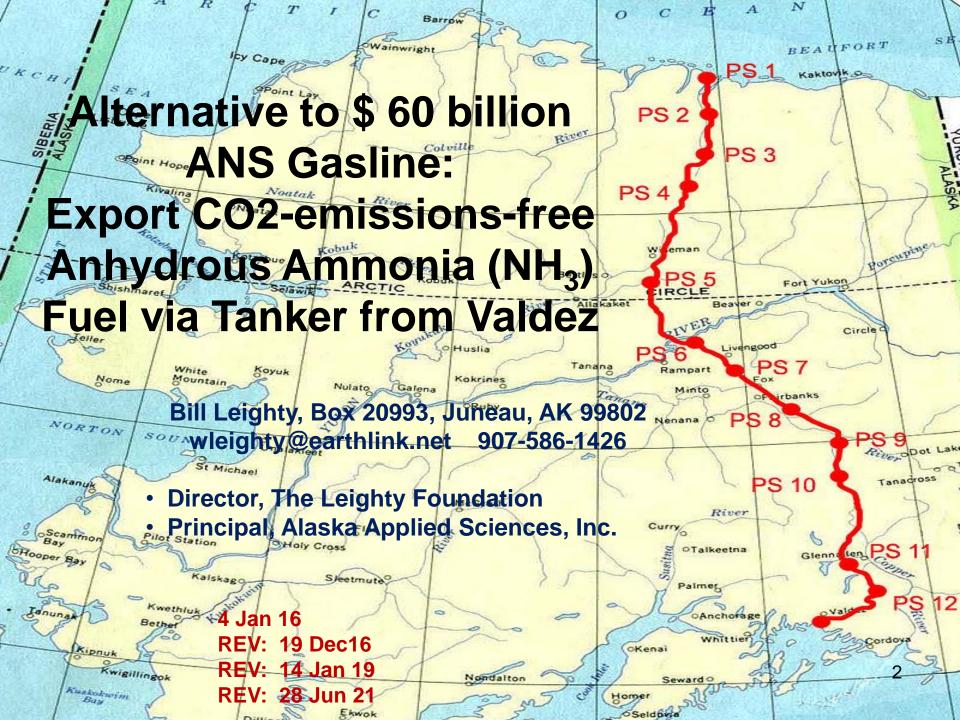
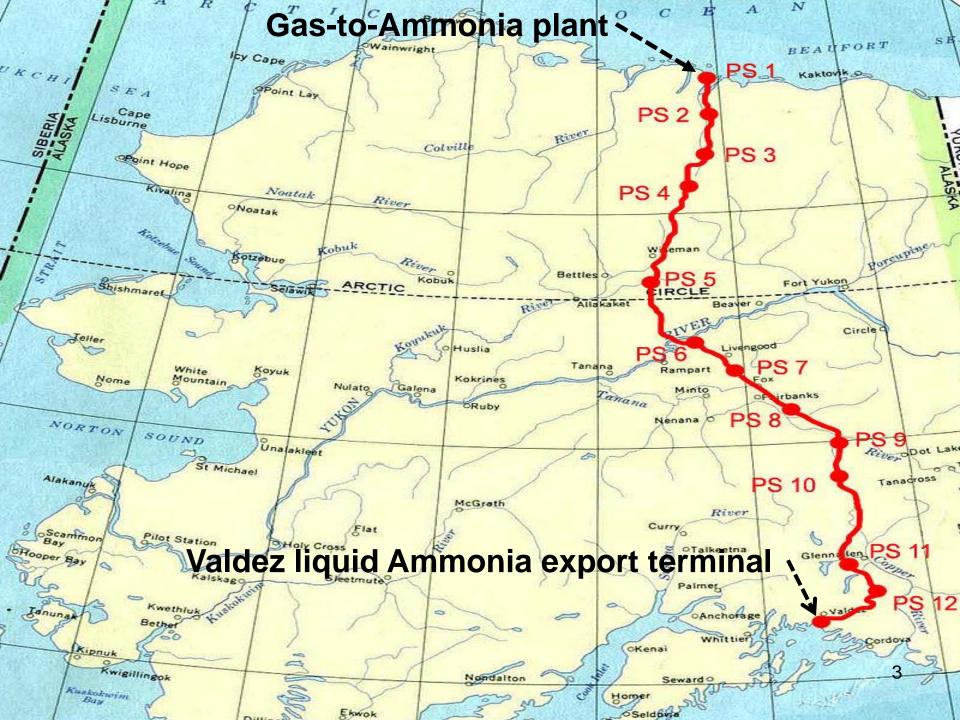
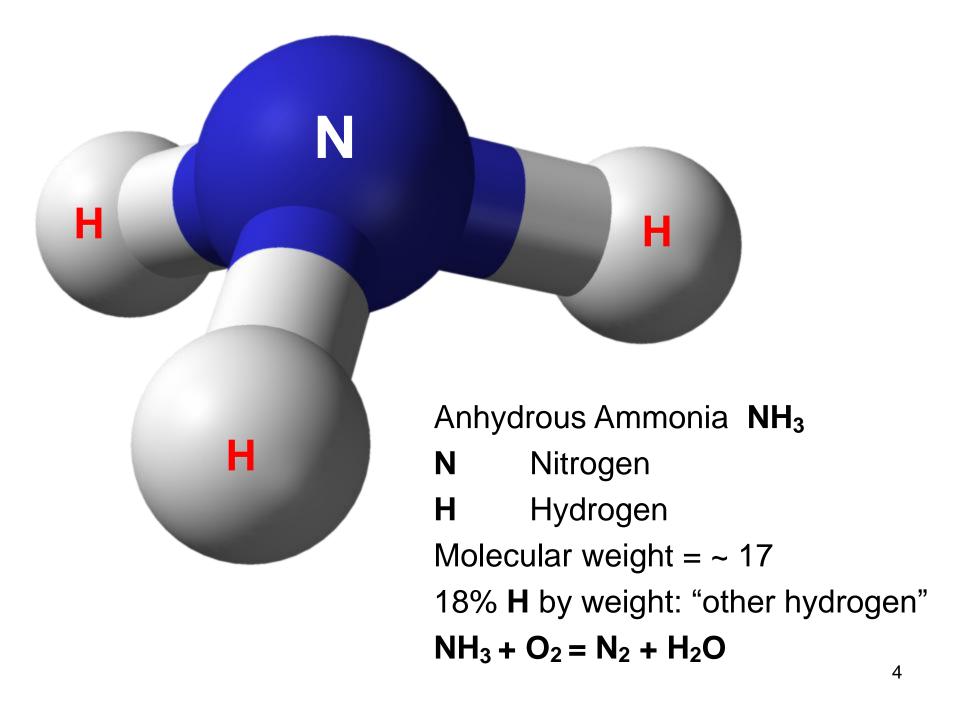




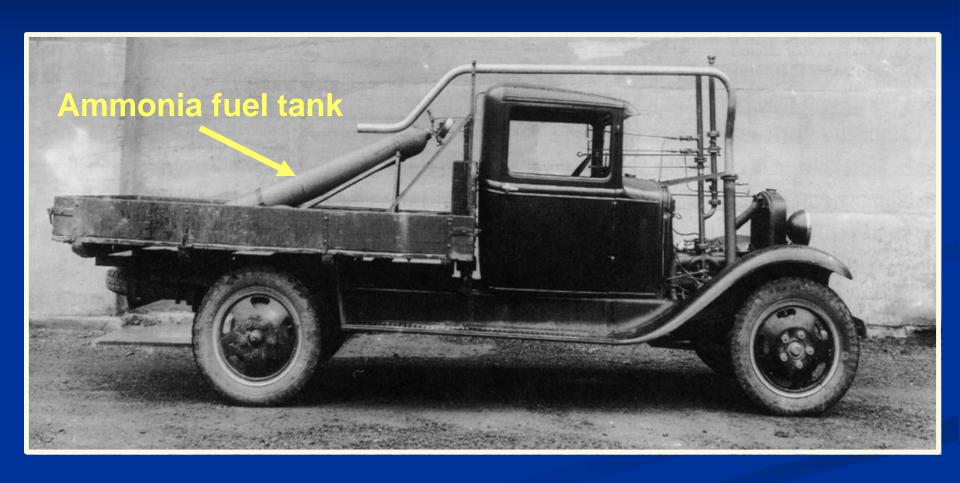
Exporting Alaska's Stranded Natural Gas as CO₂- emission- free "blue" Ammonia, a Carbon-free Hydrogen Transmission and Storage Medium and Fuel 1







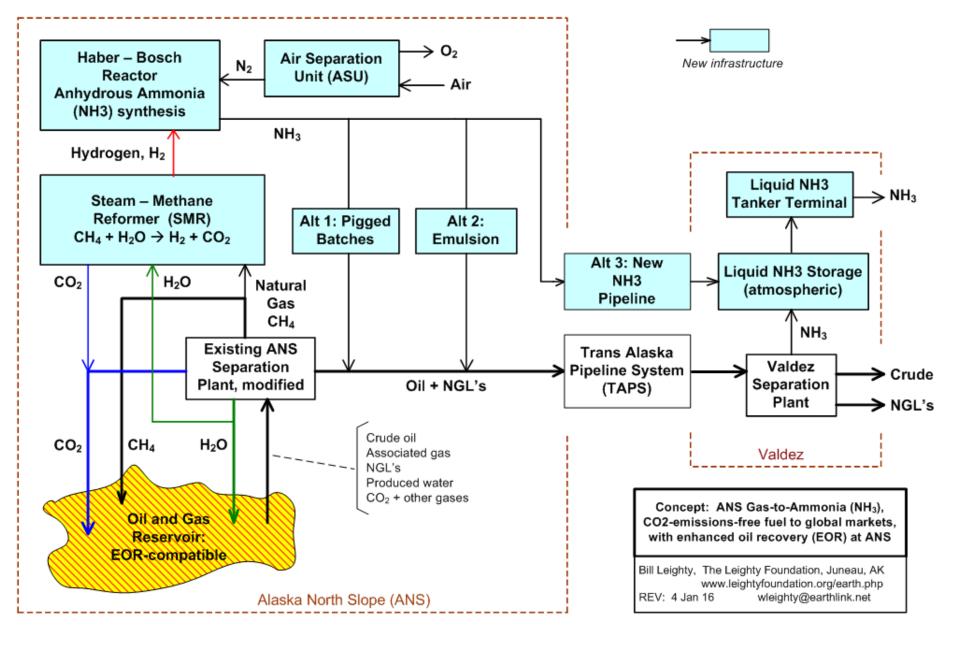
Ammonia fueled — Rjukan, Norway





Ammonia Fueled Bus: Thousands of Problem-free Miles 1943 6

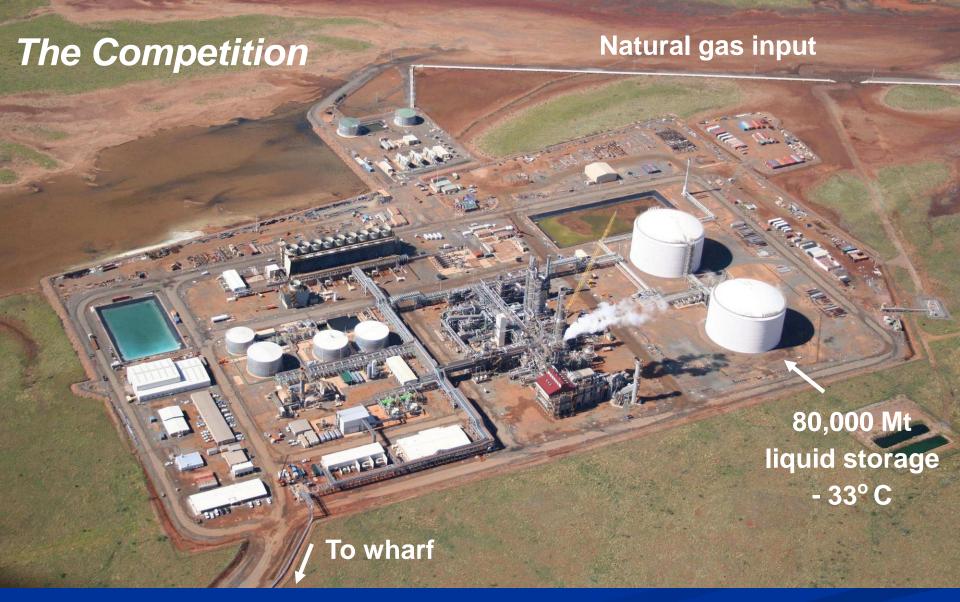








Valdez, Alaska oil export terminal A liquid anhydrous ammonia (NH₃) loading dock would be added⁰



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



Clipper Sirius 54,000 DWT LPG or NH3 tanker Fully refrigerated

Ammonia Synthesis

- Haber-Bosch process invented ~ 1905
- Steam Methane Reforming (SMR) of natural gas
 CH₄ + H₂O → H₂ + CO₂
- Hydrogen (from energy) + Nitrogen (from air)
 N₂ + (3) H₂ ← → (2) NH₃

Fundamentals - A

- 1. Convert natural gas (NG) to liquid NH₃ at ANS
- 2. Capture all byproduct CO₂; inject for EOR at ANS
- 3. Anhydrous Ammonia (NH₃) is a carbon-free fuel
- 4. Transport liquid NH₃ to new Valdez Terminal via:
 - a. Emulsion with crude oil in TAPS: Valdez phase separation
 - b. Pigged batches in TAPS (possible? piggable?)
 - c. New NH3 pipeline paralleling TAPS
- 5. Ship CO2-emissions-free "green" NH3
 - a. From new Valdez NH3 tanker terminal
 - b. 50,000 Mtd (metric tons per day) = 1 tanker per day
 - c. Japan is apparent first market: is NH3 "green"?
 - d. 50,000 Mtd = barrels NH3 per day

Fundamentals - B

- 6. Value added to TAPS
- 7. High economic potential
 - a. Income, NCF
 - b. Return on investment, ROI
 - c. Long ANS gas resource life
- 8. Mature technology: gas-to-ammonia
- 9. Mature market:
 - a. NH3 second-highest-volume chemical, global
 - b. Mostly for N-fertilizer
 - c. Many commodity tankers
- 10. Nascent fuel market:
 - a. Hydrogen-rich, High H density
 - b. C-free fuel
- 11. Is this ANS-source NH3 "green", with CO2 EOR? Will Japanese, and others, buy it?

If TAPS transmission is available:

- Both technically + economically feasible
- Pigged batch or emulsion methods
- ANS "green" NH₃ production staged:
 - Pilot plant $\sim 3,000$ short tons (tons) / day = 25,000 bpd
 - Valdez terminal needed:
 - Liquid NH₃ storage tank
 - Tanker loading dock
- Scaleup to 50,000 tons / day NH₃, requires 1.6 bcfd CH₄
 - Gas-to-NH3 plant trains @ 3,000 5,000 tons / day
 - $50,000 \text{ tons / day NH}_3 = 418,000 \text{ bpd}$
 - Market growth for "green" NH₃
- Value added to TAPS?
 - Increase flow, longer useful life
 - Lower viscosity, less pumping energy
 - Increase revenue
 - O&M cost savings

If TAPS transmission NOT available:

- 1. New liquid NH3 pipeline necessary
 - ANS to tidewater
 - To Valdez or Nikiski?
 - Parallel TAPS, share ROW, pump stations?
- 2. Optimum pipeline capacity?
- 3. Project profitability effect
- 4. No TAPS benefits

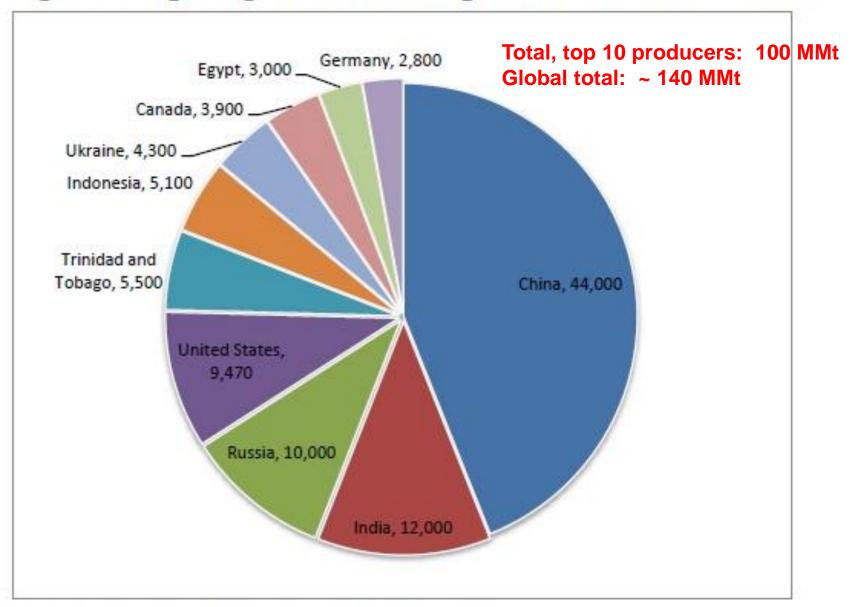
Jim Gosnell, consultant, quick study: 28 Nov 16 Houston meeting consulting contract to Alaska Applied Sciences, Inc.

- 1. 50,000 tpd NH₃: world's largest Ammonia plant
- 2. 50,000 tpd fresh, purified, feedwater: from produced?
- 3. Would double global NH₃ exports; total new tanker fleet
- 4. Capex \$ 200 million per 1,000 tpd: \$ 10 Billion @ USGC
- 5. ANS construction cost multiplier?
- 6. Unproven mixing crude + NH₃: Shell patents old
- 7. Unknown TAPS compatibility: pump stations; fuel
- 8. Unknown CO₂ value to ANS oil owners
- 9. Unknown price for ANS methane feedstock to NH₃ plant
- 10. Unknown benefit to TAPS: life extension, shut-in oil

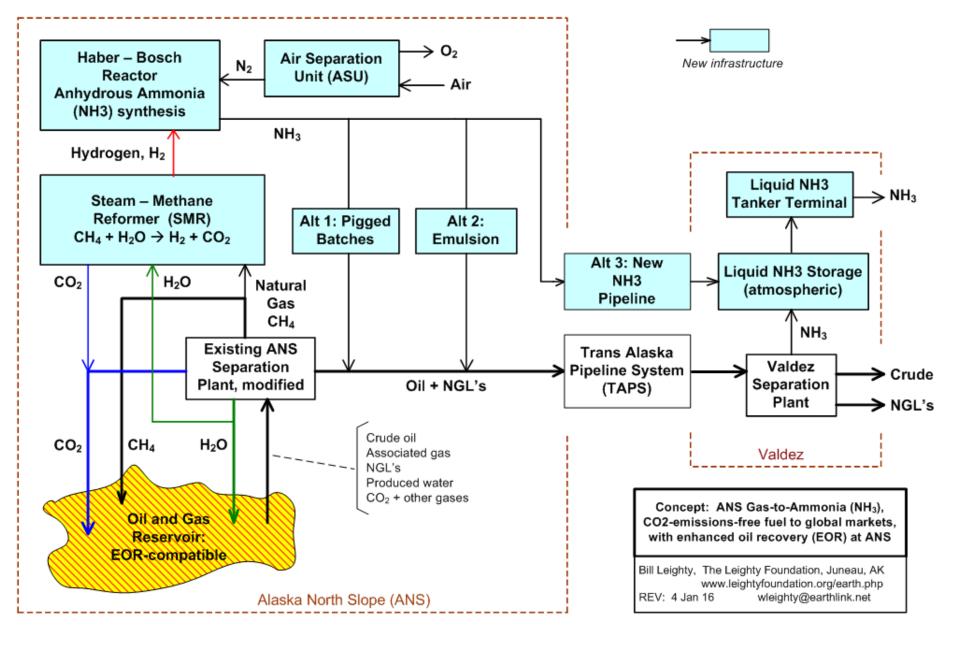
Jim Gosnell, consultant, quick study: 28 Nov 16 Houston meeting consulting contract to Alaska Applied Sciences, Inc.

- How separate High-purity NH₃ from crude at Valdez ?
- Unknown market for "green" NH₃; competition
- High-risk project for EPC companies
- Assume high capacity factor (CF, UF)
- ANS methane price \$ 0.50 / MMBtu ?
- ~ 60,000 tpd CO₂ byproduct: sequester; value to ANS?
- Profitability uncertain
- Competition with CCS anywhere?

Figure 2. Top ten global ammonia producers, 2012 (k tonnes)



Source: Authors' elaboration on USGS (2013).



Econ Modeling Assumptions

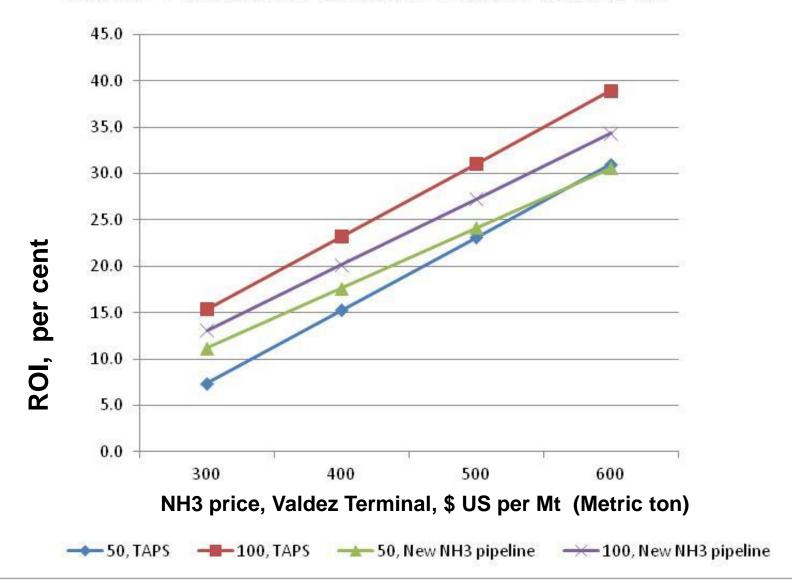
- Financing term
- Annual simple Interest rate, debt
- Cost of equity
- Debt financing portion
- Equity financing portion
- Weighted average cost of capital
- Debt : Equity ratio
- Alaska construction cost multiplier

- 30.0 years
- 6.0 per cent
- 12.0 per cent
- 100.0 per cent
- 0.0 per cent
- 6.0 per cent
- **INF** Ratio
- 1.5 Multiplier

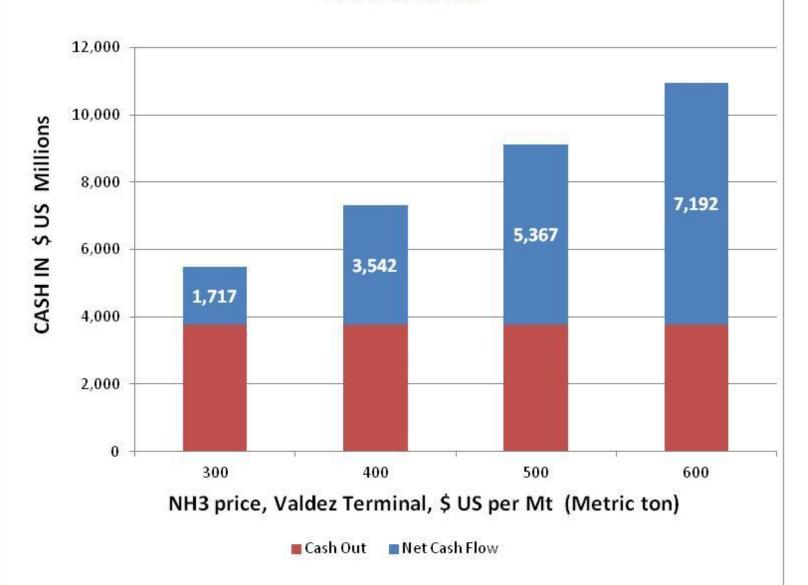
Simple ROI, ANS gas-to-Ammonia (NH3). 50,000 and 100,000 Mt / day

TAPS: NH3 from ANS to Valdez as pigged batch or emulsion

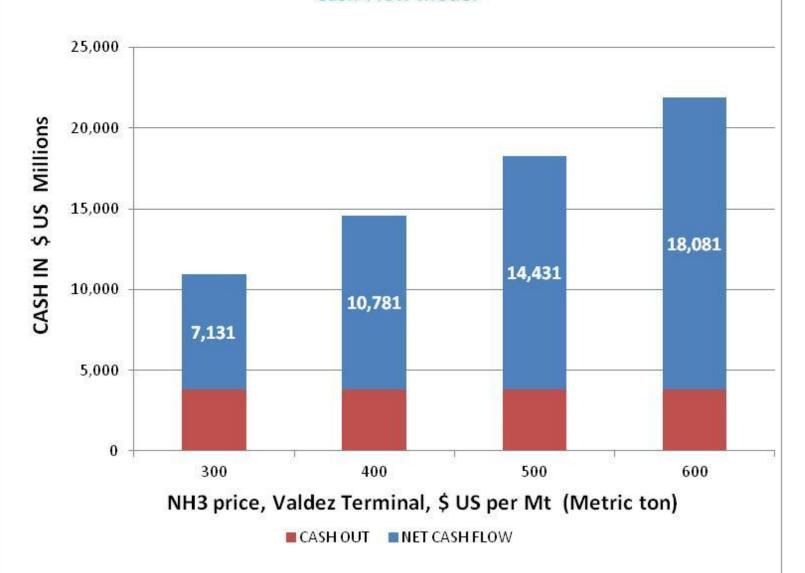
New NH3: If TAPS inavailable, via new liquid NH3 pipeline paralleling TAPS



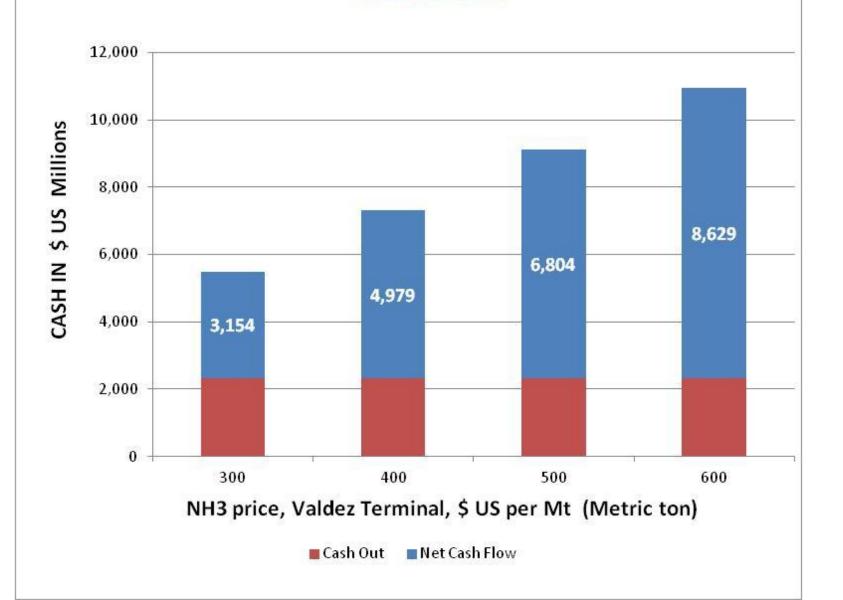
50,000 Mtd (Metric tons per day) Liquid NH3 via TAPS, ANS to Valdez



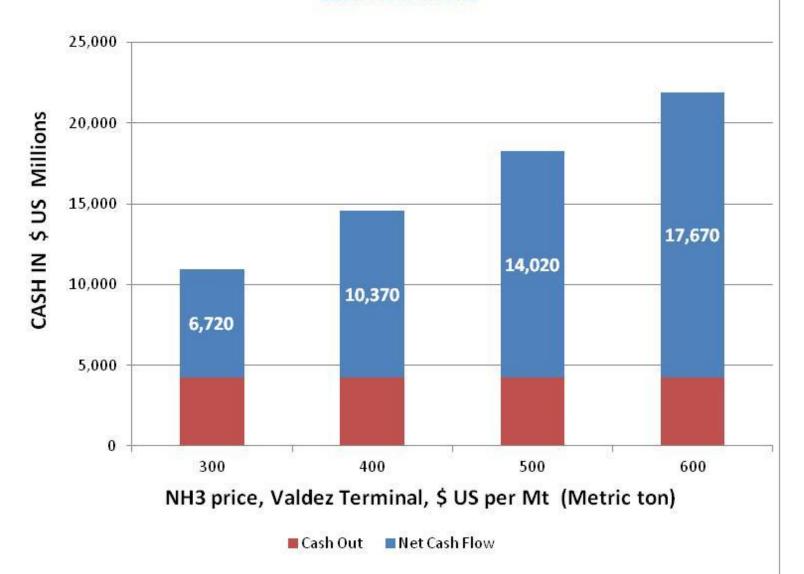
100,000 Mtd (Metric tons per day) Liquid NH3 via TAPS, ANS to Valdez



50,000 Mtd (Metric tons per day) Liquid NH3 via new NH3 pipeline, paralleling TAPS, ANS to Valdez



100,000 Mtd (Metric tons per day) Liquid NH3 via new NH3 pipeline, paralleling TAPS, ANS to Valdez



Markets - A

 Japan to import CO2-emission-free Hydrogen as "green" liquids via ocean commodity tankers as "Energy Carriers": http://www.jst.go.jp/sip/pdf/SIP_energycarriers2015_en.pdf

Liquid Hydrogen (LH2, -250 deg C)

Liquid Anhydrous Ammonia (NH3)

Toluene ← → Methylcyclohexane

Is ANS gas-source NH3 "blue"? CO2 for EOR

- Complete renewable energy systems:
 - Gathering and transmission
 - Annual-scale firming storage
 - Distribution, integration, end-use

Kawasaki

Sumitomo

Chiyoda



Siemens:

- http://www.energy.ox.ac.uk/wordpress/wp-content/uploads/2016/03/Green-Ammonia-Hughes-8.3.16.pdf
- https://www.siemens.co.uk/en/insights/potential-of-green-ammonia-as-fertiliser-and-electricity-storage.htm
- http://www.bloomberg.com/news/articles/2016-04-20/green-ammonia-made-withwind-is-future-of-fertilizer-at-siemens

Markets - C

- NH3 is fuel, chem feedstock, as well as N-fertilizer:
 - High-Hydrogen density fuel, energy carrier
 - Low-cost liquid storage: 10 bar or refrig "atmospheric"
 - ICE, CT, fuel cell: efficient, exhaust water + N2 → atmos
 - "The other Hydrogen": only 2 Carbon-free fuels
- Complete renewable energy systems:
 - Gathering and transmission
 - Annual-scale firming storage
 - Distribution, integration, end-use
- Other global markets?

Conclusions

- 1. Exporting ANS gas as "green" NH₃ fuel may be more profitable than exporting LNG. Or:
 - It may be unprofitable
 - It may not compete with "blue" NH₃ produced near tidewater
 - Profitability largely determined by:
 - ANS values for methane (CH₄) and CO₂
 - Value of liquid NH₃ mixed with crude oil for TAPS operations
- 2. If ANS tech and econ conditions are positive:

This strategic option should be thoroughly studied by a collaborative of all parties to test for relevance, economic assumptions, market, technology, profitability: \$50 – 100 K preliminary consulting cost

- 3. This study is not:
 - Ready for public attention
 - Confidential nor proprietary
 - Accurate
- 4. Japan may be the key market for "blue" NH₃
 - Interest in importing "liquid hydrogen" fuels, CO₂ emission free
 - When include them in study? Via whom?
 - What price range for NH₃ FOB Valdez ?

If TAPS transmission is available:

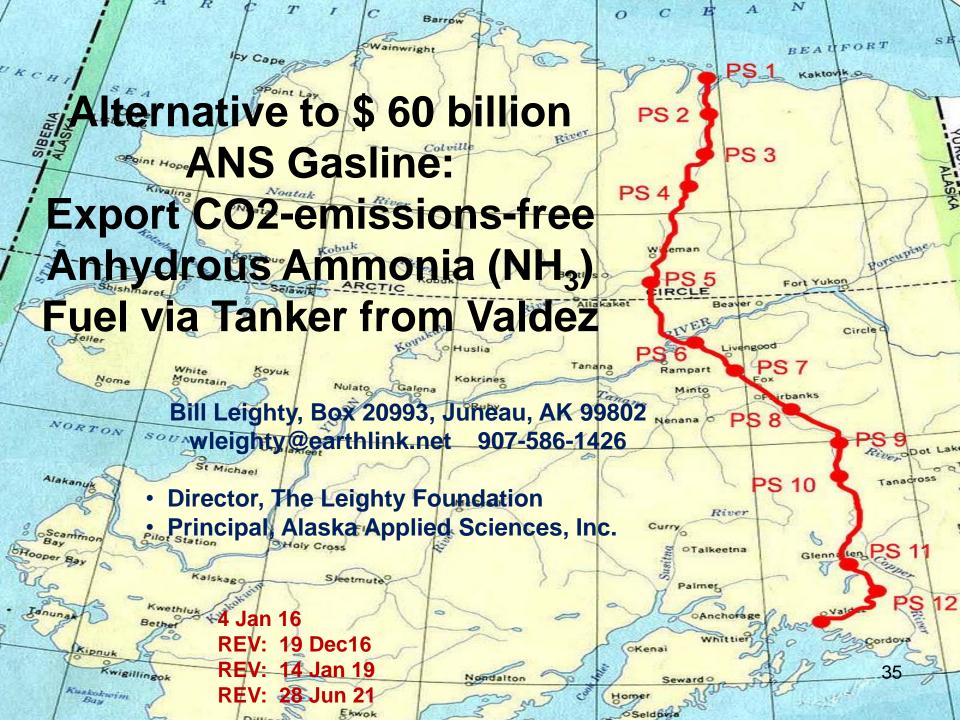
- Both technically + economically feasible
- Pigged batch or emulsion methods
- ANS "green" NH₃ production staged:
 - Pilot plant $\sim 3,000$ short tons (tons) / day = 25,000 bpd
 - Valdez terminal needed:
 - Liquid NH₃ storage tank
 - Tanker loading dock
- Scaleup to 50,000 tons / day NH₃, requires 1.6 bcfd CH₄
 - Gas-to-NH3 plant trains @ 3,000 5,000 tons / day
 - $50,000 \text{ tons / day NH}_3 = 418,000 \text{ bpd}$
 - Market growth for "green" NH₃
- Value added to TAPS?
 - Increase flow, longer useful life
 - Lower viscosity, less pumping energy
 - Increase revenue
 - O&M cost savings

Alternatives to this scheme:

- 1. New, dedicated liquid NH₃ pipeline parallels TAPS
 - To new NH3 tanker terminal at Valdez
 - Shared ROW, pumping stations
 - From new, large, ANS gas-to-NH₃ plant
 - Pipeline size, capacity (NH₃ tpd), ANS gas consumption ?
- 2. New, dedicated gaseous H2 (GH2) pipeline parallels TAPS
 - From large ANS SMR plant with 100% CCS of CO2
 - To new H-rich liquids processing plant at Valdez
 - Output may be: LH2, NH3, methylcyclohexane (ex toluene) liquid fuels
 - To new tanker terminal at Valdez for H-rich liquids
- 3. ANS gas-to-NH₃ plant produces only enough NH₃ to keep TAPS operating well: hydraulics + economics optimum. Sell delivered NH3 at Valdez as "blue", at market price

Next steps

- 1. Expert conceptual analysis:
 - ANS factors: cost, price, value
 - Showstoppers?
 - Continue investigation? By, for whom? Cost, time?
- 2. TAPS compatible?
 - Pigged batching
 - Emulsion and / or coaxial materials separation
 - Cost to modify
 - Pilot at 3,000 Mt / day Liquid Ammonia
- 3. ANS compatible for CO2-driven EOR?
 - CO2 value to ANS O&G owners
 - Methane value to ANS O&G owners
 - Max volume desired, MMscfd
- 4. With whom discuss next?
 - AK DNR Commissioner
 - Japan colleagues
- 5. Cost, feasibility: build large gas-to-NH3 plant at ANS







Exporting Alaska's Stranded Natural Gas as ${\rm CO_2}$ - emission- free "blue" Ammonia, a Carbon-free Hydrogen Transmission and Storage Medium and Fuel₃₆

End presentation 28 June 21

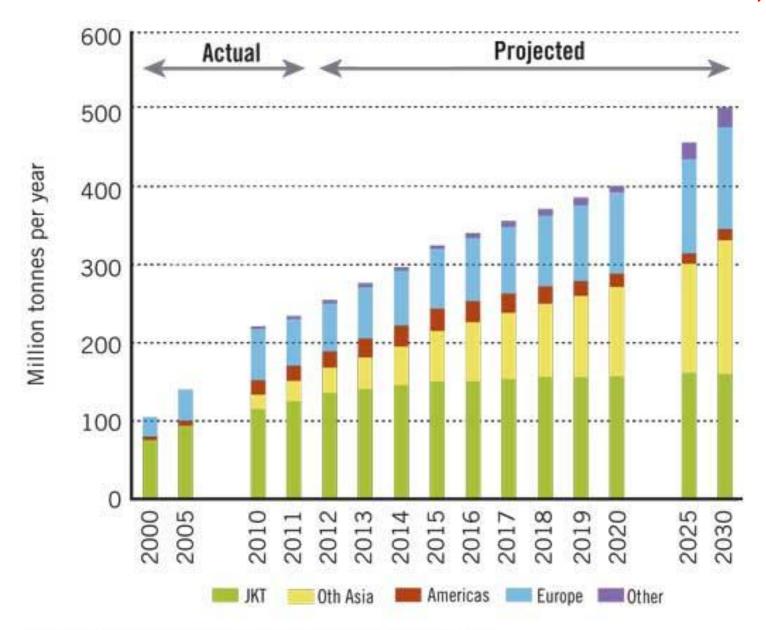
Following slides are supplemental

End presentation 20 Dec 2016 Revised 14 Jan 19

Following slides are supplemental

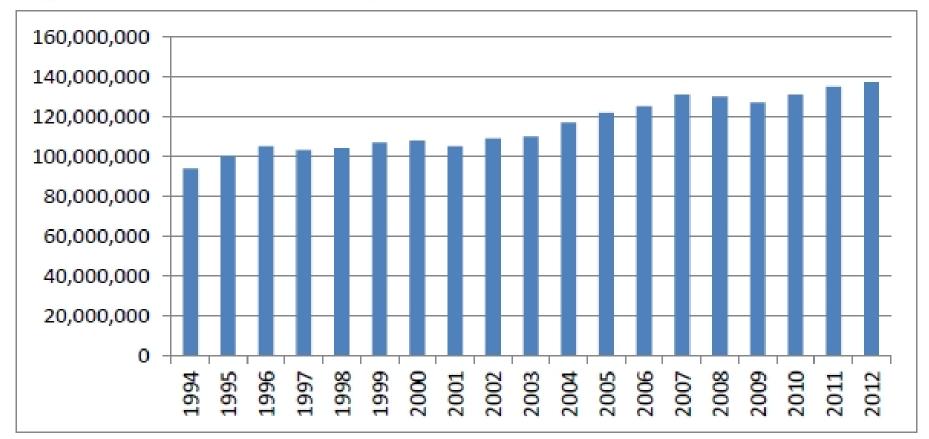
Fig. 1: Global LNG demand

Compare with Global Ammonia Demand, next slide



39

Figure 1. Global ammonia production (tonnes)



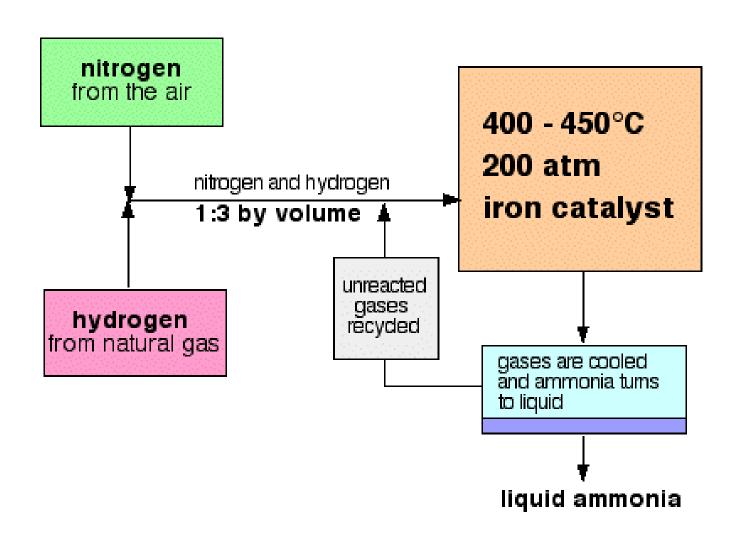
Source: Authors' elaboration on USGS (2013).

EOR resources

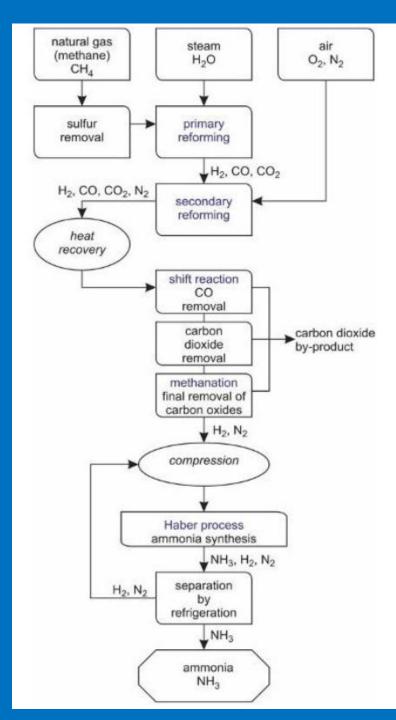
- http://www.ogj.com/articles/print/volume-112/issue-4/special-report-eor-heavy-oil-survey/co-sub-2-sub-eor-set-for-growth-as-new-co-sub-2-sub-supplies-emerge.html
 Enid, OK Koch Nitrogen plant
- 2. http://neori.org/resources-on-co2-eor/how-co2-eor-works/
- 3. http://neori.org/resources-on-co2-eor/how-co2-eor-works/
- 4. file:///C:/Data/EOR-AHEAD%20Energy%20CO2%20Enhanced%20Oil%20Recovery.html
- 5. https://www.netl.doe.gov/file%20library/research/oil-gas/small_CO2_EOR_Primer.pdf

CO2-emission-free "Green" NH₃ resources

- http://www.energy.ox.ac.uk/wordpress/wp-content/uploads/2016/03/Green-Ammonia-Hughes-8.3.16.pdf
- 2. https://www.siemens.co.uk/en/insights/potential-of-green-ammonia-as-fertiliser-and-electricity-storage.htm
- 3. http://www.bloomberg.com/news/articles/2016-04-20/green-ammonia-made-with-wind-is-future-of-fertilizer-at-siemens

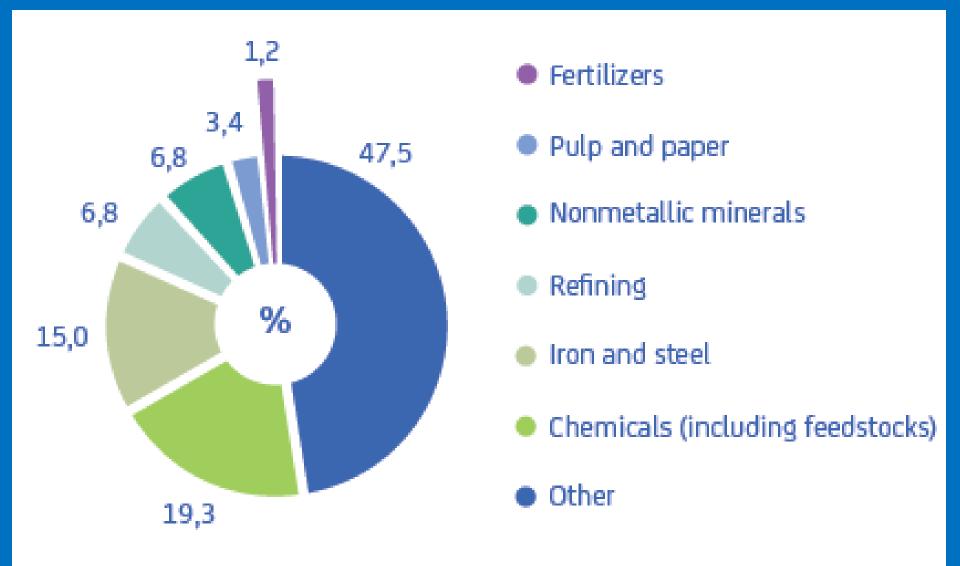


Ammonia (NH3) synthesis

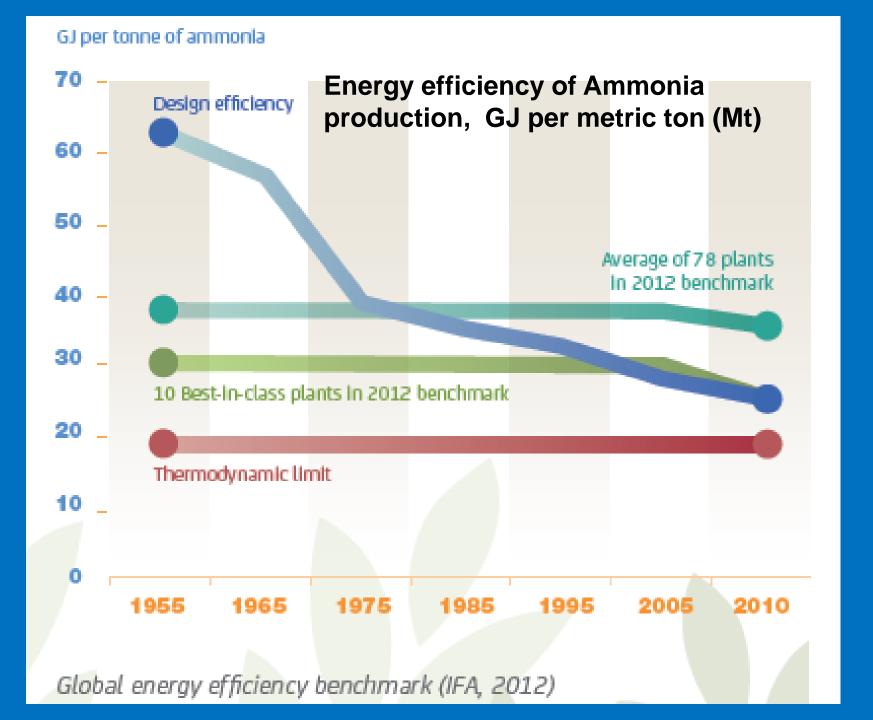


Conventional Anhydrous Ammonia (NH3) Synthesis Plant Train

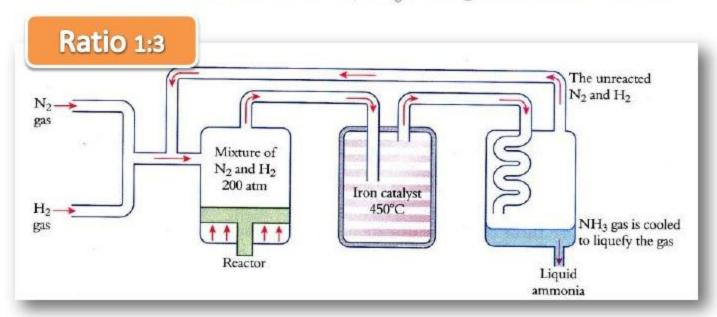
- Inputs:
 - Natural gas (methane)
 - Water
 - Air
- Typical 1,000 Metric ton per day per train
- CO2 byproduct usually wasted to air
- Typical "Ammonia plant" is 2 3 trains
- Total



World industrial energy consumption by sector (EIA, 2010)



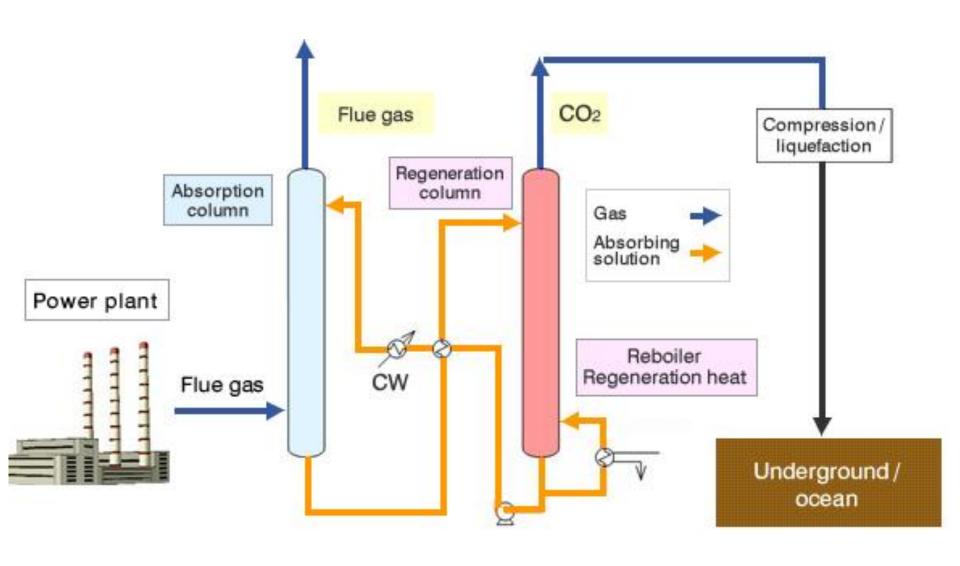
The Manufacture of Ammonia, NH₃ through the Haber Process



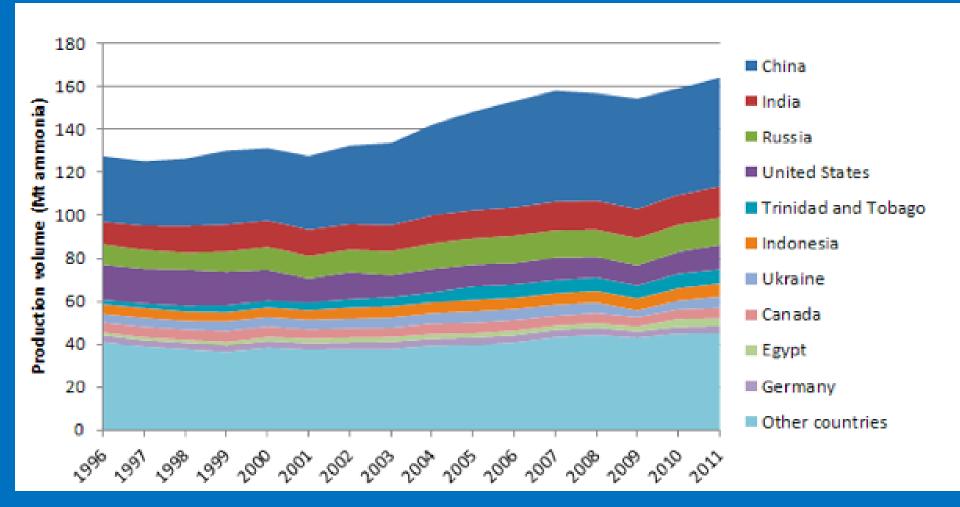
 $N_2(g) + 3H_2(g) \leftarrow \rightarrow 2NH_3(g)$

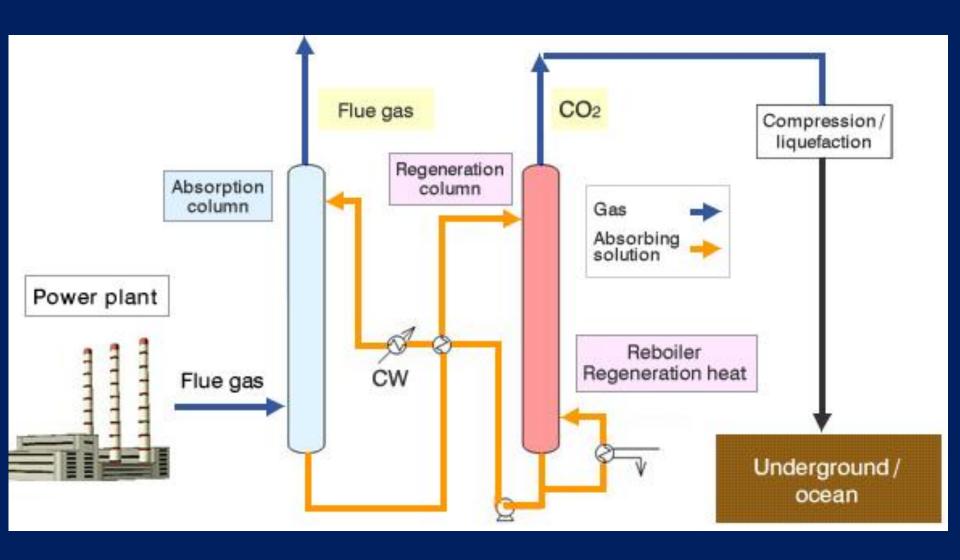
5/16/2010

rebeccacheorn@gmail.com 458 Chemistry, Catholic High School, PJ (2010)

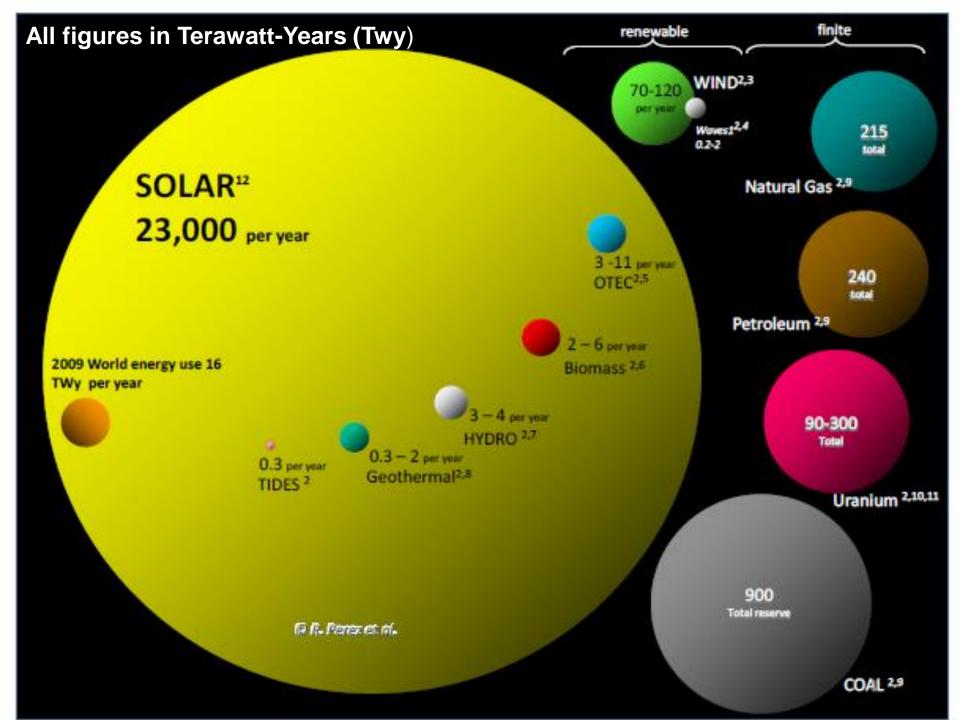


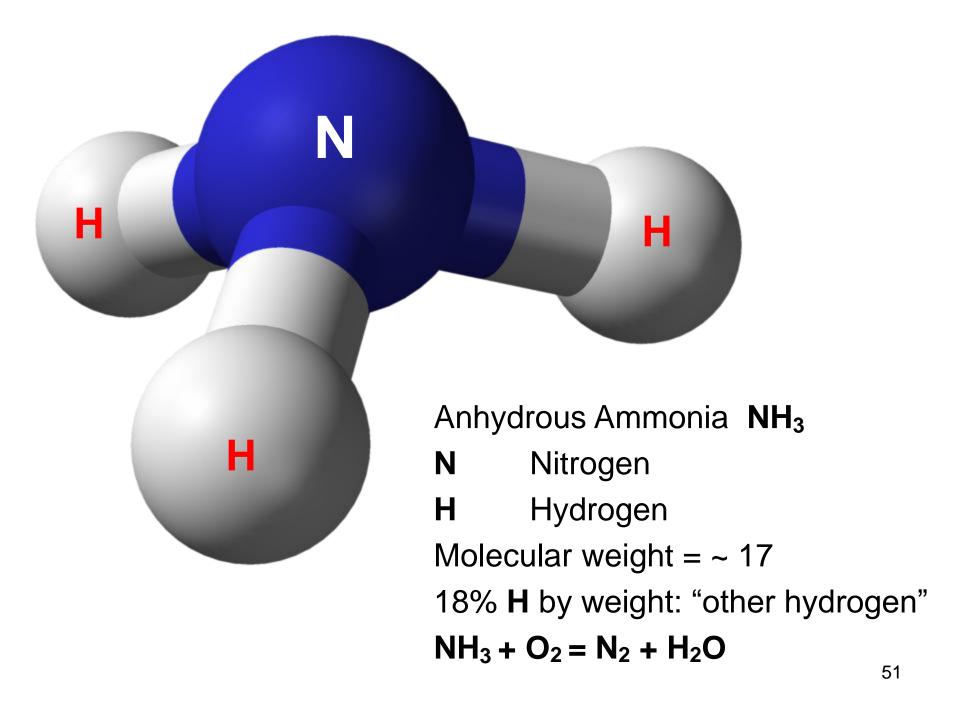
CCS from coal plant exhaust



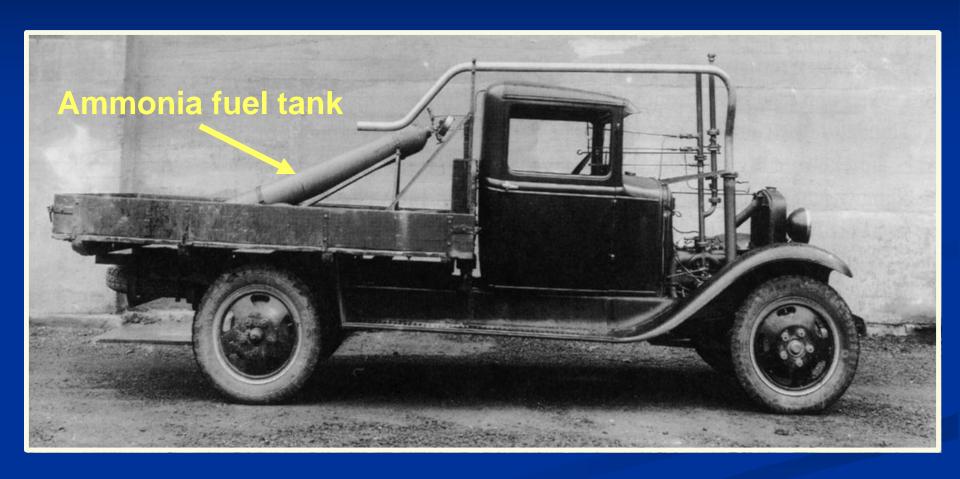


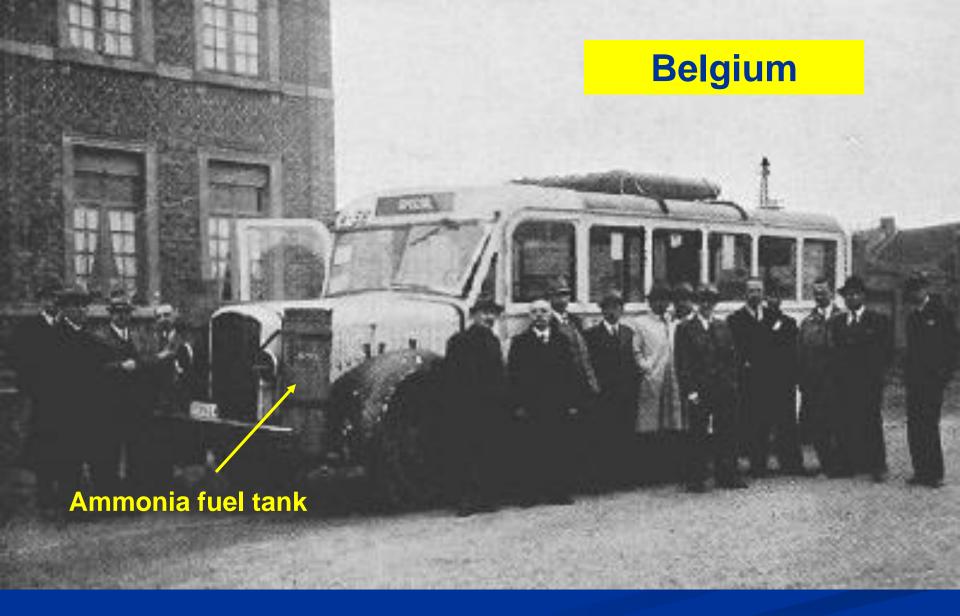
CCS from coal plant exhaust





Ammonia fueled — Rjukan, Norway





Ammonia Fueled Bus: Thousands of Problem-free Miles 1943₅₃



Ammonia Fuel Uses

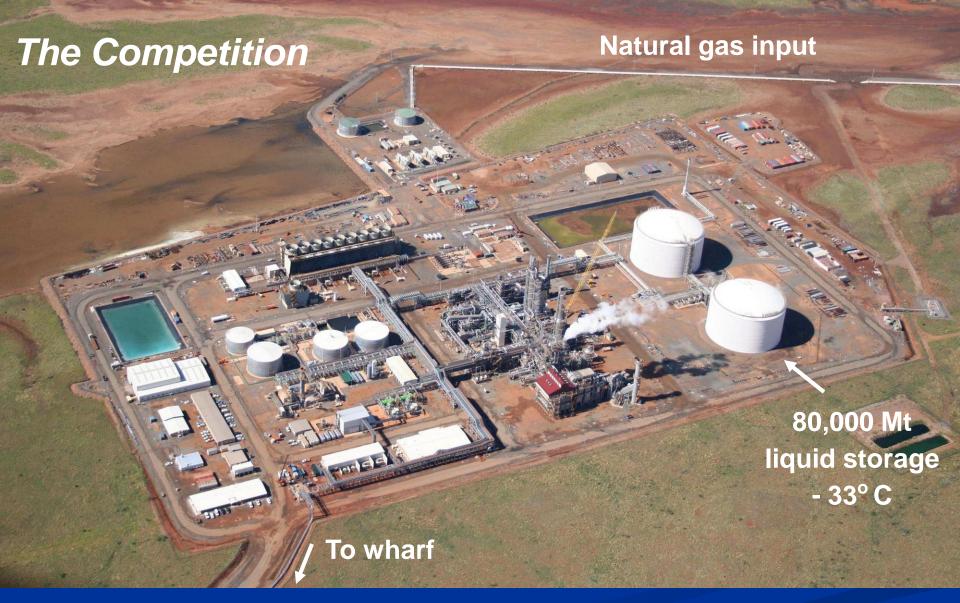
- 1. Internal Combustion Engine (ICE)
 - Diesel: NH₃ gas mixed with intake air
 - Spark-ignition: 70%+ NH₃ plus
 gasoline, ethanol, propane, NG, hydrogen
 - NOx ~ ¼ gasoline engines
- 2. Combustion Turbines
- 3. Direct Ammonia Fuel Cells:
 - Combined heat + power (CHP)
 - No NOx
- 4. Reform ("crack") to liberate hydrogen for fuel
 cells: 2NH₃ → 3H₂ + N₂



95% Global Ammonia

Synthesis
Plant
Natural Gas
1 – 3,000 tpd

Haber-Bosch process



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



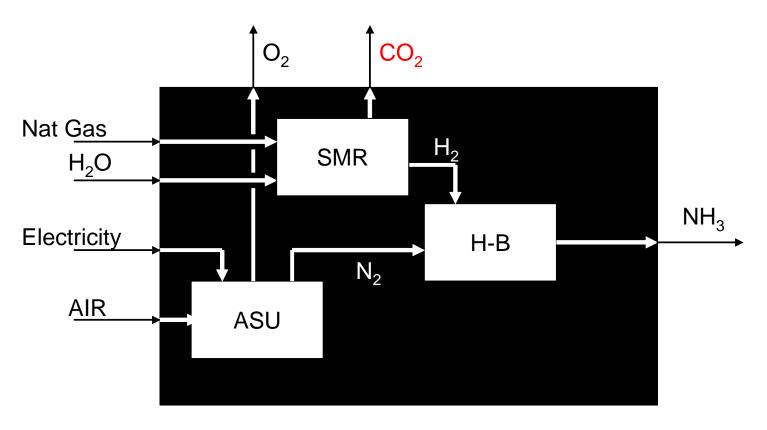
Haber-Bosch Process 1909 – 1913 BASF

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

Haber-Bosch Reactor
1921
Ludwigshafen, Germany

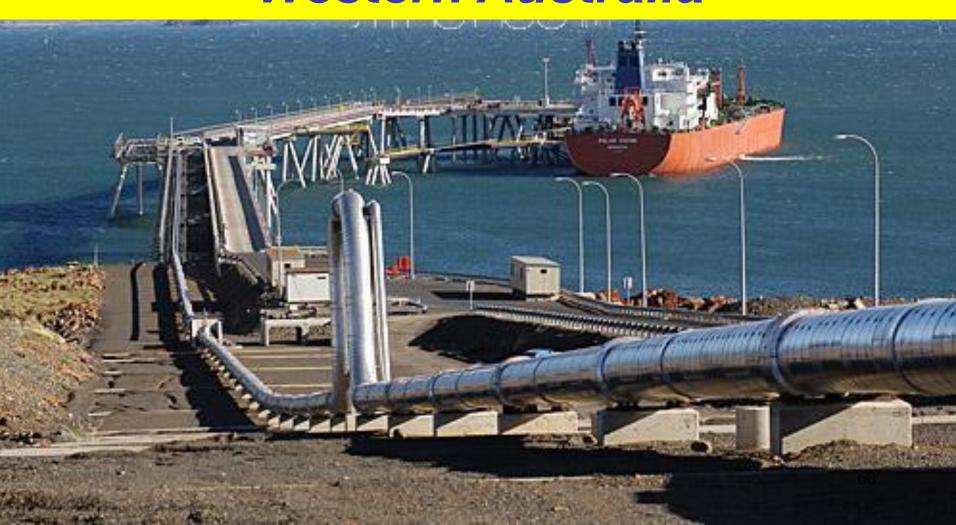
Inside the Black Box: Steam Reforming + Haber-Bosch (H-B)

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



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

Ammonia Tanker Burrup Peninsula Western Australia





Ammonia or LPG Tanker

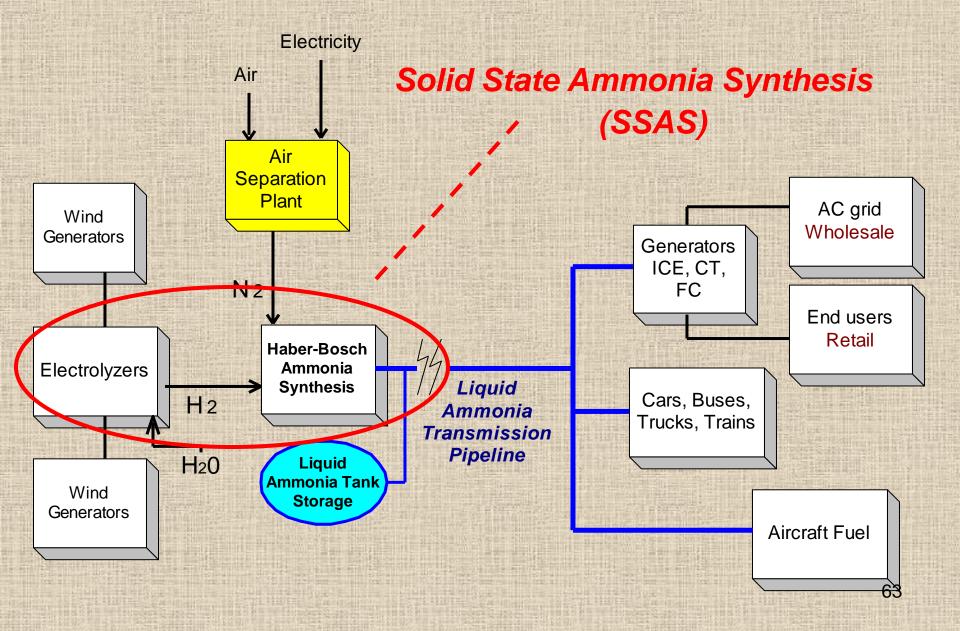
To 35,000 Mt

Refrigerated



Clipper Sirius 54,000 DWT LPG or NH3 tanker Fully refrigerated

RE Ammonia Transmission + Storage Scenario



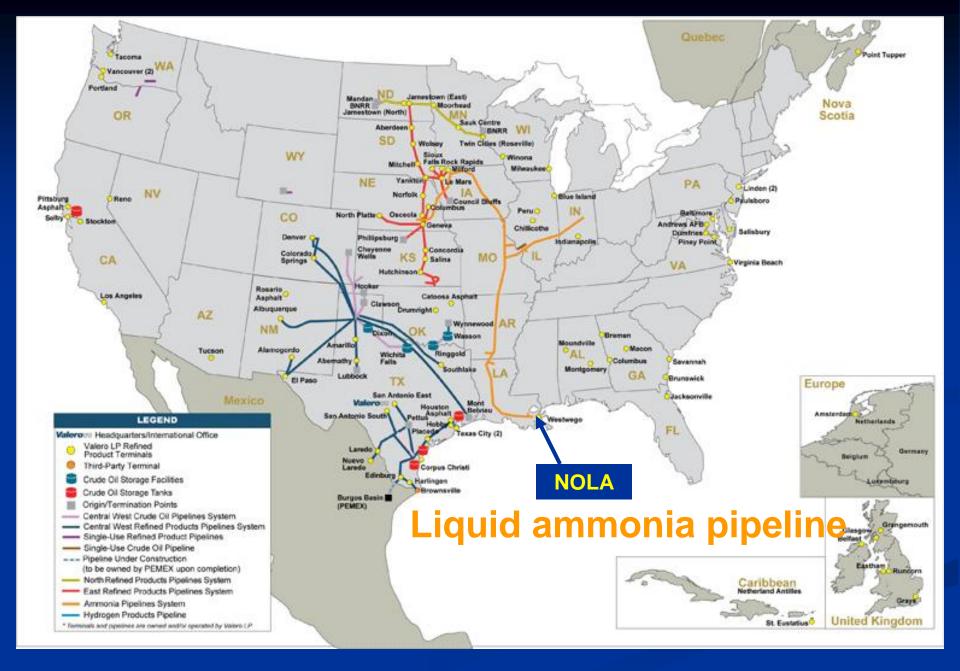


"Atmospheric" Liquid Ammonia Storage Tank (Corn Belt)

-33 C 1 Atm

Each: 30,000 Tons, 190 GWh \$ 15M turnkey

\$80/MWh = \$0.08/kWh capital cost



Capital Cost per GW-mile

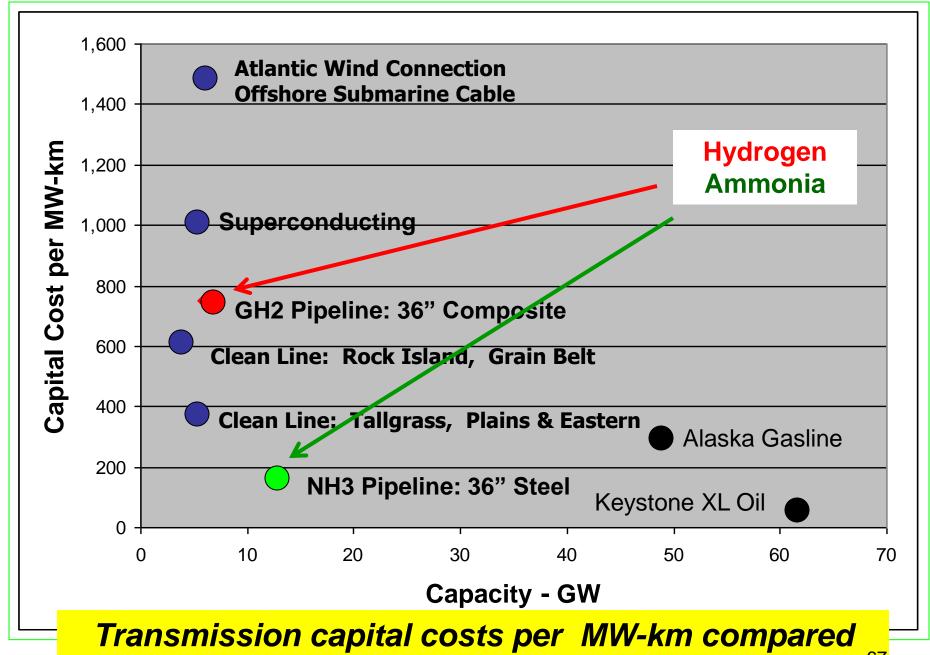
Electricity:			Capacity	
		<u>KV</u>	MW	\$M / GW-mile
•	SEIA:	765	5,000	1.3
		345	1,000	2.6
•	AEP-AWEA	765	5,000	3.2
	Consensus ?			2.5

Hydrogen pipeline:

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

Ammonia pipeline:

10", liquid, 500 miles, with pumping 0.2



Transmission capital costs per MW-km compared Pipelines have large capacity and provide large storage

320 GWh Annual firming, 1,000 MW wind

CAES (compressed air energy storage)

– O&M: \$46 / MWh typical

– Iowa: Power = 268 MW

Energy capacity = 5,360 MWh

Capital: 268 MW @\$800 / kW = \$214 M

Storage @ \$40 / kWh = \$ 13 Billion

Storage @ \$1 / kWh = \$ 325 Million

Battery

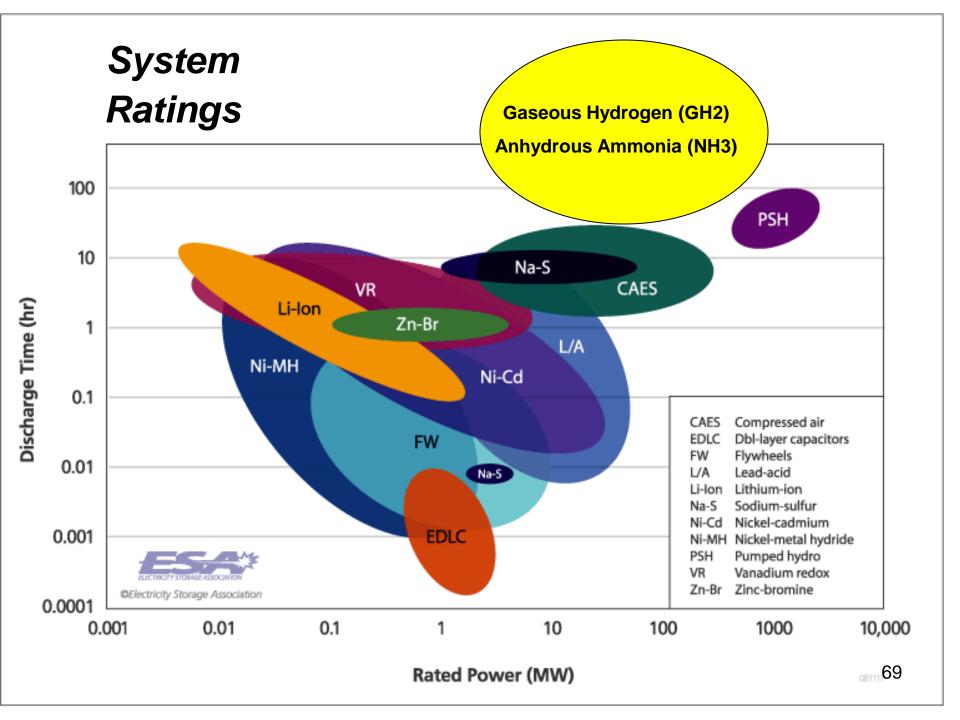
- O&M: 90% efficiency round-trip

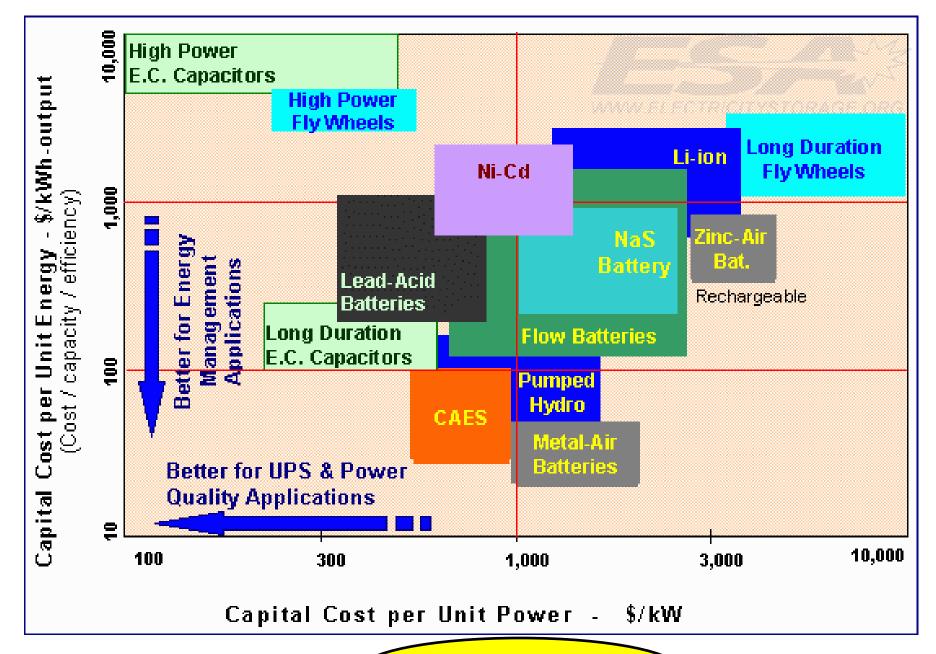
– Capital: \$500 / kWh = \$ 160 Billion

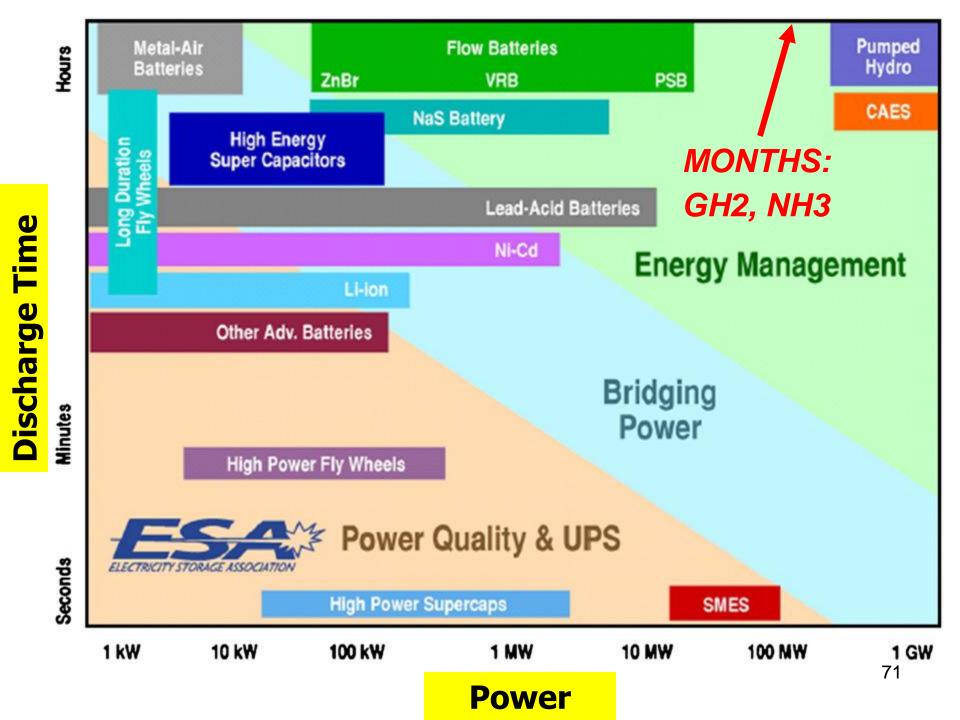
– Capital: \$300 / kWh = \$ 96 Billion

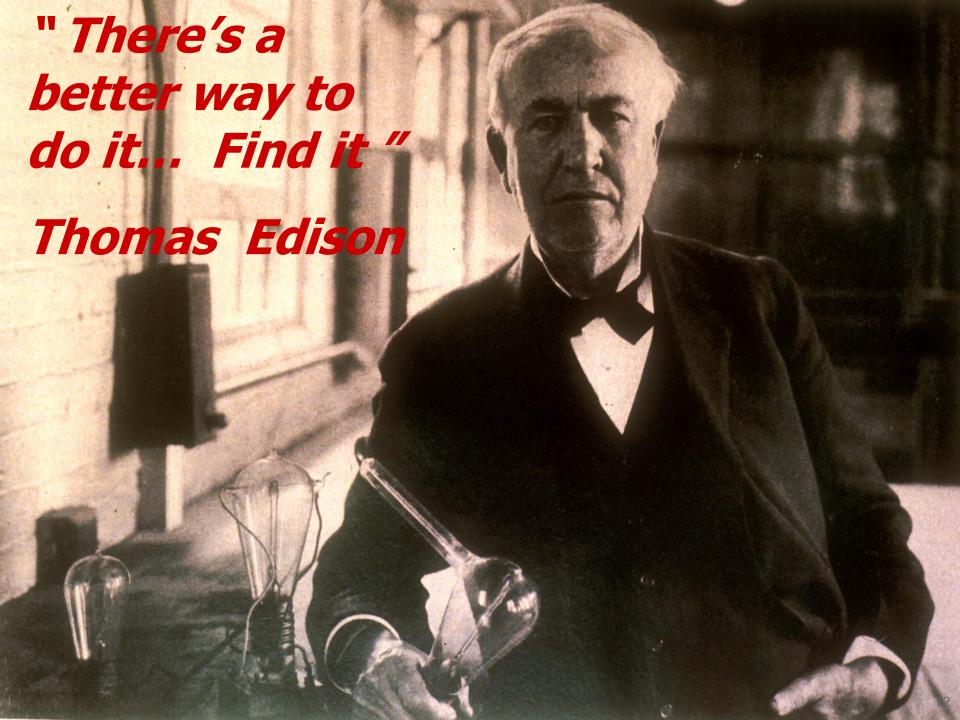
GH2 (3 hydrogen caverns) Capital \$70 Million

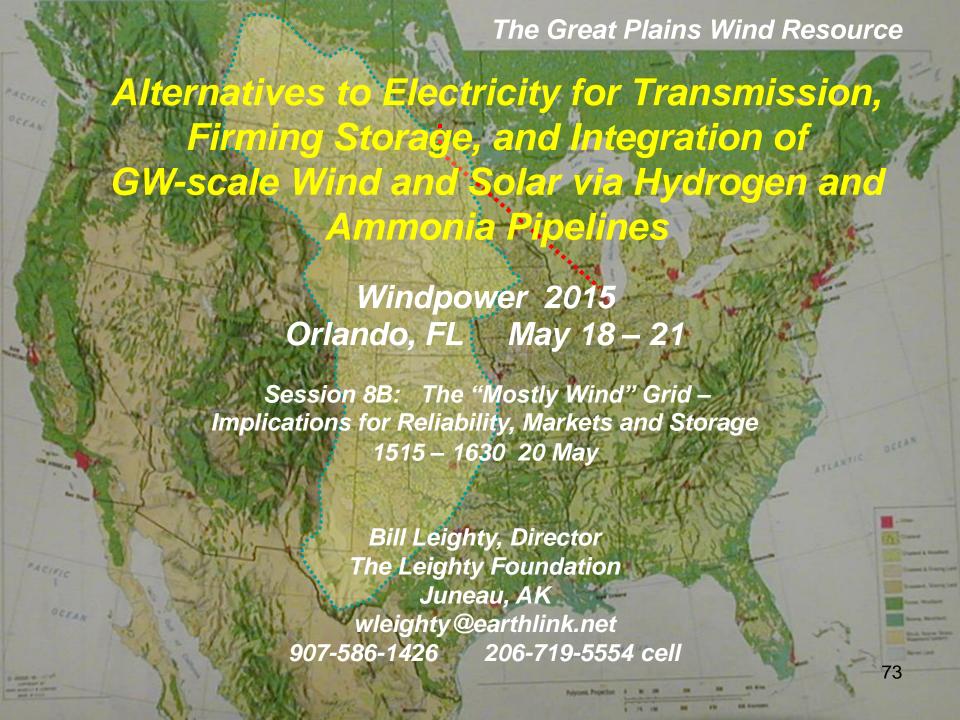
NH3 (2 ammonia tanks)
 Capital \$30 Million





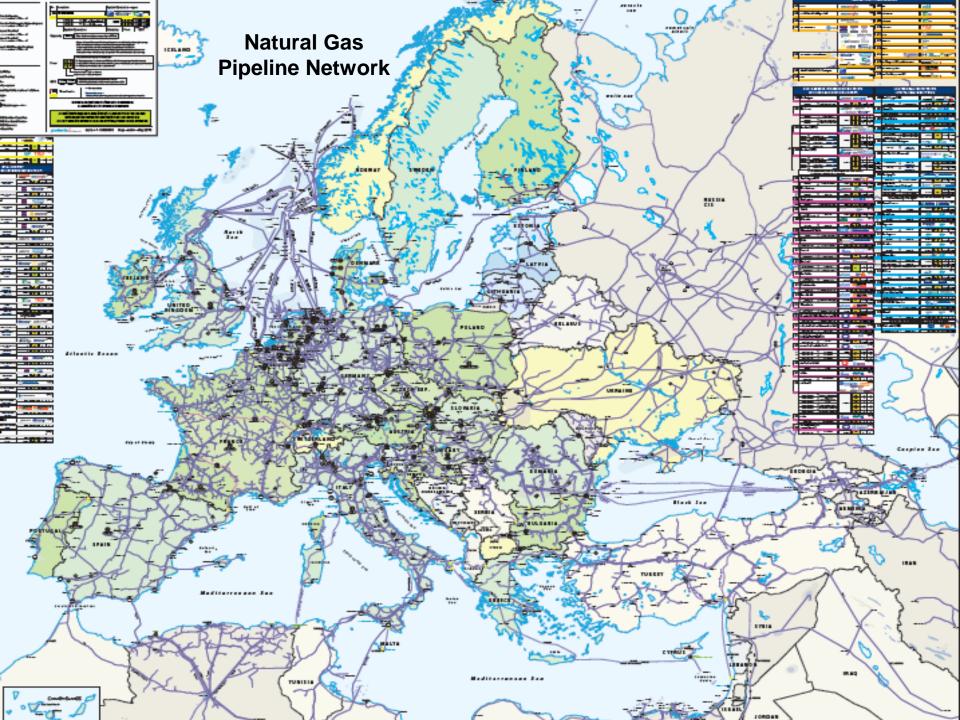








Natural Gas Transmission Pipelines, 2009





Trans Alaska Pipeline System (TAPS) Alaska North Slope (ANS) to Valdez, AK tanker loading terminal. Design capacity: 2 million barrels / day crude oil





Exporting Alaska's Stranded Natural Gas as CO₂- emission- free "blue" Ammonia, a Carbon-free Hydrogen Transmission and Storage Medium and Fuel 77