

EUEC, Phoenix, 3 5 Feb 14

Bill Leighty, Principal
Alaska Applied Sciences, Inc.
Box 20993, Juneau, AK 99802
wleighty@earthlink.net
907-586-1426 206-719-5554 cell



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Angoon, Alaska Tlingit people Southeast





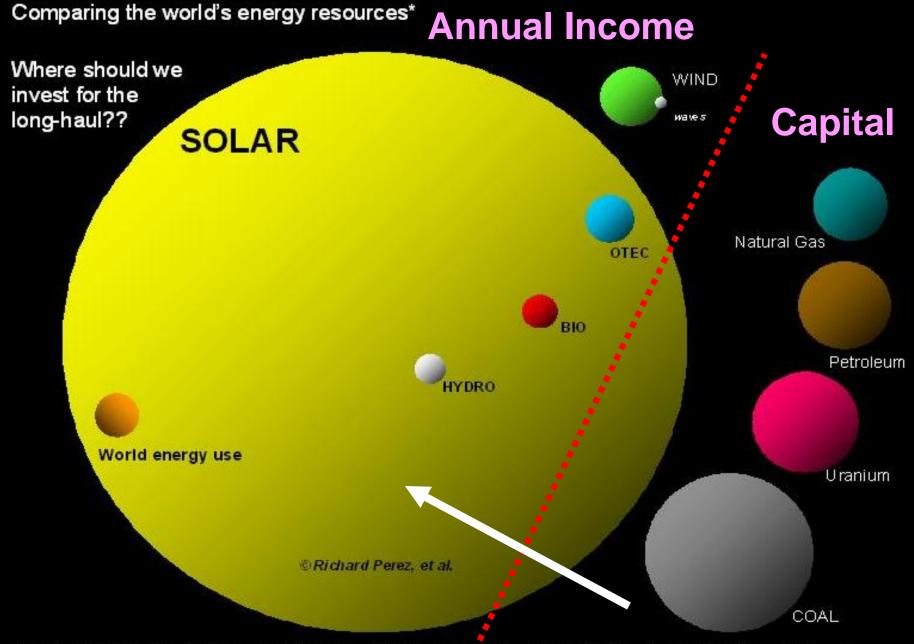
Mendenhall Glacier, Juneau, AK June '71



Mendenhall Glacier, Juneau, AK 10 October 10

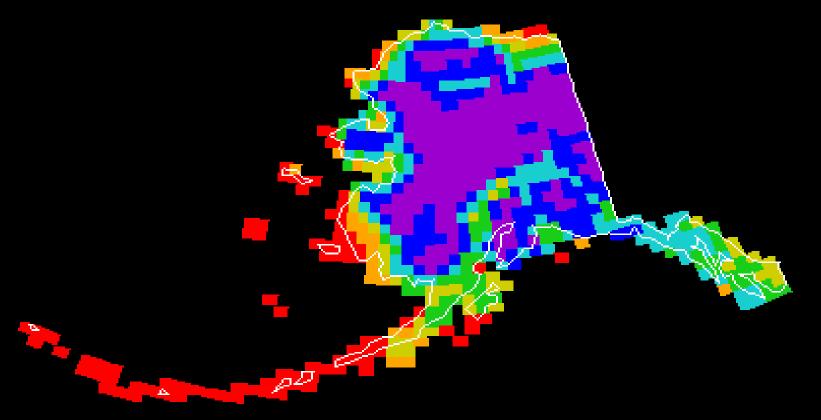


Mendenhall Glacier, Juneau, AK 10 October 10

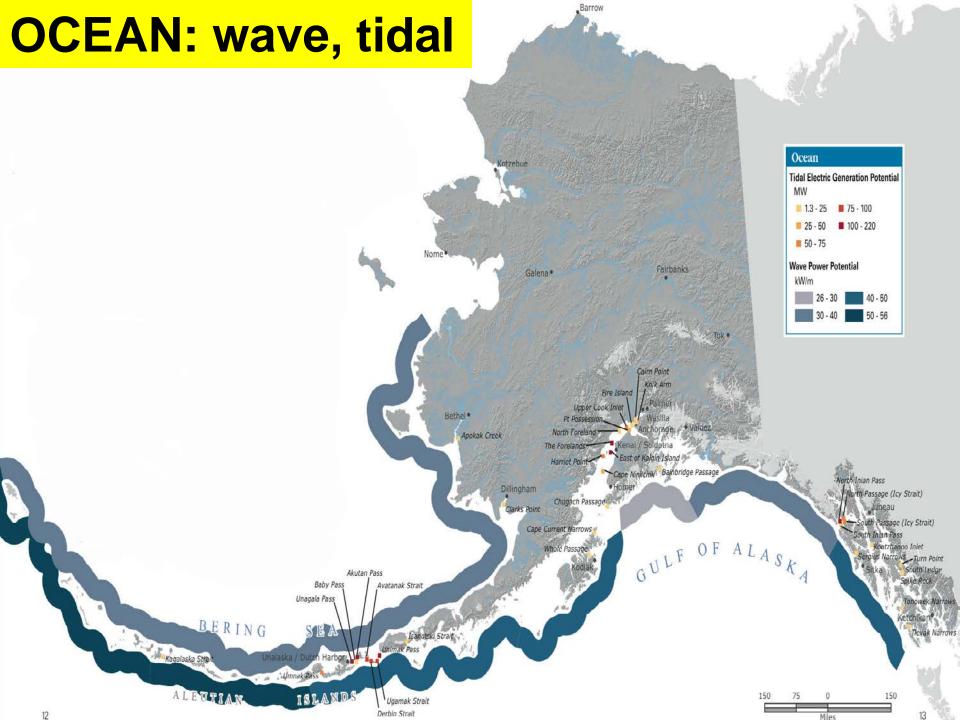


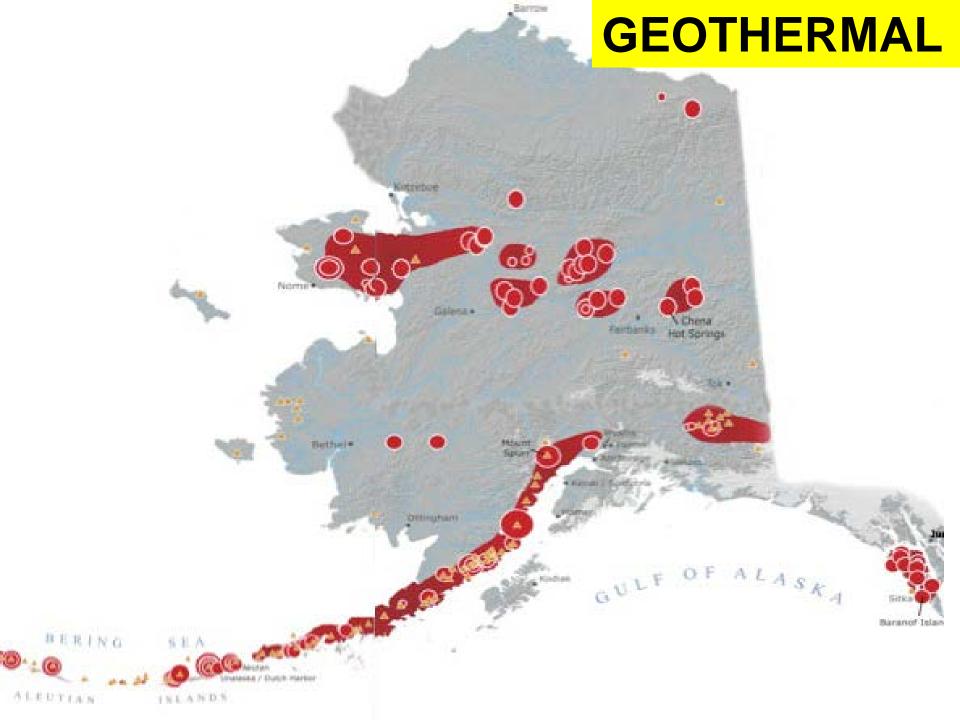
*yearly potential is shown for the renewable energies. Total reserves are shown for the fossil and nuclear "use-them, lose-them" resources. Word energy use is annual.

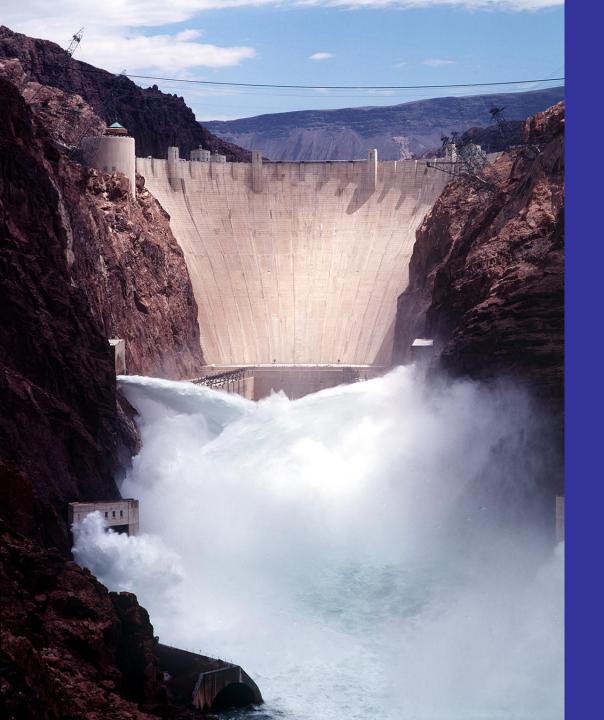
Wind Power Class



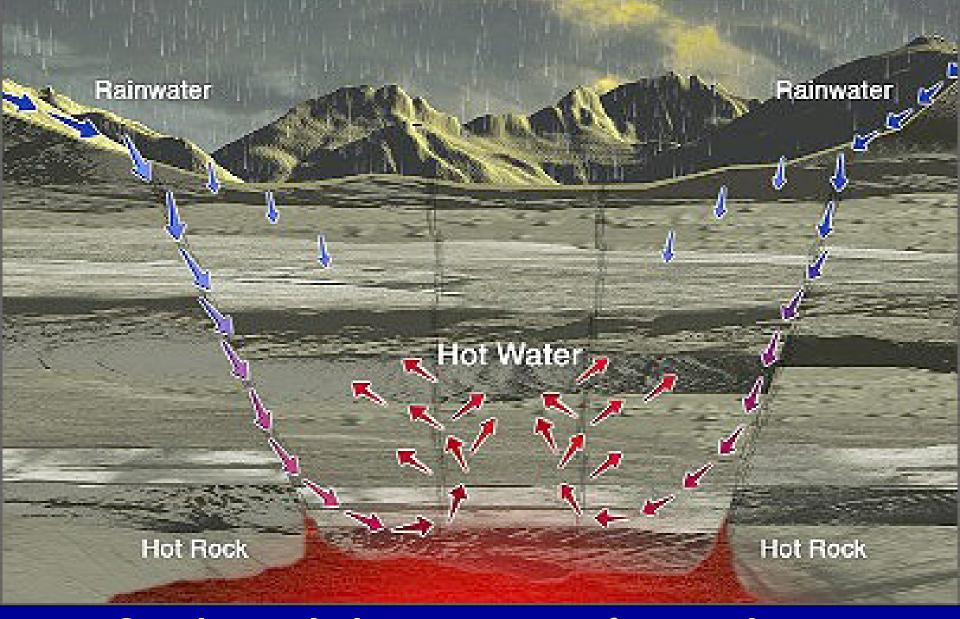
Power	Class	Speed	Power Density
	1	0.0-5.6m/s	0-200W/m2
	2		200-300W/m2
	3		300-400W/m2
	4	7.0-7.5m/s	400-500W/m2
	5	7.5-8.0m/s	500-600W/m2
	6	8.0-8.8m/s	500-800W/m2
	7	>8.8m/s	>800W/m2



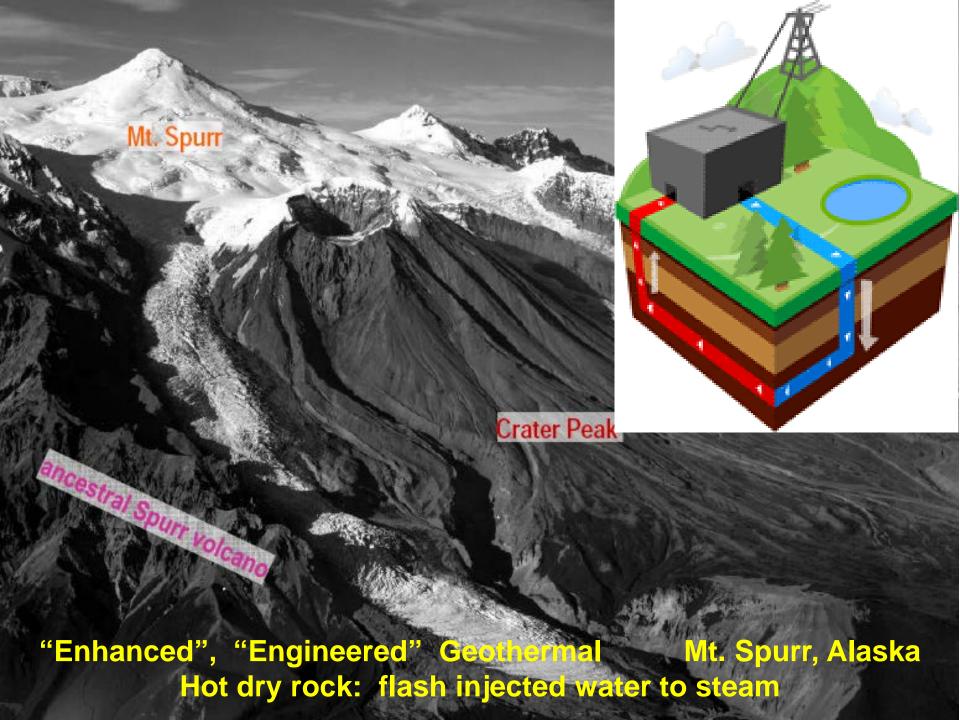


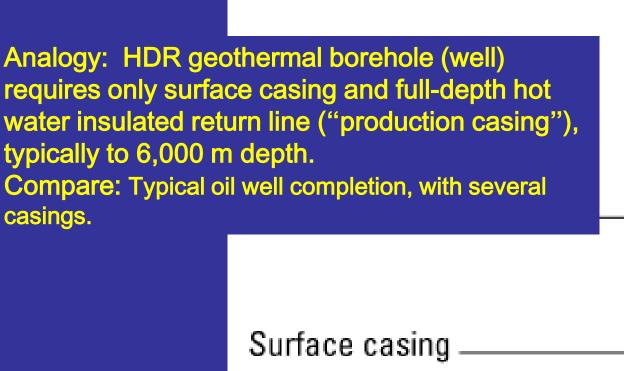


Hydro



Geothermal: hot water, surface recharge



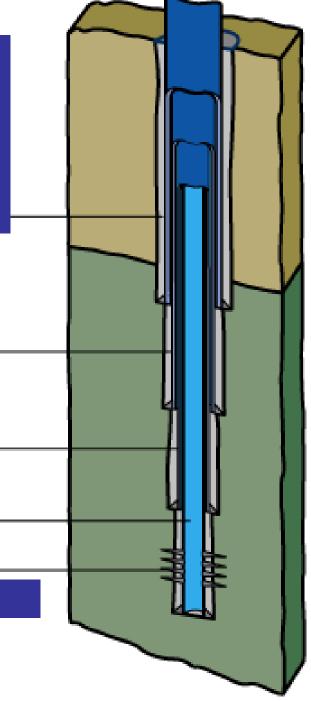


Intermediate casing.

Production casing _

Perforated interval ____

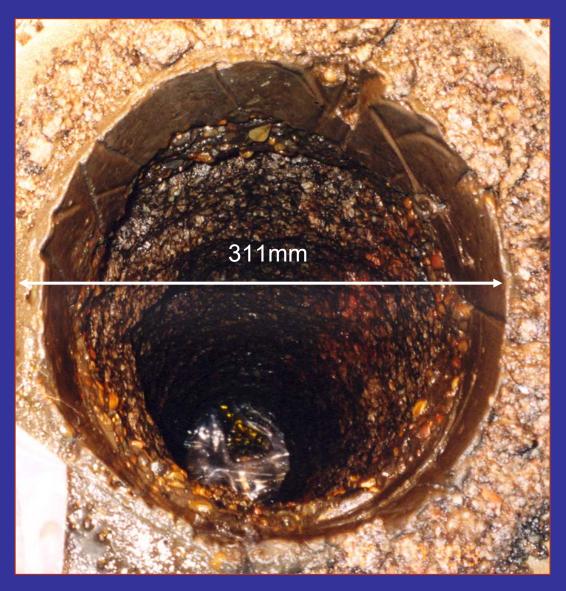
6,000 m depth in HDR



2006 BIT DESIGN



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



Alaska's Renewable Energy (RE) Goals

- 150+ community "energy islands":
 - Affordable
 - Indigenous; independence
 - Survival: outmigration
 - All energy, all uses: elec, heat, transport
 - Annual-scale, low-cost storage
- "Firm" large RE: Susitna Dam electricity
- Export large RE: "green" ammonia fuel
- Cluster industry: employment
- Prevent:
 - 1. Rapid climate change: warming
 - 2. Ocean acidification
 - 3. Sea level rise
 - 4. Species extinction

Trouble with Renewables

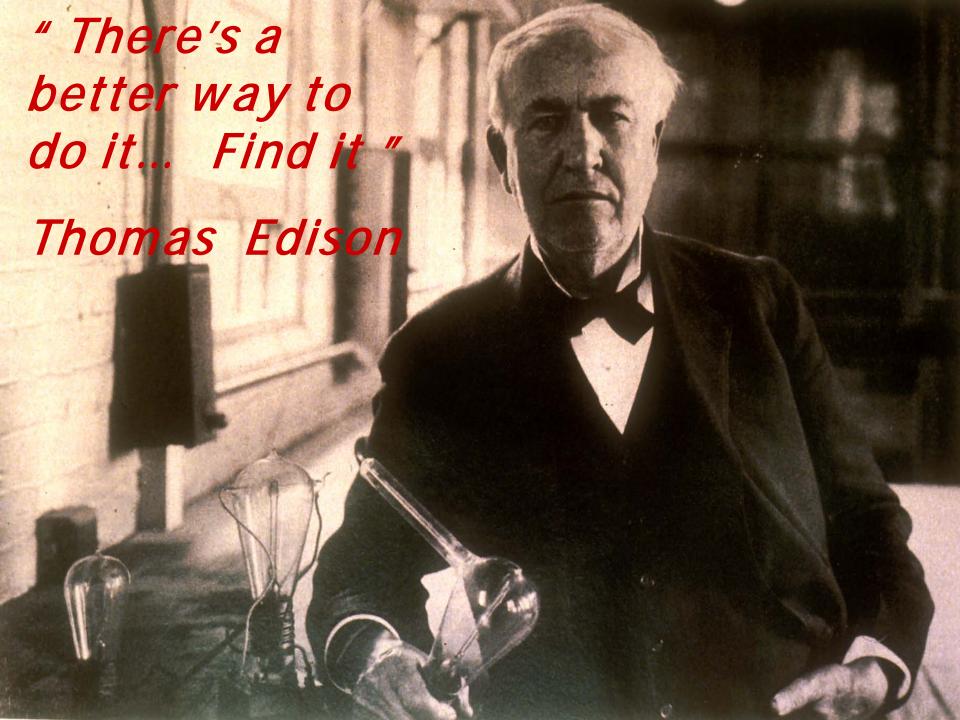
- Diffuse, dispersed: gathering cost
- Richest are remote: "stranded"
 - High intensity
 - Large geographic extent
- Time-varying output:
 - "Intermittent"
 - "Firming" integration + storage required
- "Energy island" communities, Alaska

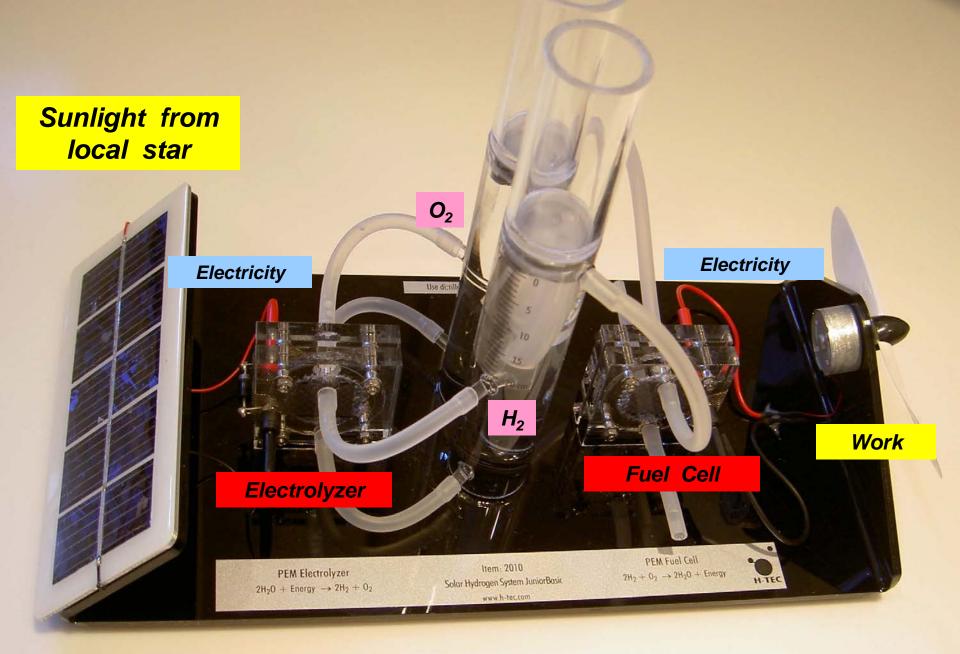
Trouble with Renewables: Big Three

- 1. Transmission and gathering
- 2. Storage: Annual-scale firming
- 3. Integration
 - Extant energy systems
 - Electricity grid
 - Fuels: CHP, transportation
 - Macro: "centralized plants"
 - Micro: distributed gen (DG), microgrids

Trouble with Renewables: Electricity Transmission

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





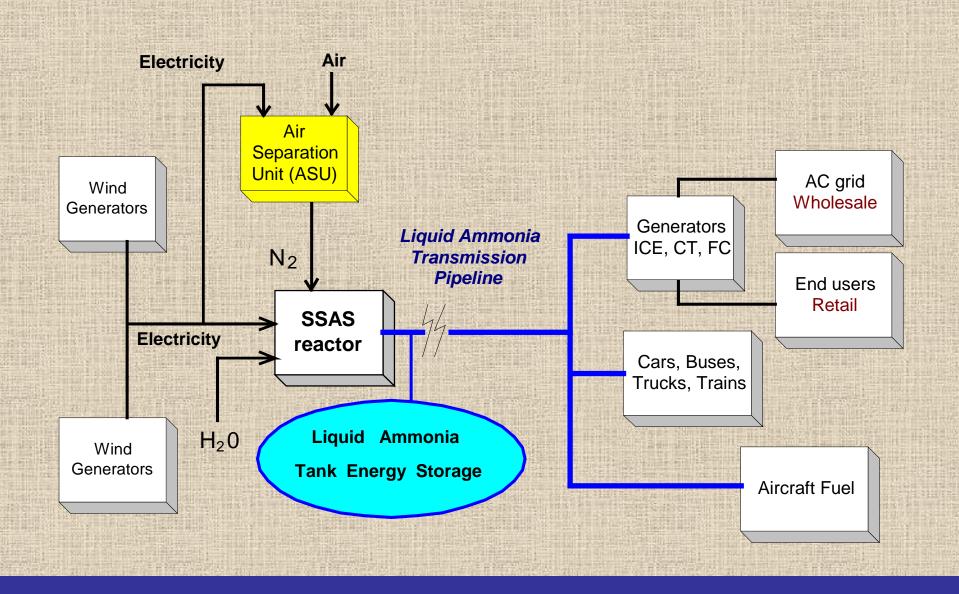
Solar Hydrogen Energy System

AEA EETF AASI Project

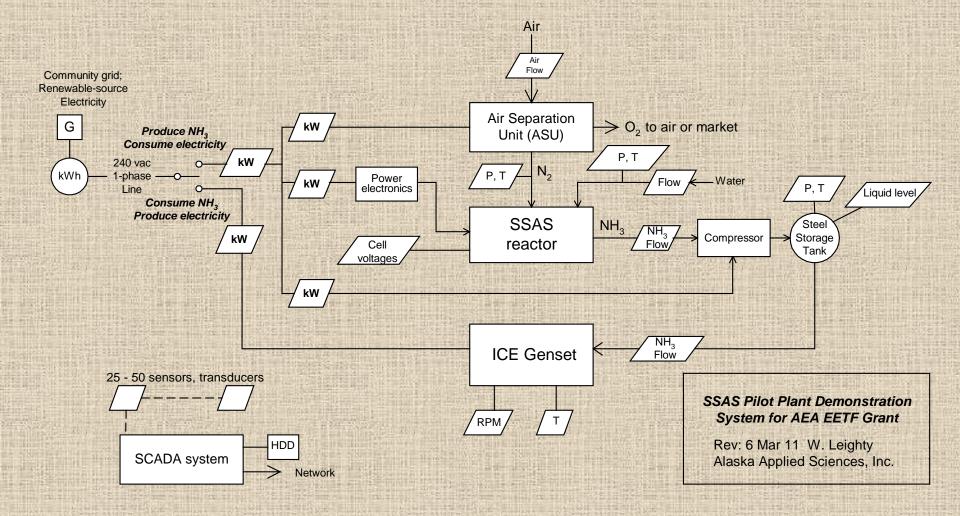
- AEA: Alaska Energy Authority, State of Alaska
- EETF: Emerging Energy Technology Fund
- AASI: Alaska Applied Sciences, Inc.
- Anhydrous ammonia (NH3) fuel from RE
- SSAS: Solid State Ammonia Synthesis
- PCC: Proton Conducting Ceramic
- AEA grants \$750K from EETF to AASI: Aug '12
- AASI in-kind \$250K
- Total \$1M

AEA EETF AASI Project

- Deliver: Containerized, transportable,
 SSAS pilot plant "ammonia microgrid" system
- Produce NH3 from RE-electricity, water, air
- Store NH3 in small tank
- Recover via CHP in ICE genset
- SCADA data export for public
- Demo around Alaska

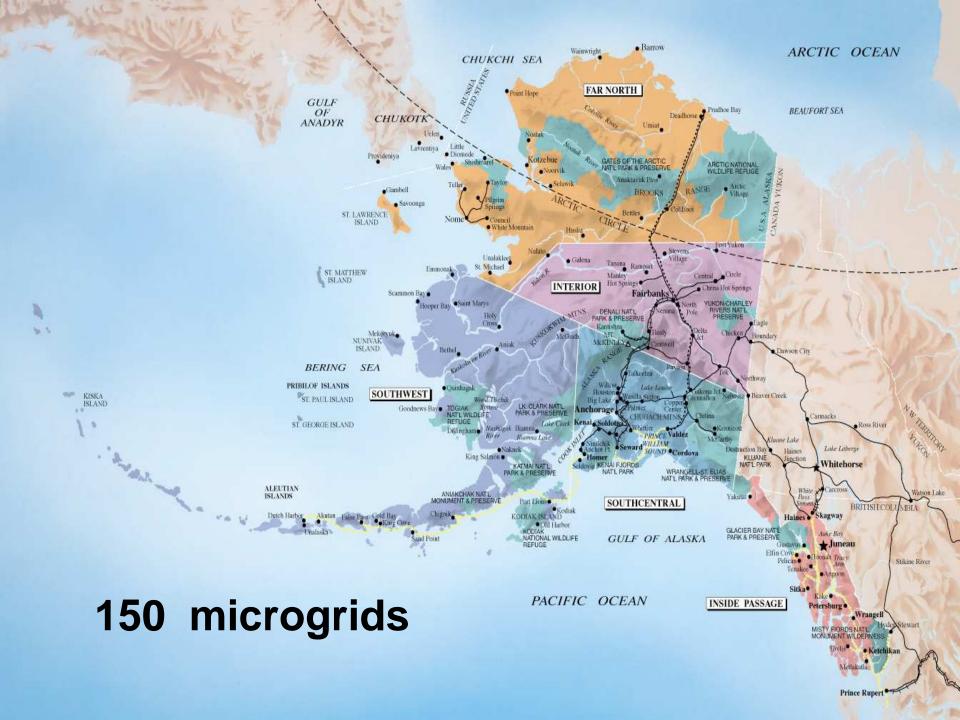


Solid State Ammonia Synthesis (SSAS)



PROJECT: Complete RE - NH₃ SSAS Storage System

- > NH3 synthesis from RE electricity, water, air (N₂)
- > Liquid NH₃ tank storage
- > Regeneration + grid feedback
- > SCADA instrumentation > UAF ACEP



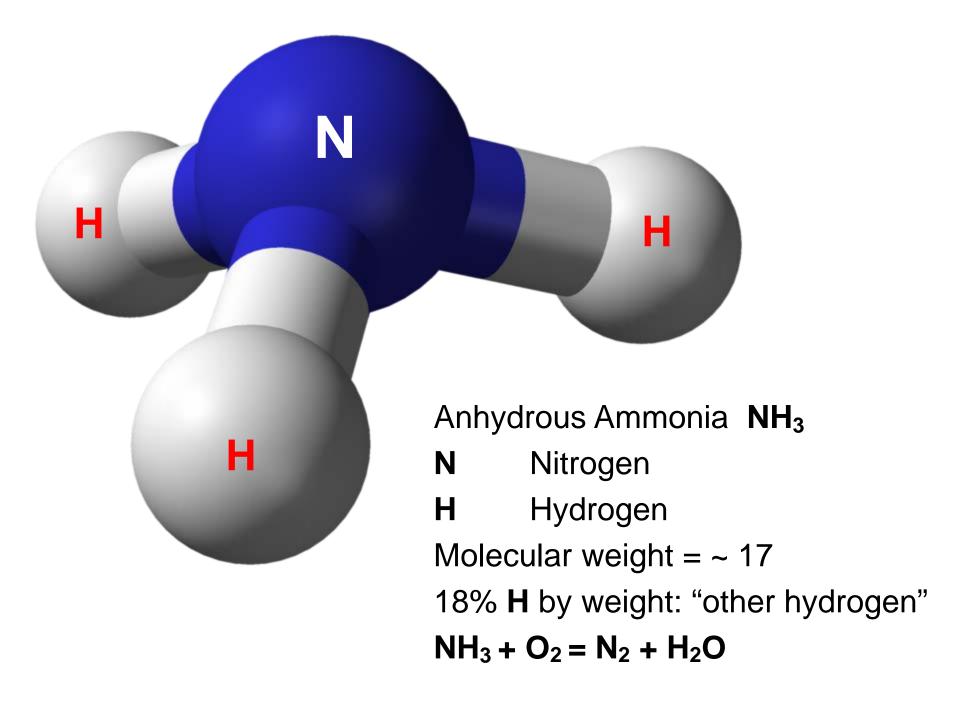
Opportunity: Alaska Microgrid Applications

- 1. Village energy "independence"
 - a. Diverse renewable sources
 - b. Low-cost tank storage
 - c. 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

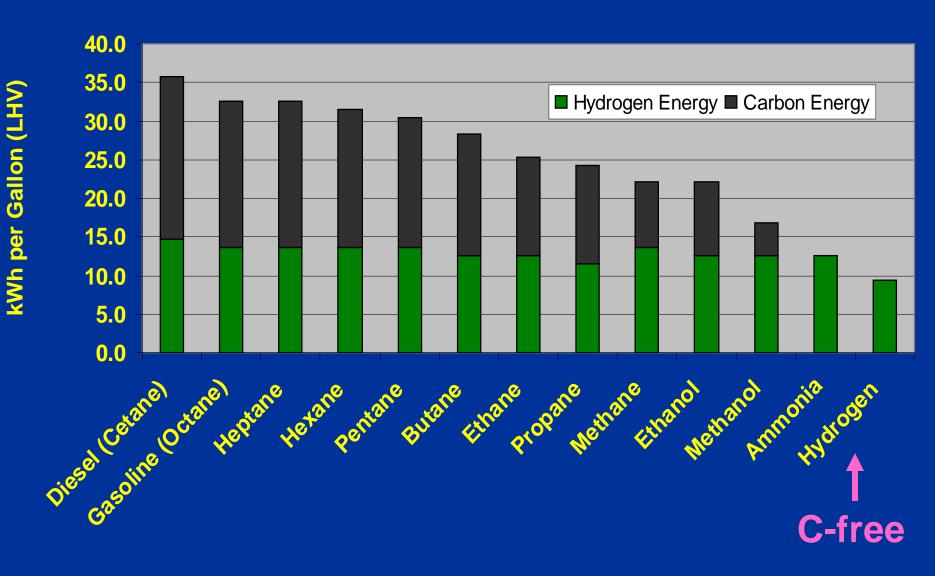
Military: Land + sea fuel

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





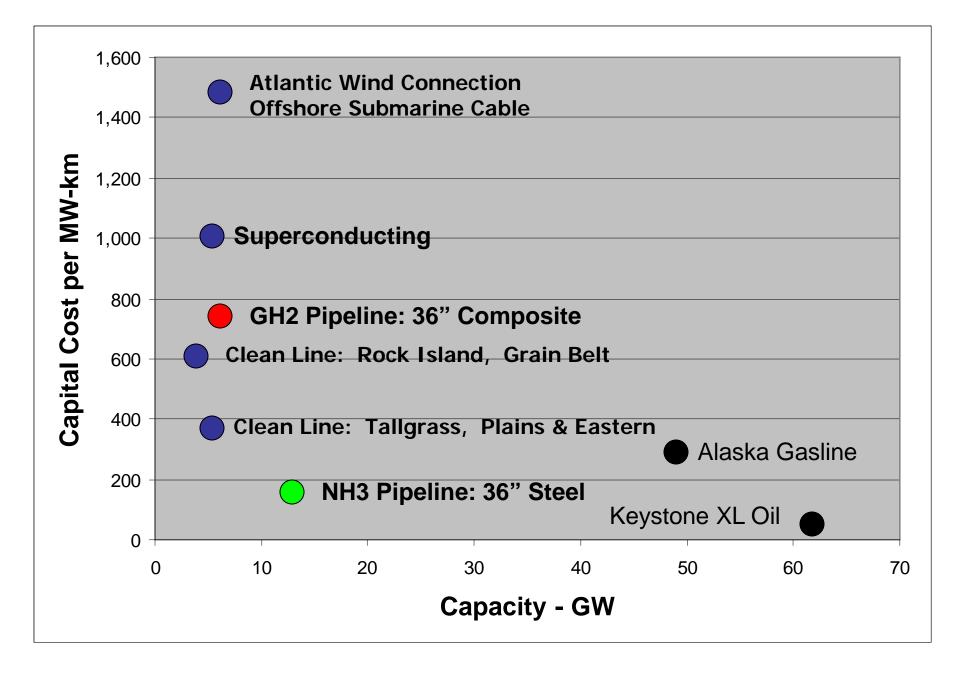
Volumetric Energy Density of Fuels (Fuels in their Liquid State)



Why Ammonia? Fertilizer and Fuel

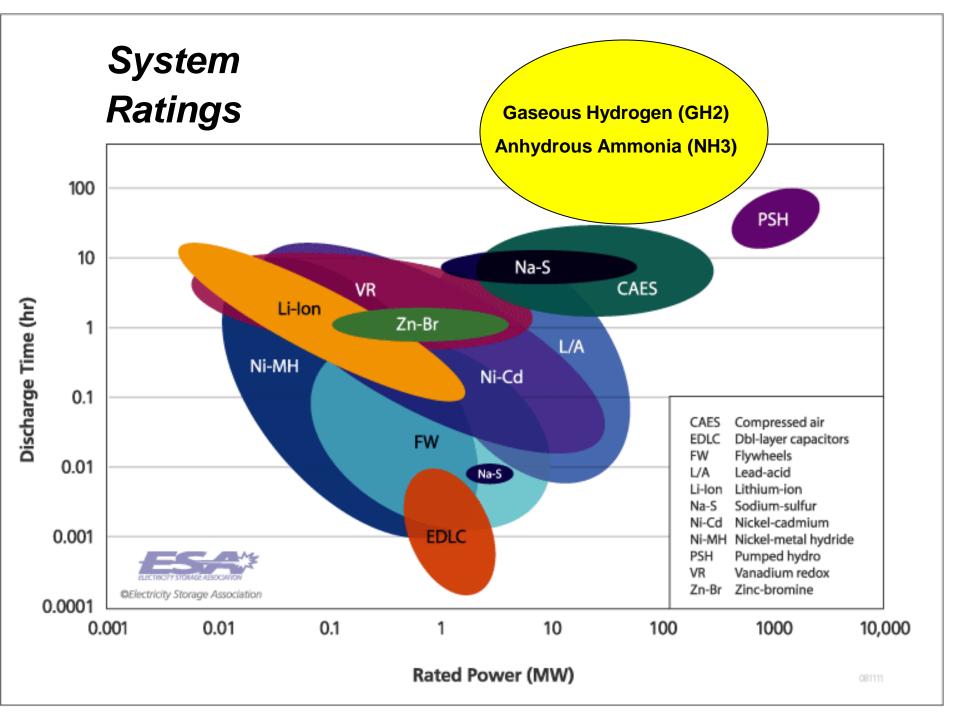
Only liquid fuel embracing:

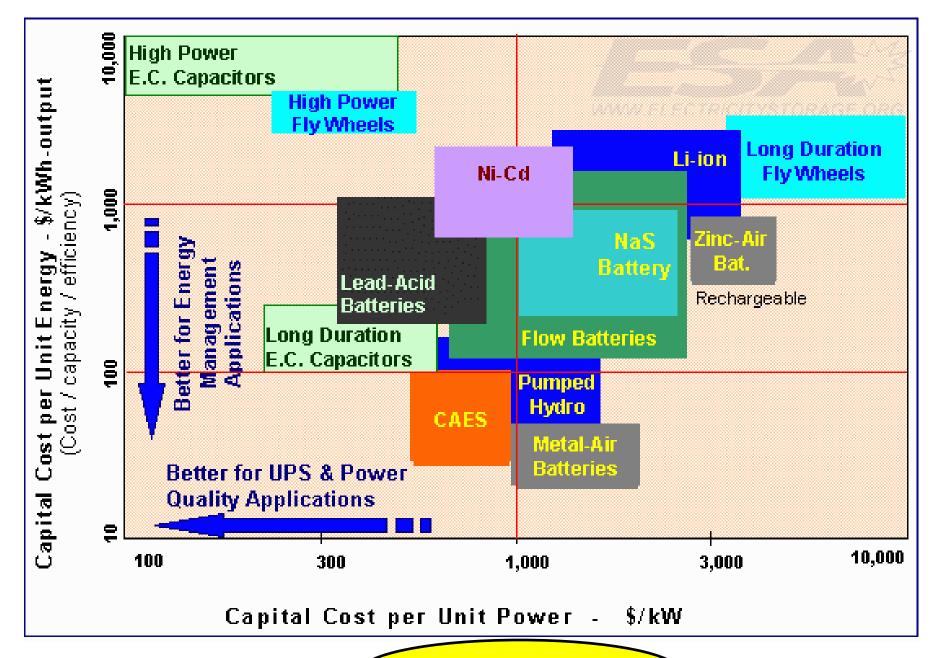
- Carbon-free: clean burn or conversion; no CO₂
 - Excellent hydrogen carrier
 - Easily "cracked" to H₂
- Reasonably high energy density
- Energy cycle inherently pollution free
 - Potentially all RE-source: elec + water + Nitrogen
 - Cost competitive with hydrocarbon fuels?
- Decades of global use,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



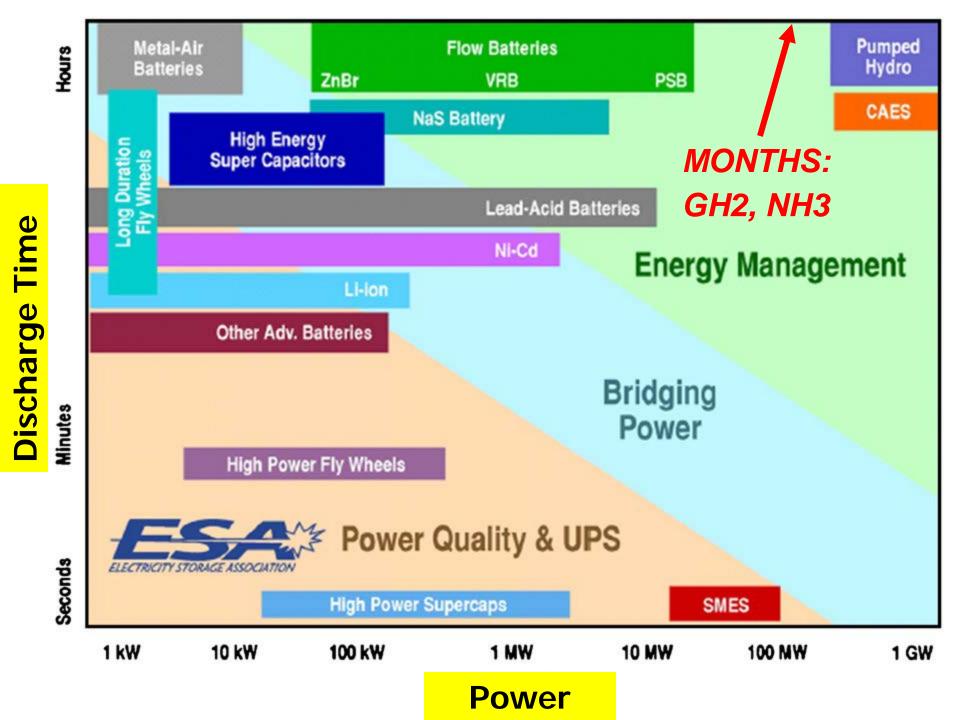
Energy Storage System Characteristics Hydrogen and Ammonia off the charts?

- 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

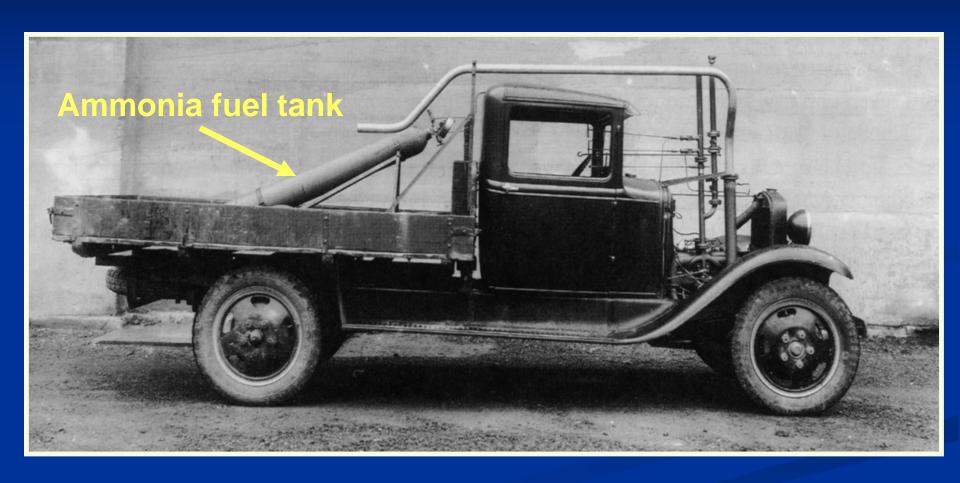


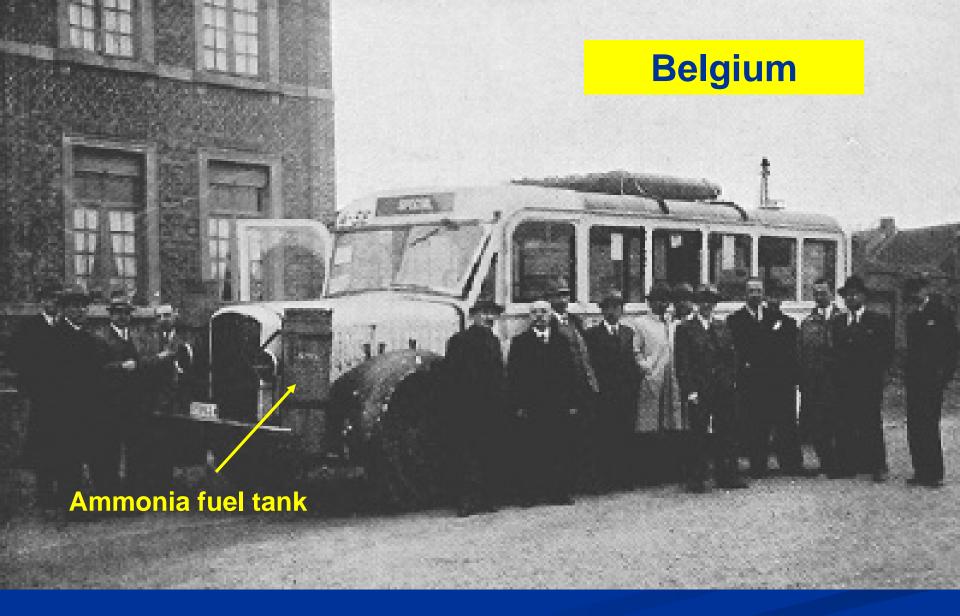


GH2 and NH3



Ammonia fueled - Norway





Ammonia Fueled Bus: Thousands of Problem-free Miles 1943



Ammonia + Gasoline Powered

• Idle: gasoline

• Full power: 80% ammonia

Summer '07 Detroit → San Francisco

2007



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

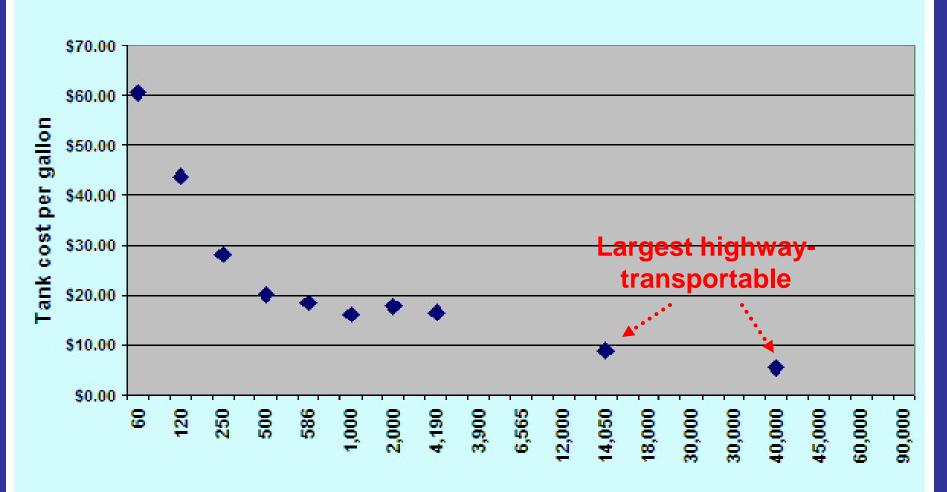


NH₃ Ag Fertilizer Tanks, Wind Generators, NW Iowa



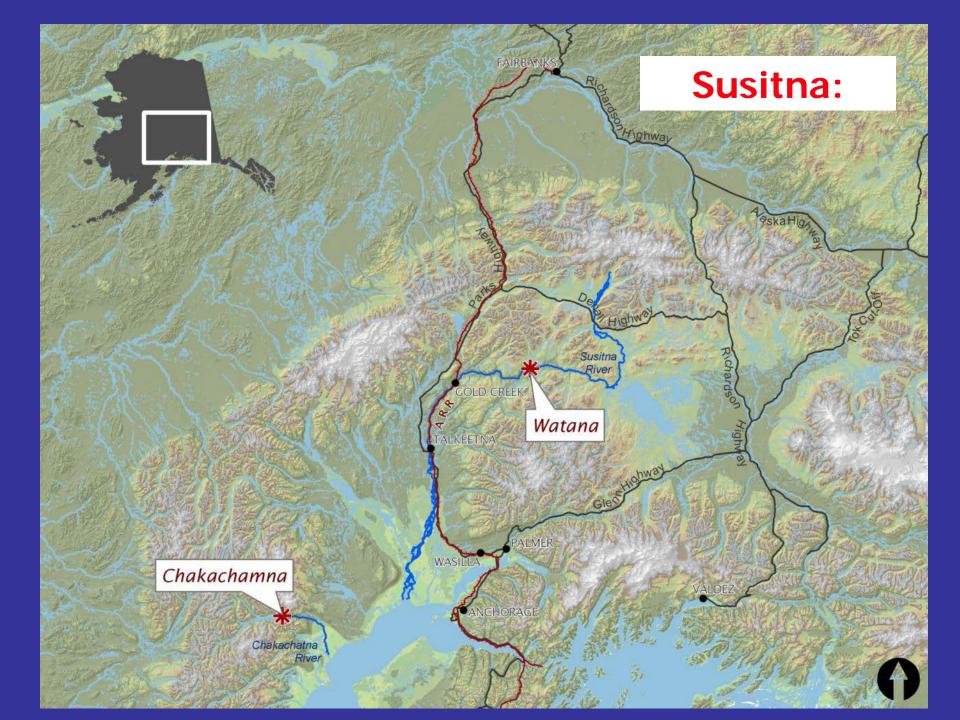
Liquid Ammonia Tank Storage

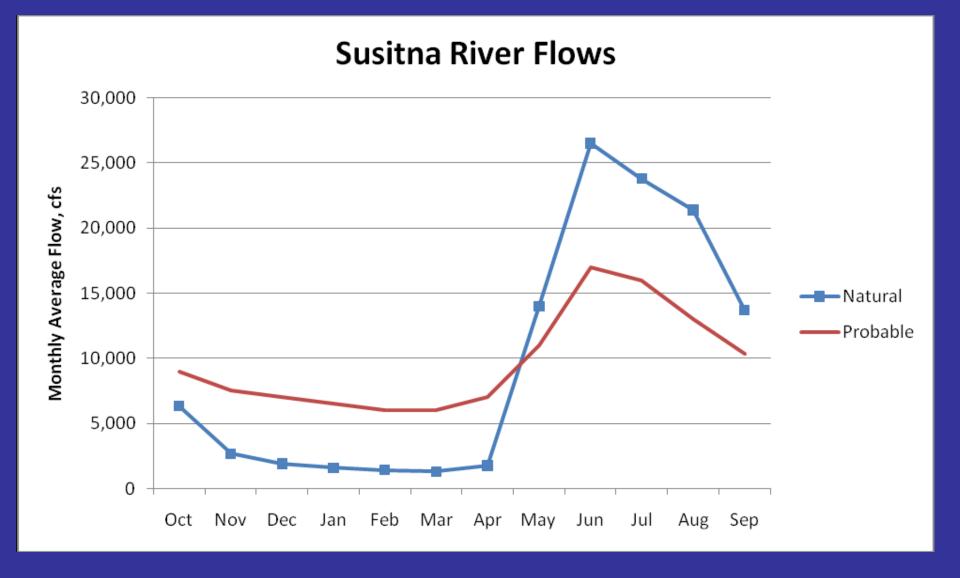
Cost per Gallon: 250 psi Ammonia Tanks



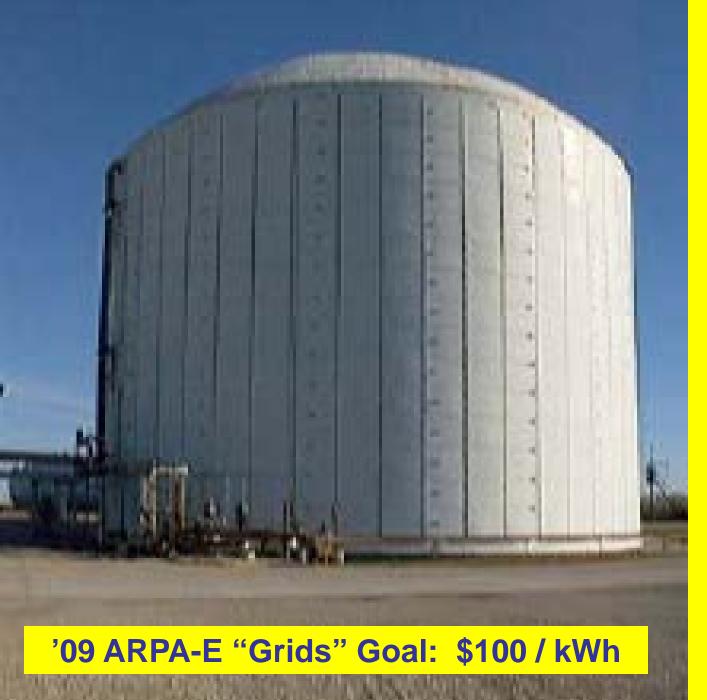
Tank capacity, gallons







Hydro "Dispatchable" with NH3 storage



"Atmospheric"
Liquid
Ammonia
Storage Tank
(corn belt)

30,000 Tons
190 GWh
\$ 15M turnkey
\$ 80 / MWh
\$ 0.08 / kWh

-33 C 1 Atm



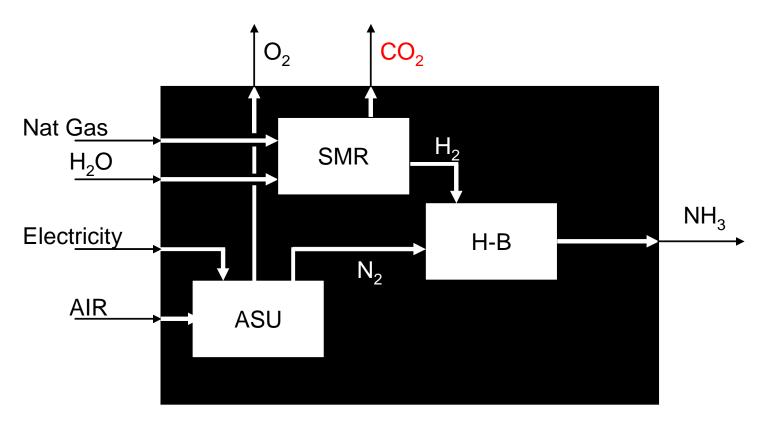
Haber-Bosch Process 1909 – 1913 BASF

- NH₃ synthesis
- Coal gasification → H2
- WW I explosives
- 40% humanity: N fertilizer

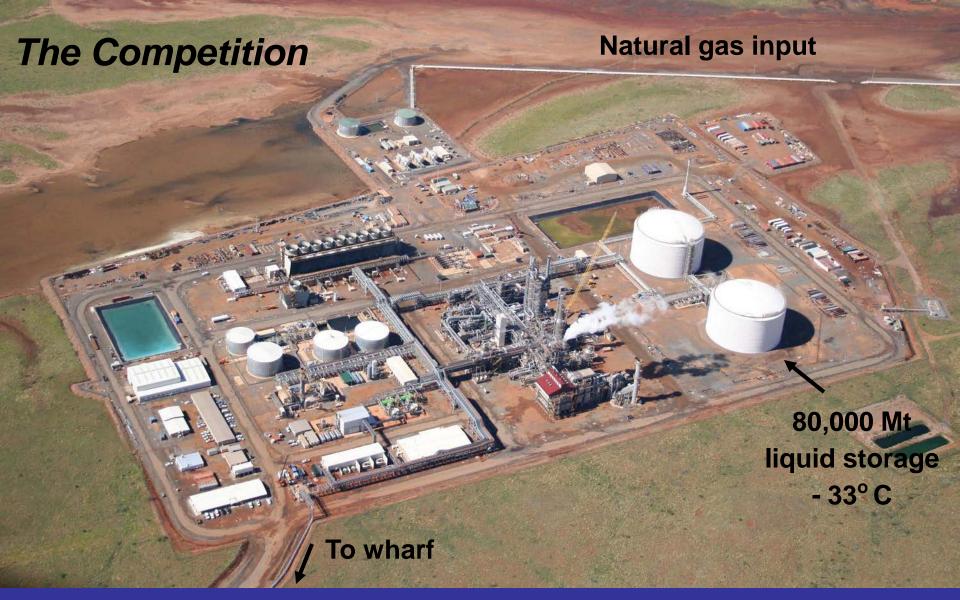
Haber-Bosch Reactor 1921 Ludwigshafen, Germany

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

$$3 \text{ CH}_4 + 6 \text{ H}_2\text{O} + 4 \text{ N}_2 \rightarrow 3 \text{ CO}_2 + 8 \text{ NH}_3$$



Energy consumption ~33 MMBtu (9,500 kWh) per ton NH_3 Tons CO_2 per ton $NH_3 = 1.8$



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



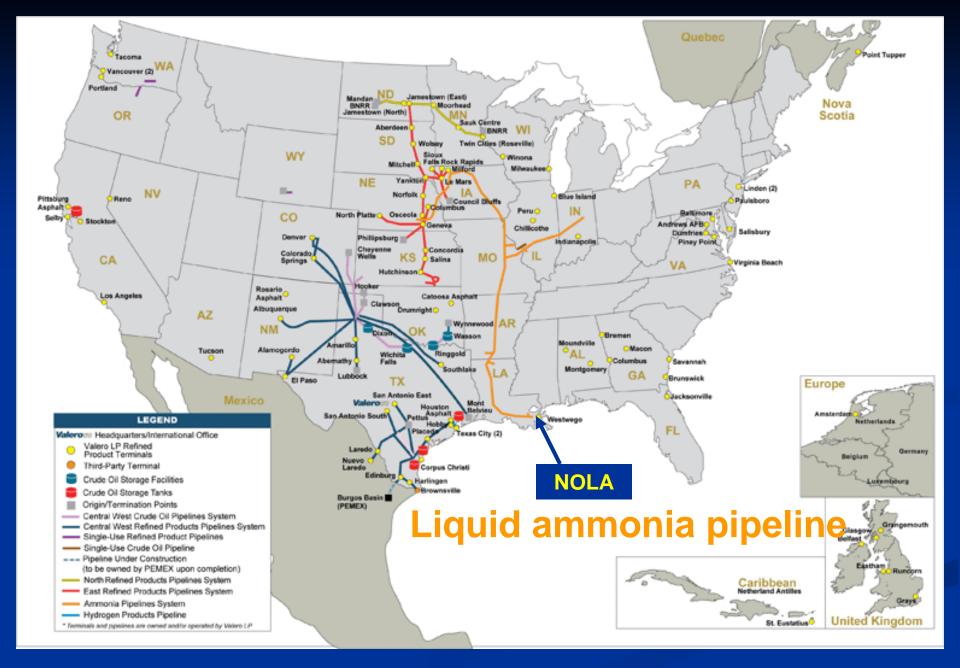
Ammonia or LPG Tanker

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



Capital Cost per GW-mile

Electricity:		Capacity	
	<u>KV</u>	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

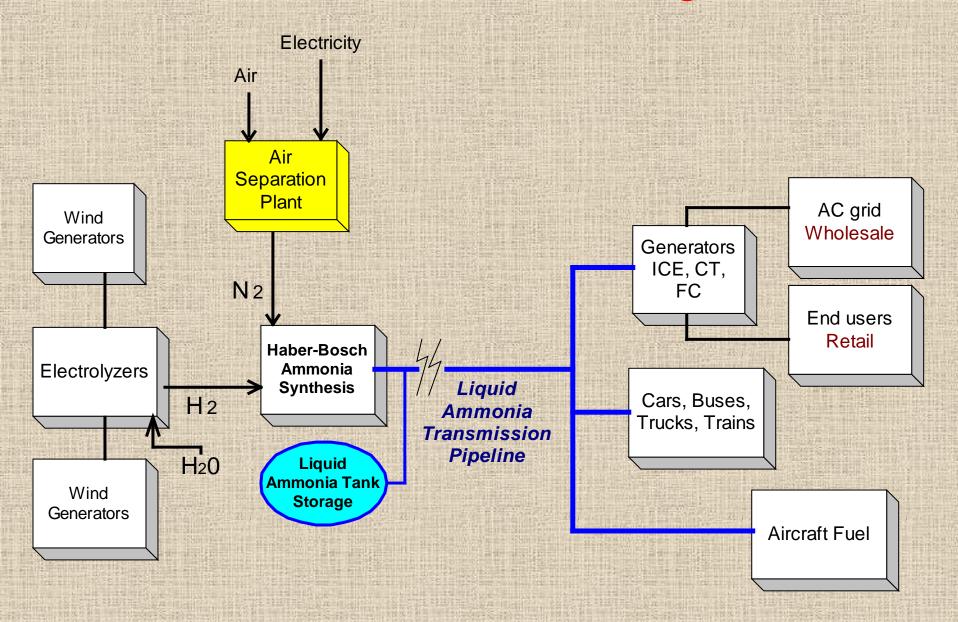
Hydrogen pipeline:

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

Ammonia pipeline:

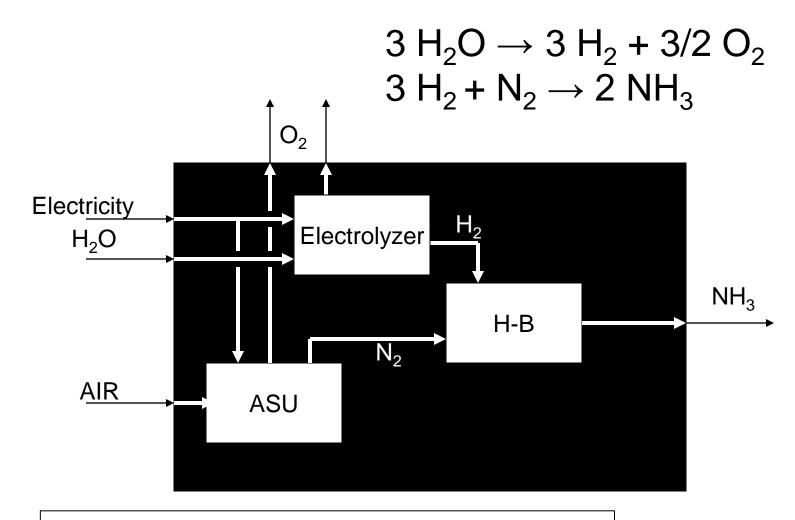
10", liquid, 500 miles, with pumping 0.2

RE Ammonia Transmission + Storage Scenario

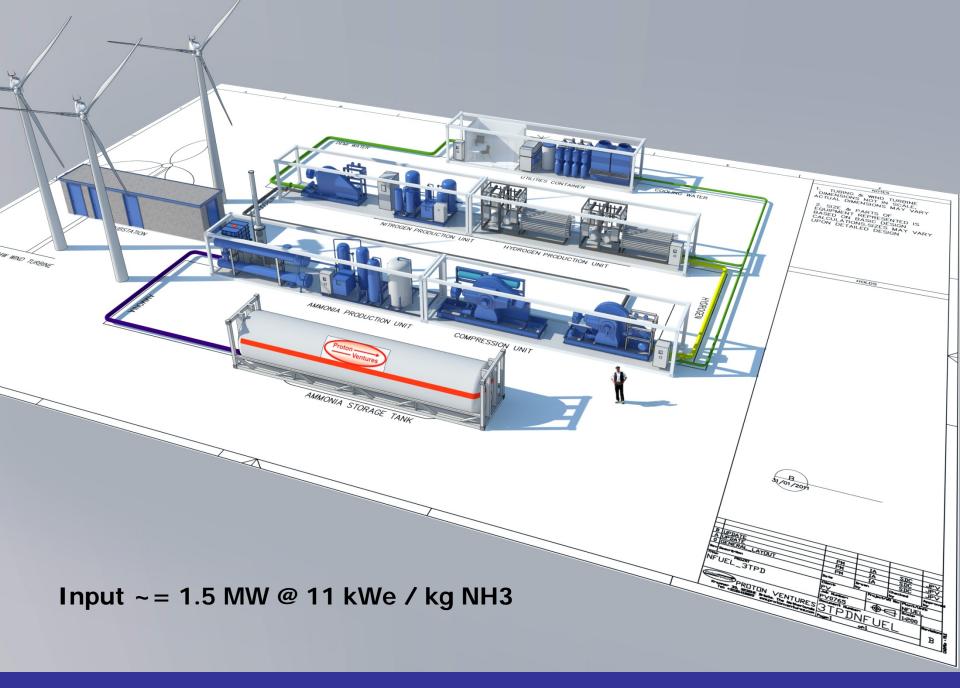




Inside the Black Box: HB Plus Electrolysis



Energy consumption ~12,000 kWh per ton NH₃

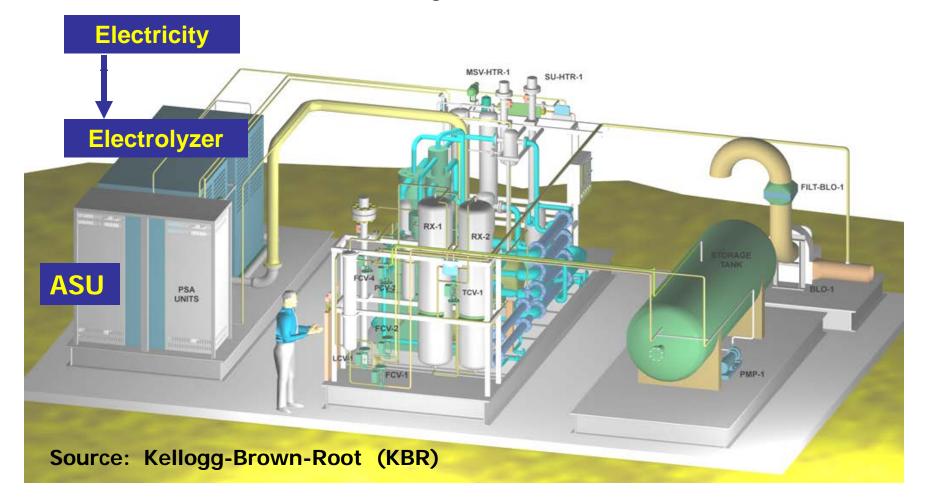


Quoted at \$4M. Delivered?

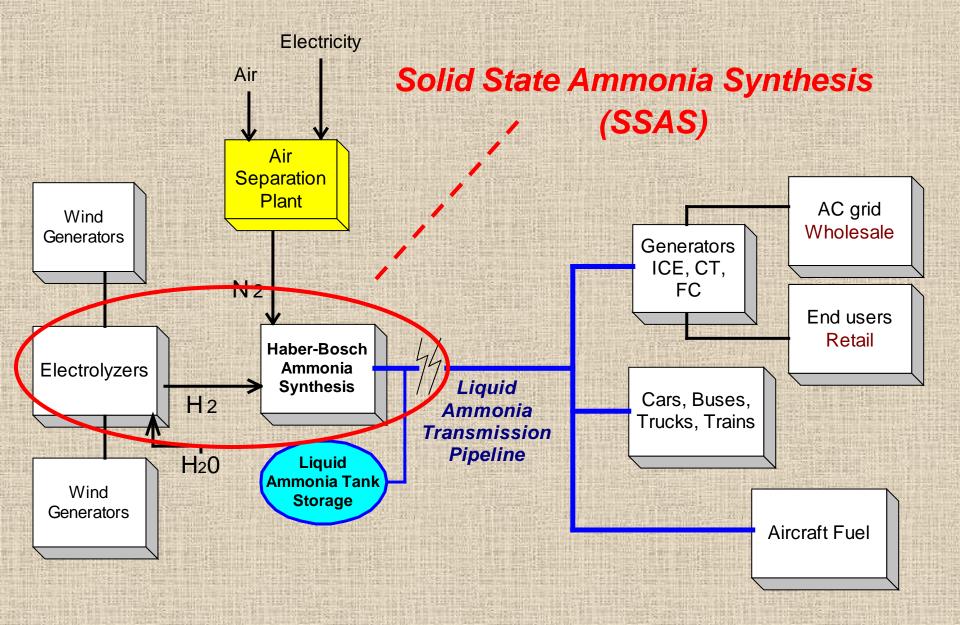
Contact: Steve Gruhn sgruhn@freedomfertilizer.com

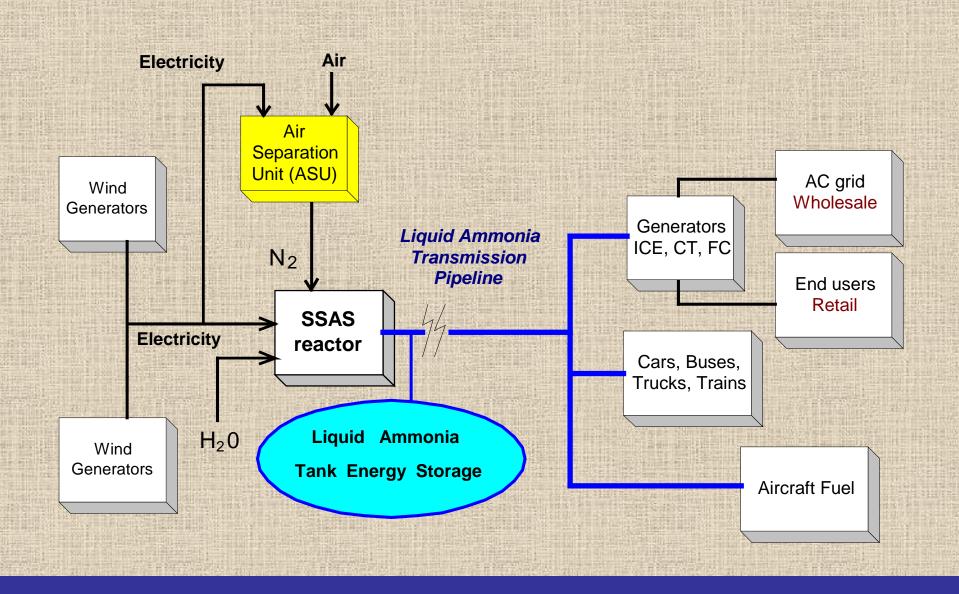


Village-scale 3 Mt / day Mini-NH3 Plant RE Electricity Haber-Bosch



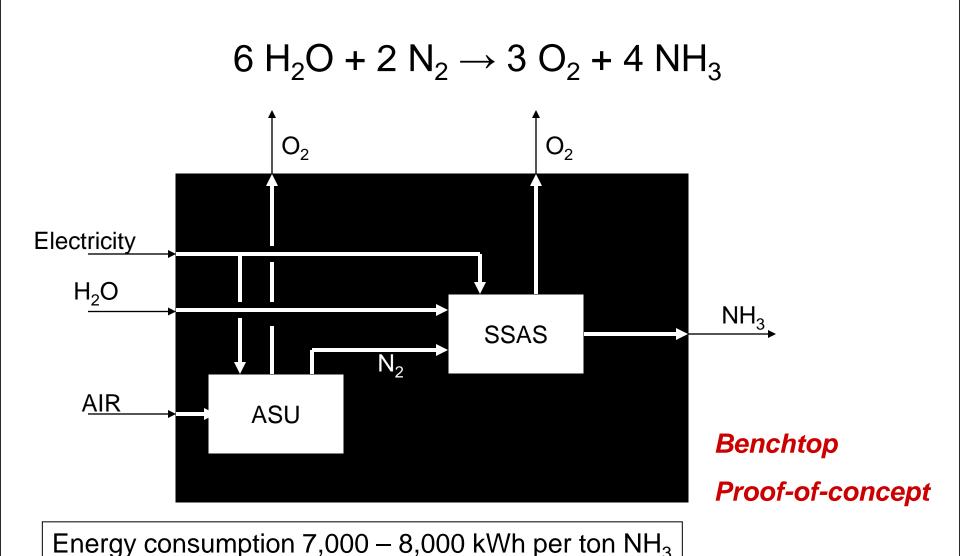
RE Ammonia Transmission + Storage Scenario



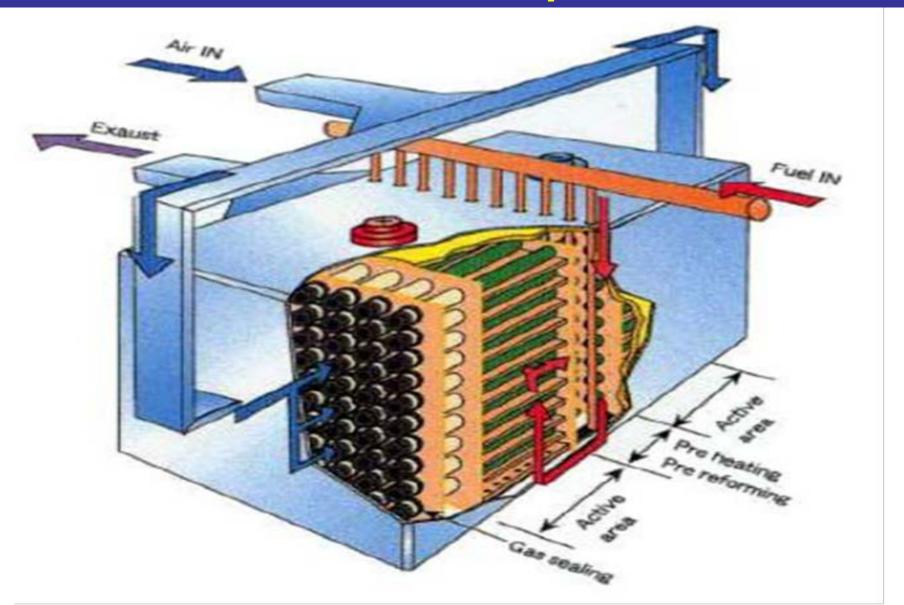


Solid State Ammonia Synthesis (SSAS)

Inside the Black Box: Solid State Ammonia Synthesis



Solid State Ammonia Synthesis (SSAS) NHThree LLC patent





Tube assembly installed in test fixture.

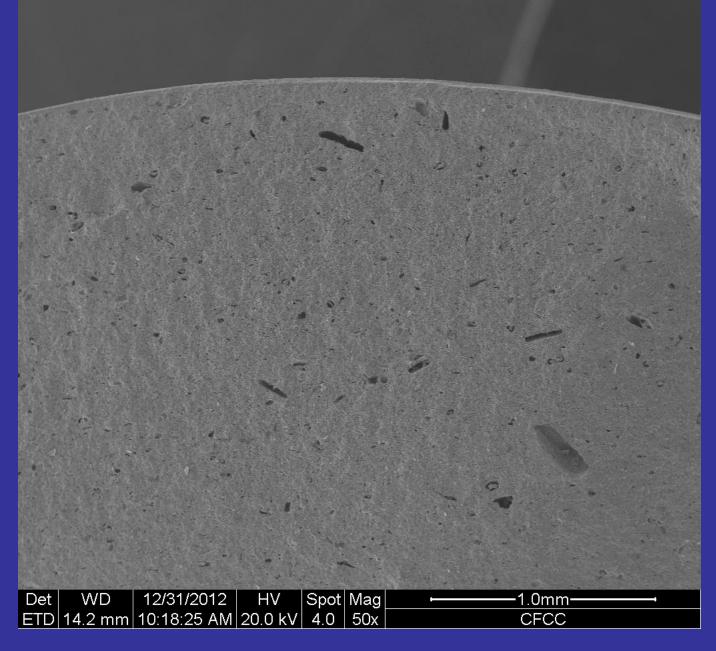
Nickel oxide cathode coating (tube interior) reduced by hydrogen to metallic nickel, ready for subsequent tests.



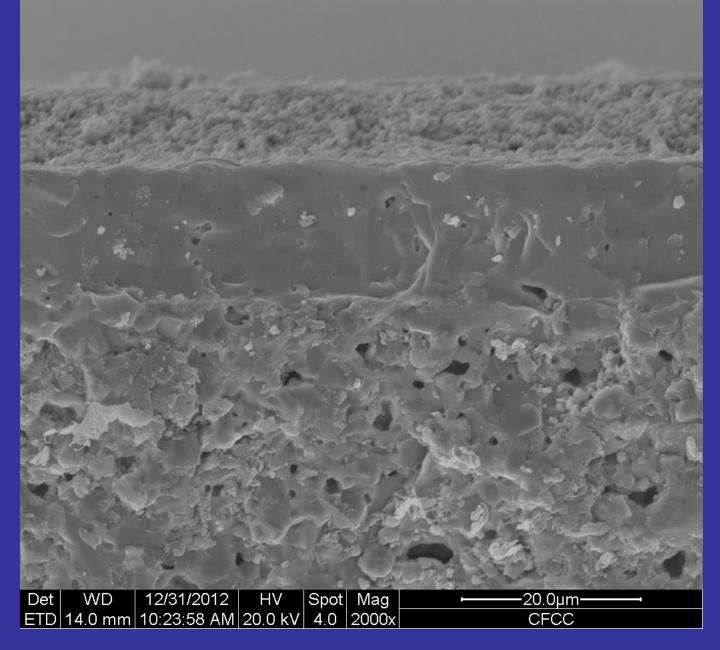
Center: PCC tube 33 cm² active area.

Current collectors installed.

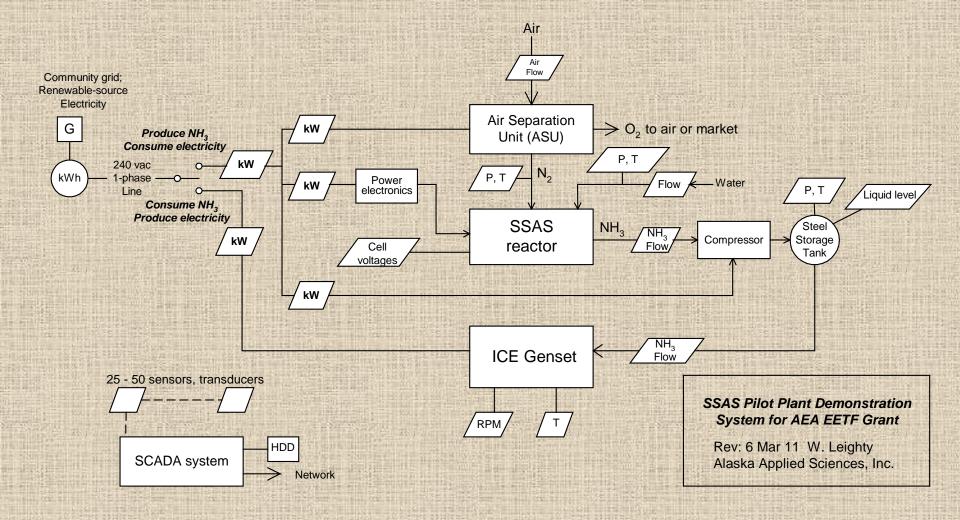
Sealed to alumina support tubes. Setup is leak-free.



50x PCC tube cross-section, anode layer (exterior)



2,000x cathode (interior)



PROJECT: Complete RE - NH₃ SSAS Storage System

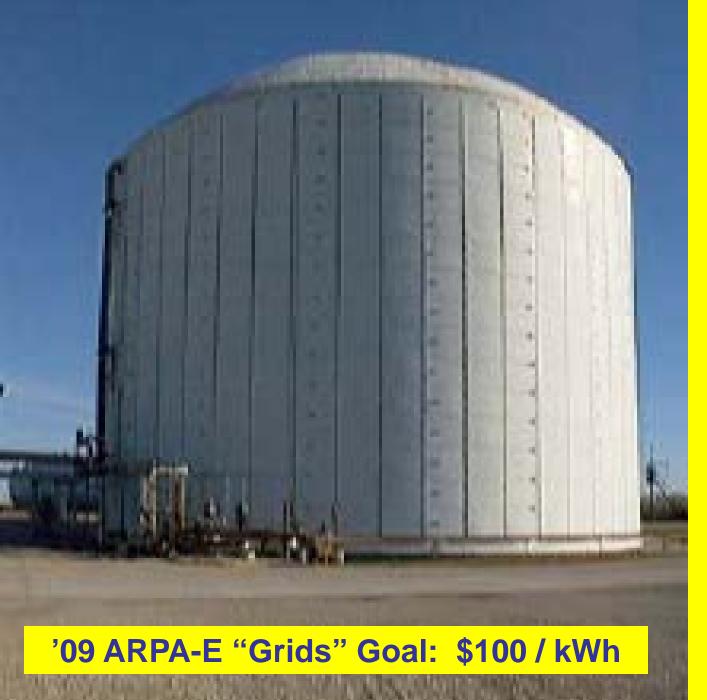
- > NH3 synthesis from RE electricity, water, air (N₂)
- > Liquid NH₃ tank storage
- > Regeneration + grid feedback
- > SCADA instrumentation > UAF ACEP

Beyond Alaska Microgrids

- Success: global application
- "Electrofuels" microgrids
- Merging RE microgrids
 - Ammonia microgrid → macrogrid
- Continental scale RE systems
- RE for all energy, all purposes
- "Run world on renewables"
- "Green" ammonia compete? C-tax?

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

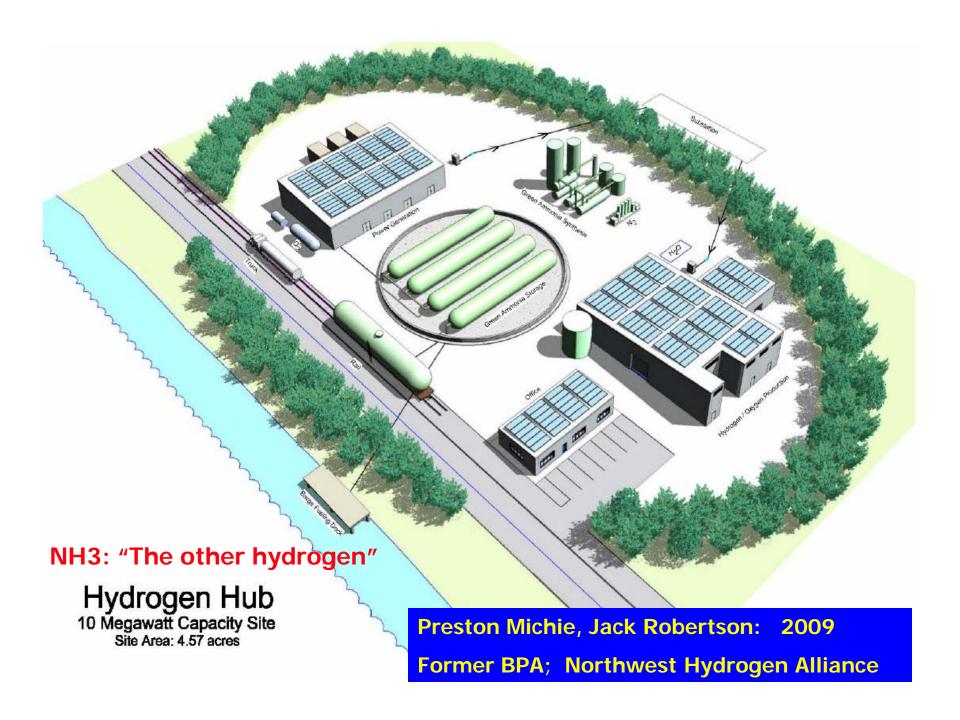
- Electricity
 - VRB (Vanadium Redox Battery)
 - O&M: 80% efficiency round-trip
 - Capital: \$500 / kWh = \$ 160 Billion
 - CAES (Compressed Air Energy Storage)
 - O&M: \$46 / MWh typical
 - Iowa Stored Energy Park:
 - Power = 268 MW
 - Energy capacity = 5,360 MWh
 - Capital: 268 MW @ \$ 1,450 / kW =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



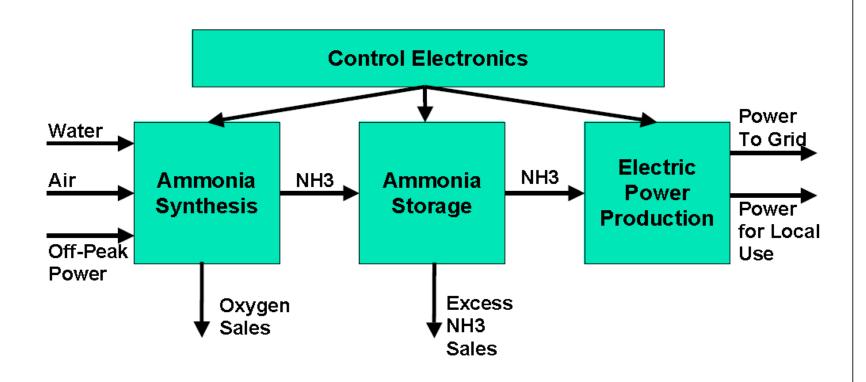
"Atmospheric"
Liquid
Ammonia
Storage Tank
(corn belt)

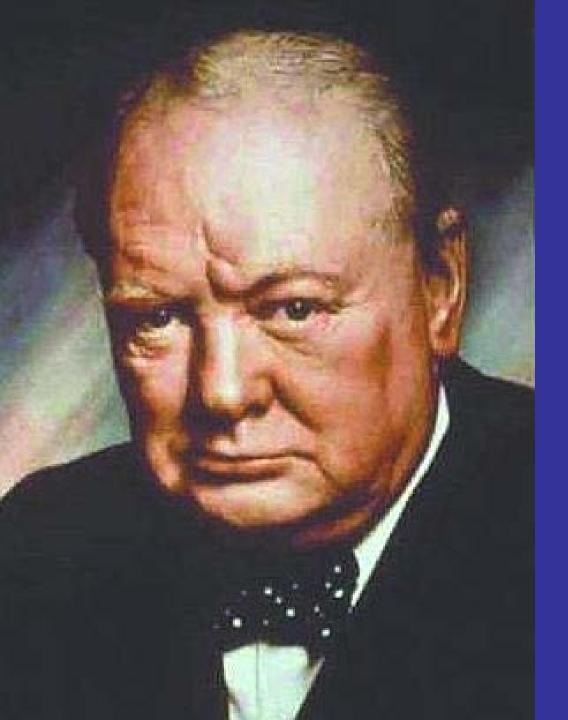
30,000 Tons
190 GWh
\$ 15M turnkey
\$ 80 / MWh
\$ 0.08 / kWh

-33 C 1 Atm



Hydrogen Hub Concept





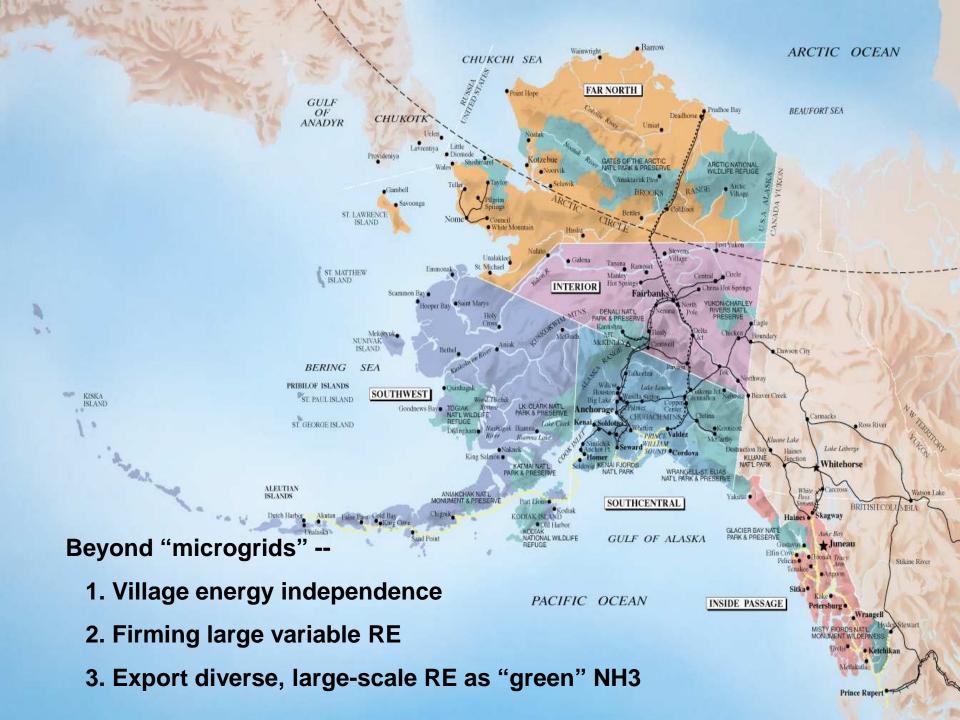
" Americans can be counted on to always do the right thing –

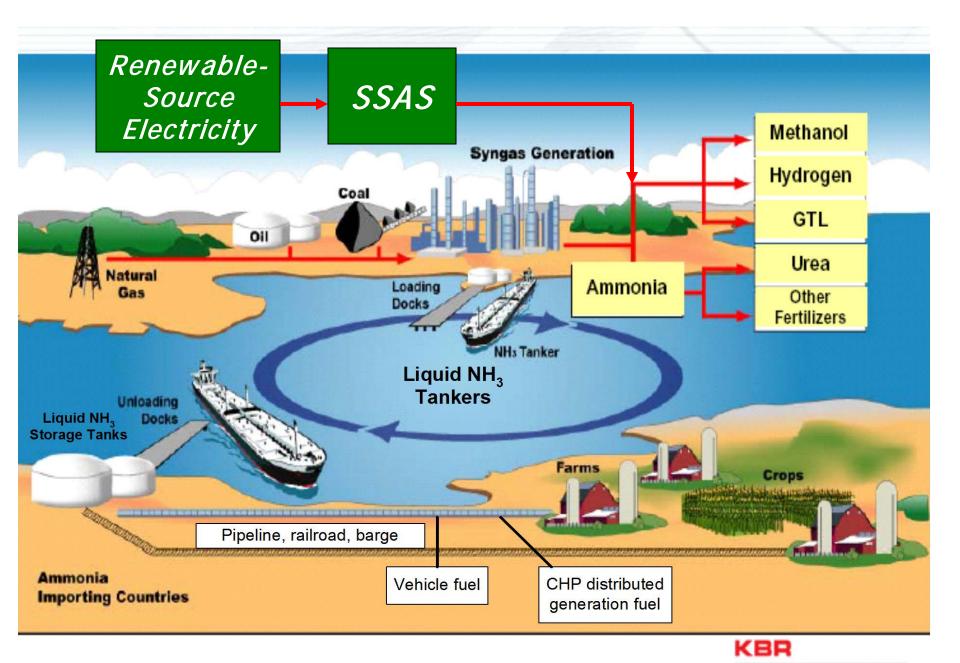
but only after they have tried everything else "

Winston Churchill

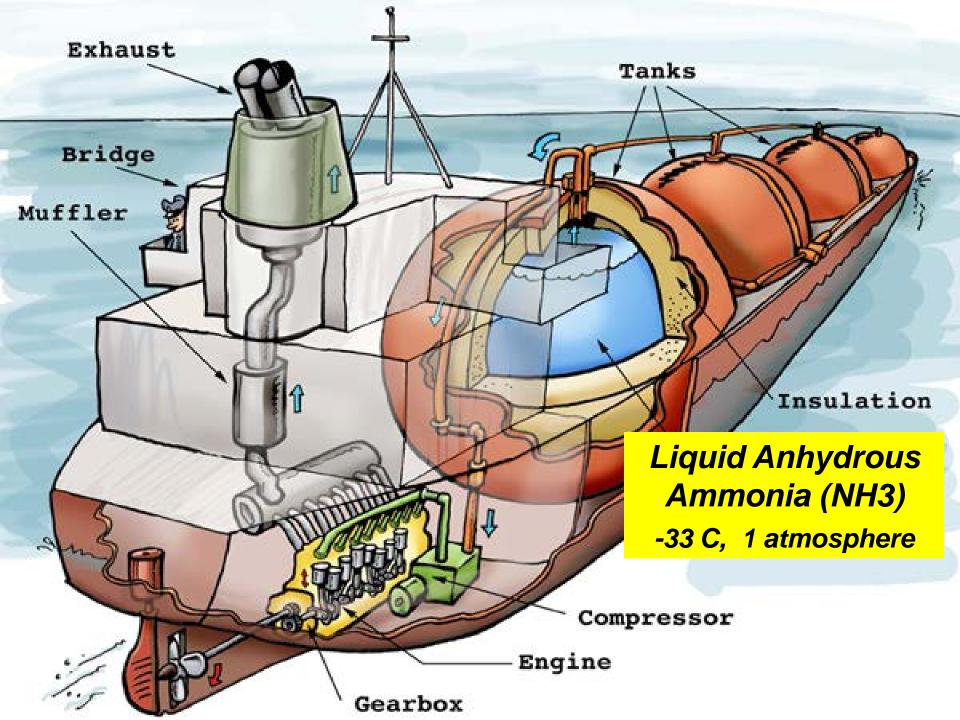
The dog caught the car.

Dan Reicher





Energy and Chemicals



Alaska Energy Authority Emerging Energy Technology Fund Project Fundamentals

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

SSAS: Solid State Ammonia Synthesis

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
 - Hydro firming, annual-scale
 - RE export as NH3 fuel
 - ALL energy: elec, heat, transport
- 2-year project

Project Fundamentals

- 1. Anhydrous ammonia (NH3) is a:
 - a. Fuel: ICE, CT, fuel cell
 - b. Transmission medium
 - c. Low-cost energy storage medium: liquid, 15 bar
- 2. NH3 made from 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. Alaska value

Project Fundamentals

- 4. SSAS unproven: needs proof-of-concept, kW-scale pilot plant
- 5. Design and build pilot plant:
 - a. Complete system: convert, store, regenerate
 - b. SCADA instrumented: public
 - c. Containerized & transportable
 - d. Upgradeable
- 6. Success:
 - a. Great value to Alaska, beyond
 - b. Scaleup to commercial
 - c. SE Alaska "RE Cluster Industry" via USFS, JEDC



PNNL, Richland, WA 25 Feb 13

L to R: John Holbrook, NHThree Bill Leighty, AASI Greg Coffey, PNNL

Test reactor is above Bill's left shoulder

Project Status

- PCC tube section in test at PNNL, Richland, WA
- AEA 1 Dec deadline: "use or lose" \$750K grant
- Alternative technology proposed
 "Nafion" membrane reactor: TRL = 0
- Fundamentals persist:

Alaska, global need

Project cancelled; \$750K grant lost

Milestone 1: failed to demonstrate technology at PNNL



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