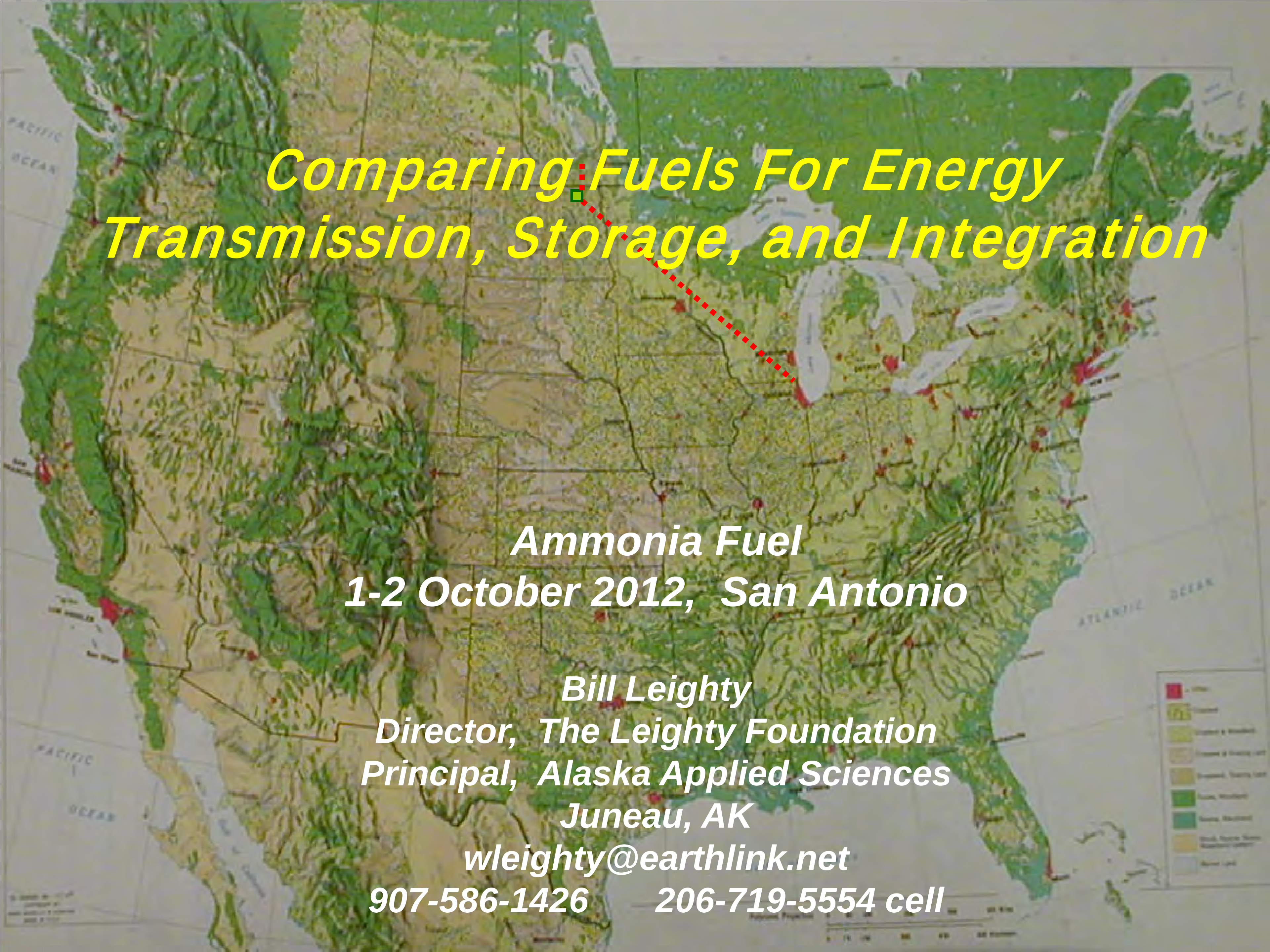

Comparing Fuels For Energy Transmission, Storage, and Integration

Ammonia Fuel
1-2 October 2012, San Antonio

Bill Leighty
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Principal, Alaska Applied Sciences
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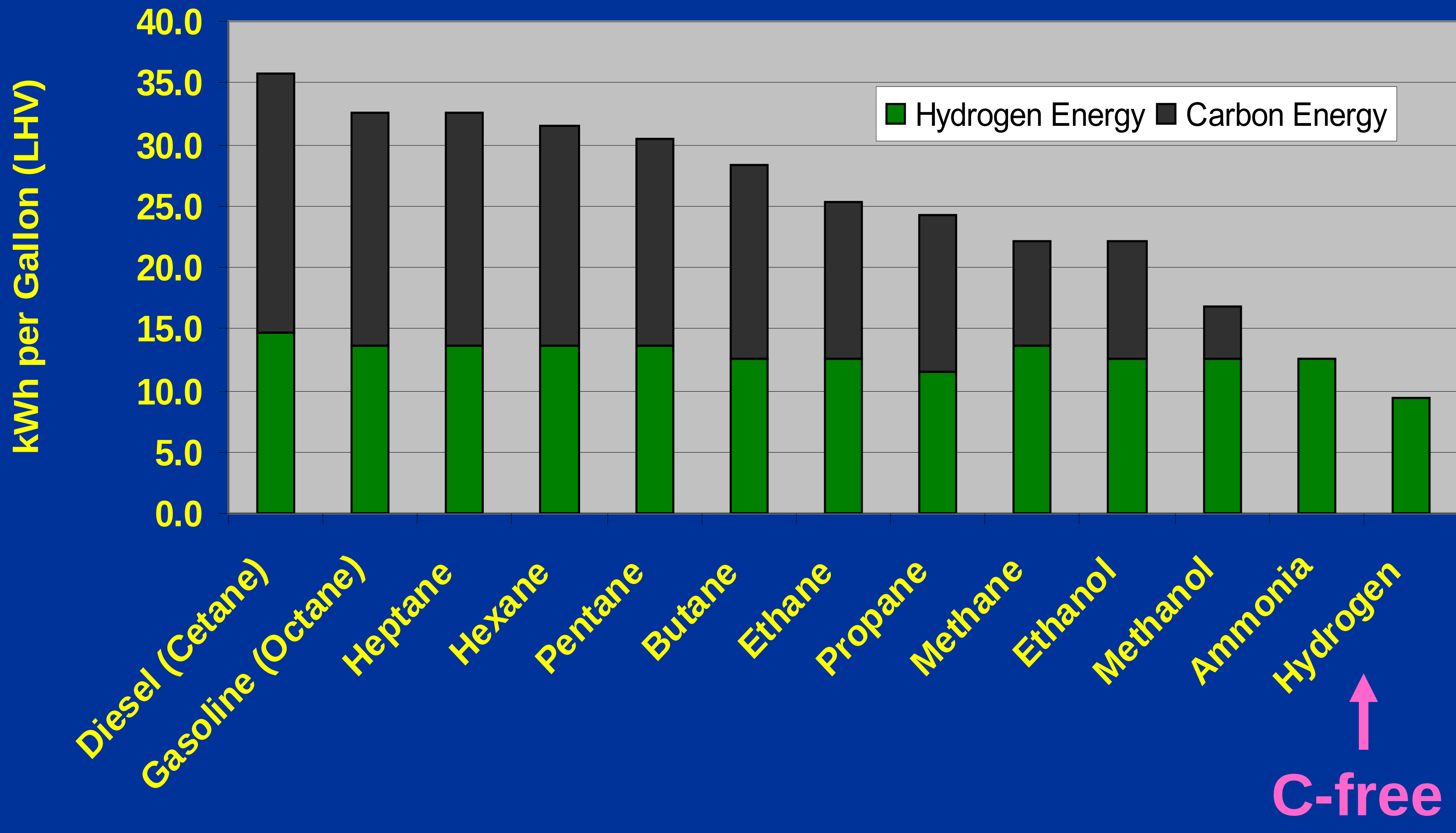
Volumetric Energy Density of Fuels
(Fuels in their Liquid State)



NH3 Fuel Association Website

	Energy Content (LHV)		Octane Number	300 Mile Range - Tank Size (30 mpg gasoline equivalent)[1]	500 km Range - Tank Size (12.75 km/litre gasoline equivalent)	Maximum Practicle Compression Ratio
	Btu/gallon	MJ/liter		Gallons	Litres	
Diesel fuel	129,500	36.10	8 - 15	8.8	34.5	23:1
Biodiesel	118,300	32.98	25	9.6	37.8	23:1
Gasoline	114,100	31.81	86 - 94	10.0	39.2	10:1
LPG (propane)	84,300	23.50	120	13.5	53.1	17:1
Ethanol	76,100	21.21	109	15.0	58.8	19:1
Methanol	56,800	15.83	109	20.1	78.7	19:1
NH3	41,700	11.62	130	27.4	107.3	50:1
CNG (3600 psi)	41,000	11.43	120	27.8	109.1	17:1
Hydrogen (10 kpsi)	16,000	4.46	130	71.3	279.5	
Hydrogen (5 kpsi)	6,500	1.81	130	175.5	688.1	
Lithium Ion Battery	3,870	1.08	NA	98.3	385.2	NA

[1] Corrected for optimal engine efficiency due to increased compression ratio

NH3 Fuel Association Website (reformatted)

	Energy Content	Energy Content	Octane	30 mpg Tank Size 300 mile Range	13 km / l Tank size 500 km Range	ICE Max Compress
	BTU / gal	MJ / liter	Number	Gallons	Liters	Ratio
Diesel	129,500	36.1	8 - 15	8.8	34.5	23
Biodiesel	118,300	32.98	25	9.6	37.8	23
Gasoline	114,100	31.81	86 - 94	10	39.2	10
LPG, LP, propane	84,300	23.5	120	13.5	53.1	17
Ethanol	76,100	21.21	109	15	58.8	19
Methanol	56,800	15.83	109	20.1	78.7	19
NH3	41,700	11.62	130	27.4	107.3	50
CNG (3,600 psi)	41,000	11.43	120	27.8	109.1	17
Hydrogen (GH2) - 700 bar	16,000	4.46	130	71.3	279.5	
Hydrogen (GH2) - 350 bar	6,500	1.81	130	175.5	688.1	
Lithium Ion Battery	3,870	1.08	NA	98.3	385.2	NA

NH3 Fuel Association Website (reformatted)

	Energy Content	Energy Content	Octane	30 mpg Tank Size 300 mile Range	13 km / l Tank size 500 km Range	ICE Max Compress
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Uranium, Plutonium, Thorium						
Deuterium, Tritium						
Electricity						

NH3 Fuel Association Website
(All Energy)

	Energy Content BTU / gal	Energy Content MJ / liter	Octane Number	30 mpg Tank Size 300 mile Range Gallons	13 km / l Tank size 500 km Range Liters	ICE Max Compress Ratio
Diesel	129,500	36.1	8 - 15	8.8	34.5	23
Biodiesel	118,300	32.98	25	9.6	37.8	23
Gasoline	114,100	31.81	86 - 94	10	39.2	10
LPG, LP, propane	84,300	23.5	120	13.5	53.1	17
Ethanol	76,100	21.21	109	15	58.8	19
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Hydrogen (GH2) - 350 bar	6,500	1.81	130	175.5	688.1	
Lithium Ion Battery	3,870	1.08	NA	98.3	385.2	NA
Uranium, Plutonium, Thorium						
Deuterium, Tritium						
Other Petrol Fuels						
Coal						
Electricity						

NH3 Fuel Association Website
(All Energy, More Properties)

	Energy Content	Energy Content	Octane	30 mpg Tank Size 300 mile Range	13 km / l Tank size 500 km Range	ICE Max Compress	GHG	Nox	H:C ratio	pH	H2O Soluble	CO2 Emiss	Buoy in air	Storage effic'y
	BTU / gal	MJ / liter	Number	Gallons	Liters	Ratio								
Diesel	129,500	36.1	8 - 15	8.8	34.5	23								
Biodiesel	118,300	32.98	25	9.6	37.8	23								
Gasoline	114,100	31.81	86 - 94	10	39.2	10								
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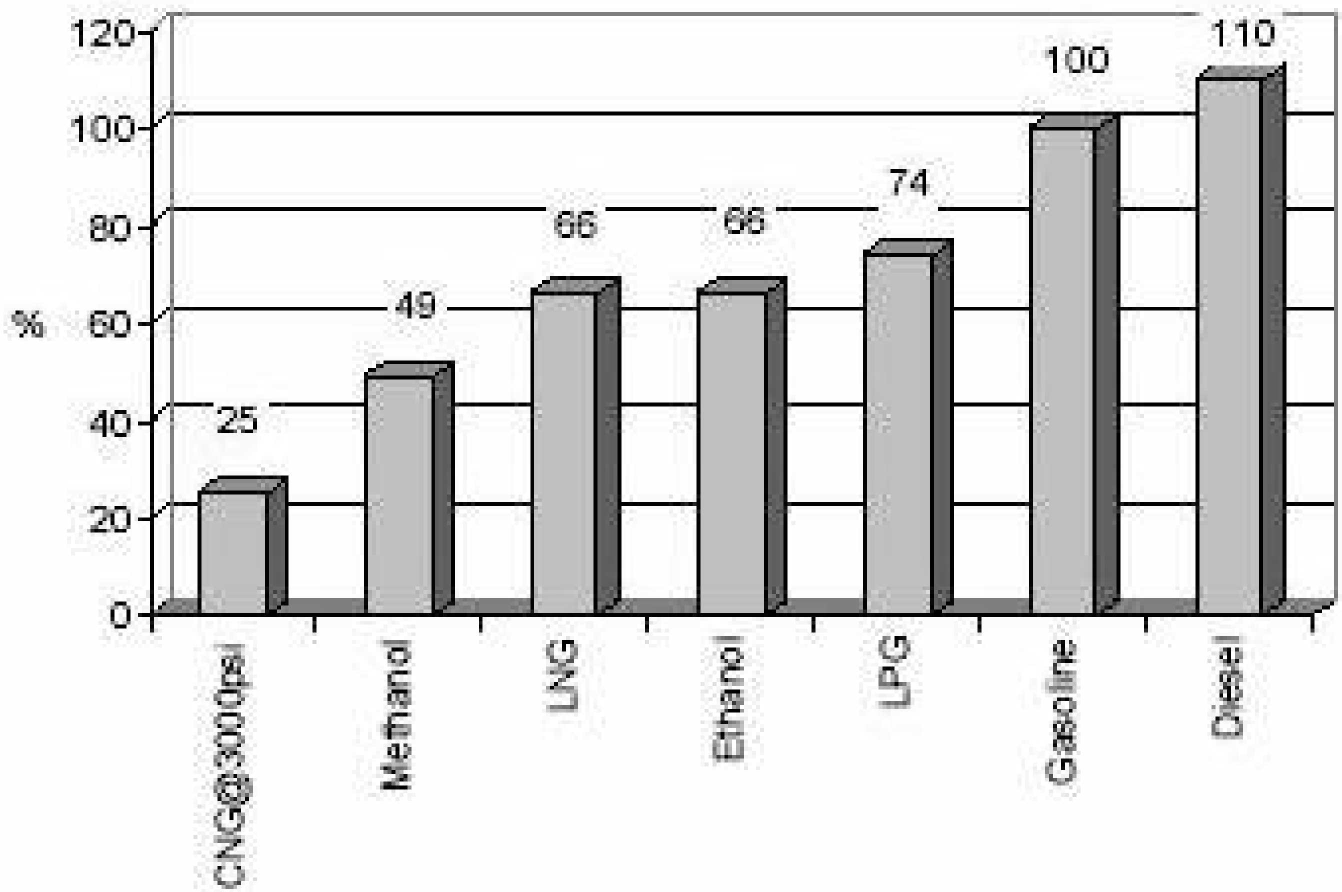
Uranium, Plutonium, Thorium														
Deuterium, Tritium														
Other Petrol Fuels														
Coal														
Electricity														

Compressed fuel tank costs

- Dynetek
- Quantum
- Lincoln
- Toyota
- Baytech Landi-Renzo, Torrance, CA

FUEL	Mass Energy Density			Volumetric Energy Density: Percent of Diesel
Higher Heating Values (HHV)	MJ/kg	BTU / lb.	BTU / gal.	
Diesel, low sulfur	45.600	19,594	138,490	100.0
Gasoline, conventional	46.500	20,007	124,340	89.8
Reformulated Gasoline (RFG)	45.400	19,530	121,848	88.0
Propane	50.200	21,597	91,420	66.0
Liquefied Petroleum Gas	50.200	21,561	91,410	66.0
Ethanol	29.800	12,832	84,530	61.0
Methanol	22.900	9,838	65,200	45.1
Ammonia, NH3 (75% H2)	24.644	10,600	60,282	43.5
Lithium Ion Battery	0.445	940	4134	2.99
Hydrogen, liquid	139.000	60,619	35,815	25.9
Hydrogen, gas, STP	139.000	59,816	42	<0.001

Source: Carl E. Schoder, “Our Carbon Free Energy Future”, Aug 12



Volumetric Fuel Energy versus Gasoline

	CNG	Methanol	LNG	Ethanol	Propane	Gasoline	Diesel
Formula	CH4	C3OH	CH4	C2H5OH	C3H8	C8H16	C12H26
Research Octane #	130	112	130	111	112	91-98	N/A
Motor Octane #	130	91	130	92	97	82-90	
Cetane #	-10	3	-10	8	5-10	8-14	40-60
Boiling Point °F/°C	-259/-162	N/A	-259/-162	N/A	-44/-42	(81-464)/ (27-240)	N/A
Energy Content (volume) (BTU/ft³) / (kJ/L)	213,300/ 7,875	425,000/ 15,688	569,200/ 21,013	570,000/ 21,027	637,500/ 25,535	862,100/ 31,825	950,400/ 35,082
Energy vs Gasoline %	25	49	66	66	74	100	110
Stoich A/F Ratio (mass)	17.3	6.5	17.3	9.0	15.7	14.7	15.0
Autoignition Temperature °F/°C	842/450	N/A	842/450	N/A	1,004/540	428/220	437/225
Peak Flame Temperature °F/°C	3,254/ 1,790	N/A	3,254/ 1,790	N/A	3,614/ 1,990	3,591/ 1,977	3,729/ 2,054
Flammability Lower Limit (volume %)	5.3	4.0	N/A	N/A	2.1	1.4	N/A
Flammability Upper Limit (volume %)	15.0	75.0	N/A	N/A	10.4	7.6	N/A

Context: Fuel Definitions

Attributes:

- Transportable
- Energy storage
- Convertible (energy → exergy)
- Safe, convenient, economical
- USA Fed designation

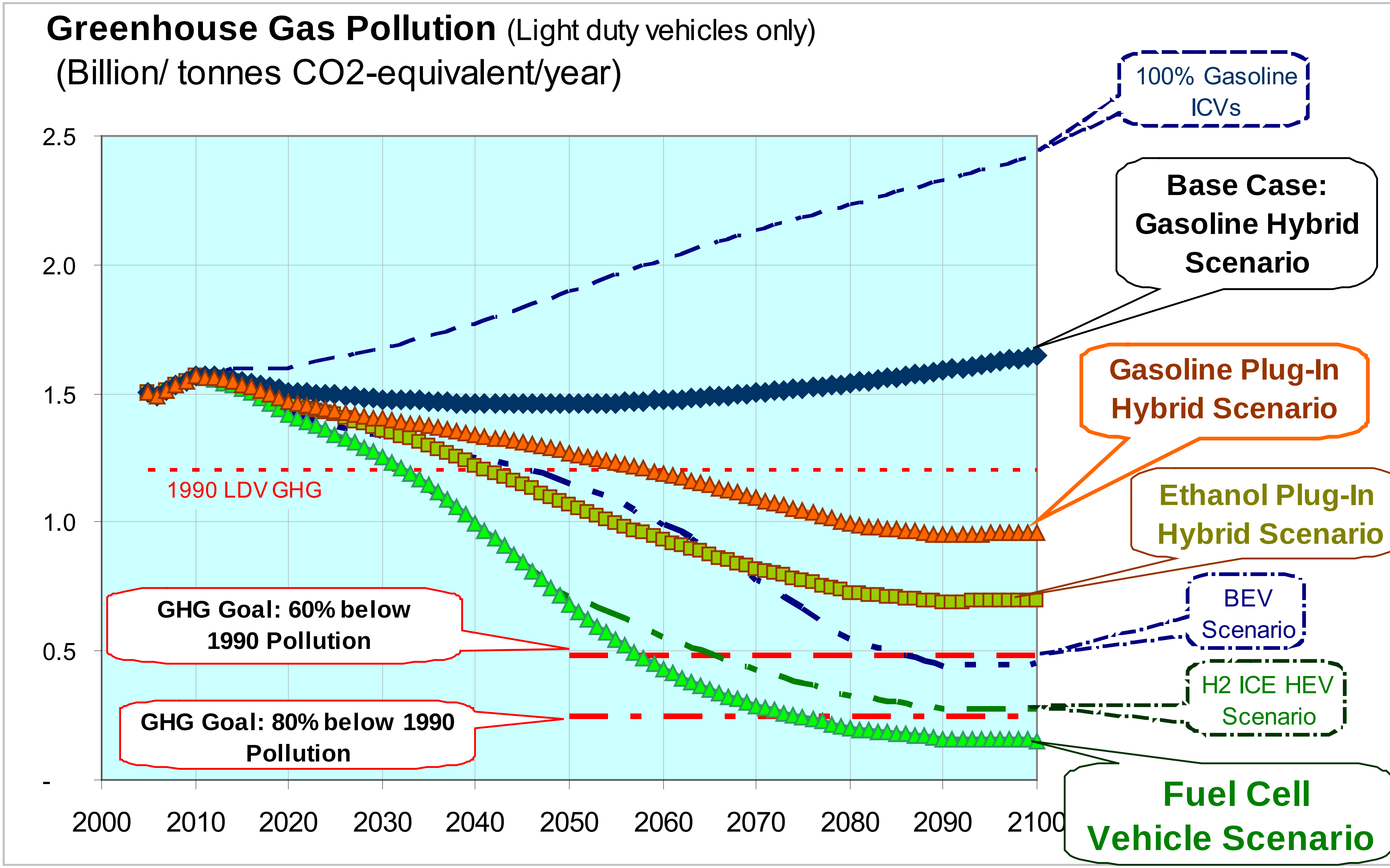
Electricity ?

- Flow of electrons
- 100% exergy
- No storage
- Real-time
- “Smart Grid” symptom

Phyllis Cuttino

Pew Environment

“ Electrification of transportation is the only way to get off foreign oil ”



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

Context: Fuel Definitions

1. A material consumed to produce energy, especially:
   a. Burned to produce heat or electricity
   b. Fissionable or fusible material used in a nuclear reactor
   c. Nutritive, food metabolized by a living organism

2. A substance that produces useful energy when it undergoes a chemical or nuclear reaction: burning, combustion, oxidation or reduction, metabolism.

3. Some radioactive substances:
   - Uranium, plutonium, thorium via fission
   - Deuterium and tritium via fusion

4. USA Fed designation

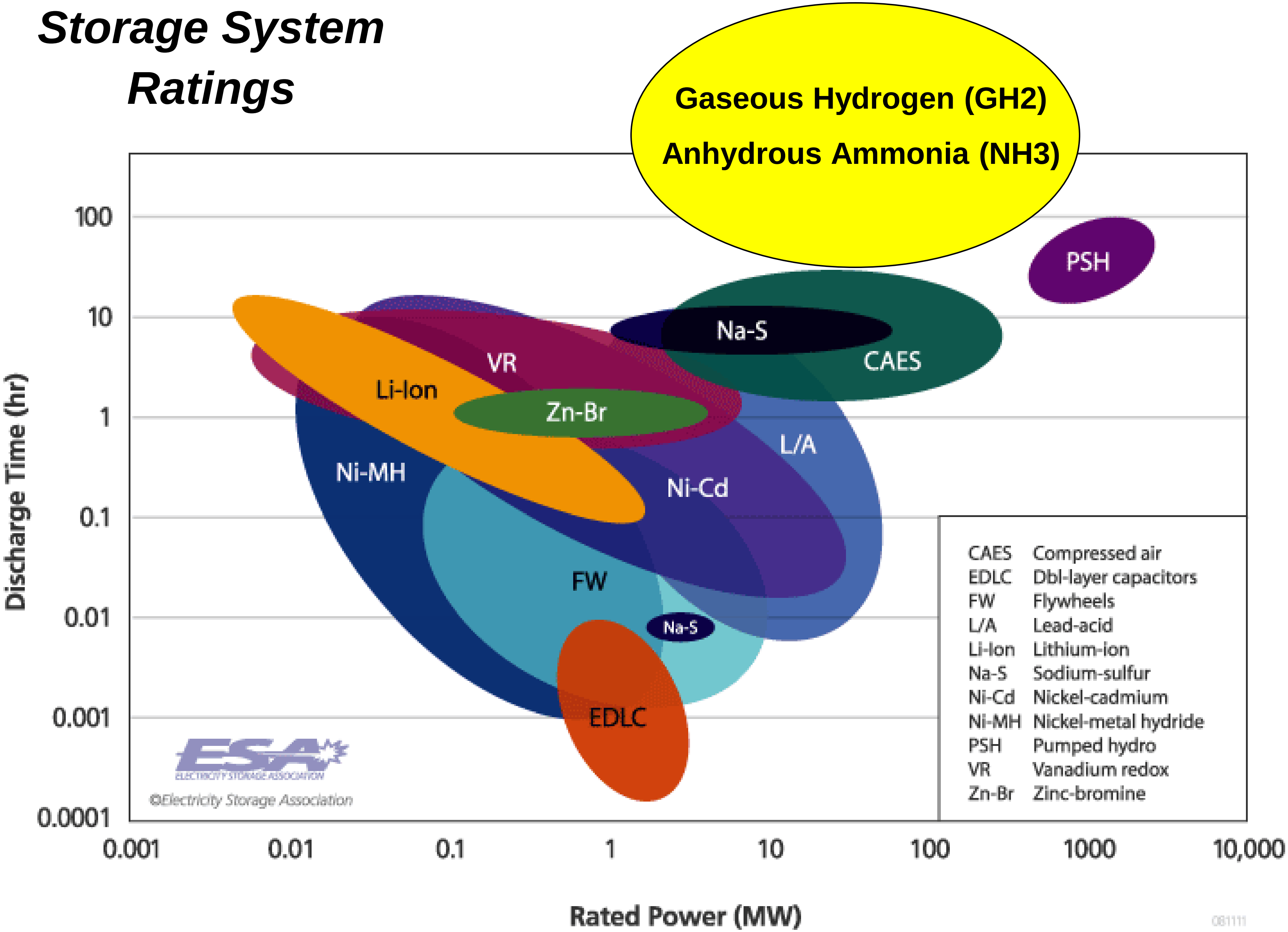
5. Electricity ? No

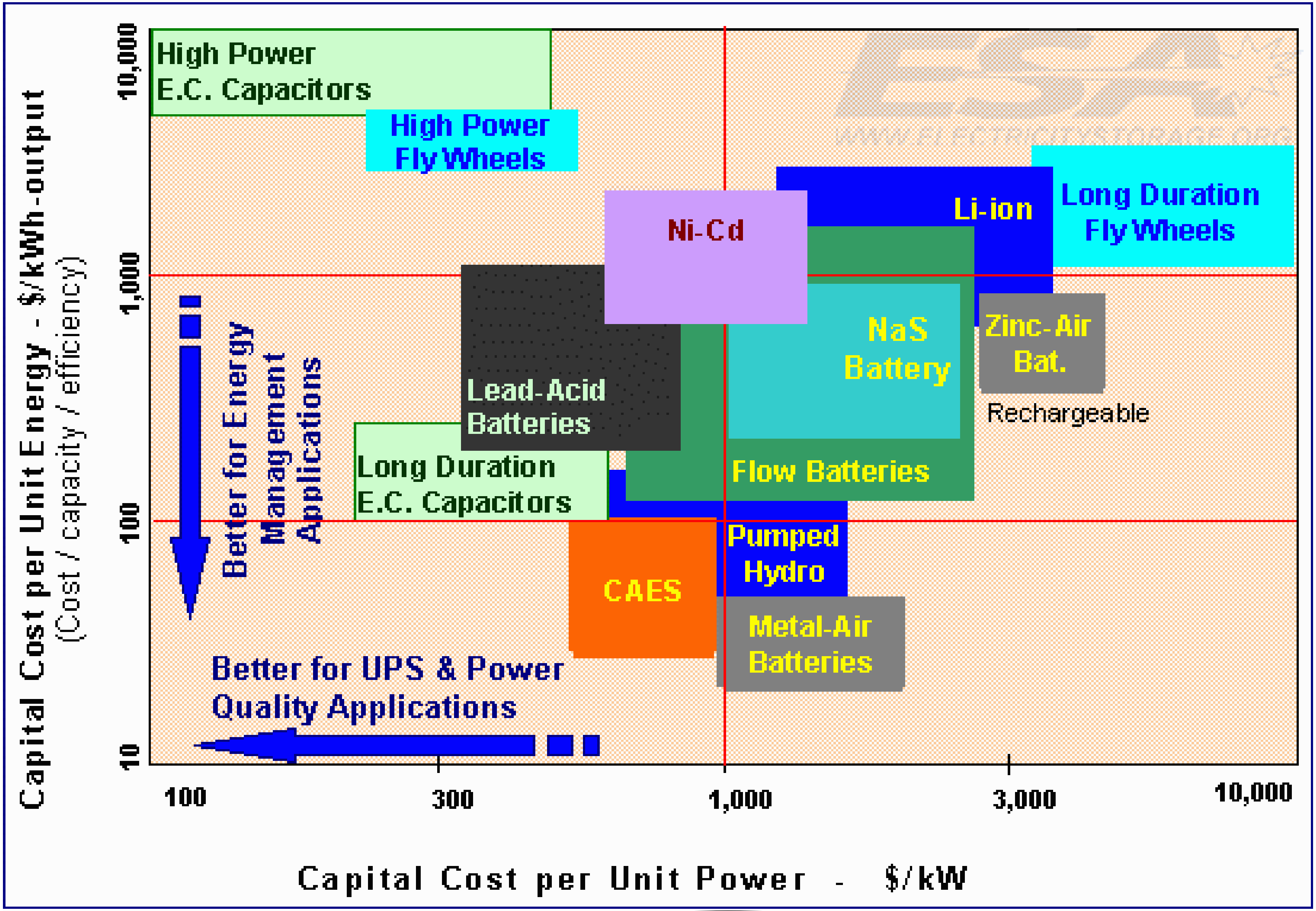
Energy Storage System Characteristics

Hydrogen and Ammonia off the charts

- *Storage capacity (Mwh, scf, nM3, Mt, gallons ….)*
- *Power (MW, scfm ….)   In / Out rate*
- *Costs*
  - *Capital*
  - *O&M*
  - *Conversion losses*
- **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**

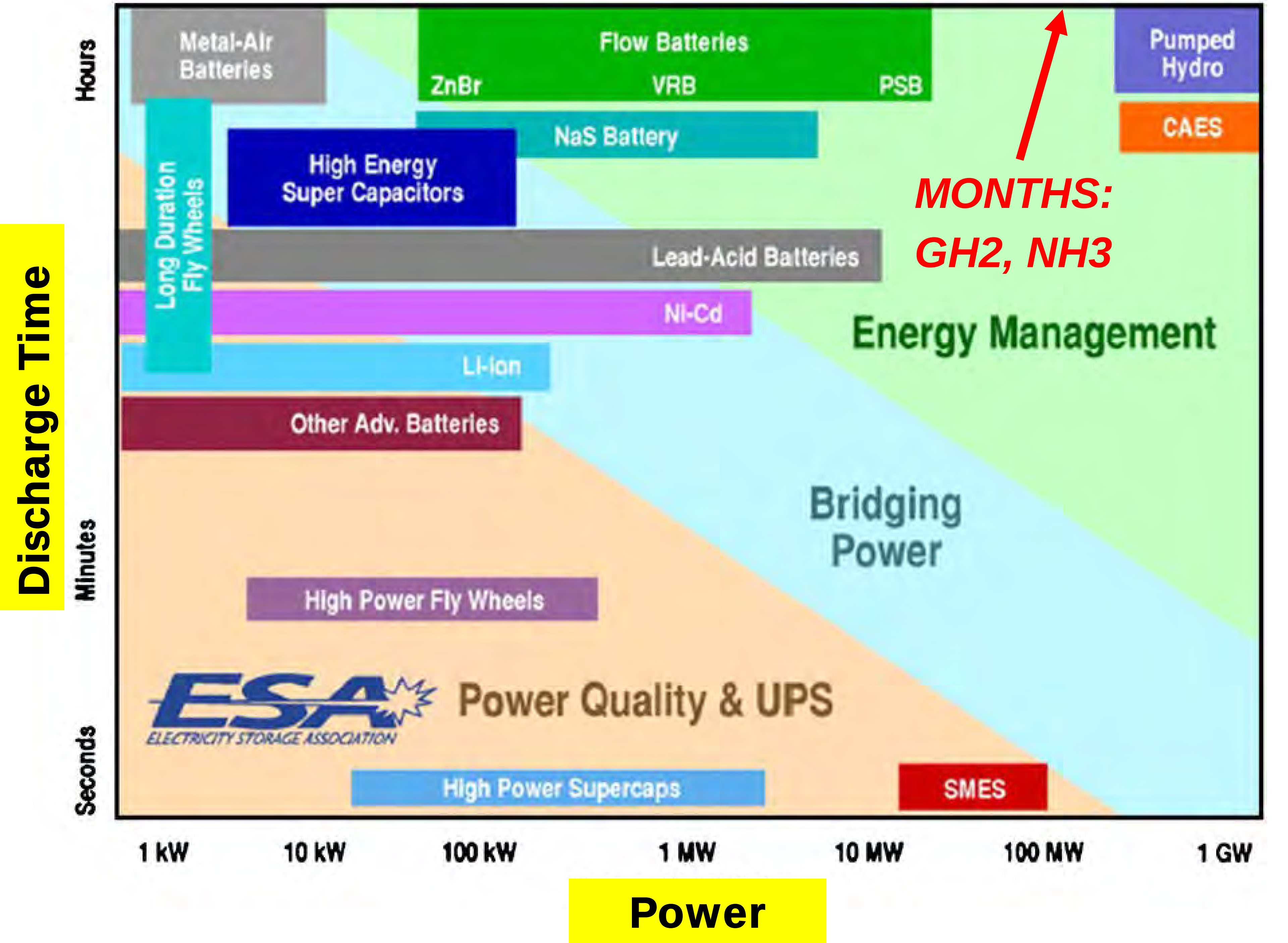
Storage System Ratings





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
Flow Batteries
Long Duration
E.C. Capacitors
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

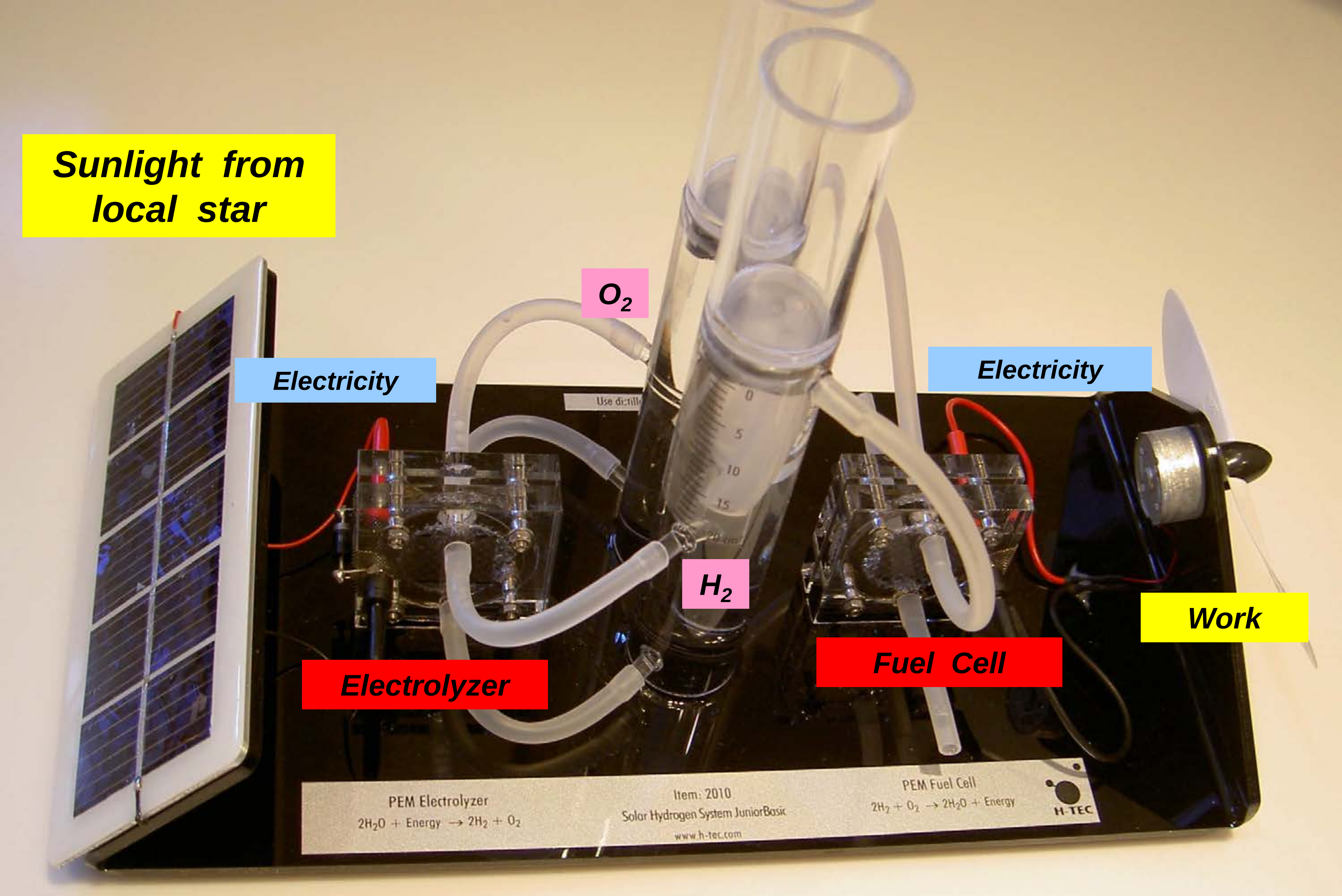
GH2 and NH3



Metal-Air Batteries
Flow Batteries
ZnBr
VRB
PSB
Pumped Hydro
CAES
NaS Battery
High Energy Super Capacitors
Long Duration Fly Wheels
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
Hours
Minutes
Seconds
Discharge Time
1 kW
10 kW
100 kW
1 MW
10 MW
100 MW
1 GW
Power

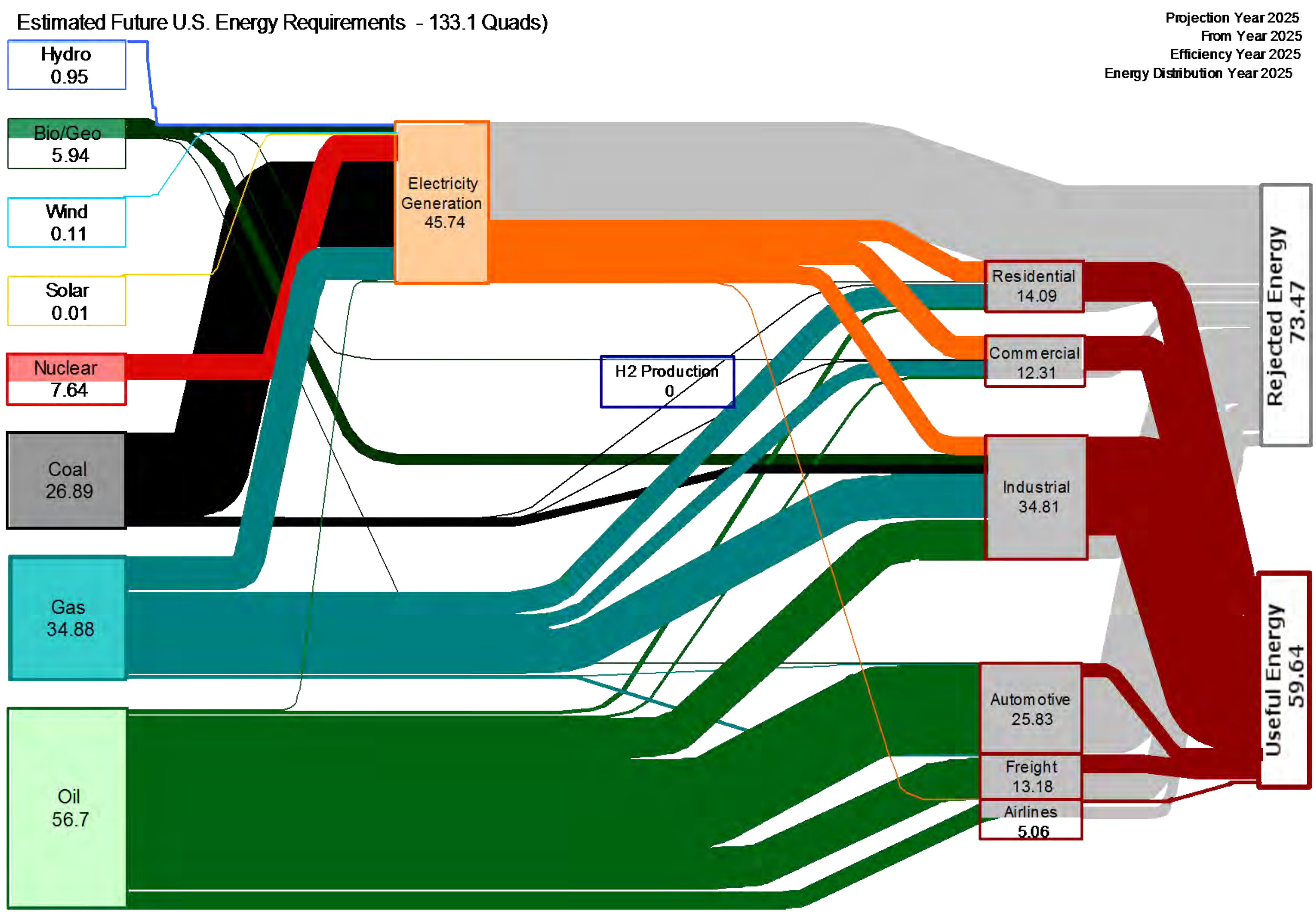
Context: Complete energy systems

- Photons + moving molecules → energy services
- Extraction: Non-renewable
  - Fossil
  - Nuclear
- Production: Renewable generation, conversion
- Transmission
- Storage
- Supply integration
- Markets, niches



Solar Hydrogen Energy System

EIA estimated 2025 energy use



Context: Why Ammonia ?
Fertilizer and 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

Markets: Supply, Demand, Price

- **Supply Push**
- **Demand Pull**
- **Price**
  - **Competition**
  - **Substitutes**
  - **Volume**
  - **Condition changes**

Market: Transportation

- Land
  - Truck
  - Rail
  - Personal vehicle
  - Military
- Air
- Marine
  - Pleasure, utility
  - Commercial
  - Shipping
  - Military: USCG, Navy

Market: Transportation

- Land, Marine
  - Liquid HC's
  - CNG, LNG
  - LPG
  - Hydrogen: GH2, LH2
  - Other: Al-Ga, Zinc

- Air
  - Liquid HC's
  - LH2

Compressed Natural Gas (CNG) Fueling: ~ 3,000 psi

Market: Ag + Construction + Industrial

- **Liquid HC's**
- **CNG, LNG**
- **LPG**
- **Hydrogen: GH2, LH2**
- **Other: Al-Ga, Zinc**

John Deere “LP” tractor

John Deere "LP" tractor

Market: Combined Heat and Power (CHP)

- Firm, quality "power"
  - Elec grid backup
  - Elec grid replace
  - Sub-cycle response
- 80% + fuel energy recovery
- Stationary, on-site
  - Genset (ICE, CT, Fuelcell)
  - Byproduct heat (HI, LO temp)
    - Heat and cool
    - Process
- Fuels
  - Natural gas (pipeline)
  - Liquid HC's (pipeline and / or tank)
  - Ammonia (pipeline and / or tank)
  - Nuclear SMR (small modular reactor)

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    - **Heat and cool**
    - **Process**
- **Fuels**
  - **Natural gas (pipeline)**
  - **Liquid HC's (pipeline and / or tank)**
  - **Ammonia (pipeline and / or tank)**
  - **Nuclear SMR (small modular reactor)**

Market: Military

- Land
- Sea
- Air
- Scale
  - Major Base
  - Forward Base
  - Ship
  - Aircraft
  - Mini, Micro 1 W → 1 kW

Market: RE Systems "Big 3"

(RE = Renewable Energy)

1. **Gathering and Transmission**
2. **Storage**
   - **Firming**
   - **Seasonal, annual**
   - **Dispatchable**
   - **Cure "intermittent"**
3. **Supply Integration**
   - **Extant energy systems**
   - **Cure "intermittent"**

Market: Fertilizer

- **N:**
  - **Embodied energy**
  - **“Corn ethanol is recycled natural gas”**
  - **NH3 and products: Urea, DAP, AN, other**
- **K, P**
  - **Embodied energy**
  - **Enables solar harvest via photosynthesis**
- **Trace minerals**
  - **Enables solar harvest via photosynthesis**

Market: Chemicals + Explosives

- **Feedstock**
- **Explosives**

Context:

Markets - Where NH3 Compete ?

- Transportation
- Combined Heat and Power (CHP)
- Ag + Construction + Industrial
- Military
- Complete RE systems
- Fertilizer
- Chemicals + Explosives

Fuel, fertilizer, feedstock ?
Distributed, centralized, networked ?
Determines salient "fuel" properties

Ammonia Demand

From C.E. Schoder Aug '12

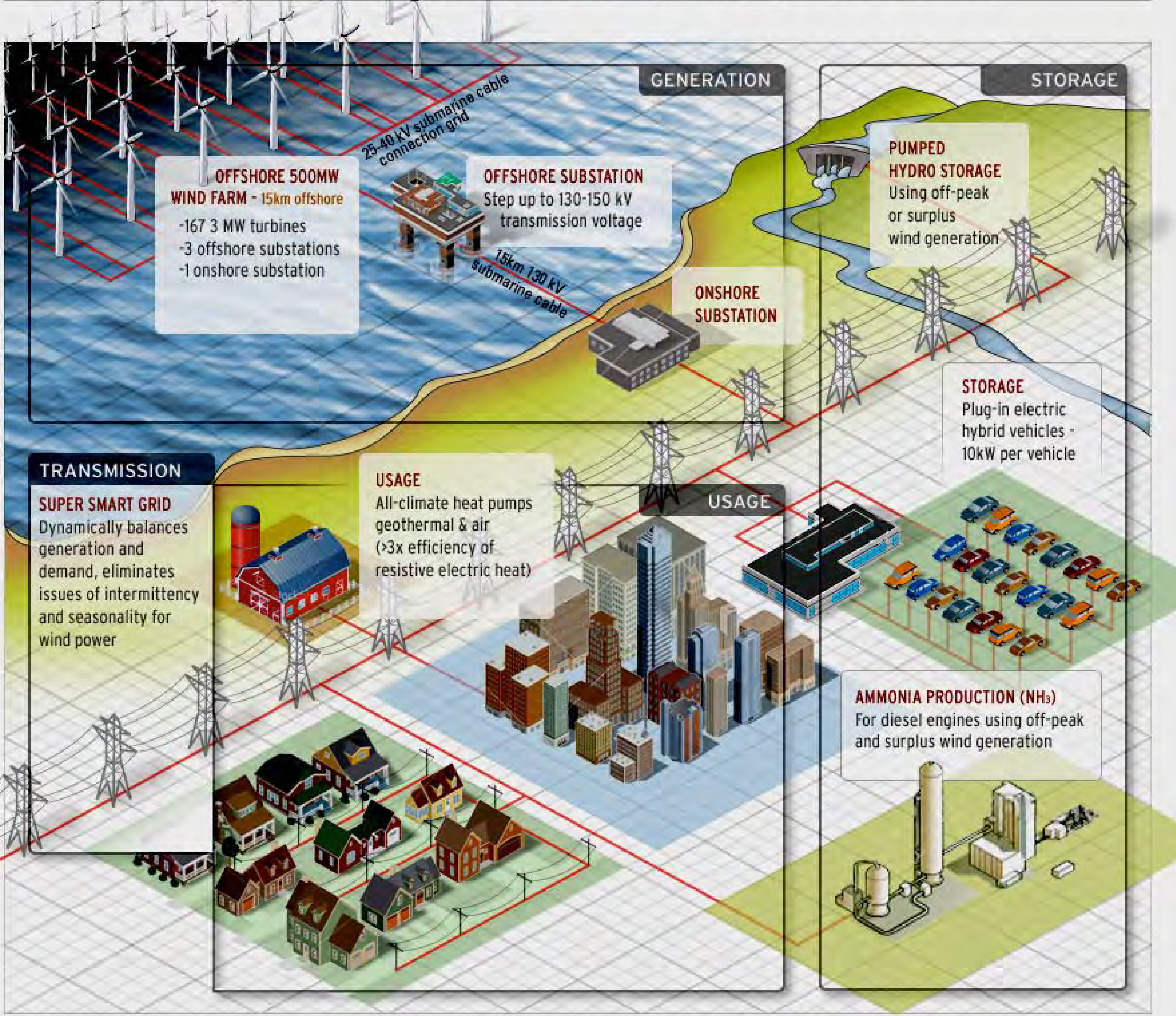
Data for two representative areas	Worldwide, IEA (6)		USA, EIA (7)	
Type of Energy Demand,	Volumetric demand	Gravimetric demand	Volumetric demand	Gravimetric demand
Energy Demand units-→	Cubic meters NH3 per day	Mtonnes NH3 per day	Cubic meters NH3 per day	Mtonnes NH3 per day
NH3 energy demand per day, using NH3 to replace fossil fuels only)	90,711,825	61,856,394	28,437,910	19,391,811
Annual (MMtonnes) (Million metric tons)				
Assuming Solid State Ammonia Synthesis				
Air Separation Unit input, air	95,519,027	65,134,424	29,944,954	20,419,464
Air Separation Unit output, nitrogen	74,585,077	50,859,564	23,382,218	15,944,334
Air Separation Unit output, oxygen	20,933,950	14,274,860	6,562,736	4,475,130
Annual (MMtonnes) (Million metric tons)				
SSAS input, water	59,744,604	40,739,845	18,729,770	12,771,830
SSAS input, nitrogen	74,585,077	50,859,564	23,382,218	15,944,334
Total inputs	134,329,681	91,599,409	42,111,988	28,716,165
SSAS output, NH_3 per day (fossil fuel replacement only)	90,711,825	61,856,394	28,437,910	19,391,811
SSAS output, oxygen	43,617,856	29,743,016	13,674,079	9,324,354
Total outputs	134,329,681	91,599,409	42,111,988	28,716,165

Complete energy systems

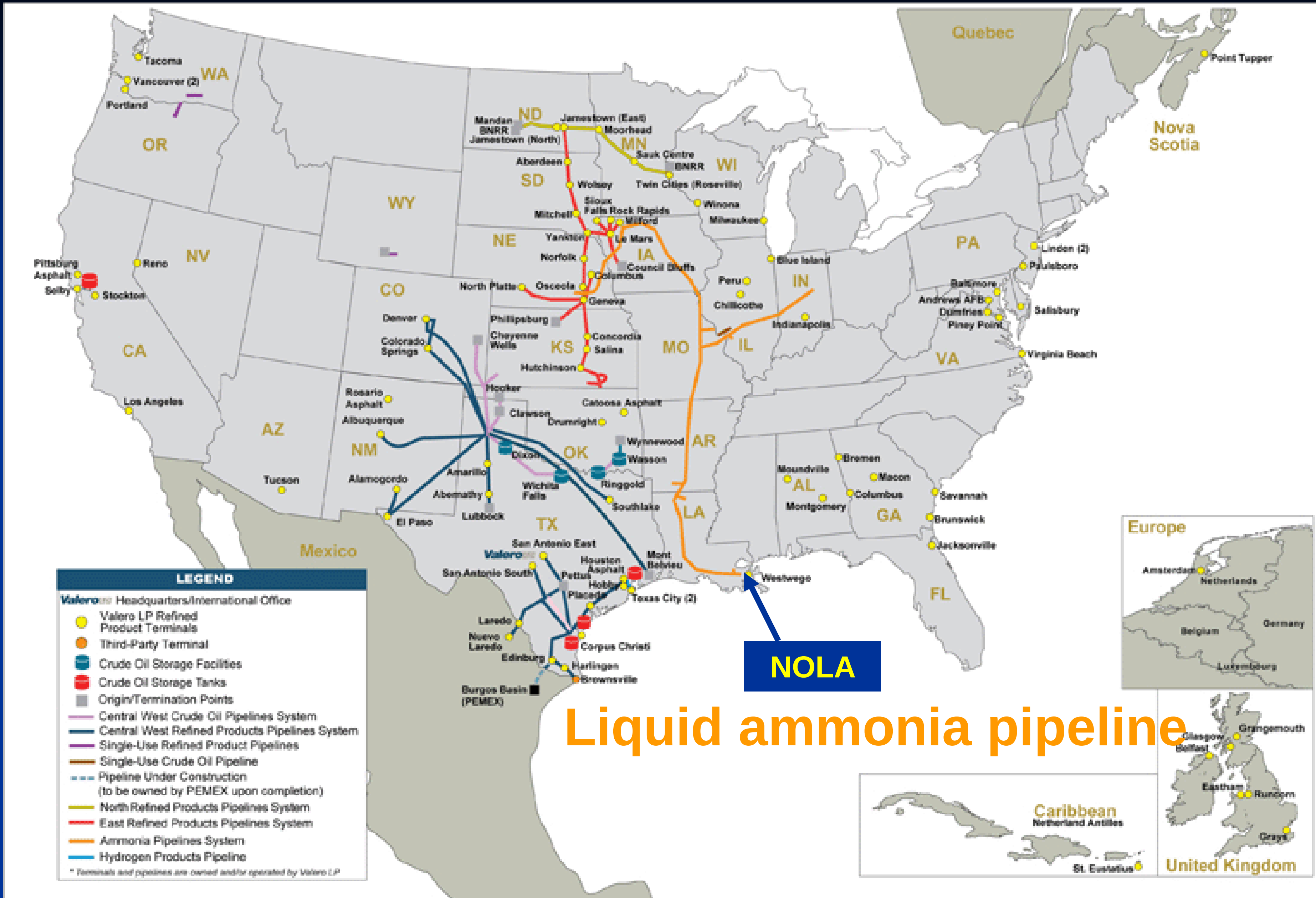
- Photons + moving molecules → energy services
- Extraction: Non-renewable
  - Fossil
  - Nuclear
- Production: Renewable generation, conversion
- Transmission
- Storage
- Supply integration
- Markets, niches

NH_3 Ag Fertilizer Tanks, Wind Generators, NW Iowa

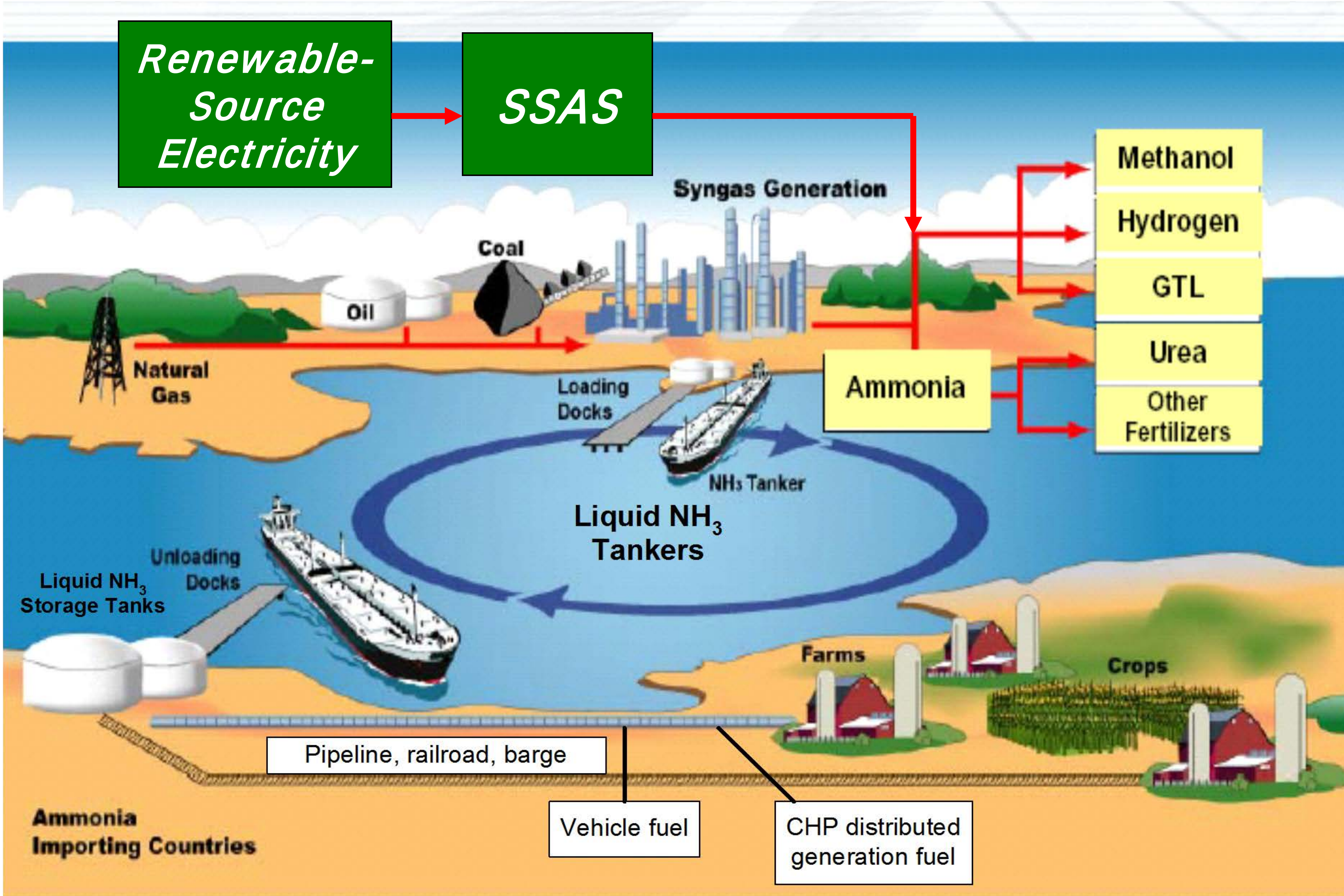
Energy as a Complete System: Generation, Usage, Storage, Transmission



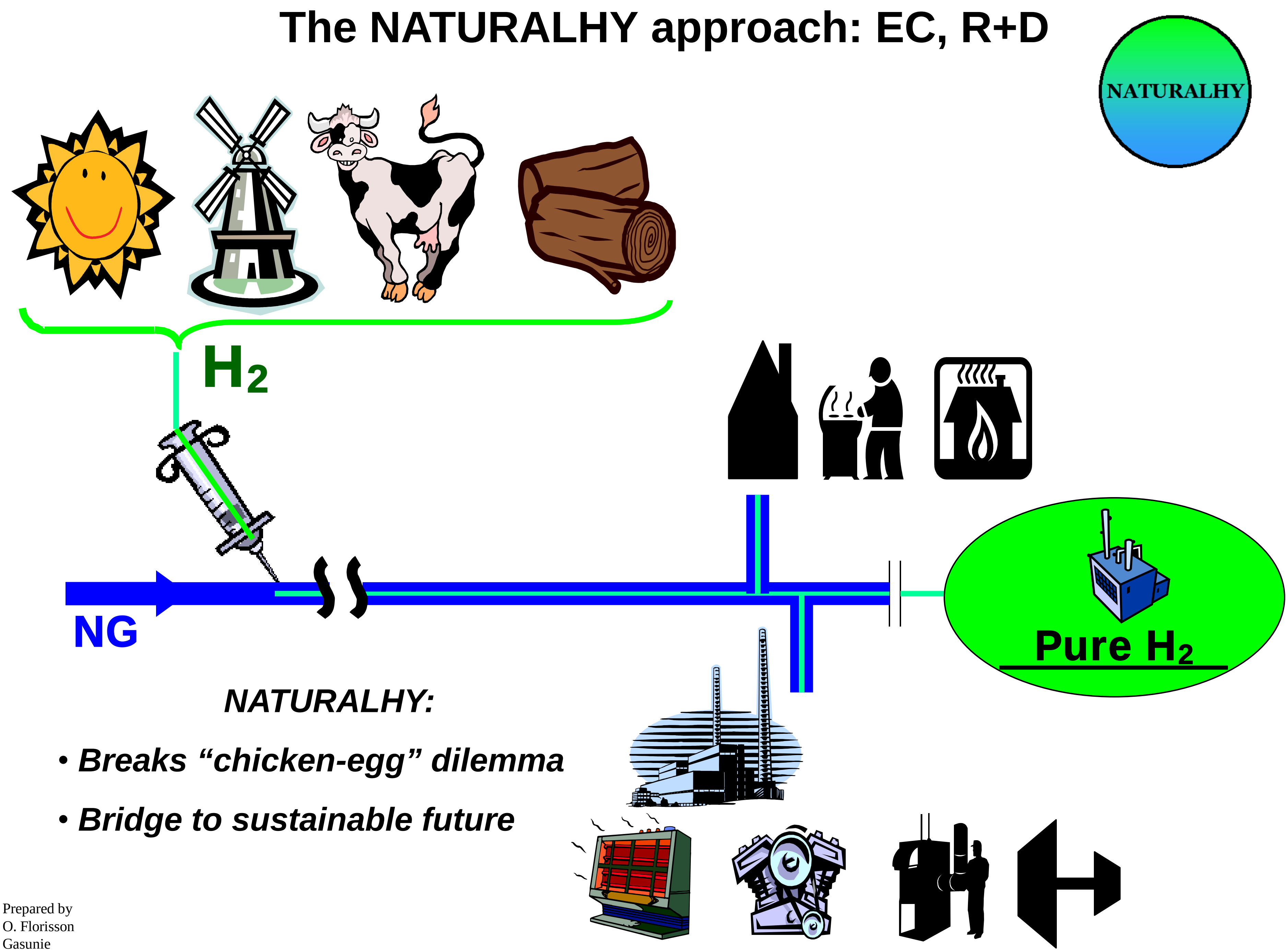
NH3 Storage

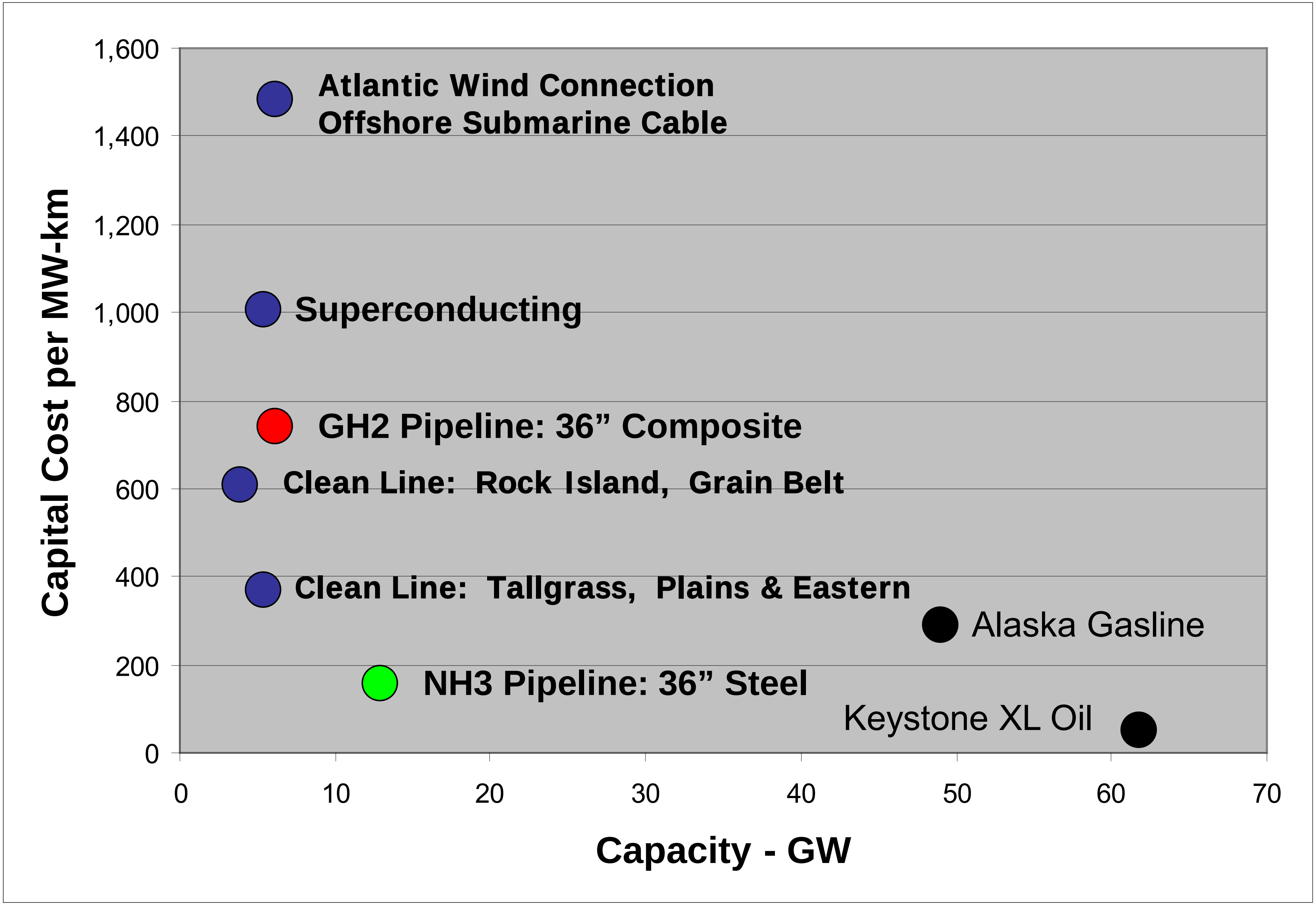


Valero LP Operations

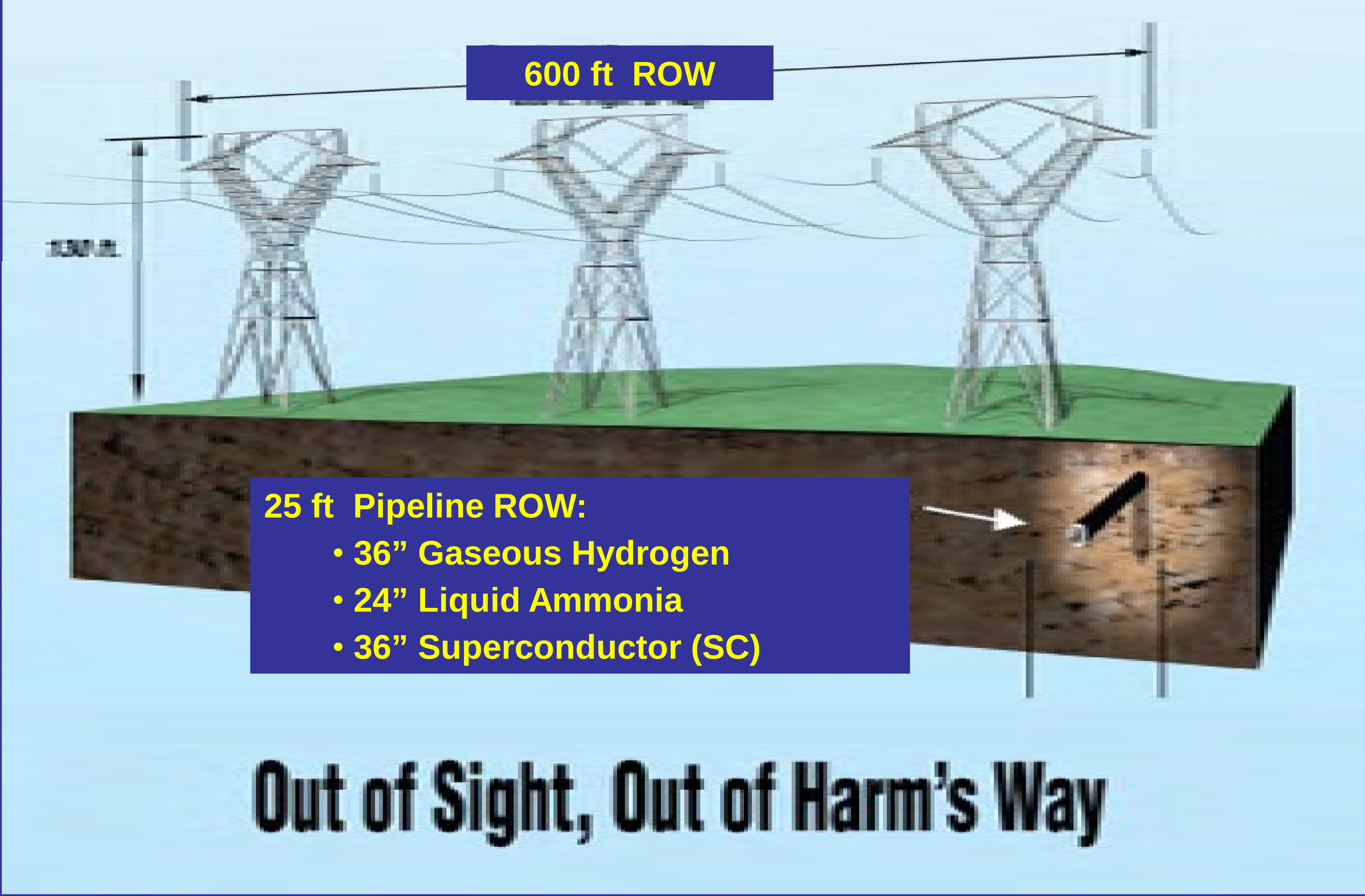


KBR
Energy and Chemicals

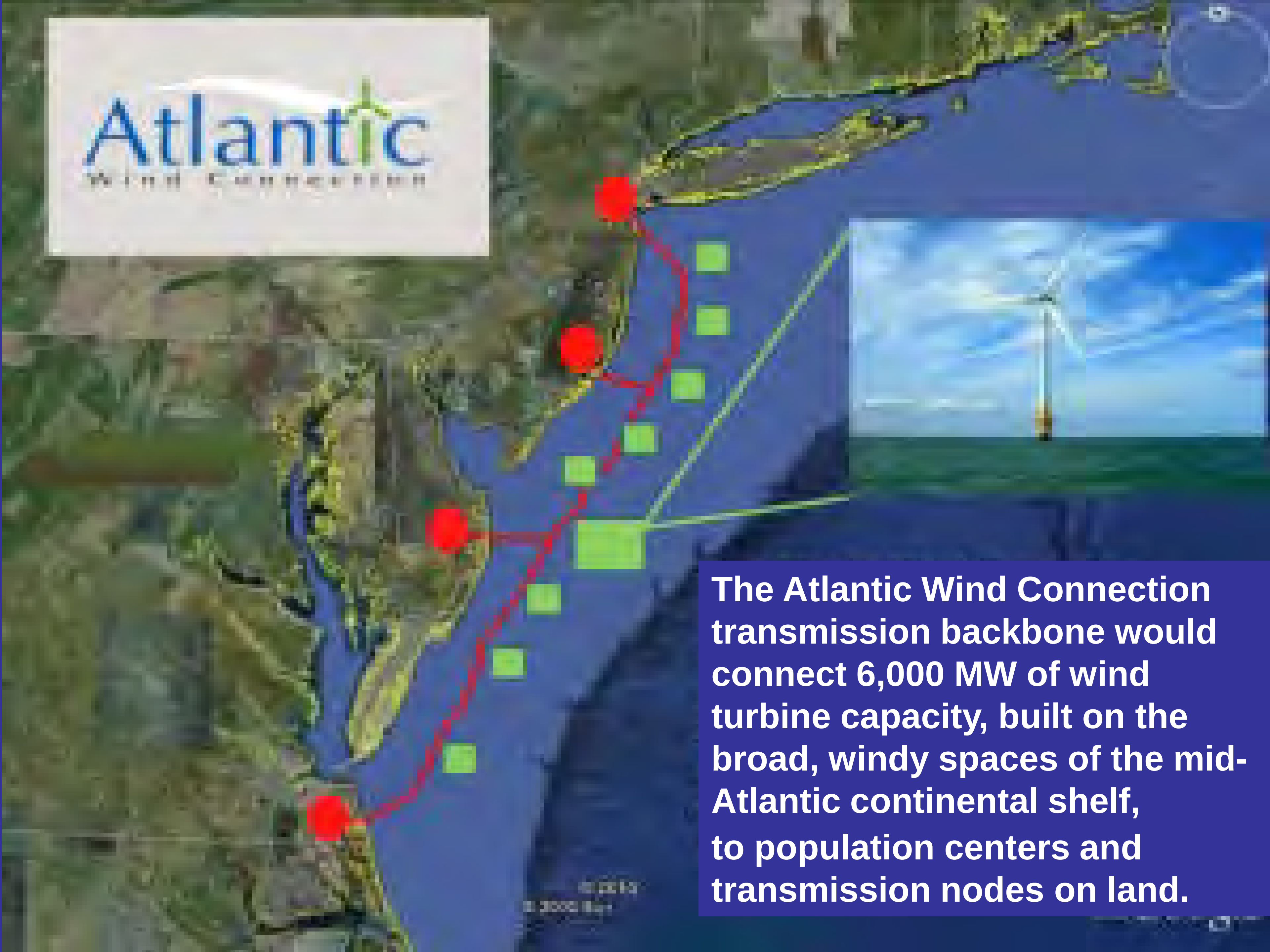

The NATURALHY approach: EC, R+D
NATURALHY
H2
NG
Pure H2
NATURALHY:
• Breaks “chicken-egg” dilemma
• Bridge to sustainable future
Prepared by
O. Florisson
Gasunie



Capital Cost per MW-km
Capacity - GW
1,600
1,400
1,200
1,000
800
600
400
200
0
0
10
20
30
40
50
60
70
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



5,000 MW alternatives: HVAC vs HVDC superconductor



The Atlantic Wind Connection transmission backbone would connect 6,000 MW of wind turbine capacity, built on the broad, windy spaces of the mid-Atlantic continental shelf, to population centers and transmission nodes on land.

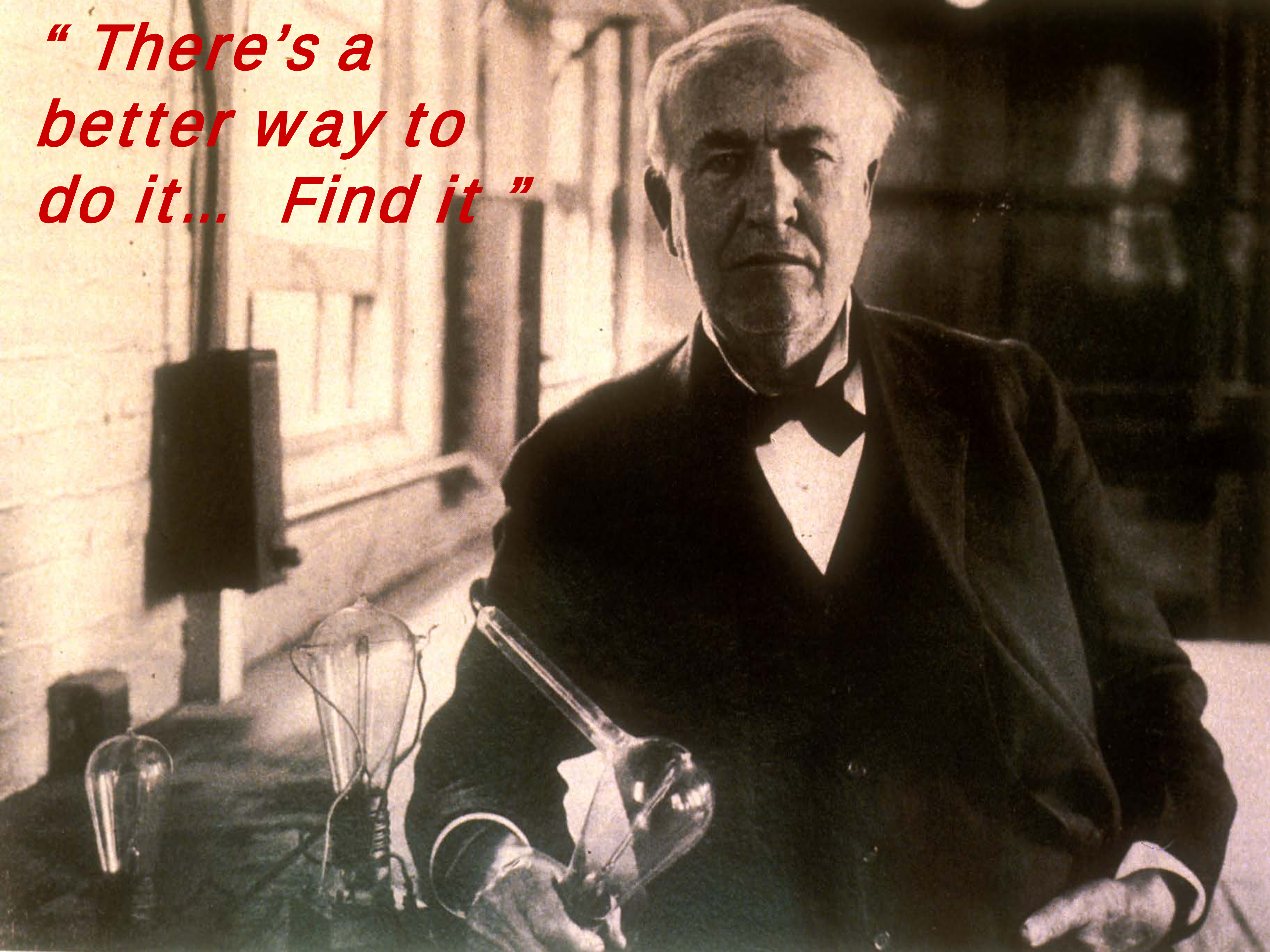
Hydrogen and Ammonia Fuels

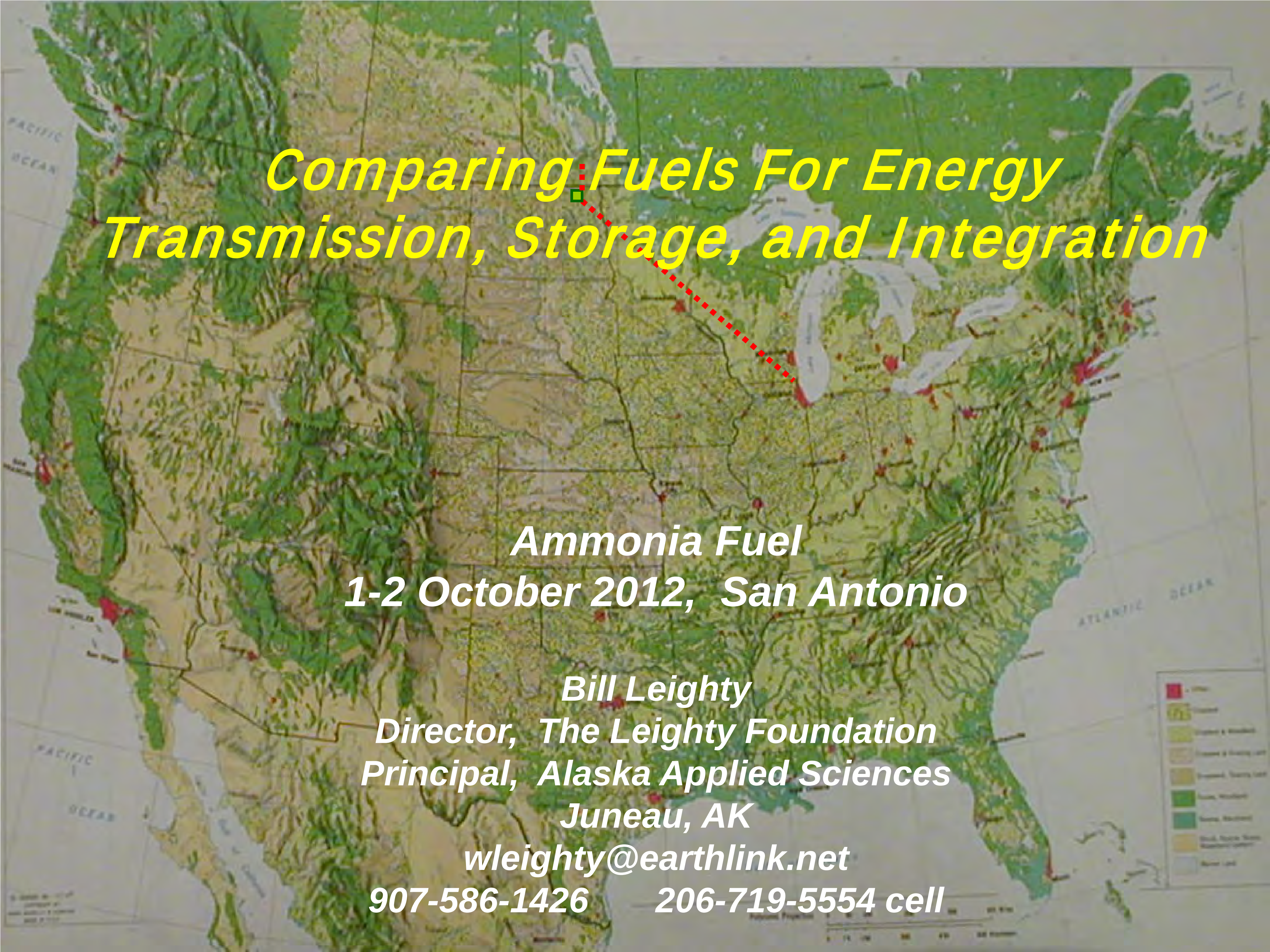
- **Solve electricity's RE problems:**
  - **Transmission**
  - **Firming storage**
  - **Grid integration: time-varying output**
- **Carbon-free**
- **Underground pipelines**
- **Low-cost storage: < $ 1.00 / kWh capital**
  - **Pipelines**
  - **GH2 salt caverns**
  - **NH3 tanks**
- **Sec'y Chu: reconsidering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

Annual Fresh Water for Energy

- *USA today*
- *All energy*

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


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



Comparing Fuels For Energy Transmission, Storage, and Integration

Ammonia Fuel
1-2 October 2012, San Antonio

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Solid State Ammonia Synthesis Pilot Plant (SSAS-PP) Demonstration System for Renewable Energy (RE) Firming Storage, Transmission, and Export

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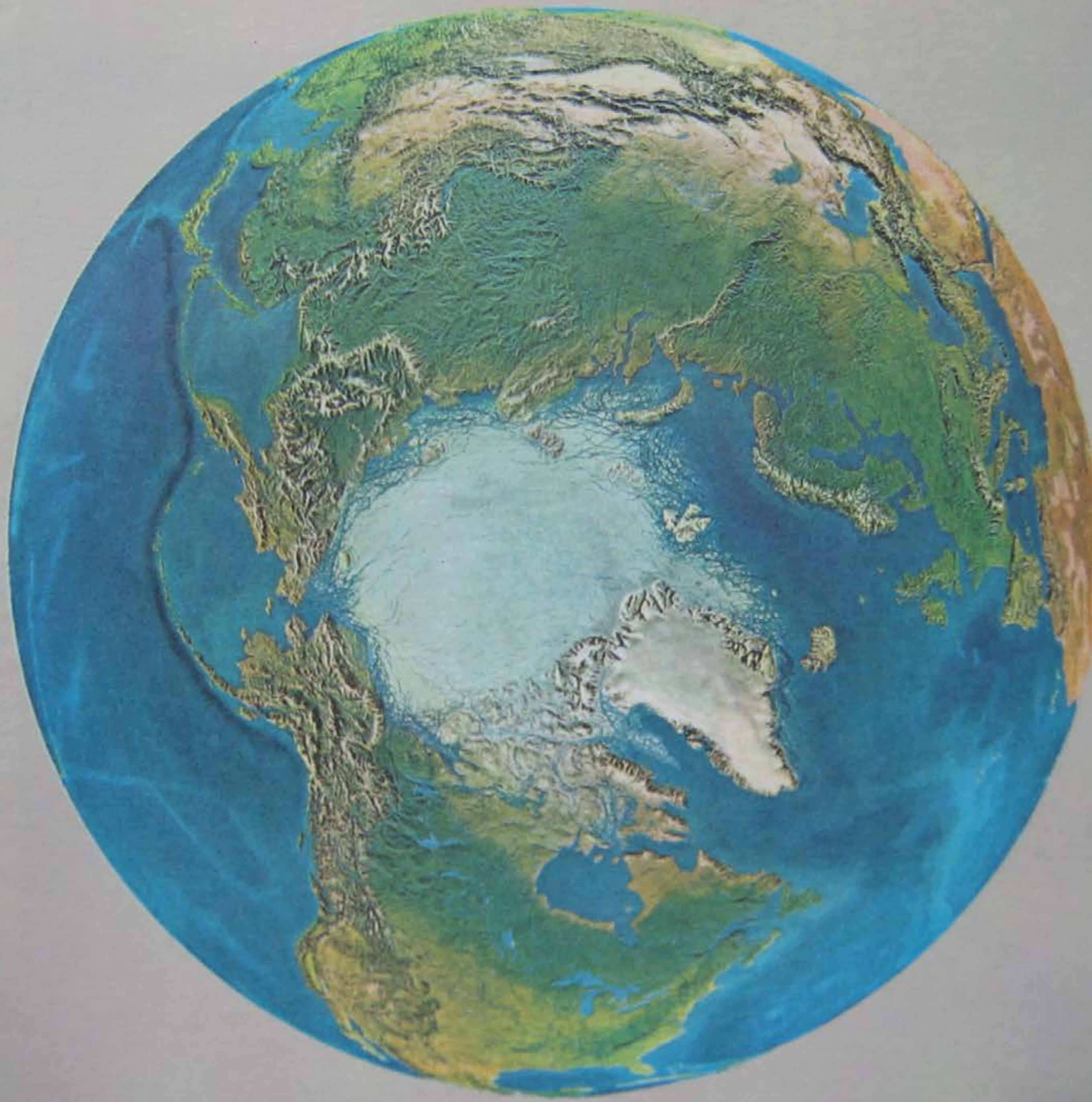
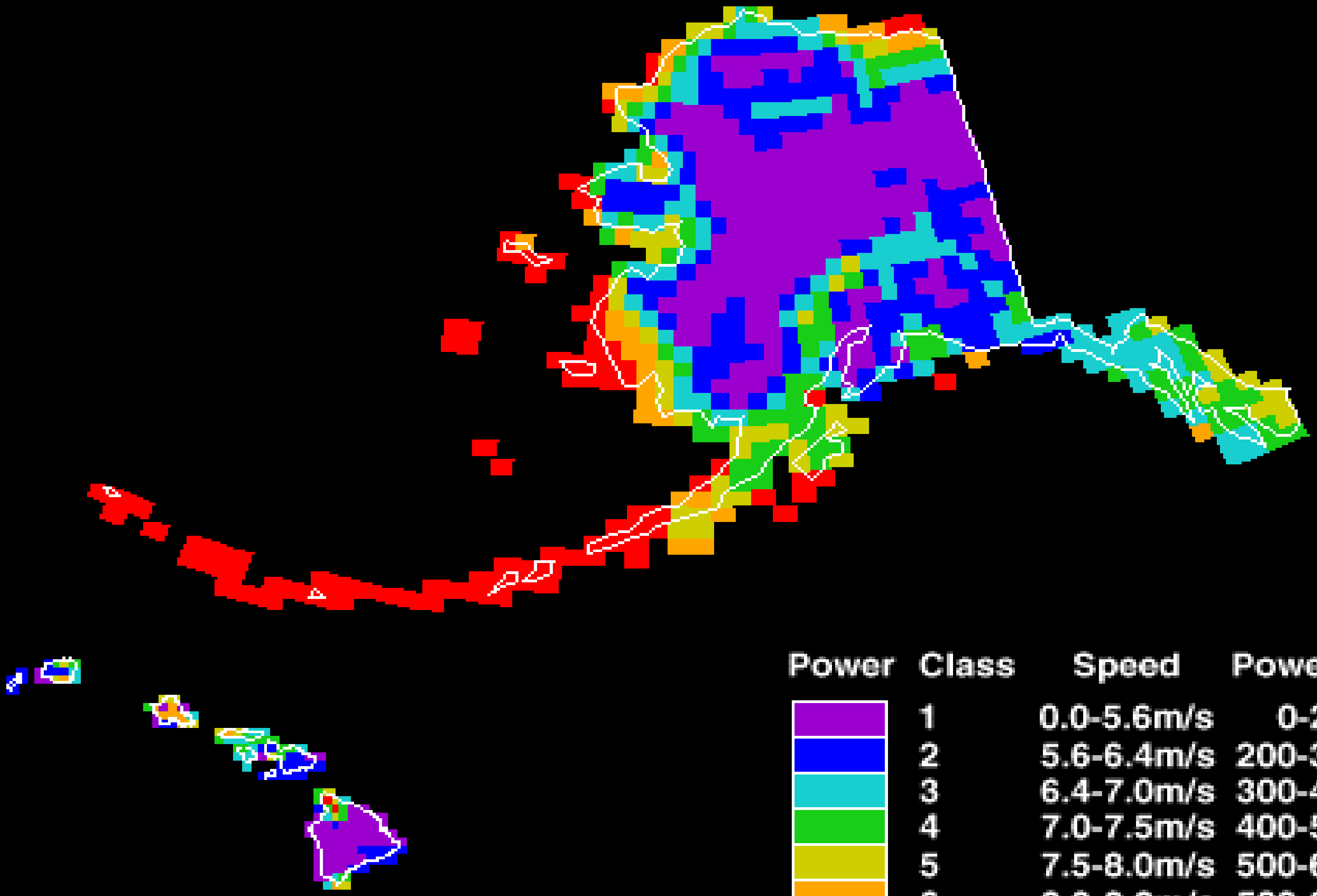


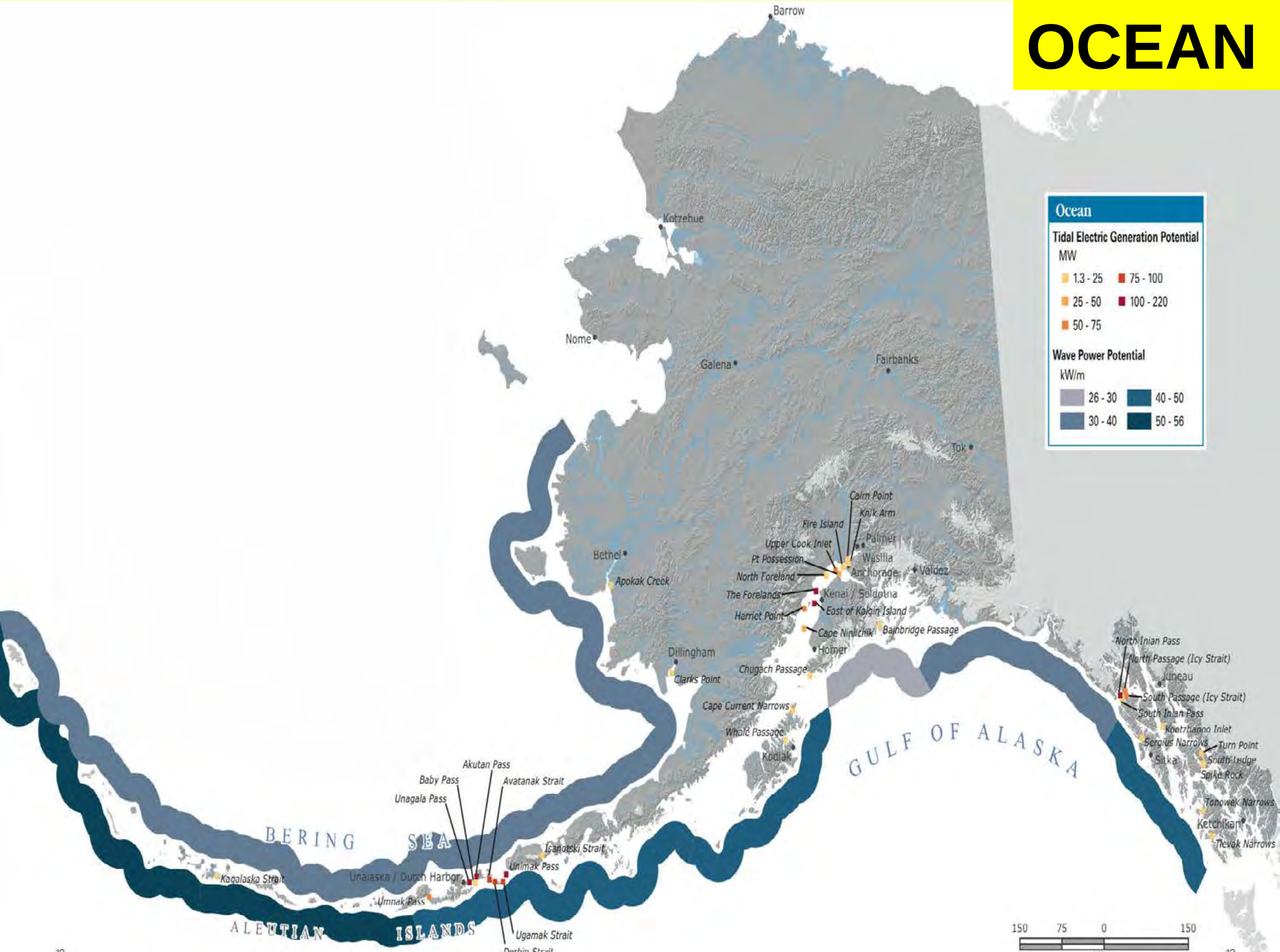
ARCTIC OCEAN
CHUKCHI SEA
BEAUFORT SEA
GULF OF ANADYR
CHUKOTK
RUSSIA
UNITED STATES
BERING SEA
PACIFIC OCEAN
GULF OF ALASKA
FAR NORTH
INTERIOR
SOUTHWEST
SOUTHCENTRAL
INSIDE PASSAGE
Barrow
Wainwright
Point Hope
Prudhoe Bay
Deadhorse
Umiat
Colville River
Noatak
Noatak River
Kotzebue
Noorvik
Selawik
GATES OF THE ARCTIC NAT'L PARK & PRESERVE
Anaktuvuk Pass
BROOKS RANGE
ARCTIC NATIONAL WILDLIFE REFUGE
Arctic Village
U.S.A. ALASKA
CANADA YUKON
ARCTIC CIRCLE
Bettles
Coldfoot
Uelen
Lavrentiya
Provideniya
Little Diomede
Wales
Shishmaref
Teller
Taylor
Pilgrim Springs
Nome
Council
White Mountain
Gambell
Savoonga
ST. LAWRENCE ISLAND
Huslia
Nulato
Unalakleet
St. Michael
Emmonak
ST. MATTHEW ISLAND
Fort Yukon
Stevens Village
Galena
Tanana
Rampart
Yukon R.
Manley Hot Springs
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.
Chicken
Eagle
Boundary
Dawson City
Scammon Bay
Hooper Bay
Saint Marys
Holy Cross
KUSKOKWIM MTNS.
McGrath
Mekoryuk
NUNIVAK ISLAND
Bethel
Aniak
Kuskokwim River
ALASKA RANGE
Paxson
Tok
Northway
Beaver Creek
Talkeetna
Willow
Houston
Big Lake
Wasilla
Sutton
Lake Louise
Gakona Jct.
Glennallen
Nabesna
Anchorage
Palmer
Copper Center
CHUGACH MTNS.
Chitina
Kennecott
McCarthy
PRIBILOF ISLANDS
ST. PAUL ISLAND
ST. GEORGE ISLAND
KISKA ISLAND
Quinhagak
Wood-Tikchik System
Goodnews Bay
TOGIAK NAT'L WILDLIFE REFUGE
LK. CLARK NAT'L PARK & PRESERVE
Lake Clark
Dillingham
Nushagak River
Iliamna
Iliamna Lake
Kenai
Soldotna
Whittier
PRINCE WILLIAM SOUND
Valdez
Ninilchik
Anchor Pt.
Seward
Cordova
Homer
Seldovia
COOK INLET
Naknek
King Salmon
KATMAI NAT'L PARK & PRESERVE
KENAI FJORDS NAT'L PARK
WRANGELL-ST. ELIAS NAT'L PARK & PRESERVE
Destruction Bay
Kluane Lake
KLUANE NAT'L PARK
Haines Junction
Carmacks
Ross River
Lake Laberge
Whitehorse
N.W. TERRITORY
YUKON
ALEUTIAN ISLANDS
ANIAKCHAK NAT'L MONUMENT & PRESERVE
Port Lions
Kodiak
KODIAK ISLAND
Old Harbor
KODIAK NATIONAL WILDLIFE REFUGE
Dutch Harbor
Akutan
Unalaska
False Pass
Cold Bay
King Cove
Sand Point
Chignik
Yakutat
White Pass Summit
Carcross
Watson Lake
BRITISH COLUMBIA
Haines
Skagway
GLACIER BAY NAT'L PARK & PRESERVE
Gustavus
Auke Bay
Juneau
Elfin Cove
Pelican
Hoonah
Tenakee
Tracy Arm
Angoon
Stikine River
Sitka
Kake
Petersburg
Wrangell
Hyder
Stewart
MISTY FIORDS NAT'L MONUMENT WILDERNESS
Thorne Bay
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
75 - 100
25 - 50
100 - 220
50 - 75
Wave Power Potential
kW/m
26 - 30
40 - 50
30 - 40
50 - 56
Barrow
Kotzebue
Nome
Galena
Fairbanks
Tok
Bethel
Apokak Creek
Dillingham
Clarks Point
Cairn Point
Knik Arm
Fire Island
Upper Cook Inlet
Palmer
Wasilla
Pt Possession
Anchorage
Valdez
North Foreland
The Forelands
Kenai / Soldotna
East of Kalgin Island
Harriet Point
Cape Ninilchik
Bainbridge Passage
Homer
Chugach Passage
Cape Current Narrows
Whale Passage
Kodiak
GULF OF ALASKA
BERING SEA
ALEUTIAN ISLANDS
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
Tongass Narrows
Ketchikan
Tlevak Narrows
Akutan Pass
Baby Pass
Avatanak Strait
Unagala Pass
Isanotski Strait
Unimak Pass
Unalaska / Dutch Harbor
Kagalaska Strait
Umnak Pass
Ugamak Strait
Derbin Strait
150
75
0
150
Miles

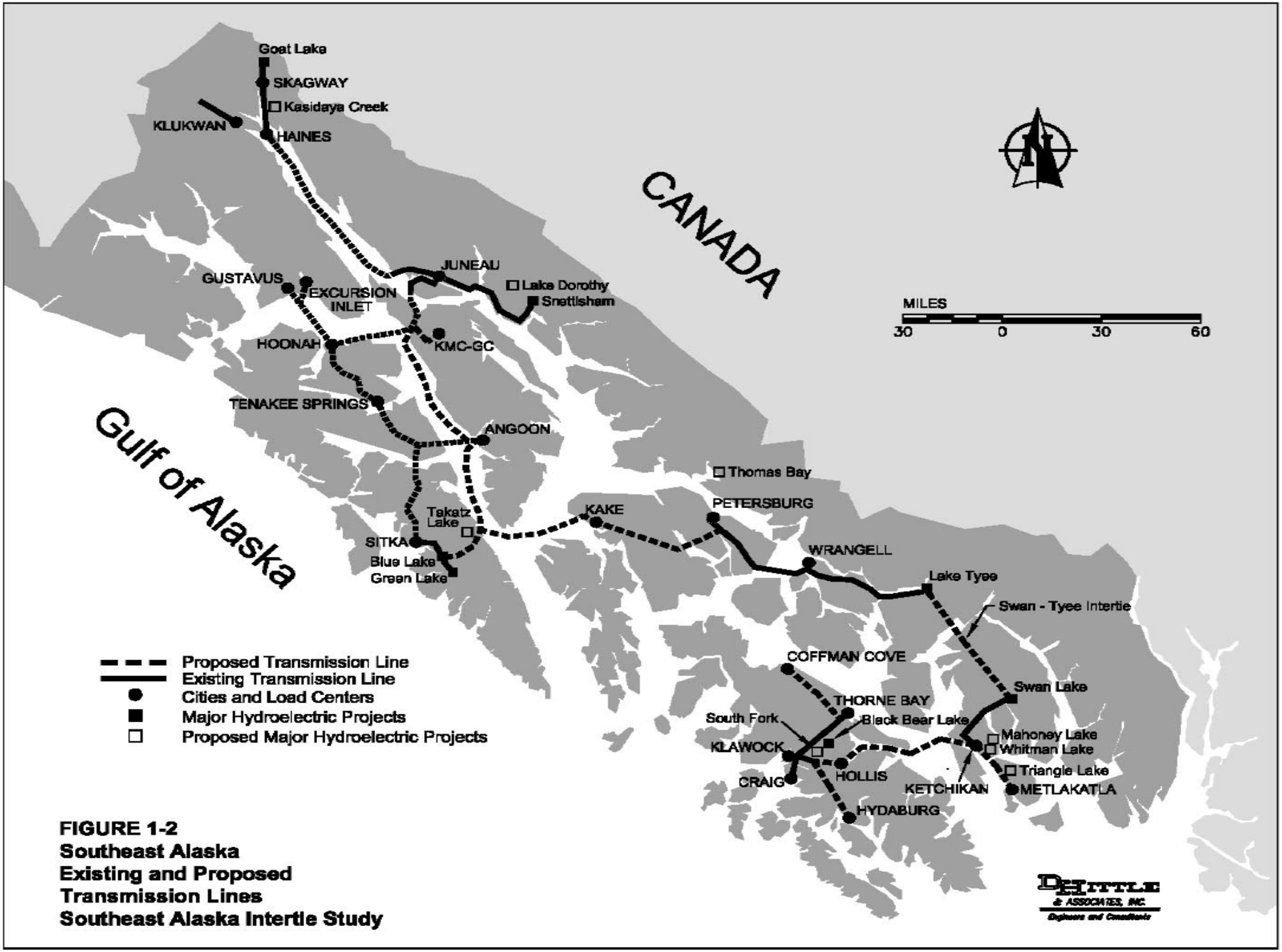


FIGURE 1-2
Southeast Alaska
Existing and Proposed
Transmission Lines
Southeast Alaska Intertie Study

AC-DC

DC-AC

Converter Stations

Superconducting (SC) electric line would leave TAPS at Fairbanks, follow Alaska Railroad to Anchorage

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

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?

Project Fundamentals

1. **Does SSAS system “work” ?**
2. **Competitive with EHB ?**
3. **Useful in Alaska ?**

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

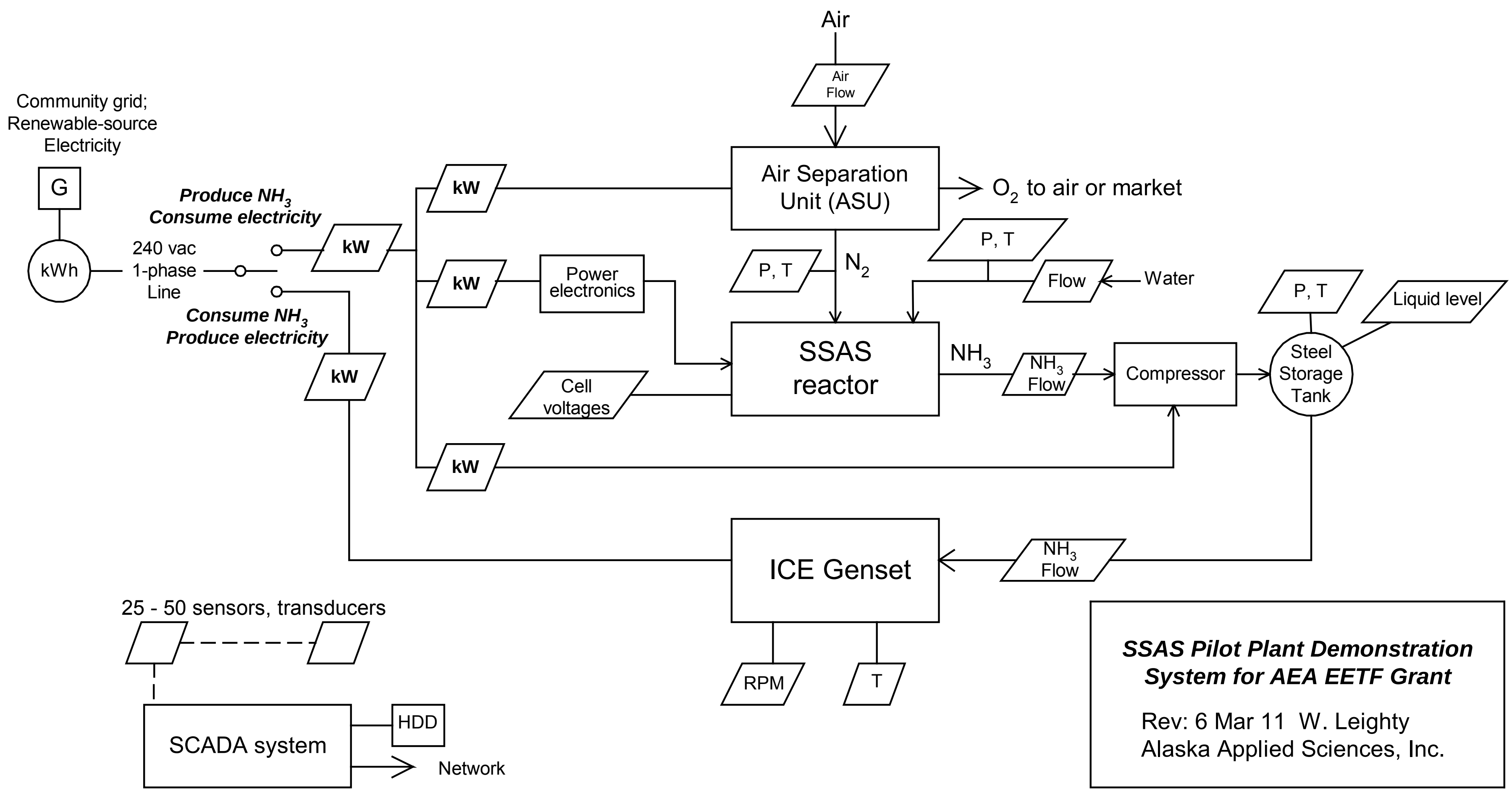
1. Test PCC tubes; accept
2. Build and test multi-tube reactor
3. Build and test BOS
4. Instrument with SCADA, remote read at UAF
5. Add regeneration: NH_3 → electricity to grid
6. Package in insulated CONEX
7. Acceptance test
8. Transport to Juneau, AK for demo
9. Demo at other AK sites as budget allows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

Project Fundamentals

1. Anhydrous ammonia (NH_3) is a fuel and transmission and low-cost energy storage medium
2. NH_3 made from renewable energy (RE) electricity, water, and air (Nitrogen, N_2) 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 NH_3 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

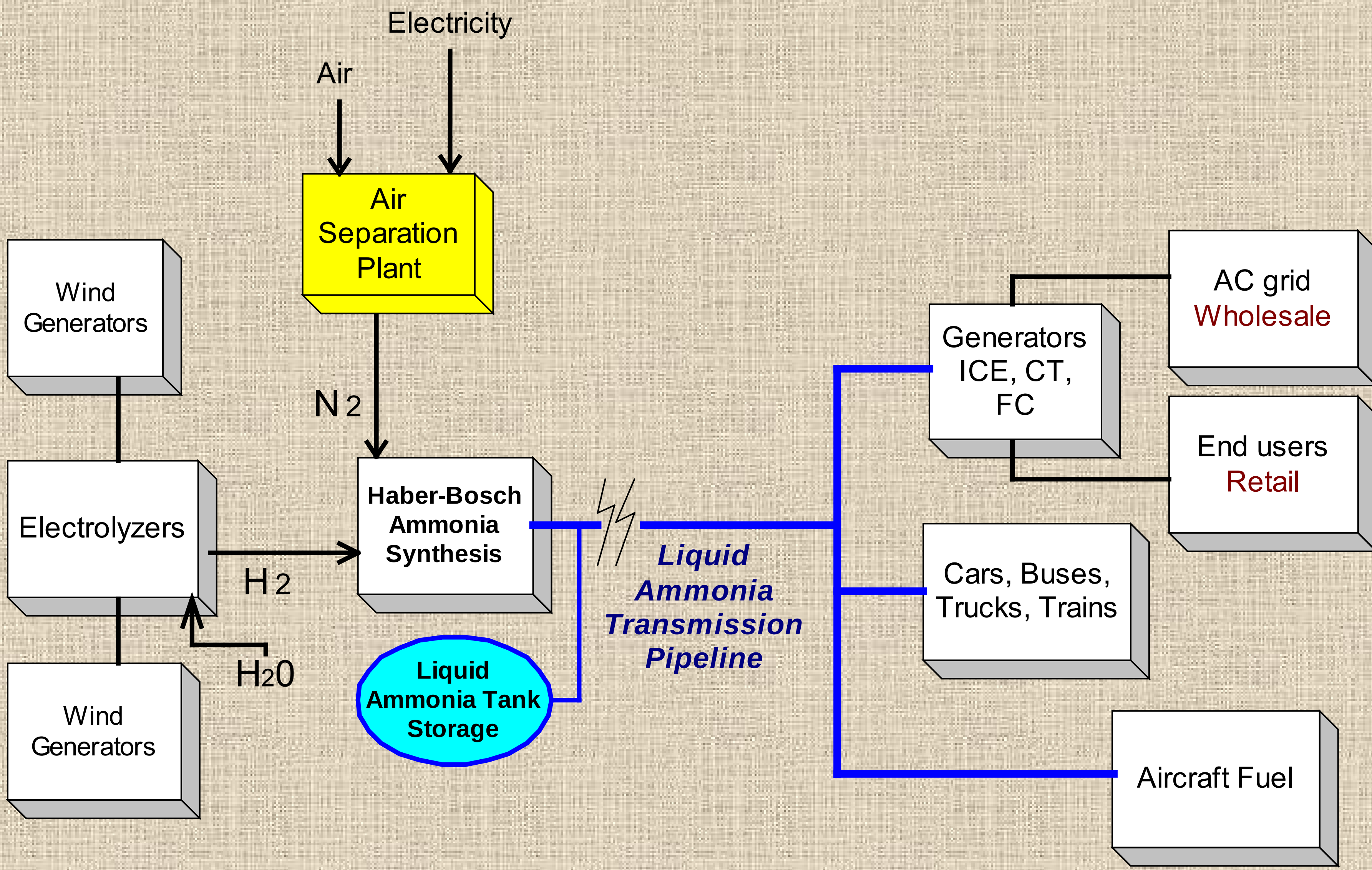
> NH3 synthesis from RE electricity, water, air (N_2)

> Liquid NH_3 tank storage

> Regeneration + grid feedback

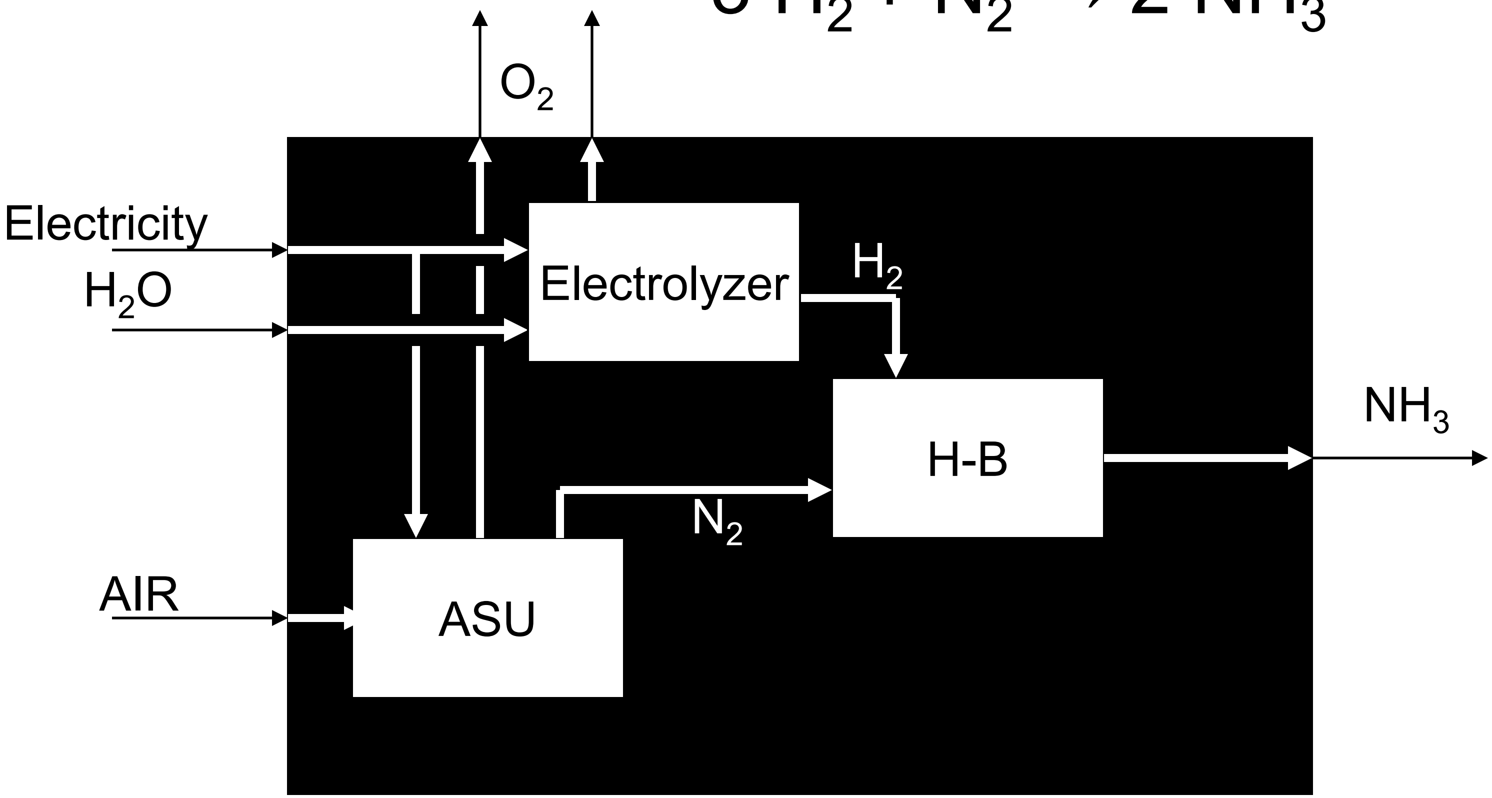
> SCADA instrumentation → UAF - ACEP

RE Ammonia Transmission + Storage Scenario: Electrolysis + Haber-Bosch (EHB)



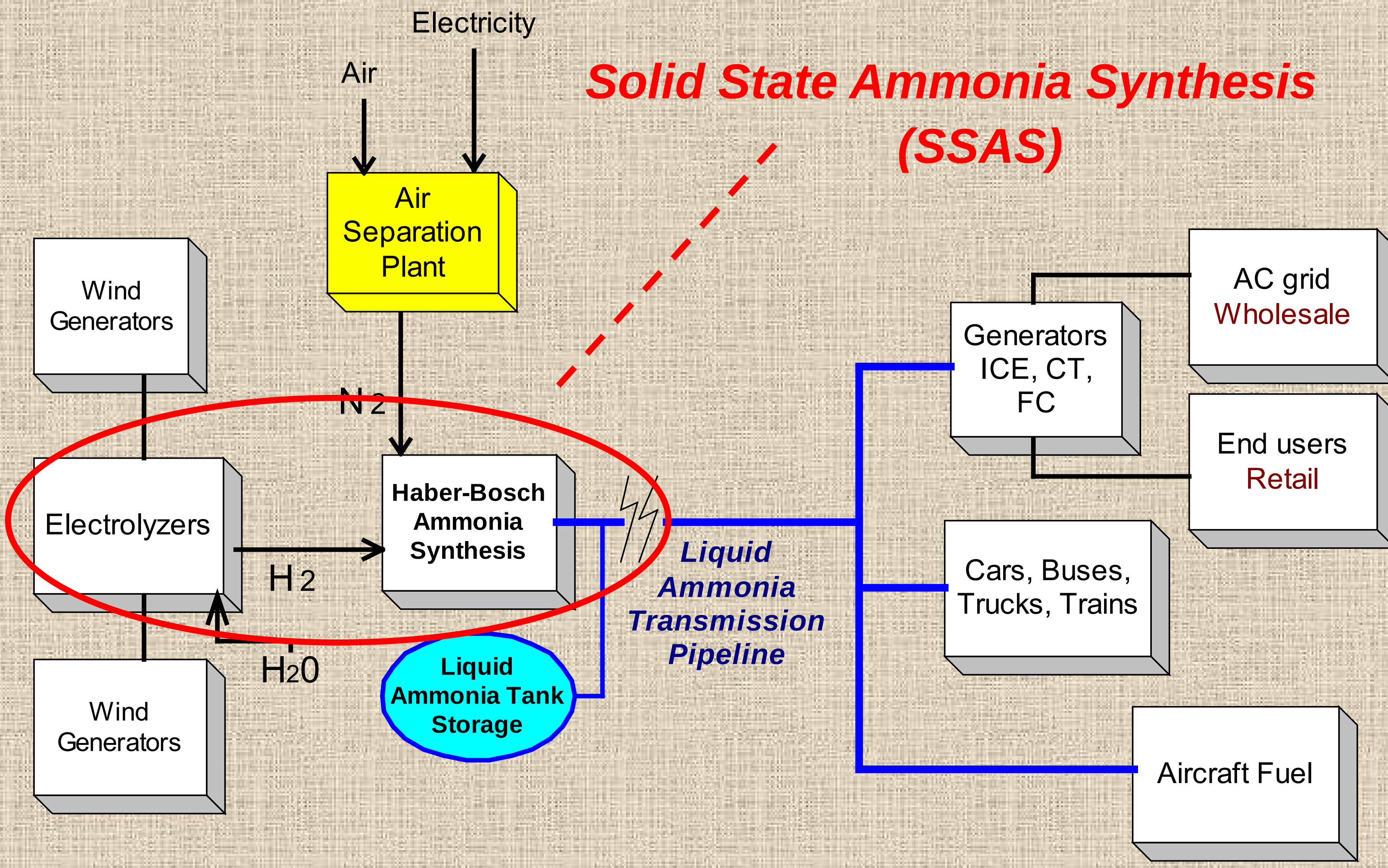
Inside the Black Box: HB Plus Electrolysis

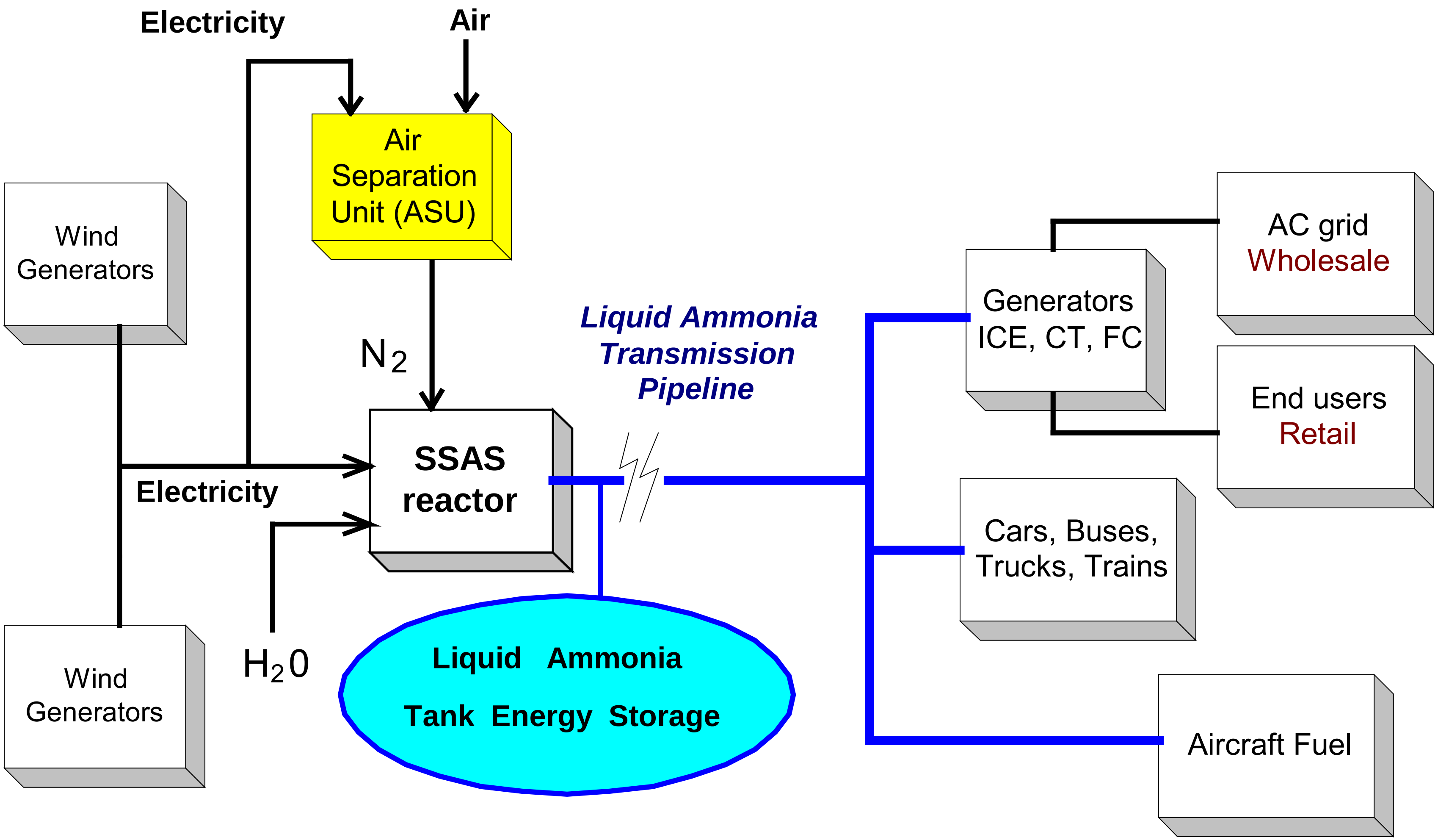
$$3\ H_2O \rightarrow 3\ H_2 + 3/2\ O_2$$
$$3\ H_2 + N_2 \rightarrow 2\ NH_3$$



Energy consumption ~12,000 kWh per ton NH_3

RE Ammonia Transmission + Storage Scenario

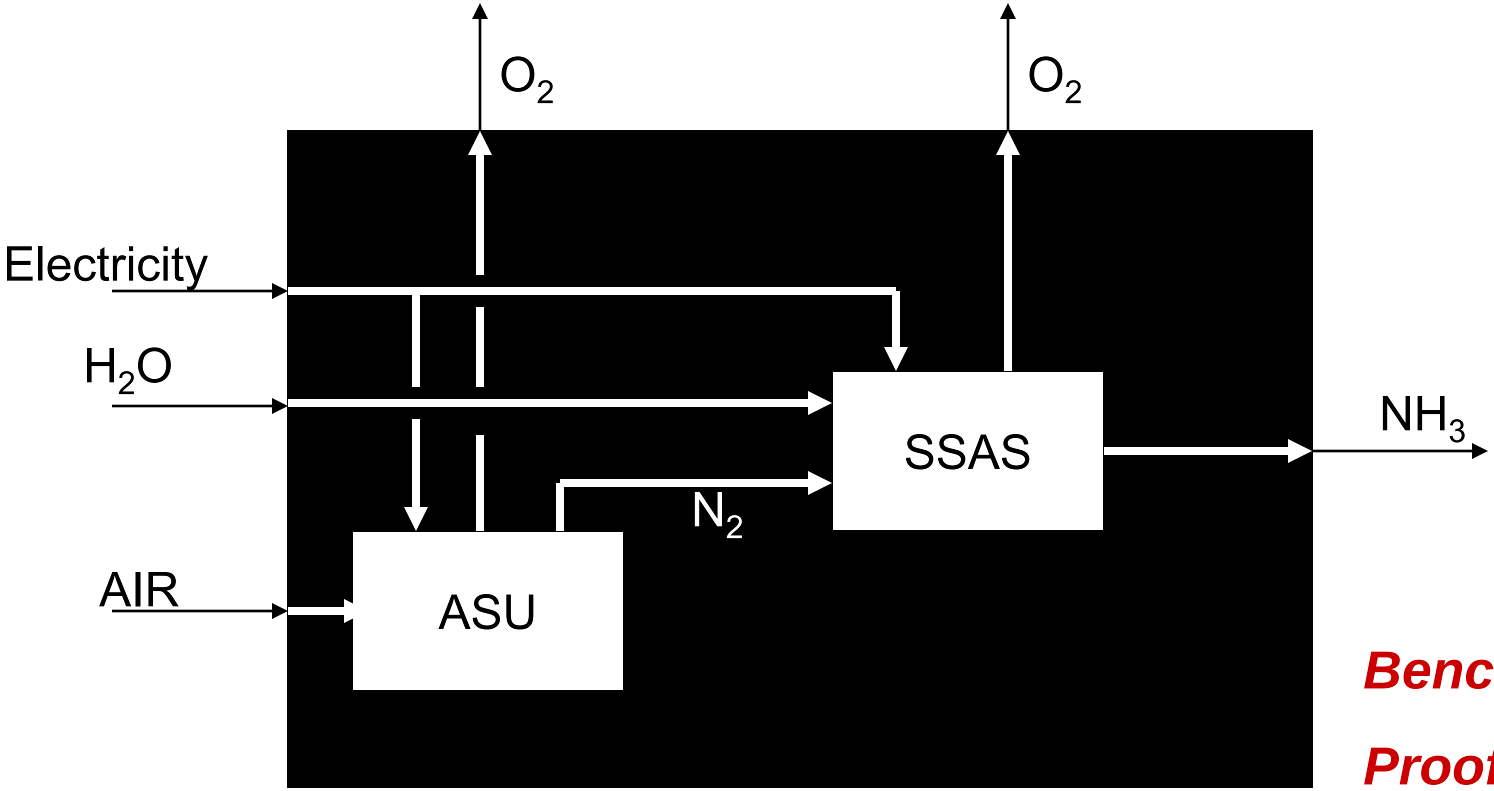




Solid State Ammonia Synthesis (SSAS)

Inside the Black Box: Solid State Ammonia Synthesis

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

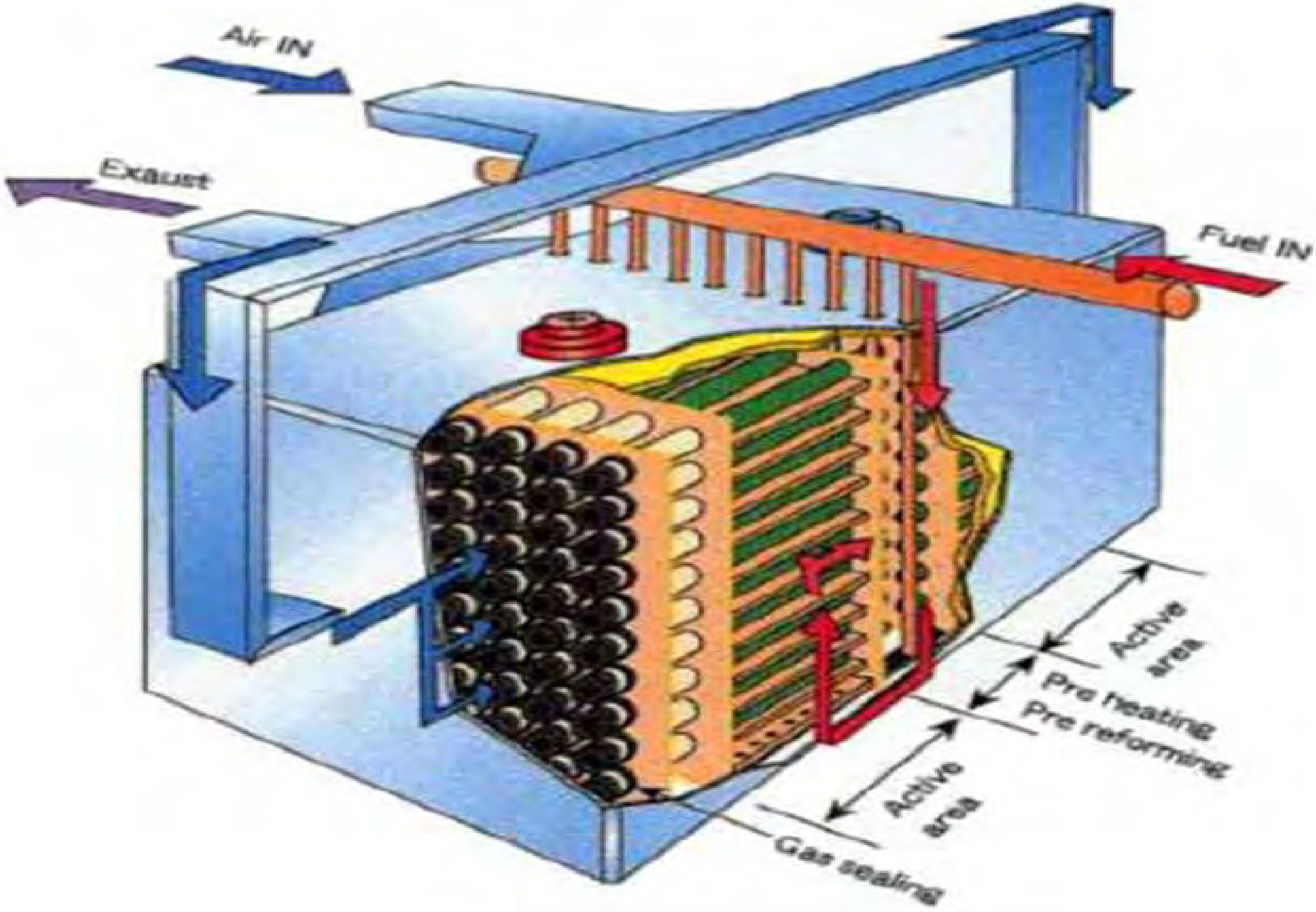


Benchtop

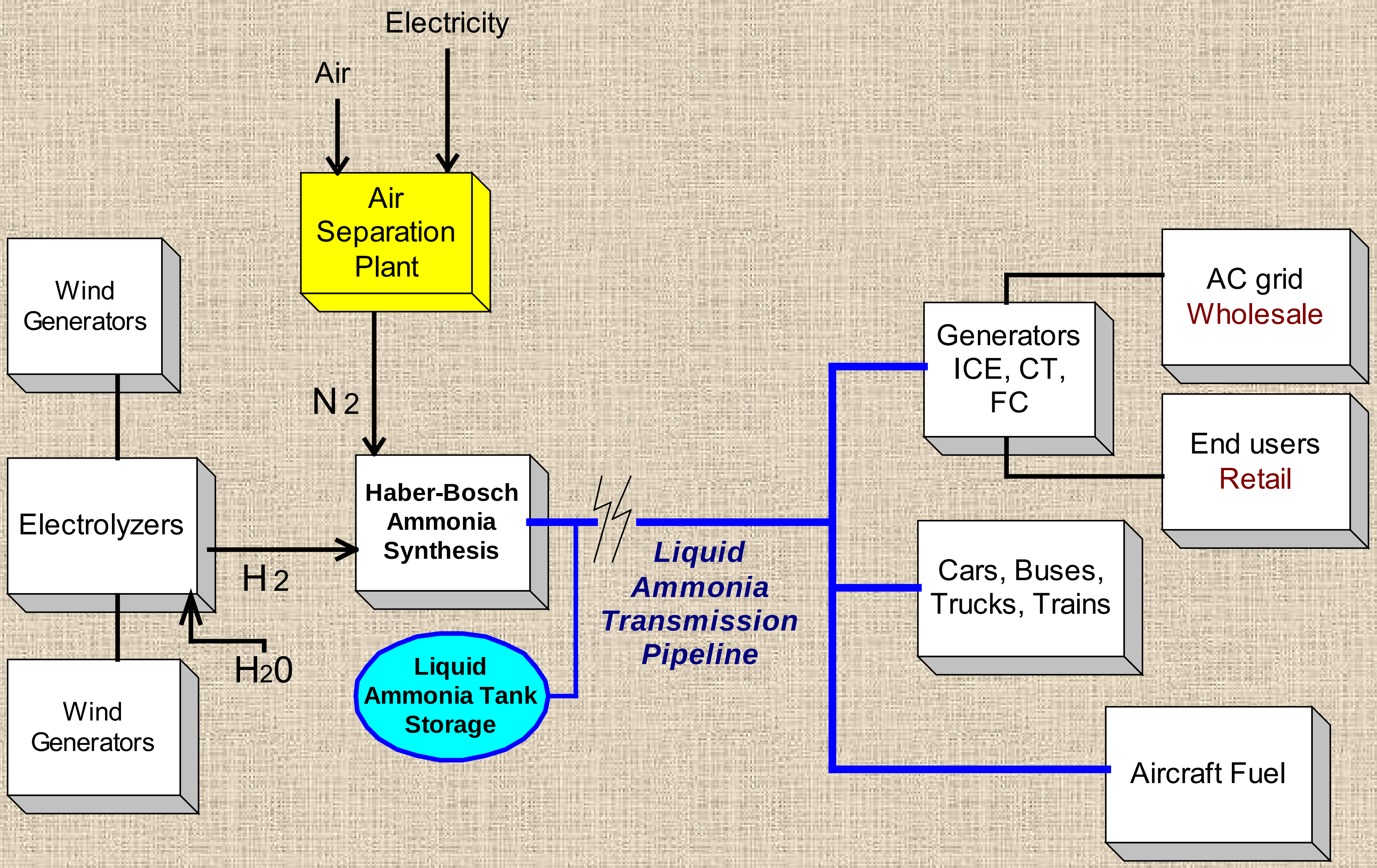
Proof-of-concept

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

Solid State Ammonia Synthesis (SSAS)
NHThree LLC patent

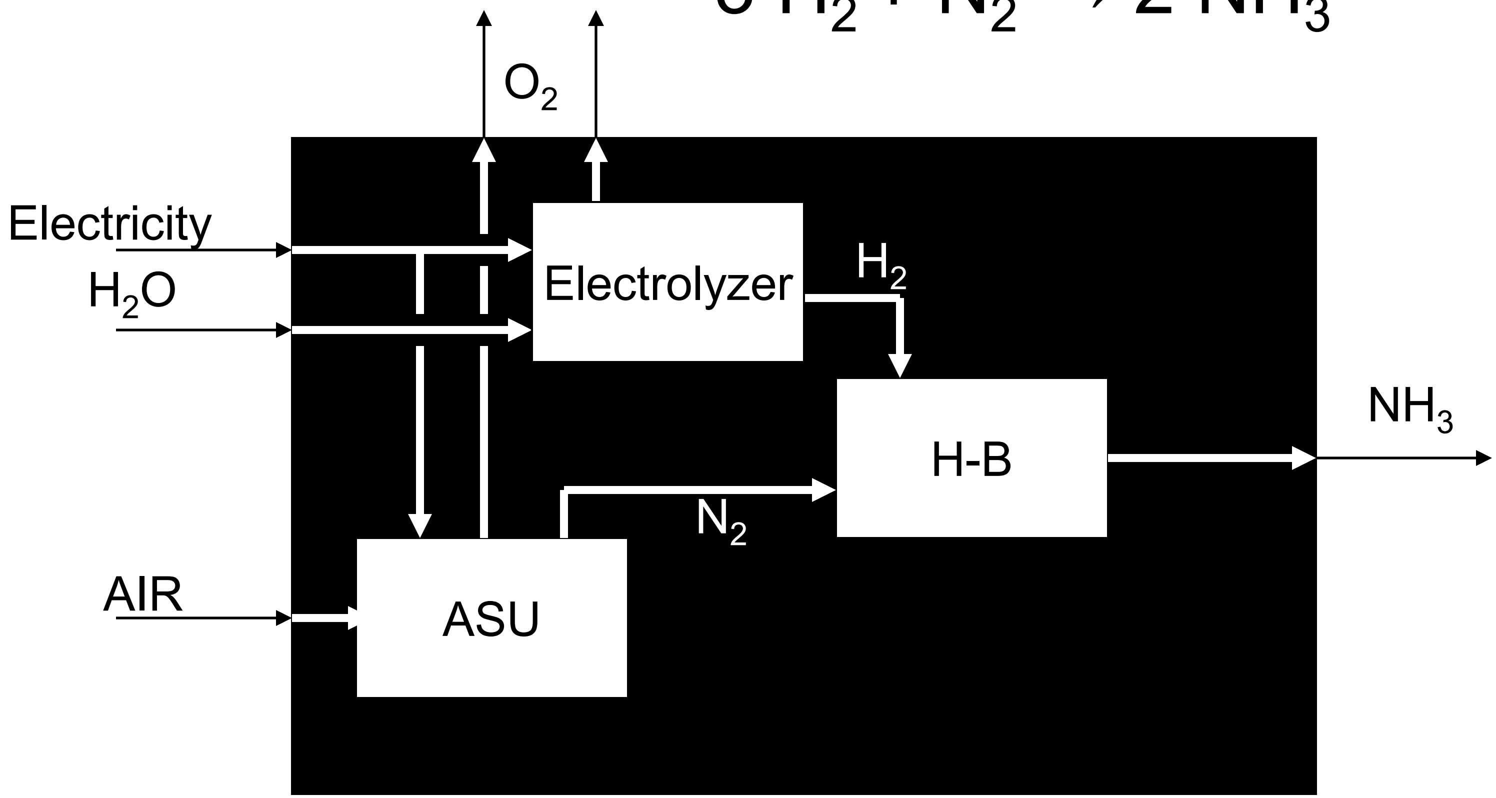


RE Ammonia Transmission + Storage Scenario



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

'09 ARPA-E "Grids" Goal: $100 / kWh

"Atmospheric" Liquid Ammonia Storage Tank (corn belt)

30,000 Tons

190 GWh

$ 15M turnkey

$ 80 / MWh

$ 0.08 / kWh

-33 C

1 Atm

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

EHB vs SSAS prelim estimates

EHB:

11-12 kWh / kg

$1,000 / kWe input capital cost

SSAS:

7-8 kWh / kg

$500 / kWe input capital cost

$200K / Mt / day capital cost

Great Reward, and Risk

Project success: SSAS “works”

- **Reactor, multi-tube**
- **Power electronics drive**
- **Regeneration from stored NH3**
- **SCADA: UAF - ACEP download**
- **Complete system functions, efficient**
- **Complete system durable, reliable**
- **Cost estimates: capital, O&M**

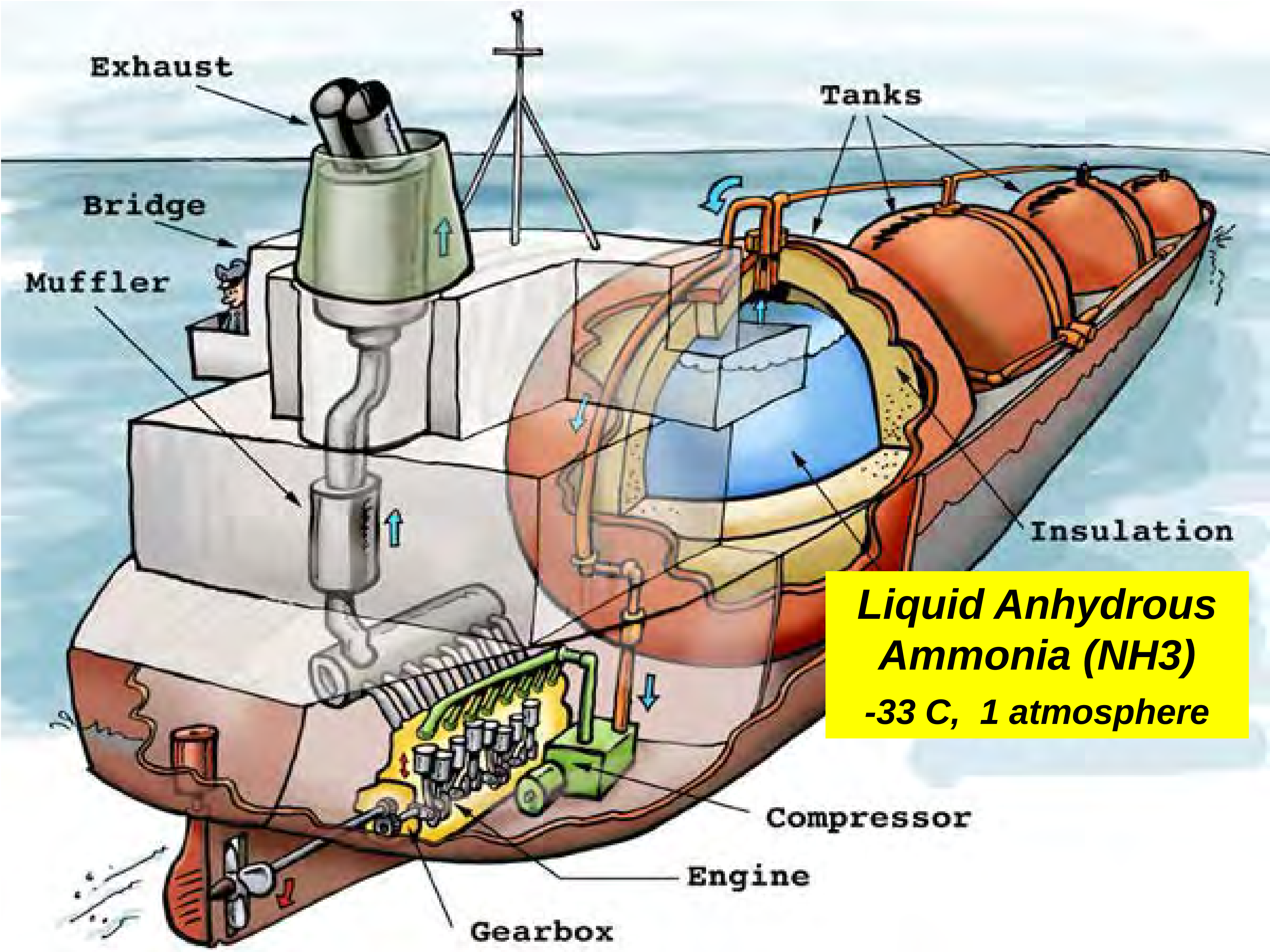
Next steps?

Great Reward, and Risk

AK renewable energy (RE) opportunities:

1. **Village energy “independence”**
2. **Annual-scale firming storage**
3. **Transmission for:**
   a. **Intrastate AK**
   b. **RE export**
4. **Fuel for military land and sea**
5. **Incubator, test sites, commercial rollout**

Scales: Village → Susitna Hydro → Global export



Liquid Anhydrous Ammonia (NH3)

-33 C, 1 atmosphere

Project Objectives

- Run AK, world on RE: all energy, beyond electricity
- Discover and demo SSAS potential
- Demo complete RE storage system
- Begin commercialization
- Attract funding

Project Goals

1. Estimate efficiency
2. Estimate capital cost:
   a. PCC tube area, tube
   b. Reactor
   c. Power electronics drive
3. Dynamics
4. TRL 5 – 6
5. Attract RE industry: AK, US, global, ARPA-E

State of the Art; Competition

- Electrolysis + “Haber-Bosch” = EHB
  - NH3 United, TX + Canada NH3
  - Proton Ventures
  - Freedom Fertilizer
- Other “SSAS”

EHB vs SSAS prelim estimates

EHB:

11-12 kWh / kg

$1,000 / kWe input capital cost

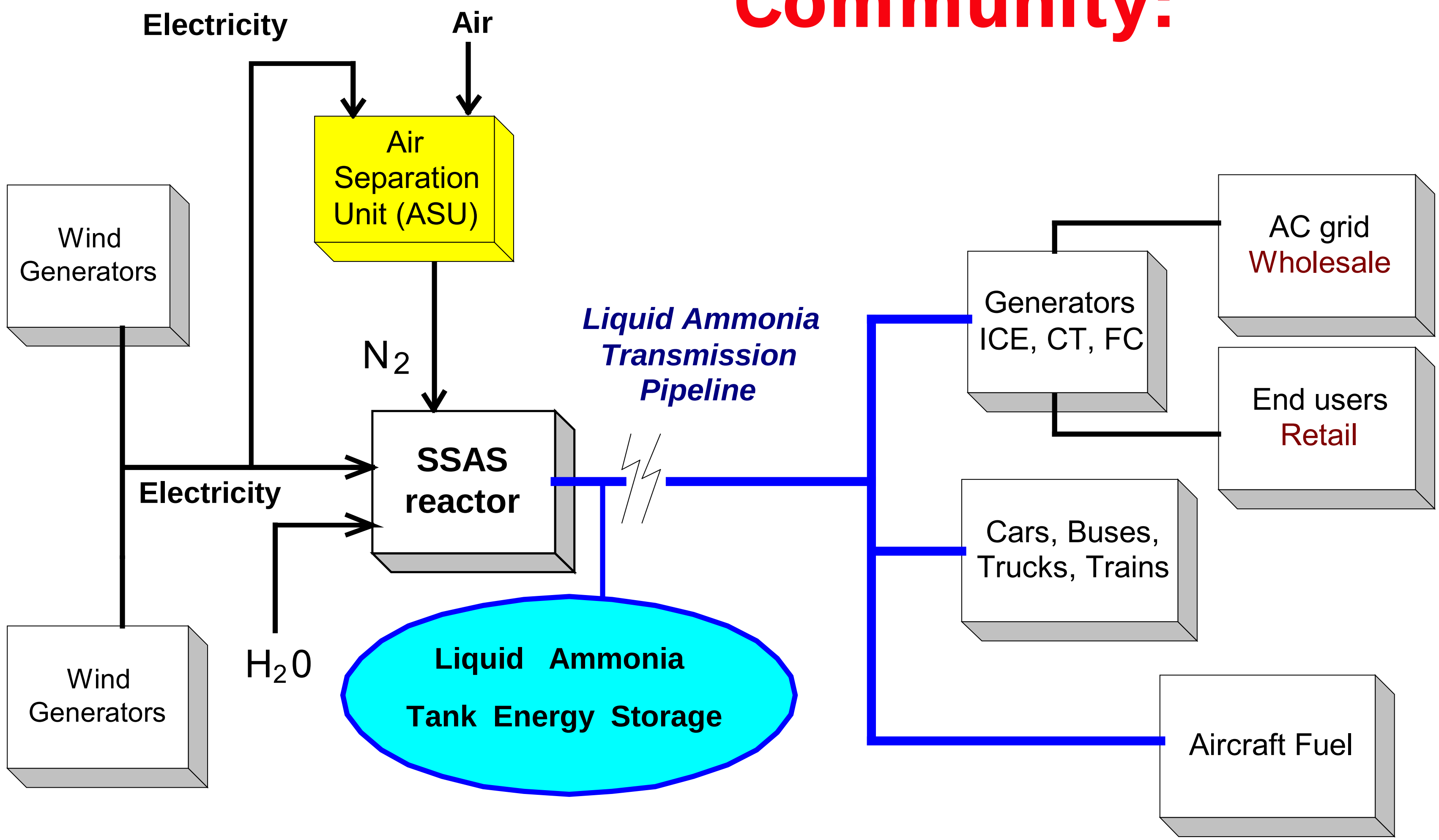
SSAS:

7-8 kWh / kg

$500 / kWe input capital cost

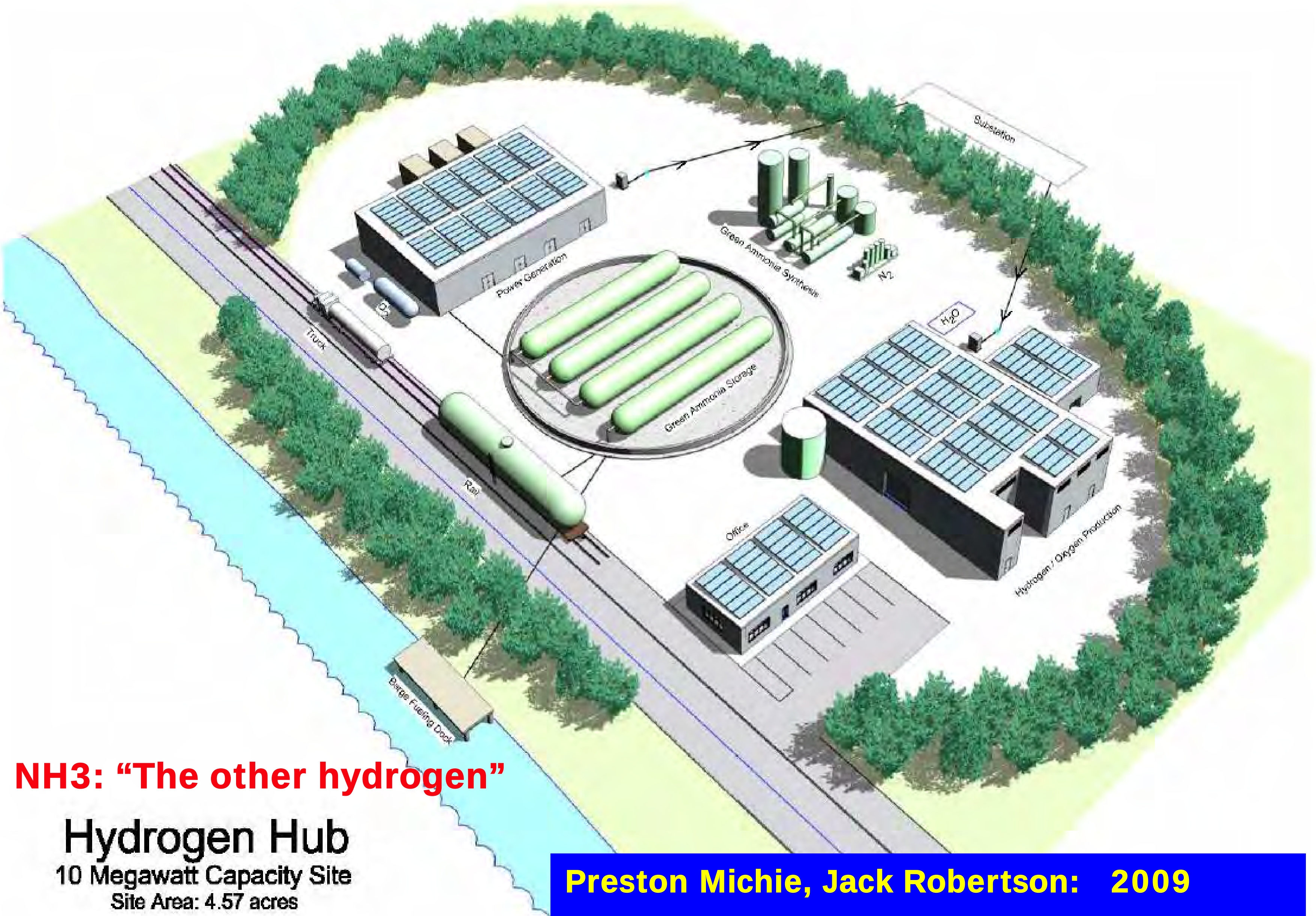
$200K / Mt / day capital cost

Community:



Solid State Ammonia Synthesis (SSAS)

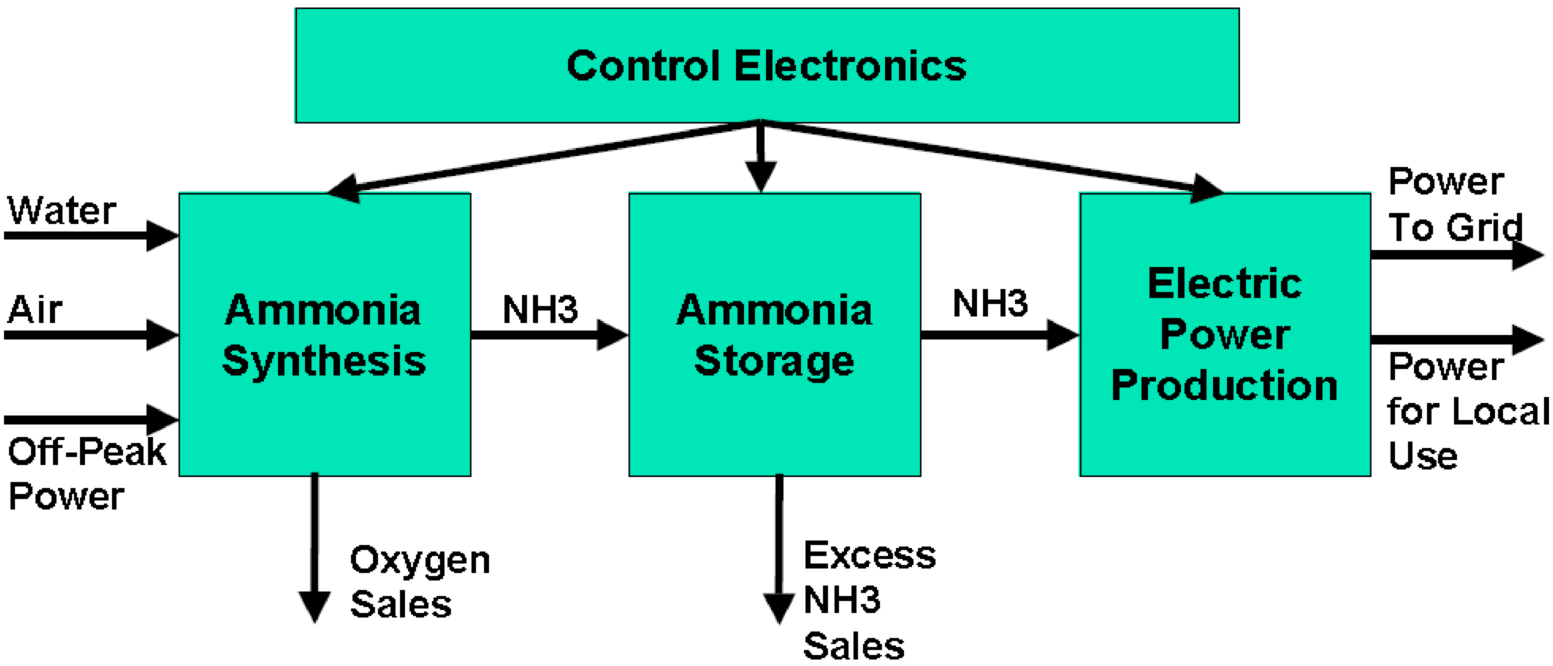
NH3: “The other hydrogen”



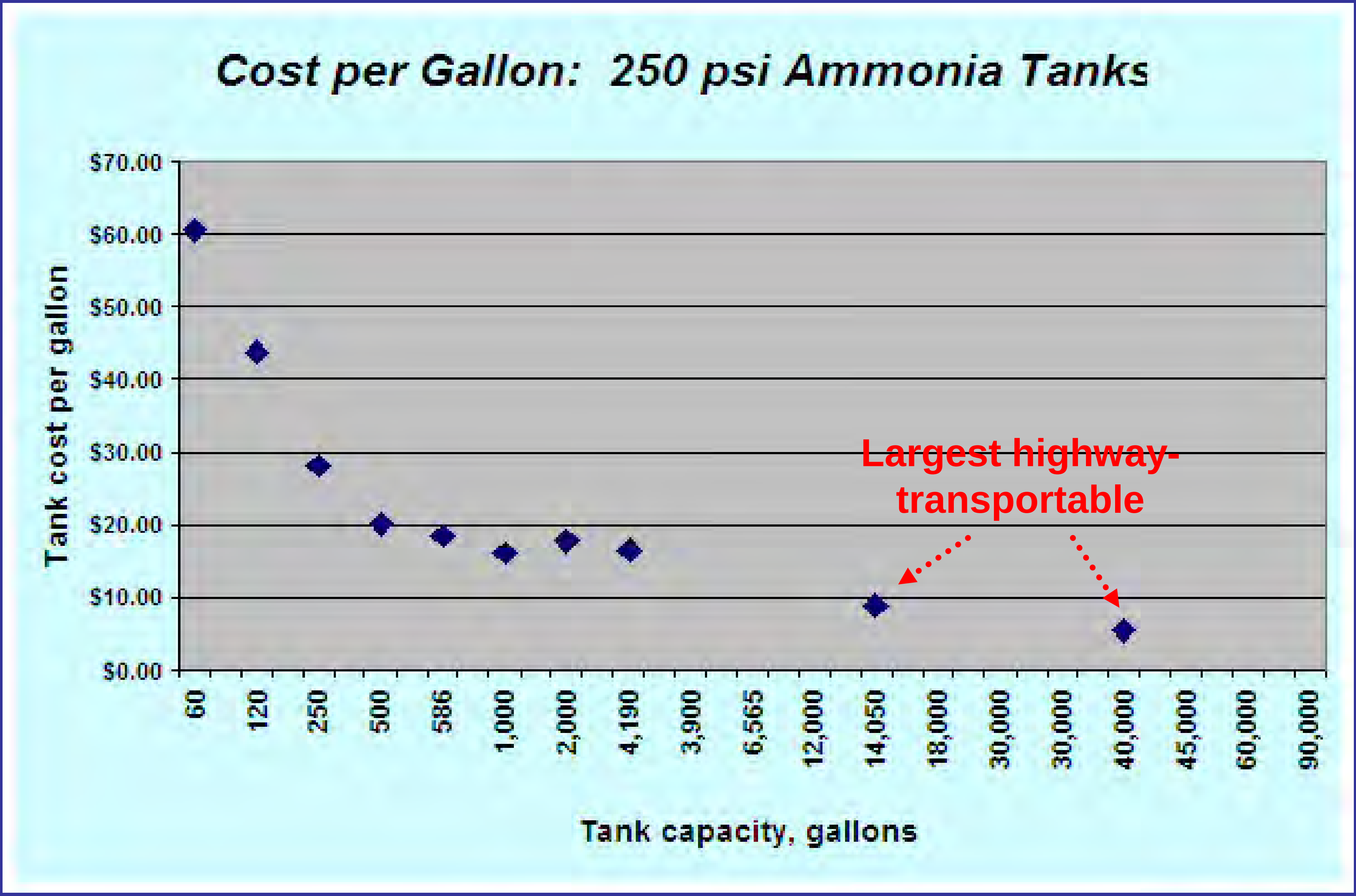
Preston Michie, Jack Robertson: 2009

Former BPA; Northwest Hydrogen Alliance

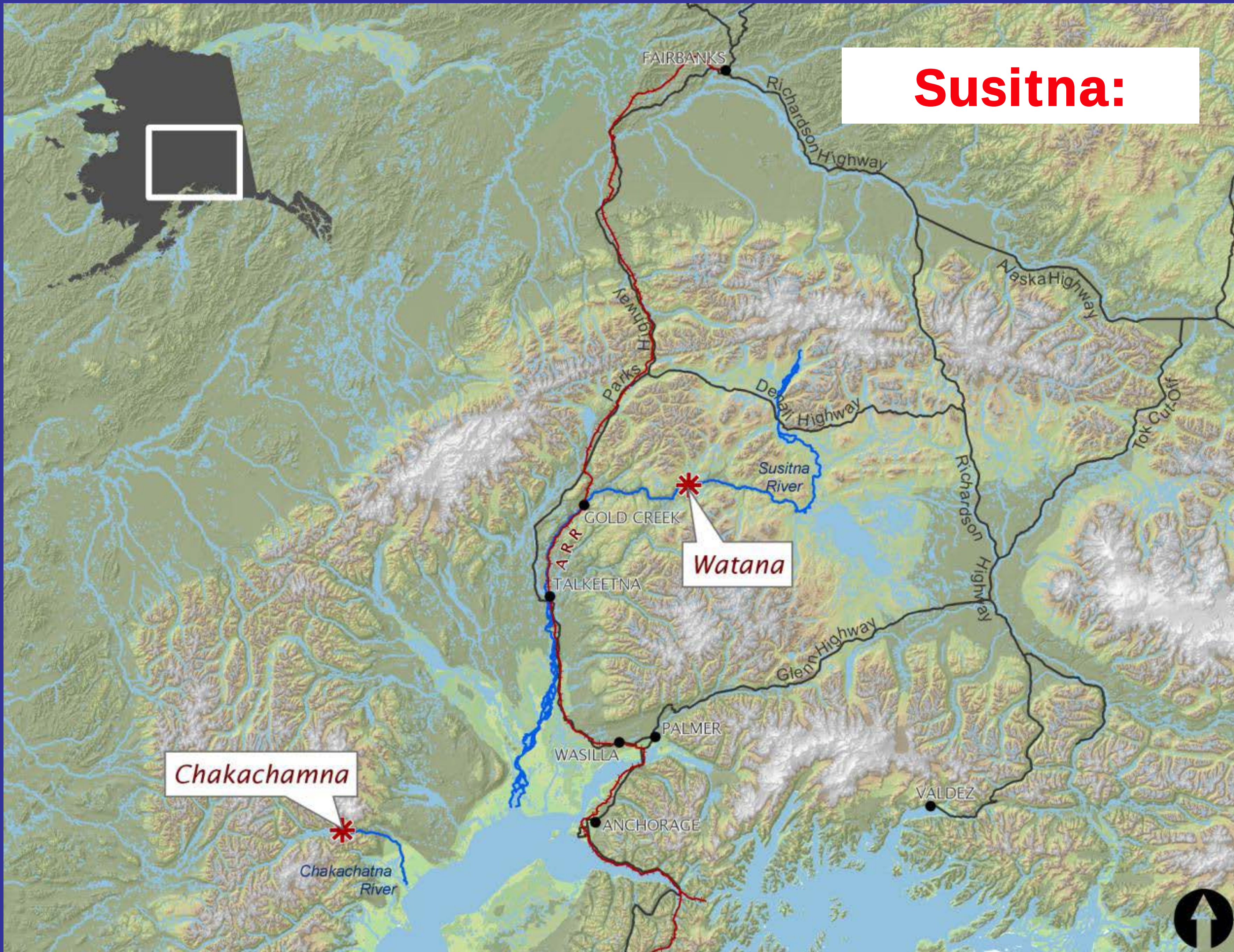
Hydrogen Hub Concept

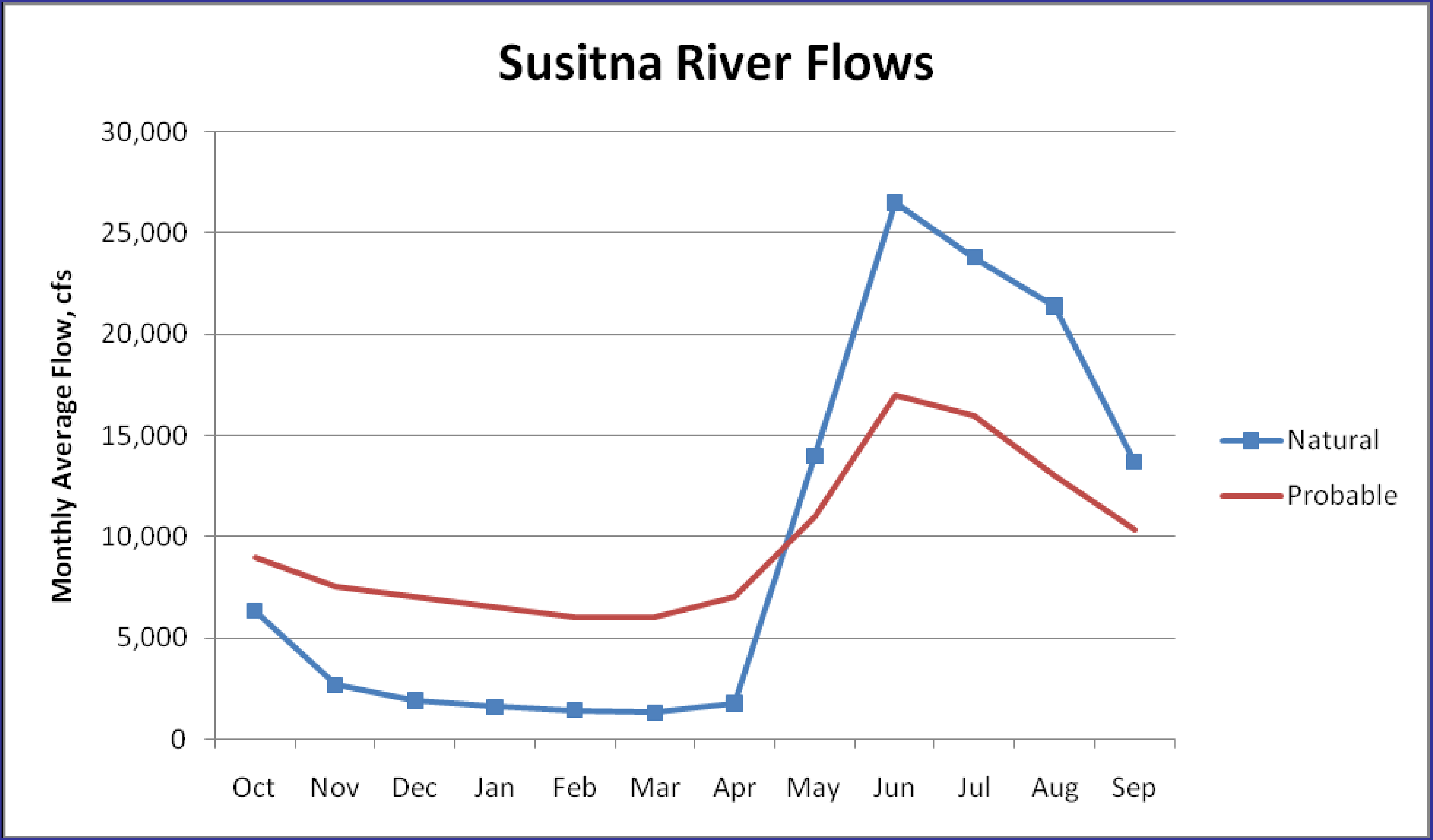


Liquid Ammonia Tank Storage



Susitna:


FAIRBANKS
Richardson Highway
Alaska Highway
Parks Highway
Denali Highway
Susitna River
Tok Cut-Off
GOLD CREEK
Watana
ARR
TALKEETNA
Richardson Highway
Glenn Highway
PALMER
WASILLA
Chakachamna
ANCHORAGE
VALDEZ
Chakachatna River



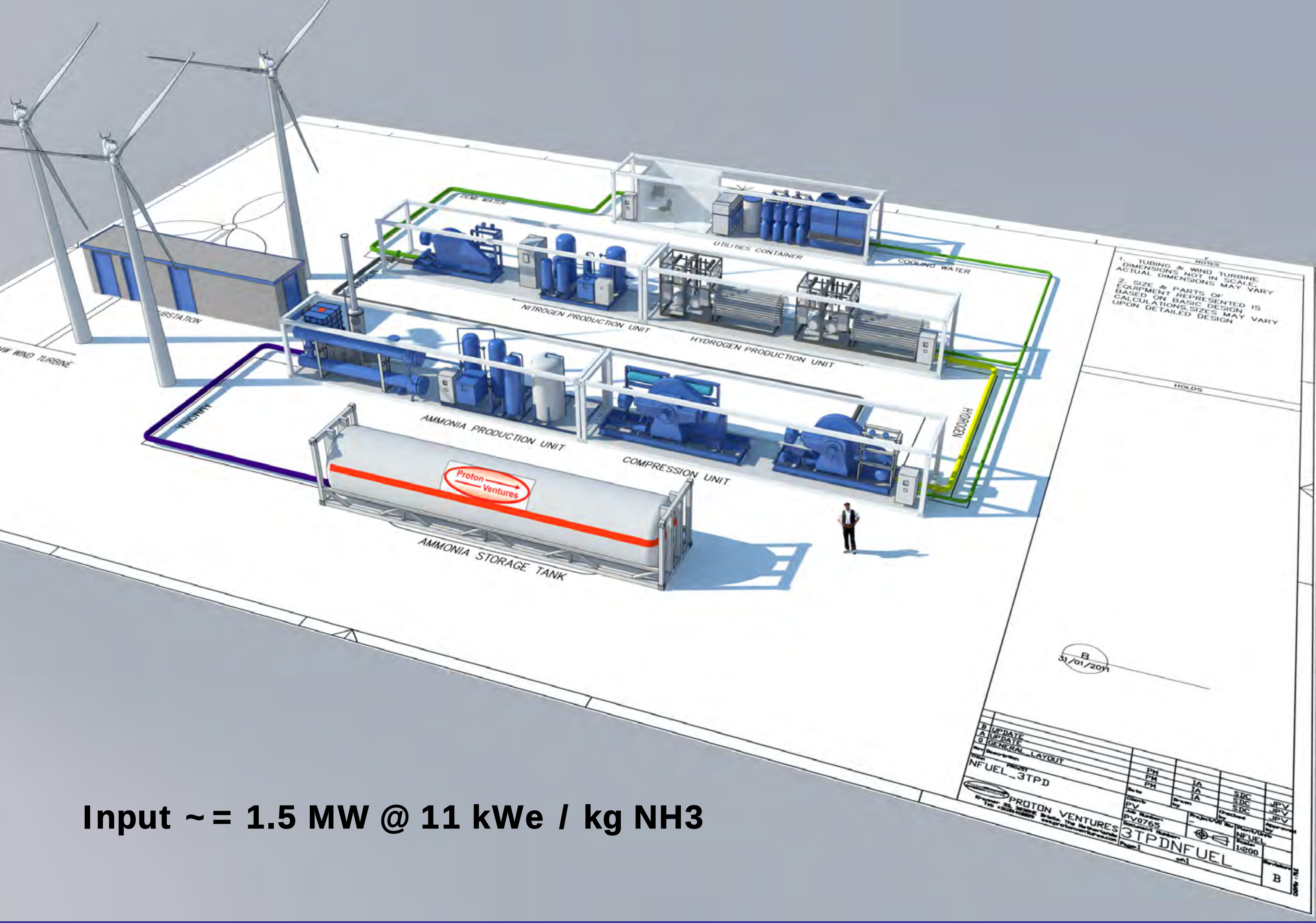
Susitna River Flows
Monthly Average Flow, cfs
30,000
25,000
20,000
15,000
10,000
5,000
0
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Natural
Probable

Military: Land + sea fuel

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

State of the Art; Competition

- Electrolysis + “Haber-Bosch” = EHB
  - Proton Ventures
  - Freedom Fertilizer
  - NH3 United, TX + Canada NH3
- Other “SSAS” suppliers
- Do not deploy novel, complex systems in Alaska villages: EHB too risky ?



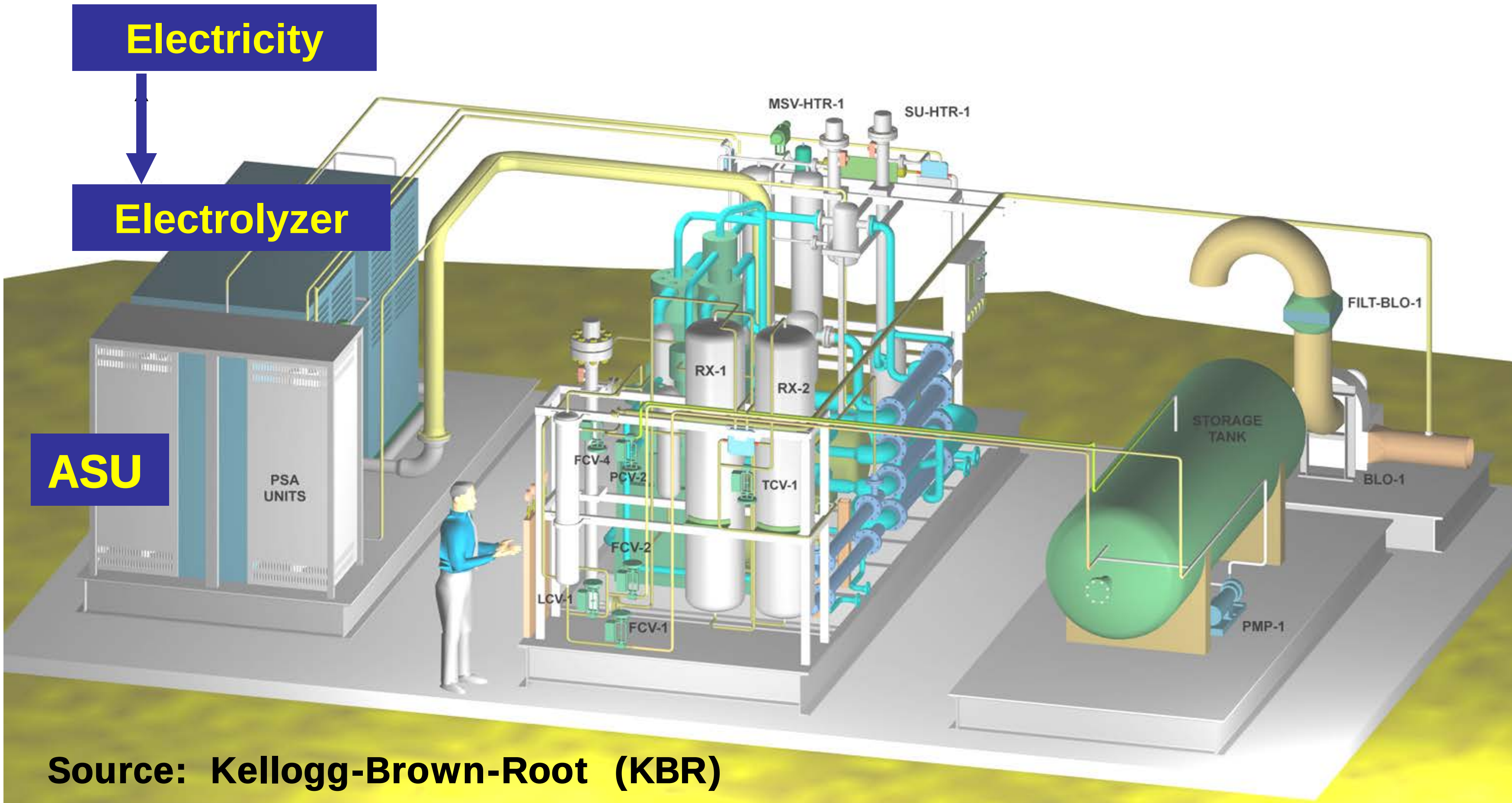
Input ~= 1.5 MW @ 11 kWe / kg NH3

3 Mt / day Electrolysis + Haber-Bosch (EHB) NH3 plant by Proton Ventures

Quoted at $4M.   Delivered ?

Contact: Steve Gruhn   sgruhn@freedomfertilizer.com

Village-scale 3 Mt / day Mini-NH3 Plant RE Electricity Haber-Bosch



Source: Kellogg-Brown-Root (KBR)

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” NH_3 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

Markets: Supply, Demand, Price

- Supply Push
- Demand Pull
- Alaska incubator, rollout
- Price
  - Competition
  - Substitutes
  - Volume
  - Condition changes

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