NH3 Fuel - Let's Roll!

NH3 XII

Norm Olson

September 20 – September 23, 2015

Chicago, IL

NH3 – An Environmentally Friendly, Versatile Chemical

Fuel

Fertilizer

Refrigerant

Wringing Out the Last Few Drops

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British Petroleum R/P Ratio

	U.S. R/P				China R/P			
	2012	2013	2014	2015	2012	2013	2014	2015
Oil	10.8	10.7	12.2	11.4	9.9	11.4	11.9	11.9
Natural Gas	13.0	12.5	13.6	13.4	29.8	28.9	28.0	25.7
Coal	239	257	266	262	33.0	31.0	31.0	30.0

Reserves-to-production (R/P) ratio – If the reserves remaining at the end of any year are divided by the production in that year, the result is the length of time that those remaining reserves would last if production were to continue at that rate.

Proved reserves of oil – Generally taken to be those quantities that geological and engineering information indicates with reasonable certainty can be recovered in the future from known reservoirs under existing economic and operating conditions.

Source: BP statistical Review of World Energy, June 2012, 2013, 2014 , 2015

International Energy Agency 2012

What causes oil supply disruptions?

The three most common reasons for disruption in the supply of oil are unforeseen technical problems, the weather – such as seasonal storms in the Gulf of Mexico - and civil unrest - such as the civil war in Libya in 2011. Military or terrorist attacks which target energy infrastructure for political motives, or disputes between governments, while rare, are other significant concerns for world oil markets.

Is the U.S. Fracking Boom a Bubble?

- Rather than a panacea, then, shale is making Americans complacent about the need to find alternative fuels that can match the needs of the future. It may be welcome, but it is a stopgap, a temporary fix providing a breathing space which would best be used exploring a sustainable fuel of the future.

Newsweek , 7-15-2014

Risk Mitigation – What If?

Fracking wreaks serious environmental damage?
Production from fracked wells declines rapidly and overall world petroleum supply declines?
Methane leakage from horizontal fracking operations creates more overall greenhouse gas emissions than coal?
The Mideast and/or other oil production regions experience violence-induced oil supply disruptions?
Global warming is taken seriously and the demand for cost-effective solutions becomes real?
Nations seek liquid fuel and food independence, requiring one chemical to meet both needs?
Practical solutions are sought to provide locally produced liquid fuel, N-fertilizer and refrigeration?

Ideal Fuel Criteria

Production Flexibility – Wind, Solar, Biomass, Nuclear, Coal , Natural Gas, Hydro, OTEC, etc.

Extensive, Existing, Low-Cost Delivery Infrastructure

Cost Competitive with Gasoline

Environmentally Optimal – Zero Measurable Criteria Pollutant Emissions

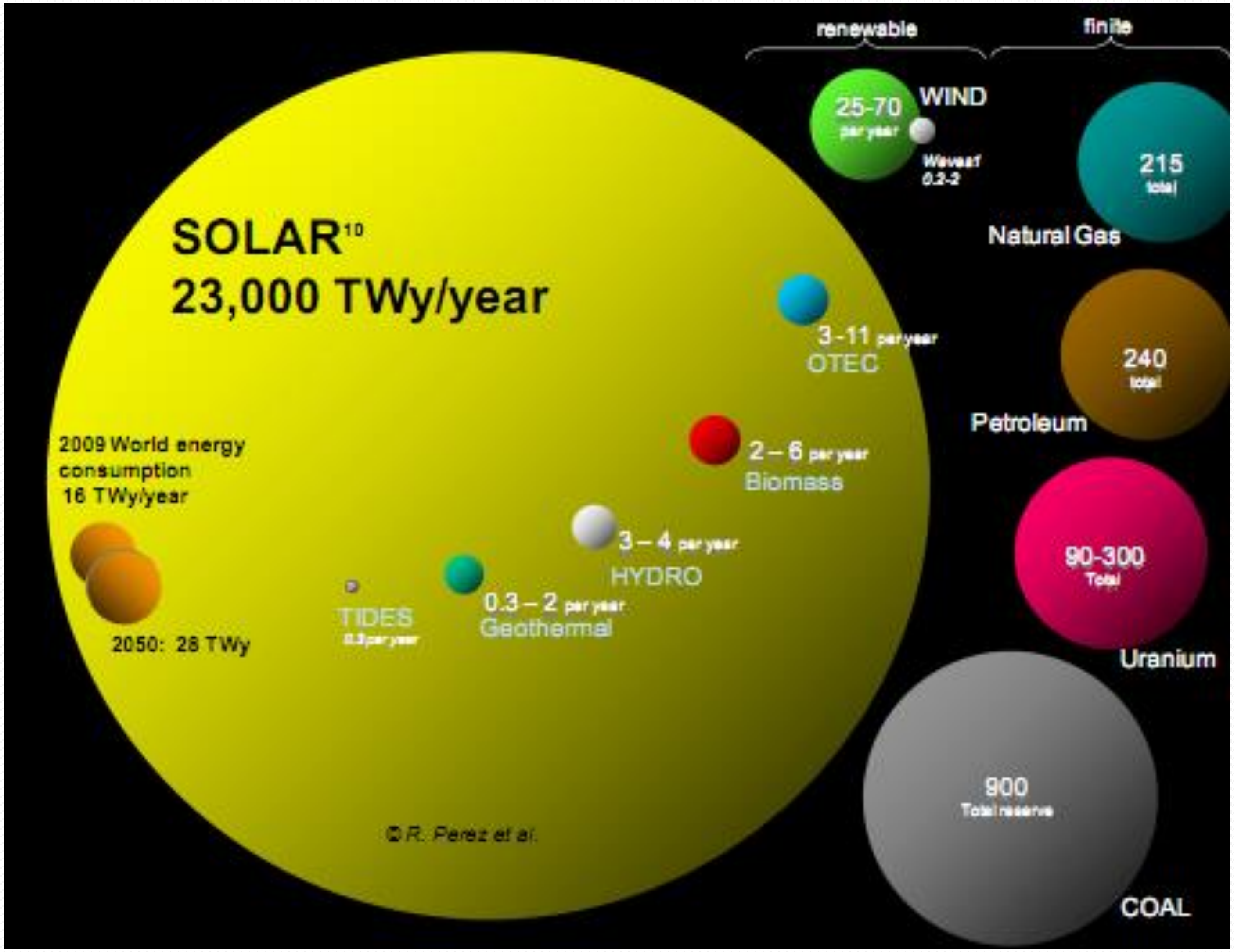
End Use Flexibility – IC (SI & CI) Engines, Fuel Cells, Gas Turbines, etc.

Extremely High Engine Efficiency/High Octane Rating

Proven, Acceptable Safety Record

Very Simple Refinery – Small & Large-Scale Units Commercially Available.

Renewable Energy



Renewable Energy

George Parks Quote

"If I were to be rewarded for success and reprimanded for failure, I would pursue NH_3 (ammonia) as the most promising hydrogen carrier to meet the 2015 Freedom Car goals."

George Parks, Conoco Phillipps, Freedom Car Team

Loose translation – Freedom Car targets are virtually impossible to attain using hydrogen.

My perspective – a world-wide hydrogen fuel storage and delivery system is unaffordable. All other alternative fuel choices are less than optimal.

Freedom Car Targets w/ 2005 NH3 Comparison

Parameter	Units	2007	2010	2015	NH3 (2005)
Spec. Energy	kWh/kg	1.5	2	3	3.0
Energy Density	kWh/L	1.2	1.5	2.7	2.7
Storage Cost	$/kWh	6	4	2	2.1
Fuel Cost	$/gal. Gas equiv	3	1.5	1.5	1.7*

*$280/ton ammonia

Competing Alternative Fuels

Hydrogen – low energy density, extremely high infrastructure costs

Biogas (methane) – biomass is the only practical, renewable feedstock

Electric vehicles – low range, high cost, long charging (refueling) times

Drop-in fuels – high cost, biomass is the only practical, renewable feedstock

Alcohols (methanol, ethanol, butanol) – biomass is the only practical, renewable feedstock

DME – made from biomass, high carbon to hydrogen ratio, vapor heavier than air.

NH3 – all of the advantages of hydrogen plus higher energy density, significantly lower infrastructure costs (similar to propane/LPG), and lower energy production costs (relative to 700 bar or liquid hydrogen)

Is Biomass the Solution?

2011 International Energy Agency Roadmap – Biofuels for Transport
"Biofuels can provide up to 27% of world transportation fuels by 2050"

United States Department of Energy – "Billion Ton Study"
Last updated 2011. Next update scheduled for June, 2016.
One billion ton of biomass provides ~ 30% of U.S. transportation fuel needs.

Answer: NO!

NH3 – Something for (Almost) Everyone

Perfect For:

- Environmentalists
- Capitalists
- Countries desiring to be Energy Independent
- Philanthropists – Third World Sustainable Development
- Persons in Search of Practical (Technically and Economically Viable) Solutions

A Problem For:

- Investors in competing fuels
- Persons who want to continue alternative fuels research indefinitely
- Person's who claim NH3 is too dangerous but have no scientific data to support their conclusion.

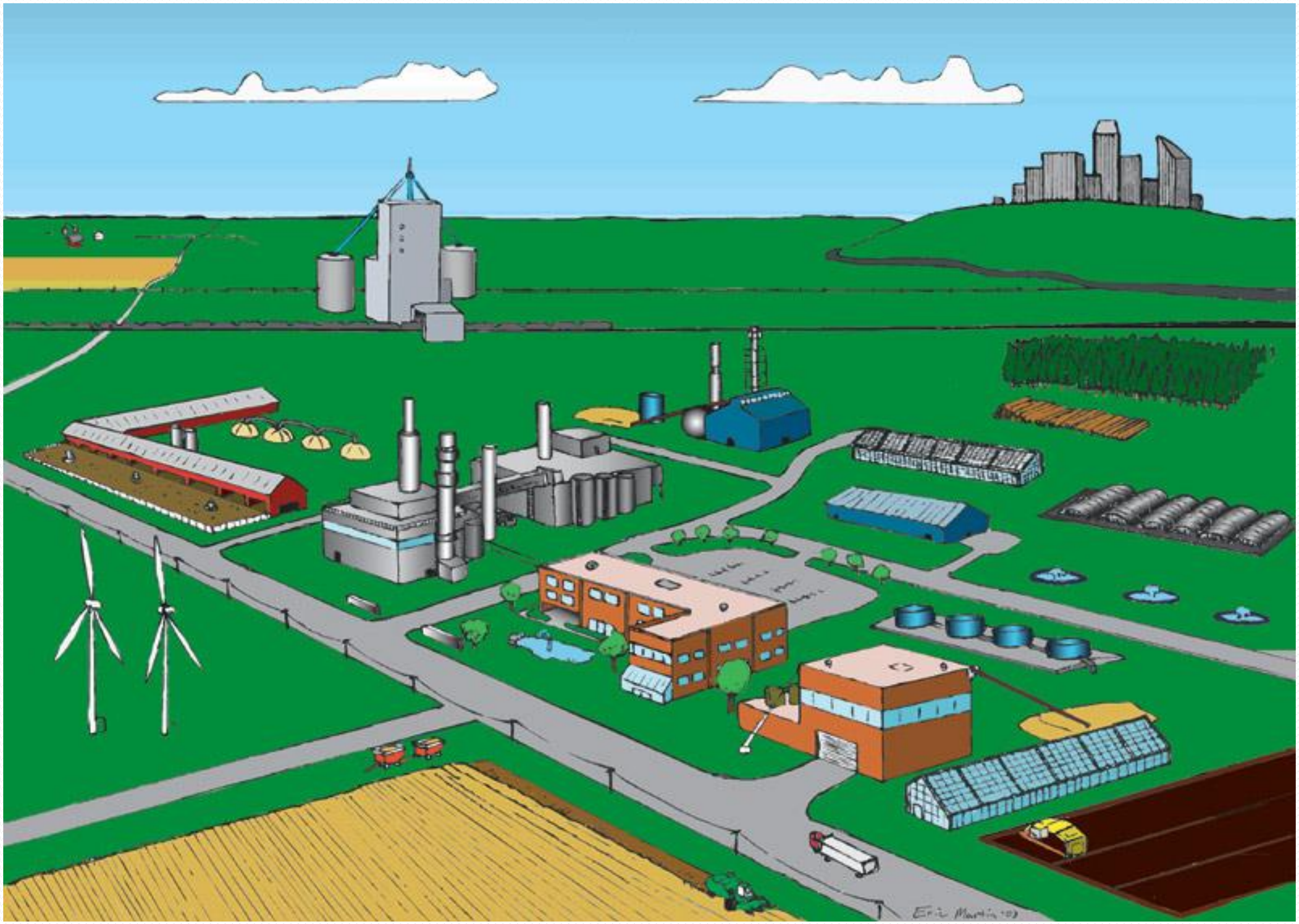
Sustainable, Self-Sufficient Community

NH_3 fertilizer made from a fraction of the net increase in crop residue (e.g. corn stalks) due to the addition of NH_3 fertilizer , allows a transition from subsistence farming to income-producing farming.
NH_3 fuel allows for locally produced transportation fuels and rural combined heat & power (CHP) units.
NH_3 refrigerant allows for efficient and environmentally friendly cold food and perishables storage.

Where another of our other favorite chemicals (H_2O) exists, one relatively simple refinery producing NH_3 can provide enhanced sustainable food production, transportation fuel, distributed electrification via CHP units and refrigerated storage. This provides and excellent base for local self-sufficiency and an improved standard of living.

Petroleum refineries are very complex and require a very large scale.

Bio-Refinery

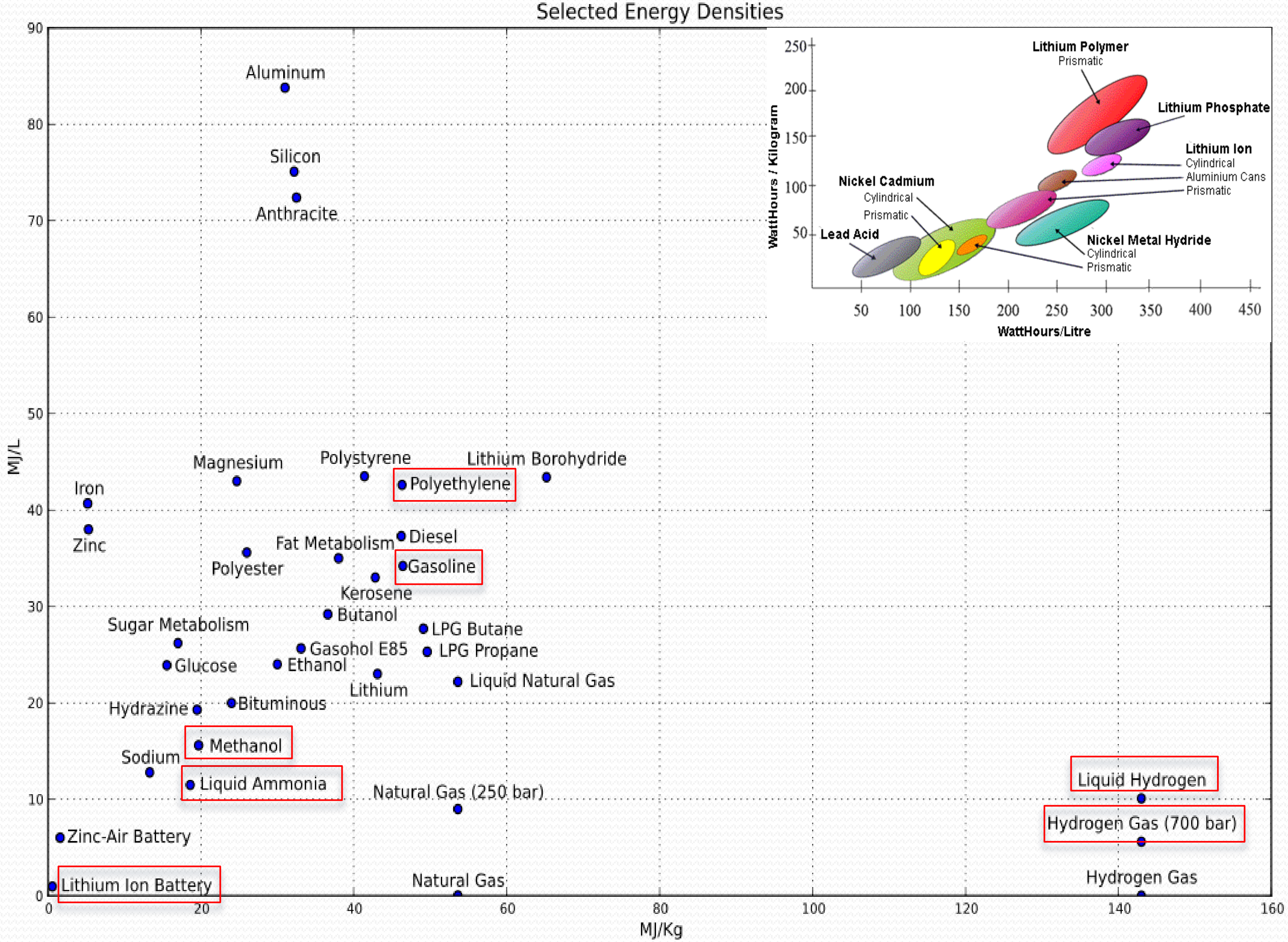


NH3 Facts

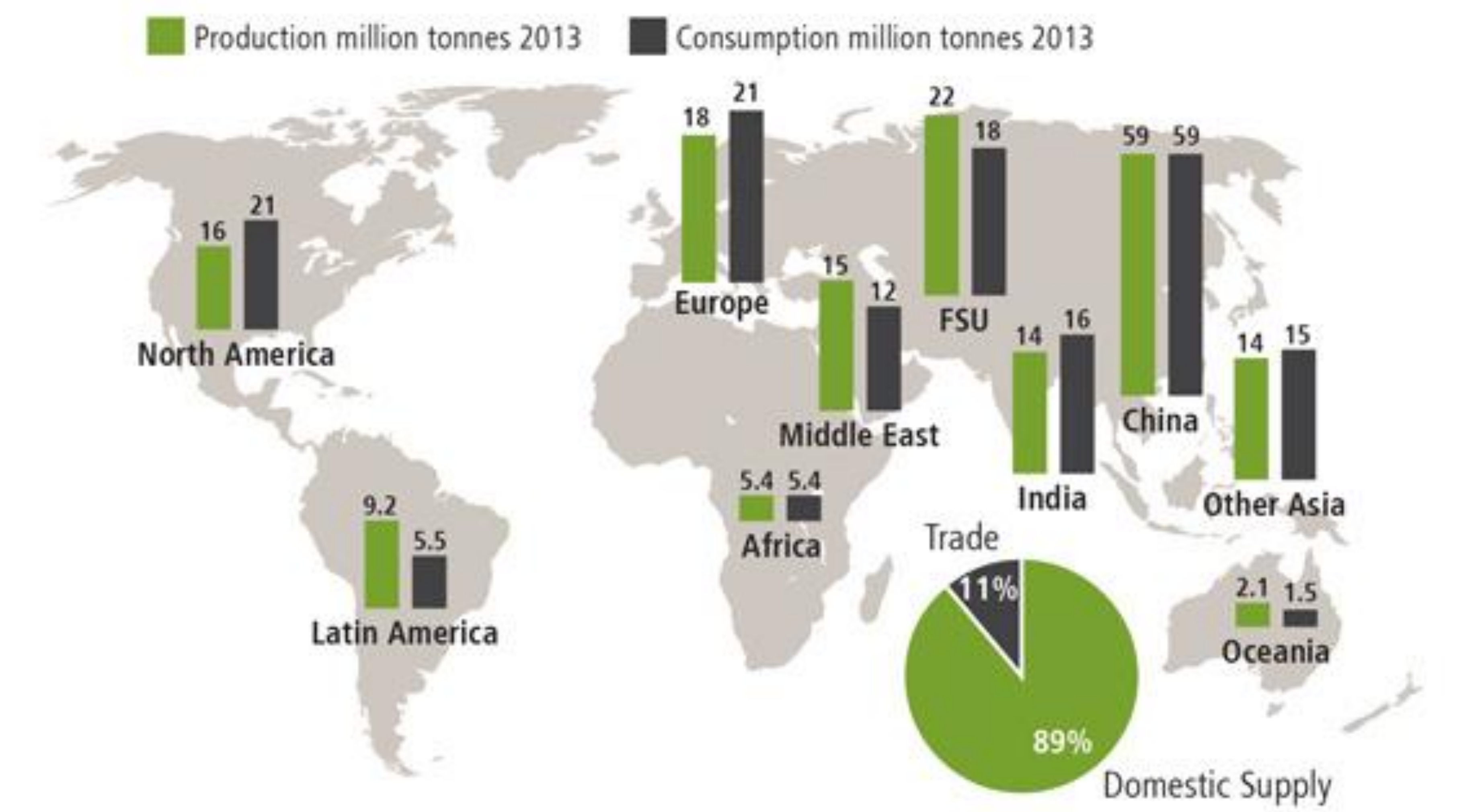
NH3 Fertilizer Application

Anhydrous ammonia expands into a gas as it is injected into the soil where it rapidly combines with soil moisture.

Fuel Energy Densities

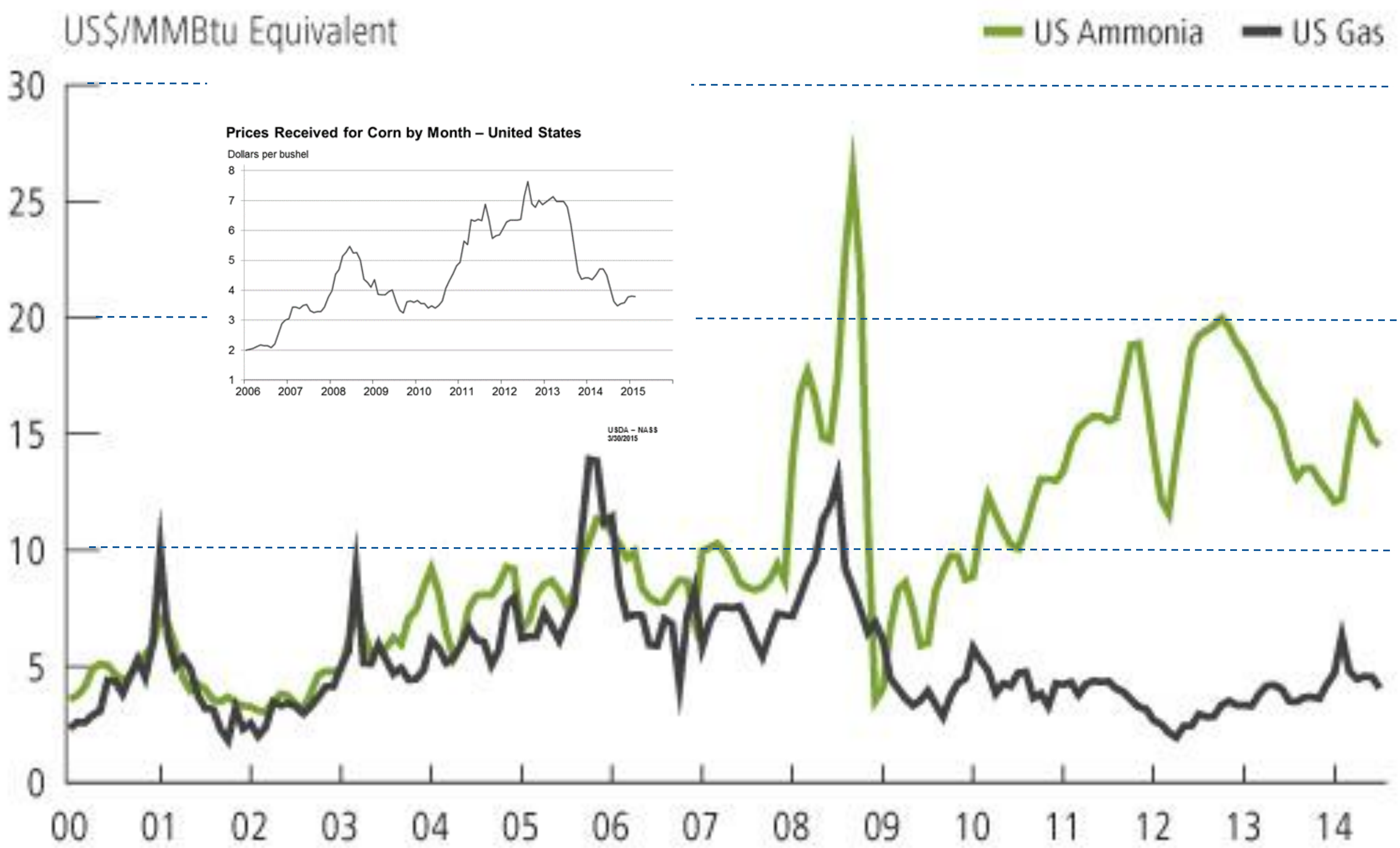


Global Ammonia Profile



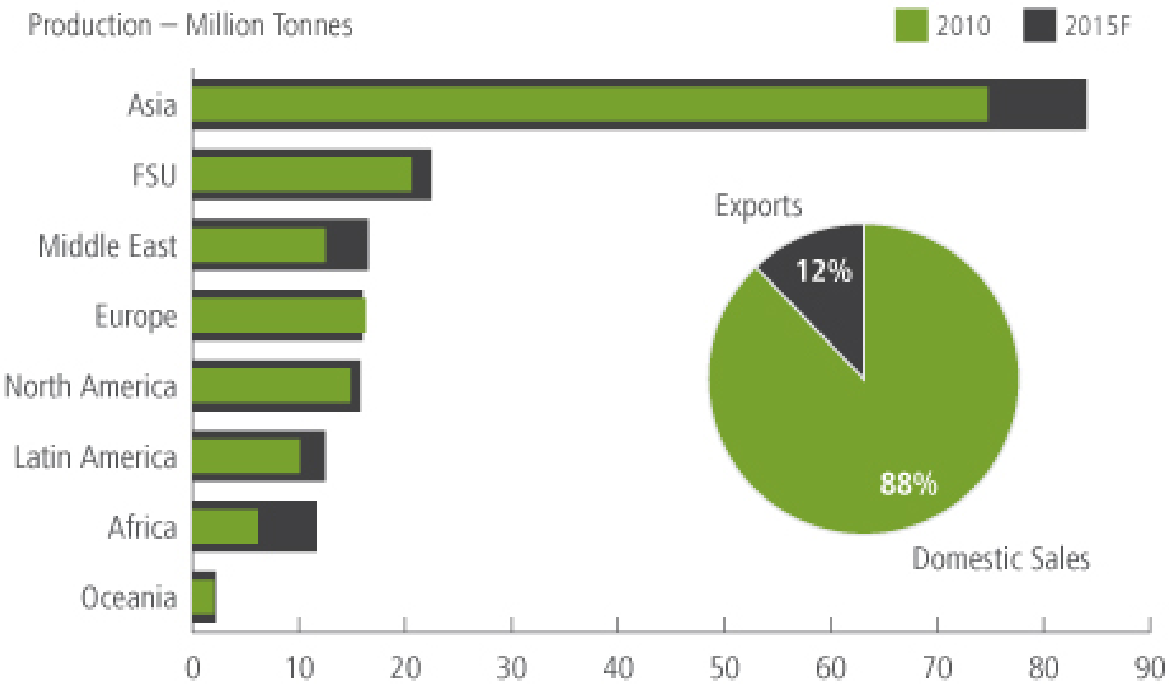
Source: Fertecon, CRU, PotashCorp August 31, 2014

Historical NH3 vs NG Costs



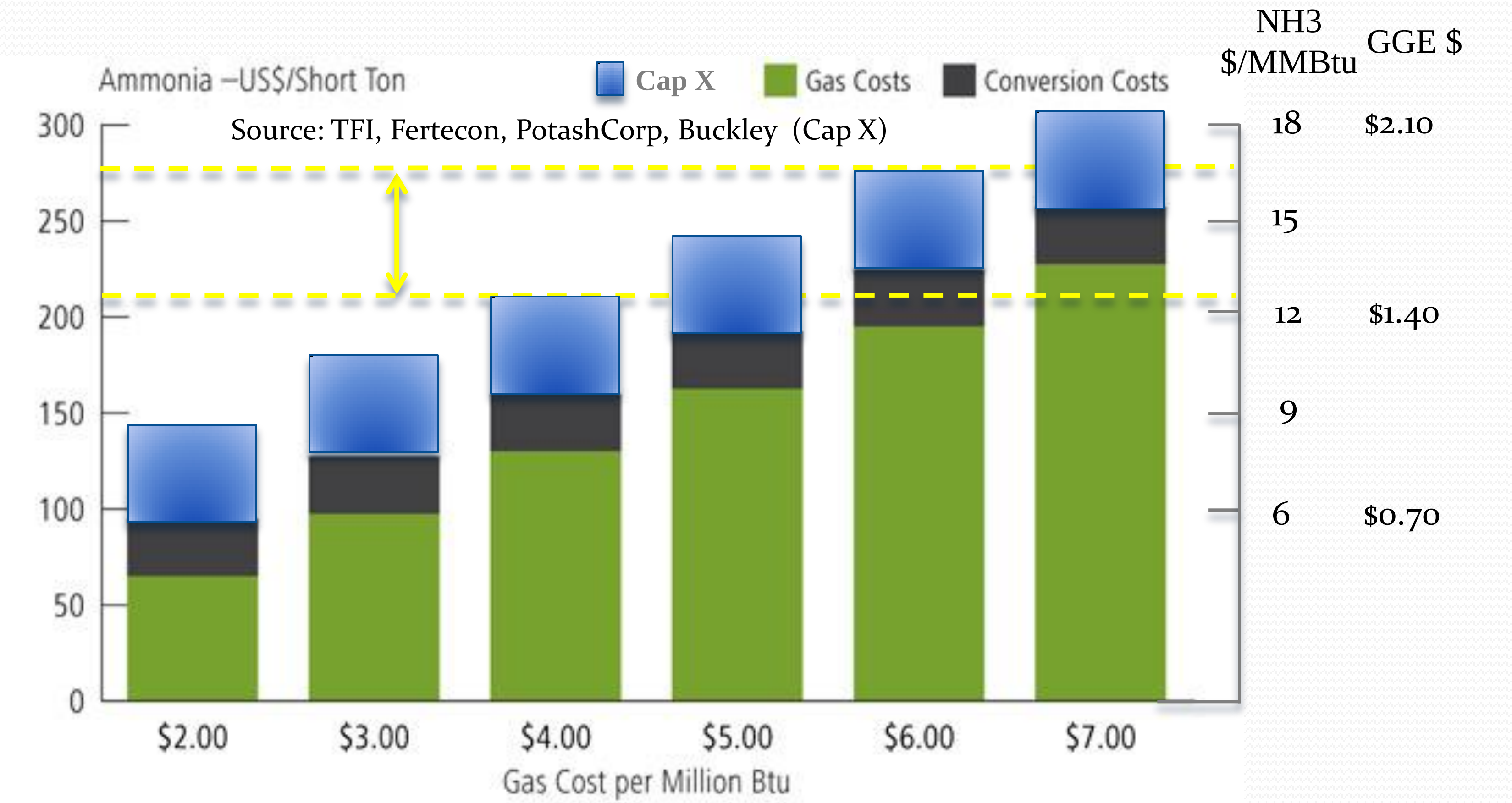
Source: NYMEX Henry Hub, Fertecon, PotashCorp March 31, 2014

NH3 Production



Source: Fertecon

NH3 Production Costs w/ Cap X



Natural Gas Represents More Than 75 Percent of US Producers' Costs
Natural gas is the most important feedstock in ammonia production and, depending on price, makes up 70-85 percent of the US cash cost of producing ammonia. Cap X: $1500/ton, 30 year amortization, ~$50/ton

Gasoline @ $3.50/gallon = $30/MMBtu

Delivery Infrastructure

NH3 is in the top three chemicals shipped worldwide.

Ammonia Storage & Transport

NH3 Distribution Hub

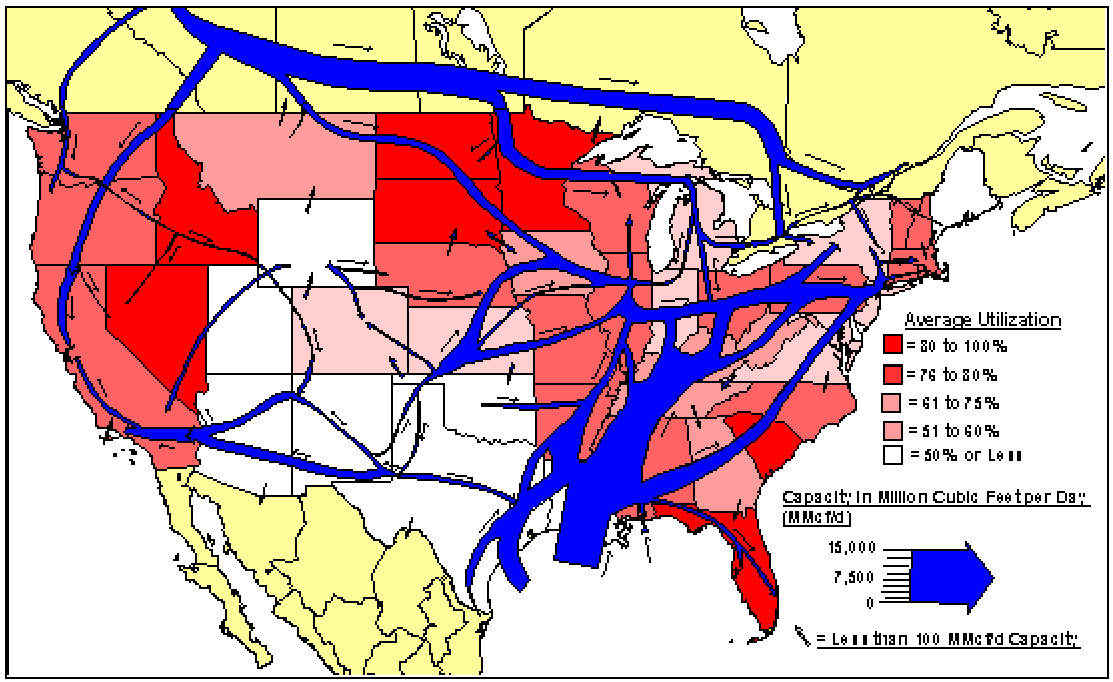
U.S. Ammonia Pipeline

Nearly 3000
Miles Total

Iowa NH3 Outlets

Over 800 retail ammonia (the “Other Hydrogen”) outlets currently exist in Iowa.

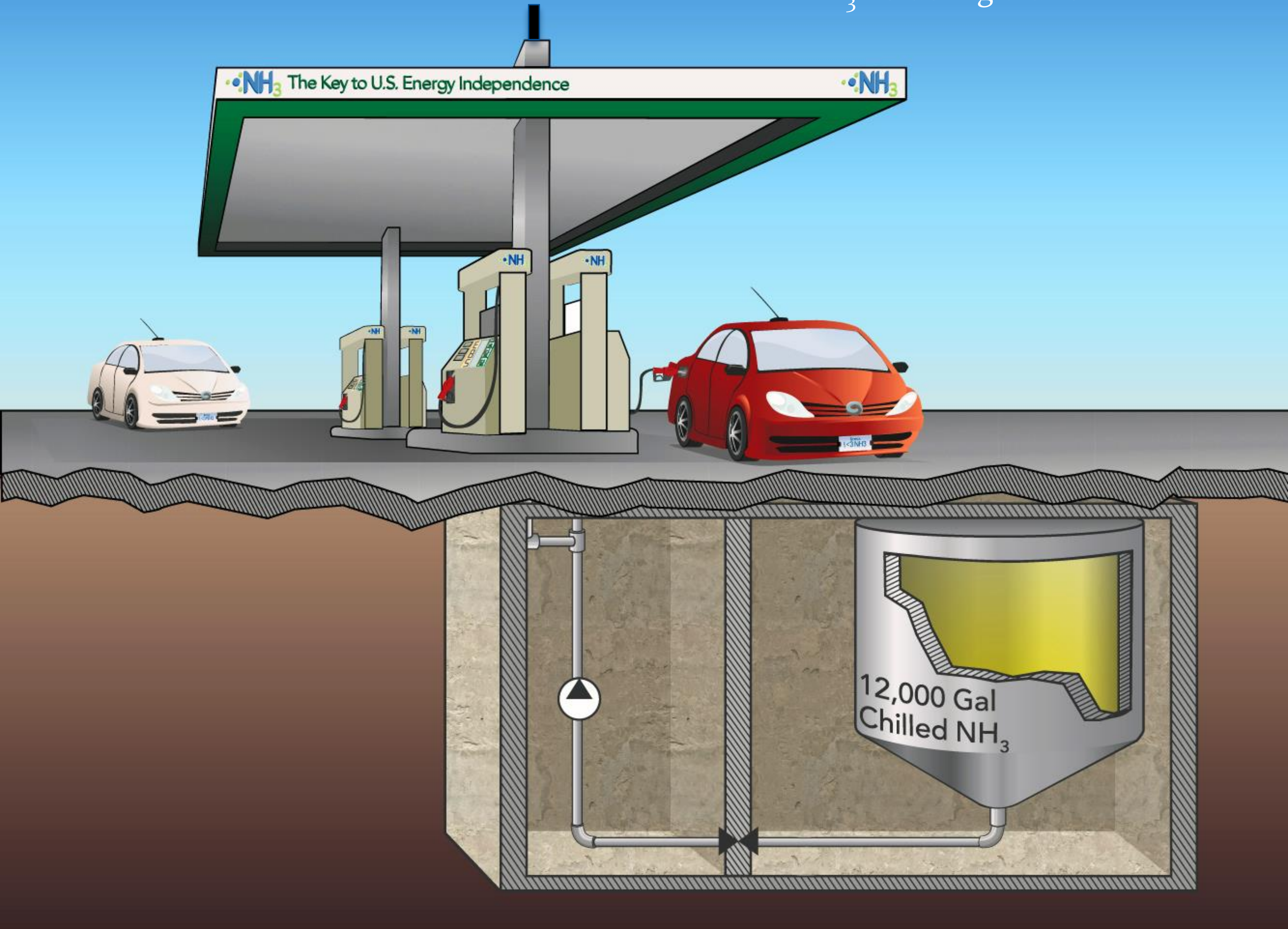
Natural Gas Pipelines



EIA

NH3 Fuel Details

NH_3 Refueling Station



Fueling Station – Refrigerated NH3

The refrigerated ammonia storage system is designed such that if a small or significant release of ammonia were to occur in the storage, heating, or pumping systems, the released ammonia liquid and vapor would be contained in a vault and vented through a vertical stack extending upward. As the ammonia vapors warm and disperse from the elevated stack, the ammonia/air plume will be positively buoyant and will have no ability to slump back to grade. This storage method essentially eliminates the grade-level risk associated with the storage of refrigerated ammonia.

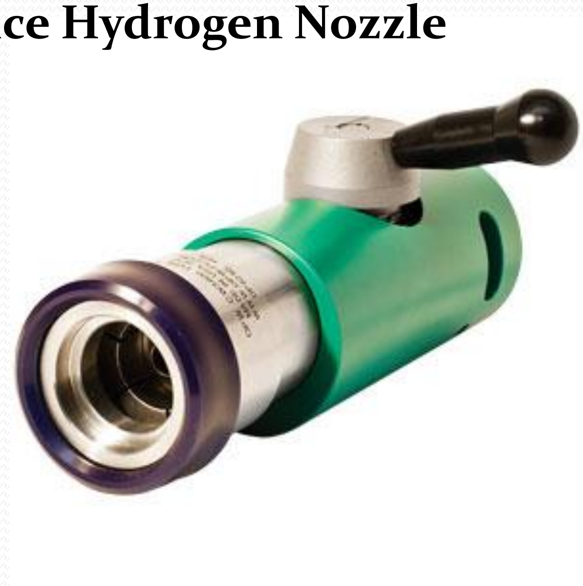
In summary, the hazards and risks associated with the truck transport, storage, and dispensing of refrigerated anhydrous ammonia are similar to those of gasoline and LPG. The design and siting of the automotive fueling stations should result in public risk levels that are acceptable by international risk standards. Previous experience with hazardous material transportation systems of this nature and projects of this scale would indicate that the public risk levels associated with the use of gasoline, anhydrous ammonia, and LPG as an automotive fuel will be acceptable.

Source: CQRA 09-06-6708, Quest Consultants Inc., 2009

Refueling Components

In-Line Hydrogen Breakaway

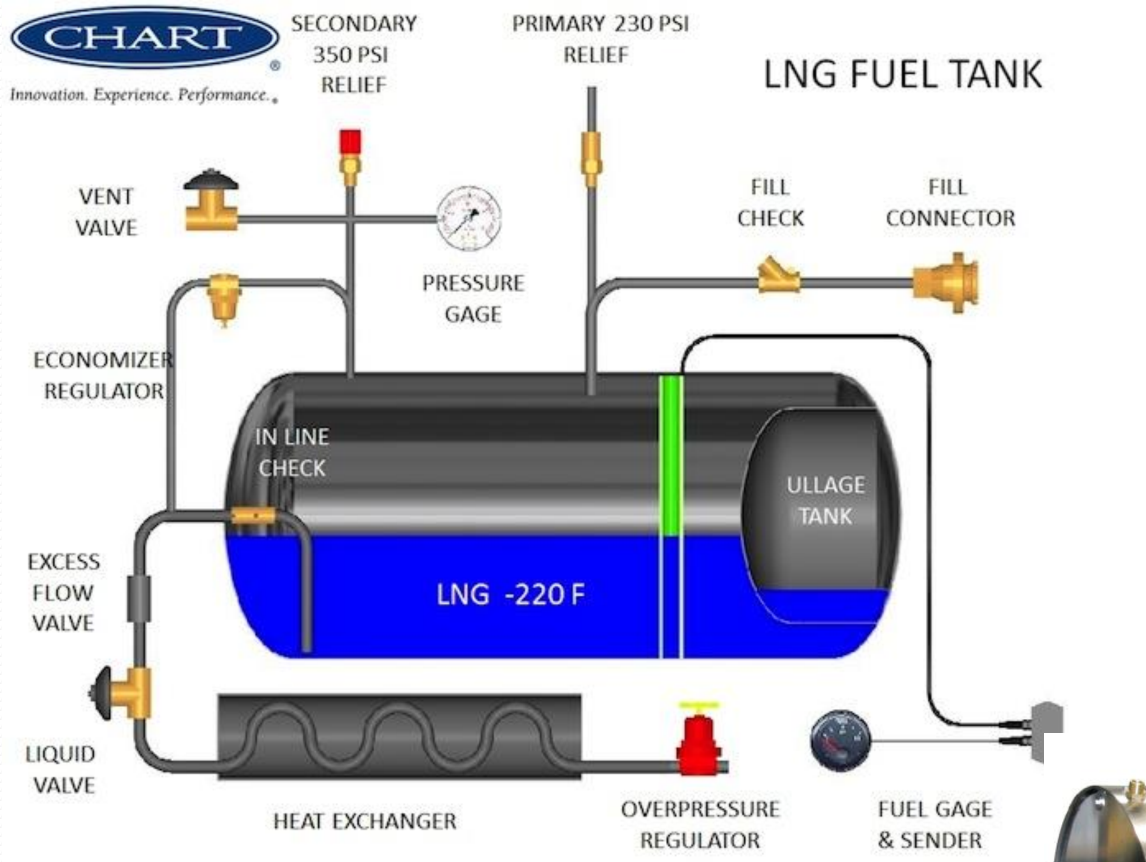
CW3600/CW5000 Series Self-Service Hydrogen Nozzle



L Series Hydrogen Fueling Receptacle

Source: OPW

LNG Tank Configuration

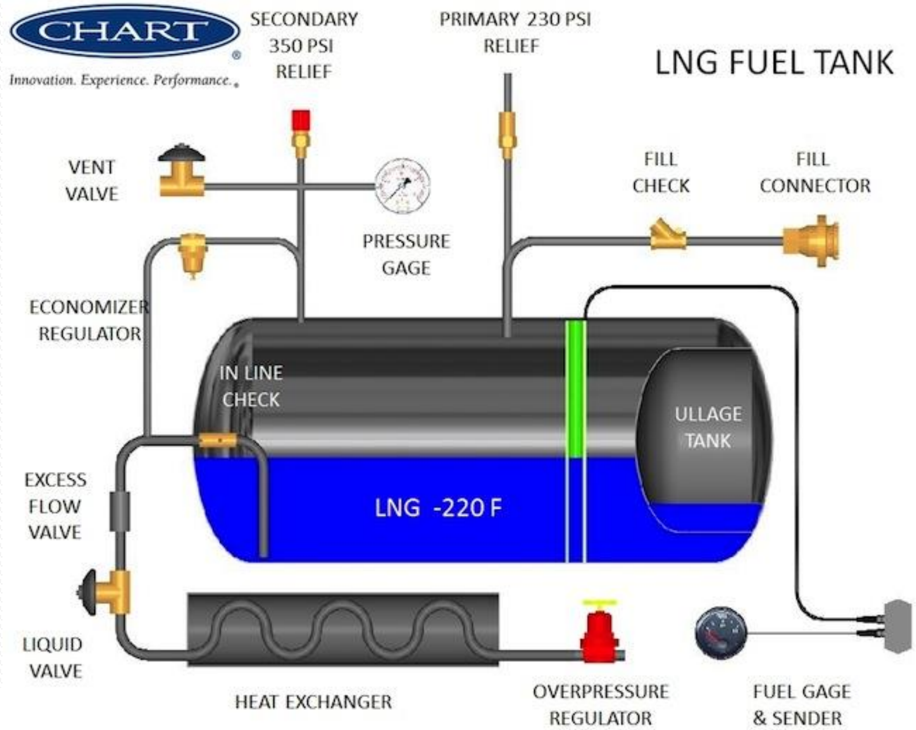


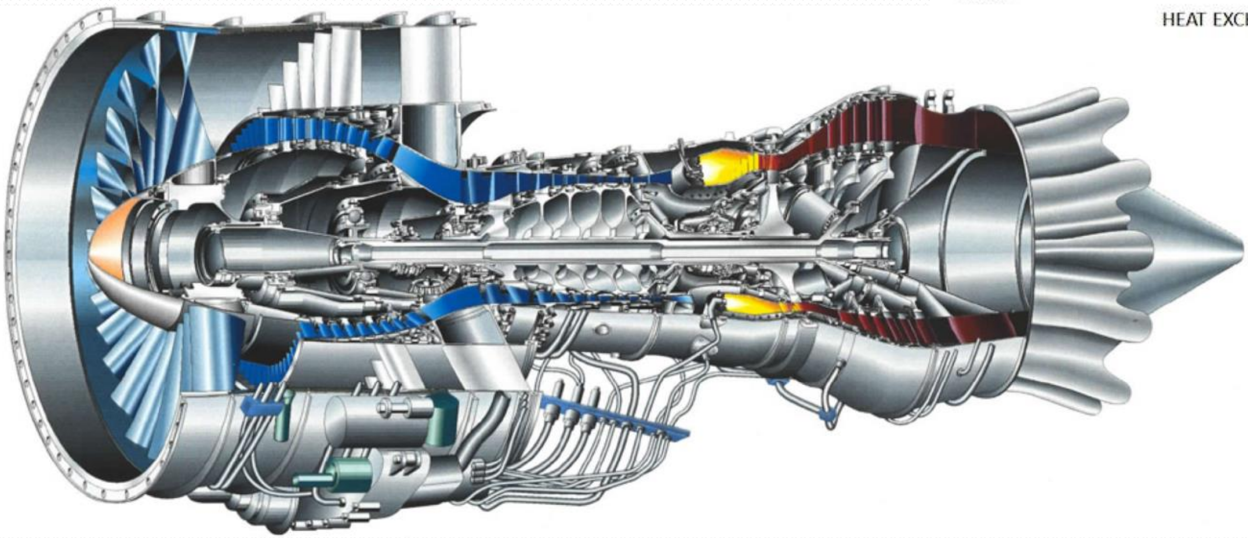
NH3 Safety

Two types of people oppose NH3 based on safety issues:

- Those lacking the factual data of the relative safety of NH3 fuel vs other fuels
- Those having a stake in competing alternative fuels

Airplane Complexity vs NH3 Fuel System





Safety I

- **NH3 is a common, naturally occurring chemical found in or used by nearly all animal life forms. It is not a carcinogen and is not a greenhouse gas. Its ozone depletion number is zero.**
- **NH3 is safer than propane and as safe as gasoline when used as a transportation fuel.**
- **The Iowa Energy Center funded a comparative quantitative risk assessment (CQRA) study completed March 2009, by Quest Consultants Inc., Norman, Oklahoma. "Comparative Quantitative Risk Analysis of Motor Gasoline, LPG, and Anhydrous Ammonia as an Automotive Fuel", June, 2009.**
- **"Safety assessment of NH3 as a transportation fuel", Nijs Jan Duijm, Frank Markert, Jette Lundtang Paulsen, Riso National Laboratory, Denmark, February, 2005**

Safety II

- **NH3 plant operators – hydrogen vs NH3**
- **NH3 safety is an engineering issue. It can be made to be as safe as is necessary.**
- **NH3 is classified by DOT as a non-flammable liquid and an inhalation hazard (not a poison)**
- **The degree of safety for NH3 Fuel is an *engineering decision* and does not require any technology miracles/breakthroughs (unlike hydrogen and electric vehicles).**

Crude Oil vs NH3 Train Derailment Stats

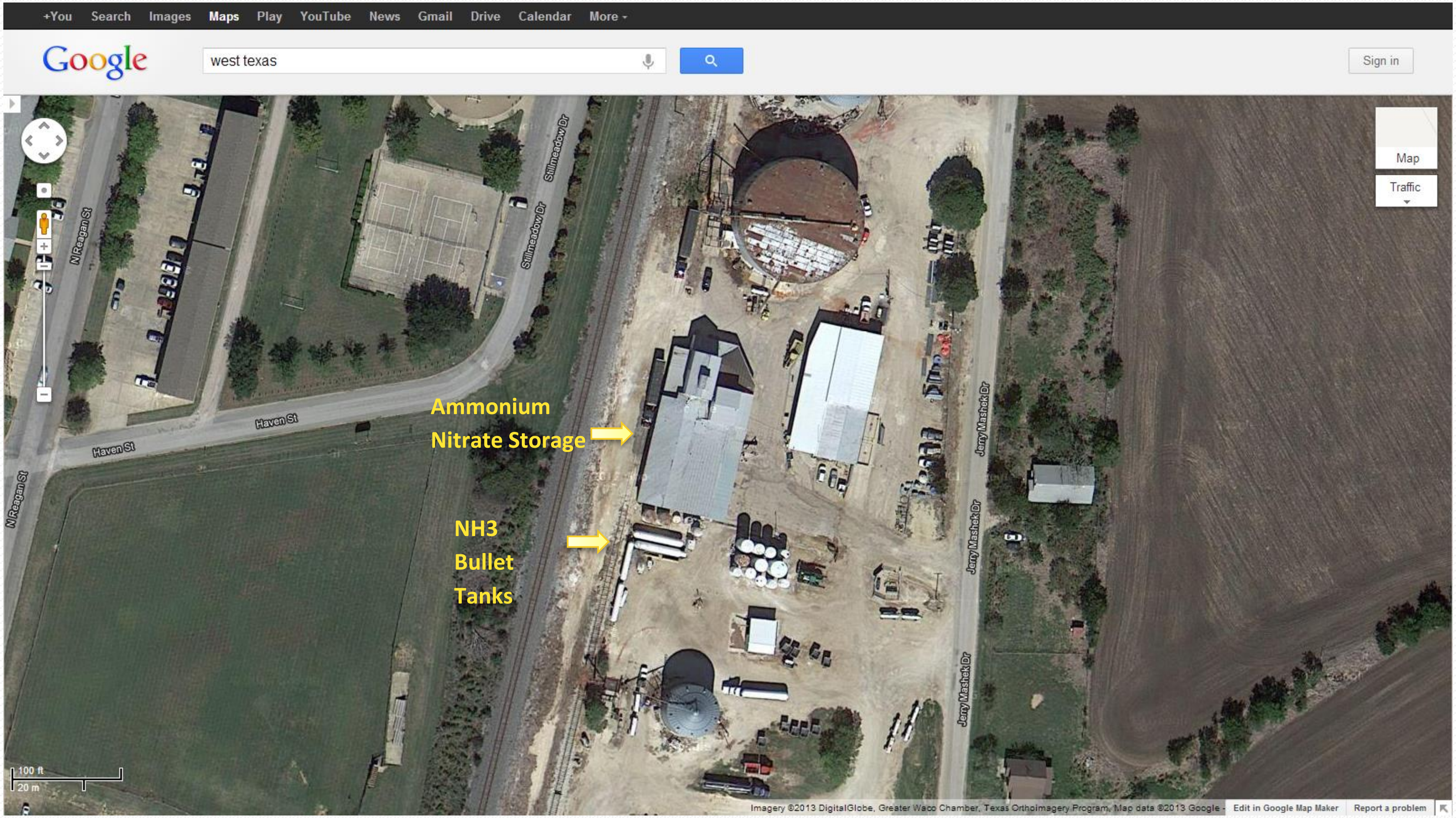
	Lac-Mégantic	Minot
Cargo	Crude oil	Anhydrous ammonia
Date	06-Jul-13	18-Jan-02
Time	01:15	01:37
Train speed	56 mph	41 mph
Cars in train	72	112
Ruptured cars	4	5
Gallons released	1,500,000	240,000
People living within affected area	2,000	11,600
Fatalities	47	1
Sustained serious injuries	?	11
Minor injuries	?	322
Damages/Clean-up Costs	$50million/$200 million	$2 million/$8million

Sources: David Nugent, 9/19/2013 correspondence. Wikipedia. NTSB/RAR-04/01.

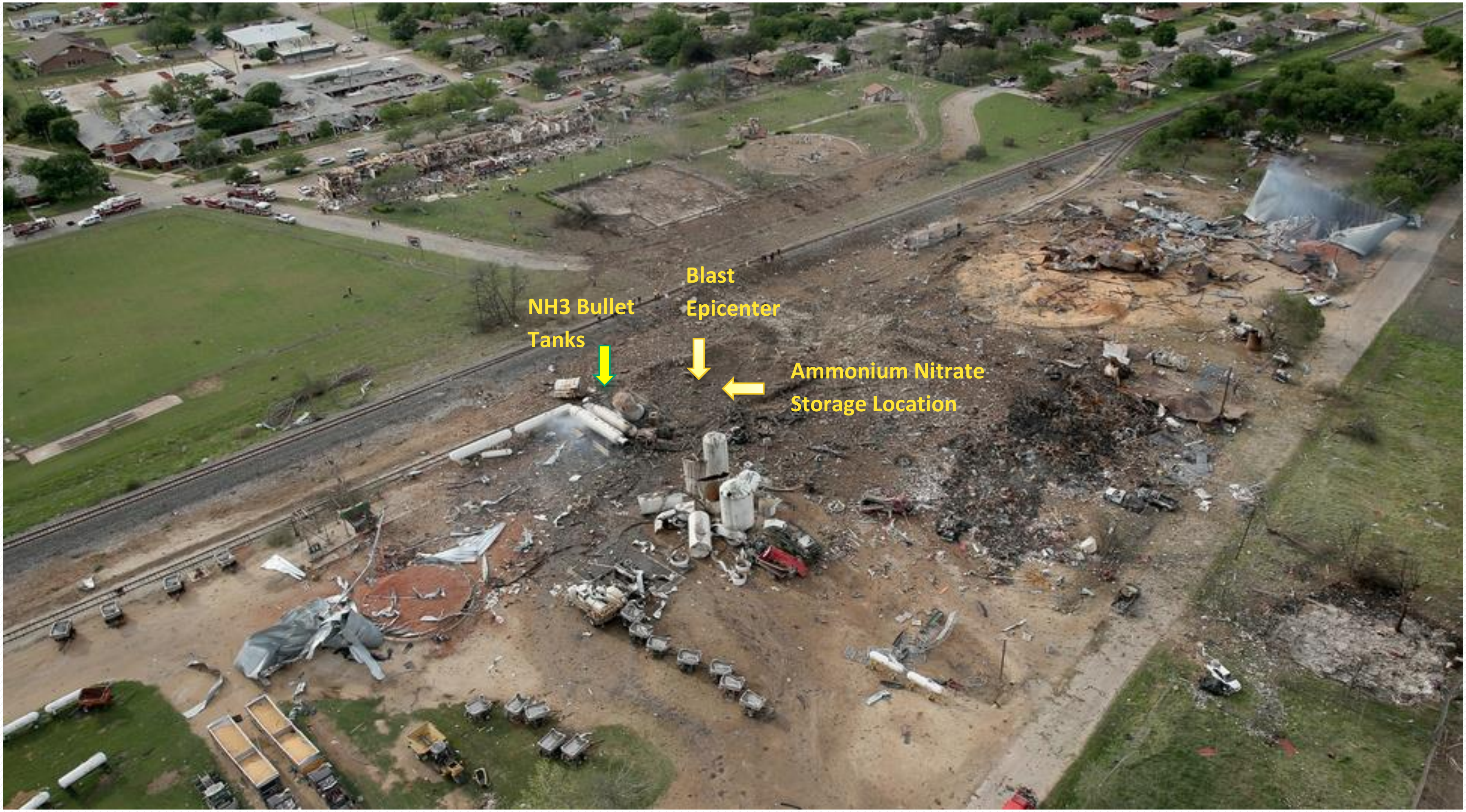
Minot vs. Lac-Mégantic Derailments

Minot vs Lac-Mégantic Derailments

West Texas Explosion – Not NH3 Related



West Texas Explosion – <u>Not NH3 Related</u>



Worldwide Activity – NH3 Vehicles

Japan – Federally funded, 3 year research and demonstration program involving a NH3 gas turbine,NH3 combustion, and NH3 storage of hydrogen. A significant amount of additional research is being conducted. Toyota has numerous patents on NH3 engines and NH3 fuel cells.

ARPA –E – Signifigant discussion on NH3 fuel at August, 2015 meeting

U.S. – NH3 Car converted S10 pick-up to NH3, conversion, NH3 tractor HEC for Jay, Sturman Industries – Long Beach, Iowa State University – NH3 CI engine dual fuel, SI engine research, Texas Tech

Canada – Hydrofuel, Natural Resources Canada - DAFC, NH3 Canada, GreenNH3

Italy – Bigas International, SAVIA project

China – "What a Transportation Revolution in China Looks Like, Can China find a fuel alternative for its swelling number of transportation vehicles?", January 16, 2014

Great Britain – UK's Science and Technology Facilities Council (STFC)

Korea – Korean Institute for Energy Research (KIER)

Worldwide Activity – NH3 Production

Netherlands – Proton

Japan –

Wind to NH_3 – U Minn Morris

SSAS

Texas Tech – Flemming, electrolyzer, NH_3 production

HEC – electrolyzer, single pass NH_3 production

Canada - Green NH_3

Korea – Korean Institute for Energy Research (KIER)

Japan – Leading the Way

NH_3 FA Conference Presentations – Japan has made more presentations than any other country outside of the U.S.

Nationally funded ammonia gas turbine and ammonia hydrogen storage project: Energy Carrier project of the Cross-Ministerial Strategic Innovation Promotion Program of the Council for Science, Technology and Innovation.
Read more at: http://phys.org/news/2014-12-power-technology-ammonia-combustion-gas.html#jCp

Toyota Patents:
https://www.collectiveip.com/companies/toyota-motors/patents?fin=Norihiko+Nakamura&q=ammonia+engine

NH3 Fuel – What is Needed?

Research and demonstration on small-medium (< 5MGPY) scale NH3 production.

Research and demonstrations using NH3 in turbines, engines, and fuel cells.

Design and demonstration of super safe refueling systems.

Development of standards and protocols for NH3 use as a fuel.

Japanese affiliate of the NH3 Fuel Association.

Summary 1

- **NH3 meets critical 2015 Freedom Car targets today**
- **NH3 has a very extensive, worldwide transportation and storage infrastructure already in place.**
- **H2 and NH3 can have very low tailpipe greenhouse gas emissions (with controls)**
- **H2 and NH3 can be made from electricity and water (+air for NH3)**
- **NH3 can replace diesel fuel, gasoline, natural gas and propane in many fuel-related applications**
- **NH3 is a hydrogen dense chemical, ~50% greater (volume basis) than 10k psi hydrogen.**

Summary 2

- **Most NH3 is currently produced from coal and natural gas**
- **NH3 can be produced using renewable energy (Including wind, solar, OTE, hydro, etc.)**
- **NH3 diesel (CI) and spark-ignition (SI) engines have been demonstrated**
- **Direct NH3 fuel cells are being developed**
- **NH3 is not a greenhouse gas. It is an very prevalent, naturally occurring chemical**
- **Any transportation fuel has associated safety risks but NH3 is as safe as gasoline and safer than propane according to two, highly-credible studies.**
- **Hydrogen stored, delivered and utilized in the form of NH3 has numerous significant benefits including very low infrastructure costs.**

NH3 – An Exceptional Chemical