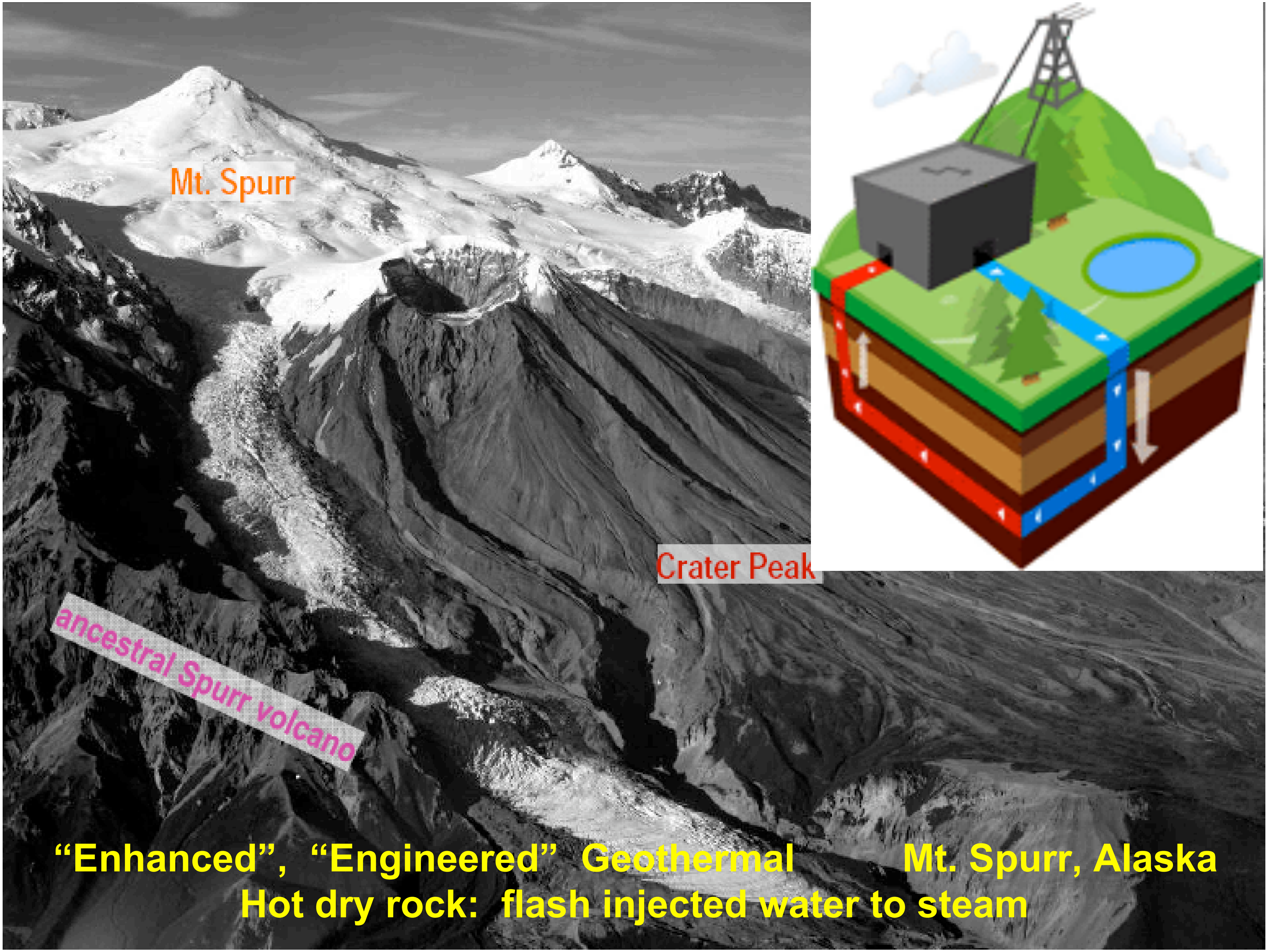
28 Sept 09
Alaska Applied Sciences, Inc.
Juneau, AK
Bill Leighty, Principal

Rejected 30 Sept 09

GEOTHERMAL

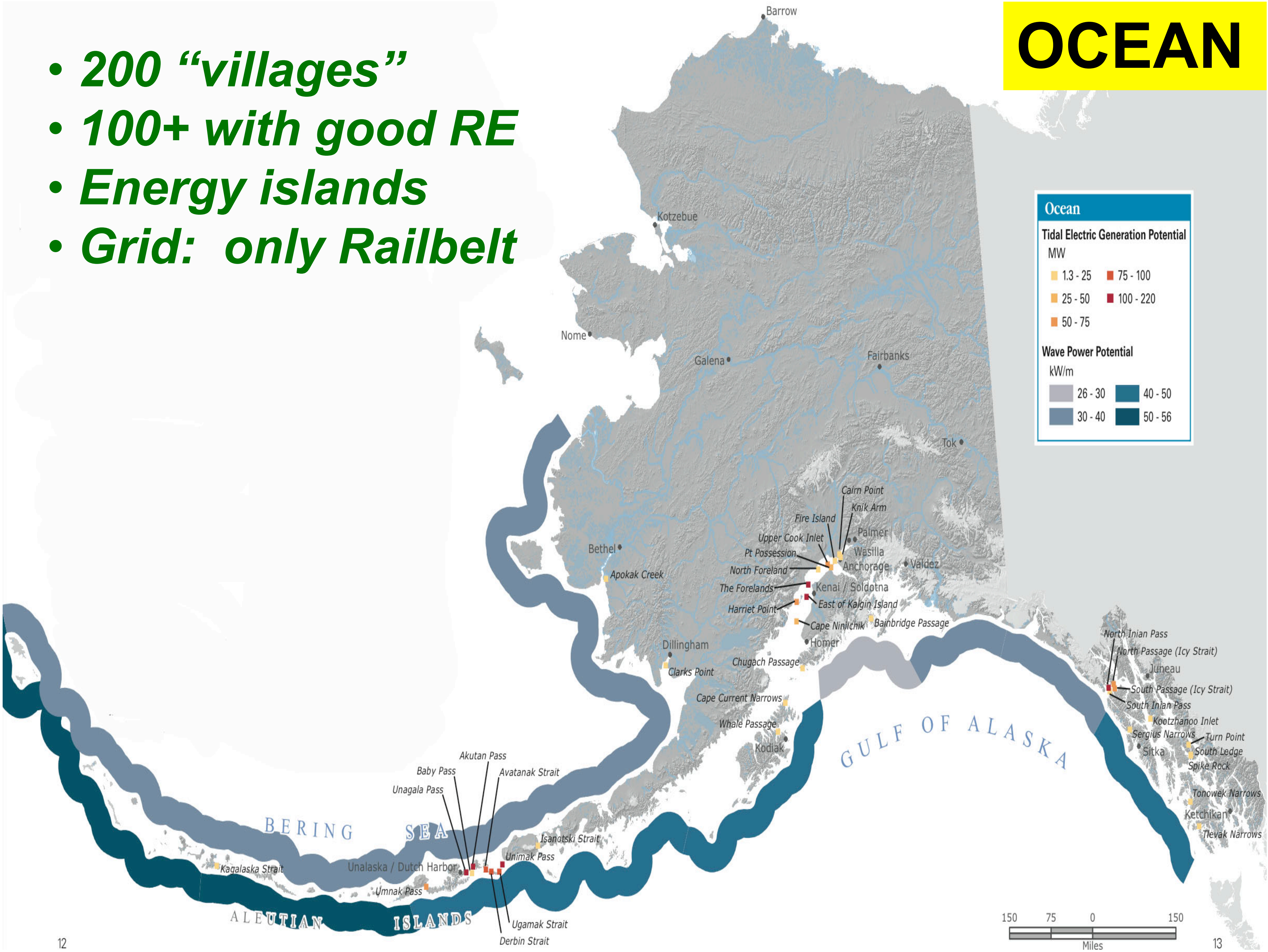
- ***200 "villages"***
- ***100+ with good RE***
- ***Energy islands***
- ***Grid: only Railbelt***




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

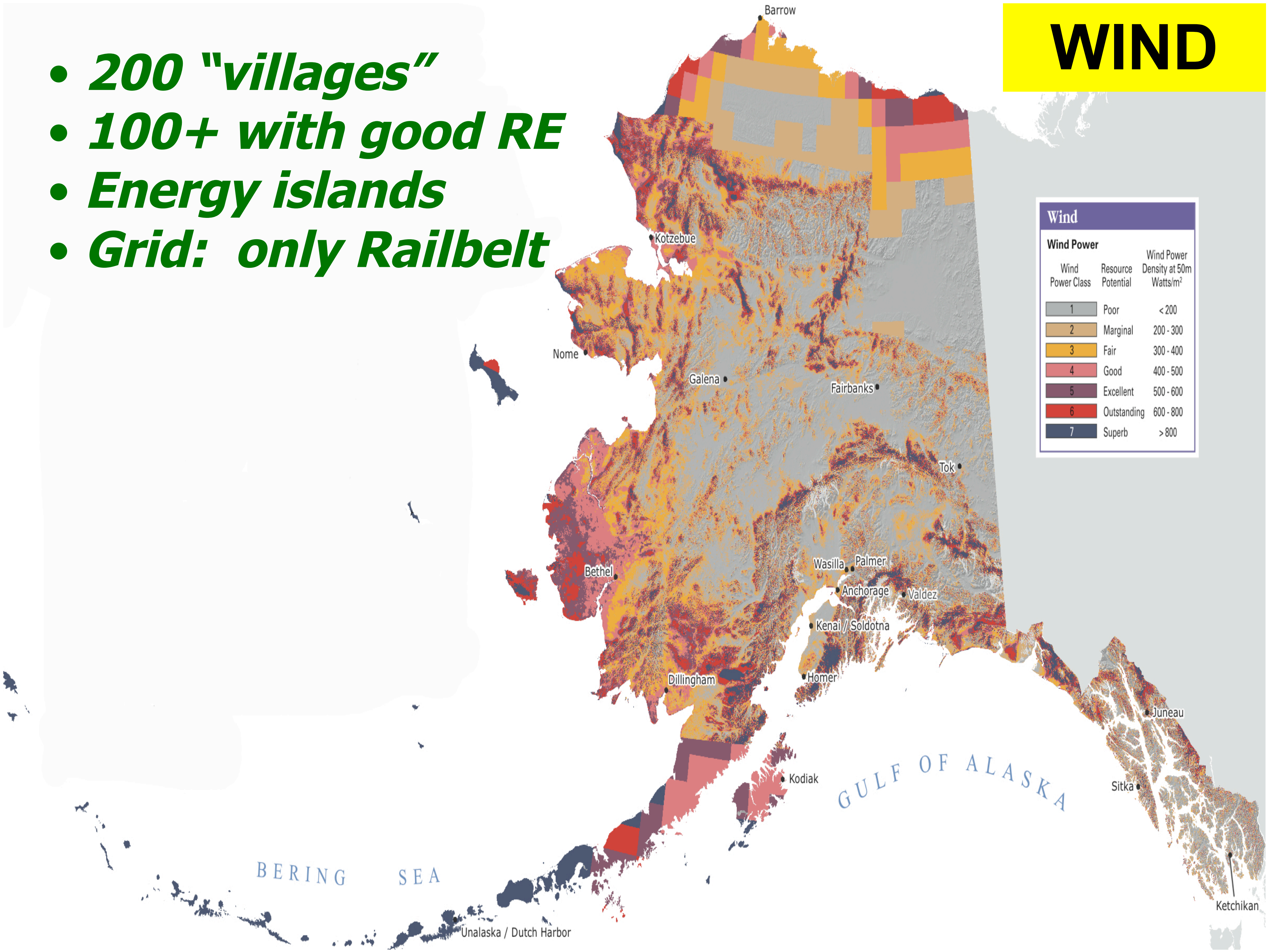
- ***200 "villages"***
- ***100+ with good RE***
- ***Energy islands***
- ***Grid: only Railbelt***

OCEAN



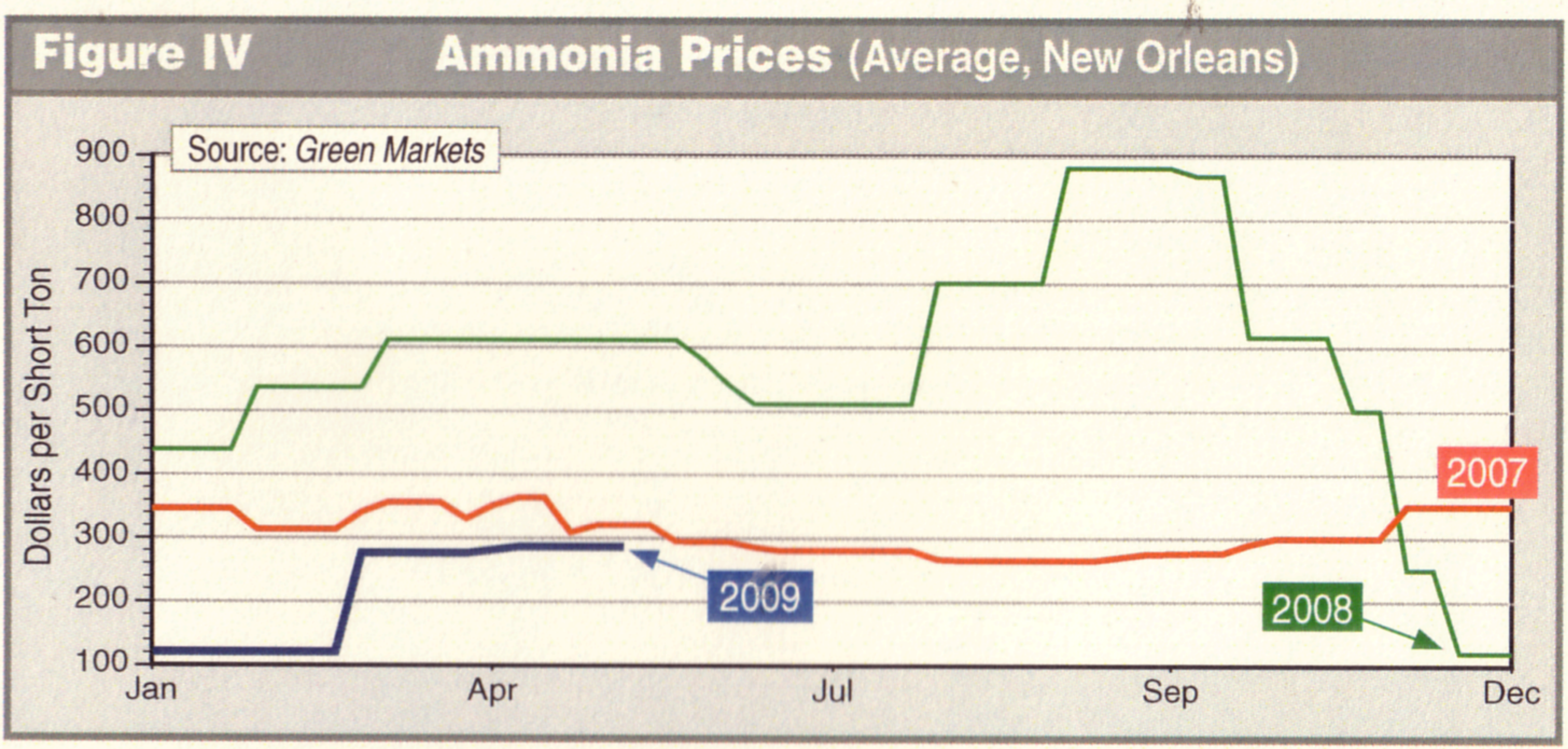
WIND

- ***200 "villages"***
- ***100+ with good RE***
- ***Energy islands***
- ***Grid: only Railbelt***



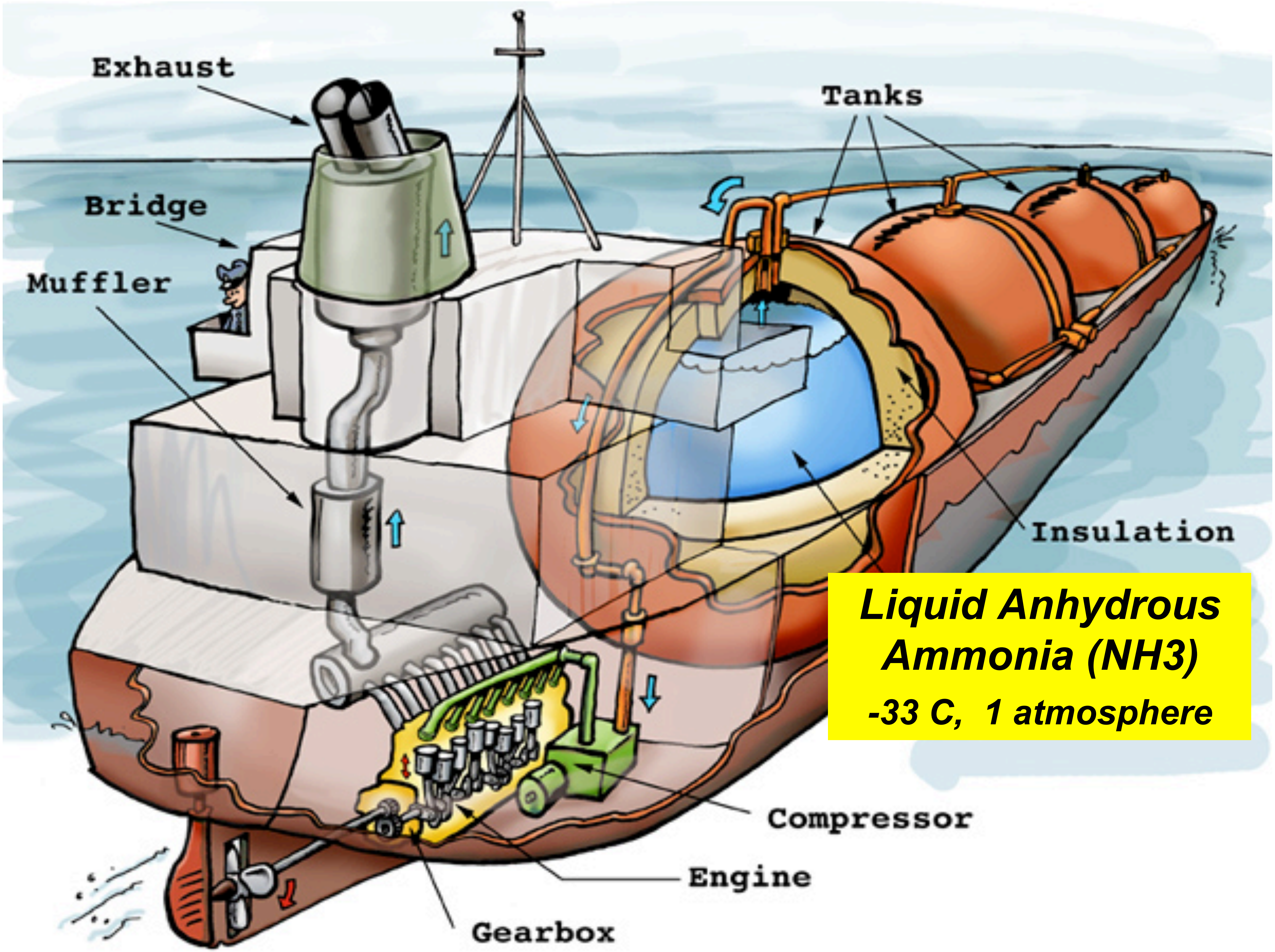
Denali Commission Summary

- R&D plus pilot plant: NHThree LLC
- Simulate Alaska community energy island
- SSAS offer RE-source internal energy independence?
  - Discover, demonstrate
  - Technical: conversions efficiency; byproduct heat used?
  - Economic: capital, O&M costs?
- Deploy at UAS Tech Center, Juneau
- Operate in two modes on AEL&P grid:
  - Hydroelectricity-to-NH3
  - NH3-to-AEL&P grid
- SCADA data collect, analyze
- Modify system hardware + software
- Relocate to smaller community?
- Final report; conference papers; wide distribution
- Implications for export of large-scale, stranded AK RE ?

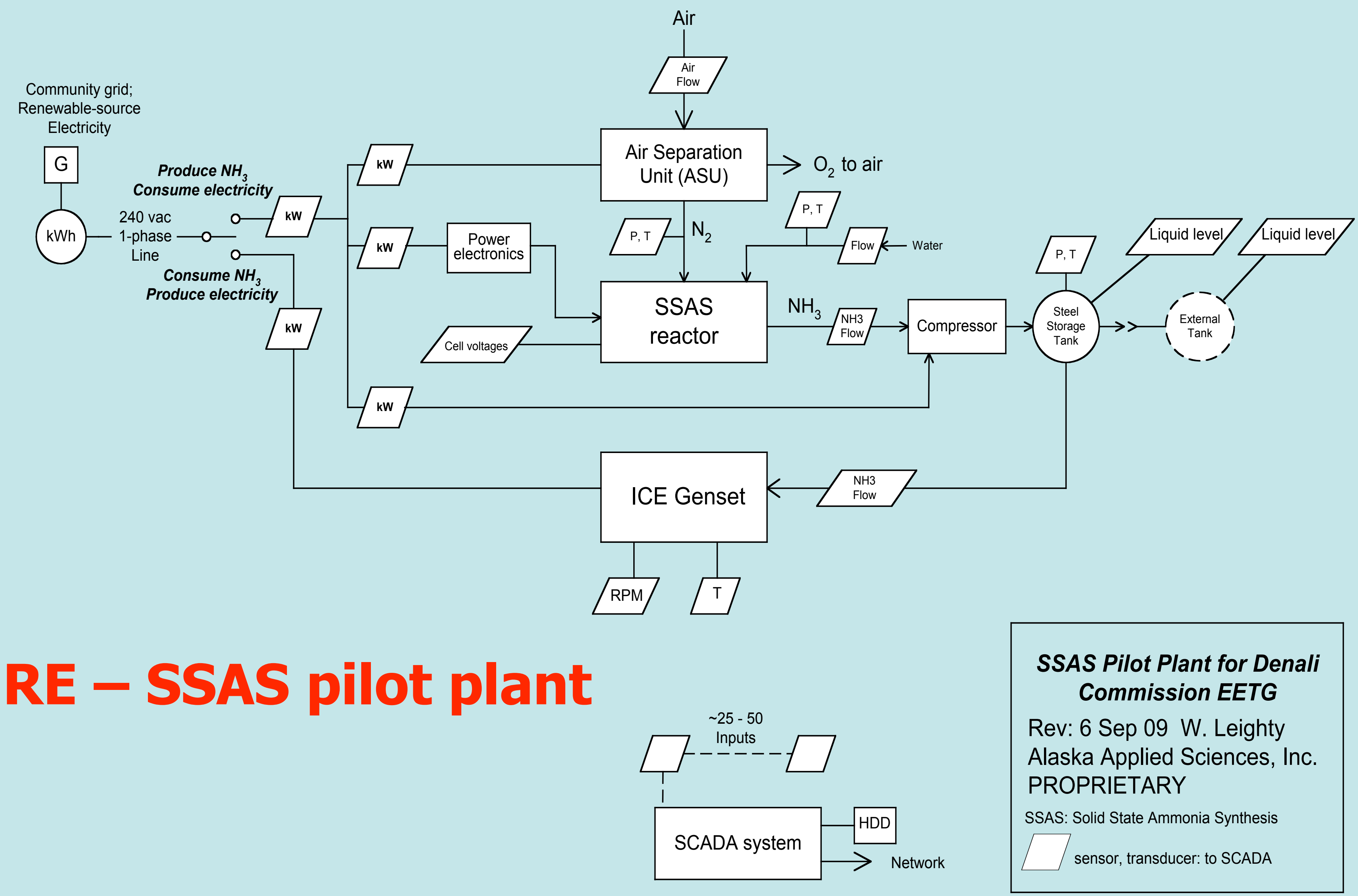


Anhydrous Ammonia (NH3) wholesale price,

NOLA (New Orleans, LA), 3 years


Exhaust
Bridge
Muffler
Tanks
Insulation
Liquid Anhydrous Ammonia (NH3)
-33 C, 1 atmosphere
Compressor
Engine
Gearbox

Ammonia ship at Burrup Peninsula Western Australia



RE – SSAS pilot plant

Figure 1. Complete, containerized SSAS renewable energy conversion and storage system pilot plant

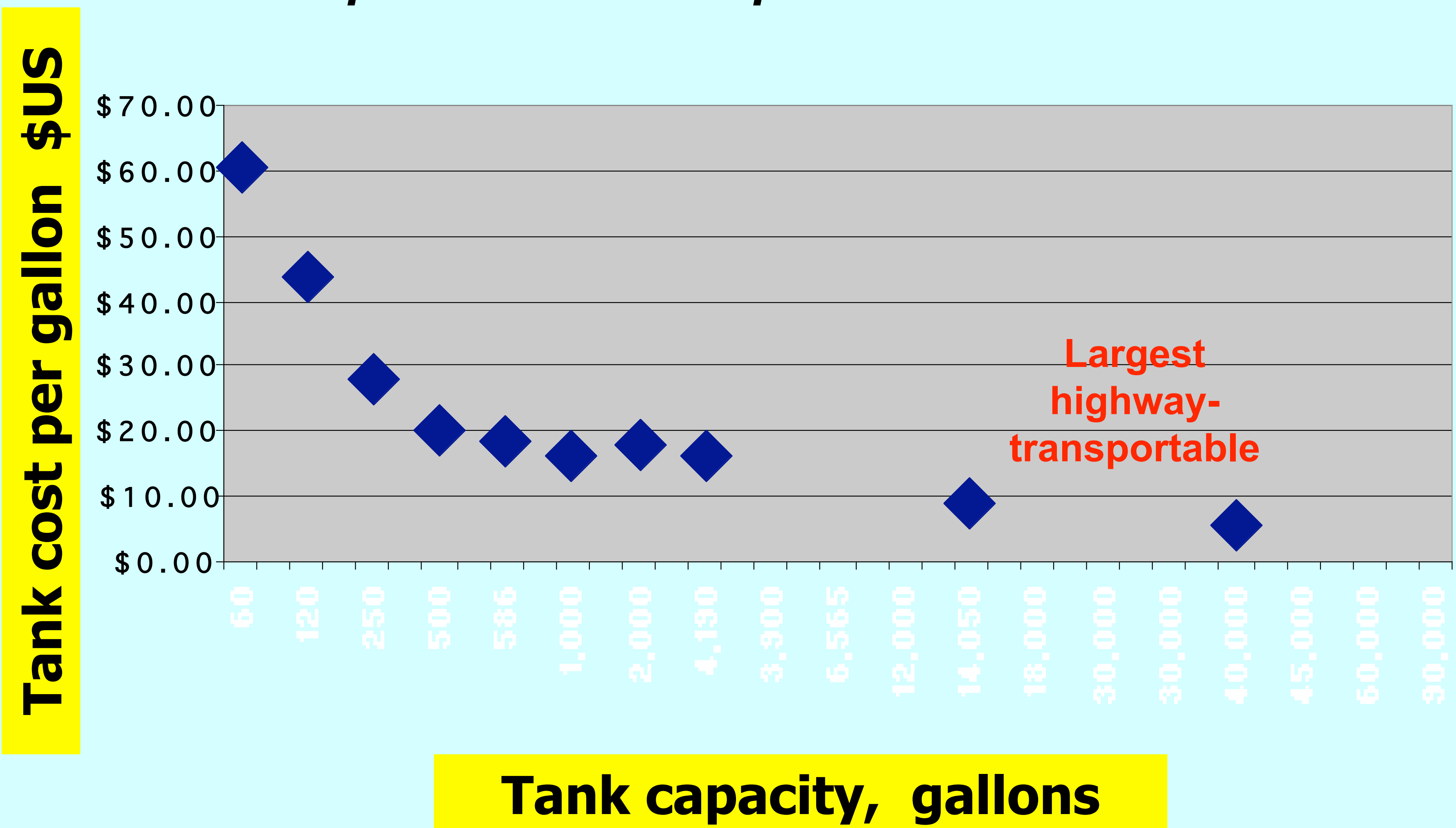
1,000 hours, ICE, 6 cyl, 100 hp
75% ammonia, 25% propane

Hydrogen Engine Center, Algona, IA

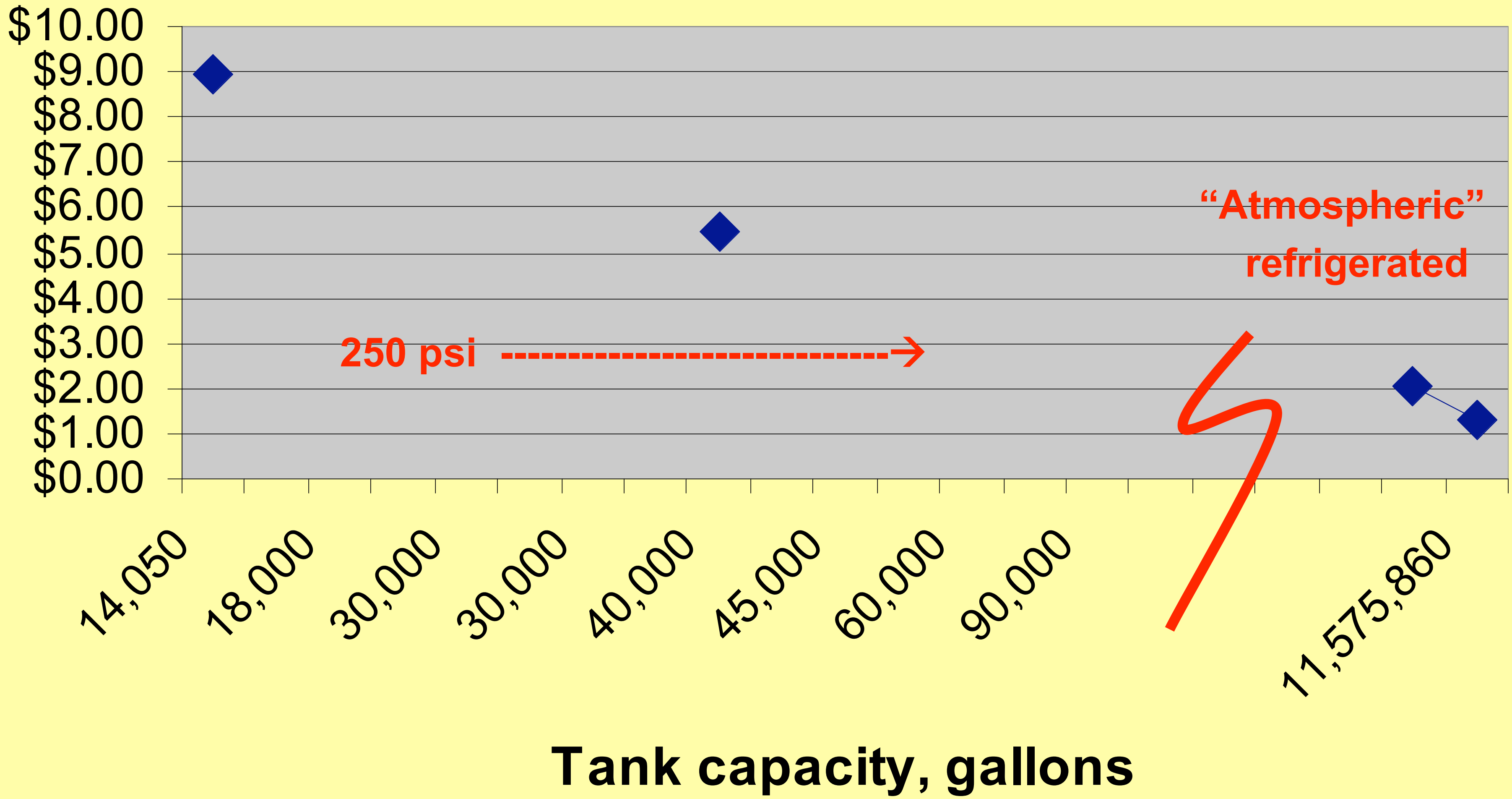
1,000 hours, ICE, 6 cyl, 100 hp

75% ammonia, 25% propane

Cost per Gallon: 250 psi Ammonia Tanks



Cost per Gallon: 250 psi vs "Atmospheric"



Liquid Ammonia Storage Tank

30,000 Tons

$15M turnkey

-33 C

Ammonia

534 kg H2

$ 10,000

Hydrogen gas

350 kg H2

$ 400,000

Energy Storage Alternatives

"Electricity"

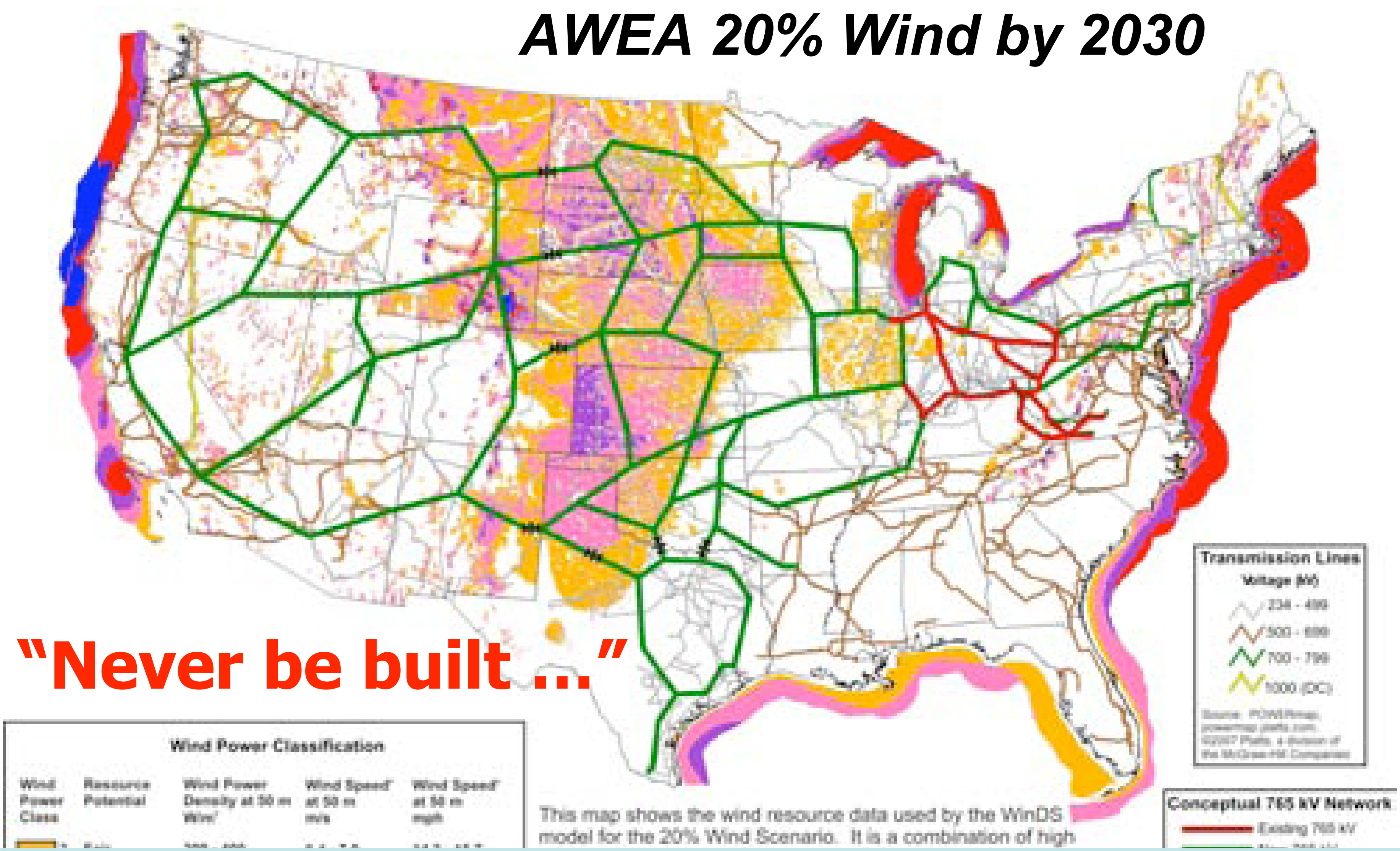
- Batteries
  - Lead-acid
  - Nickel-cadmium
  - Lithium ion
  - Sodium sulfur
- Pumped hydro (PHS)
- Compressed air (CAES) (large ans small scale)
- Natural gas - coupled (NGS)
- Flow batteries (FBES)
- Flywheel (FES)
- Superconducting magnetic (SMES)
- Supercapacitors

Energy Storage Alternatives

Other

- Natural gas
- Chemical
- Synthetic HC's
  - Fisher- Tropsch Liquids (FTL's)
  - Gas- To- Liquids (GTL's)
- Thermal energy (TES)
- NEW
  - Compressed hydrogen (35 – 70 bar typical) → ICE or fuel cell vehicles (FC-HES)
  - "Hydricity"
    - Gaseous Hydrogen (GH2) in caverns and pipelines
    - LH2: liquid hydrogen
  - Ammonia in tanks

AWEA 20% Wind by 2030



"Never be built ..."

Frontier Line + Transwest Express ~= 115 GW

Wind Potential ~= 3,000 GW

Carmakers Commit to Hydrogen Fuel Cell Cars ?

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

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

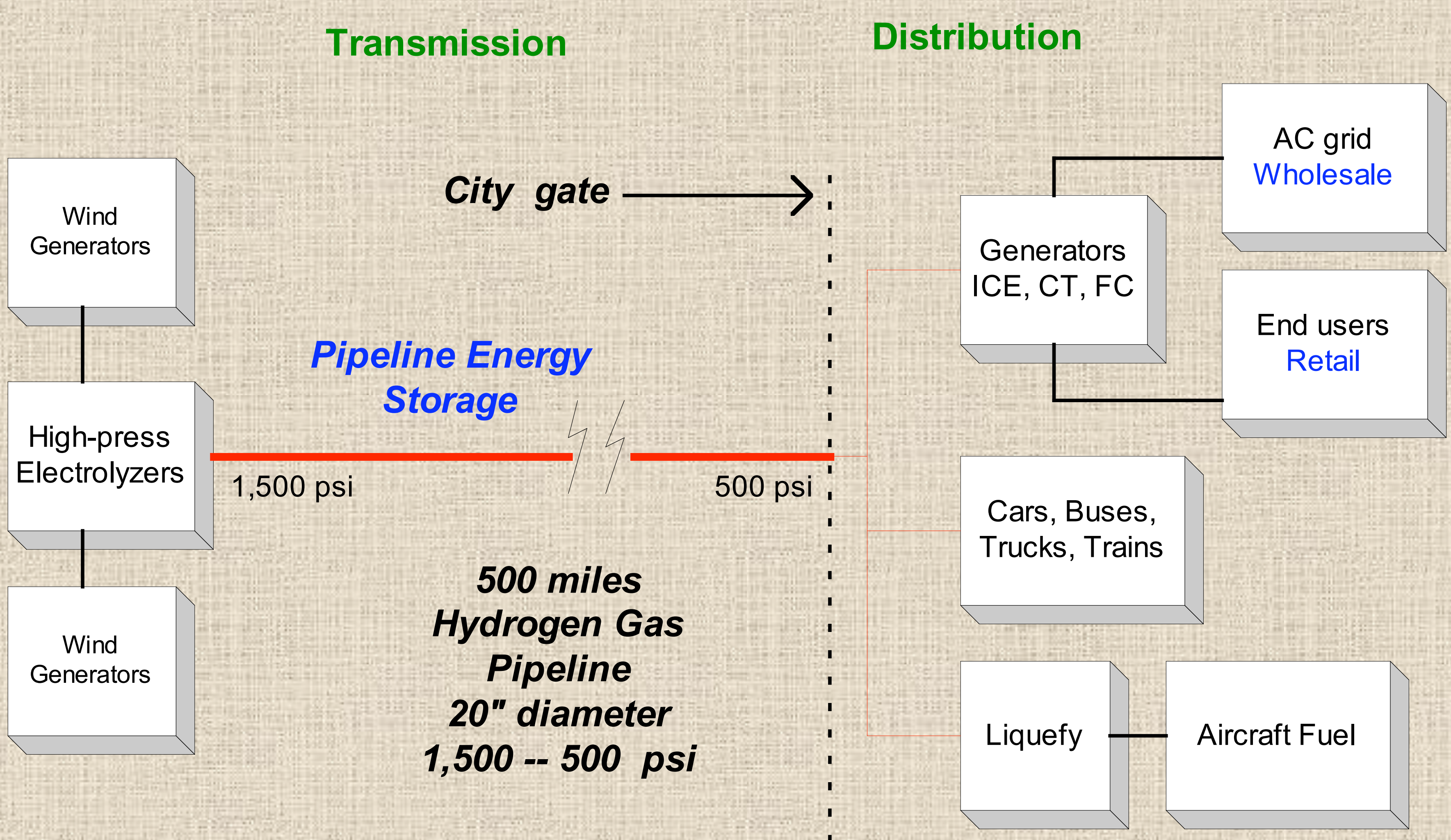
- Serial production ~ 2015: "… quite significant number" of electric vehicles powered by fuel cells
- Vague; lobbying for fed FCV funds restore ?
- Will need H2 fuel: "… hydrogen infrastructure has to be built up with sufficient density …"

Carmakers' letter Oct 09: FCV's production 2015, Need H_2 fuel !

Hydrogen Fuel Cell Hybrid Electric Vehicle: HFCHEV

Personal Vehicle On-board Storage 300 mile range; estimated OEM cost per vehicle

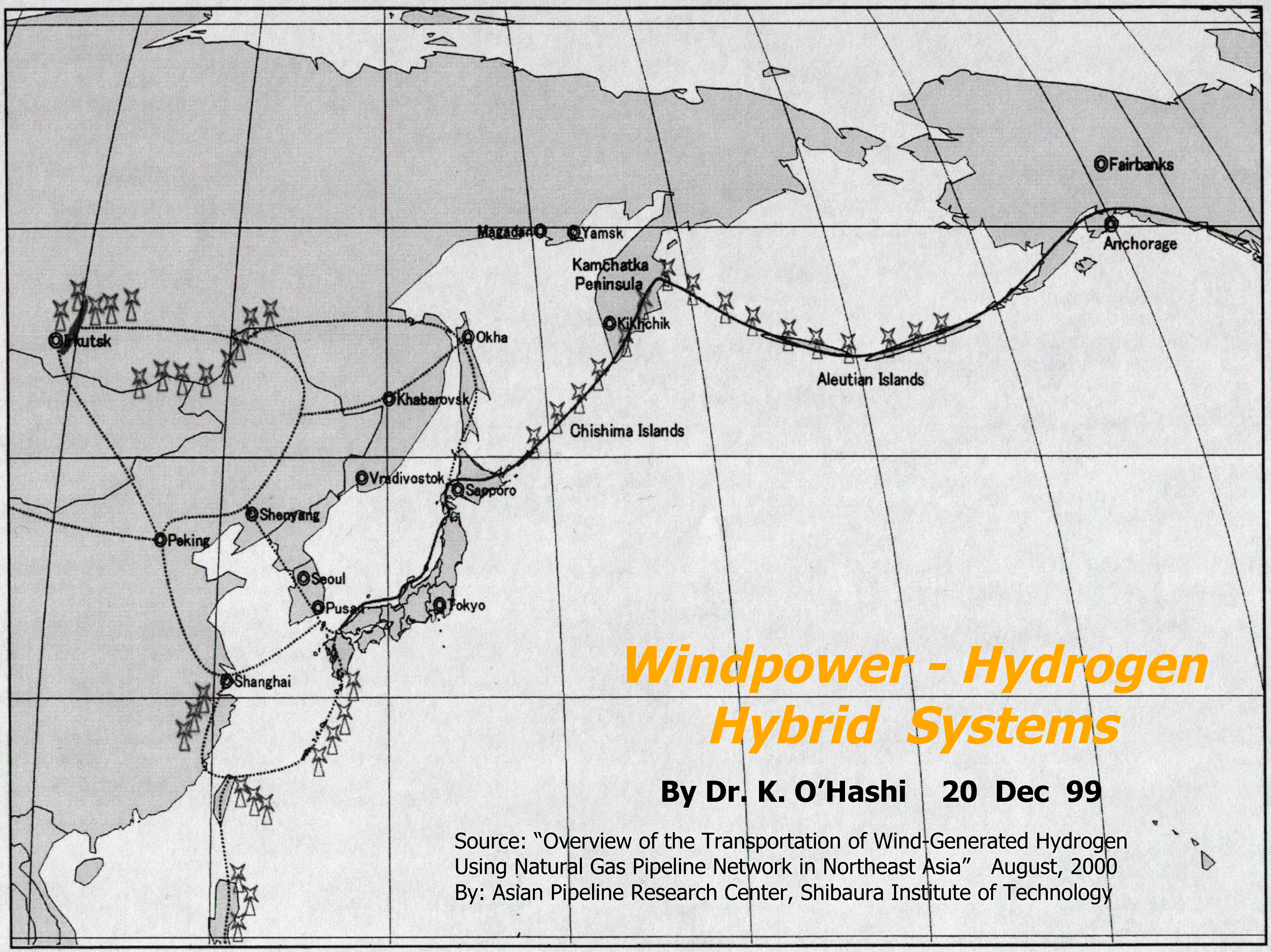
	Storage cost	Hybrid drive train efficiency	Storage capacity
Gasoline, diesel	$ 100	25 %	10 gal
Electricity: batteries	$ 10,000	90 %	kWh
CNG	$ 300	25 %	? scf
H2 (70 bar) ICEHV	$ 4,000	35 %	5 kg
H2 (70 bar) FCHEV	$ 3,000	60 %	3 kg
Ammonia (20 bar)	$ 300	45 %	15 gal


Transmission
Distribution
City gate
Wind Generators
High-press Electrolyzers
Wind Generators
Pipeline Energy Storage
1,500 psi
500 psi
500 miles
Hydrogen Gas
Pipeline
20" diameter
1,500 -- 500 psi
AC grid
Wholesale
Generators
ICE, CT, FC
End users
Retail
Cars, Buses, Trucks, Trains
Liquefy
Aircraft Fuel

Domal Salt Storage Caverns

Hydrogen vs Ammonia Storage: Large-scale, capital cost per MWh

GH2 salt cavern:	**$ 120 → 55**
– **150 bar, 200,000 m^3 physical**	
– **\$70 → \$30 per m^3 physical**	
– **Alton project**	
NH3 tank	**$ 60**
– **30,000 Mt**	
– **"Atmospheric" refrigerated**	
Diesel, large surface tanks	**$??**

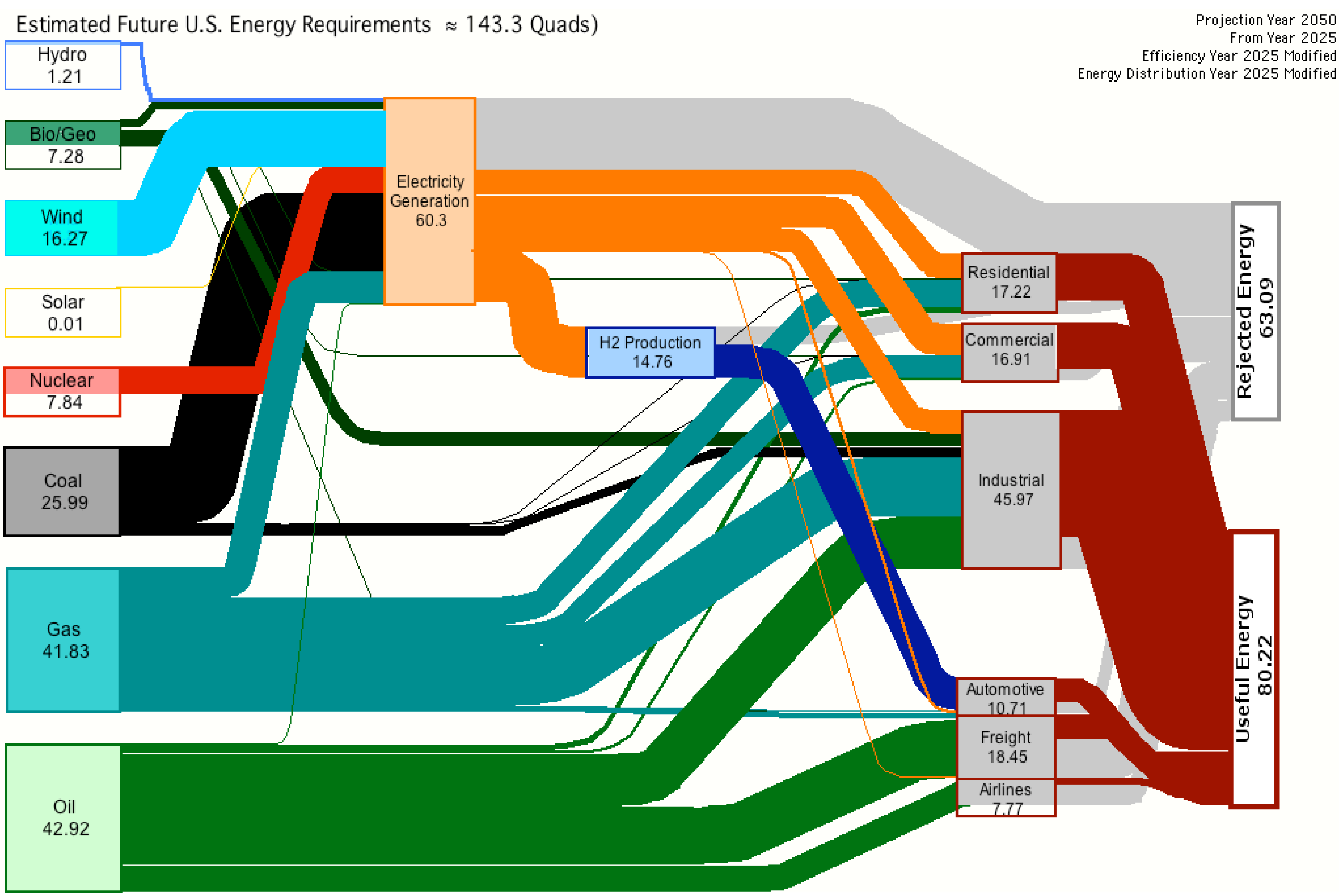


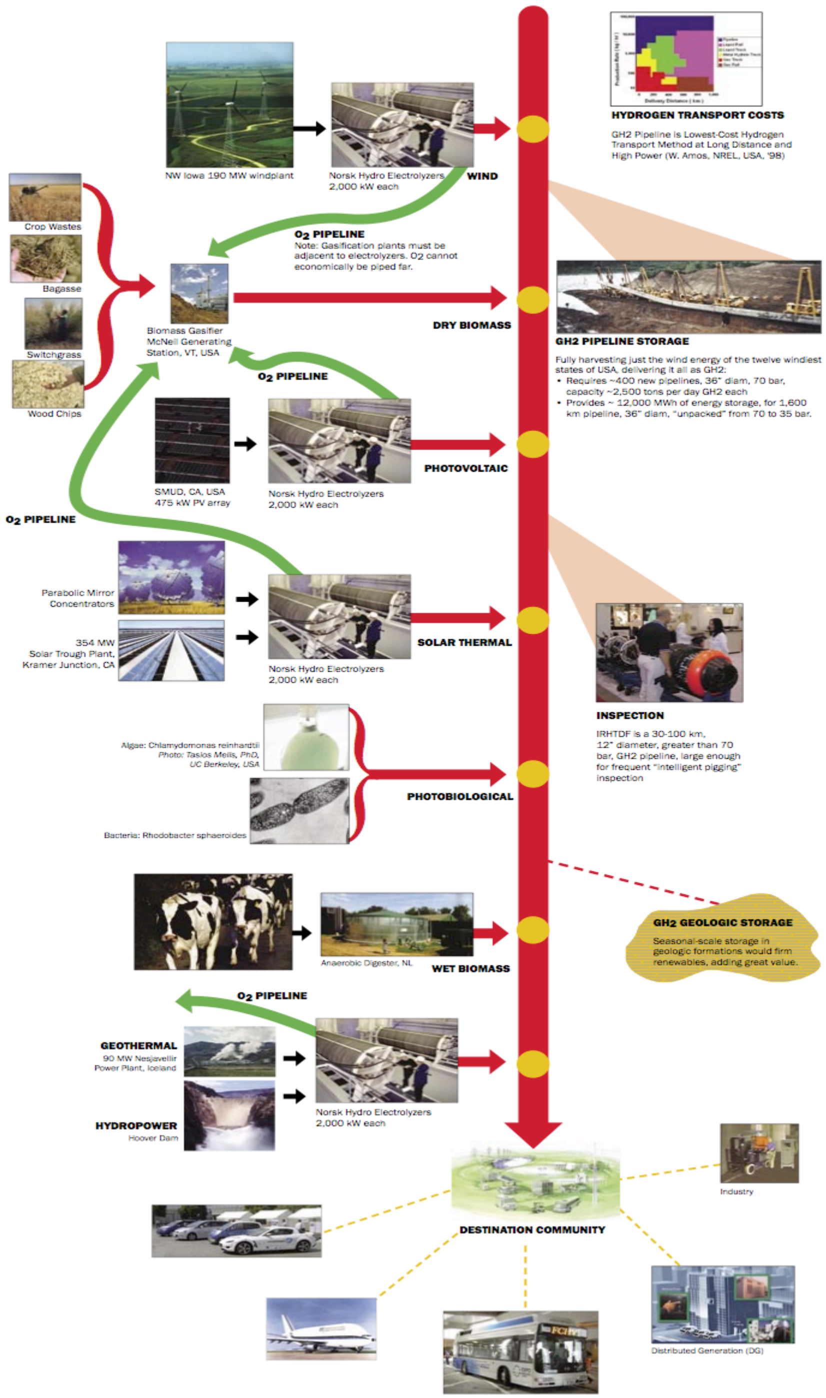
Windpower - Hydrogen Hybrid Systems

By Dr. K. O'Hashi 20 Dec 99

Source: "Overview of the Transportation of Wind-Generated Hydrogen Using Natural Gas Pipeline Network in Northeast Asia" August, 2000
By: Asian Pipeline Research Center, Shibaura Institute of Technology

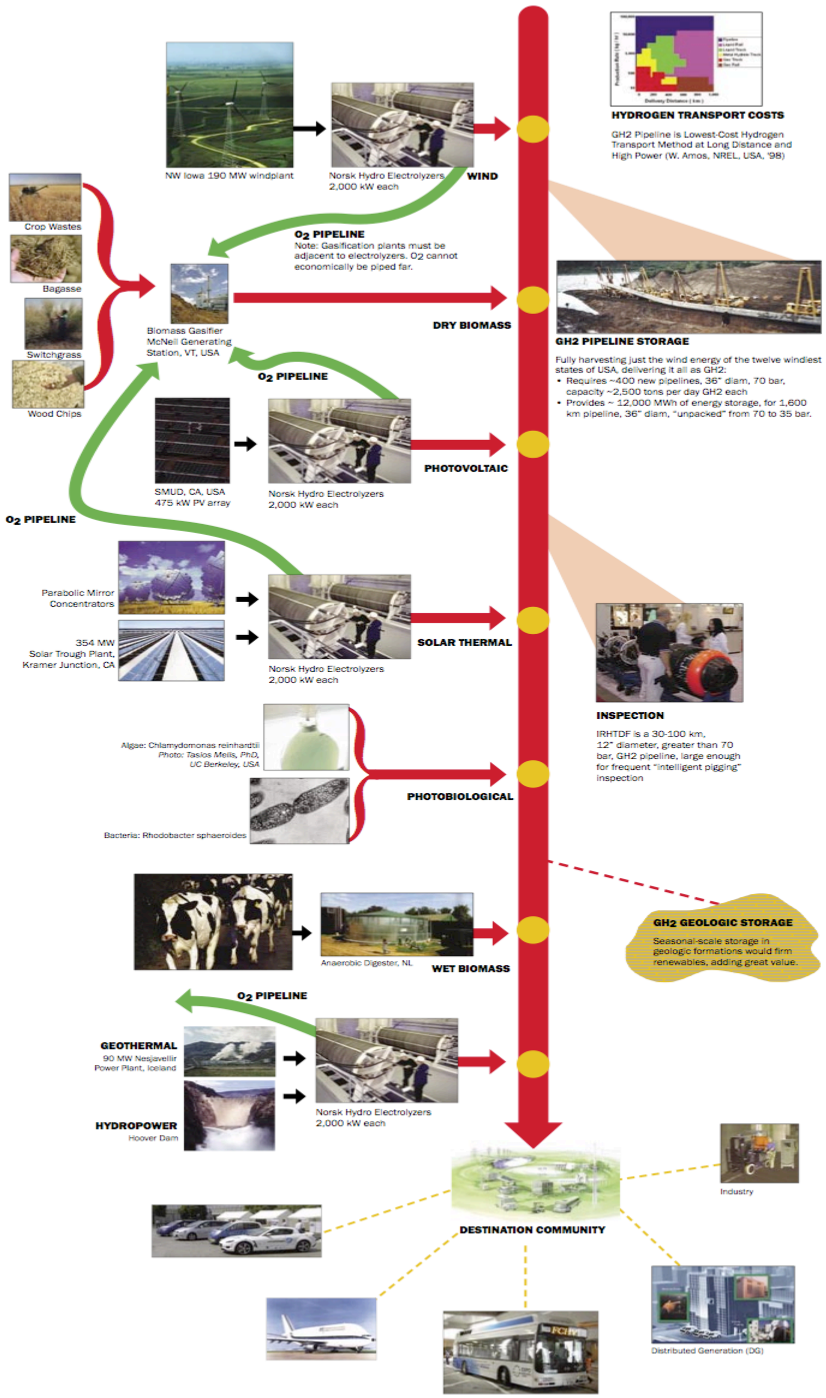
USDOE-EIA: Estimated 2050 energy use (H_2 fleet using wind electrolysis)





Pilot-scale Hydrogen Pipeline System: Renewables

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



International Renewable Hydrogen Transmission Demonstration Facility

(IRHTDF)

Pilot plant

Global opportunity: IPHE project

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**
        @$ 30 / kWh = $ 10 Billion
- **GH2 (3 hydrogen caverns) Capital $70 Million**
- **NH3 (2 ammonia tanks) Capital $30 Million**

“ 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

Jon Wellinghof

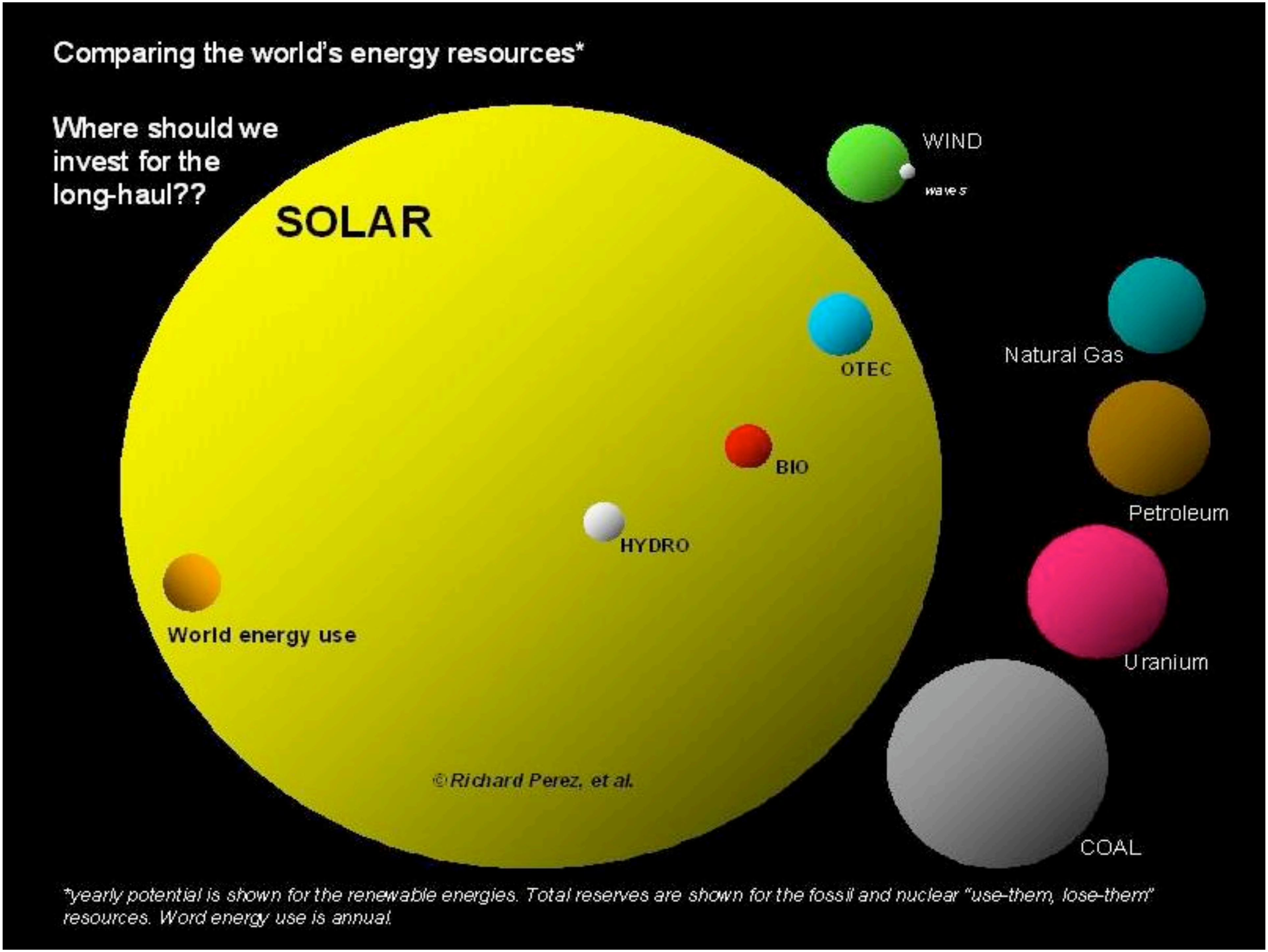
FERC* Chairman

About new coal + nuclear plants:

" We may not need any, ever "

NY Times, 22 Apr 09

*** FERC = Federal Energy Regulatory Commission**


Comparing the world's energy resources*
Where should we invest for the long-haul??
SOLAR
WIND
waves
OTEC
Natural Gas
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.

Ammonia Fuel Production with Firming Storage from Diverse, Stranded, Renewable Energy Resources

DVD's, handouts, your card

Sixth Annual Ammonia Fuel Conference
13 October, Kansas City

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

END 13 Oct 09

Sixth Annual Ammonia Fuel Conference

Kansas City

Bill Leighty

The Leighty Foundation

1: Adequate Renewables

- **Run the world; humanity's <u>needs</u>**
- "Distributed" and "Centralized"
- Affordable, benign
- Diverse, synergistic
- Richest are "stranded"
  - Far from markets
  - No transmission

2: When we realize these as emergencies:

- Global Warming, Rapid Climate Change
- Energy Security and Cost
- Peak Oil and Natural Gas

We must quickly invest in:

- Energy conservation, efficiency
- Large, new energy supplies:
  - CO_2 – emissions - free
  - Indigenous
  - Both distributed, centralized

3: Shortest path to benign, secure, abundant energy

- Renewables
  - Diverse
  - Diffuse
  - Dispersed
- Centralized:
  - Large, rich; lower cost than distributed ?
  - But **stranded (no transmission)**
- Ammonia and Gaseous hydrogen (GH2) pipelines
  - Conversion, gathering
  - Transmission
  - Storage: tanks, salt caverns
  - Distribution
- Affordable annual-scale firming:
  - Ammonia: surface tanks
  - GH2: salt caverns – large, deep, solution-mined, geology-limited
- Pilot plants needed:
  - Every major new industrial process
  - IRHTDF

3: Shortest path to benign, secure, abundant energy

- Anhydrous Ammonia (NH3) pipelines, tanks
  - Conversion, gathering
  - Transmission
  - Storage: tanks
  - Distribution
- Pilot plants needed:
  - Every major new industrial process
  - ’08 Farm Bill Sec 9003:
    “Renewable Fertilizer Research”

4: Ammonia's principal value

- NOT fuel or fertilizer
- Gather, transmit, store:
  - – Large-scale, diverse, stranded renewables
  - – FIRM time-varying-output renewables
    - Pipeline transmission, storage
    - "Renewables – nuclear Synergy …", C. Forsberg
- Benign, if from renewables
- Global opportunity
- Ammonia "sector", not "economy"
  - – Transportation fuel: ground, air
  - – DG electricity, CHP, retail value
  - – Fertilizer

5: Pilot plants needed

- **Every major new industrial process**
- **Diverse, large-scale, stranded**
- **Renewables-source systems**
- **IRHTDF ?**

END 13 Oct 09

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