# NH3 – The Optimal Alternative Fuel

## NH3 XIII

Norm Olson

September 18 – September 21, 2016

Los Angeles, CA

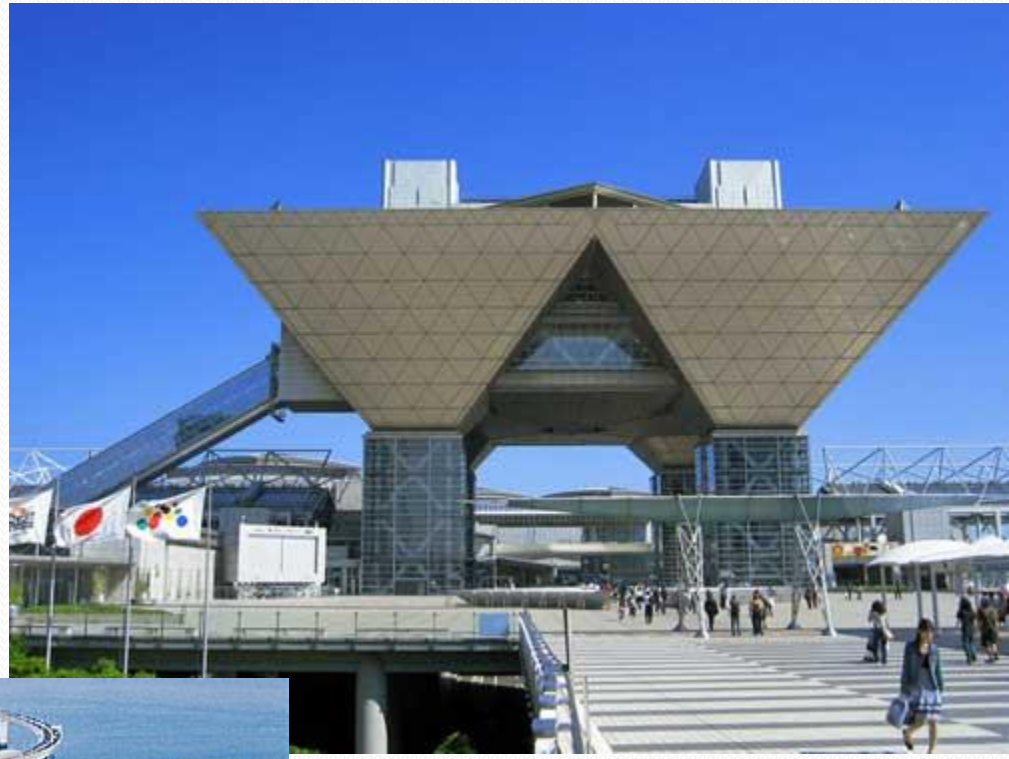
# Welcome Visitors!
# (11 Countries)

| | |
|---|---|
| Japan | 18 |
| Canada | 5 |
| Australia, UK | 4 |
| Korea | 3 |
| Belgium, Netherlands, Norway | 2 |
| Botswana, China, Morocco | 1 |

# Nakamura-san　Enoshima Island

# Ryokan ree-o con

# Tokyo Big Site



**“The size of your dreams must always exceed your current capacity to achieve them. If your dreams do not scare you, they are not big enough.”**

Ellen Johnson Sirleaf

# Critical Mass

Critical Mass - An amount necessary or sufficient to have a significant effect or to achieve a result.

What is our desired result?

To bring the optimal fuel to the world!

# NH3 – Optimal Fuel, Versatile Chemical

Fuel

Fertilizer

Energy Storage

Refrigerant

# What Makes NH3 Optimal?

- **Affordabilty**
- Safety
- Efficiency
- Environmental Performance
- Sustainability
- Production Flexibility
- End-Use Flexibility
- County Building

# Affordability

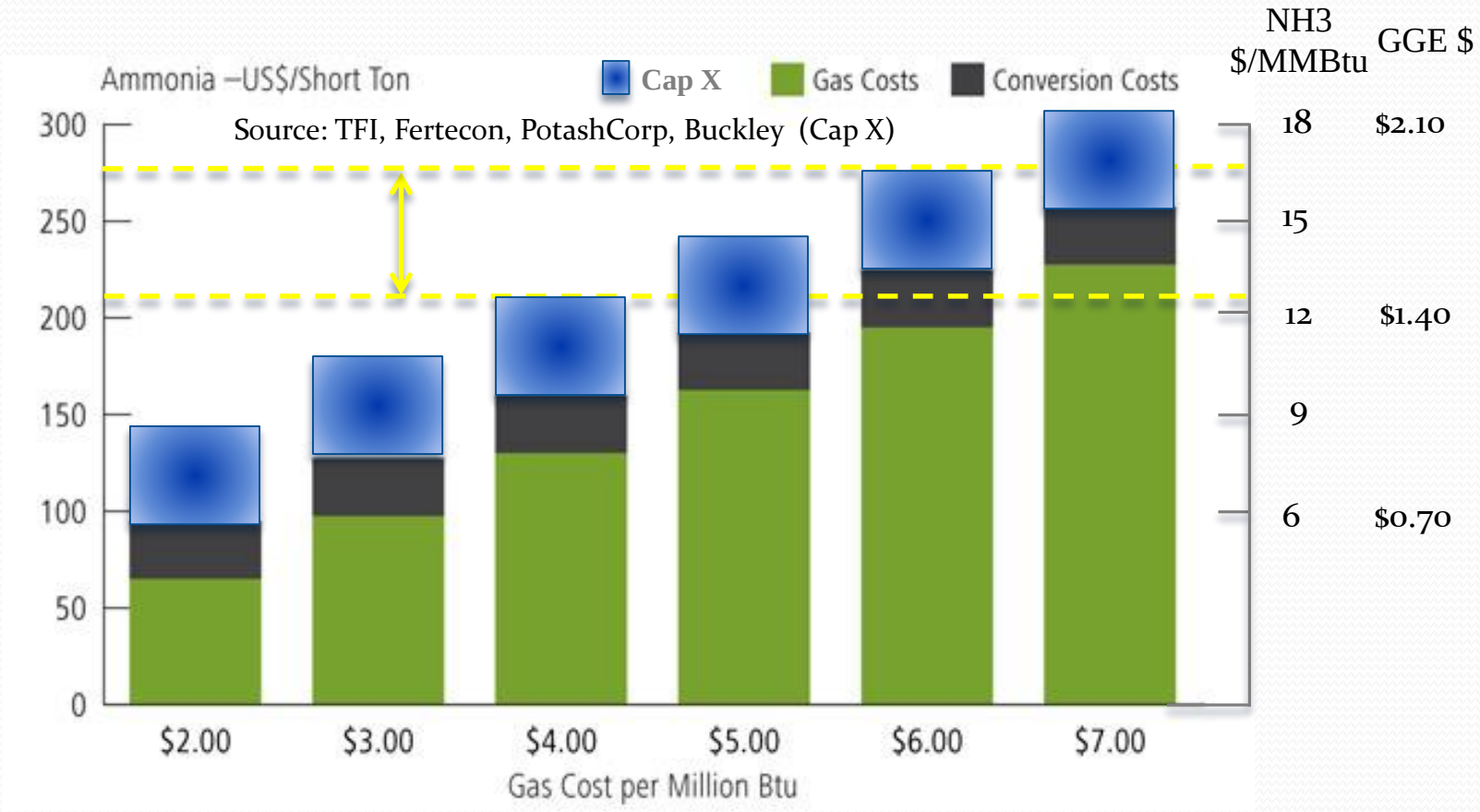
**Production Cost**

H2 Source - natural gas now, renewable and nuclear energy (+H2O) future
Production Capital Cost – relatively low-cost, very scalable, relatively simple
Production Operating Cost – energy costs low (kwh/ton from KBR)

**Infrastructure Cost**

Very low, similar to propane. Extensive, worldwide infrastructure in place now.
A single liquid fuel infrastructure would be much more cost effective than a multi-fuel infrastructure.
IC engines, fuel cells and gas turbines designed specifically for NH3 would become optimally efficient and low-cost when mass produced.

# NH3 Production Costs w/ Cap X



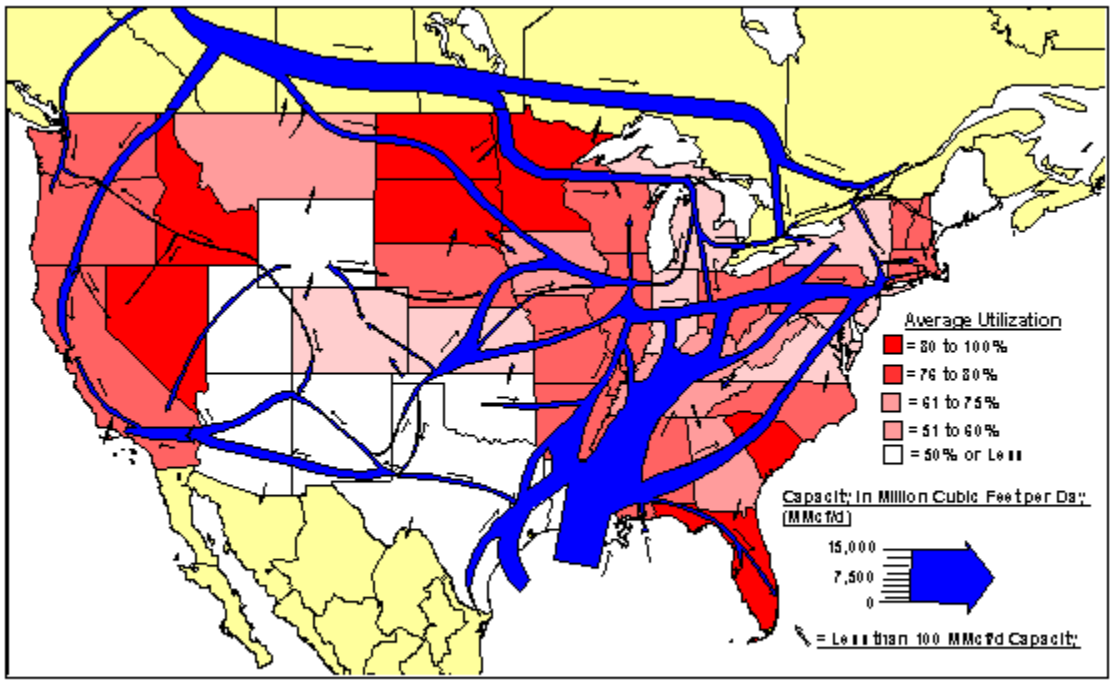

**Natural Gas Represents More Than 75 Percent of US Producers' Costs**
Natural gas is the most important feedstock in ammonia production and, depending on price, makes up 70-85 percent of the US cash cost of producing ammonia. Cap X: $1500/ton, 30 year amortization, ~$50/ton

Gasoline @ $3.50/gallon = $30/MMBtu

# Ammonia Storage & Transport



# Natural Gas Pipelines



# What Makes NH3 Optimal?

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# Safety

Two highly credible safety reports
- Riso
- Quest – Toyota comments

Decades of safe operational experience

800 retail outlets in Iowa alone

Second most transported chemical

Numerous design choices – as safe as it needs to be
- Pressurized storage – safe enough to meet most stringent standards
- Chilled storage - -28 F $NH_3$, -265F LNG, -420F $H_2$
- Chemical storage – Amminex, ammonium carbonate (solid)

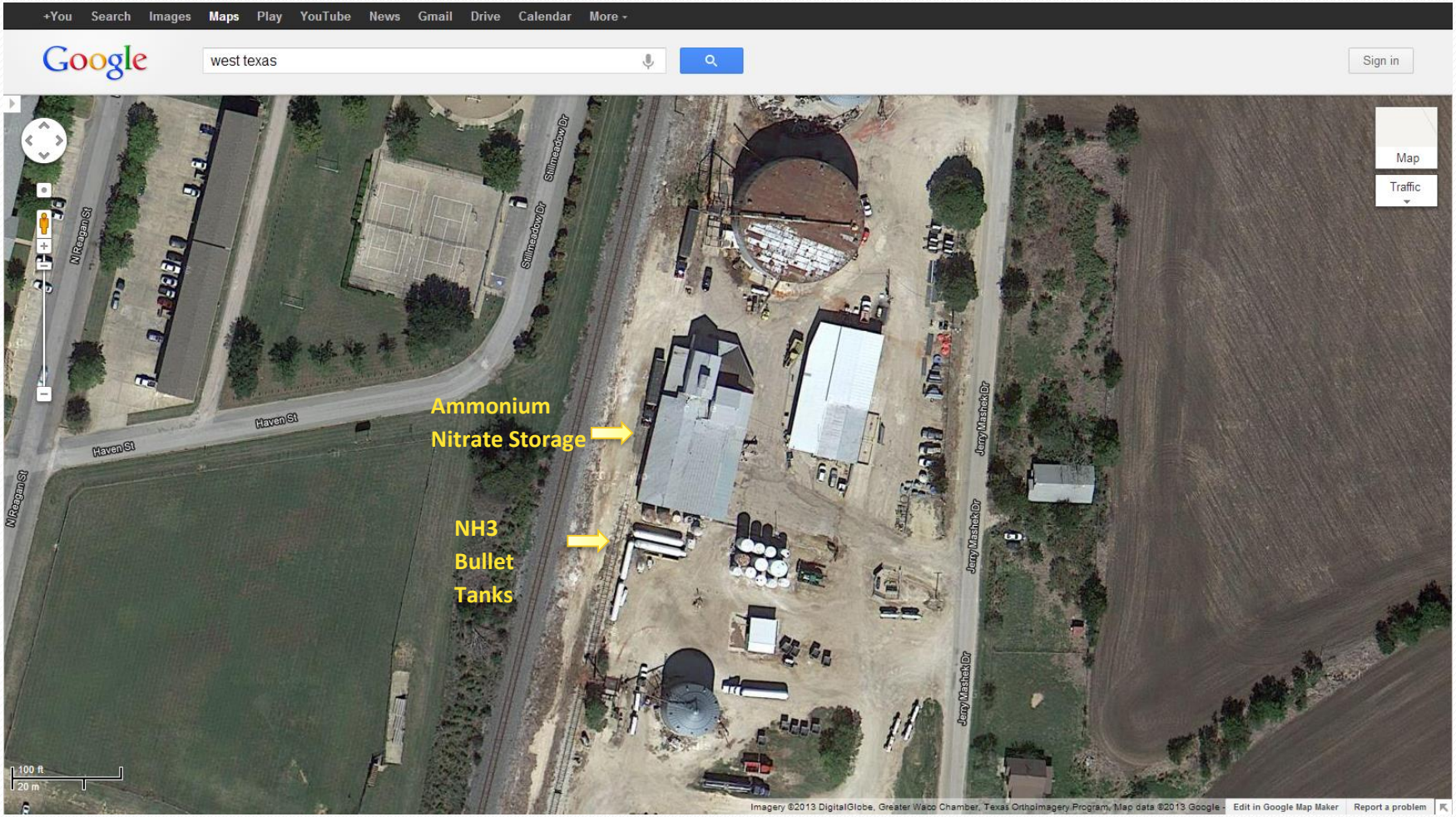
# Safety I

- **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 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).**

# West Texas Explosion – Not NH3 Related



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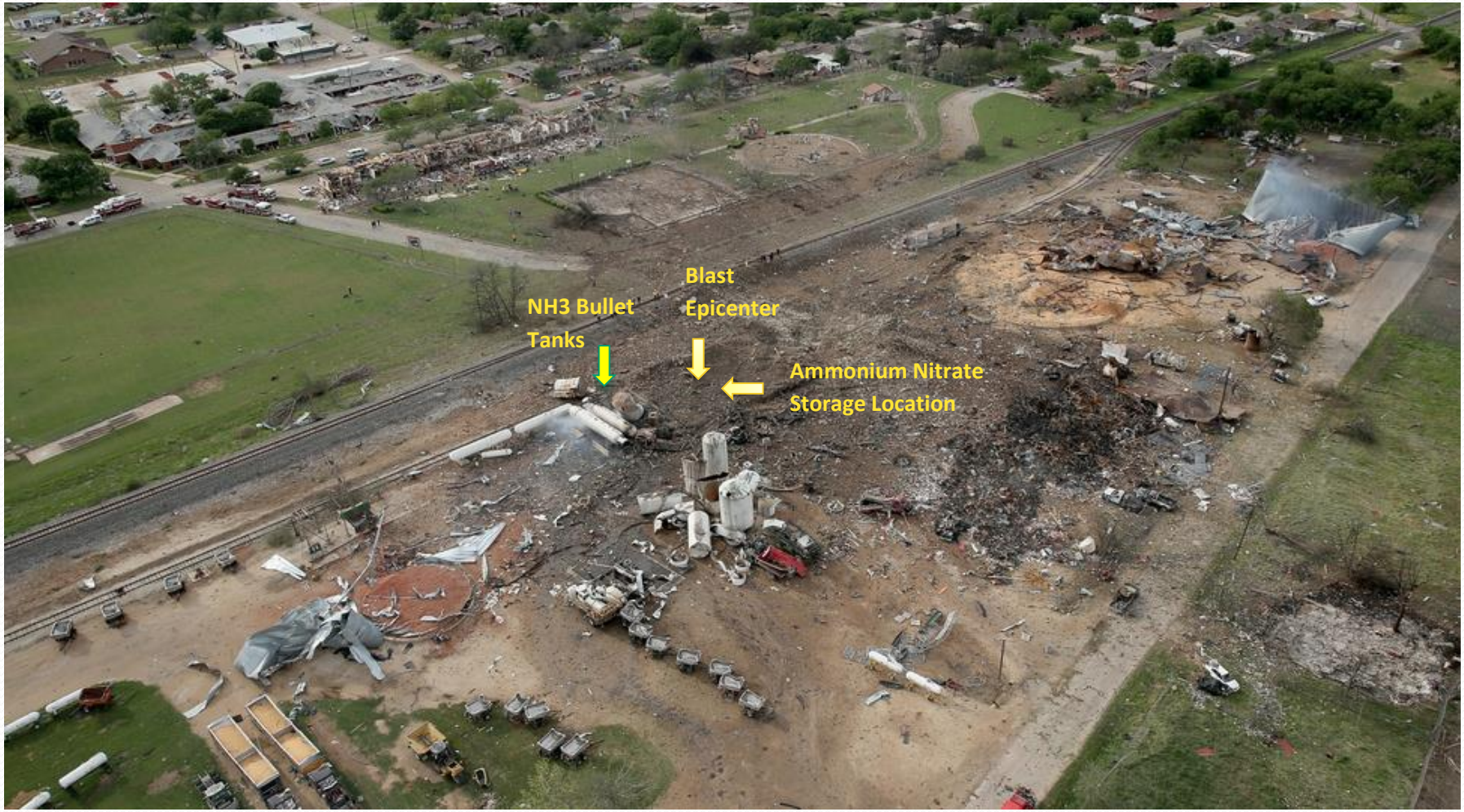


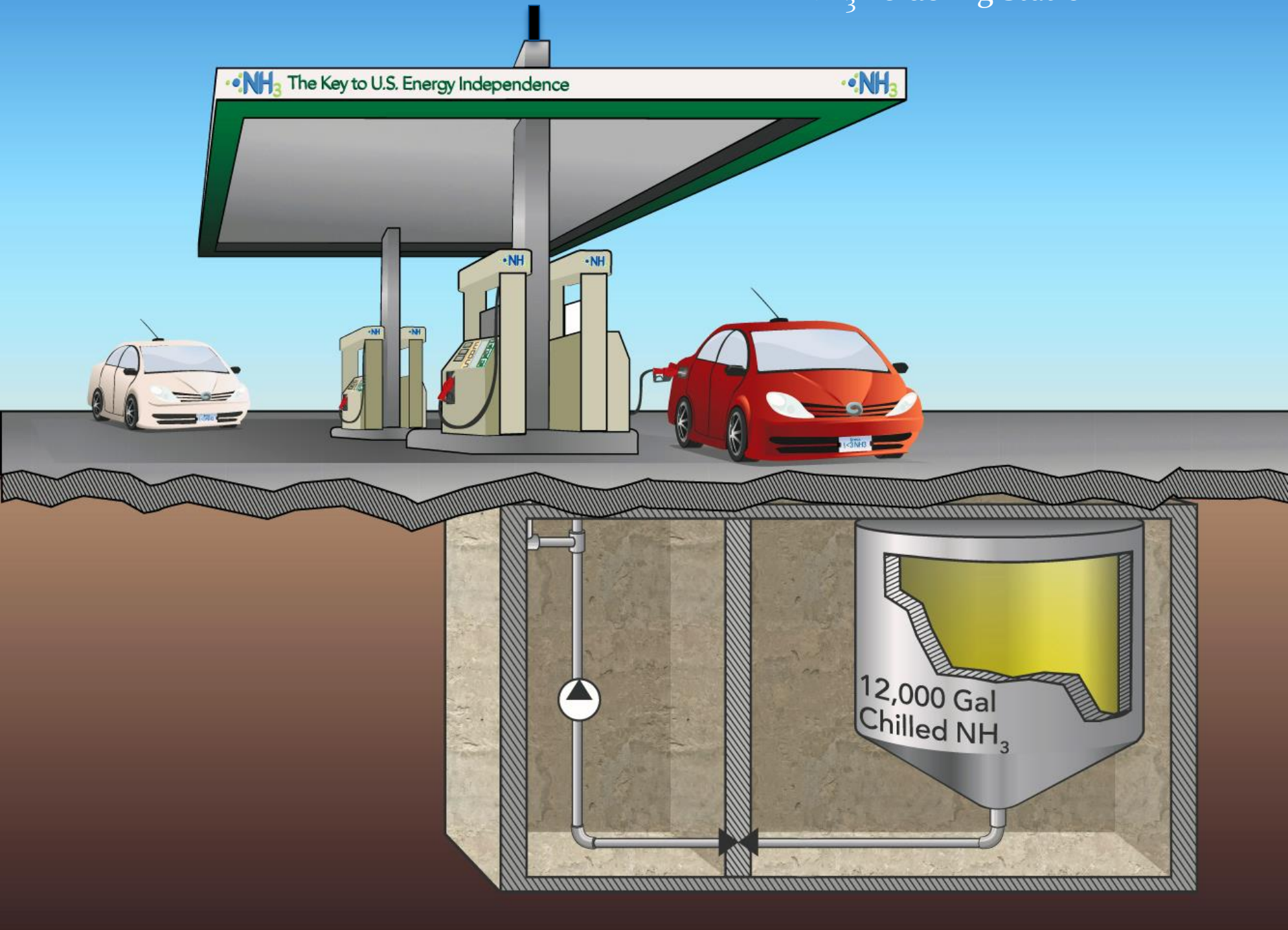
# Fueling Station – Refrigerated NH3

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

# $NH_3$ Refueling Station



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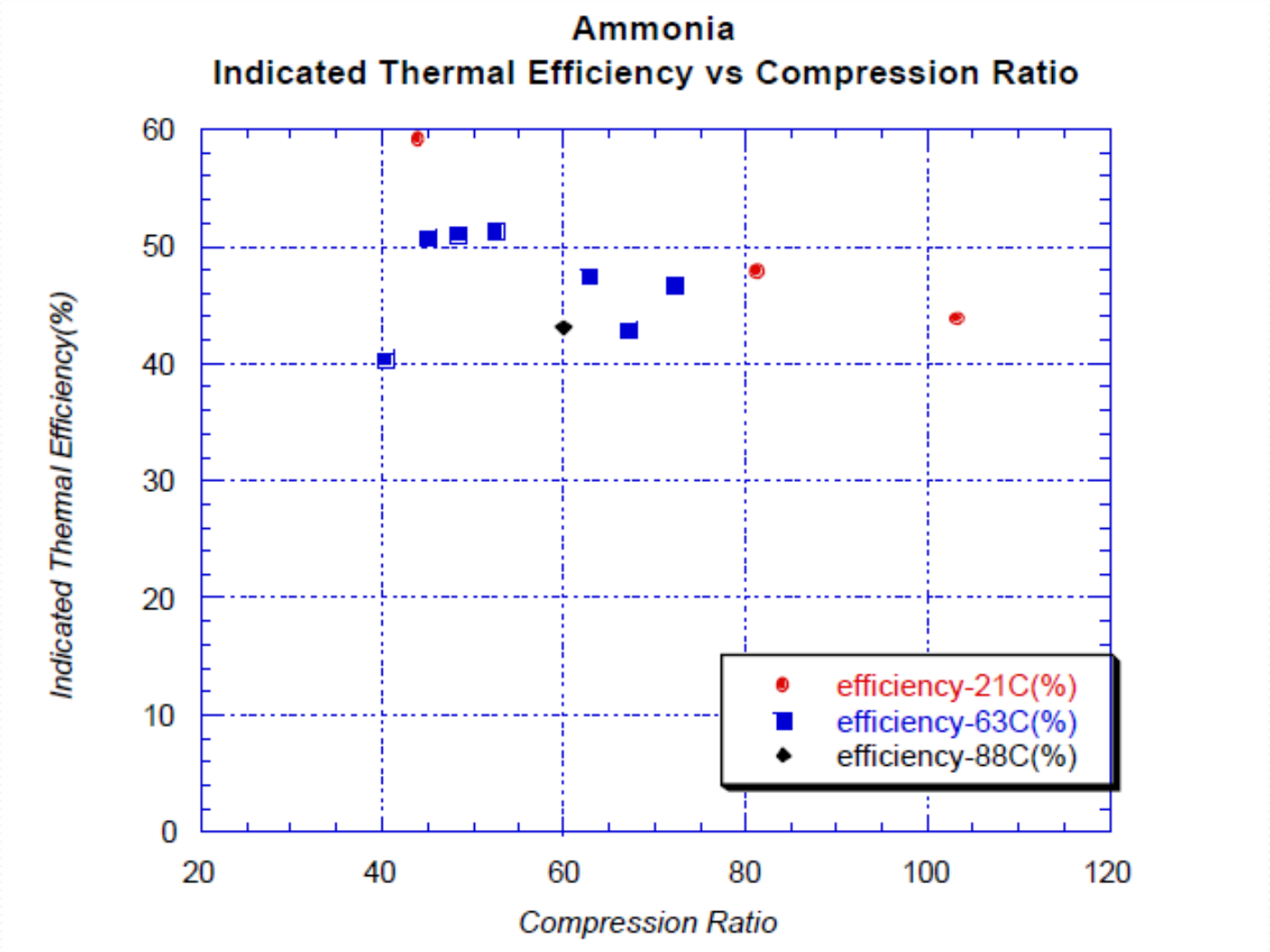
# NH3 IC Engine Efficiency




Source: Van Blarigan, Sandia National Lab, 2001

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# Cleaner Than Hydrogen?!

No carbon
$NH_3$ used to clean up NOx
Zero measurable pollutants possible with IC engines
Not a greenhouse gas
Ozone depletion number of zero
Not a known carcinogen
Huge natural occurrence in the earth's nitrogen cycle
Natural mechanisms for spill remediation

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# Sustainability

As long as the sun continues to shine, the earth' s atmosphere contains significant amounts of nitrogen, there is some readily available source of hydrogen, and iron is available as a catalyst….

$NH_3$ will be sustainable on planet earth!

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# Production Flexibility

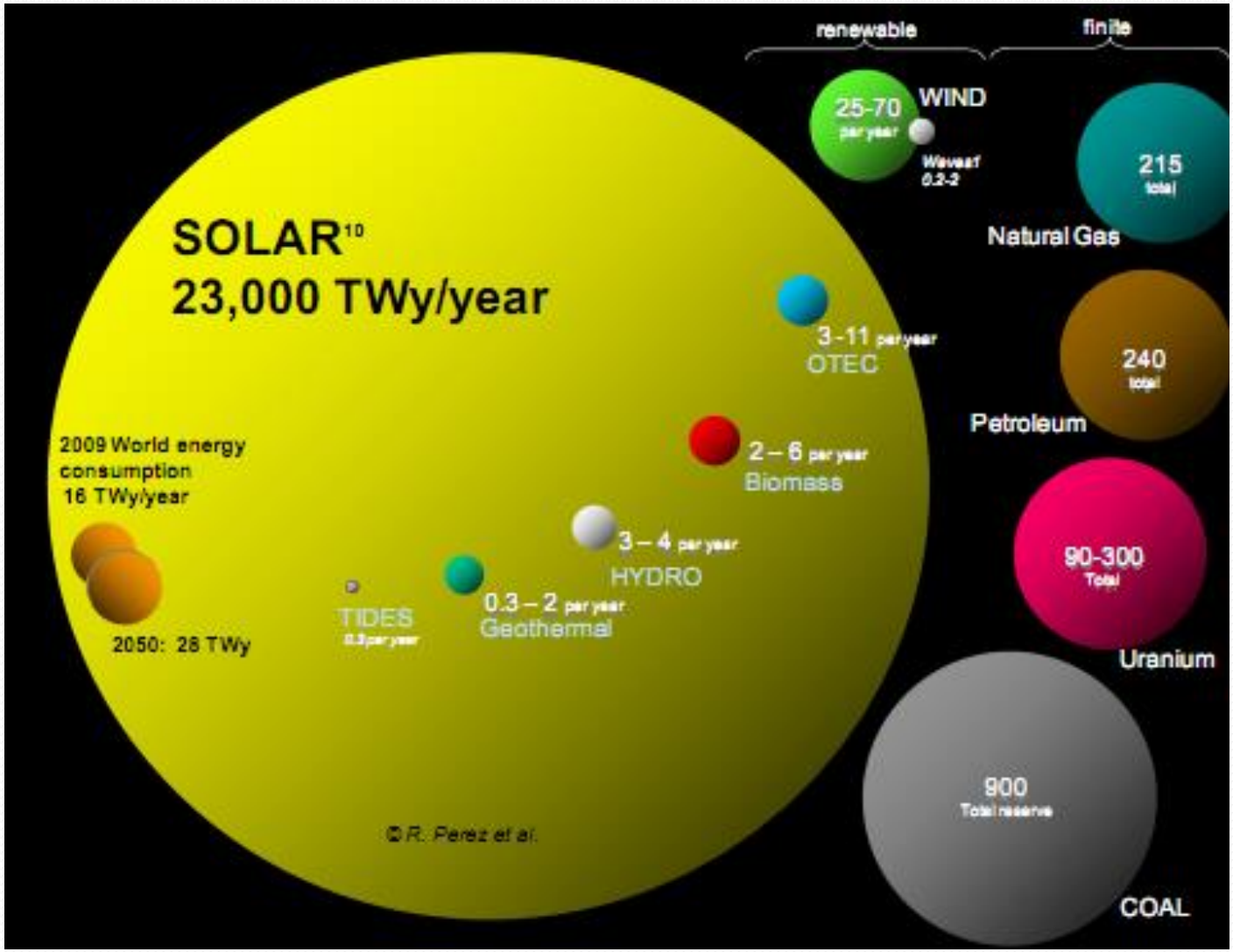
$NH_3$ can be produced using any and all primary energy sources including but not limited to …. Solar, natural gas, wind, nuclear, OTEC, coal, hydro, etc.

Scalability of $NH_3$ production plants is very good and could range from units as small as one ton per year to mega-ton production facilities.

Affordable $NH_3$ could be produced from (carbon free) natural gas now and from any renewable energy source (and water) in the near future.

Several promising new alternative $NH_3$ production technology alternatives are being developed (i.e. alternatives to Haber-Bosch)

# Renewable Energy



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# End Use Flexibility

SI engines
CI engines – dual fuel now…high compression future
Fuels cells
Gas turbines
Burners

Optimizing prime movers for a single fuel has huge benefits. An engine designed to use both gasoline and ethanol severely compromises the efficiency potential of ethanol, a very high octane fuel.

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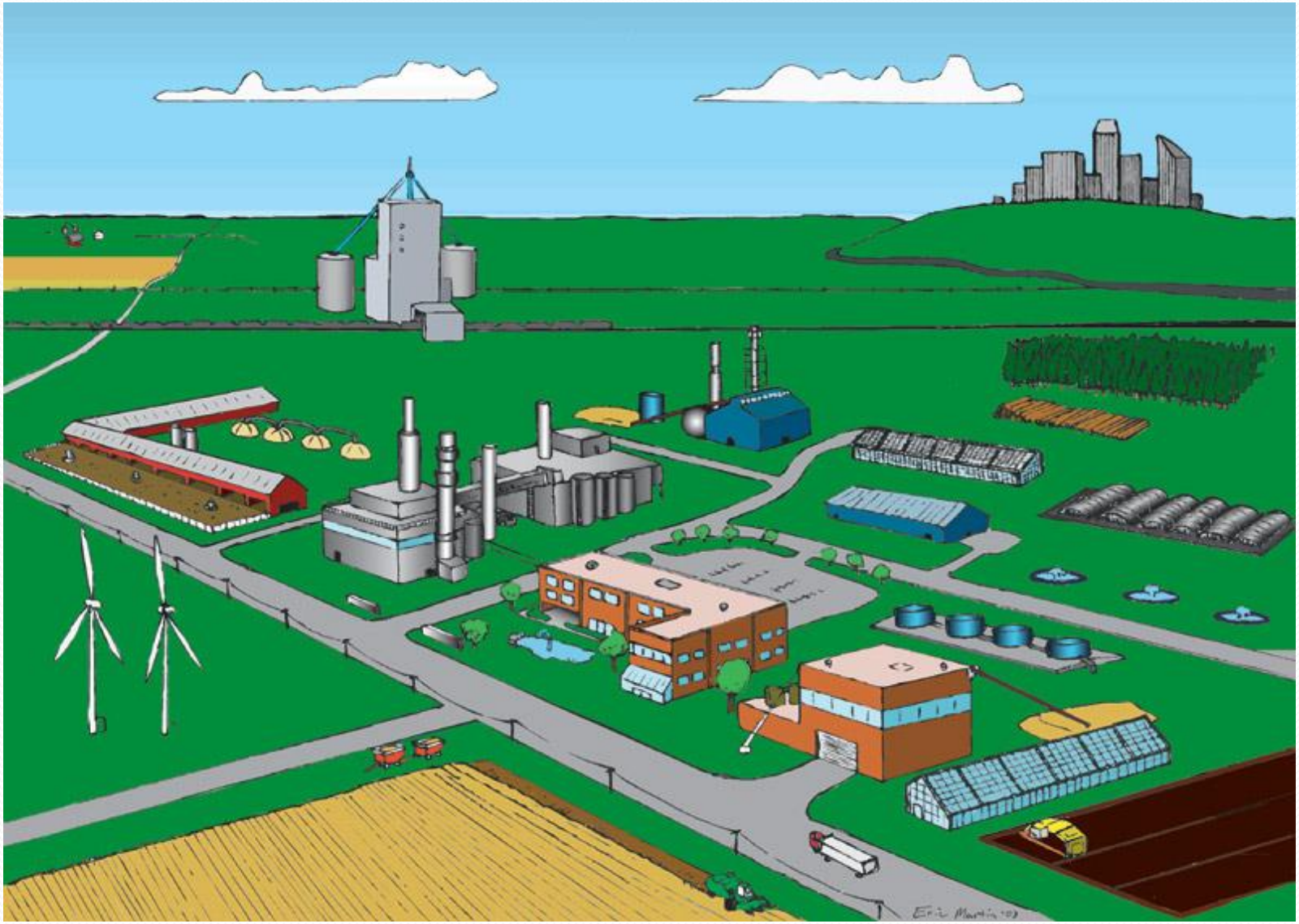
# Sustainable, Self-Sufficient Community

$NH_3$ 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; a versatile transportation fuel; distributed electrification via CHP units; long-term, efficient renewable energy storage; and efficient refrigeration systems. This provides an excellent base for local self-sufficiency and a greatly improved standard of living.

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

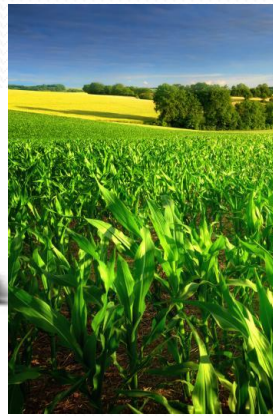
# Bio-Refinery



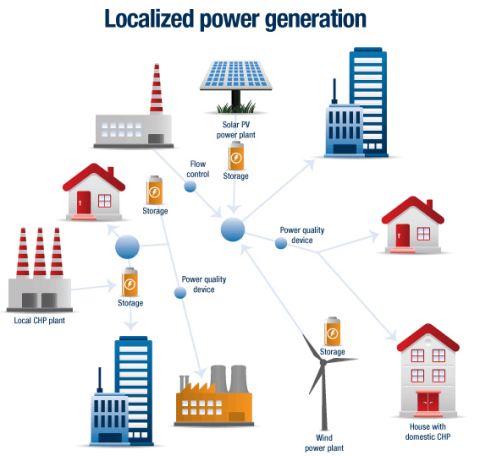
# NH3 Big Picture

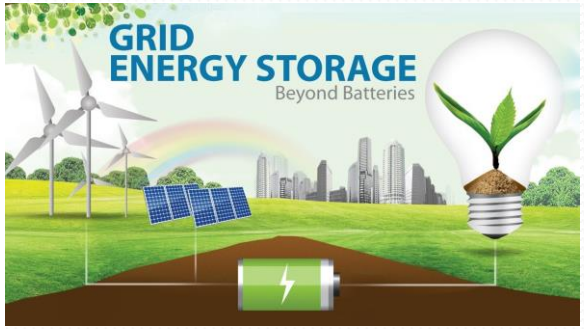
**$NH_3$ $NH_3$ $NH_3$ $NH_3$ $NH_3$ $NH_3$ $NH_3$ $NH_3$ $NH_3$ $NH_3$ $NH_3$**

**Transportation**



**Agriculture**



# Worldwide $NH_3$ Activity

Japan – Federally funded, 3 year research and demonstration program involving a $NH_3$ gas turbine,$NH_3$ combustion, and $NH_3$ storage of hydrogen. A significant amount of additional research being conducted. Toyota has numerous patents on $NH_3$ engines and $NH_3$ fuel cells. Excellent representation at $NH_3$ XIII.

U.S. – $NH_3$ XIII; ARPA –E – FOA issued; Iowa State University – $NH_3$ CI engine dual fuel, SI engine research; $NH_3$ tractor demonstration by HEC for Jay Scheumacher; $NH_3$ Car converted S10 pick-up to $NH_3$; Sturman Industries engine – Long Beach; Texas Tech $NH_3$ fuel research.

Siemens $NH_3$ Data

Canada – Hydrofuel, Natural Resources Canada - DAFC, $NH_3$ Canada, Green$NH_3$

Italy – Bigas International, SAVIA project

# Worldwide $NH_3$ Activity

Netherlands – Proton Ventures modular $NH_3$ production.

China – First attendee $NH_3$ XIII; "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)

# 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.  Efficiency and emissions data.

Design and demonstration of super-safe refueling systems.

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

International NH3 Fuel Association.

Market, Market, Market

# Conclusion

$NH_3$:

- is clearly, the most affordable carbon-free fuel
- is the most efficient fuel in an internal combustion engine
- has optimal environmental performance
- has production flexibility second to none
- has excellent end-use flexibility (tunable fuel)
- has tremendous business development opportunities
- is the optimal choice for an alternative fuel

Many times “all of the above” or diversity is very beneficial – primary energy source diversity, food diversity, locations to live, music

Some times selecting one, optimal choice (standardization) has huge benefits – meanings of words, standard weights and measures, transportation/generation fuels.

Optimized engine/fuel cell/turbine cost/efficiency/emissions; optimized, non-redundant infrastructure; safety protocol optimization; optimized production effectiveness…

Prodigious business opportunity and tremendous world-wide benefits.

# NH3 – The Optimal Alternative Fuel