NH_3 Fuel
"The Other Hydrogen"

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NH_3 VIII

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San Antonio, Texas

Potential NH_3 Fuel Advantages

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

Existing Delivery Infrastructure

Cost Competitive

Environmentally Friendly

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

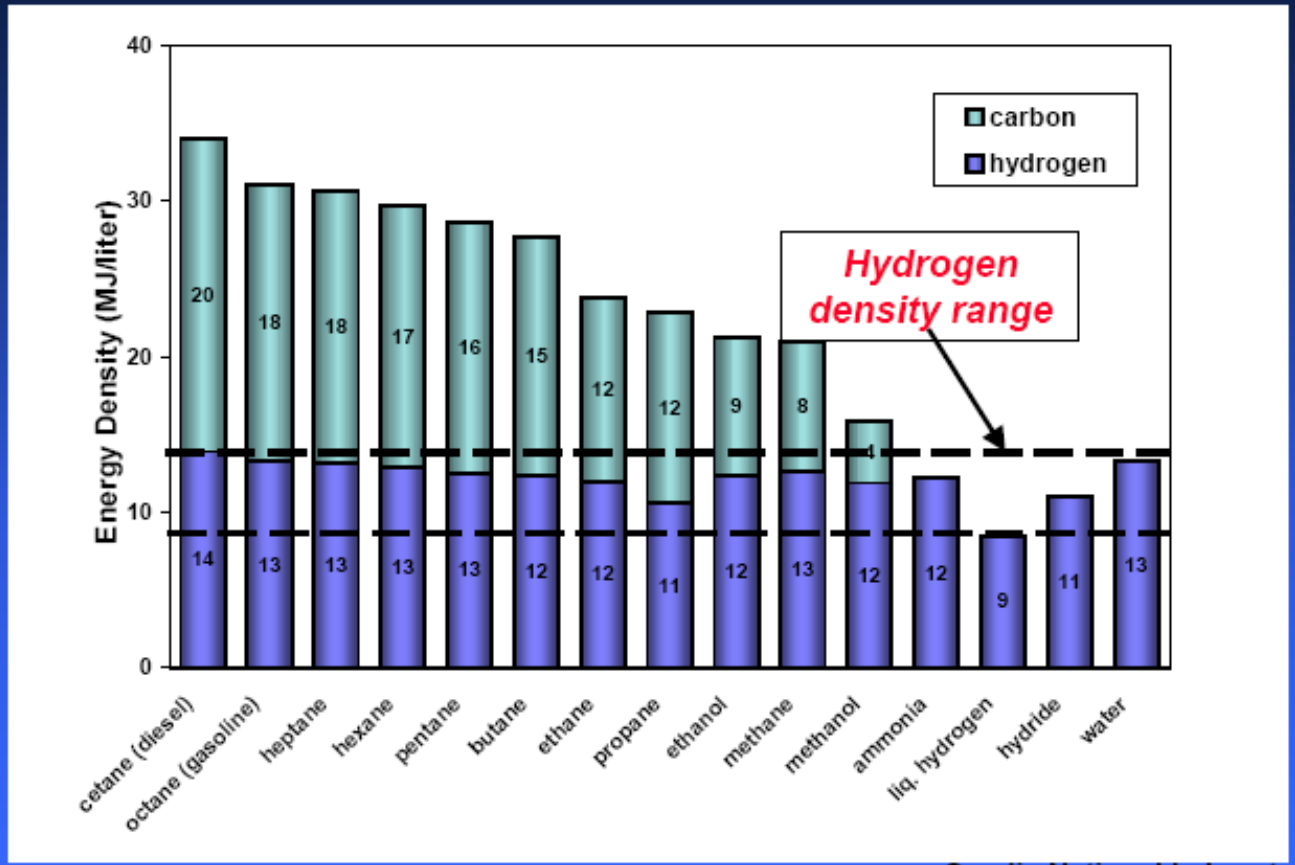
Proven, Acceptable Safety Record

Freedom Car Targets w/ 2005 NH_3 Comparison

Parameter	**Units**	**2007**	**2010**	**2015**	**NH_3** (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*

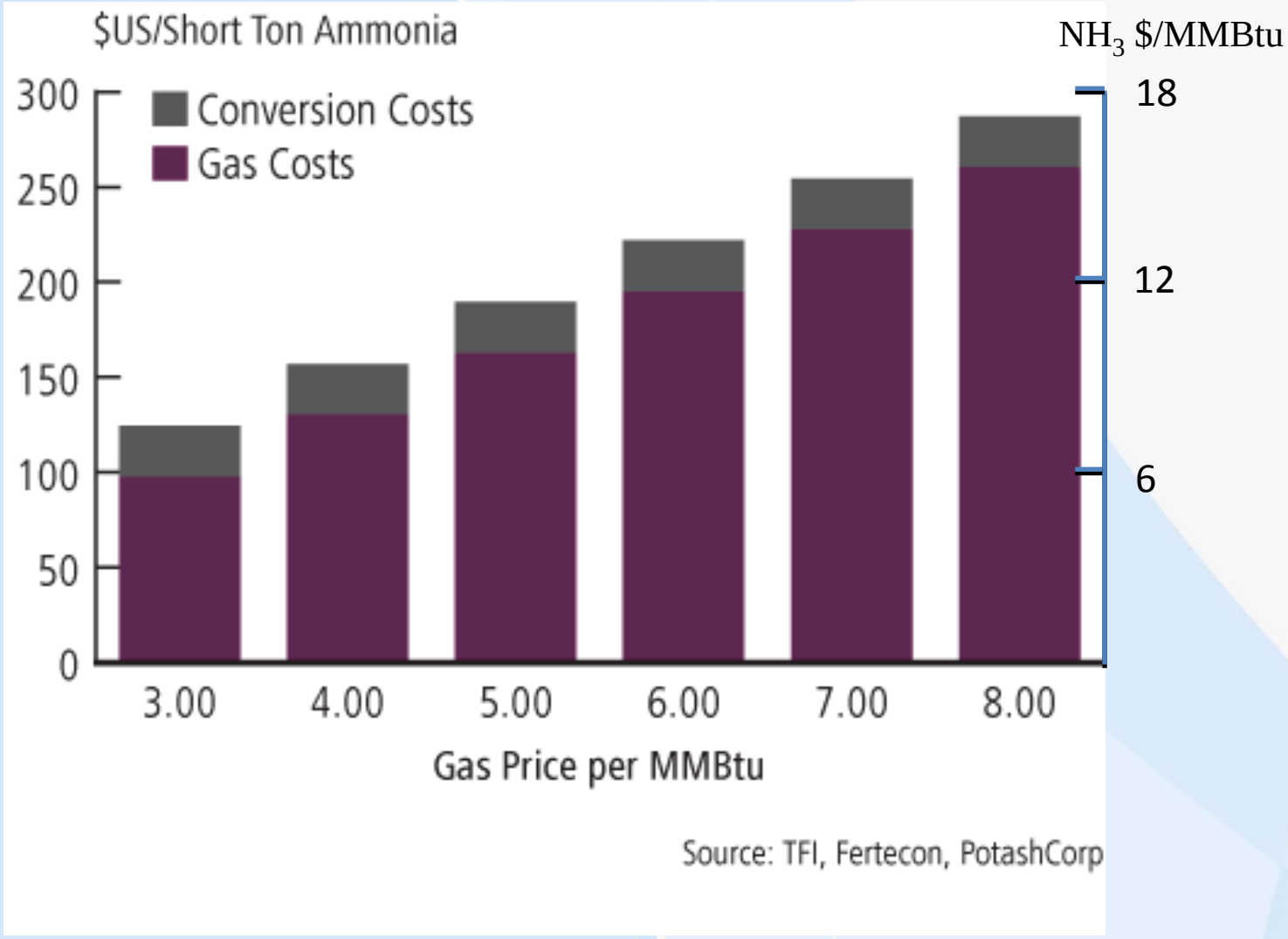
*$280/ton ammonia

Energy densities (LHV) for fuels in liquid state



From George Thomas, BES workshop 5/13/03

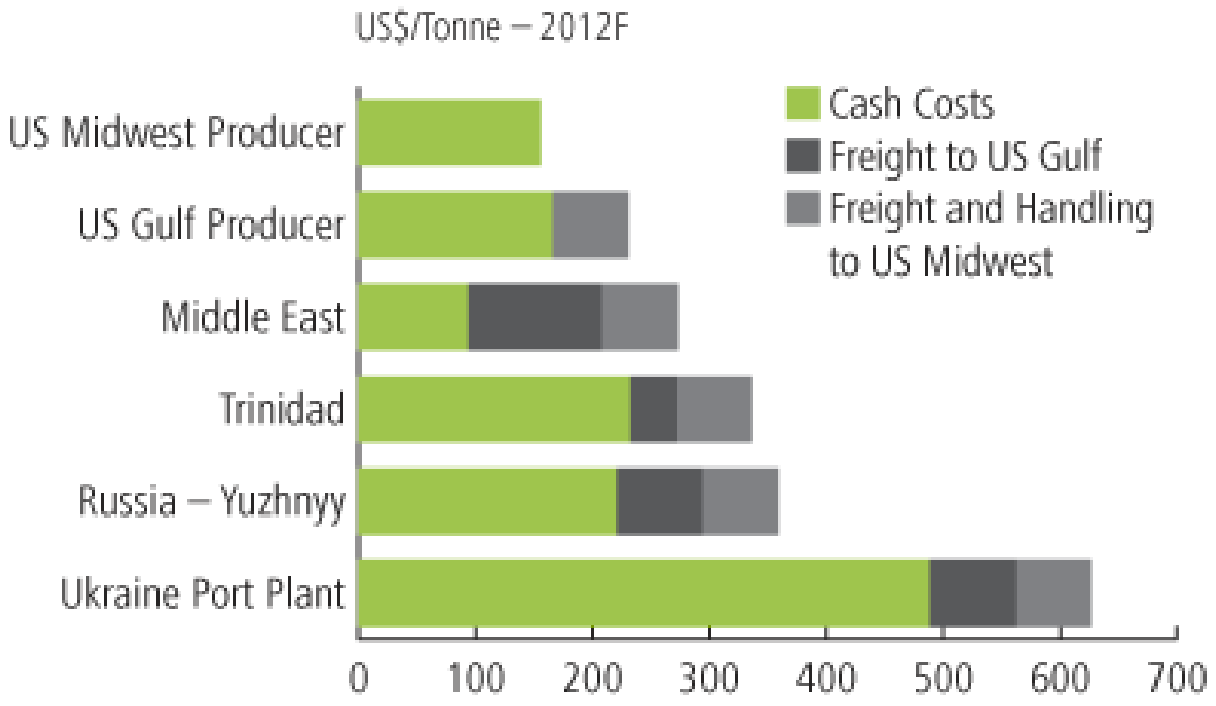
NH_3 Production Costs



Gasoline at $3.50/gallon = $30/MMBtu

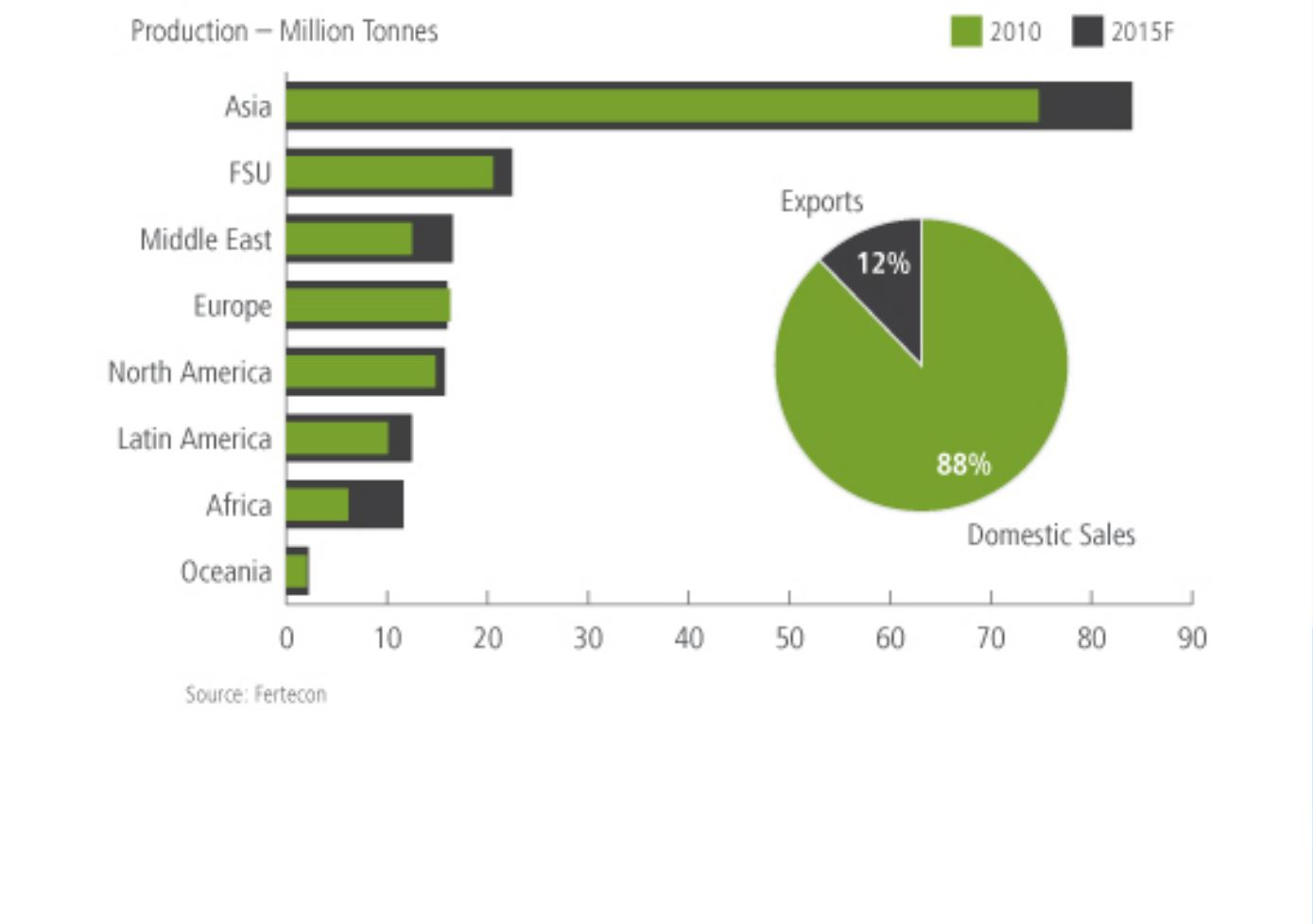
US Midwest Delivered Ammonia Cost

Interior plants have significant delivered cost advantage



Source: Fertecon; Blue, Johnson & Associates; PotashCorp

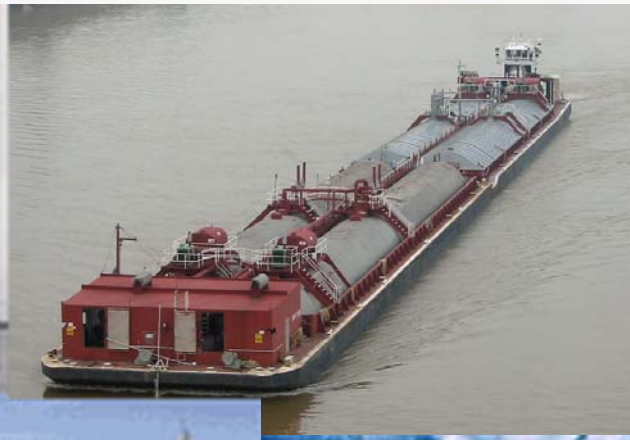
NH_3 Production



Delivery Infrastructure

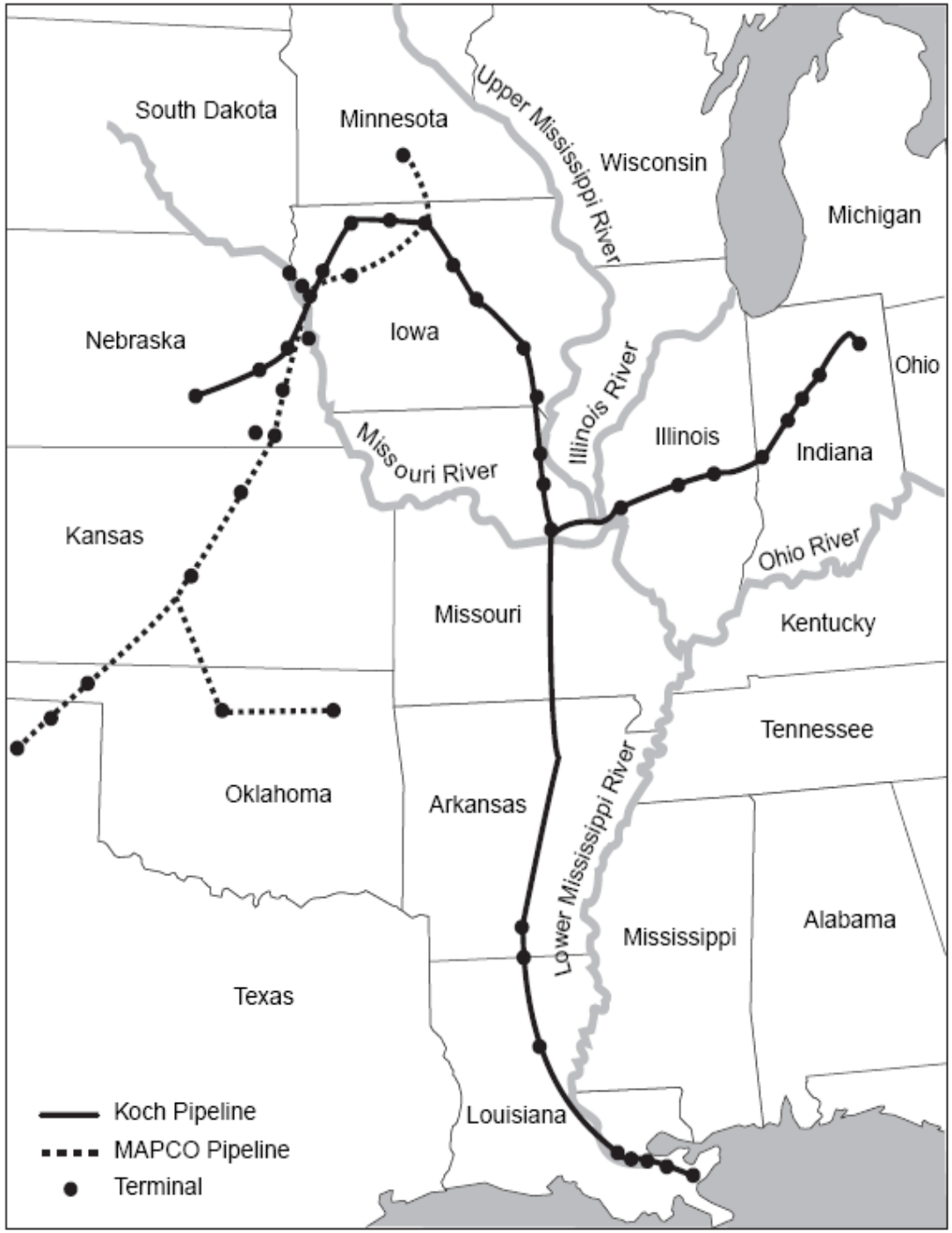
NH_3 is one of the top three chemicals shipped worldwide.

Ammonia Storage & Transport



U.S. Ammonia Pipeline

Nearly 3000 Miles Total



Iowa NH_3 Outlets

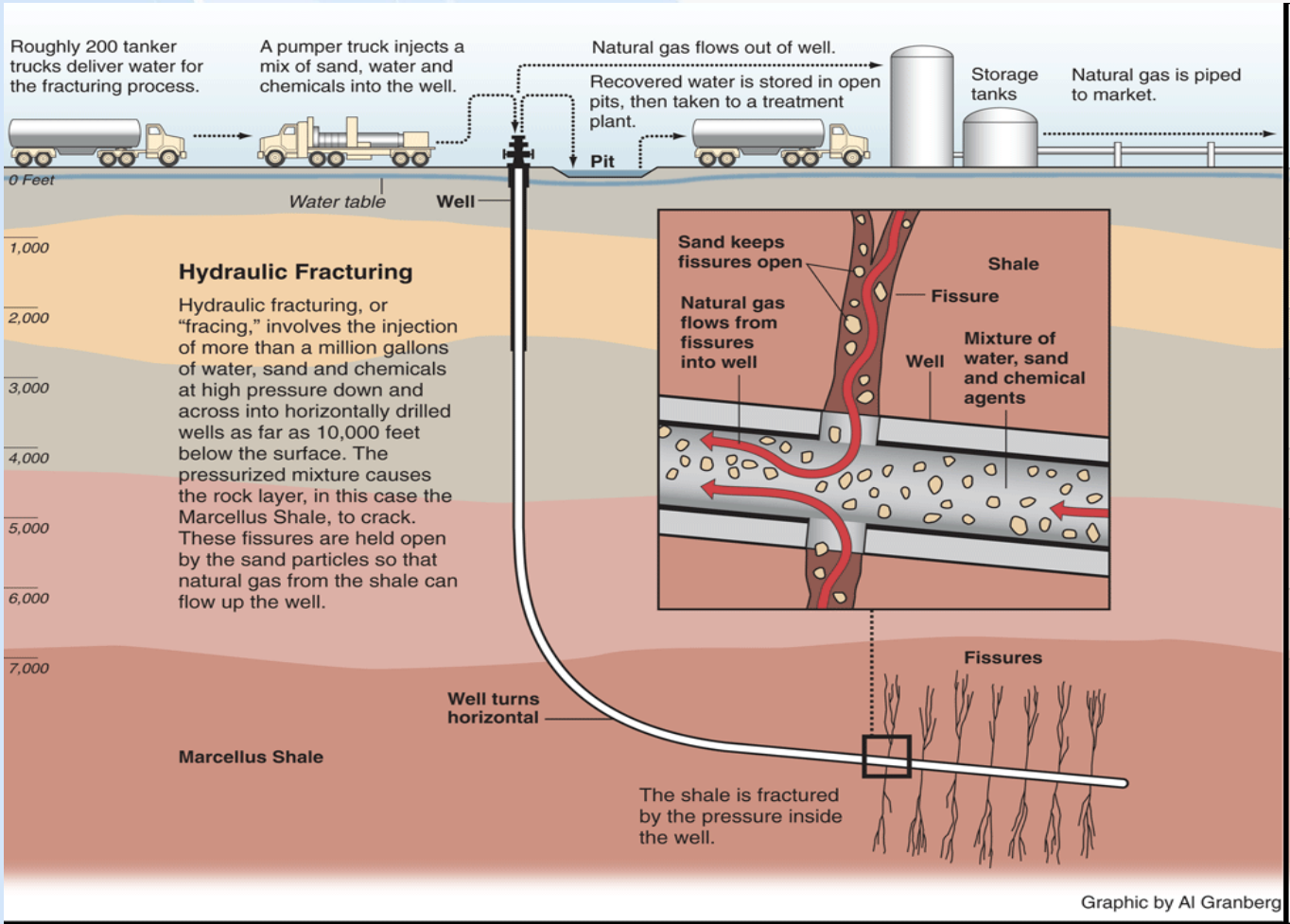
Over 800 retail ammonia (the “Other Hydrogen”) outlets currently exist in Iowa.

NH_3 and Natural Gas

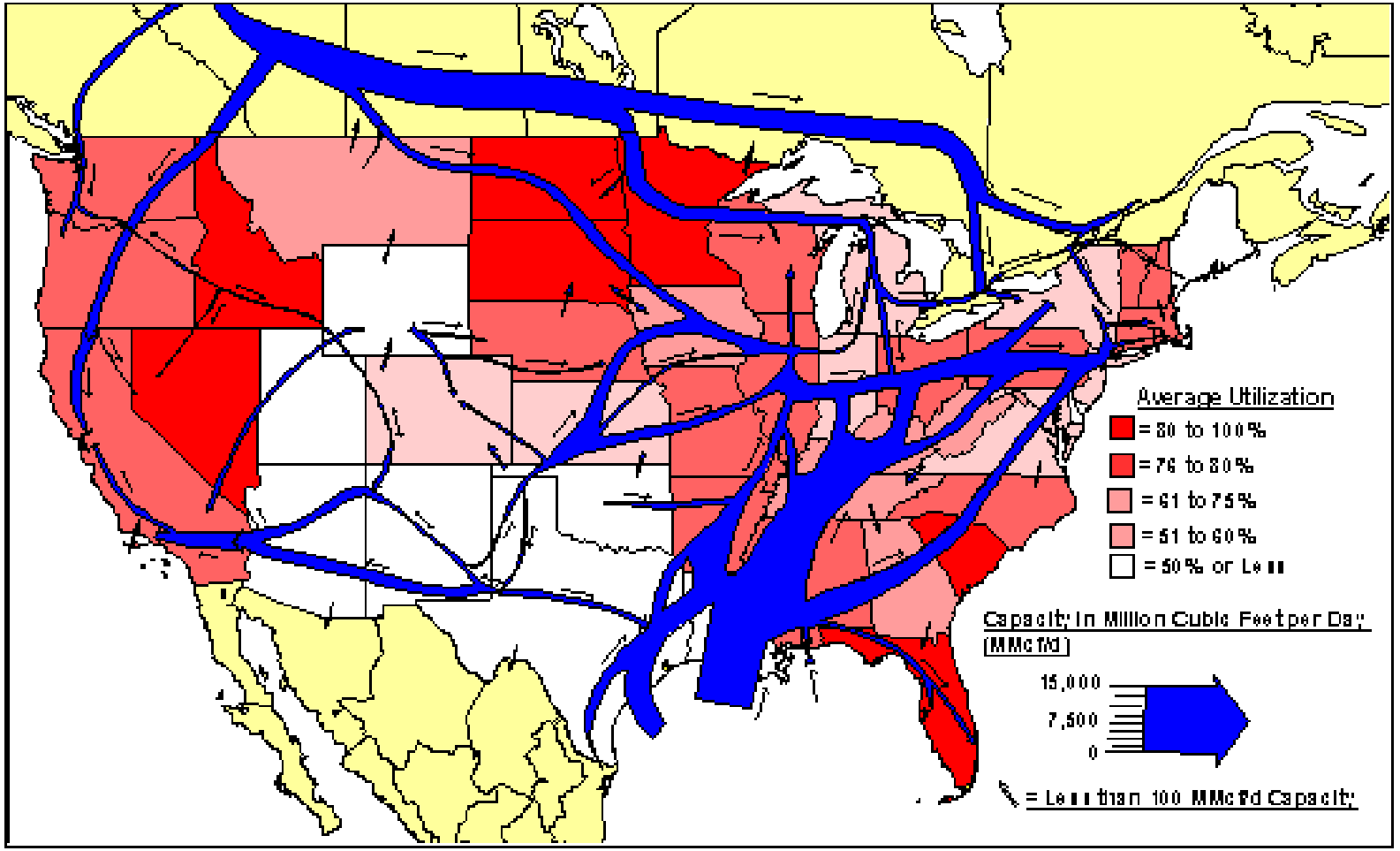
Convert CH_4 to NH_3 at well head, sequester CO_2 in natural gas well to extend well production and use natural gas pipeline (with modifications) to ship NH_3

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

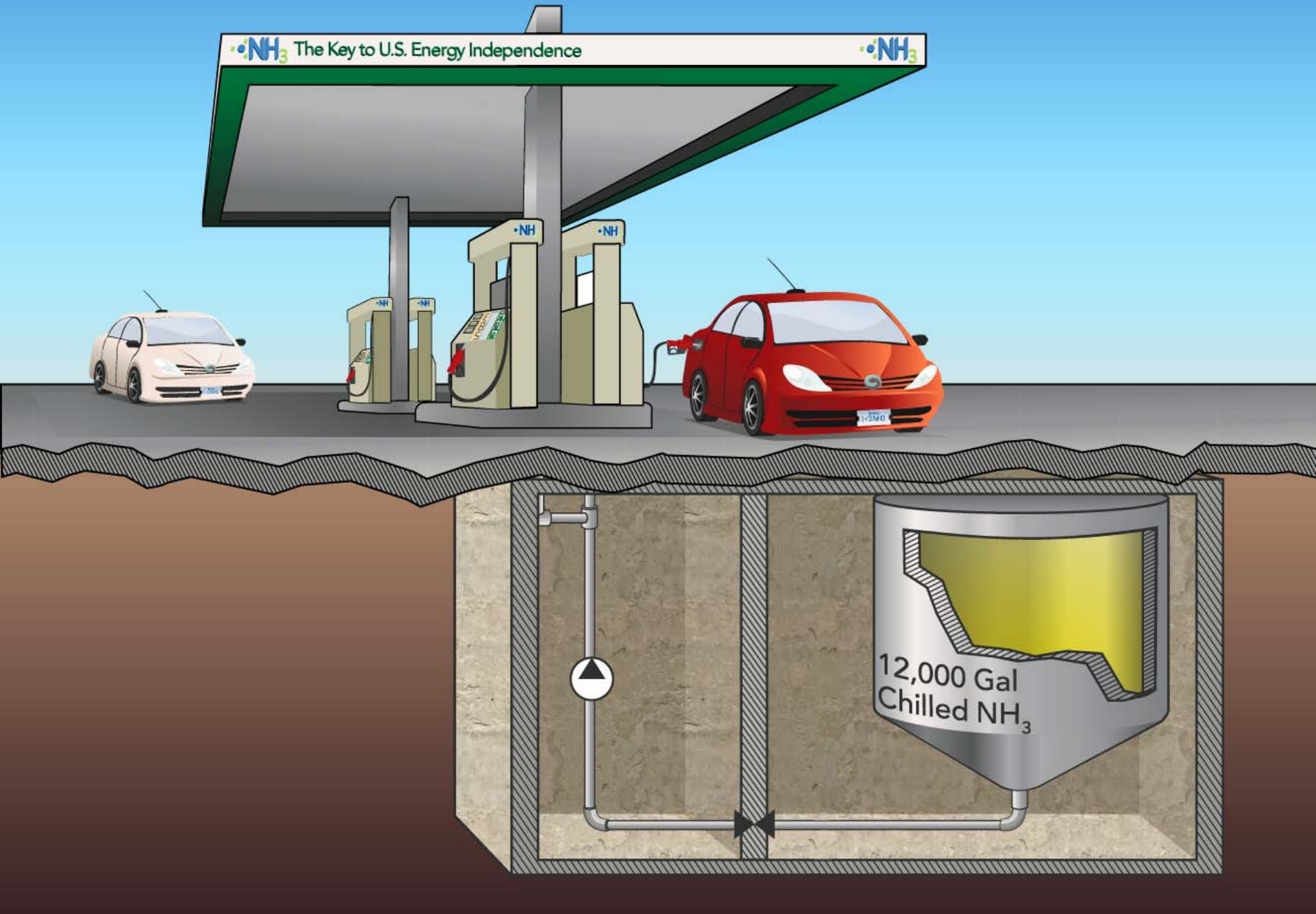
More efficient energy transport



Natural Gas Pipelines



NH_3 Refueling Station



Safety

- NH_3 is a common, naturally occurring chemical found in all animal life forms. It is not a carcinogen and is not a greenhouse gas.
- NH_3 is safer than propane and as safe as gasoline when used as a transportation fuel.
- Iowa Energy Center funded a comparative quantitative risk assessment (CQRA) study completed March 2009, by Quest Consultants Inc., Norman, Oklahoma
- “Safety assessment of NH3 as a transportation fuel,” Nijs Jan Duijm, Frank Markert, Jette Lundtang Paulsen, Riso National Laboratory, Denmark, February 2005
- NH_3 plant operators
- NH_3 safety is an engineering issue. It can be made to be as safe as is necessary.
- NH_3 is classified by DOT as a non-flammable liquid and an inhalation hazard (not a poison).

Vehicle On-Board Storage

Properly designed, pressurized (250 psi rated) NH_3 vehicle fuel tanks meet international requirements for acceptable safety.

Concerns?

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

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

VOC's + NOx + O_2 + Sunlight = ozone = smog+

NOx + H_2O + NH_3 = ammonium nitrate = smog-

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

NH3 Fertilizer Application

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

Potential End Use Applications

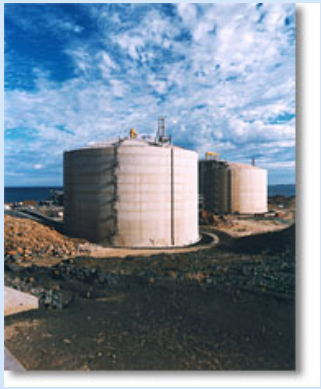
- Spark-Ignition Internal-Combustion Engines
- Diesel Engines
- Direct Ammonia Fuel Cells
- Gas Turbines
- Gas Burners (including residential furnaces)

Future Compatibility




Hydrogen + Nitrogen

Ammonia



Storage & Delivery – Pipeline, Barge, Truck, Rail

Stationary Power

Fertilizer

Transportation

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.

R/P Ratio

	U.S. R/P Ratio	China R/P Ratio
Oil	10.8	9.9
Natural Gas	13.0	29.8
Coal	239	33.0

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

Past/Present Iowa Energy Center Funded Work

Dr. Andreja Bakac
Novel ammonia synthesis

Dr. Song Charng Kong
Ammonia use in diesel and spark ignition engines

Dr. Johna Leddy
Novel ammonia synthesis

Dr. Terrence Meyer
Ammonia combustion

Quest Consultants
Comparative Risk Assessment Analysis

More Work To Do?

Additional Research Areas?
Demonstrations - vehicles/engines/gas burners/others?
Marketing?
Auto Manufacturers Participation?
Collaborations?
DOE Support?
State Support?
What Else?

Summary 1

- NH_3 meets critical 2015 Freedom Car targets today.
- NH_3 has an extensive, worldwide transportation and storage infrastructure already in place.
- H_2 and NH_3 can have very low tailpipe greenhouse gas emissions (with controls).
- H_2 and NH_3 can be made from electricity and water (+air for NH3).
- NH_3 can replace diesel fuel, gasoline, natural gas and propane in many fuel-related applications.
- NH_3 is a hydrogen dense chemical, ~50% greater (volume basis) than 10k psi hydrogen.

Summary 2

- Most NH_3 is currently produced from coal and natural gas.
- NH_3 can be produced using renewable energy (Including wind, solar, OTE, hydro, etc.)
- NH_3 diesel (CI) and spark-ignition (SI) engines have been demonstrated.
- Direct NH_3 fuel cells are being developed.
- NH_3 is not a greenhouse gas. It is a prevalent, naturally occurring chemical.
- Any transportation fuel has associated safety risks but NH_3 is as safe as gasoline and safer than propane according to two, highly-credible studies.
- Hydrogen stored, delivered and utilized in the form of NH_3 has several significant benefits.

Questions?

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