NH$_3$ – The **Optimal** Alternative Fuel

2017 AIChE Annual Meeting

NH3 Energy+ Topical Conference

November 1-2, 2017

Minneapolis, Minnesota

Norm Olson

President - NH3 Fuel Association
NH\textsubscript{3} – Optimal Fuel, Versatile Chemical

Fuel

Fertilizer

Energy Storage

Refrigerant
NH3 FA and AIChE Meeting

Become a member of the NH3 FA and attend the AIChE Annual Meeting at a significant discount (see details at link below).

https://nh3fuelassociation.org/join-us/


NH3 Energy+ Topical Conference. 40 presentations!
Recent Developments

Netherlands Conference (~150 attendees) - Europe’s First! Shell, Yara, Ammonia Casale, IEA, Siemans, Proton Ventures, etc. 2017
Yara Announces Solar PV to NH3 project in Australia
Japan Program 2015-2018
Siemens wind to NH3 project in Great Britain 2016-2017 (UMM 2008)
IEA – white paper 2017
Ammonia Casale – 10 tpd unit announced 2017
Australia – 1st non-U.S. NH3 FA chapter 2017
ARPA-E DOE – 13 NH3 fuel related projects 2017
AIChe – 40 presentations 2017
ACS – first ever NH3 fuel session in 2017
Hydrofuel - Greg Vezina, 1981
Global NH3 Fuel Federation 2016... and many more
NH3 Production vs U.S. Gasoline Use


2016 World NH3 Production: 180 million tonne = ~80 Billion Gallon = ~40 Billion GGE

~3.5x
NH₃ Affordability

Similar to propane infrastructure costs
2nd most transported chemical in world
Over 3000 miles of NH₃ pipeline in U.S.
800 retail outlets in Iowa alone
1.3 times more hydrogen than liquid H₂ (by volume)
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
## NH3 vs Hydrogen Storage Costs

<table>
<thead>
<tr>
<th>Application</th>
<th>NH3 (250 psi)</th>
<th>CNG (3200 psi)</th>
<th>H2 (10k psi)</th>
<th>Cryo NH3 (-28 F)</th>
<th>Cryo H2 (-423 F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>On-board vehicle ¹</td>
<td>$700</td>
<td>$1500</td>
<td>$6000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Filling station</td>
<td>$68,000²</td>
<td></td>
<td>$2,643,840³</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Large storage facility</td>
<td></td>
<td></td>
<td></td>
<td>$20 million⁴</td>
<td>$81.6 million³</td>
</tr>
</tbody>
</table>

¹Phone conversation with John Coursen, Worthington Industries, February 17, 2017. **Relative** ~costs ~50 liter tank: LPG/ NH3 - $700, CNG (3200 psi) - $1500, Hydrogen (10,000 psi) - $6000.

²1Phone conversation with Don Wallace, Trinity Containers. 18,000 gallon NH3 bullet tank - $68,000. @80% fill capacity = 14,400 gallon x 5lbs/gallon x 0.176 lbs H2/lb NH3 /2.2 lbs/kg = 5760 kg = $11.81/kg H2.


⁴Rentech Press Release, January 12, 2012. Chilled NH3 20,000 ton = $20 million. 20k ton x 2000 x 0.176 /2.2 lbs/kg = 3.2 million kg. H2.
What Makes NH$_3$ Optimal?

- Affordability
- Safety
- **Efficiency**
- Environmental Performance
- Sustainability
- Production Flexibility
- End-Use Flexibility
- County Building
# Production Energy Efficiency

<table>
<thead>
<tr>
<th>Method</th>
<th>kWh/kg H2</th>
<th>%LHV</th>
</tr>
</thead>
<tbody>
<tr>
<td>NH3 via Haber-Bosch</td>
<td>2.26&lt;sup&gt;1&lt;/sup&gt;</td>
<td>6.8%</td>
</tr>
<tr>
<td>700 bar H2 Refueling (880 bar)</td>
<td>2.85&lt;sup&gt;2&lt;/sup&gt;</td>
<td>8.5%</td>
</tr>
<tr>
<td>Liquid H2</td>
<td>10&lt;sup&gt;2&lt;/sup&gt;</td>
<td>30.1%</td>
</tr>
<tr>
<td>Liquid H2 (advanced)</td>
<td>7&lt;sup&gt;2&lt;/sup&gt;</td>
<td>21.1%</td>
</tr>
</tbody>
</table>


Efficiency in Engines

Octane, Octane, Octane

NH₃’s very high octane rating (>120) and high (tunable) resistance to detonation allow the use of extremely high compression ratios and therefore IC engines with the highest possible efficiencies.
Nissan SOFC Vehicle – 60% Eff. ?

https://www.youtube.com/watch?v=HF-eE8pRzMw
What Makes $\text{NH}_3$ Optimal?

- Affordability
- **Safety**
- Efficiency
- Environmental Performance
- Sustainability
- Production Flexibility
- End-Use Flexibility
- County Building
Numerous design choices – As safe as it needs to be.

Pressurized storage – safe enough to meet most stringent standards
Chilled storage – safer yet: -28 F NH3, -265F LNG, -420F H2
Chemical storage – Too safe? Amminex, ammonium carbonate (solids)
## Table 1: Toxicity Classes: Hodge and Sterner Scale (CCOHS)

<table>
<thead>
<tr>
<th>Corresponding NFPA Ratings (LC50)</th>
<th>Toxicity Rating</th>
<th>Commonly Used Term</th>
<th>Oral LD50 (Single dose to rats) mg/kg</th>
<th>Inhalation LC50 (Exposure of rats for 4 hours) ppm</th>
<th>Dermal LD50 (Single application to skin of rabbits) mg/kg</th>
<th>Probable Lethal Dose for Man</th>
</tr>
</thead>
<tbody>
<tr>
<td>6 (&gt;20,000)</td>
<td>6</td>
<td>Relatively Harmless</td>
<td>15,000 or more</td>
<td>100,000</td>
<td>22,600 or more</td>
<td>1 litre (or 1 quart)</td>
</tr>
<tr>
<td>5 (2500-20,000)</td>
<td>5</td>
<td>Practically Non-toxic</td>
<td>5000-15,000</td>
<td>10,000-100,000</td>
<td>2820-22,590</td>
<td>1 litre (or 1 quart)</td>
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<tr>
<td>4 (100-500)</td>
<td>3</td>
<td>Moderately Toxic</td>
<td>50-500</td>
<td>100-1000</td>
<td>44-340</td>
<td>30 ml (1 fl. oz.)</td>
</tr>
<tr>
<td>3 (100-500)</td>
<td>2</td>
<td>Highly Toxic</td>
<td>1-50</td>
<td>10-100</td>
<td>5-43</td>
<td>4 ml (1 tsp)</td>
</tr>
<tr>
<td>2 (500-2500)</td>
<td>4</td>
<td>Slightly Toxic</td>
<td>500-5000</td>
<td>1000-10,000</td>
<td>350-2810</td>
<td>600 ml (1 pint)</td>
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<tr>
<td>0 (0-100)</td>
<td>1</td>
<td>Extremely Toxic</td>
<td>1 or less</td>
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### Source:
Canadian Centre for Occupational Health and Safety (CCOHS). NFPA data addition by Norm Olson, NH3 FA.

LC50/4hour (ppm): NH3 - 2000; Chlorine – 146.5; Methyl Isocyanate – 5 (Source: Praxair, other)
What Makes NH$_3$ Optimal?

- Affordability
- Safety
- Efficiency
- **Environmental Performance**
- Sustainability
- Production Flexibility
- End-Use Flexibility
- County Building
Cleaner Than Hydrogen?!

No carbon
NH₃ 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
What Makes NH$_3$ Optimal?

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

NH₃ will be sustainable on planet earth!
What Makes NH₃ Optimal?

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

NH3 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 NH3 production plants is very good and could range from units as small as one ton per year to mega-ton production facilities.

Affordable NH3 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 NH3 production technology alternatives are being developed (i.e. alternatives to Haber-Bosch)
Nuclear Synergism – Fusion?

Time of Day

Load

Capacity

+20 Nuclear Capacity

NH₃ Production

Peaking Units Required

Nuclear Capacity (Baseload)
What Makes NH₃ Optimal?

- Affordability
- Safety
- Efficiency
- Environmental Performance
- Sustainability
- Production Flexibility
- **End-Use Flexibility**
- County Building
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, another very-high octane fuel.
What Makes NH$_3$ Optimal?

- Affordability
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- Production Flexibility
- End-Use Flexibility
- Country Building
Sustainable, Self-Sufficient Community

NH₃ allows a country to develop a local:

1. transportation fuel economy
2. power generation economy
3. renewable energy storage economy
4. fertilizer and food production economy (up to 4x yield improvements)
5. a bio-based (crop-based) chemical production economy
6. A refrigeration industry

Petroleum refineries are very complex and require a very large scale.
Bio-Refinery
Renewable Energy: Stranded and Long-term Storage

A significant amount of renewable energy will either be stranded (i.e. produced remotely and converted to a form that can be transported long distances) or will need long-term storage. Chemical storage likely be used for these two applications. NH$_3$ will likely be the most cost-effective option for chemical storage.

Once renewable energy is stored as NH$_3$, it is more efficient and cost-effective to use the NH$_3$ as a liquid transportation fuel in FCV and/or ICEV than to convert it to electricity and deliver it through the grid to EV filling stations for use in EV’s.
Effective Energy Storage

Available Storage Technologies

Source: Hydrogenius Technologies. NH3 addition by NKO.
NH₃ Big Picture

NH₃ NH₃ NH₃ NH₃ NH₃ NH₃ NH₃ NH₃ NH₃

Transportation

Agriculture
Conclusion

NH₃:
- 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

Prodigious business opportunities and tremendous world-wide benefits.
Top Technology Developments

Vaccines
Synthetic Ammonia Fertilizer (Haber-Bosch)
Personal Computer
Internet
NH₃ Energy?
NH₃ – The Optimal Alternative Fuel

Thank You!

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https://nh3fuelassociation.org/