Making Ammonia Fuel From Alaska's Abundant Stranded Renewable Energy

Ammonia Fuel Conference
Detroit, MI
27 September 10

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MUST Run the World on Renewables – plus Nuclear ?

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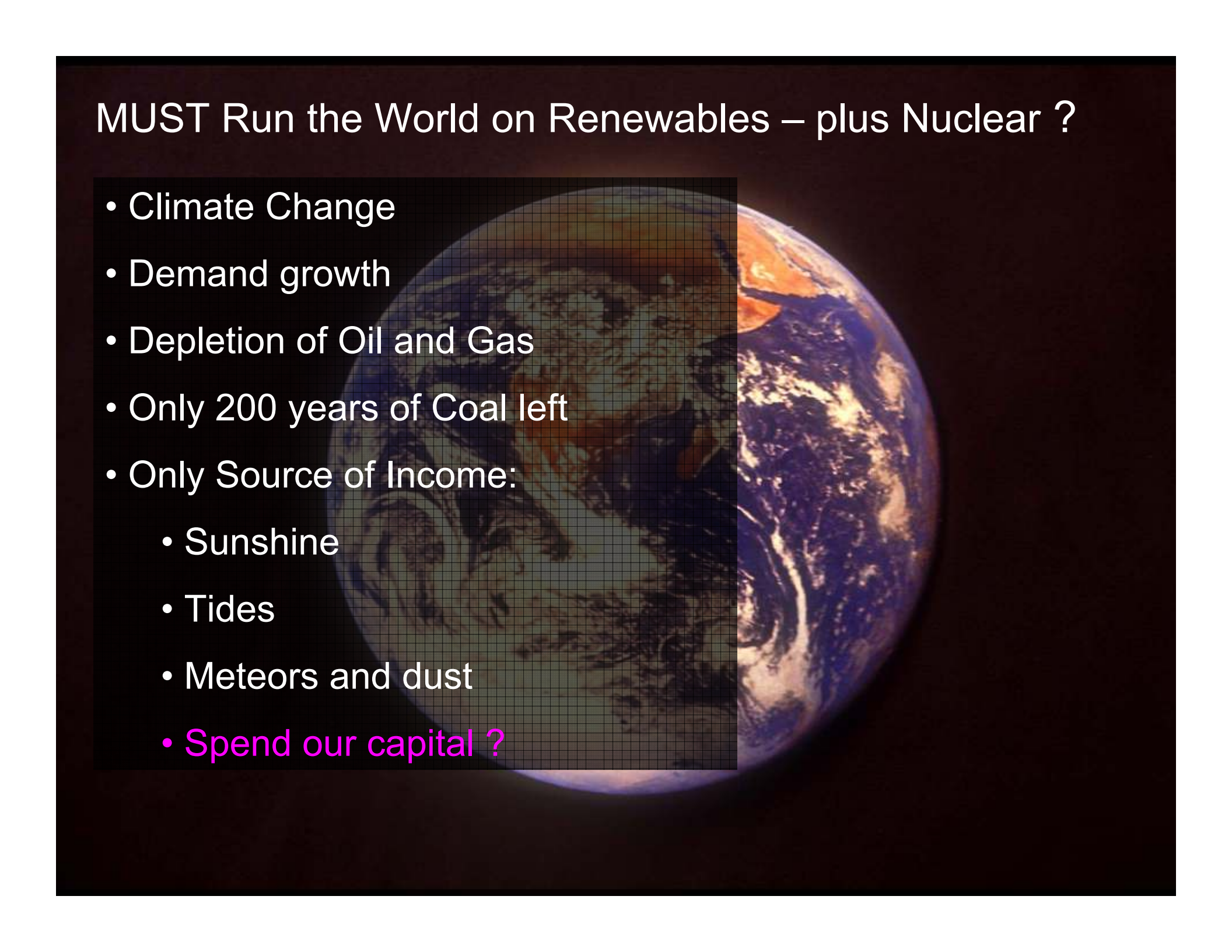


- Climate Change
- Demand growth
- Depletion of Oil and Gas
- Only 200 years of Coal left
- Only Source of Income:
  - Sunshine
  - Tides
  - Meteors and dust
  - Spend our capital ?

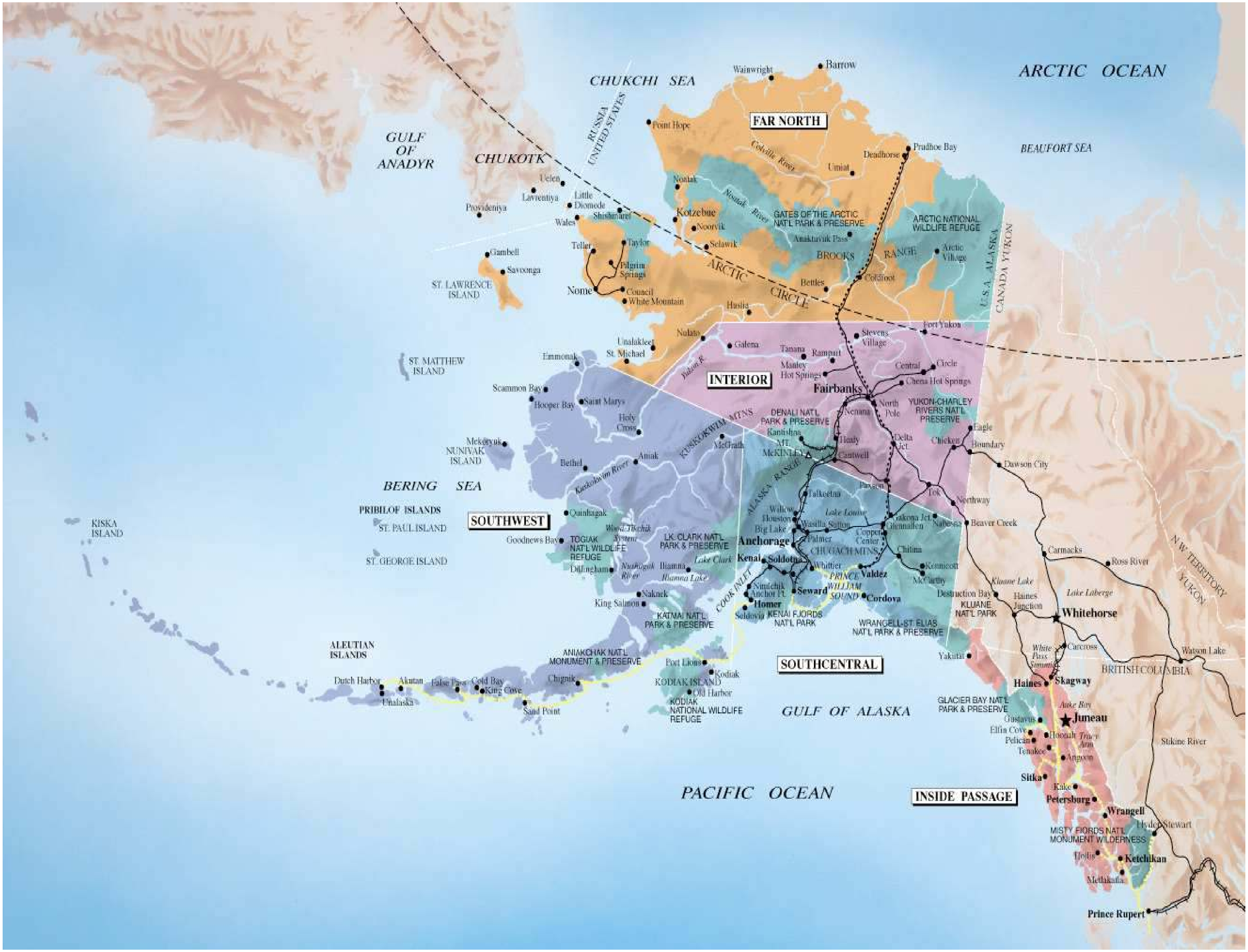
“ Americans can be counted on to always do the right thing –

but only after they have tried everything else ”

Winston Churchill

The dog caught the car.

Dan Reicher



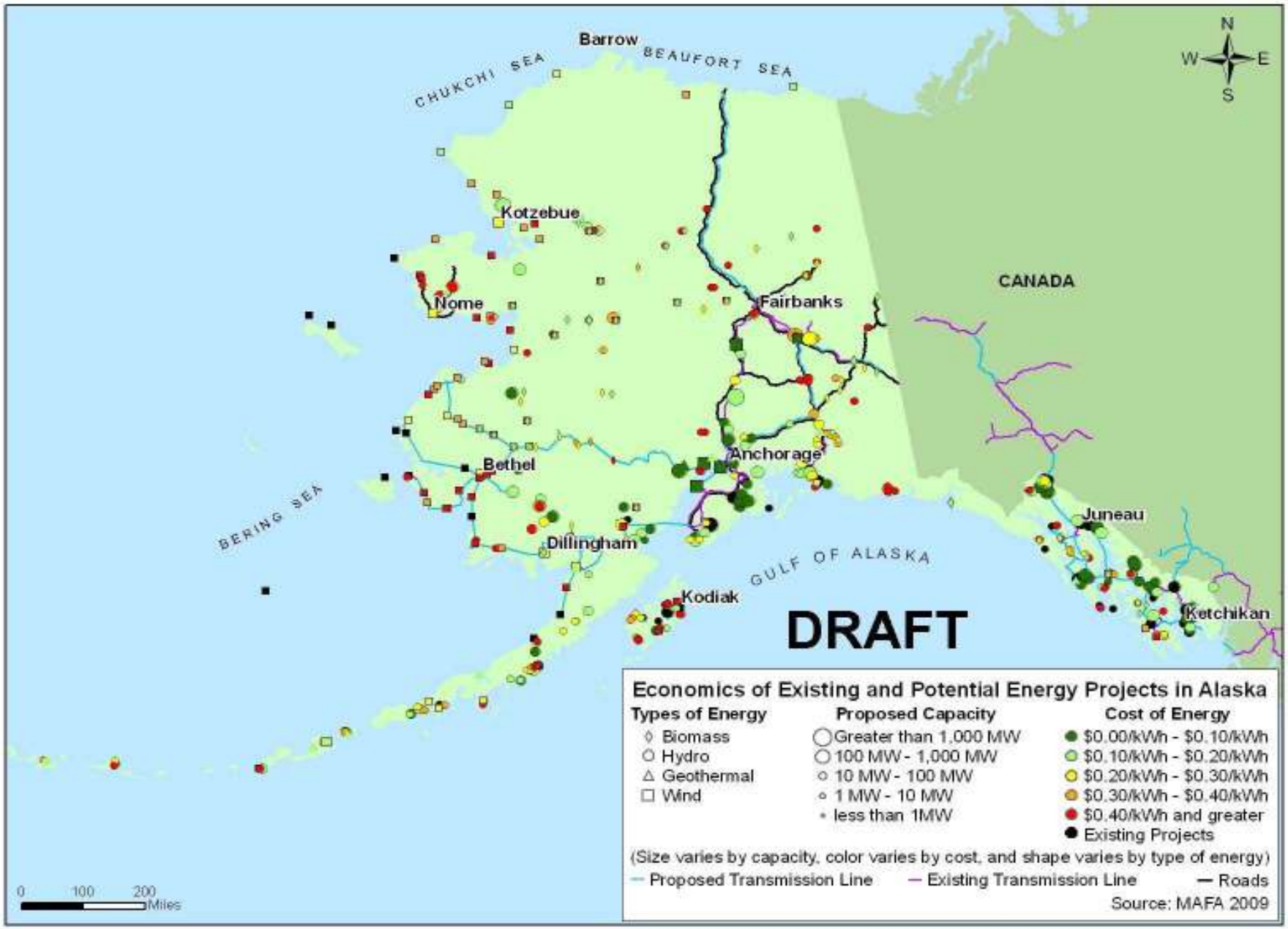
ARCTIC OCEAN
CHUKCHI SEA
BEAUFORT SEA
GULF OF ANADYR
CHUKOTK
RUSSIA
UNITED STATES
FAR NORTH
INTERIOR
SOUTHWEST
SOUTHCENTRAL
INSIDE PASSAGE
BERING SEA
GULF OF ALASKA
PACIFIC OCEAN
Barrow
Wainwright
Point Hope
Prudhoe Bay
Deadhorse
Colville River
Umiat
Noatak
Noatak River
Kotzebue
Noorvik
Selawik
GATES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

Proposed ANS* Gas Pipeline

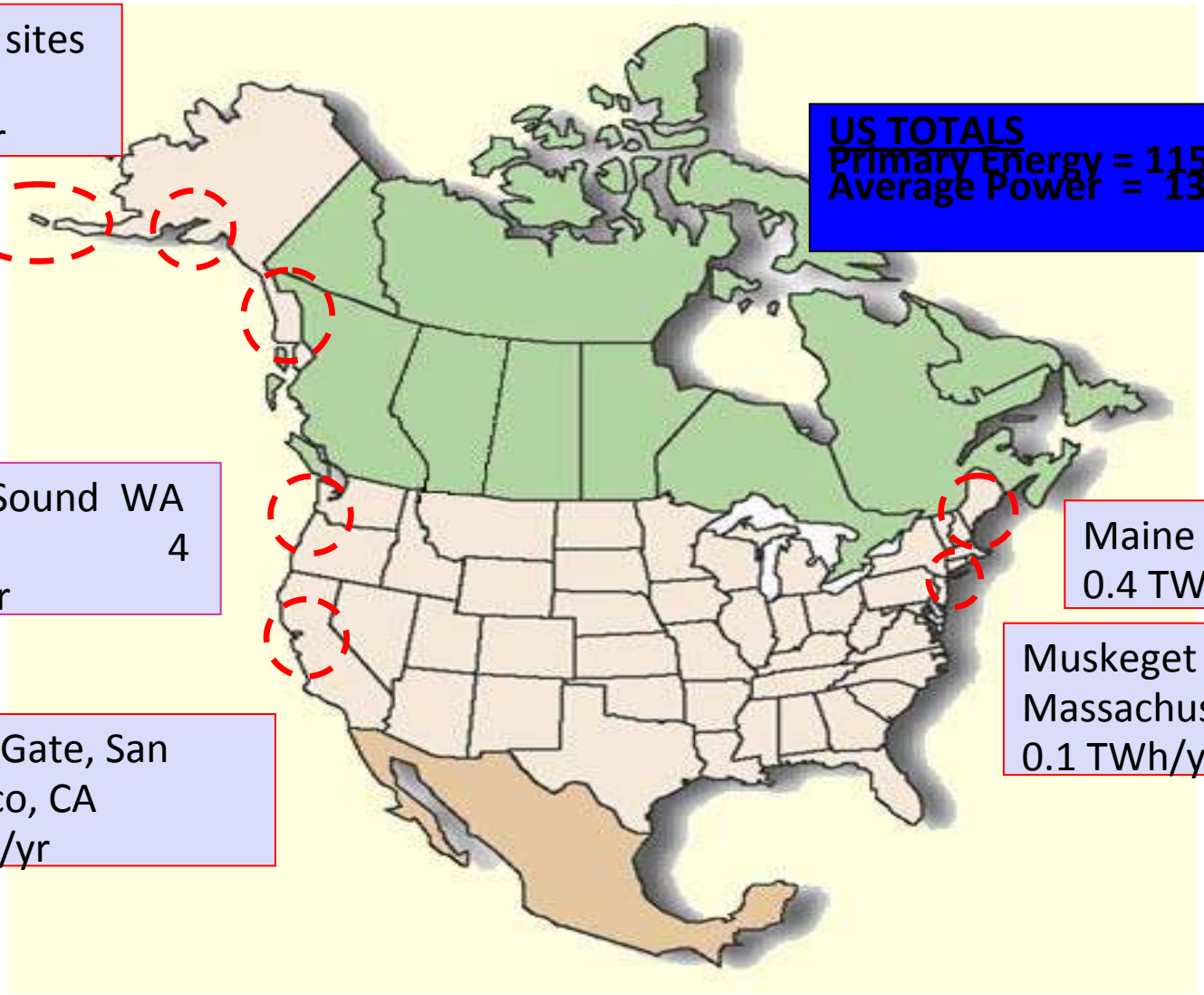
"ALCAN" Alaska Highway Route

TransCanada Pipelines

* Alaska North Slope


Barrow
CHUKCHI SEA
BEAUFORT SEA
N
W
E
S
Kotzebue
Nome
Fairbanks
CANADA
Anchorage
Bethel
BERING SEA
Juneau
Dillingham
GULF OF ALASKA
Kodiak
Ketchikan
DRAFT
Economics of Existing and Potential Energy Projects in Alaska
Types of Energy
Biomass
Hydro
Geothermal
Wind
Proposed Capacity
Greater than 1,000 MW
100 MW - 1,000 MW
10 MW - 100 MW
1 MW - 10 MW
less than 1MW
Cost of Energy
$0.00/kWh - $0.10/kWh
$0.10/kWh - $0.20/kWh
$0.20/kWh - $0.30/kWh
$0.30/kWh - $0.40/kWh
$0.40/kWh and greater
Existing Projects
(Size varies by capacity, color varies by cost, and shape varies by type of energy)
Proposed Transmission Line
Existing Transmission Line
Roads
Source: MAFA 2009
0
100
200
Miles

Tidal Current Energy



Many good sites in Alaska
109 TWh/yr

US TOTALS
Primary Energy = 115 Twh/yr
Average Power = 13,000 MW

Puget Sound WA
8 sites 4
TWh/yr

Maine 7 Sites
0.4 TWh/yr

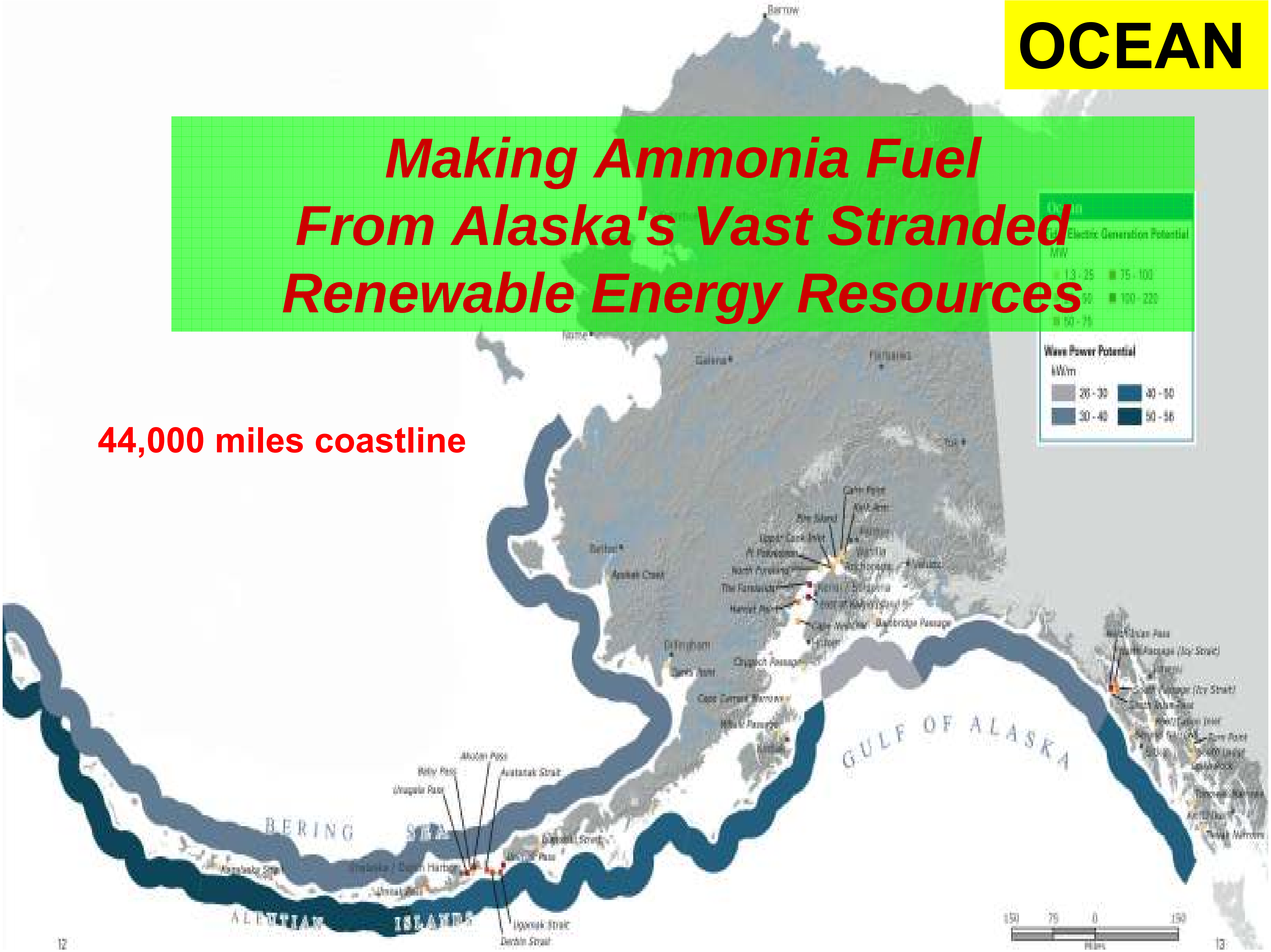
Muskeget Channel
Massachusetts
0.1 TWh/yr

Golden Gate, San Francisco, CA
<2 TWh/yr

OCEAN

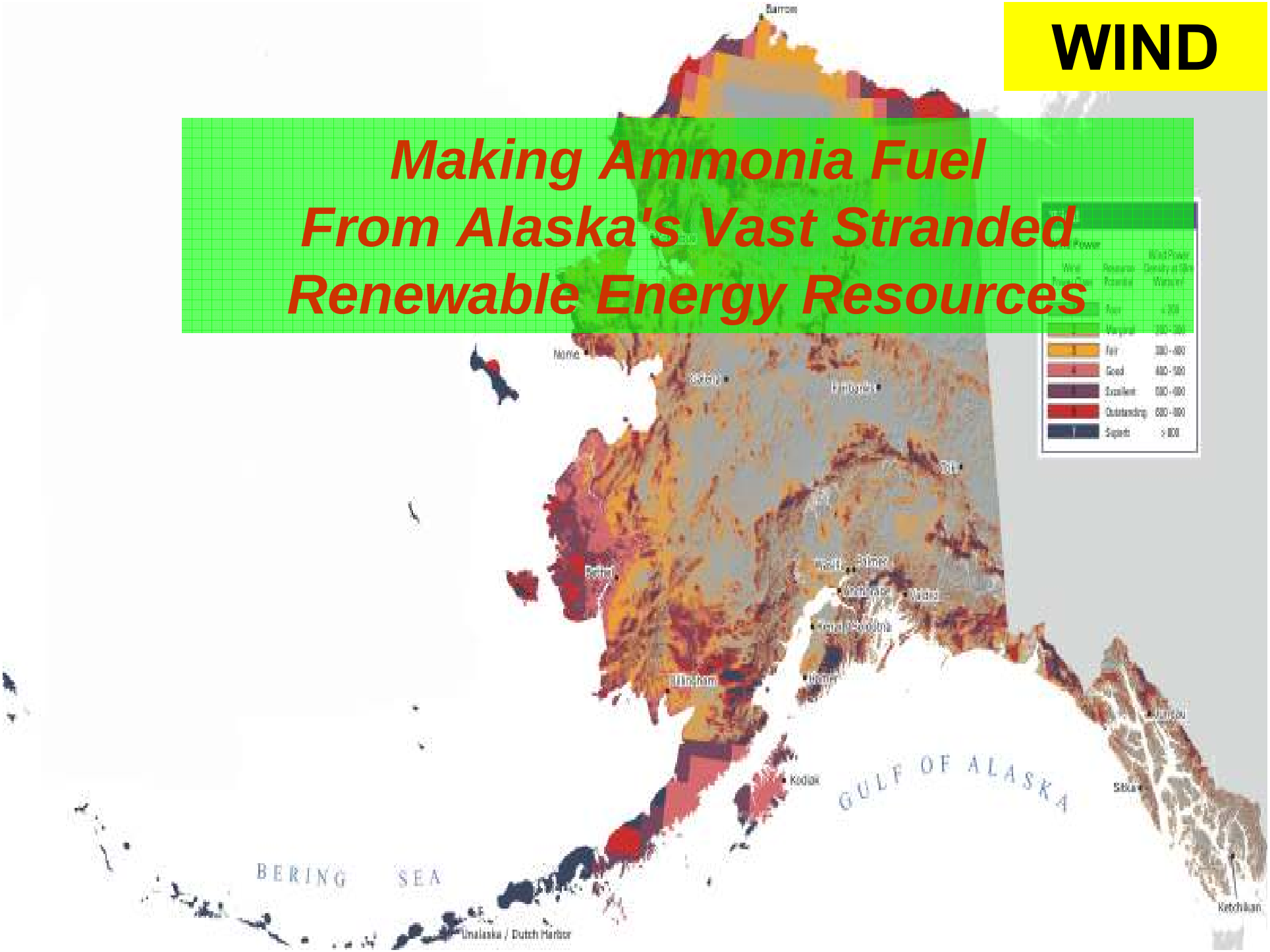
Making Ammonia Fuel From Alaska's Vast Stranded Renewable Energy Resources

44,000 miles coastline



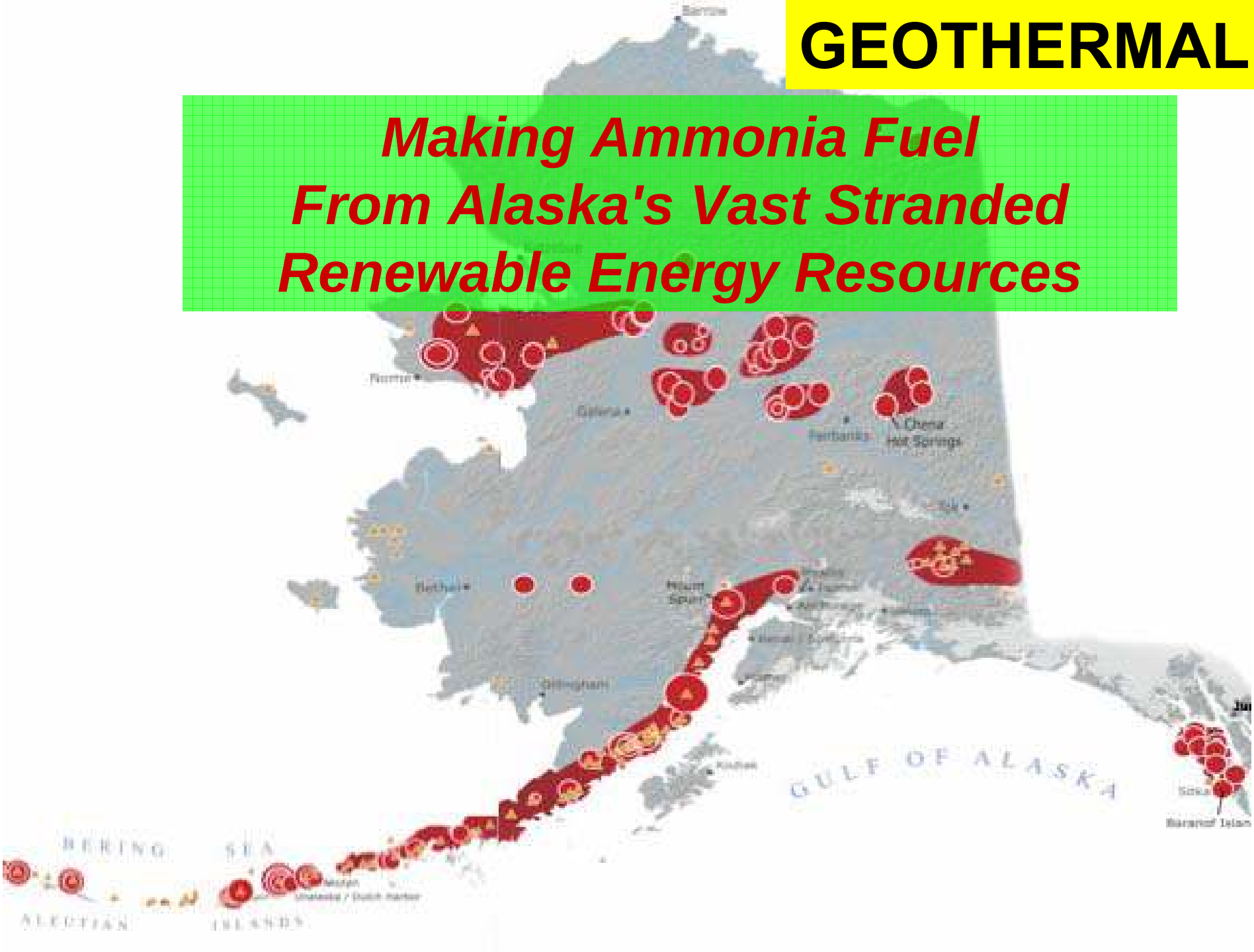
WIND

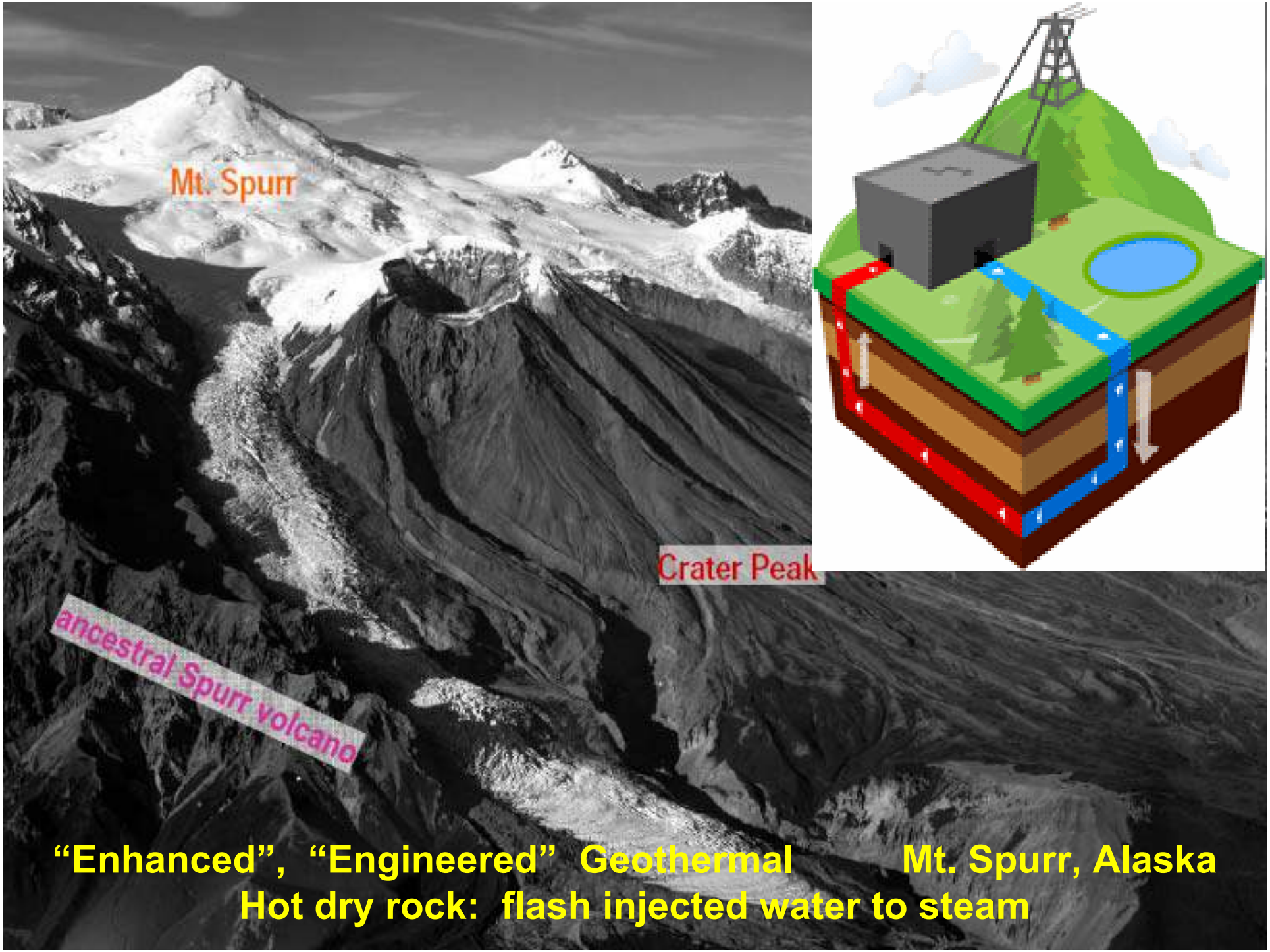
Making Ammonia Fuel From Alaska's Vast Stranded Renewable Energy Resources



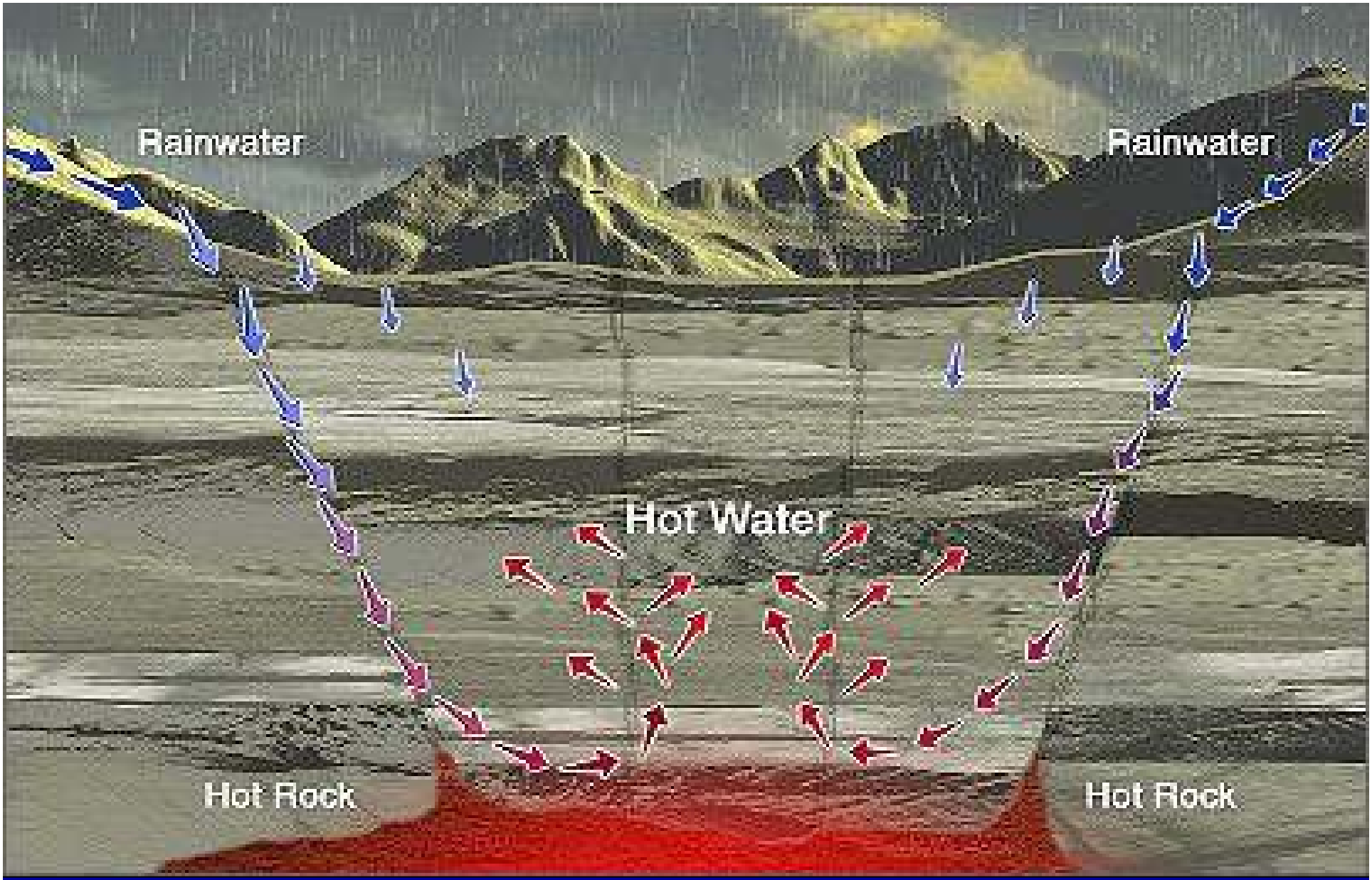
GEOTHERMAL

Making Ammonia Fuel From Alaska's Vast Stranded Renewable Energy Resources





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



Geothermal: hot water, surface recharge

Alaska

- 650,000 pop
- Railbelt:
  - 60% pop
  - Only “grid”
- 200 “villages”
- 100+ with good RE
- Energy islands
- 44,000 miles coast > all other states
- Other Renewables Unknown:
  - Solar
  - Instream kinetic (rivers)
  - Biomass


180°0'0"
170°0'0"
160°0'0"
150°0'0"
140°0'0"
130°0'0"
120°0'0"
70°0'0"
60°0'0"
NORTHERN ALASKA-NORTH SLOPE COAL PROVINCE
Beaufort Sea
ARCTIC OCEAN
ALASKA
CANADA
12% world coal
CENTRAL ALASKA-NENANA COAL PROVINCE
SOUTHERN ALASKA-COOK INLET COAL PROVINCE
Gulf of Alaska
EXPLANATION
Coal rank in coal fields
Anthracite
Bituminous
Lignite
Subbituminous
Coal fields
0 62 125 250 375 500 MILES
0 90 180 360 540 720 KILOMETERS
USGS
science for a changing world

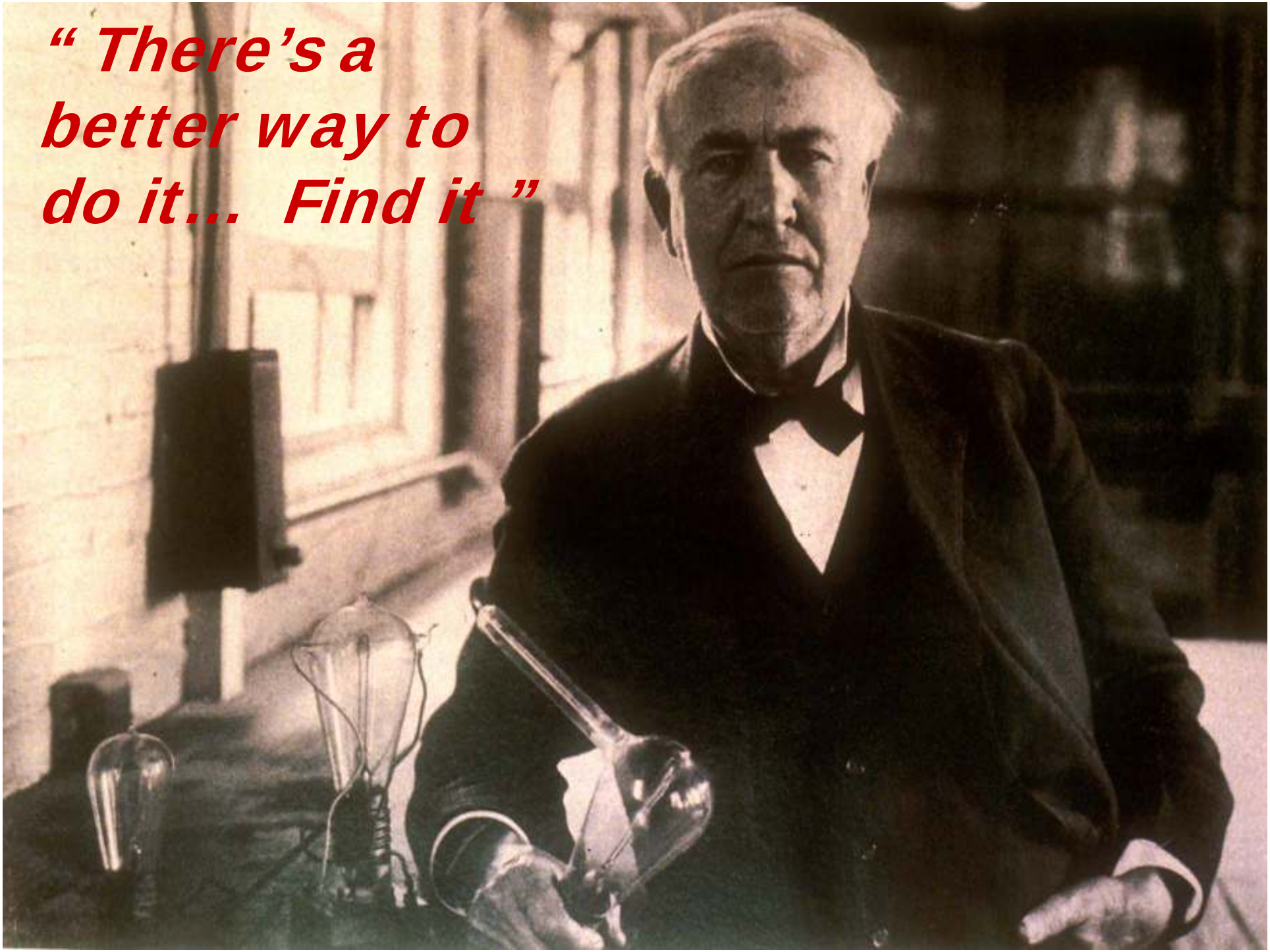
Alaska Business Opportunities: RE – NH3 "Green" Ammonia

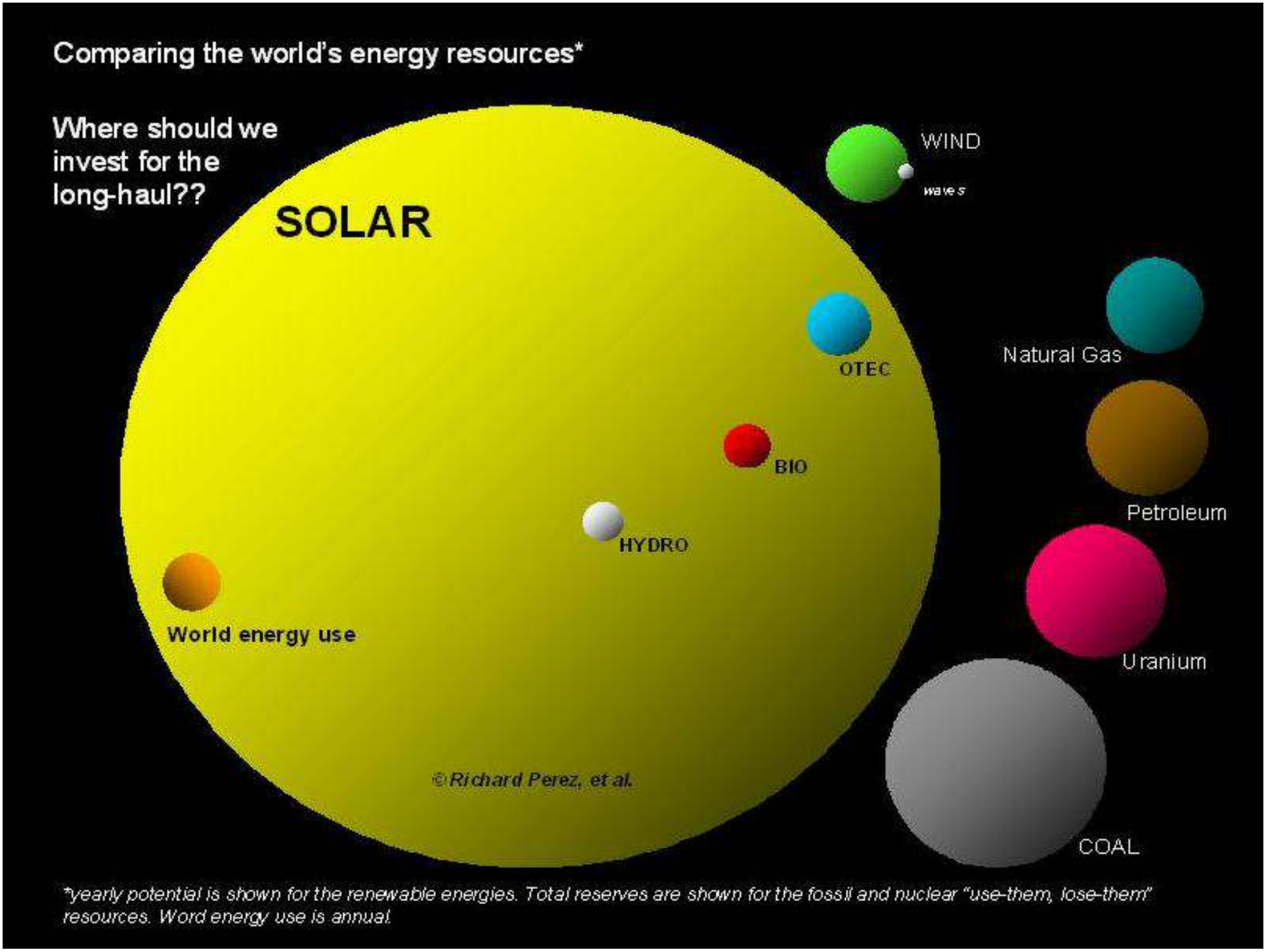
Monetizing Alaska's vast RE

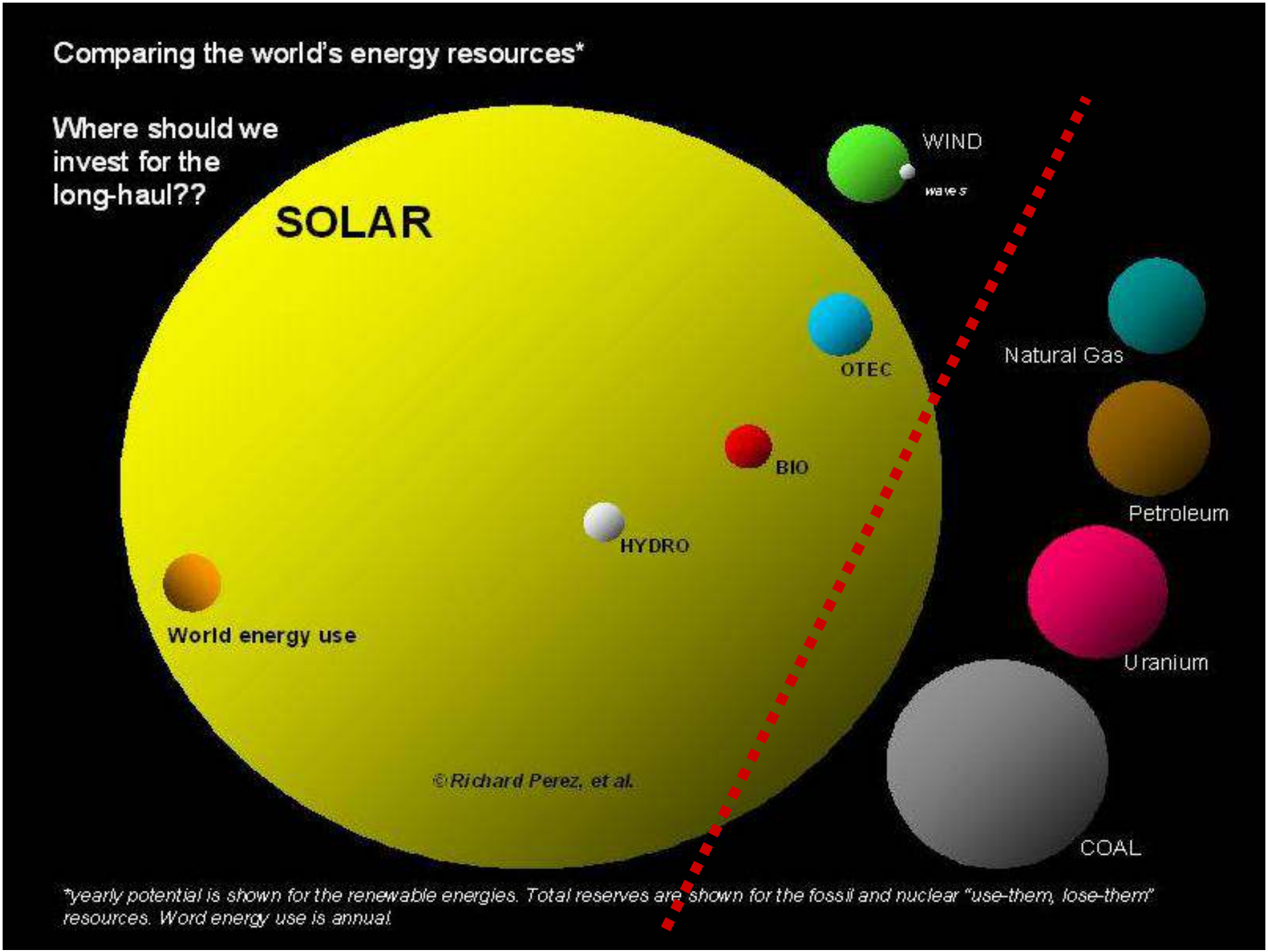
1. **Export from GW-scale RE: Increase cash IN**
2. **Village energy "independence"**
   - **Indigenous renewables; diverse**
   - **Seasonal, diurnal variability**
   - **Storage as NH3: pressurized tanks**
   - **Reduce cash OUT**

Alaska Business Opportunities: Business is About Cash Flow

- **Maximize cash IN**
- **Minimize cash OUT**
- **Short, long term NCF, IRR, NPV**
- **Enterprises:**
  - **State, Communities**
  - **People of Alaska**
  - **Capital Investors**


“ There’s a
better way to
do it… Find it ”


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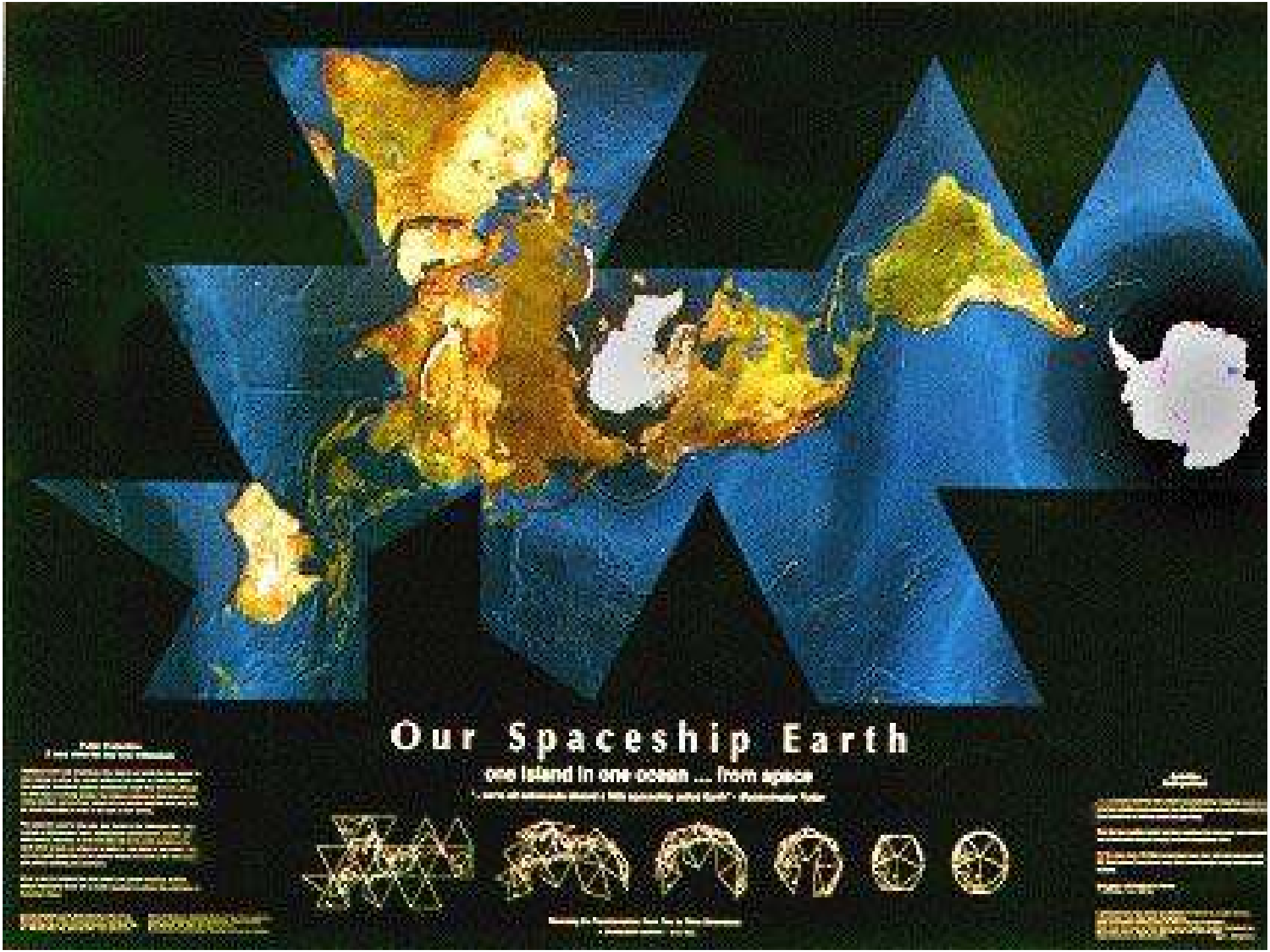
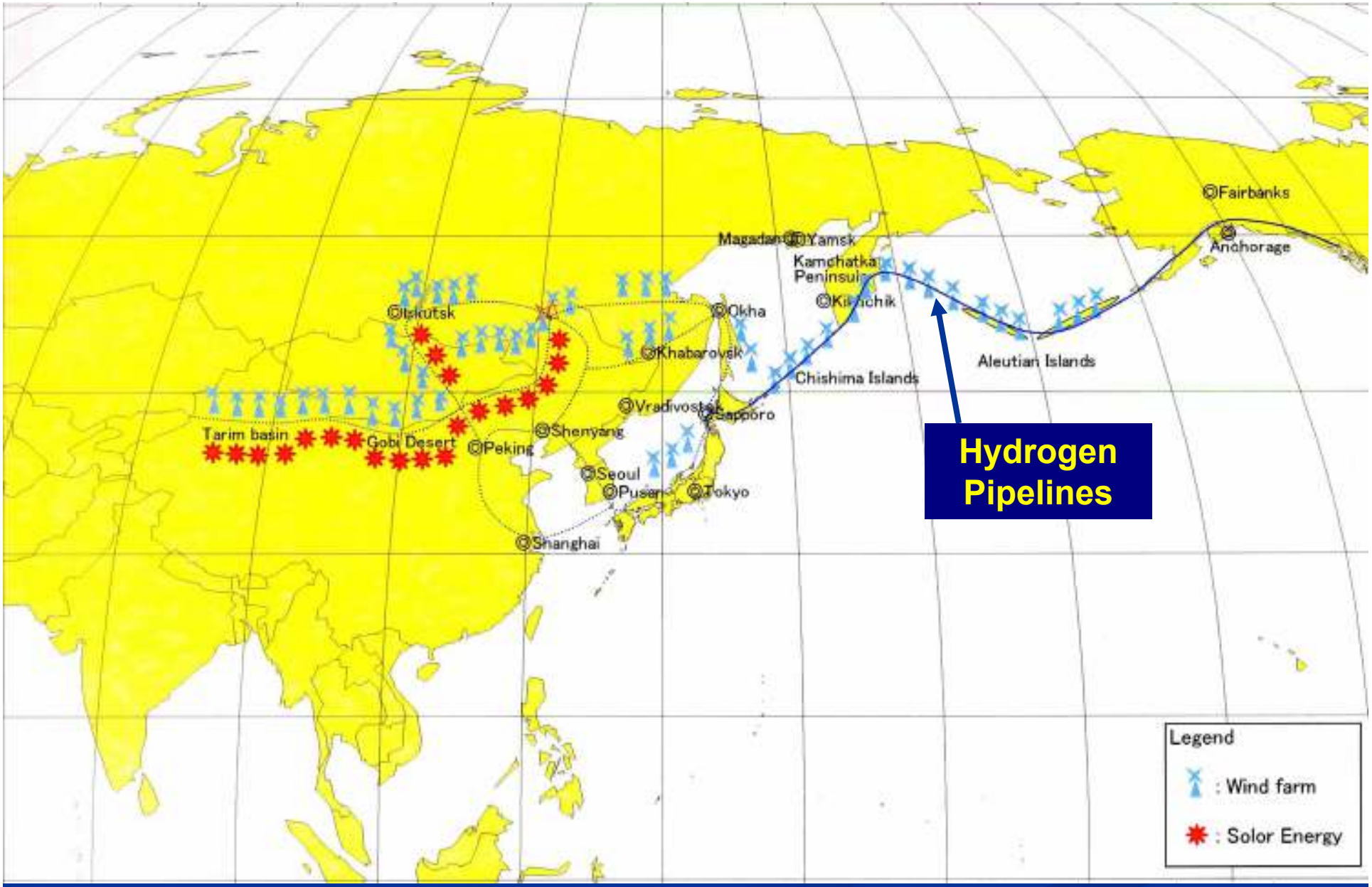
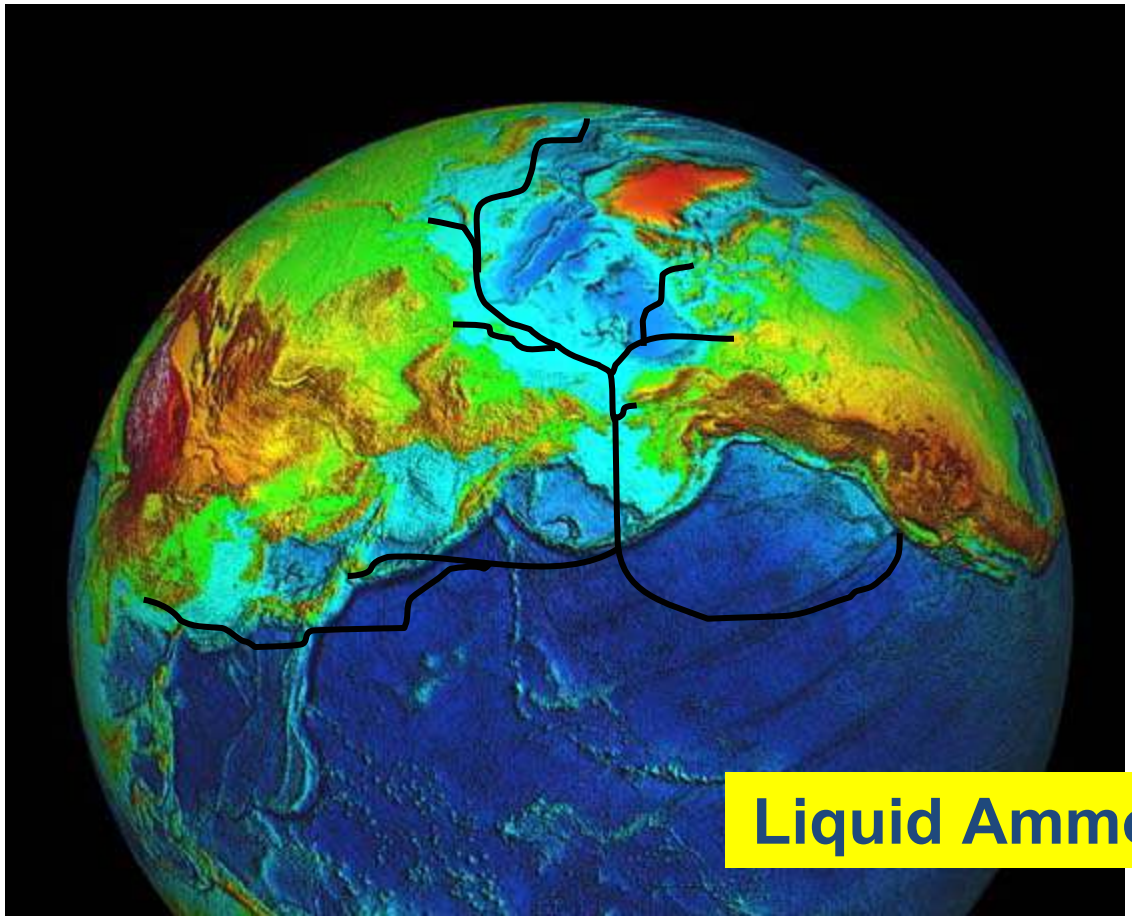

Our Spaceship Earth
one island in one ocean ... from space



Map by K. O'Hashi, Nippon Steel

Alaska in the future global energy economy

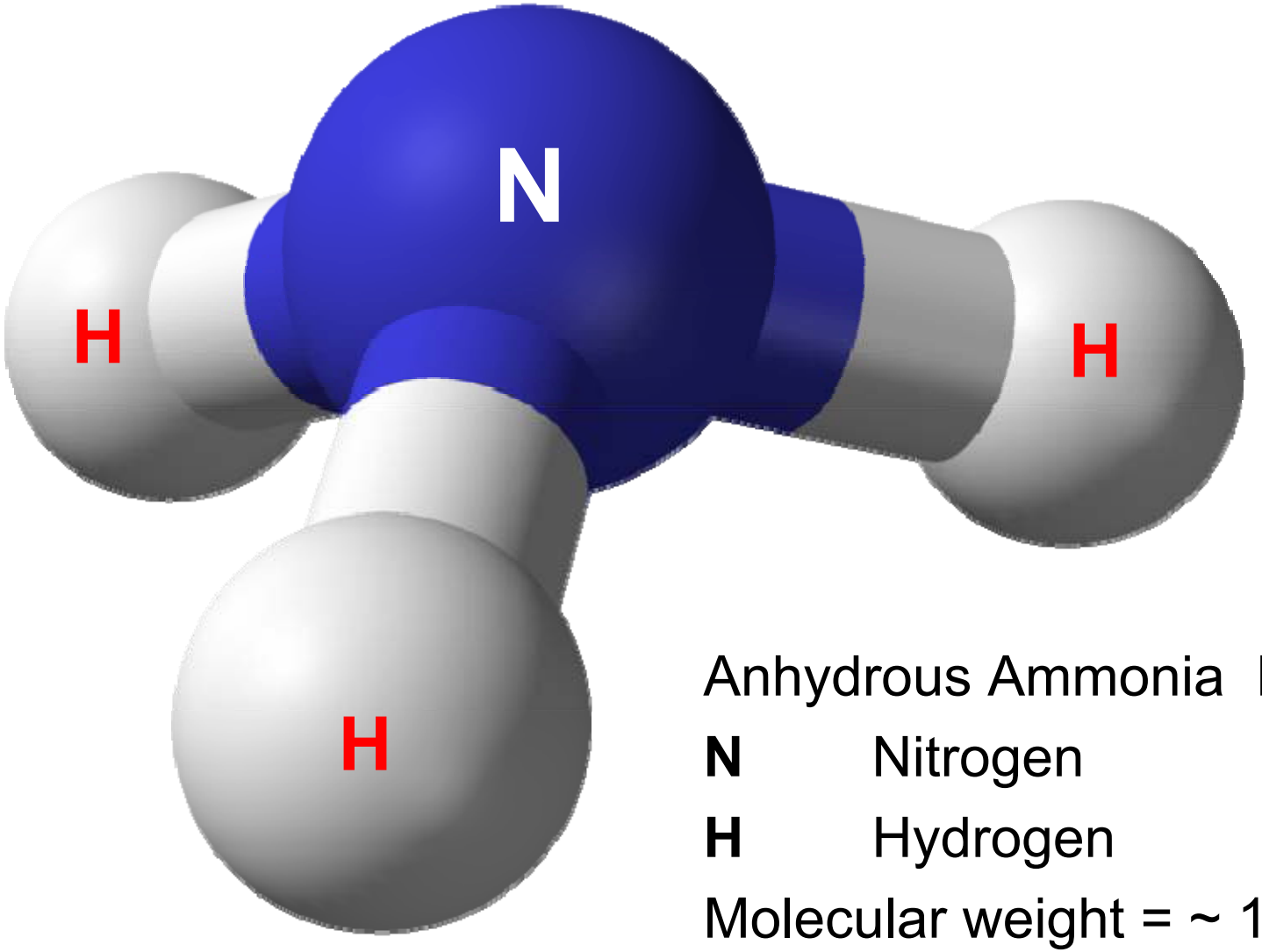


ACEP

Why Ammonia ?
Fertilizer and Fuel

Only liquid fuel embracing:

- Energy cycle inherently pollution free
  - Potentially all RE-source: elec + water + Nitrogen
  - Cost competitive with hydrocarbon fuels ?
- Carbon-free: clean burn or conversion; no CO_2
  - Excellent hydrogen carrier; easily “cracked” to H_2
  - Reasonably high energy density
- 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



Anhydrous Ammonia **NH_3**

N Nitrogen

H Hydrogen

Molecular weight = ~ 17

18% **H** by weight: “other hydrogen”

$NH_3 + O_2 = N_2 + H_2O$

Ammonia
534 kg H2
EACH

Hydrogen gas
350 kg H2

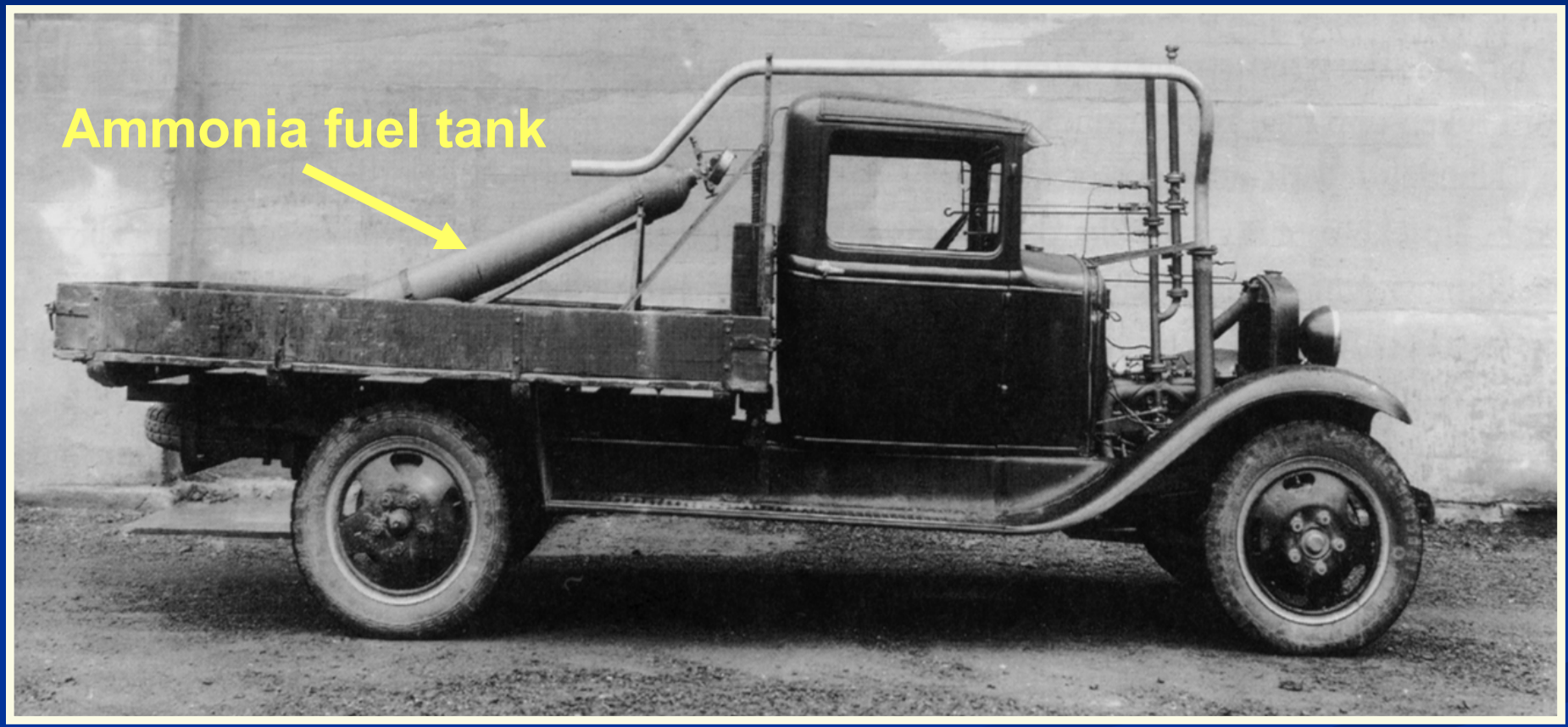
Streetcar

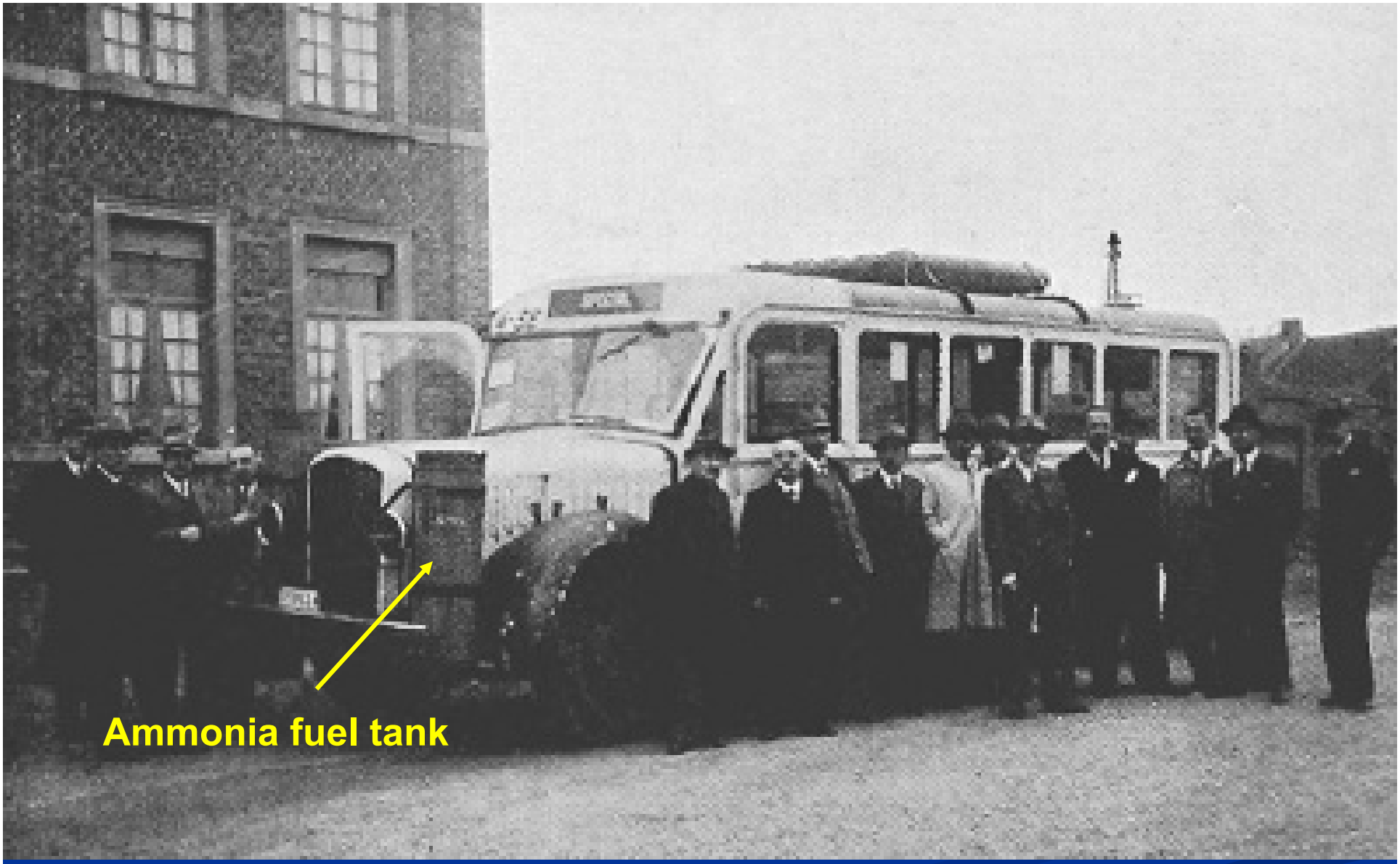
New Orleans

1871

“Ammoniacal Gas Engine”

Ammonia fueled – Norway 1933





Belgium, 1943

Ammonia Fueled Bus: Thousands of Problem-free Miles

X-15 rocket plane: NH3 + LOX fuel

Mach 6.7 on 3 Oct 67

199 missions between 1959 and 1968

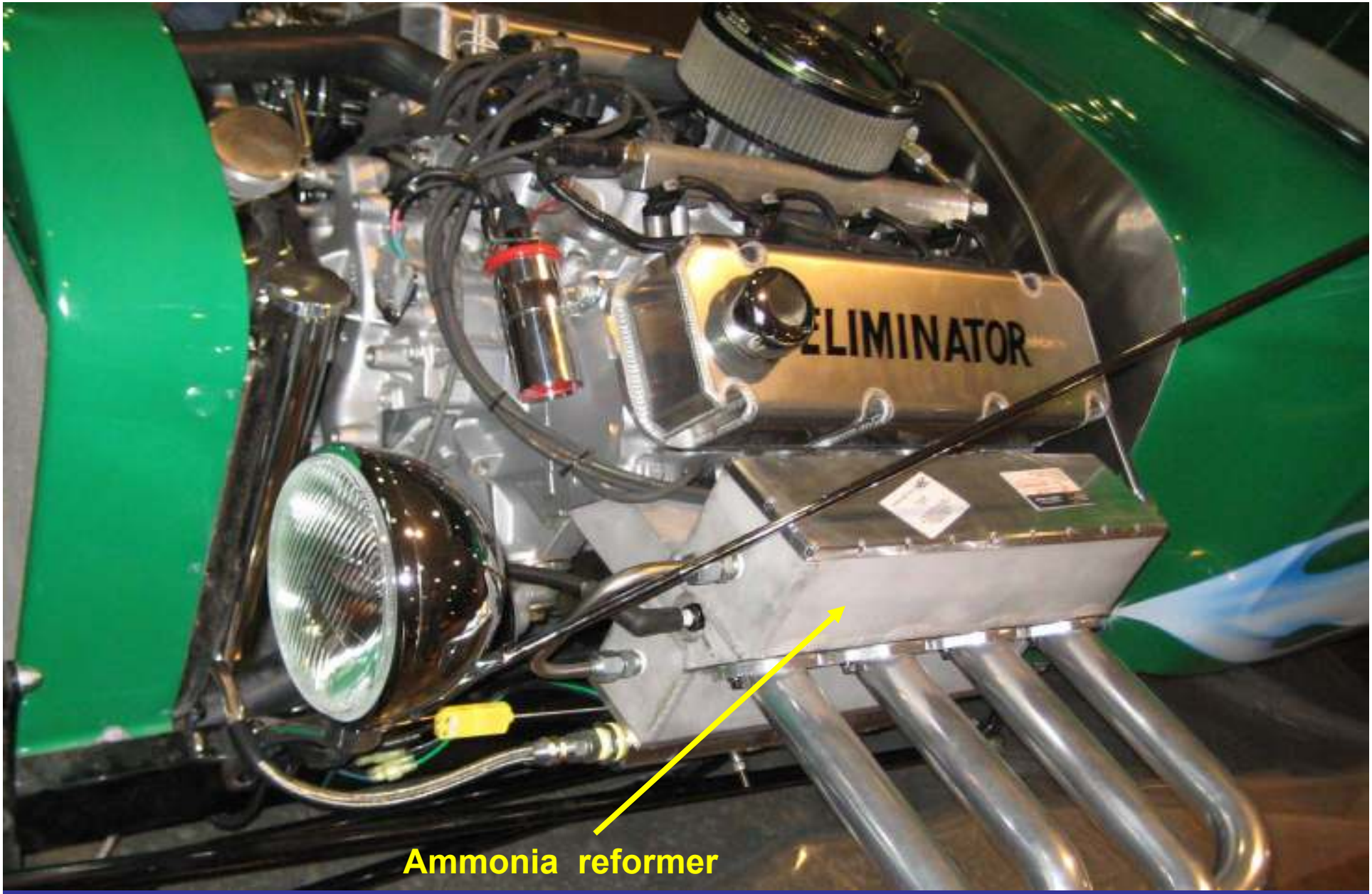
University of Michigan

Ammonia + Gasoline Powered

- Idle: gasoline
- Full power: 80% ammonia

Summer ’07 Detroit → San Francisco

'08: 1,000 hours, ICE, 6 cyl, 100 hp
75% ammonia, 25% propane



Oct ’09 Ammonia Fueled V-8 with Hydrogen Injection: Reformed from NH_3
Hydrogen Engine Center, Algona, IA

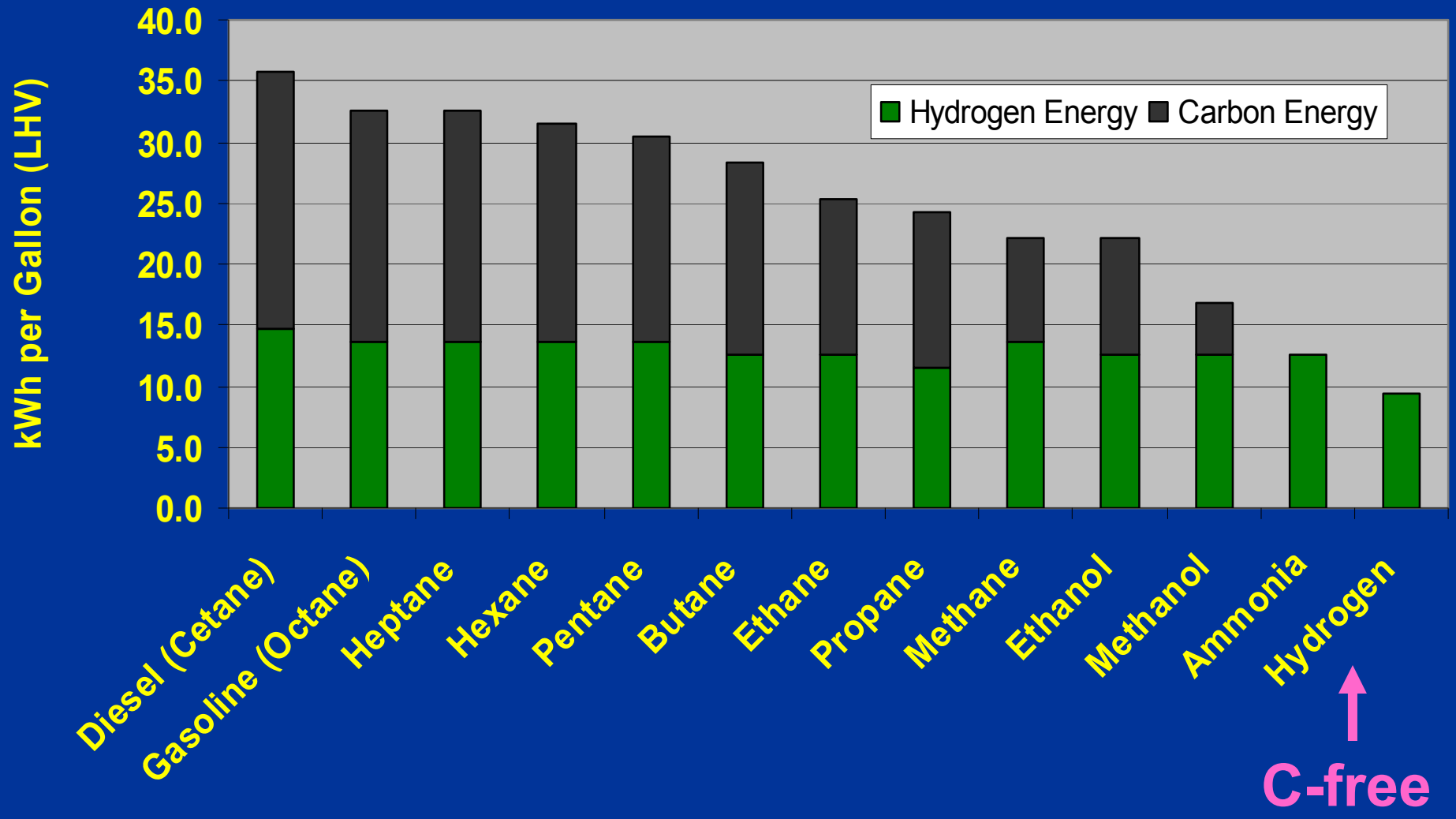
Ammonia Fuel Uses

- 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
- Combustion Turbines
- Direct Ammonia Fuel Cells:
  - Combined heat + power (CHP)
  - No NOx
- Reform ("crack") to liberate hydrogen for fuel cells: $2NH_3 \rightarrow 3H_2 + N_2$

Ammonia Properties

- C-free fuel: unique physical, chemical properties
- Carbon-free energy cycle, system
- # 2 global industrial chemical trade
- 95%+ from stranded natural gas
  - ~ $1.00 / MMbtu
  - Trinidad, Australia, Quatar, Algeria, Russia
  - Other from coal gasification → hydrogen + Haber-Bosch
- Liquid at >125 psi at room temperature
- ~ Half energy density gasoline or diesel,
  volume or weight
- Easily "cracked" to H_2 + N_2 at end-use
- Low flammability, flame spread

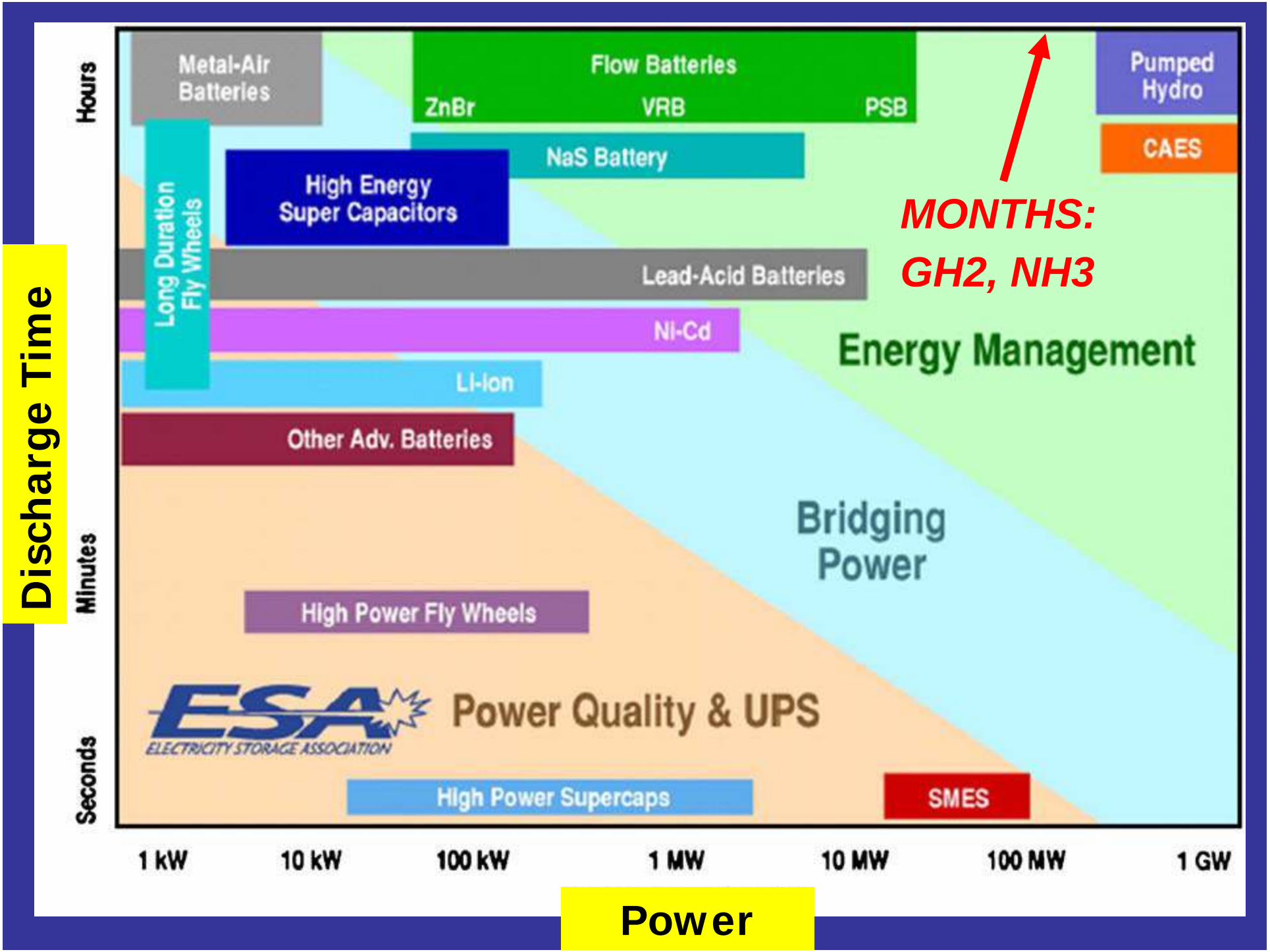
Volumetric Energy Density of Fuels
(Fuels in their Liquid State)

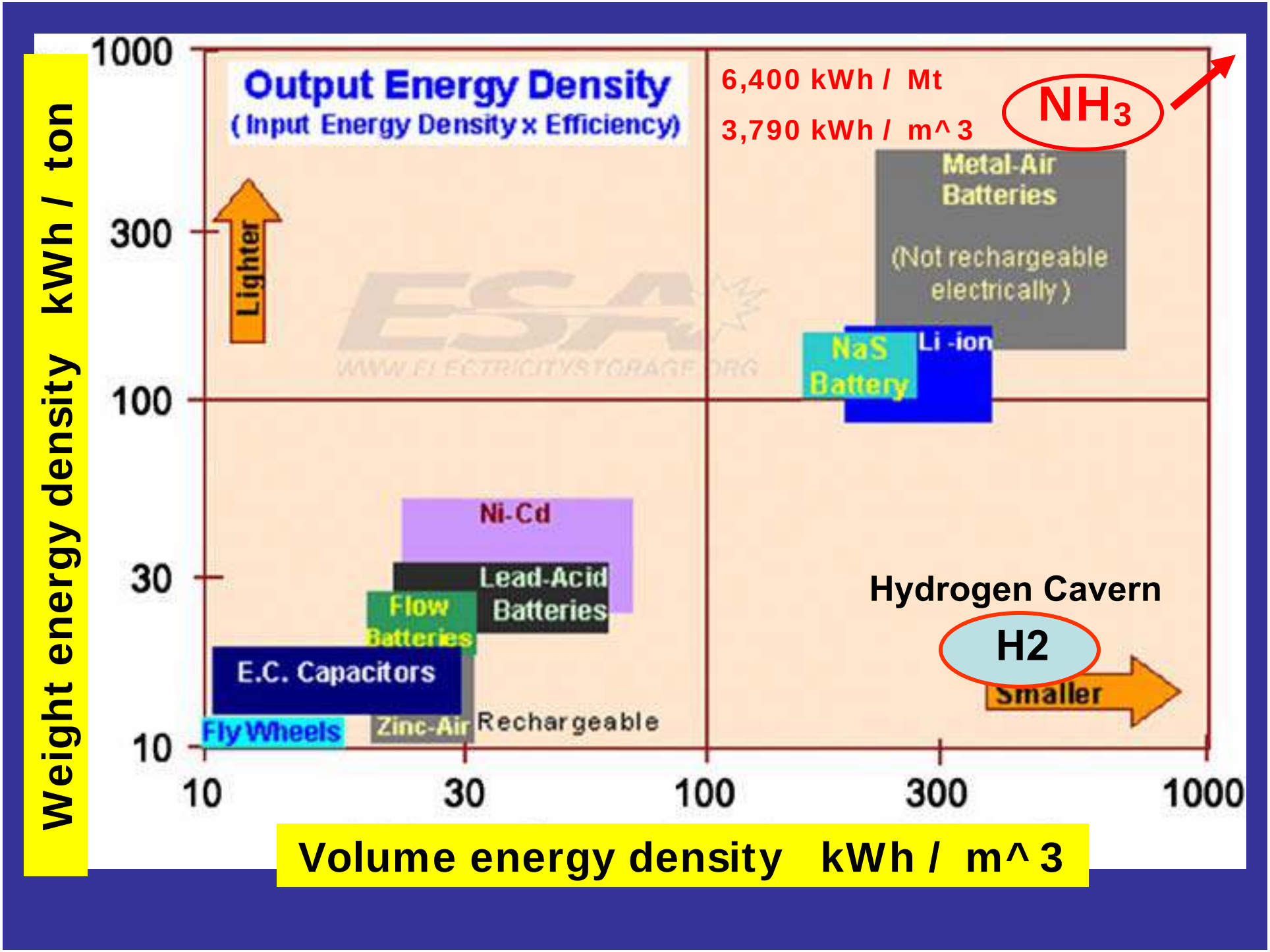


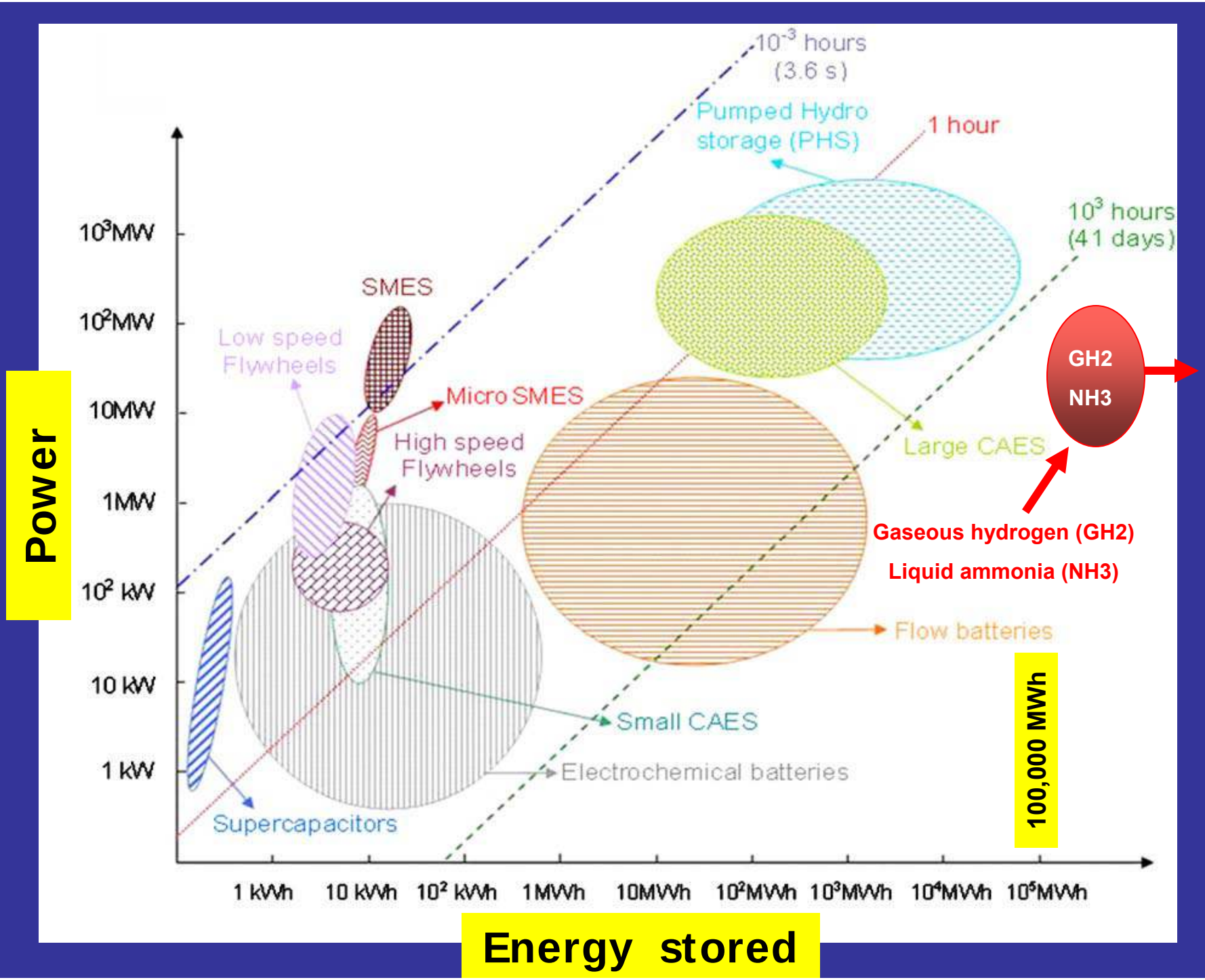
Ammonia Properties

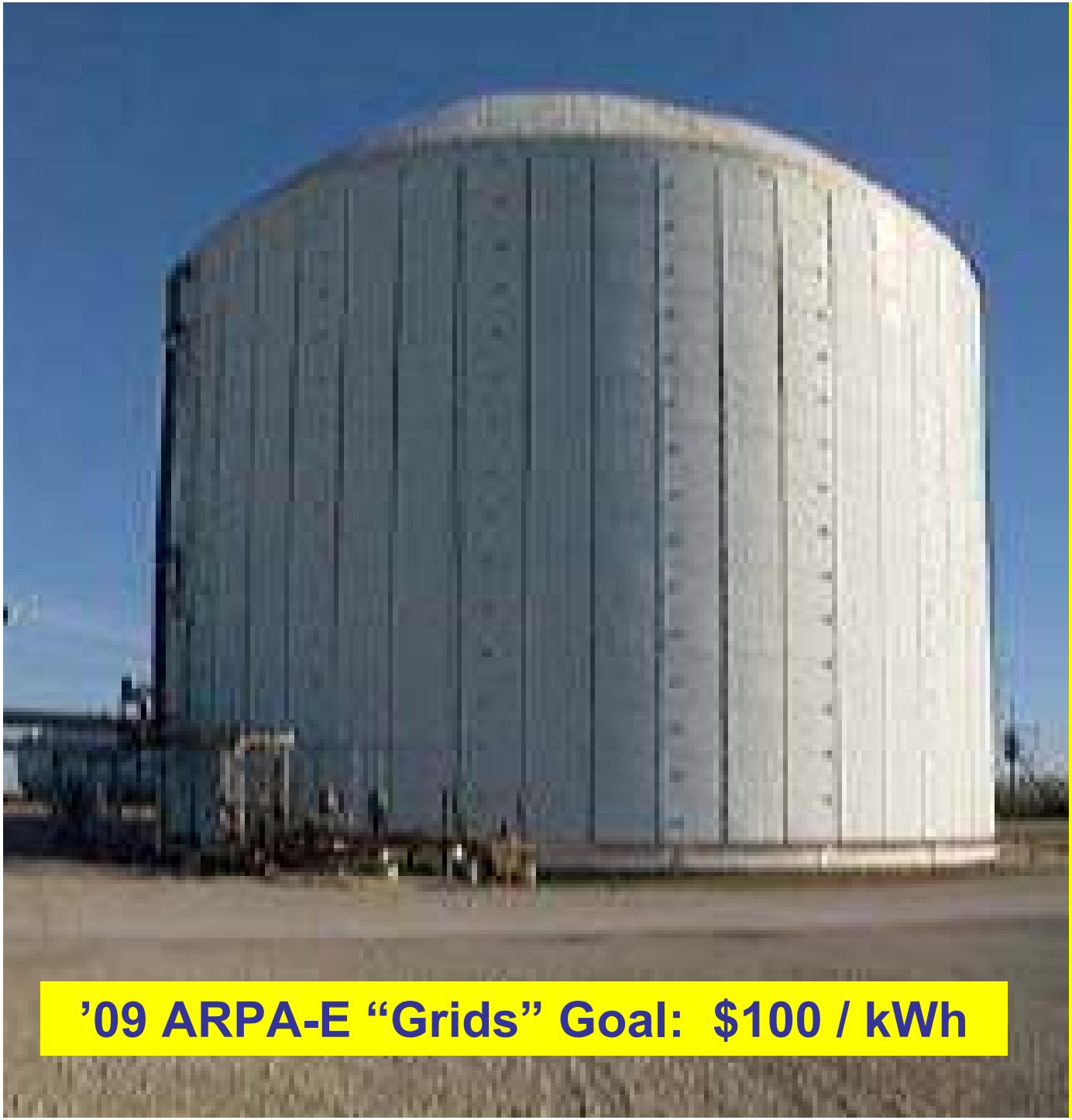
- Forms:
  - "Anhydrous" NH_3 : useful as fuel
  - Urea: (2) NH_3 + CO_2
  - Ammonium nitrate: NH_4NO_3
  - UAN: aqueous urea + ammonium nitrate
- Decades infrastructure + safety record

  ~14 MMt / year in USA, mostly fertilizer
  - Inhalation hazard; detected @ 5 ppm
  - OSHA, NIOSH regs + exposure limits
  - Toxic to aquatic life


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
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


Weight energy density kWh / ton
1000
300
100
30
10
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
10
30
100
300
1000
Volume energy density kWh / m^3


Power
10^3MW
10^2MW
10MW
1MW
10^2 kW
10 kW
1 kW
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
100,000 MWh
1 kWh
10 kWh
10^2 kWh
1MWh
10MWh
10^2MWh
10^3MWh
10^4MWh
10^5MWh
Energy stored



’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

"Firm" Energy Essential

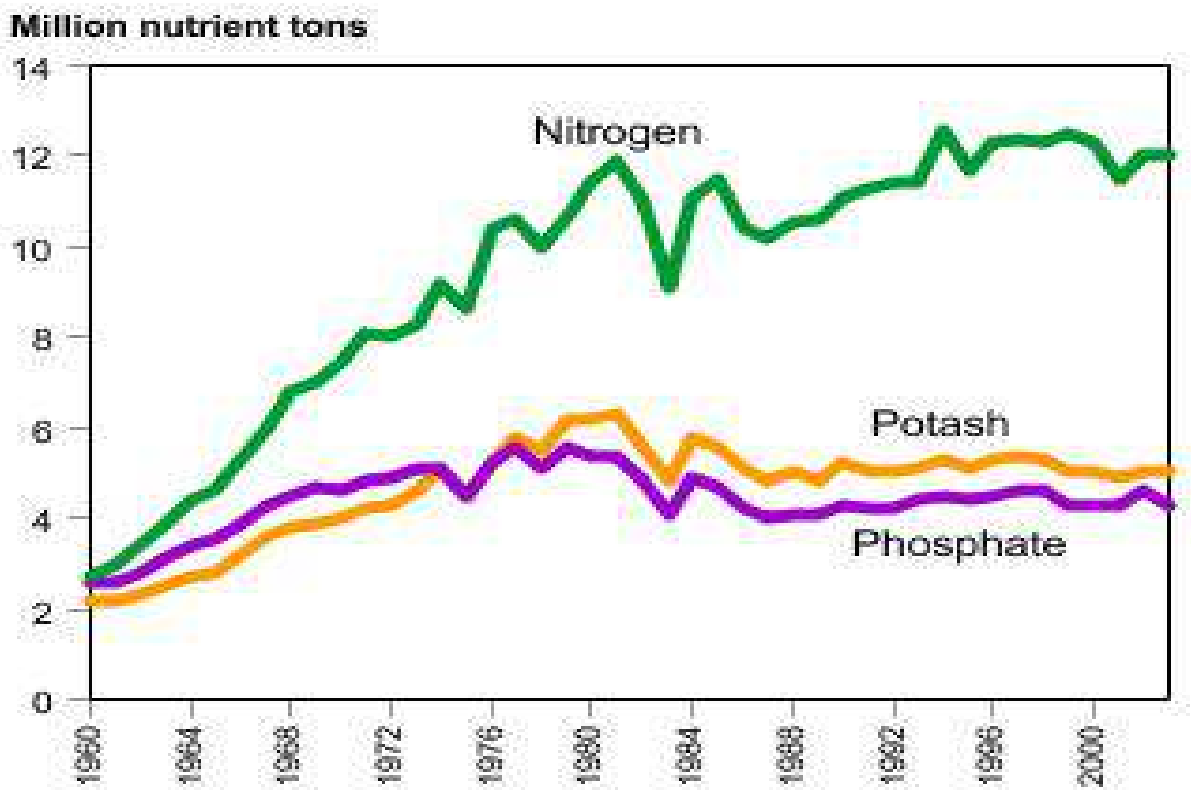
- **Rural Alaska, Islands, Humanity**
- **Every hour, every year**
- **Dispatchable**
- **Strategically: indigenous, secure**
- **Market price: worth more**
- **Bankable large projects**
- **Risk avoidance:**
  - **Rapid climate change**
  - **Death**

Alaska Business Opportunities: RE – NH3 = "Green" Ammonia

1. **Export GW-scale RE: Increase cash IN**
2. **Energy "independence": Reduce cash OUT**
   - **Villages, communities**
   - **Indigenous renewables; diverse**
   - **Seasonal, diurnal variability**
   - **Storage as NH3 in pressurized tanks**
   - **"Firm" energy**

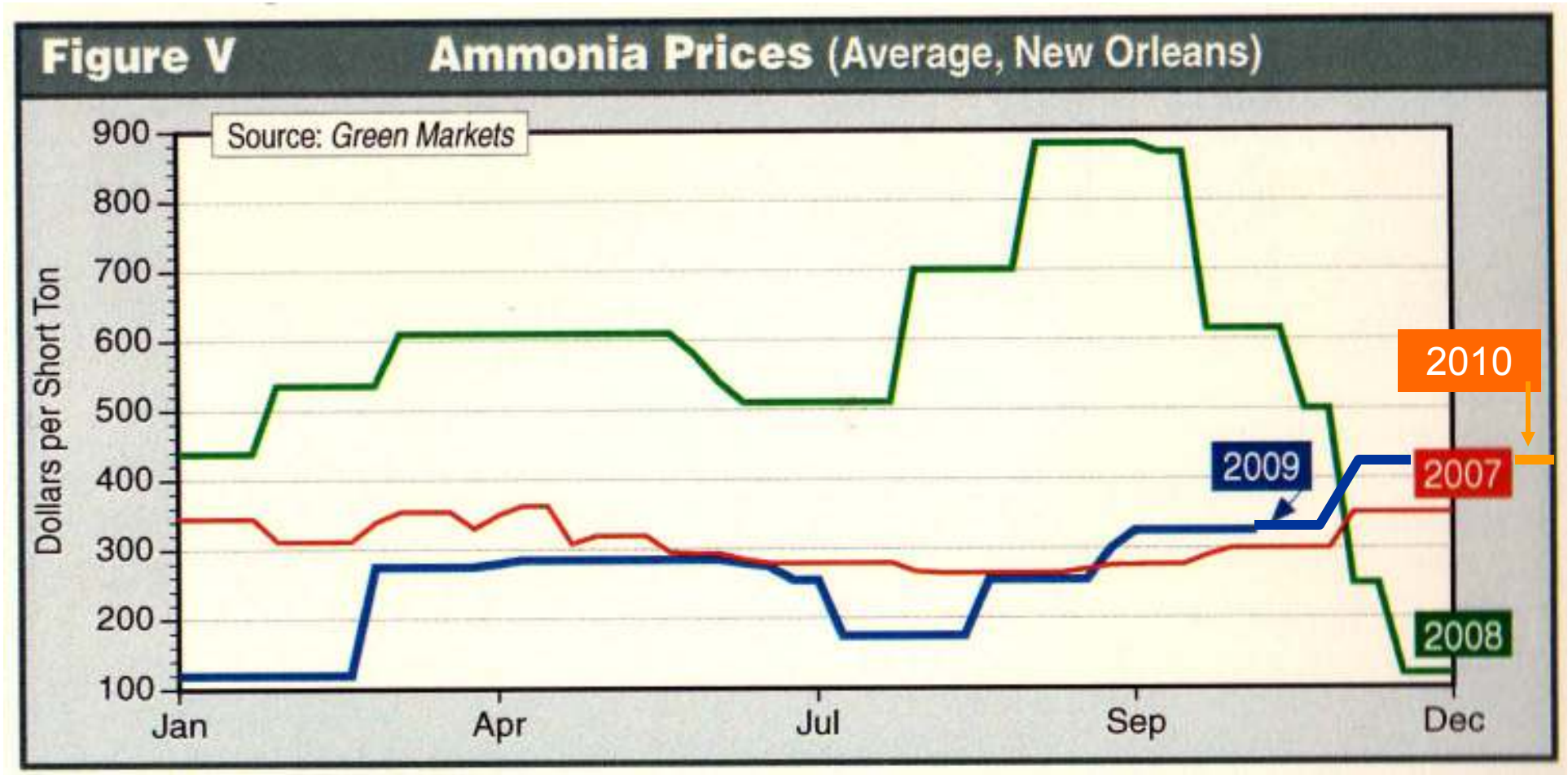
Expect N-Fertilizer Consumption to Rise:
World Food Supply

Figure 4.4.2--Consumption of primary plant nutrients, 1960-2003

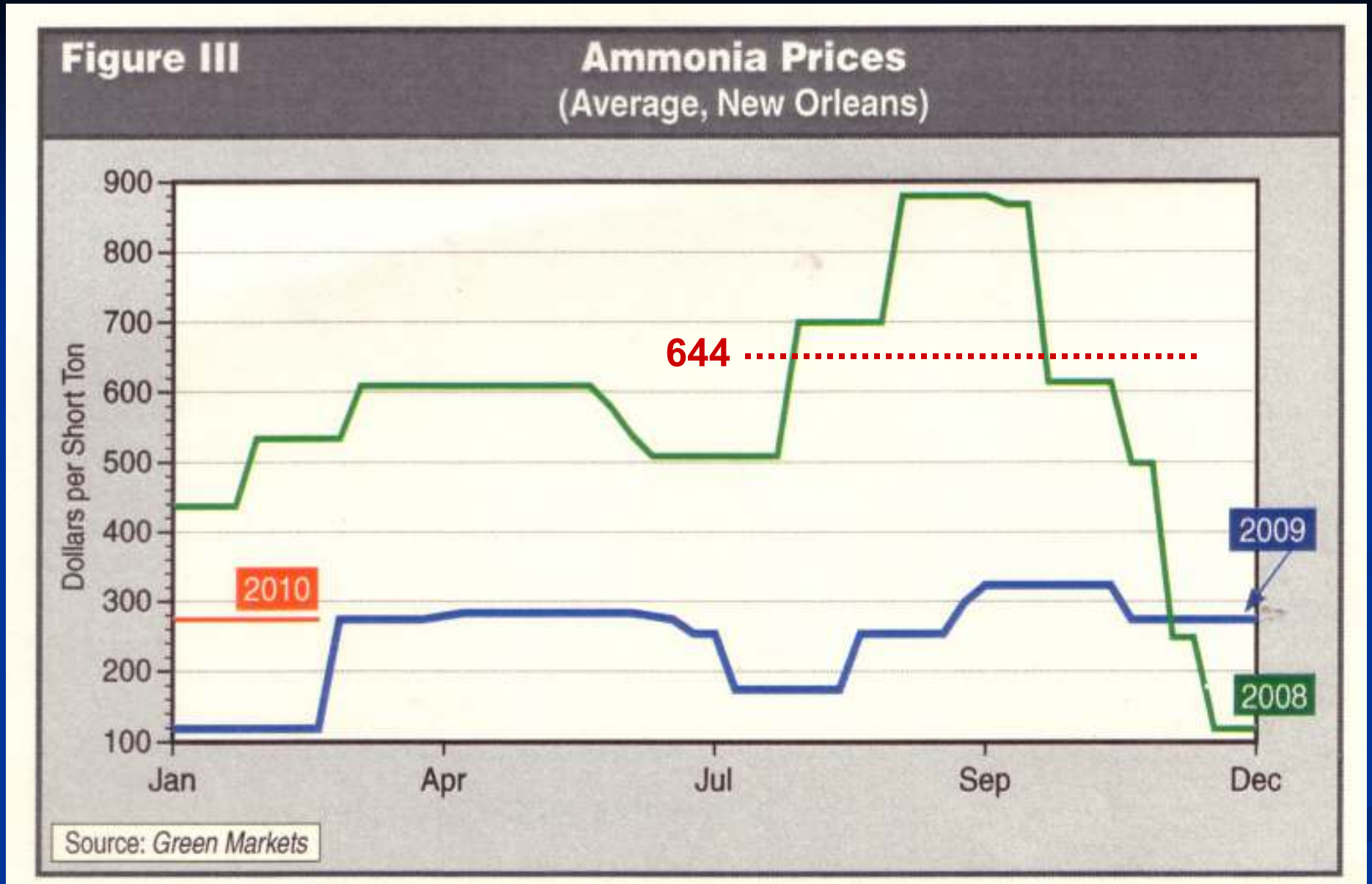


40% of humanity requires Haber-Bosch synthetic N-fertilizers

ERS

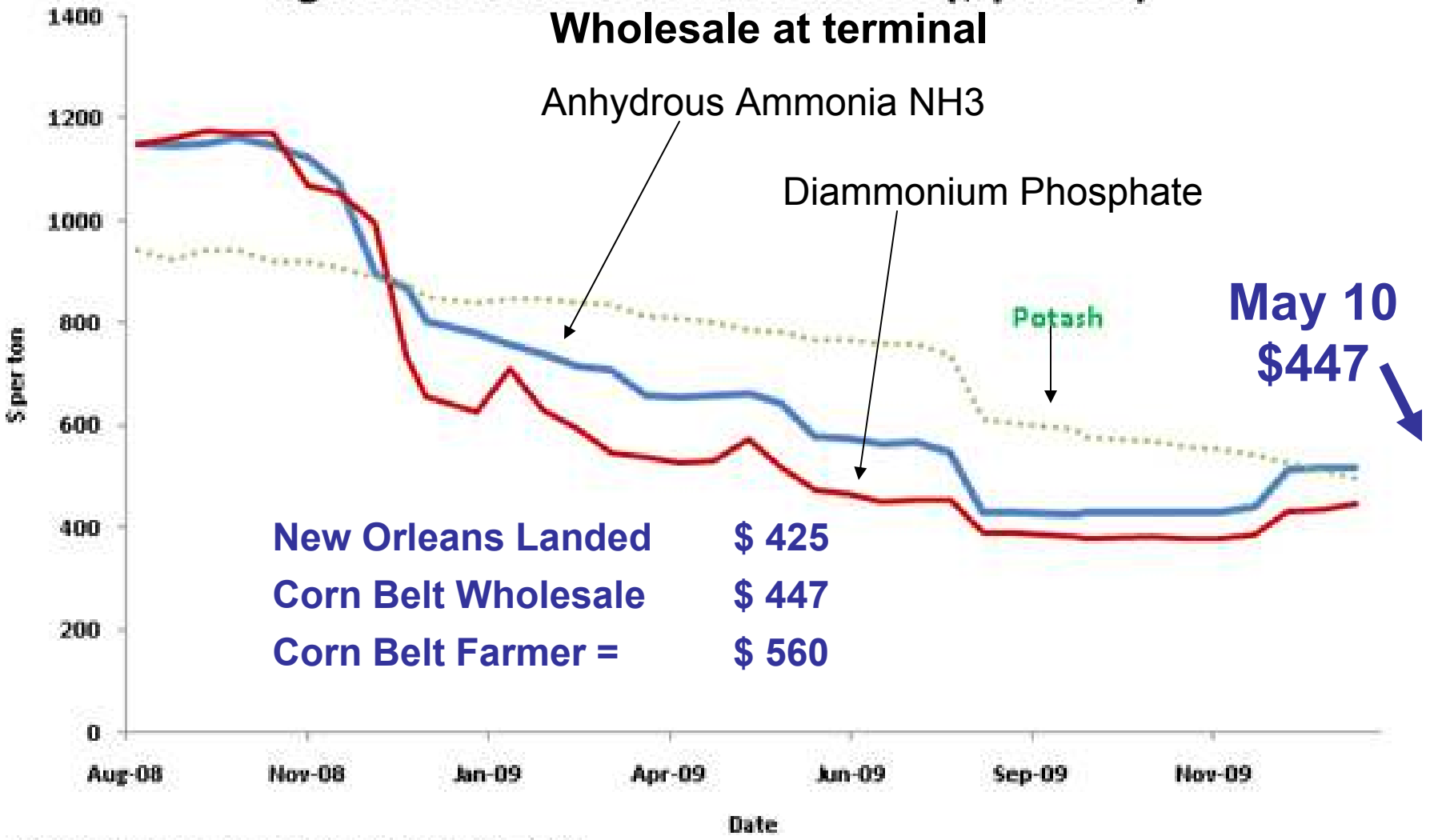


Anhydrous Ammonia (NH3) wholesale price, NOLA (New Orleans, LA)

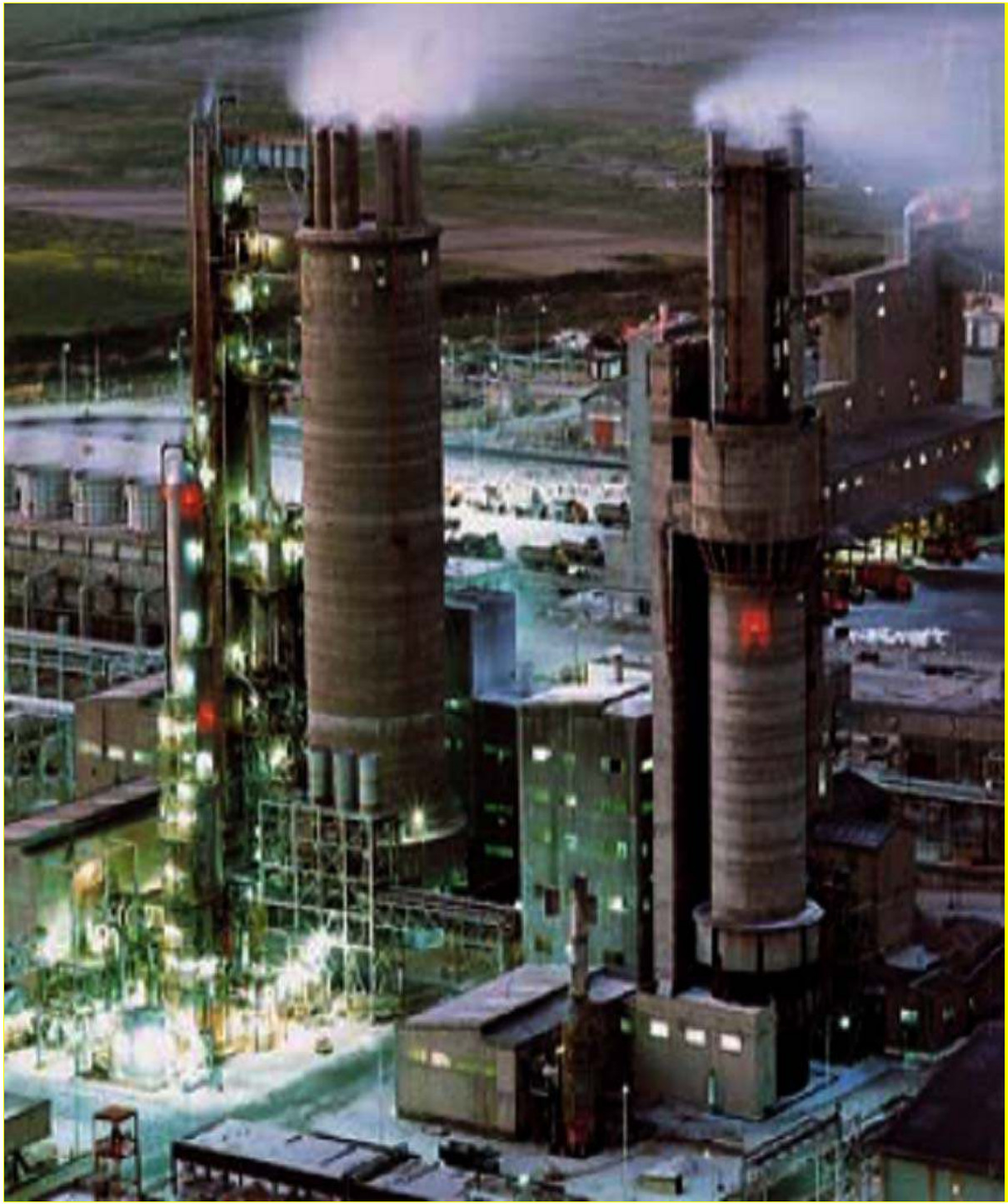


Anhydrous Ammonia (NH3) wholesale price, NOLA (New Orleans, LA)

Figure 1. Fertilizer Prices in Illinois ($ per ton)
Wholesale at terminal



Source: Agricultural Marketing Services, U.S.D.A.



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

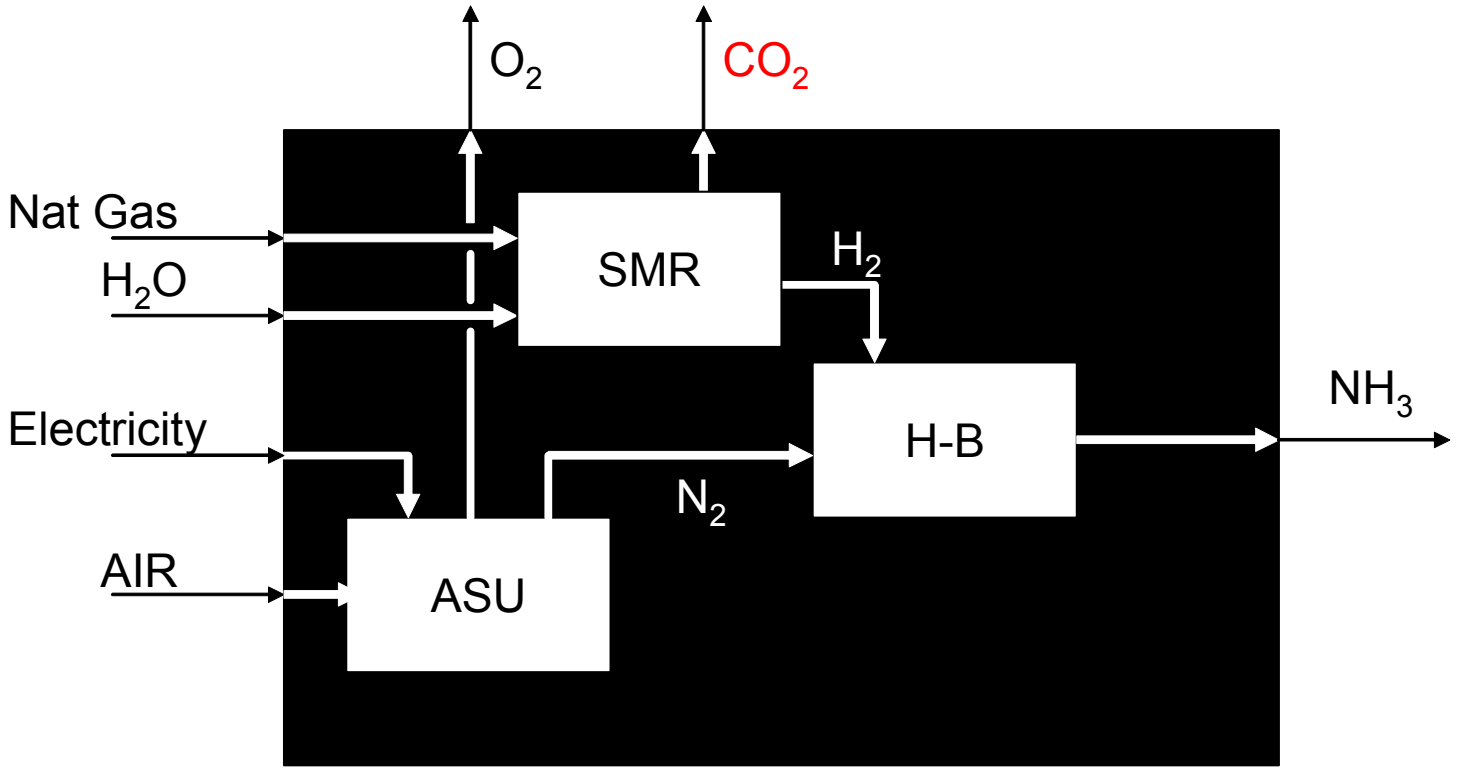
Haber-Bosch Reactor

1921

Ludwigshafen, Germany

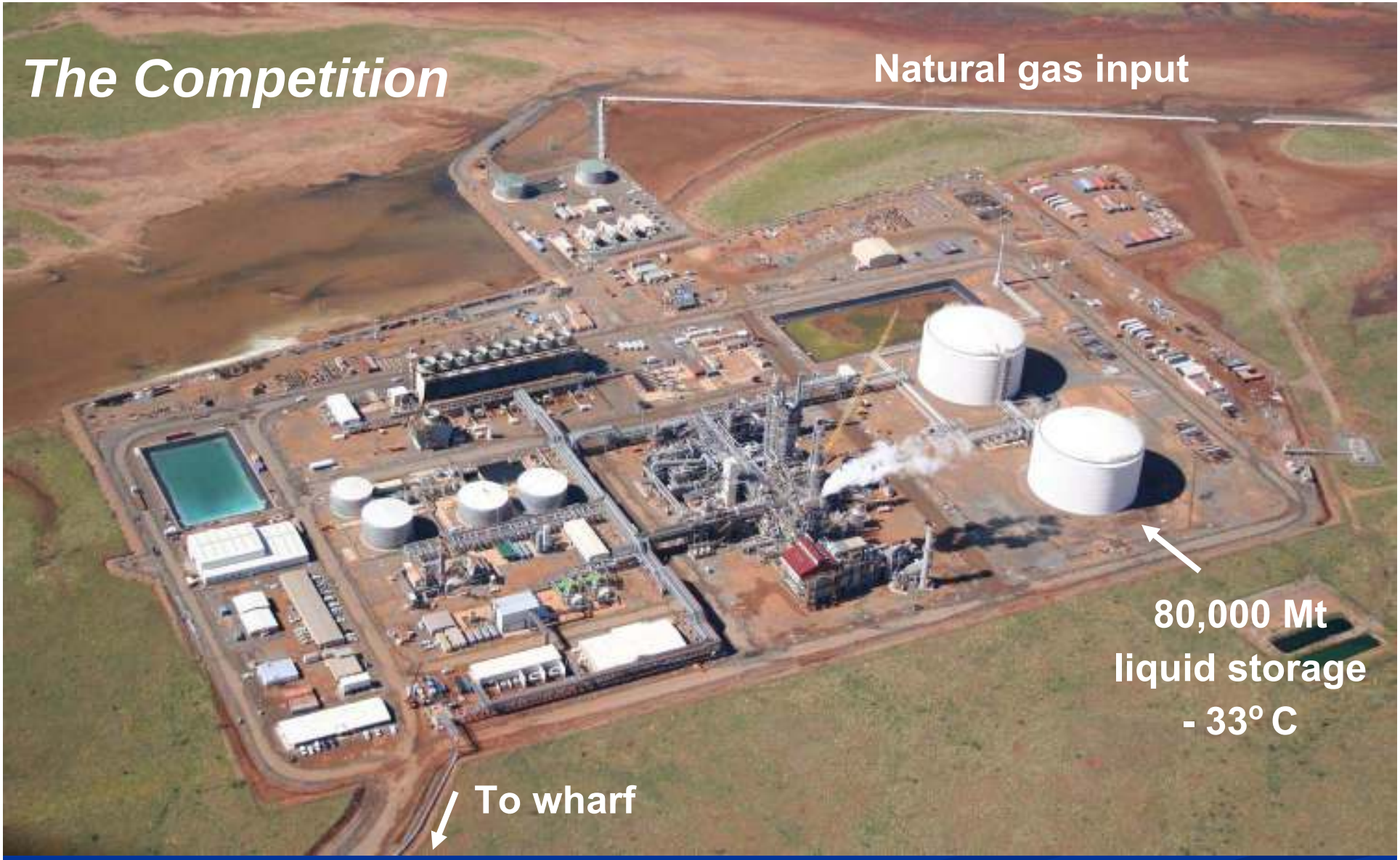
Inside the Black Box: Steam Reforming (SMR) + Haber-Bosch

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



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

The Competition



Burrup Peninsula, NW Australia, Natural Gas to Ammonia Plant

760,000 Mt / year

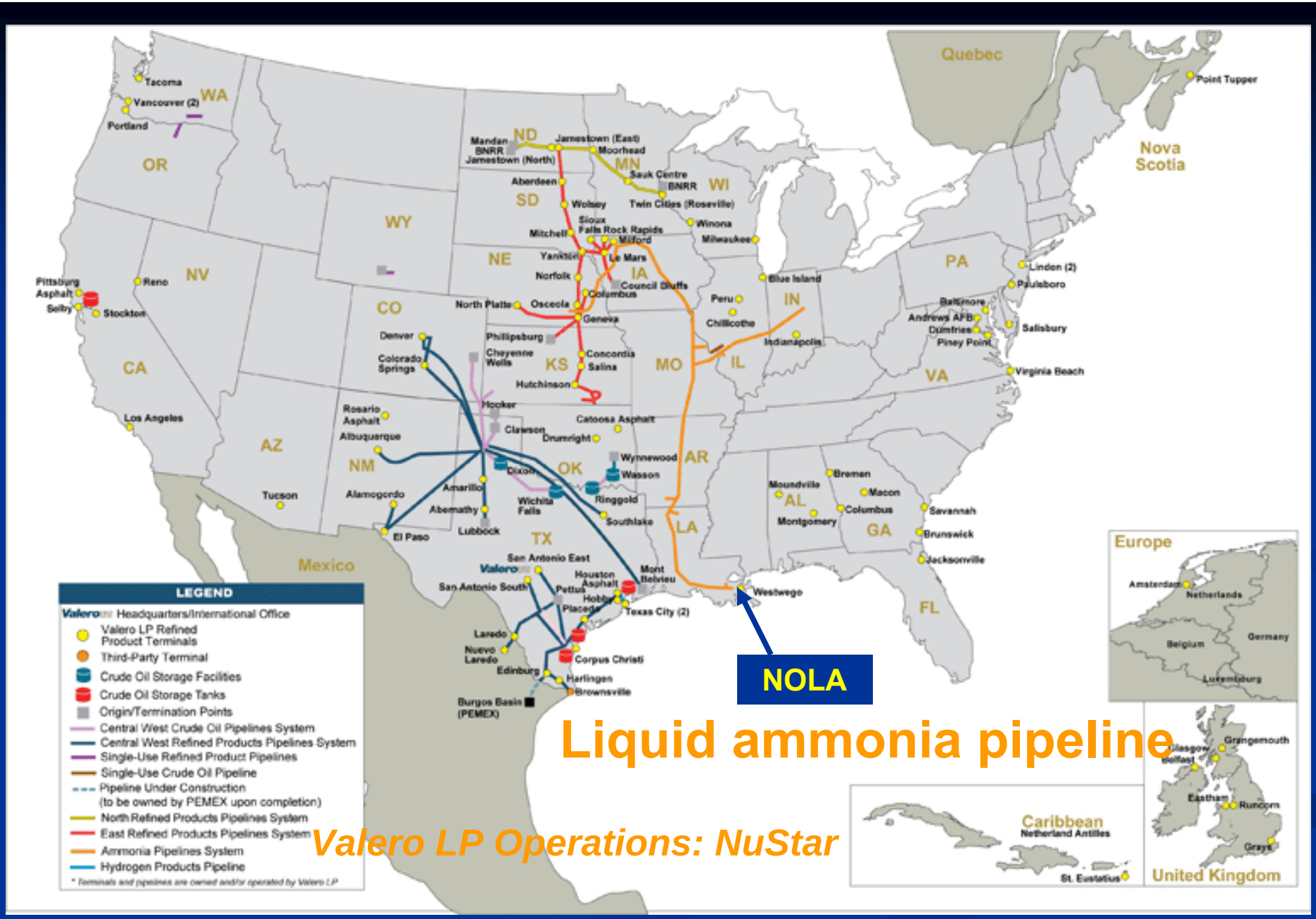
$US 650 million capital cost ‘06

Ammonia Tanker
Burrup Peninsula
Western Australia

Ammonia or LPG Tanker

9,000 – 35,000 Mt

Refrigerated

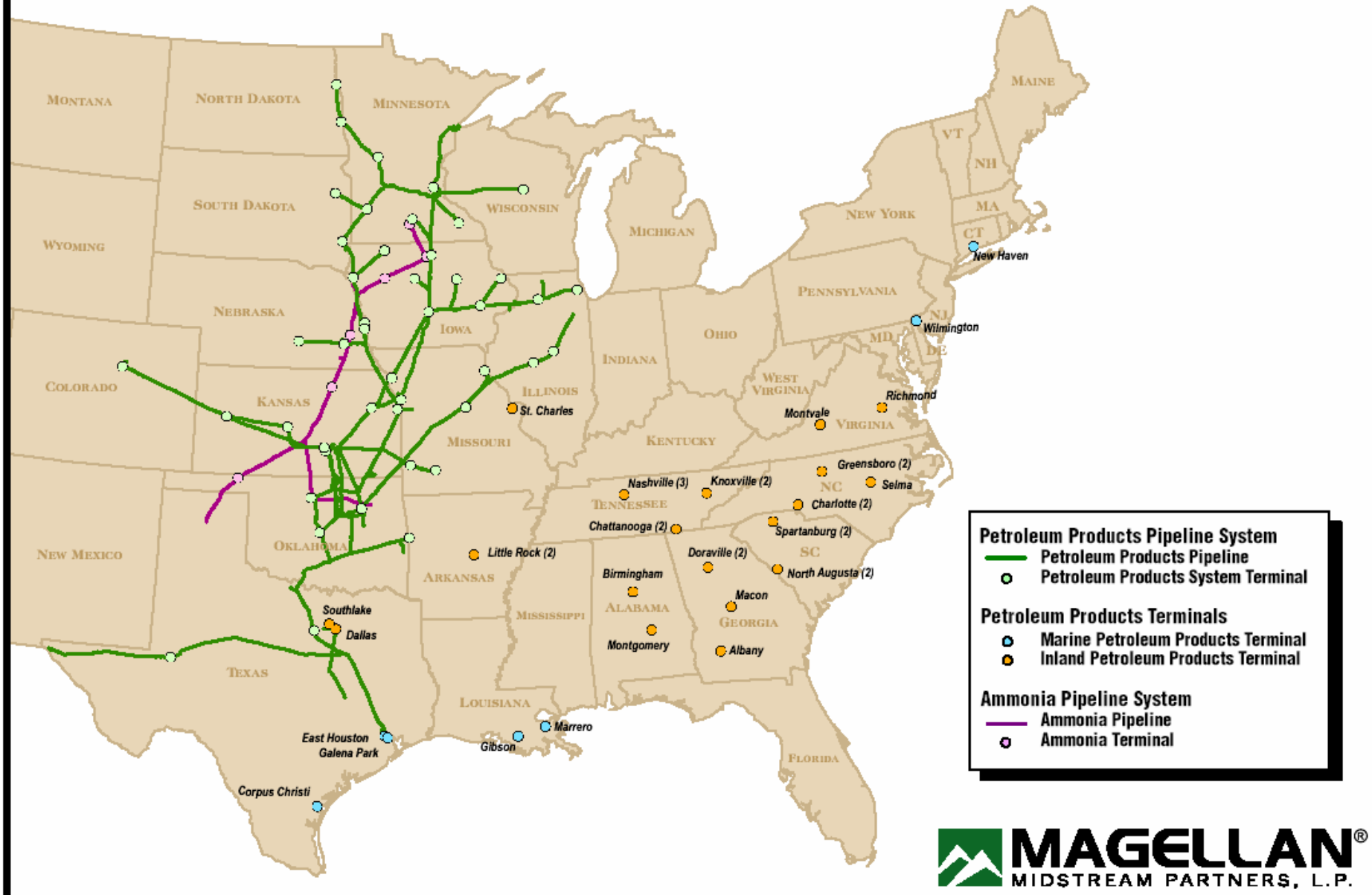


Liquid ammonia pipeline

Valero LP Operations: NuStar

USA imports ~70% of NH3

Asset Portfolio



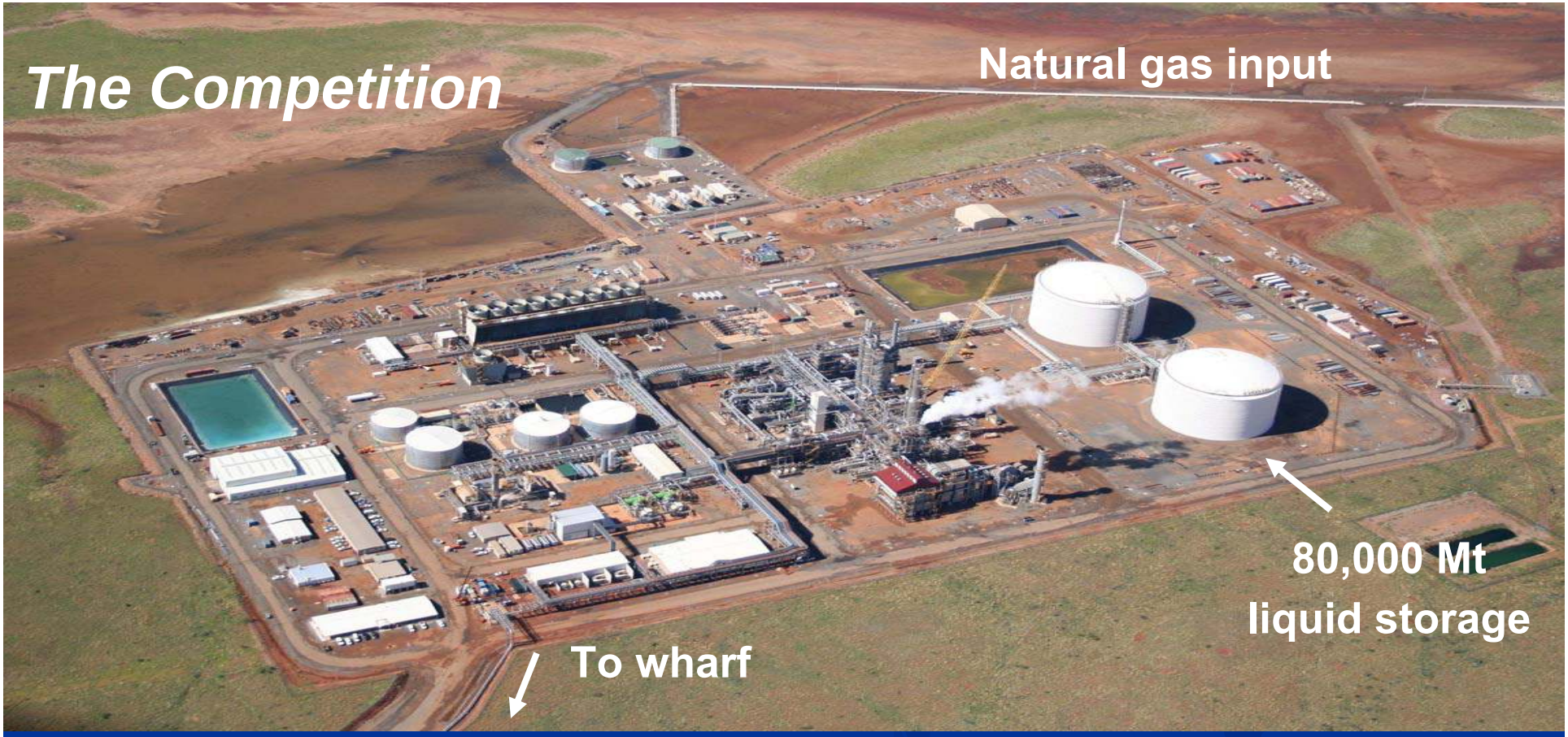
MAGELLAN®
MIDSTREAM PARTNERS, L.P.


Ammonia Storage Terminal
Mississippi River
Winona, MN

USA NH3 Infrastructure

- ~ 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

The Competition



Global Ammonia = 140 million Mt / year

- **#2 chemical**
- **200 plants, nat gas + coal**
- **~ 500 Million Bbl oil**
- **~ 2% oil**
- **~ 0.5% energy**

14 million Mt / yr USA; 60% imported; corn ethanol

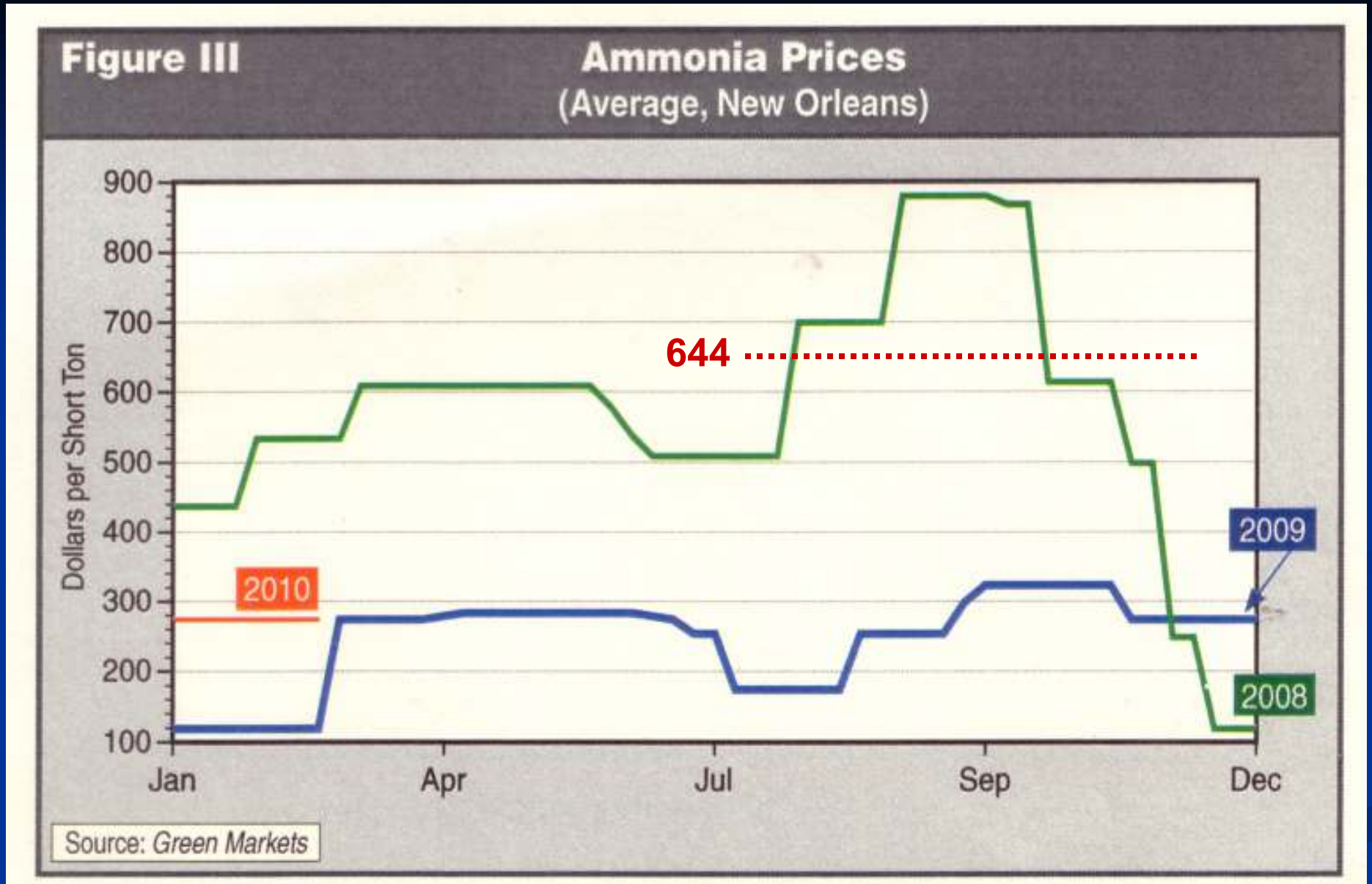
Cost: Ammonia from Stranded Natural Gas (NG)

> Burrup, Australia Plant: 750,000 Mt / year
> $650M capital @ 15% capital recovery factor (CRF)
> 34 MMBtu NG / Mt NH3
> NG cost $1.20 / MMBtu long-term
> Tanker shipping to New Orleans, LA (NOLA) $50 / Mt
> CO2 emission 1.8 Mt / Mt NH3

	C-tax 0	C-tax $50 / Mt CO2	C-tax $100 / Mt CO2
Capital	98	98	98
NG	41	41	41
Shipping	50	50	50
C-tax	0	90	180
Plant O&M	2	2	2
Total NOLA / Mt	**$191**	**$281**	**$371**

1. 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?**

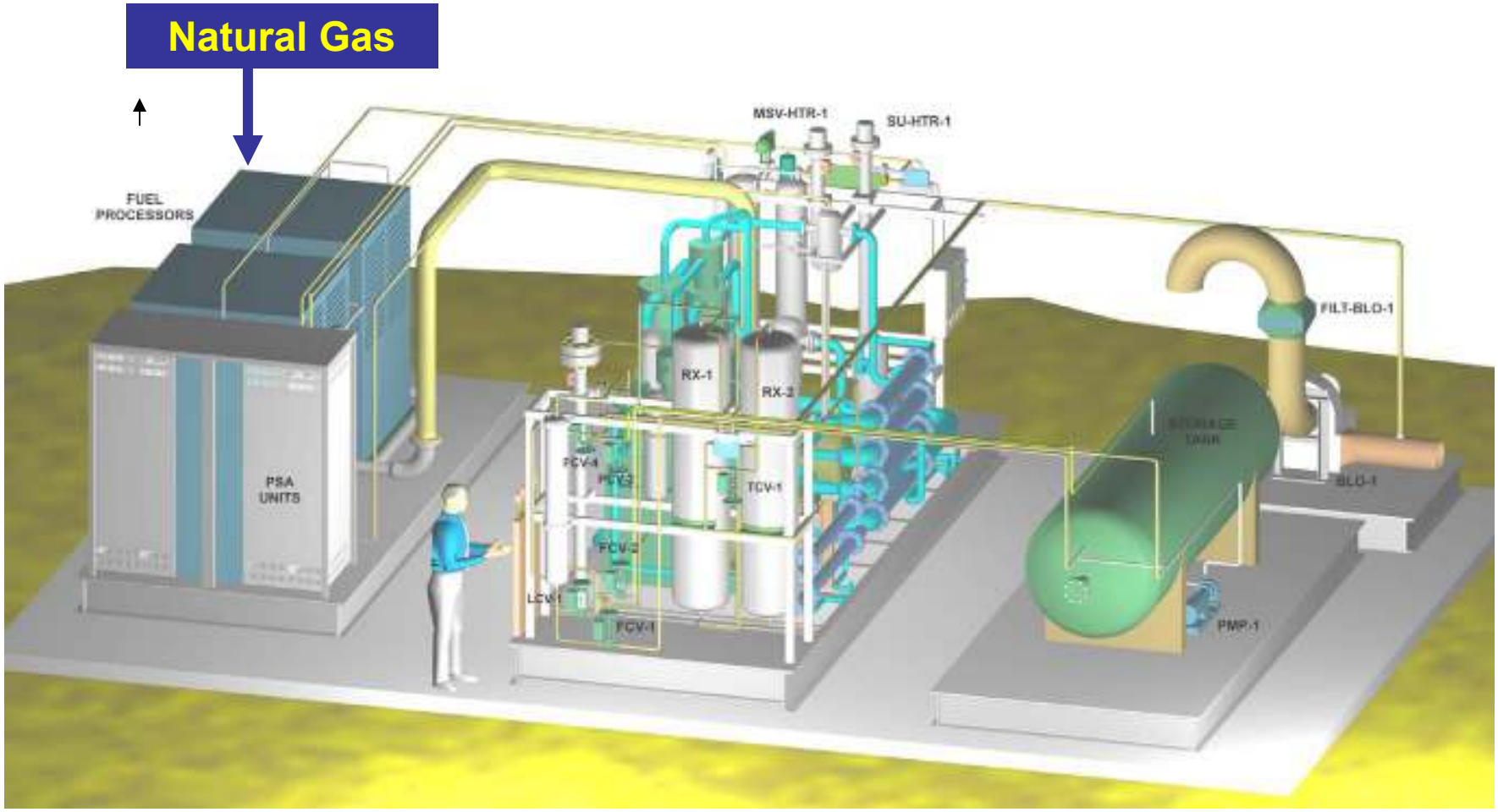


Anhydrous Ammonia (NH3) wholesale price, NOLA (New Orleans, LA)

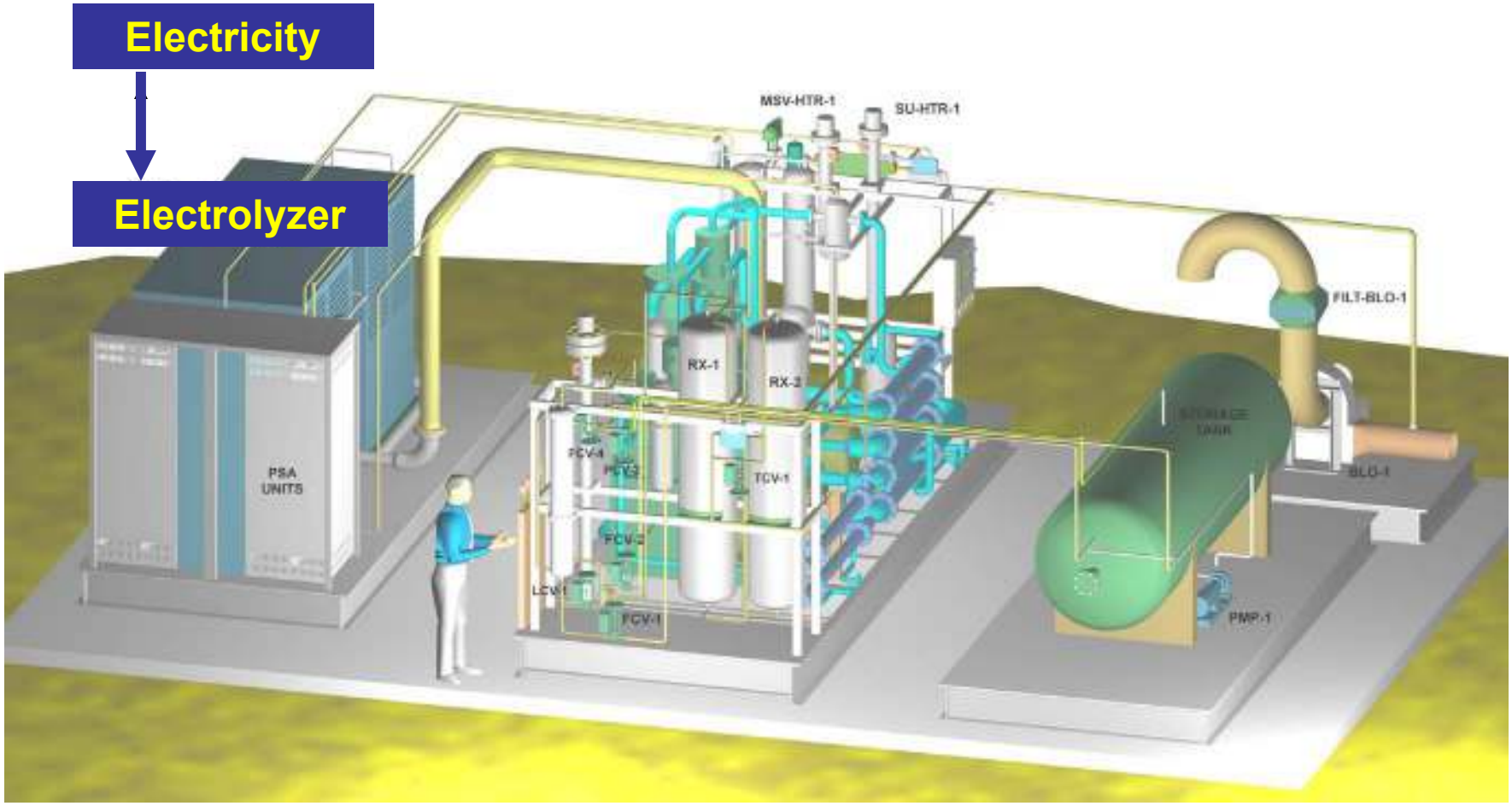
2. Decrease Cash OUT: Village "Energy Independence" via RE Generation + Storage

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

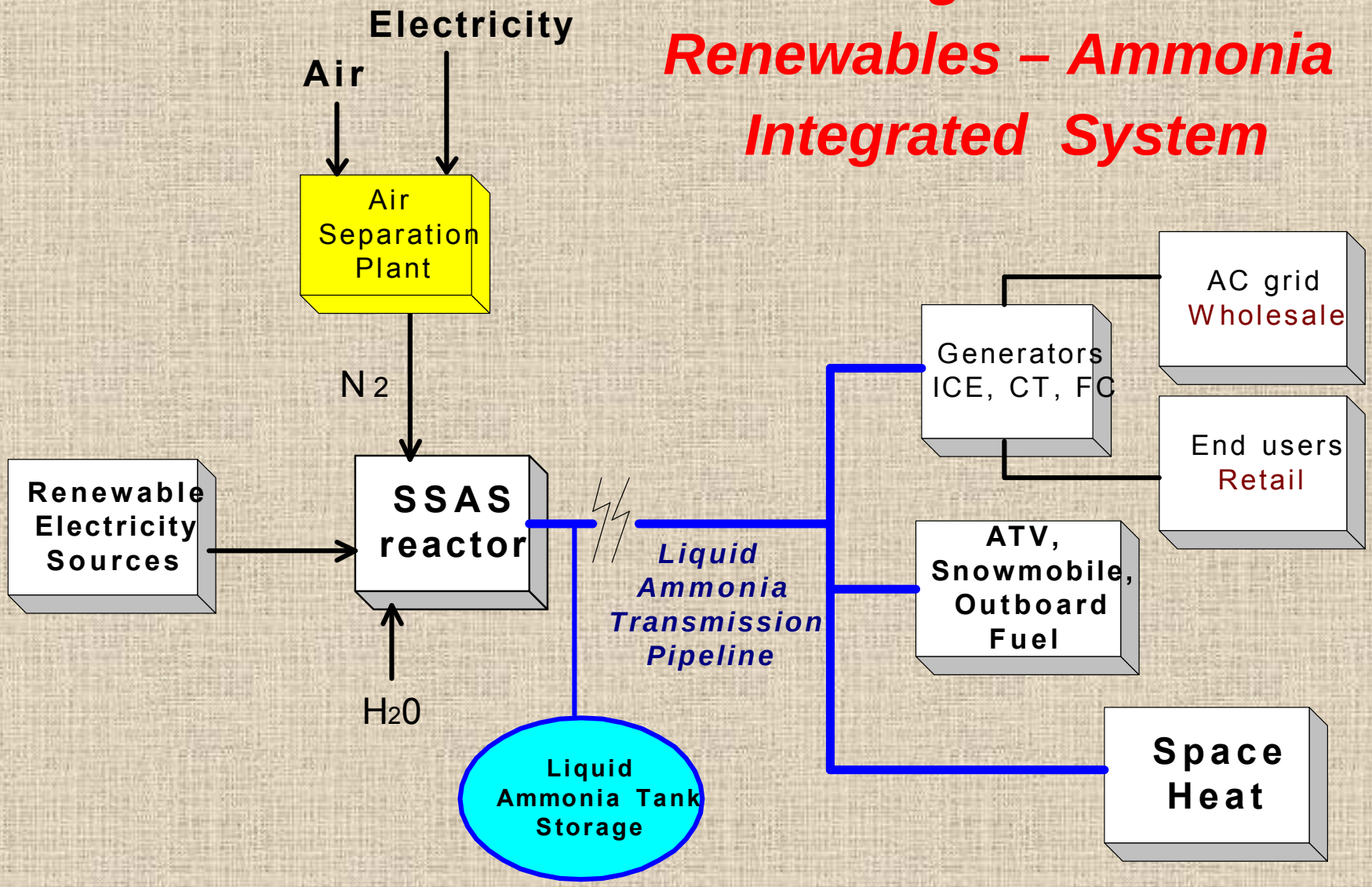
Village-scale
3 Mt / day Mini-NH3 Plant
Natural Gas Fueled Haber-Bosch



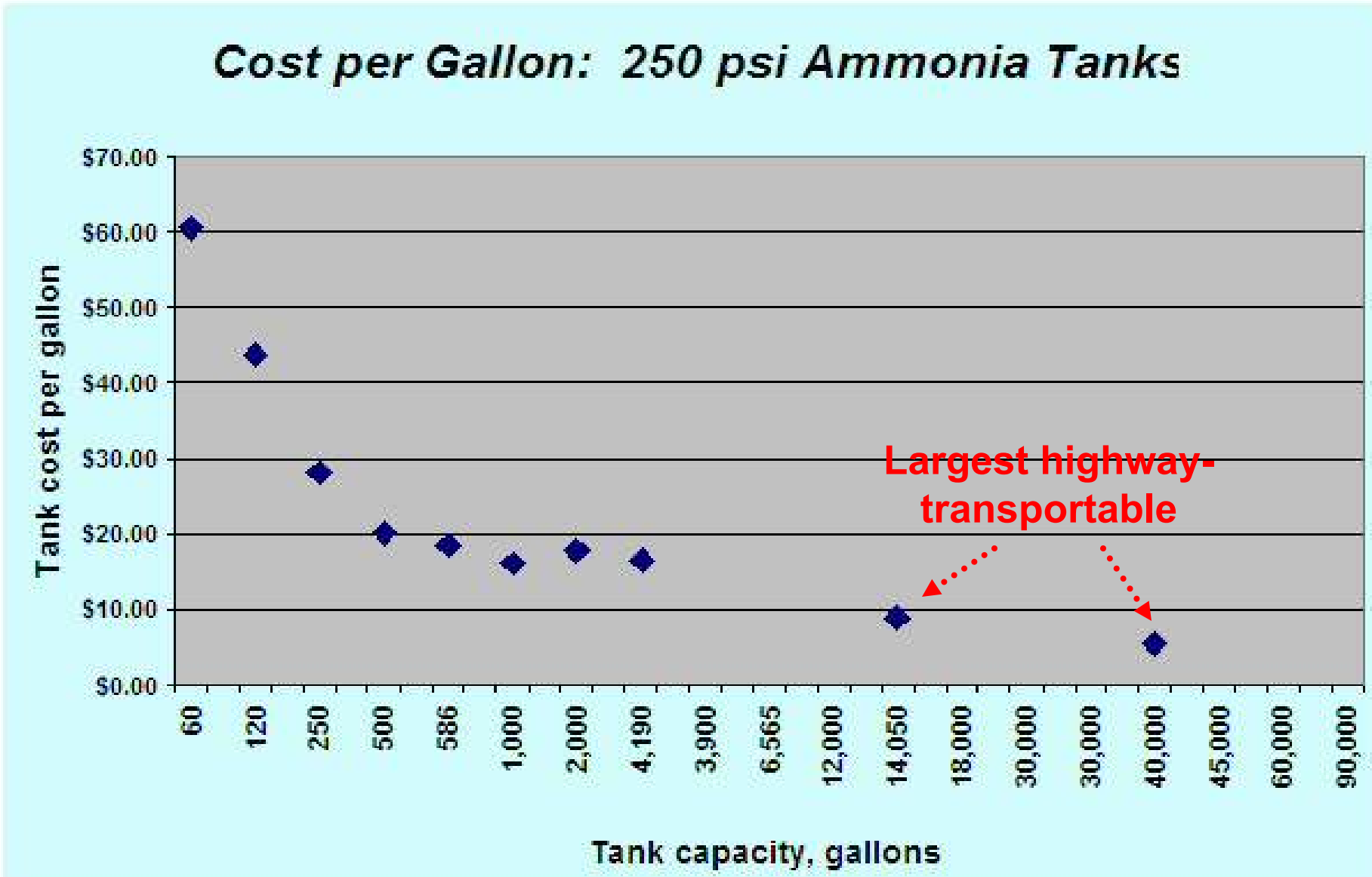
Village-scale
3 Mt / day Mini-NH3 Plant
RE Electricity Haber-Bosch



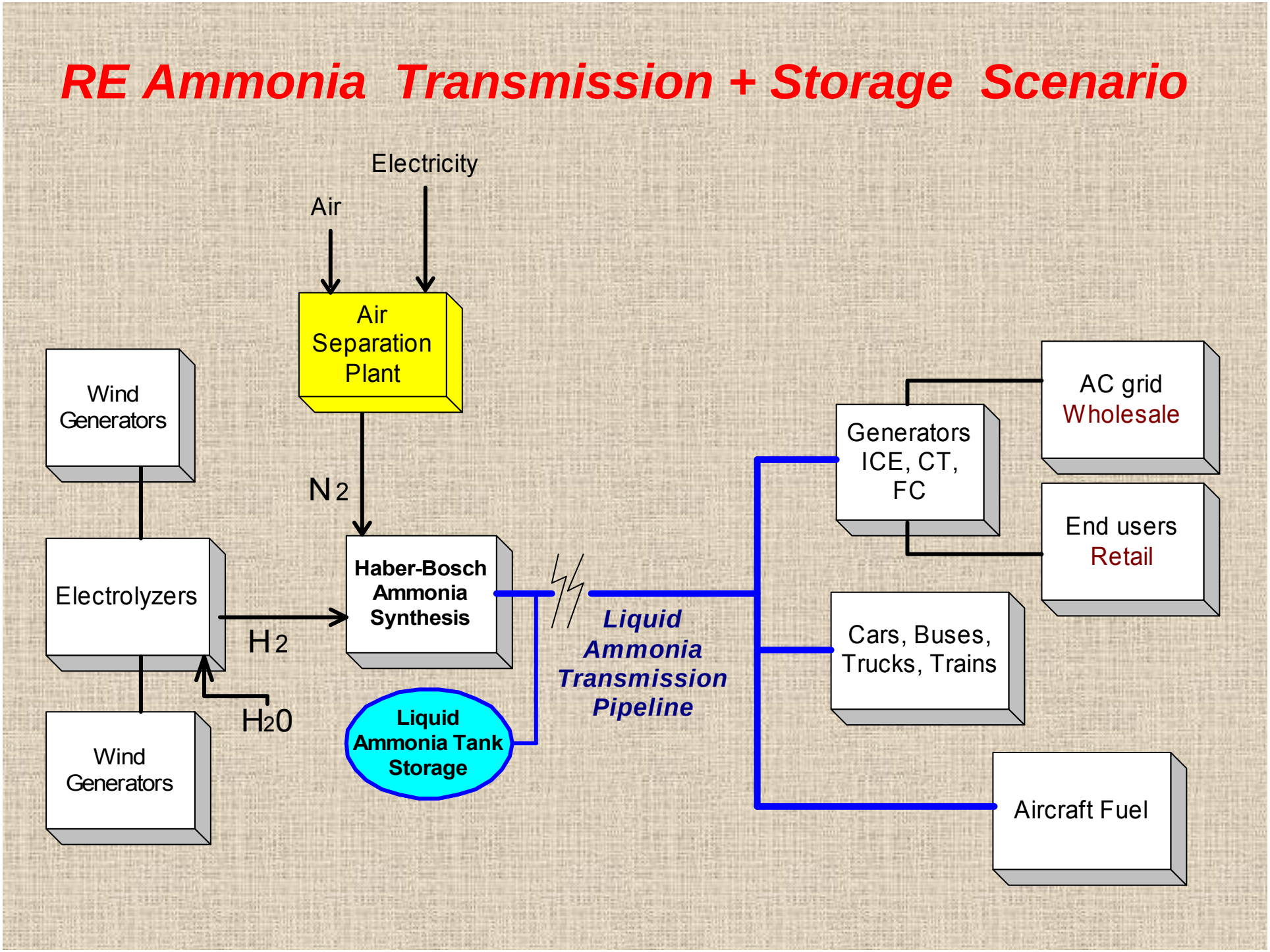
"Village" SSAS Renewables – Ammonia Integrated System



Liquid Ammonia Tank Storage



RE Ammonia Transmission + Storage Scenario

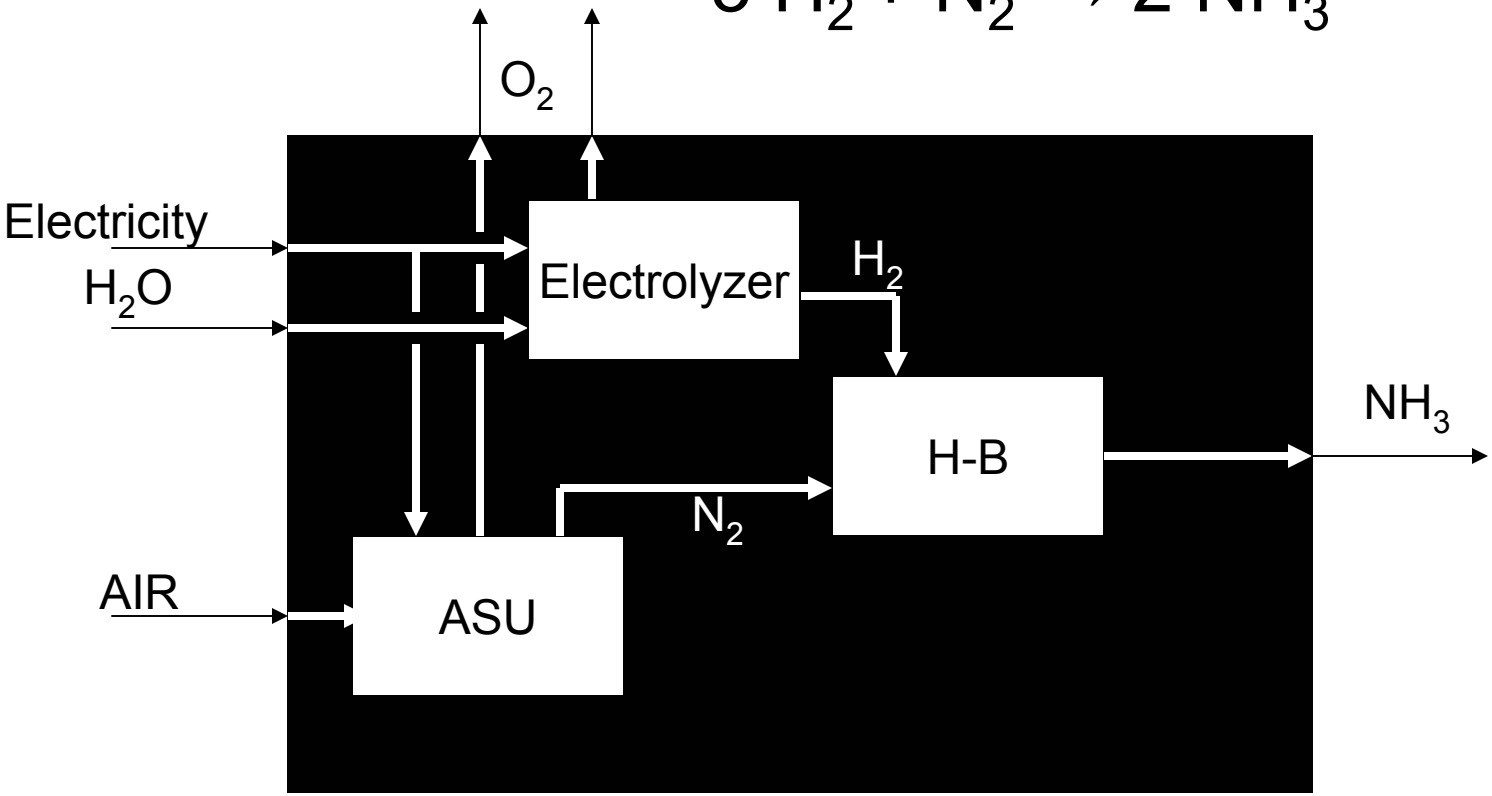


Wind – to – Ammonia Potential, NW Iowa


Norsk Hydro
Electrolyzers
2 MW each
Ammonia from
hydrogen
from zero-cost
off-peak hydro

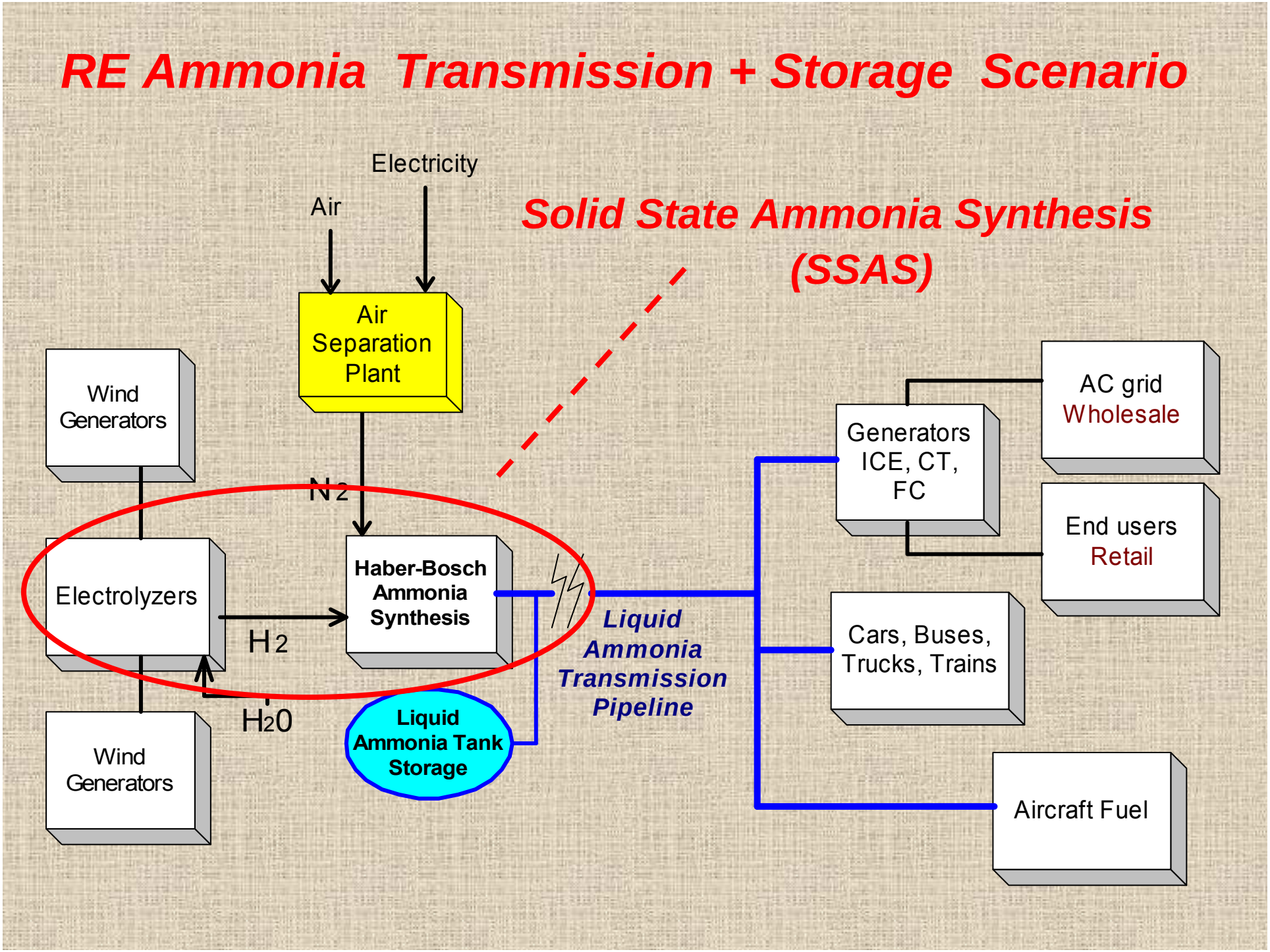
Inside the Black Box: HB Plus Electrolysis

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



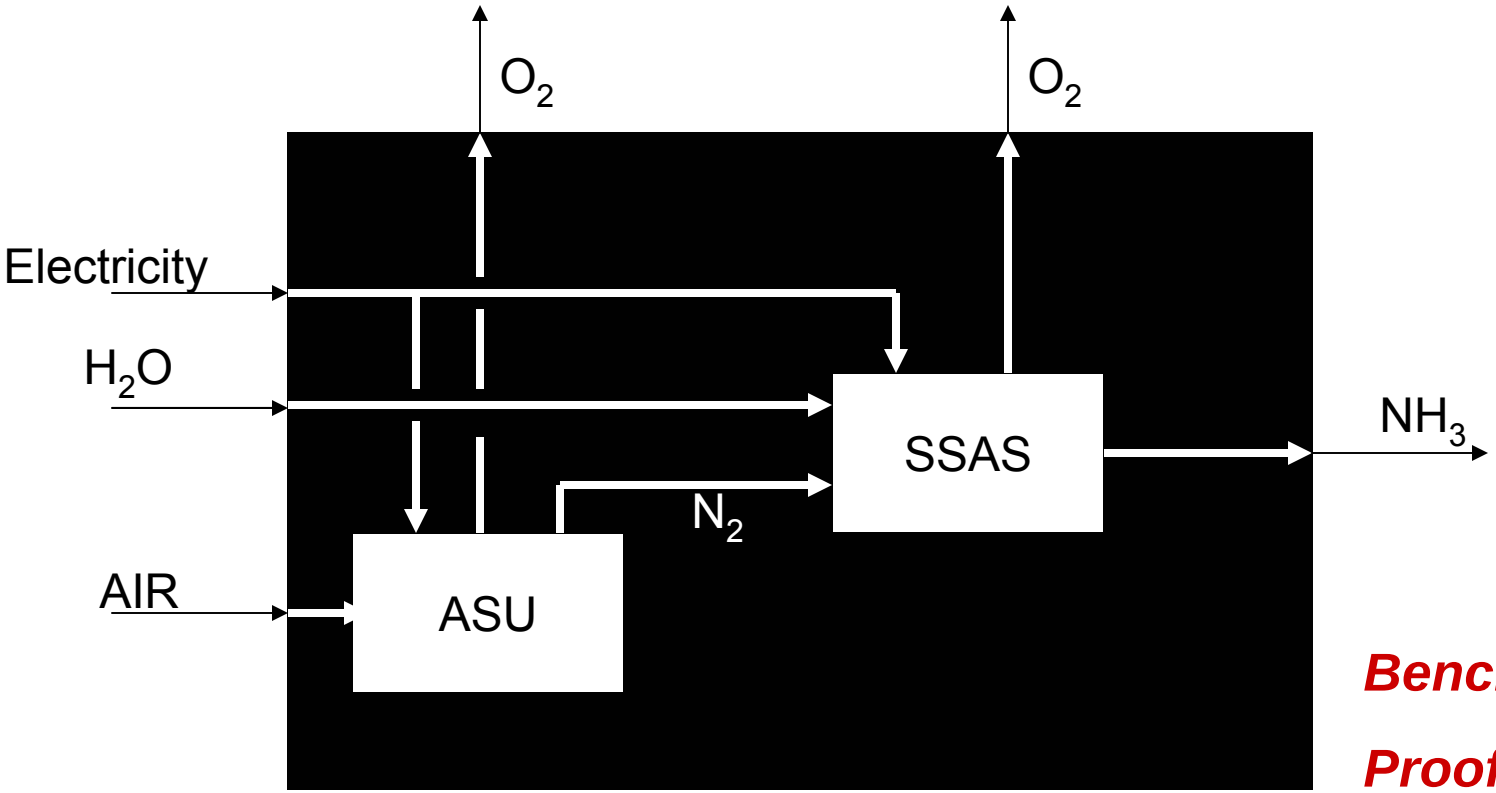
Energy consumption ~12,000 kWh per ton NH_3

RE Ammonia Transmission + Storage Scenario



Inside the Black Box: Solid State Ammonia Synthesis

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

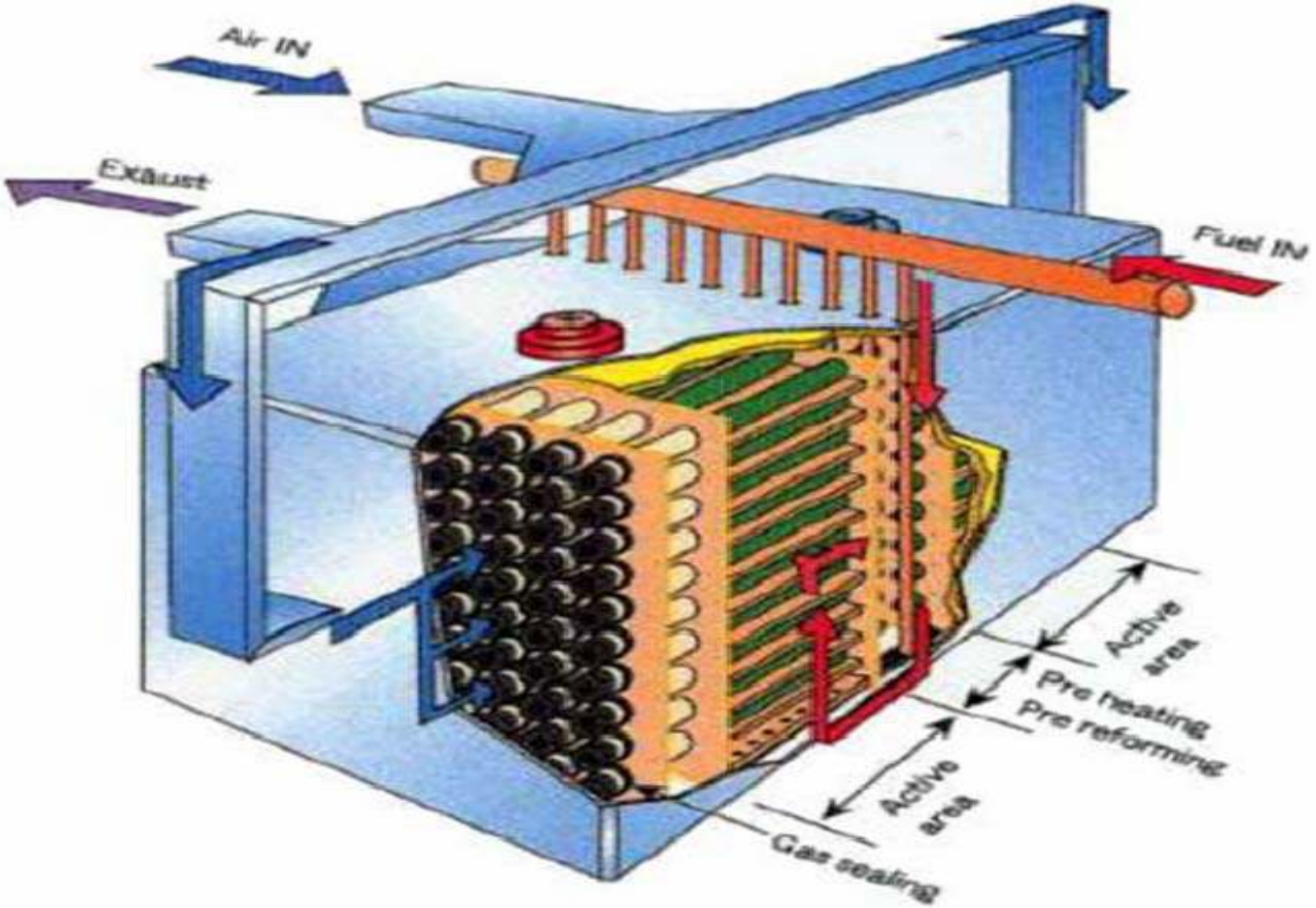


Benchtop

Proof-of-concept

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

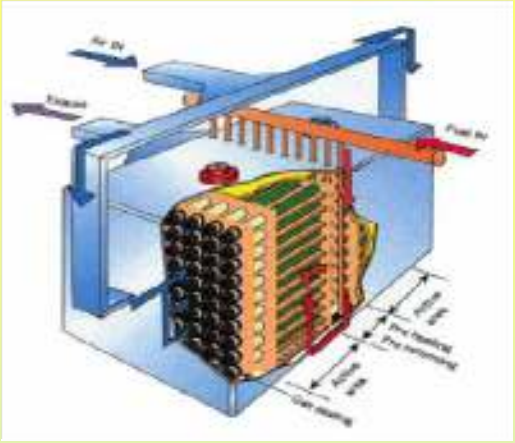
Solid State Ammonia Synthesis (SSAS)
NHThree LLC patent



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

Solid State Ammonia Synthesis (SSAS)



- Goals:
  - Renewables-source ammonia (NH3)
  - Compete with natural gas source NH3
- High energy conversion efficiency
  - ~50% better than electrolysis → hydrogen + H-B
  - No hydrogen production
- Electricity + water + nitrogen → ammonia
- ~ 50% lower capital cost
- SSAS reactor: SOFC * in reverse

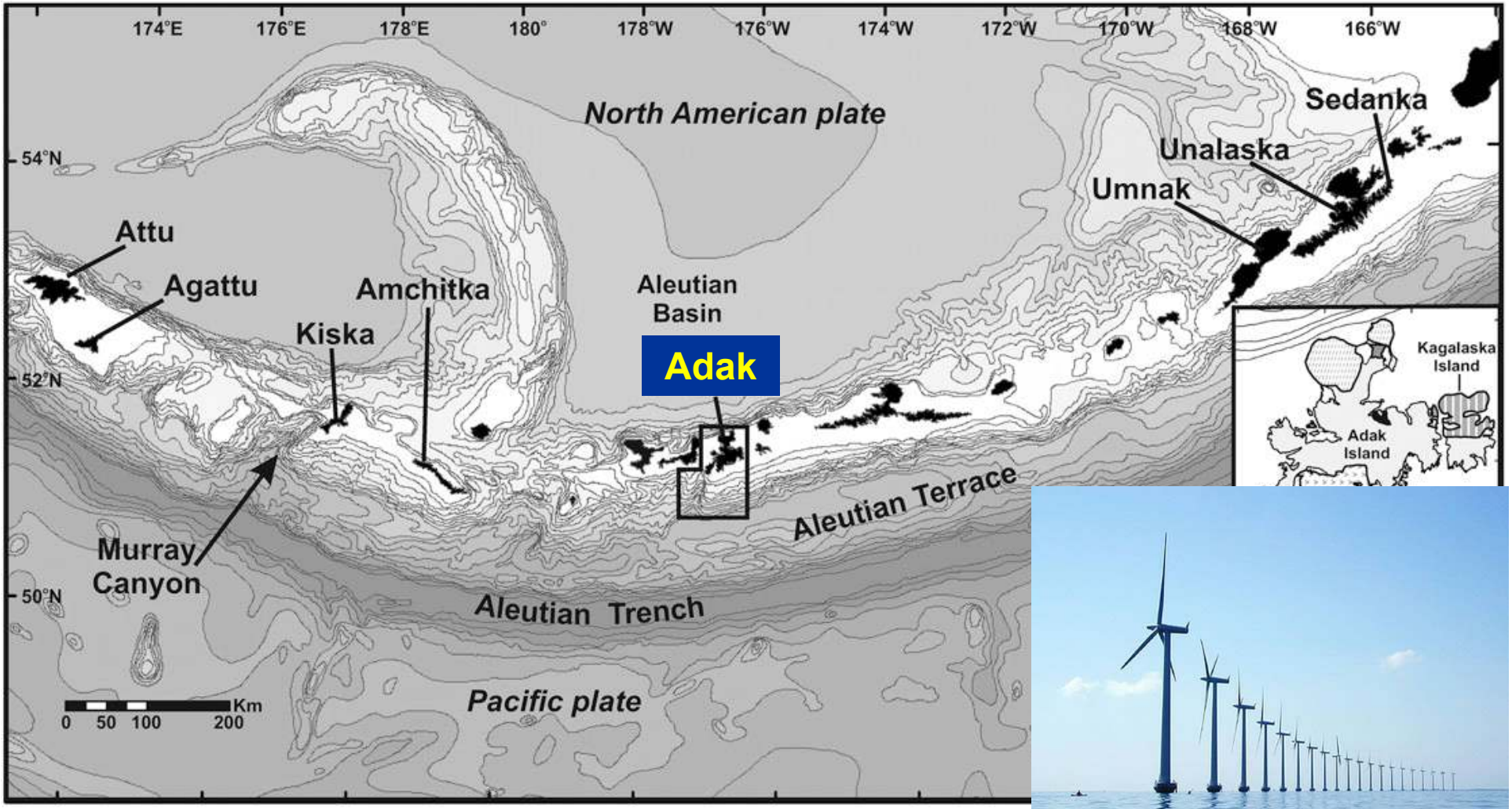
*** SOFC: Solid oxide Fuel Cell**

SSAS vs H-B NH3 Synthesis

Solid State Ammonia Synthesis vs Haber – Bosch

Renewable-source electricity input

- **H-B per MW input**
  - **Capital $1.5 M**
  - **2 tons / day output**
- **SSAS per MW input**
  - **Capital $650 K**
  - **3.2 tons / day output**



Adak, Alaska
Aleutian Islands
Class 7 Wind: Capacity Factor (CF) >45% ?


Sea of
Okhotsk
KAMCHATKA
Bering Strait
Monday
Sunday
Komandorskis Ostrova
(Commander Islands)
Date Line
N
ALASKA
Bering Sea
SHEMYA
ATTU
DUTCH HARBOR
Aleutian Islands
AGATTU
KISKA
AMCHITKA
Adak
0 100 200 300
MILES
Pacific Ocean

"Green" Ammonia (NH3) Output

> 2,000 MW Adak Wind-to-ammonia Plant

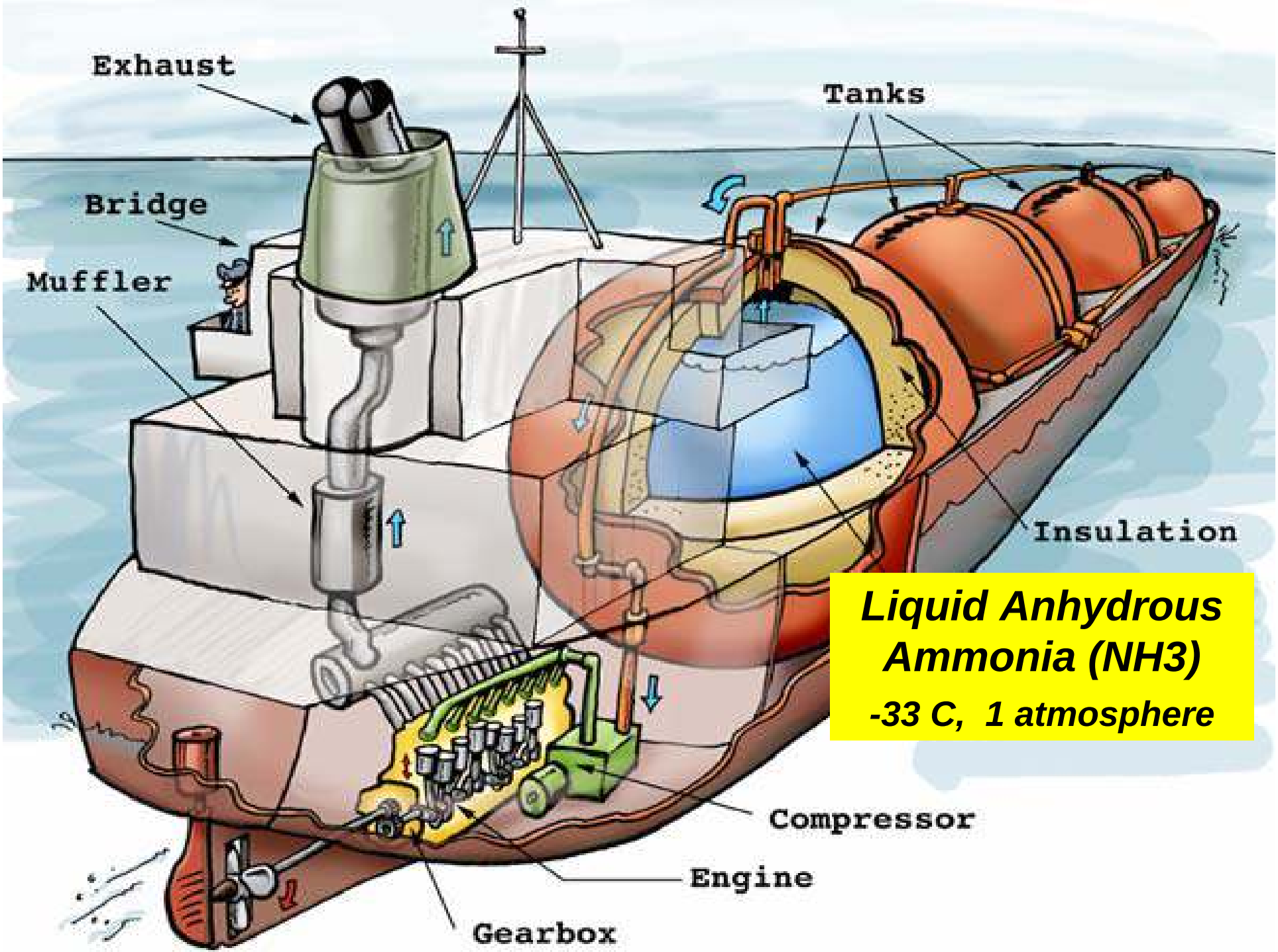
> $5 B total capital @ $2,500 / kW

> 45% Capacity Factor (CF)

Windplant Annual Energy Production

As electricity:	**21,600**	**MWh / day**
	7,884,000	**MWh / year**

Convert to NH3 by:	**Electrolysis + H-B @ 12 MWh / Mt**	**SSAS @ 7.5 MWh / Mt**
Mt (tons) / year	**657,000**	**1,050,000**
Sales @ $300 / Mt (plant gate)	**$197 M**	**$315 M**
Simple ROI	**4%**	**6%**


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

"Green" Ammonia (NH3) Output

- *> 2,000 MW Adak Wind- to- ammonia plant*
- *> $5 B total capital @ $2,500 / kW*
- *> 45% Capacity Factor (CF)*
- *> 15% Capital Recovery Factor (CRF)*

Windplant Annual Energy Production
As electricity: 7,884,000 MWh / year

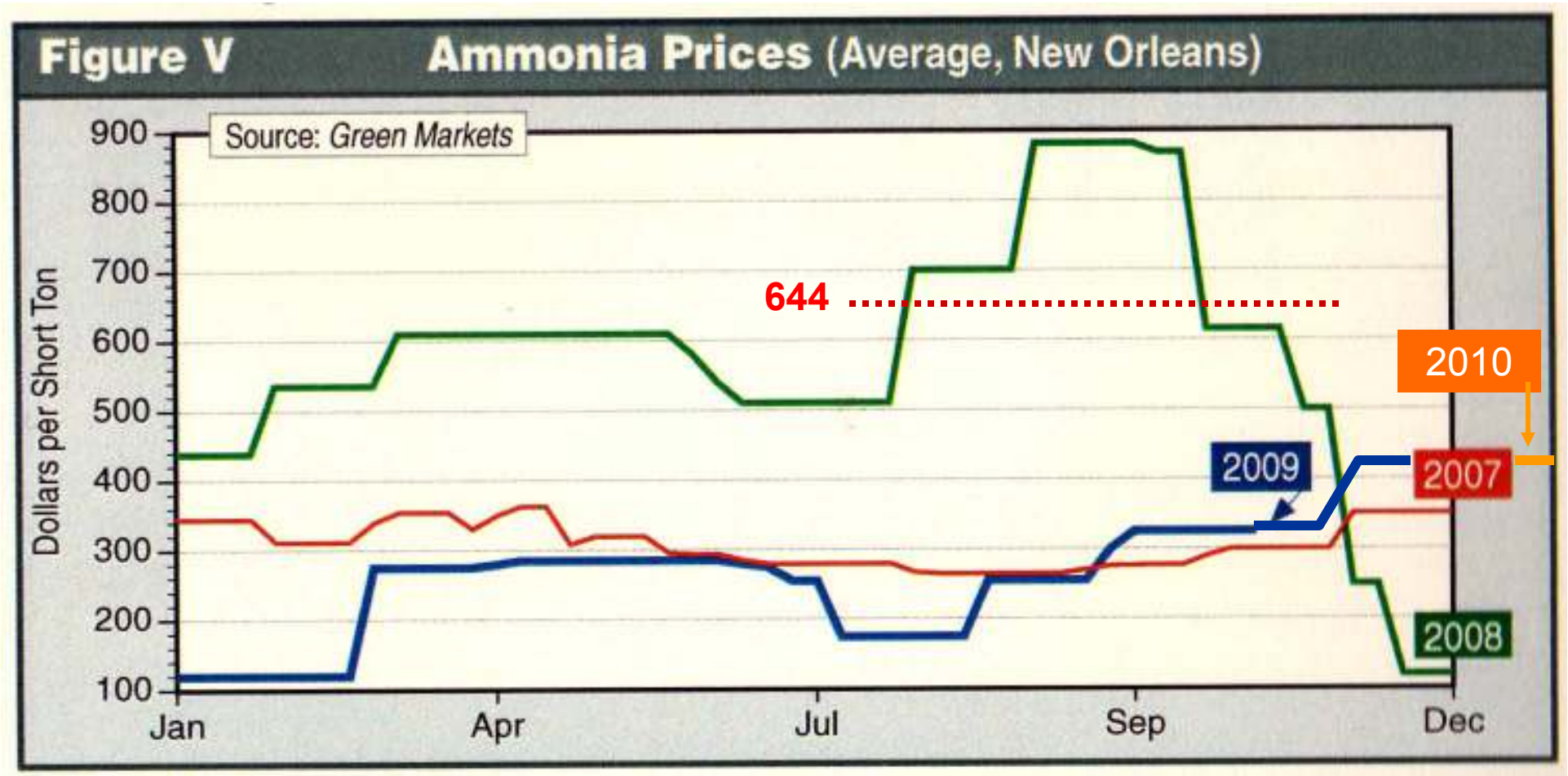
	Electrolysis + H-B	SSAS
Sales: Mt (tons) / year	657,000	1,050,000
Total Cost of Sales:		
Capital @ 15% CRF	$750M	$750M
Plant O&M @ $0.03 / kWh	24M	24M
Input energy	0	0
TOTAL	$774M	$774M
Cost / Mt NH3	$1,178	$ 737
Shipping @ $50 / Mt	50	50
Total NOLA / Mt	$1,228	$ 787

"Green" Ammonia (NH3) Output

- *> 2,000 MW Adak Wind- to- ammonia plant*
- *> $5 B total capital @ $2,500 / kW*
- *> 45% Capacity Factor (CF)*
- *> 12% Capital Recovery Factor (CRF)*

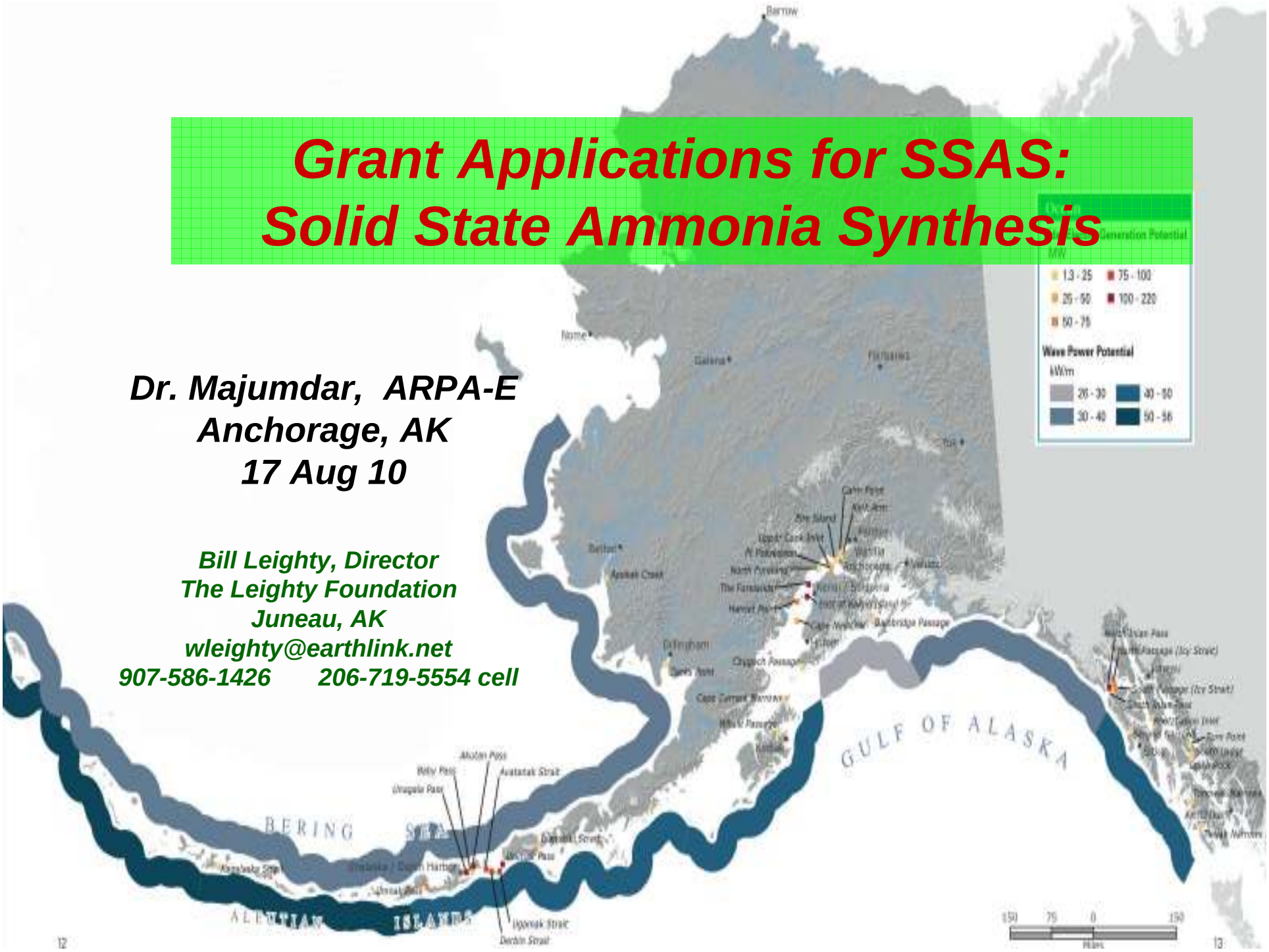
Windplant Annual Energy Production
As electricity: 7,884,000 MWh / year

	Electrolysis + H-B	SSAS
Sales: Mt (tons) / year	657,000	1,050,000
Total Cost of Sales:		
Capital @ 12% CRF	$600M	$600M
Plant O&M @ $0.03 / kWh	24M	24M
Input energy	0	0
TOTAL	$624M	$624M
Cost / Mt NH3	$ 949	$ 594
Shipping @ $50 / Mt	50	50
Total NOLA / Mt	$ 999	$ 644



Anhydrous Ammonia (NH3) wholesale price, NOLA (New Orleans, LA)

Grant Applications for SSAS: Solid State Ammonia Synthesis



Dr. Majumdar, ARPA-E
Anchorage, AK
17 Aug 10

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

SSAS R+D+Demo Concept

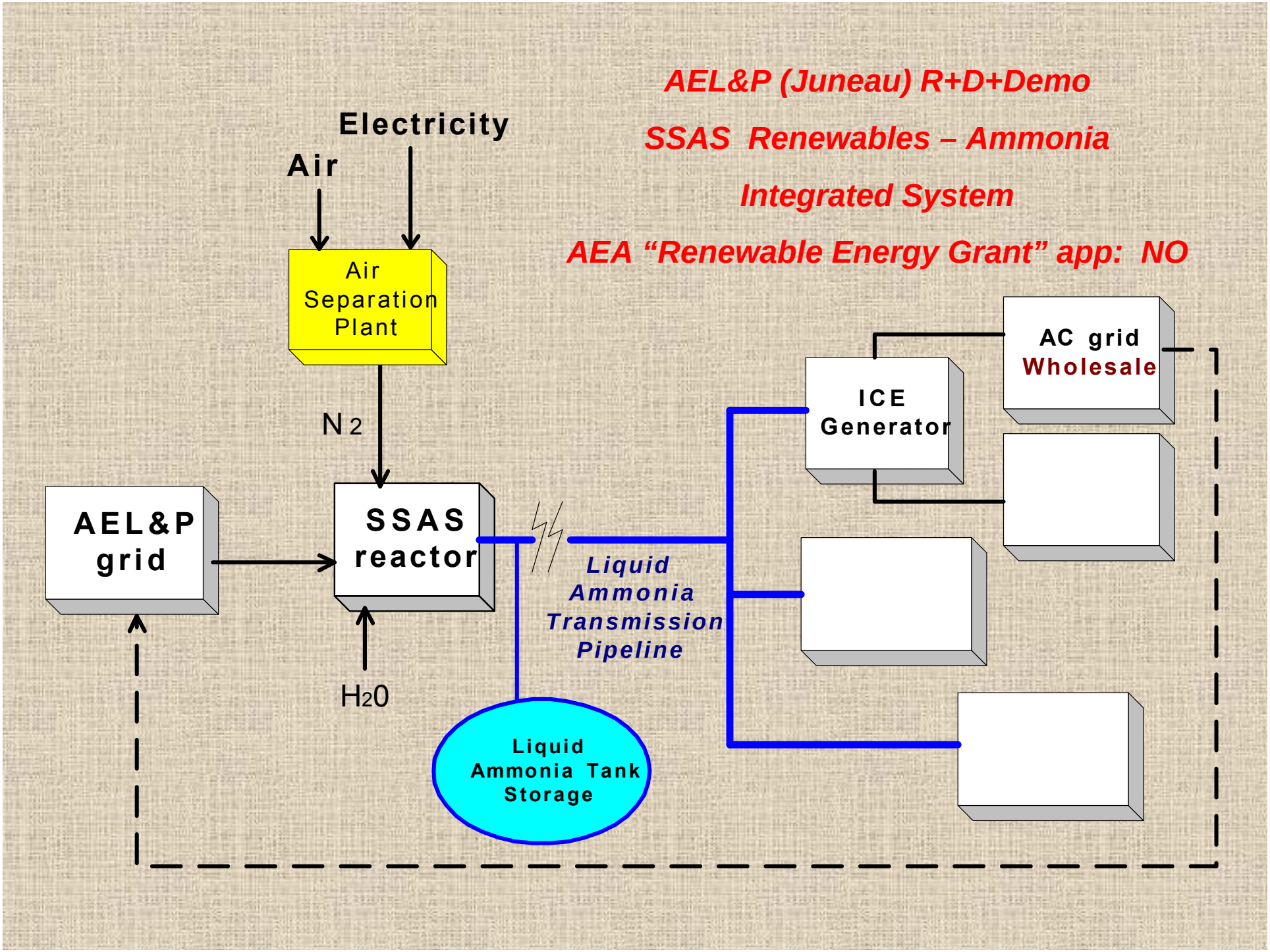
- $4 – 5 M total program
- Simulate Alaska community energy island
- SSAS offer RE-source internal energy independence ?
  - Discover, demonstrate tech & econ advantages
  - Conversions efficiency; byproduct heat used
  - Economic: capital, O&M costs
- R&D plus demo pilot plant:
  - NHThree LLC patented IP
  - PCC tube mfg pilot plant

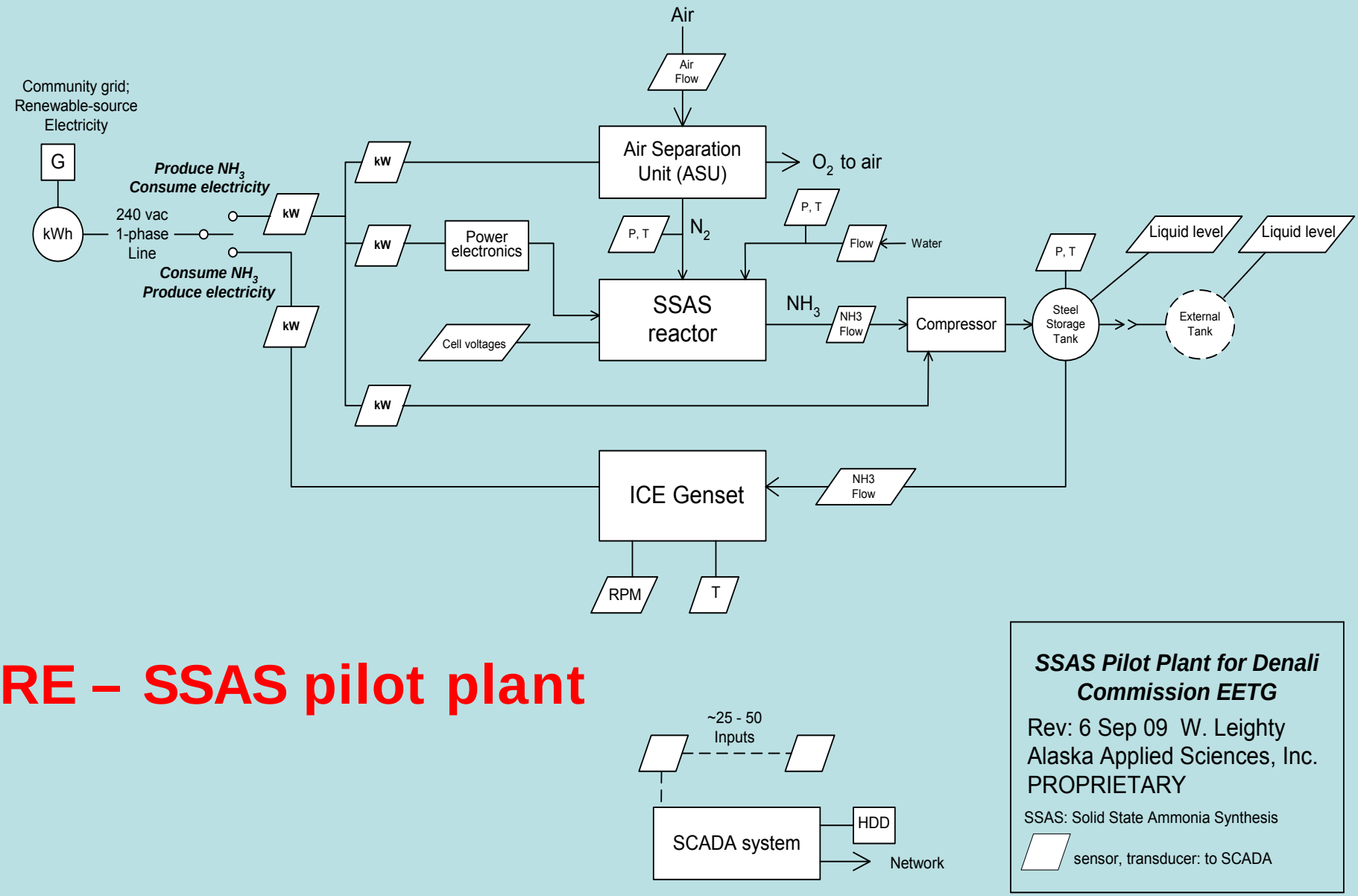
SSAS R+D+Demo Concept

- 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
- Implications for export of large-scale, stranded AK RE

TDX Power, Inc., St. Paul Island

Candidate SSAS Pilot Plant Advanced Test Site


AEL&P (Juneau) R+D+Demo
SSAS Renewables – Ammonia
Integrated System
AEA "Renewable Energy Grant" app: NO
Electricity
Air
Air Separation Plant
N2
AEL&P grid
SSAS reactor
H20
Liquid Ammonia Transmission Pipeline
Liquid Ammonia Tank Storage
ICE Generator
AC grid Wholesale



RE – SSAS pilot plant

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

SSAS Grant Applications

- ’08 AELP via AK HB152 (RE demos)
- ’09 NHThree LLC via ARPA-E
- ’09 AASI via Denali Commiss EETG
- ’10 Coffman + NHThree LLC via ARPA-E

'08 AEL&P Grant Application: Renewable Energy, AEA, HB152

- Alaska Electric Light & Power (AEL&P) Juneau
- R+D+Demonstration of SSAS system
- $800K, round one, HB152 grants
- Advance SSAS from lab scale: tech + econ feasible
- Statewide application:
  - "Energy Islands"
  - "Energy Independence"
  - Village survival: imported energy cost, delivery
  - Scaleup: export NH3, tanker
- Demonstrate in major AK city, first: Juneau
- Redeployed to remote community
- Not funded by AEA: no R&D

Sept '09 AASI Grant Application: Denali Commission (Alaska) EETG (Emerging Energy Technology Grant program)

- **Alaska Applied Sciences, Inc., Juneau (AASI)**
- **$800K: SSAS R+D+Demonstration (same as AEL+P)**
- **Not funded by Denali:**
  - **Timing mismatch**
  - **NHThree LLC prime subcontractor: single-source**
  - **NHThree LLC ARPA-E application pending: mfg plant**
- **Statewide application:**
  - **"Energy Islands"**
  - **"Energy Independence"**
  - **Village survival: imported energy cost, delivery**
- **Demonstrate in major AK city, first: Juneau**
- **Close loop to AEL+P hydro grid**
- **Redeploy to village if successful**
- **Eight support letters**

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 ?

SSAS Commercialization: R + D + Demonstration Funding Required by NHThree LLC

Pilot Plant for PCC tubes	**$ 2.5 M**
Portable Pilot Plant: RE → NH3 → RE	**1.0 M**
Portable Pilot Plant transport, install, ops	**.5 M**
R+D + Management	**1.0 M**
Total	**$ 5.0 M**

SSAS Commercialization: R + D + Demonstration Potential Funding Sources

Alaska SB220 "EETG"	**$ 1 M**
Iowa Power Fund	**1 M**
ARPA-E "unsolicited"	**1 M**
Farm Bill Sec 9003 Approp	**1 M**
Foundations	**?**
Private equity	**1 M**
Total	**$ 5 M**

Alaska Business Opportunities: RE – NH3 "Green" Ammonia

Monetizing Alaska's vast RE

1. **Export from GW-scale RE: Increase cash IN**
2. **Village energy "independence"**
   - **Indigenous renewables; diverse**
   - **Seasonal, diurnal variability**
   - **Storage as NH3: pressurized tanks**
   - **Reduce cash OUT**

Alaska's Immediate Opportunity: SSAS

- Village energy "independence" - degree
  - Diverse, indigenous RE sources
  - Convert % to NH_3
  - Storage as NH_3 in steel tanks: annually-firm
  - Deliver energy services: CHP, heat, transport,
  - Competitive price: $6-8 / gallon diesel + heat fuel
- SSAS R&D and Demonstration
  - NHThree LLC owns SSAS IP patent
  - PCC tube mfg pilot plant
  - RE – SSAS pilot plant → AK village(s)

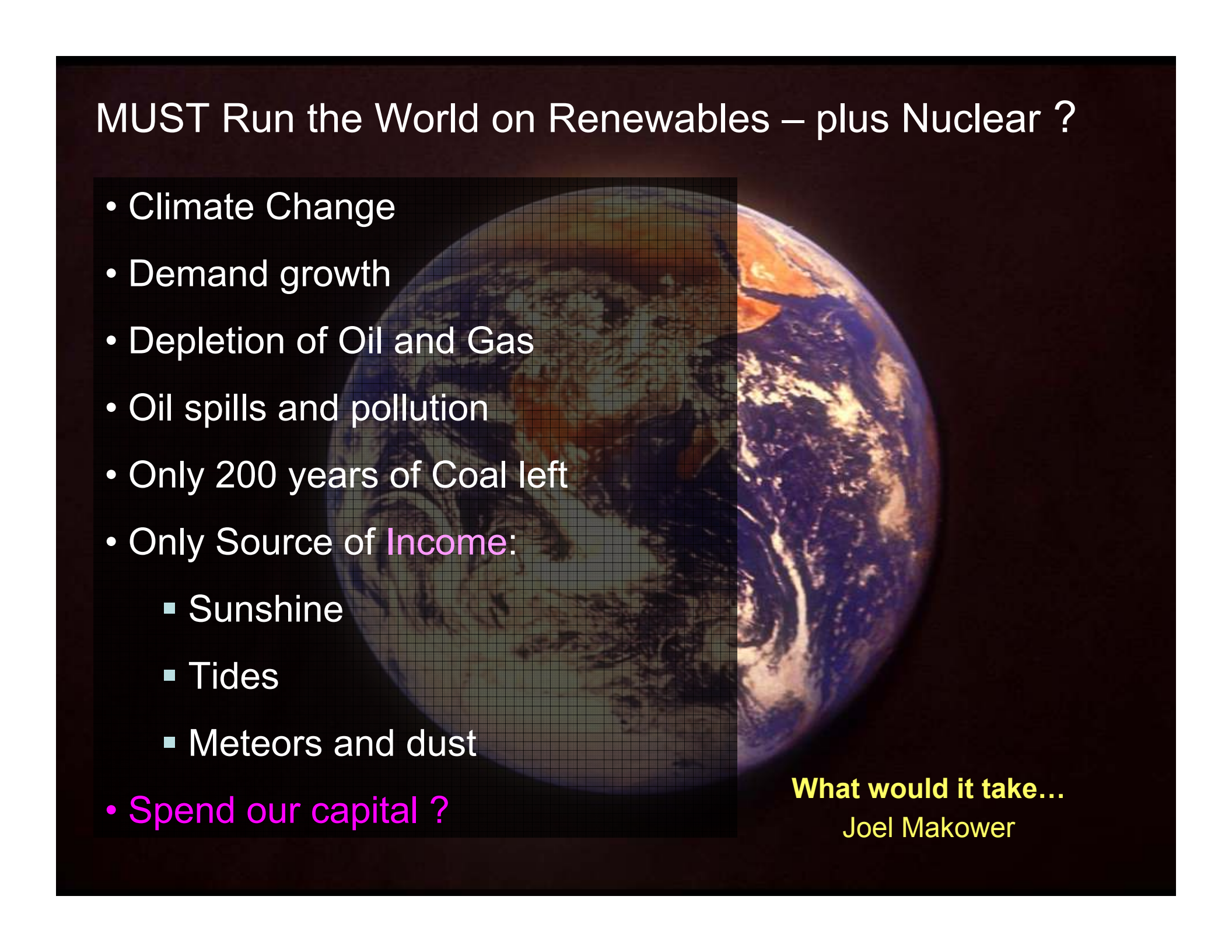
Alaska's Immediate Opportunity: SSAS

- Funding Collaboration: State of AK, Denali, Fed, Industry
  - $4-5M total R&D&Demo
  - EETG funds
    - SB220 State $2.5M
    - Denali Commission $2.5M
    - USDA: '08 Farm Bill Sec 9003 "RE Fertilizer Research"
- Set stage for GW-scale NH_3 export via SSAS
  - Diverse RE
  - Capital cost; CF; lower cost of energy (COE) ?
- Barriers
  - EPA: Ammonia not a fuel
  - DOE: Currently not interested; "toxic"; electricity transmis
  - Industry: too risky, no fuel market, hazardous

NH3 plant gate costs, per metric ton, estimate ~130 MMt / year global

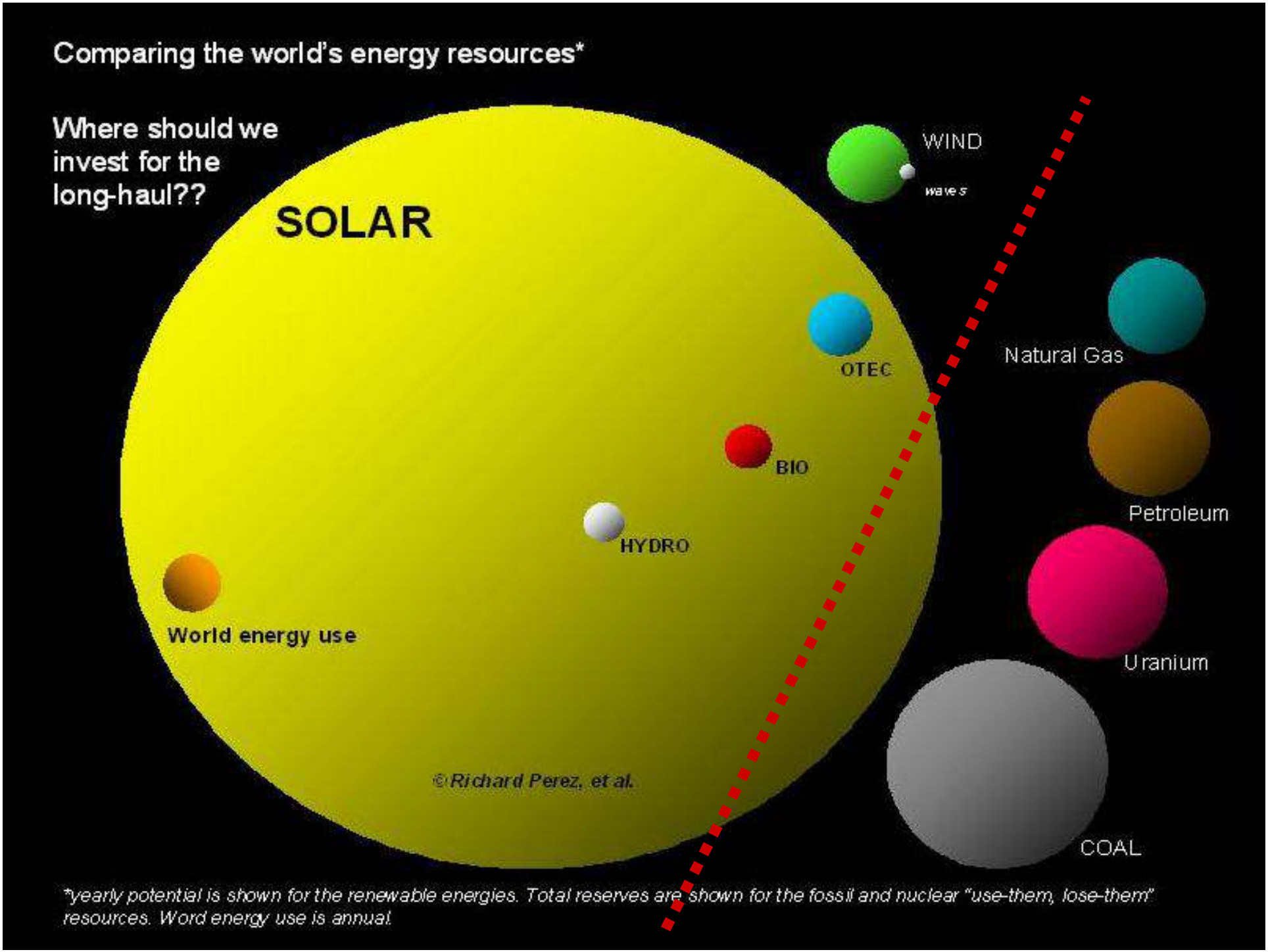
• Stranded NG → SMR → H-B	$ 200
• Wind → electrolysis → H-B	1,000
• Wind → SSAS	600

MUST Run the World on Renewables – plus Nuclear ?



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

What would it take…
Joel Makower


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

“ 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

Making Ammonia Fuel From Alaska's Abundant Stranded Renewable Energy

Ammonia Fuel Conference
Detroit, MI
27 September 10

Bill Leighty, Director
The Leighty Foundation
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DVD's available

SUMMARY: Dr. Majumdar, ARPA-E

- ARPA-E FOA applications
  - NHThree LLC — FIRST ROUND
  - Coffman + NHTHree LLC — GRIDS
  - Hydrogen Discoveries, Inc — GRIDS
  - Alaska Applied Sciences, Inc. — GRIDS
- AK laboratory: innovation + save $
  - 220 villages: islands, most have RE
  - Anhydrous ammonia (NH3) storage, fuel: "independence", survival
- Handoff: print, DVD, CD

END presentation

Following slides are supplementary

ARPA-E help

- “Broad Funding Announcement” current?
- Workshop on RE systems; global context
- Reconsider NH3 and GH2 proposals
- SSAS: Denali Commission ’09 proposal
- Ammonia a fuel: DOE list
- Send rep to 7th Ammonia Fuel Conference 27-28 Sept, Detroit

SUMMARY: Dr. Majumdar, ARPA-E

"Run world on renewables" problems:

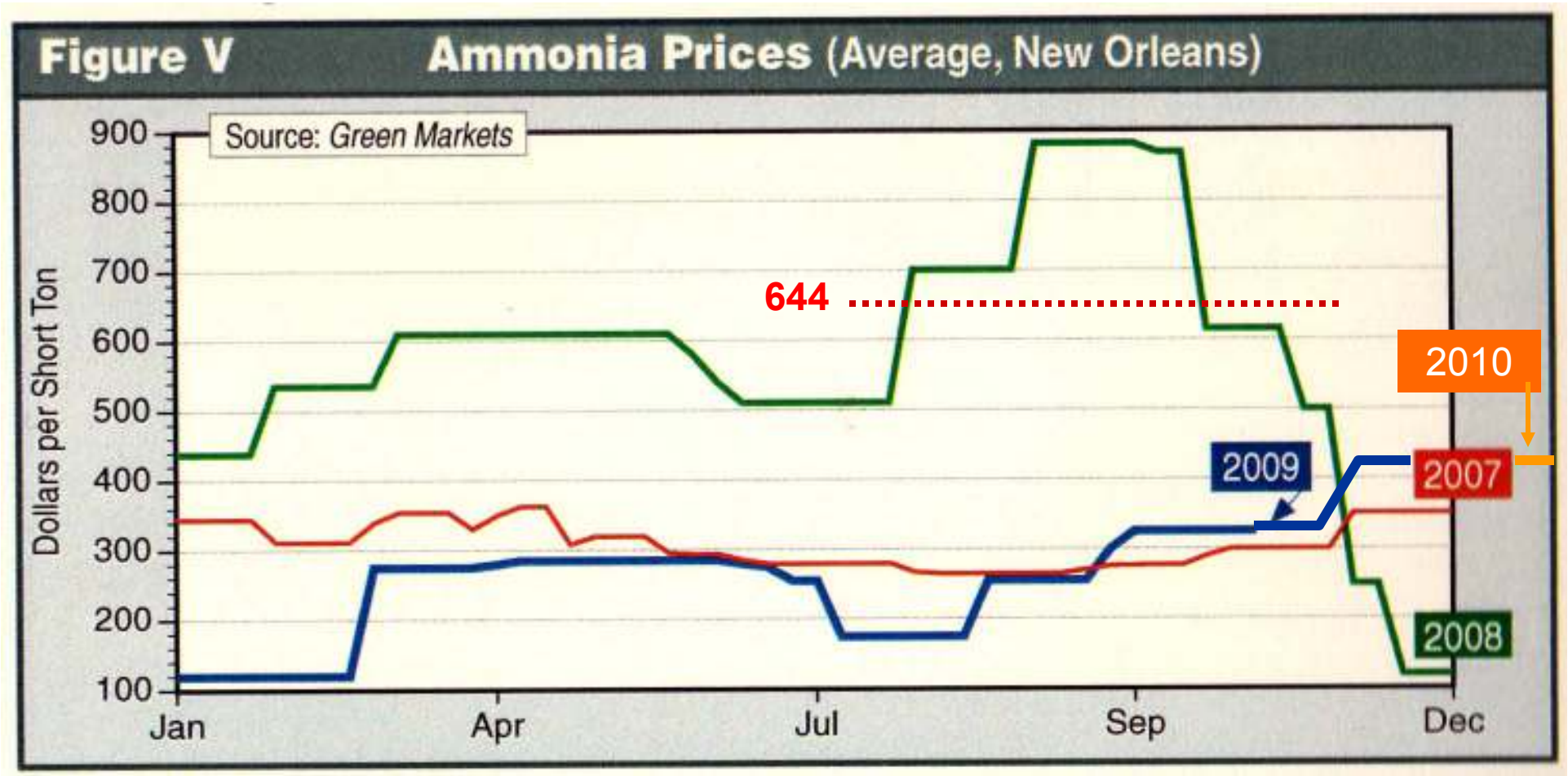
1. Transmission
2. Firming, dispatchable storage
3. Electricity grid integration
4. Curtailed RE generation

"Green" Ammonia (NH3) Output

- *> 2,000 MW Adak Wind- to- ammonia plant*
- *> $5 B total capital @ $2,500 / kW*
- *> 45% Capacity Factor (CF)*
- *> 12% Capital Recovery Factor (CRF)*

Windplant Annual Energy Production
As electricity: 7,884,000 MWh / year

	Electrolysis + H-B	SSAS
Sales: Mt (tons) / year	657,000	1,050,000
Total Cost of Sales:		
Capital @ 12% CRF	$600M	$600M
Plant O&M @ $0.03 / kWh	24M	24M
Input energy	0	0
TOTAL	$624M	$624M
Cost / Mt NH3	$ 949	$ 594
Shipping @ $50 / Mt	50	50
Total NOLA / Mt	$ 999	$ 644



Anhydrous Ammonia (NH3) wholesale price, NOLA (New Orleans, LA)

ARPA-E help

- Collaborative funding SSAS R&D&Demo:
  - $4 – 5M total
  - AK: SB220 “EETG”
  - AK: Denali Commission “EETG”
  - IA: Iowa Power Fund, OEI, State
  - ’08 Farm Bill Sec 9003 “RE fertilizer research”
  - ARPA-E “unsolicited”

Other Alaska GW-scale Stranded RE

- **Higher capacity factor (CF) → 100%**
- **Lower cost of energy (COE)**
- **Tanker transport affordable**
  - **Geothermal**
  - **Wave, tidal**
  - **Instream kinetic**
  - **Solar**
  - **Biomass**