Who's Your Favorite Chemical?

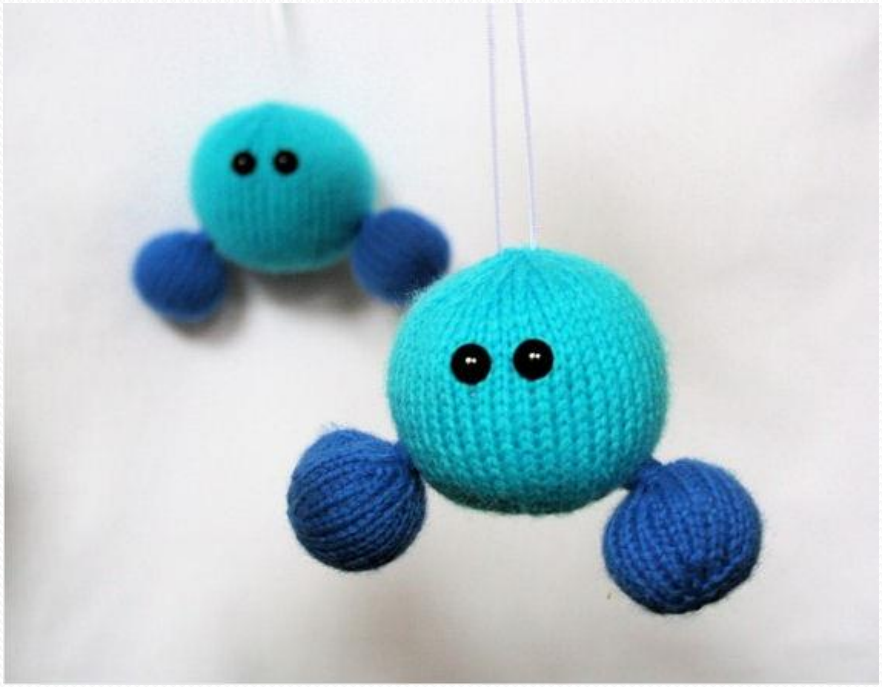
Norm Olson

NH3 XI

September 21 – September 24, 2014

Des Moines, Iowa

Two Likely Candidates



NH3 – An Environmentally Friendly, Versatile Chemical

World Energy Facts

World Primary Energy Consumption 2011

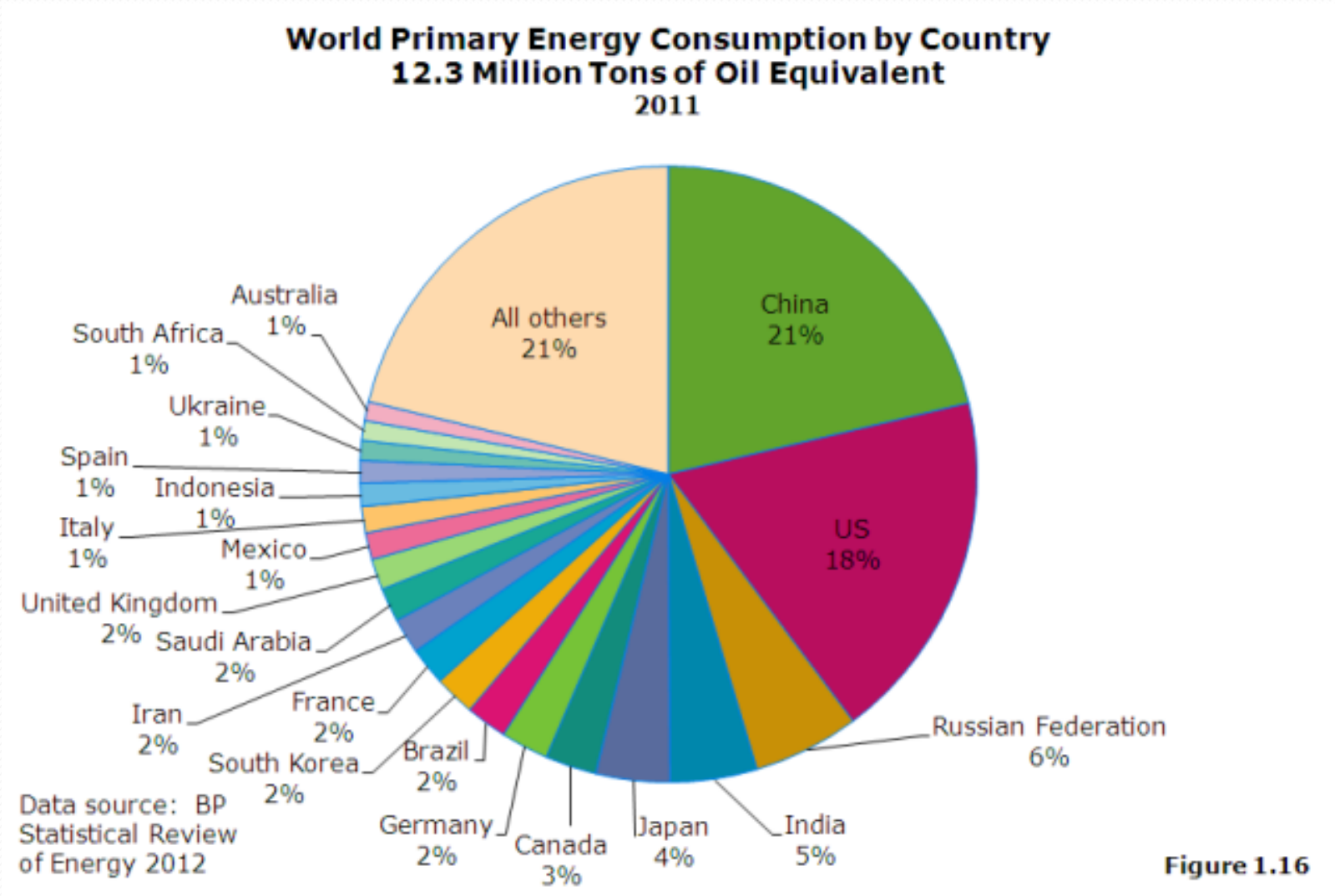


Figure 1.16

International Energy Agency

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.

Natural Gas ?

U.S. Gas Volatility, Higher Prices Coming Despite Shales, JP Morgan Exec Says

As part of a "U.S. Century" fueled by global shale gas dominance, domestic natural gas prices will rise and volatility will return in the next three to five years, a JP Morgan executive told participants at the LDC Gas Forum Mid-Continent in Chicago Tuesday.

Source: NGI's Shale Daily, September 16, 2013

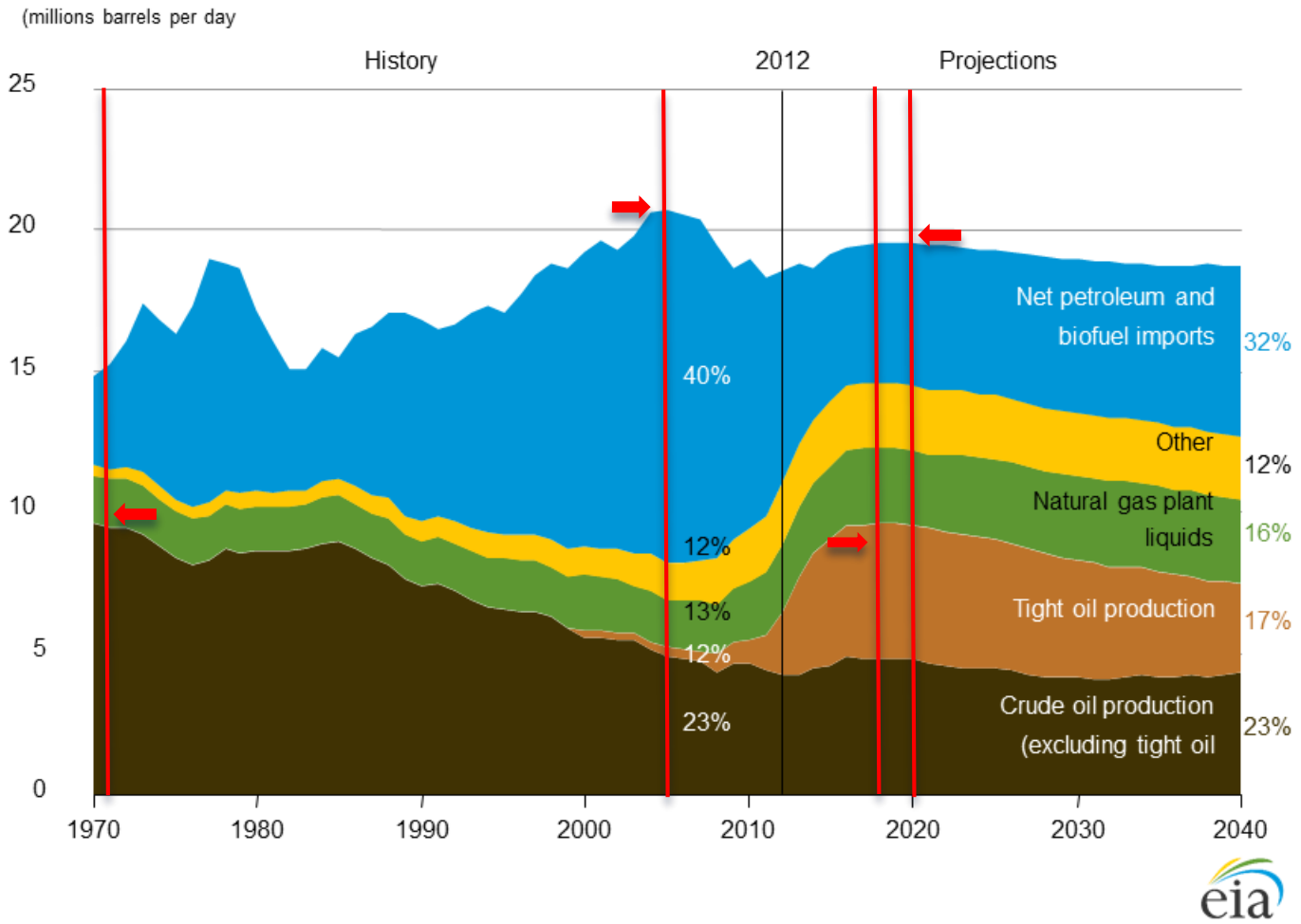
Is the U.S. Fracking Boom a Bubble?

- 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

EIA 2014 Early Release – Peak Oil 2020?

Figure 1. U.S. petroleum and other liquid fuels supply by source, 1970-2040



British Petroleum R/P Ratio

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

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

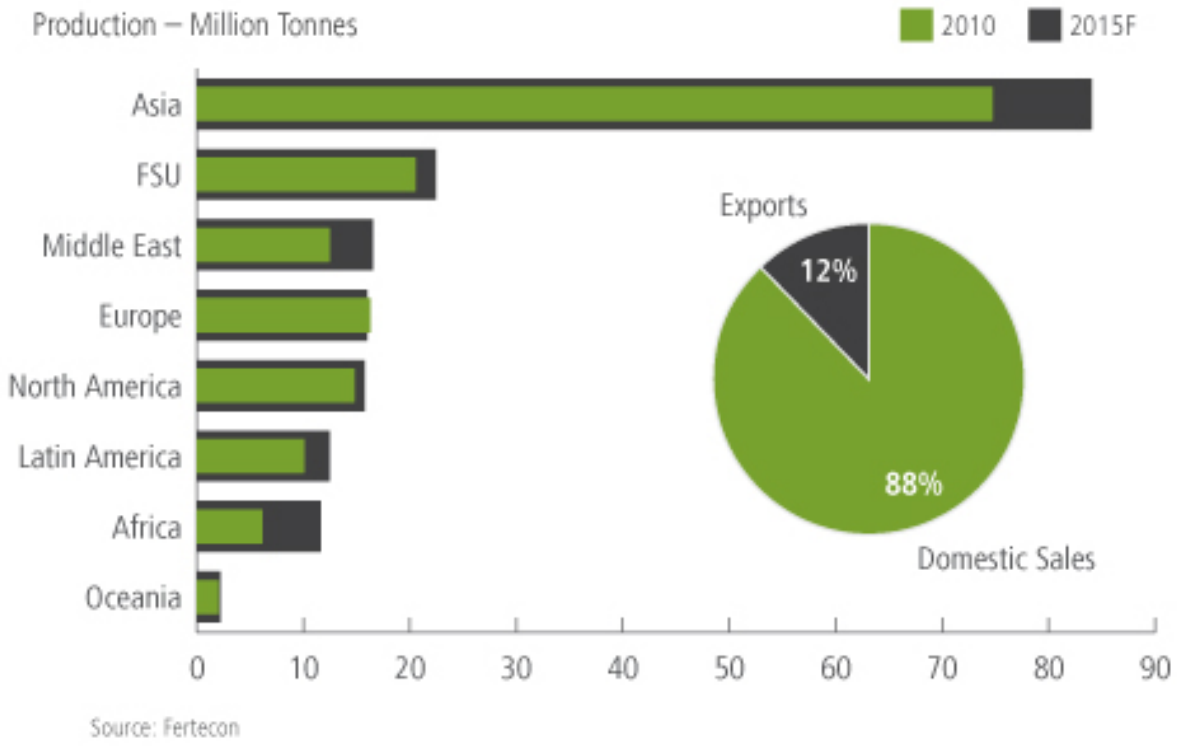
Risk Mitigation – What If?

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 other oil production regions experience violence-induced oil supply disruptions?
Global warming is taken seriously and the demand for cost-effective solutions becomes real?

Wringing Out the Last Few Drops

NH3 Facts

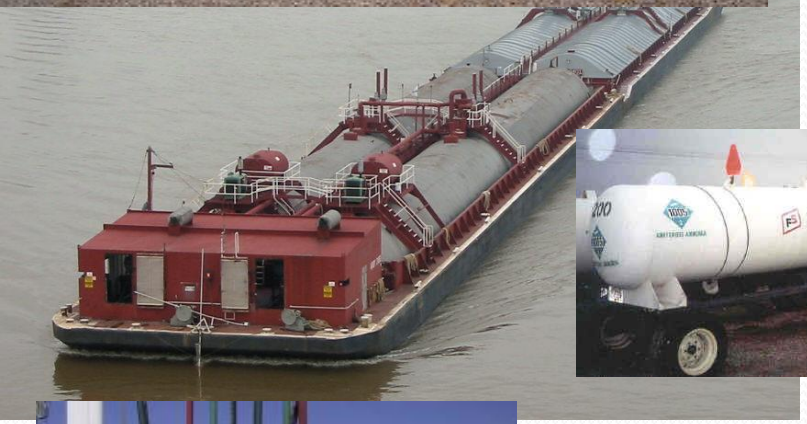
NH3 Production



Delivery Infrastructure

NH_3 is in the top three chemicals shipped worldwide.

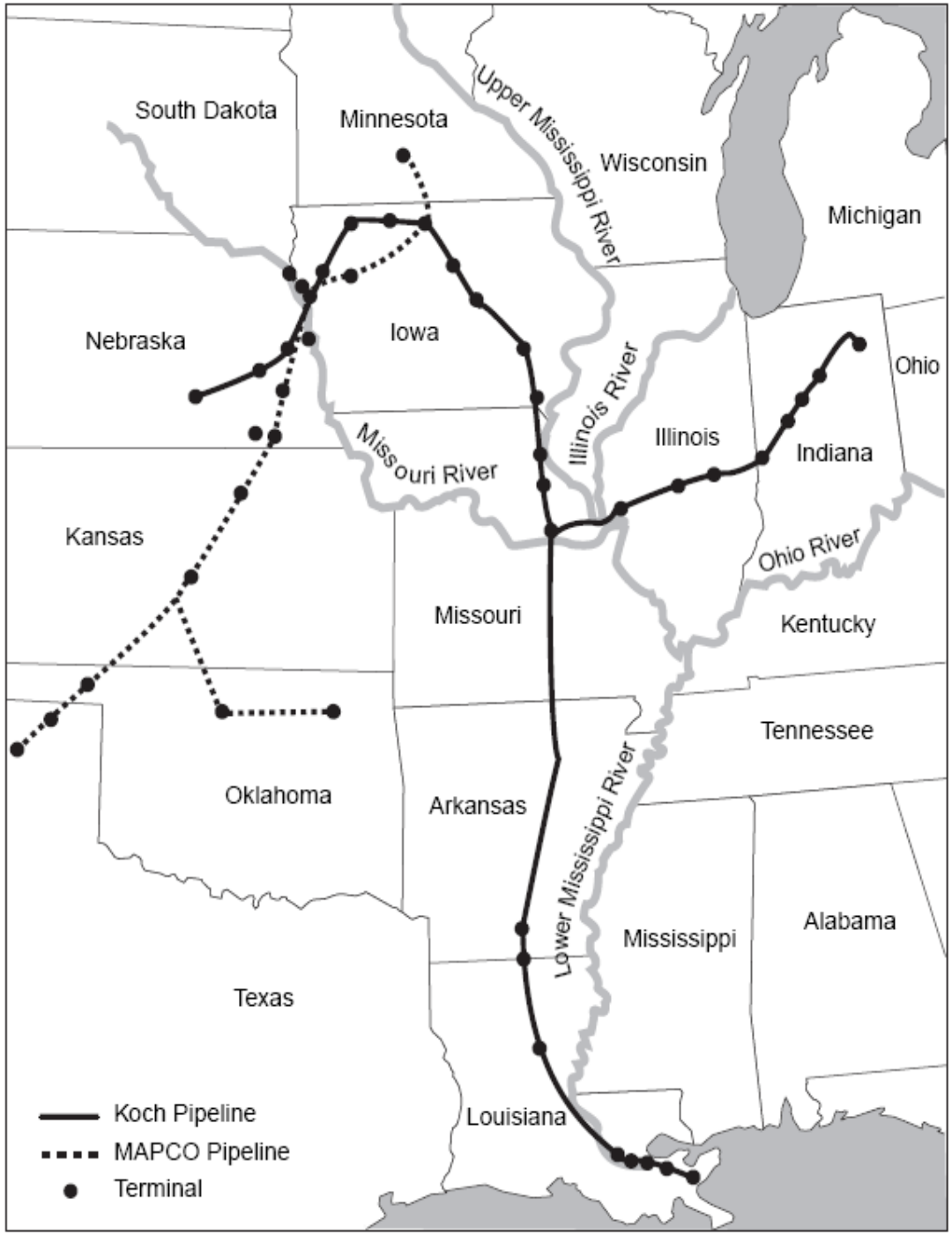
Ammonia Storage & Transport



NH3 Distribution Hub

U.S. Ammonia Pipeline

Nearly 3000 Miles Total



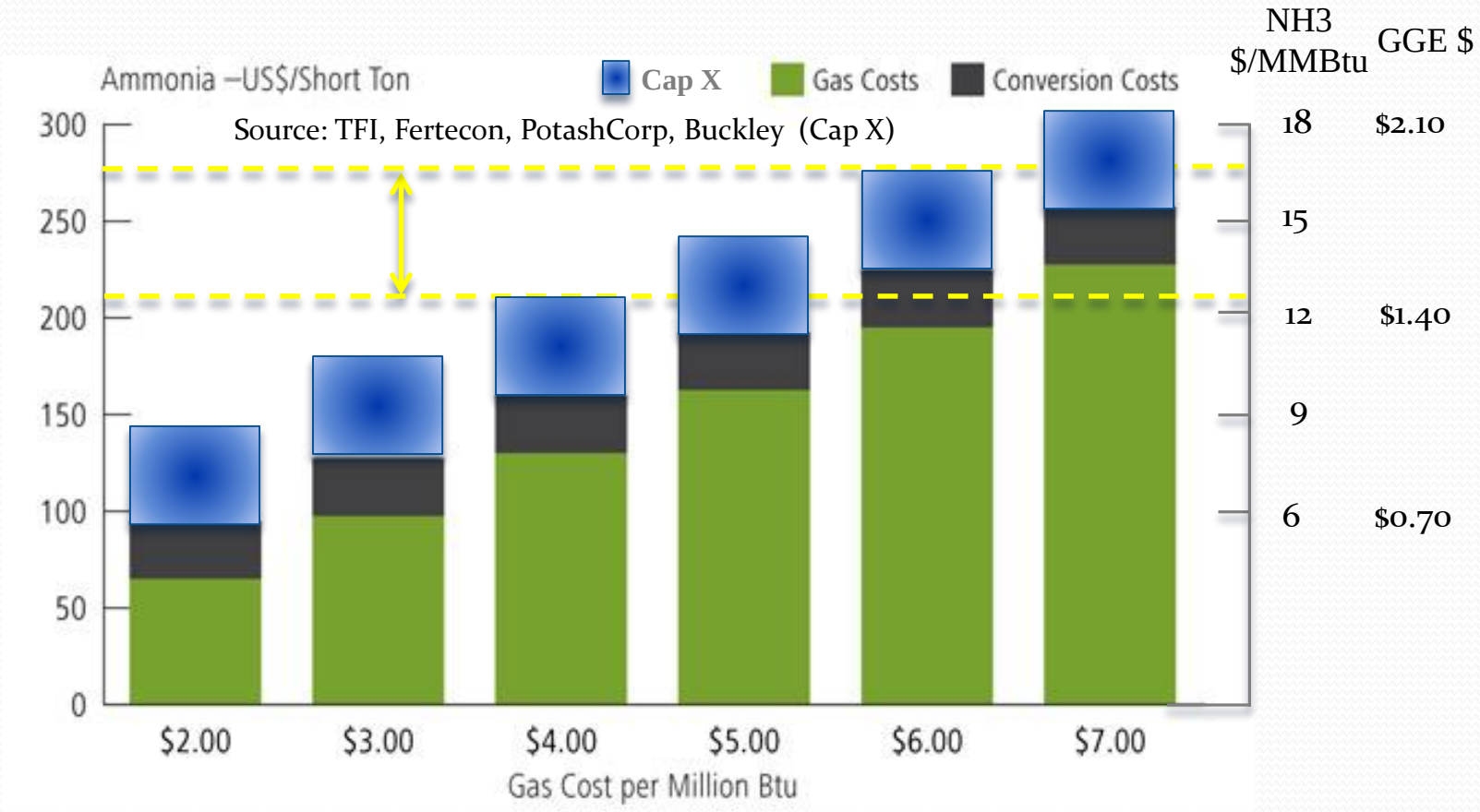
Iowa NH_3 Outlets

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

NH3 Fertilizer Application

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

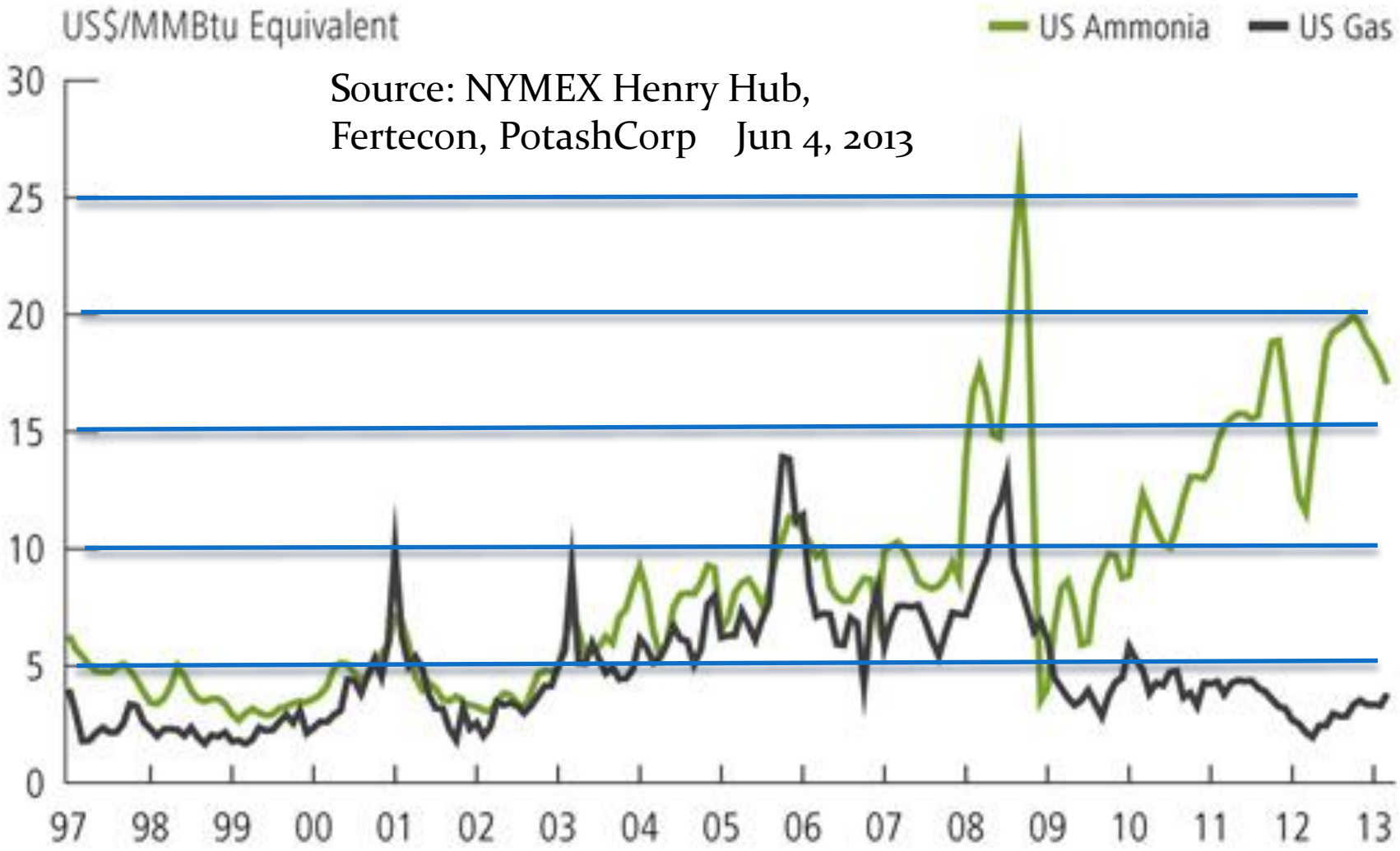
NH3 Production Costs w/ Cap X



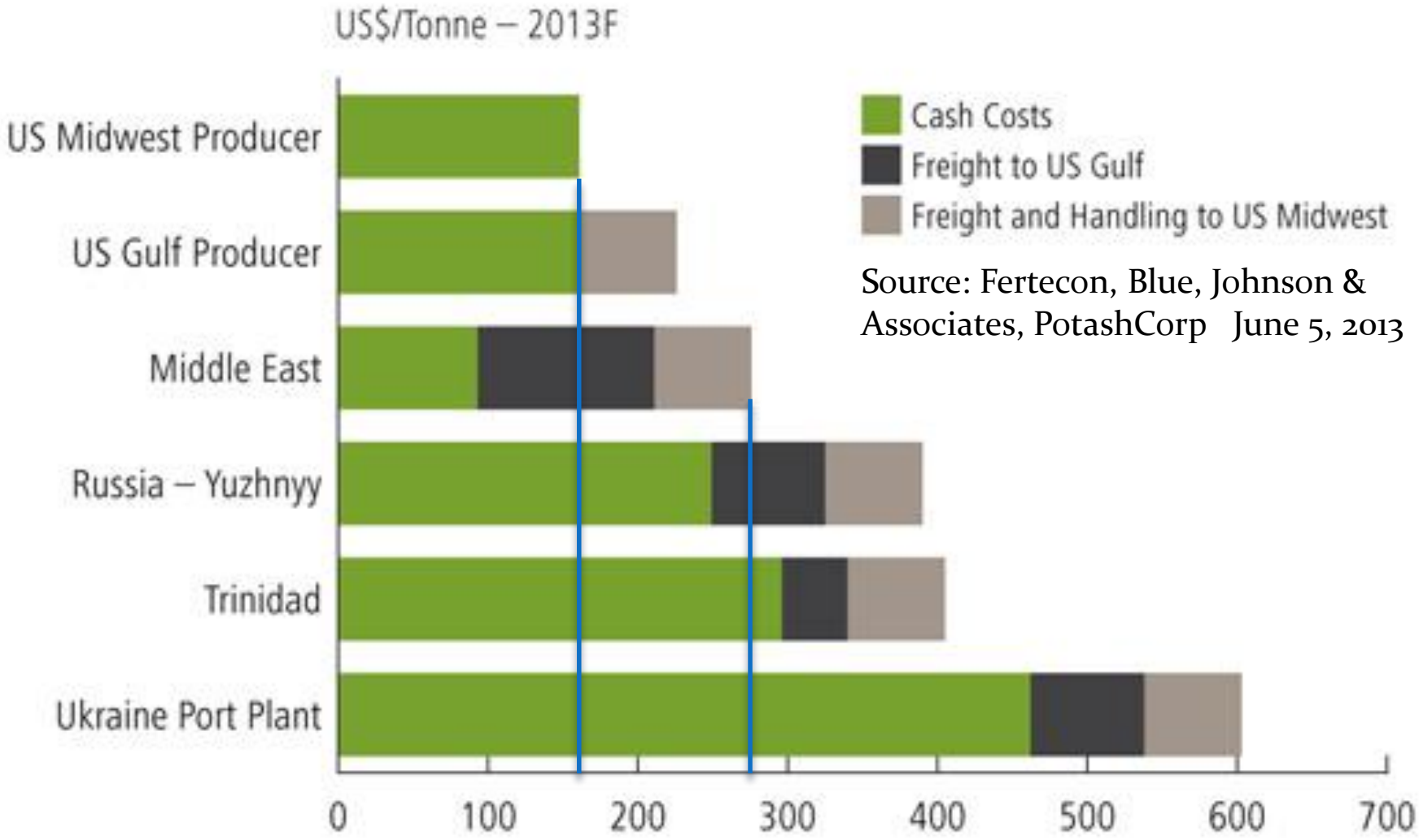
Natural Gas Represents More Than 75 Percent of US Producers' Costs
Natural gas is the most important feedstock in ammonia production and, depending on price, makes up 70-85 percent of the US cash cost of producing ammonia. Cap X: $1500/ton, 30 year amortization, ~$50/ton

Gasoline @ $3.50/gallon = $30/MMBtu

Historical NH3 vs NG Costs



US Midwest Delivered Ammonia Cost



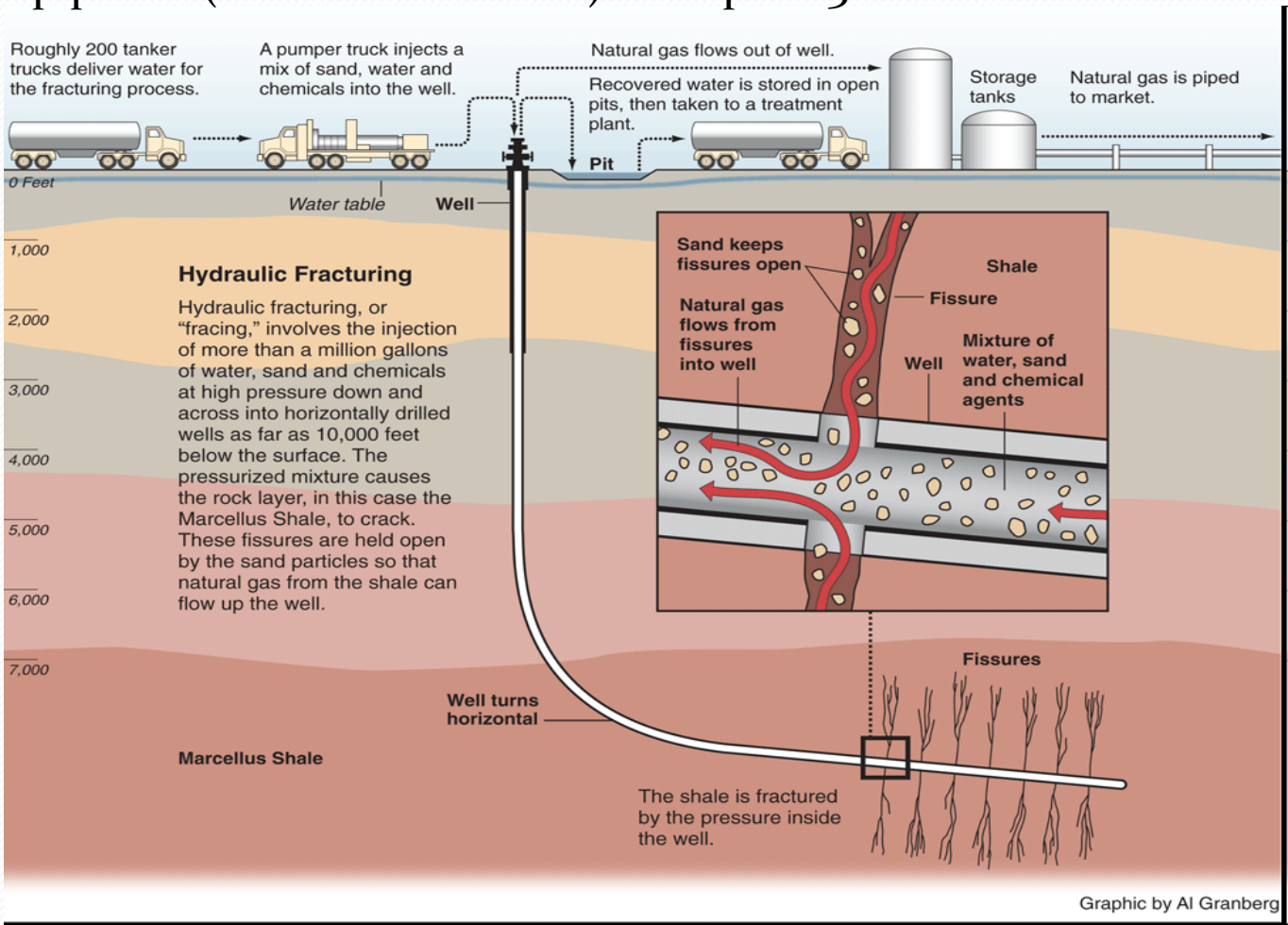
Source: Fertecon, Blue, Johnson & Associates, PotashCorp June 5, 2013

NH_3 and Natural Gas

Convert CH_4 to NH_3 at well head, sequester CO_2 in enhanced oil recovery (EOR) and natural gas wells to extend well production. Use natural gas pipeline (with modifications) to ship NH_3.

1.5 times more energy capacity when transporting NH_3 than CH_4 for a given pipeline size

More efficient energy transport

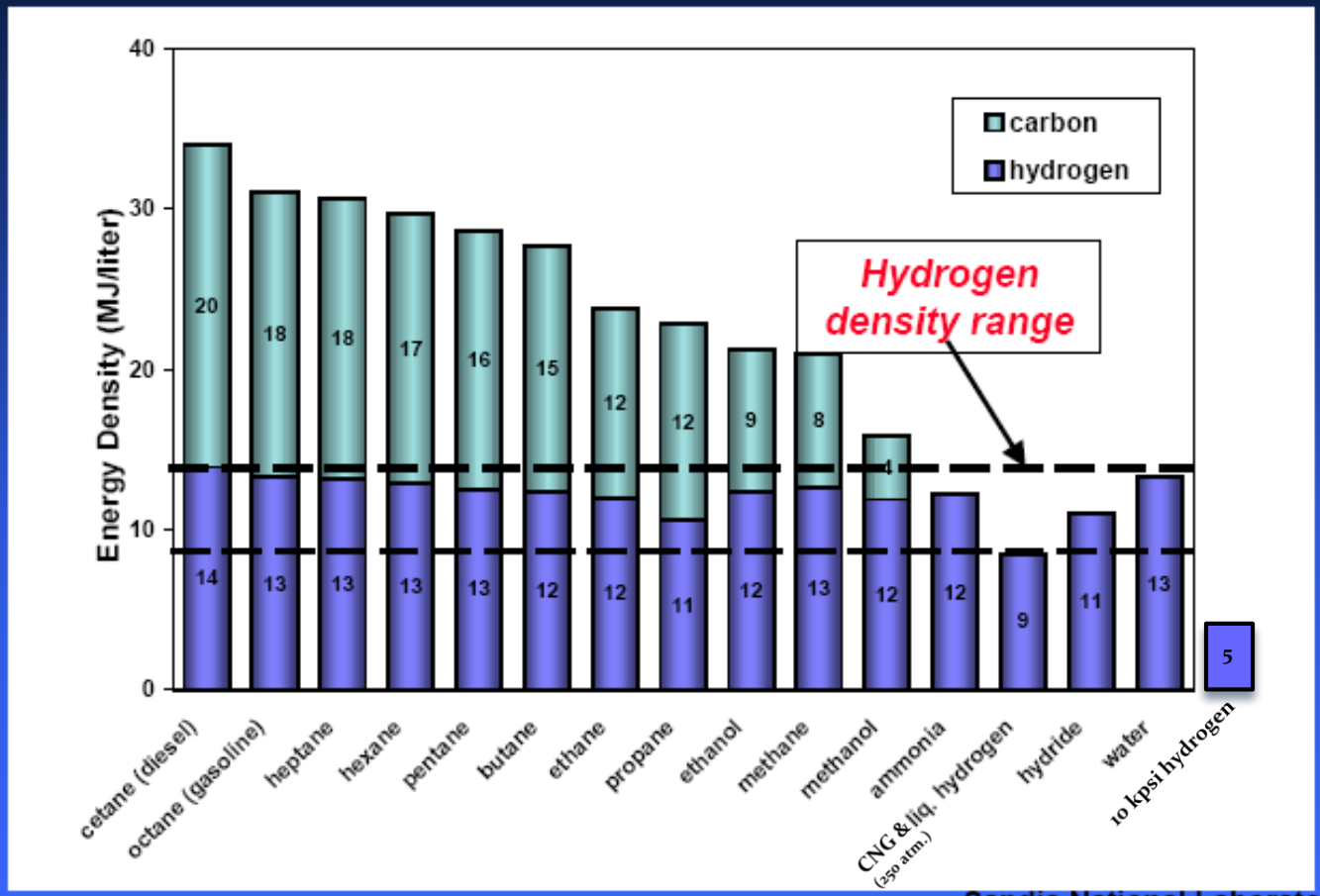


NH3 Fuel Details

NH3 Fuel

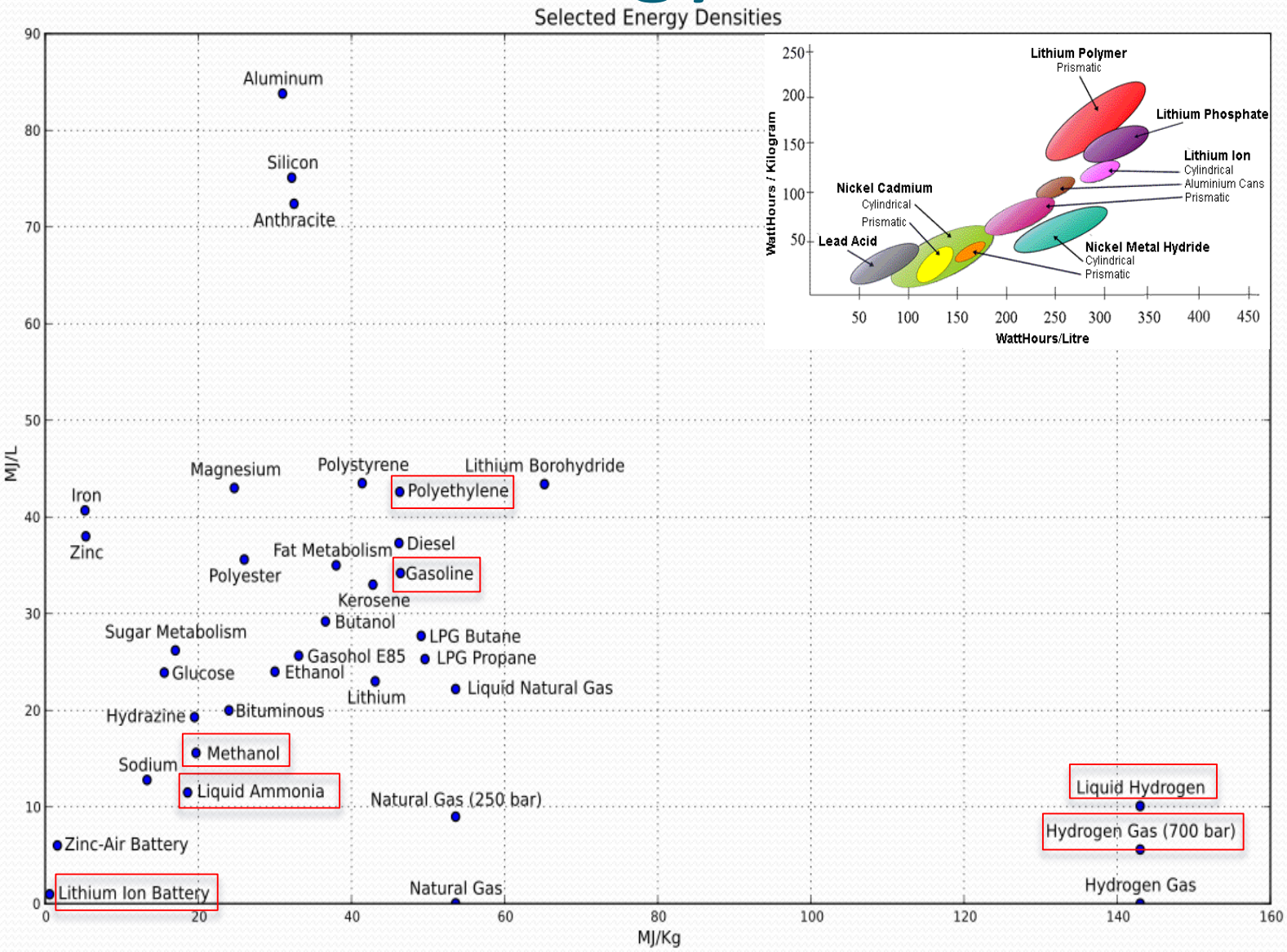
- Cleaner burning than hydrogen
- 30% higher volumetric energy density than liquid hydrogen
- Very high octane/high IC engine efficiency potential (>50%)
- Direct ammonia fuel cells have significant potential
- Relatively low-cost, safe fuel tanks.
- A low-cost liquid fuel.
- Not a greenhouse gas.
- Ozone depletion number of zero.

Energy densities (LHV) for fuels in liquid state

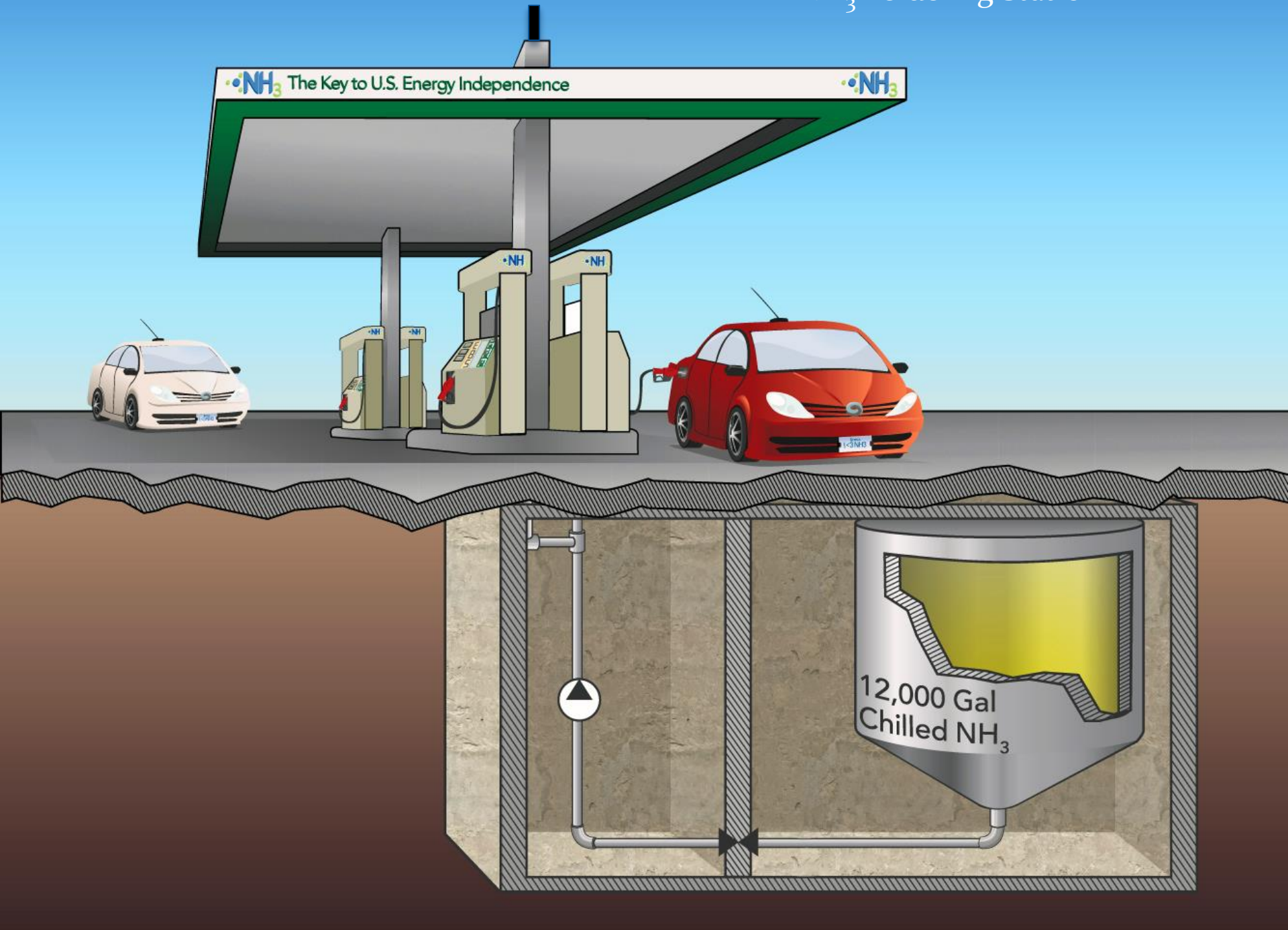


From George Thomas, BES workshop 5/13/03

Fuel Energy Densities



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

Vehicles: On-Board Storage Fuel Tanks

Atmospheric (Non-pressurized) cryogenic tanks provide higher energy density and safer operating conditions than pressurized tanks

NH3: -28 F Boiling Point (BP)

NH3: -108 F Melting Point (transparent solid)

LNG: -265 F BP

LH2: -423 F BP

Cryo NH3 can be contained in 250psi rated tanks if stored beyond atmospheric pressure stage. LNG and LH2 must be vented if stored beyond "hold " time.

Properly designed, pressurized (250 psi rated) NH3 vehicle fuel tanks meet international requirements for acceptable safety.

Refueling Components

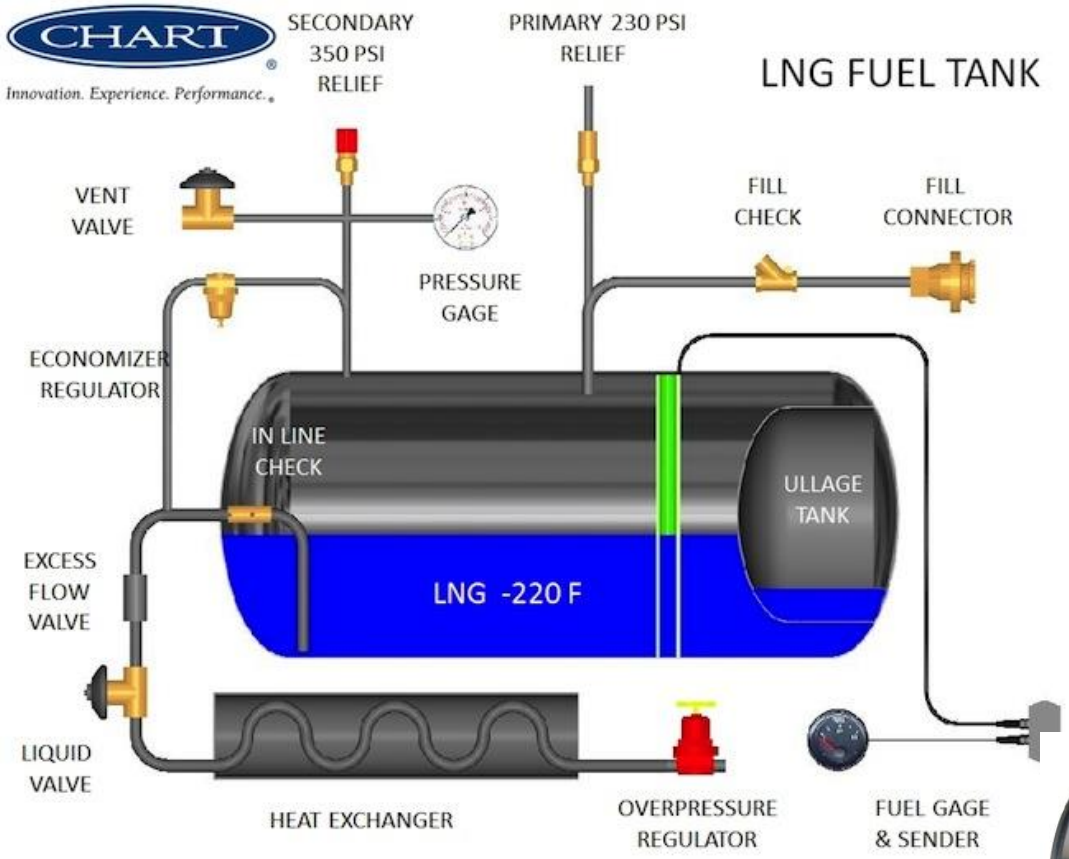
In-Line Hydrogen Breakaway

CW3600/CW5000 Series Self-Service Hydrogen Nozzle

L Series Hydrogen Fueling Receptacle

Source: OPW

LNG Tank Configuration



End Use Applications

- Spark-Ignition Internal-Combustion Engines
- Diesel Engines
- Direct Ammonia Fuel Cells
- Gas Turbines
- Gas Burners (including residential furnaces)

NH3 Fuel 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.**

NH3 Fuel 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.**

NH3 Fuel Advantages

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

Existing Delivery Infrastructure

Cost Competitive

Environmentally Optimal – Zero Measurable Criteria Pollutant Emissions

End Use Flexibility – IC and CI Engines, Fuel Cells, Gas Turbines, etc.

Extremely high efficiency/high octane rating

Proven, Acceptable Safety Record

NH3 Safety

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).**

Vehicle Fuel Tank Risks

It is also important to note that the risk associated with traveling in a vehicle powered by any one of these fuels is dominated by accidents that do not result in a release of the fuel. As described in the National Safety Council database referenced in Section 1, very few traffic accidents result in a release of the fuel powering the automobile. Since anhydrous ammonia and LPG are stored in similar pressurized tanks, there is no reason to believe that the risks associated with the passengers in an automobile would go up or down due the use of anhydrous ammonia as the fuel.

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

Minot vs. Lac-Mégantic Derailments

Minot vs Lac-Mégantic Derailments

Minot, ND NH3 Spill

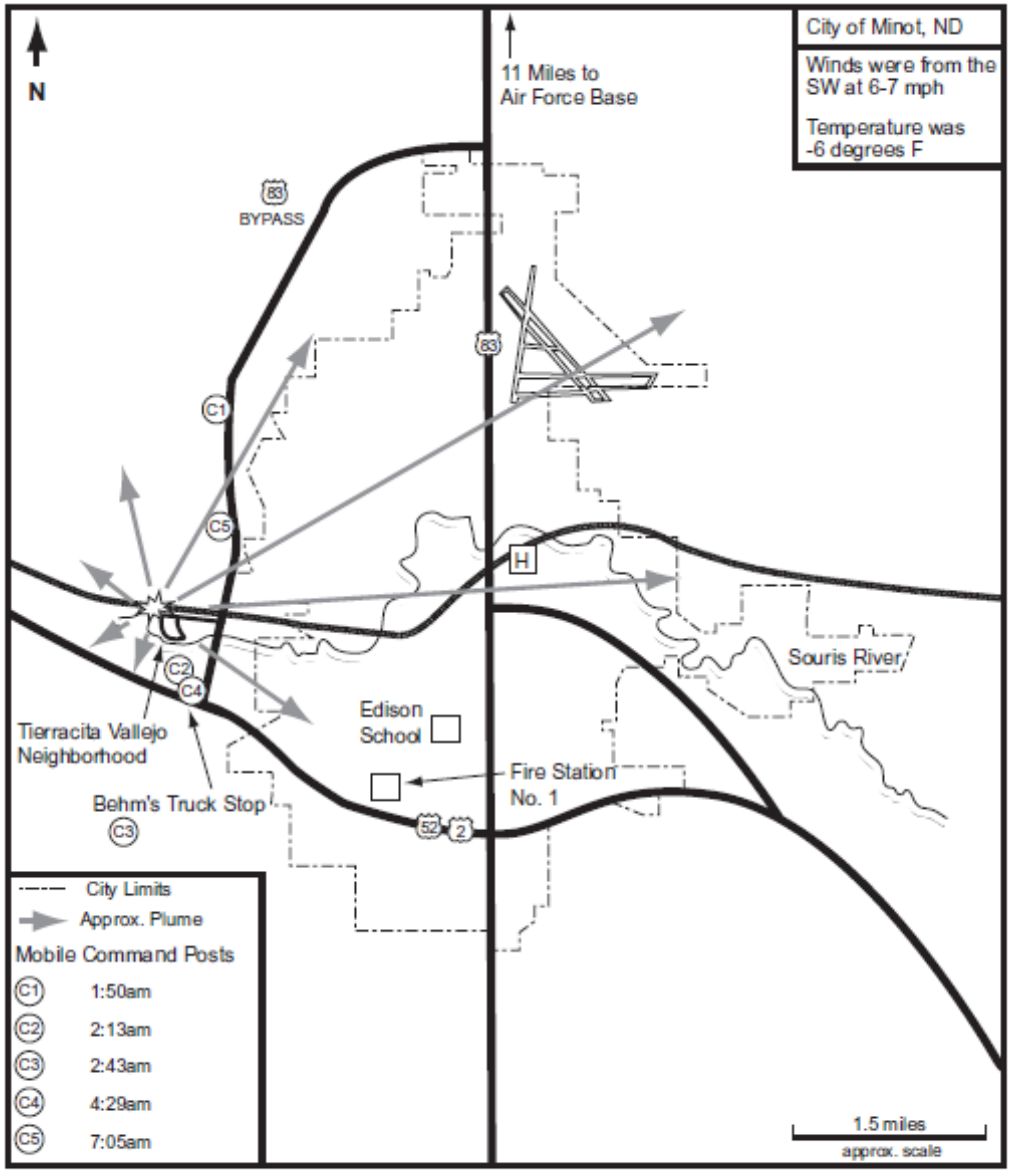


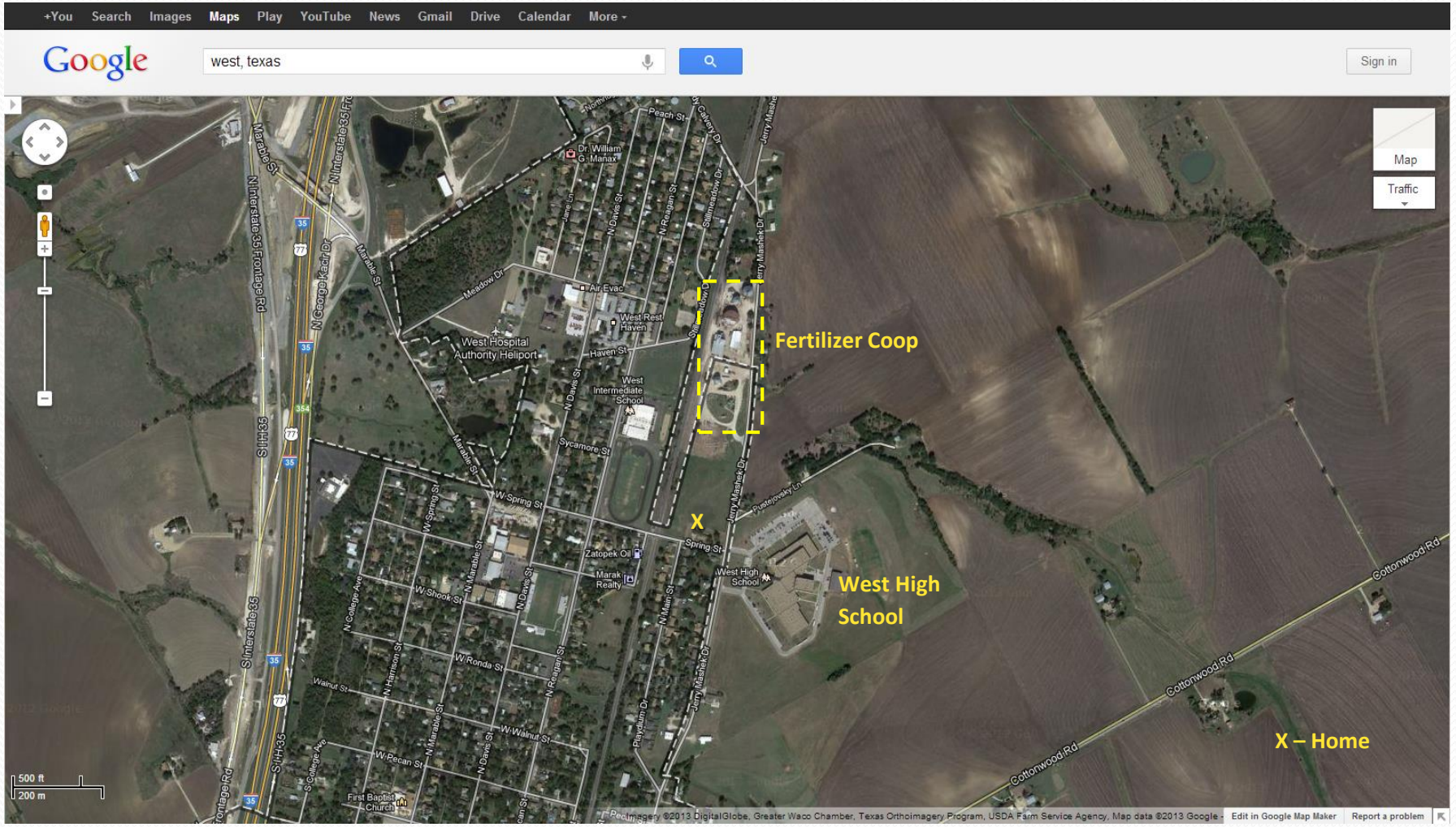
Figure 5. Map of derailment area.

Crude Oil vs NH3 Train Derailment Stats

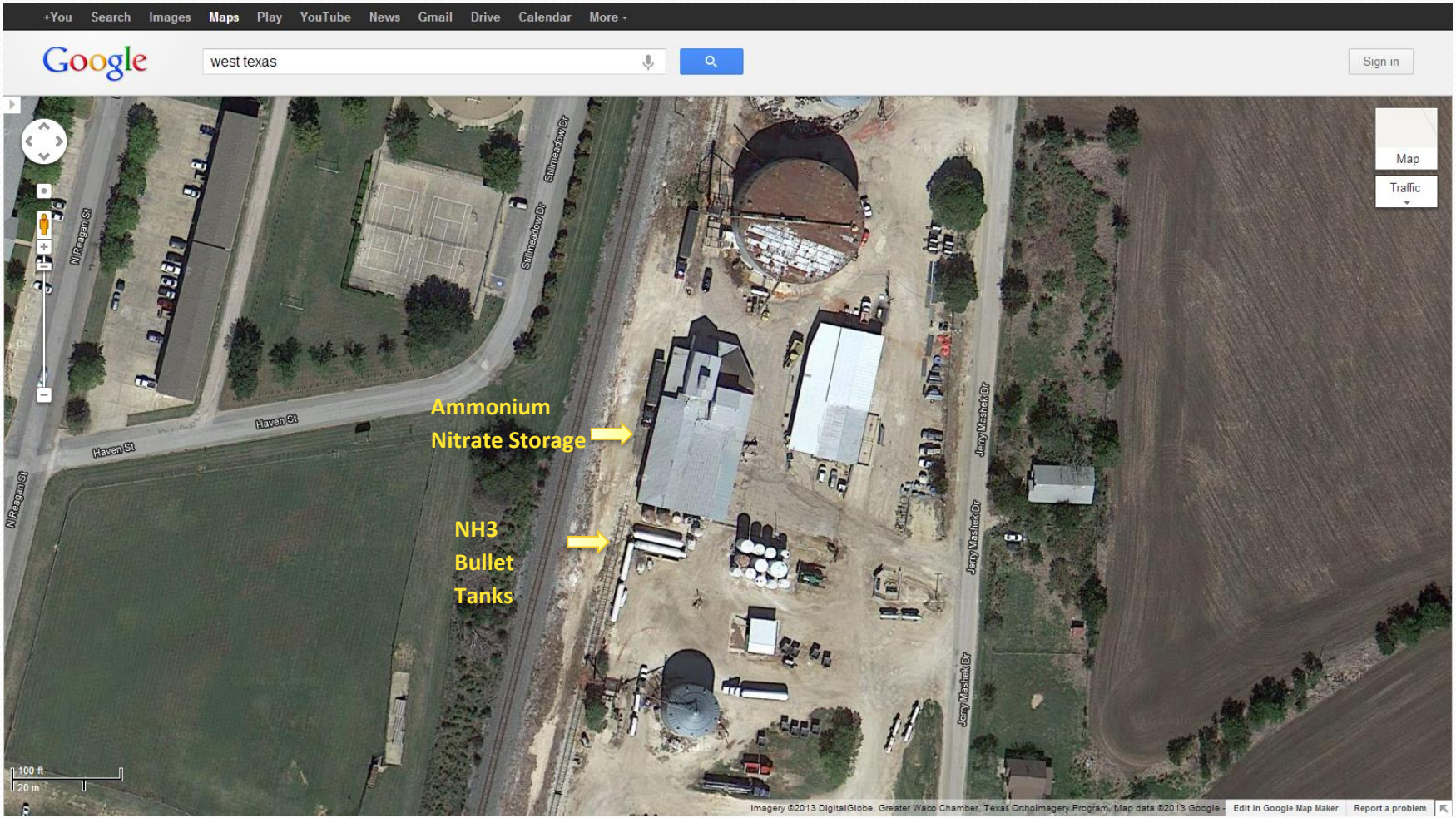
	Lac-Mégantic	Minot
Cargo	Crude oil	Anhydrous ammonia
Date	06-Jul-13	18-Jan-02
Time	01:15	01:37
Train speed	56 mph	41 mph
Cars in train	72	112
Ruptured cars	4	5
Gallons released	1,500,000	240,000
People living within affected area	2,000	11,600
Fatalities	47	1
Sustained serious injuries	?	11
Minor injuries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

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

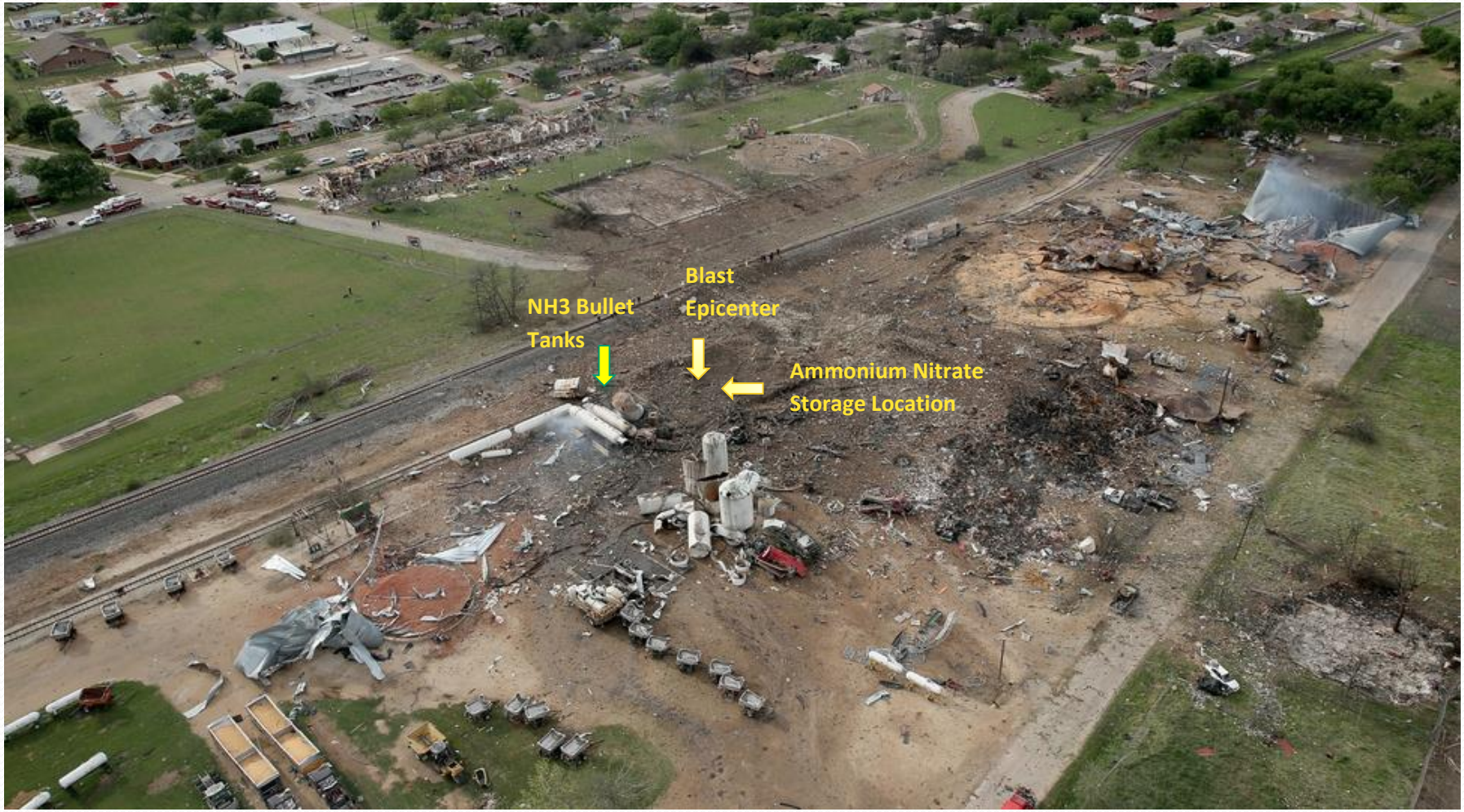
West Texas Explosion – Not NH3 Related



West Texas Explosion – Not NH3 Related



West Texas Explosion – Not NH3 Related



Concerns?

Ephedrine and Pseudoephedrine $C_{10}H_{15}NO$

Methamphetamine $C_{10}H_{15}N$

VOC's + NOx + O2 + Sunlight = ozone = smog+

NOx + H2O + NH_3 = ammonium nitrate = smog-

NH_3 is actually used to clean up NOx emissions at coal plants

DOE Proposed Solutions

- President Bush – Ethanol, hydrogen
- President Obama – EV's, Drop-in fuels

Drop-in fuels can only be made from biomass. Electricity and hydrogen can both be produced using all primary energy sources. Hydrogen and EV's have their own significant (insurmountable) set of problems.

NH3 – A Favorite Chemical

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.
NH_3 is an excellent medium for long-term (chemical) storage of renewable energy.

Where our other favorite chemical (H_2O) exists, one relatively simple refinery producing NH_3 can provide enhanced sustainable food production, transportation fuel, distributed electrification via CHP units, refrigeration/air conditioning and long-term (> 6 months) renewable energy storage. This provides an excellent base for local self-sufficiency and an improved standard of living.

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

Future Compatibility




Hydrogen + Nitrogen

Ammonia

Storage & Delivery – Pipeline, Barge, Truck, Rail

- Stationary Power
- Green Refrigerant
- Fertilizer
- Renewable Energy Storage
- Transportation

OK, 2nd Favorite Chemical Is Pretty Impressive