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_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/

AIChE 2017 Annual Meeting. October 29-November 3. Minneapolis, MN

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 NH_3 project in Australia
Japan Program 2015-2018
Siemens wind to NH_3 project in Great Britain 2016-2017 (UMM 2008)
IEA – white paper 2017
Ammonia Casale – 10 tpd unit announced 2017
Australia – 1st non-U.S. NH_3 FA chapter 2017
ARPA-E DOE – 13 NH_3 fuel related projects 2017
AIChE – 40 presentations 2017
ACS – first ever NH_3 fuel session in 2017
Hydrofuel - Greg Vezina, 1981
Global NH_3 Fuel Federation 2016… and many more

NH3 Production vs U.S. Gasoline Use

U.S. Gasoline Consumption: 143 Billion Gallon (2015)

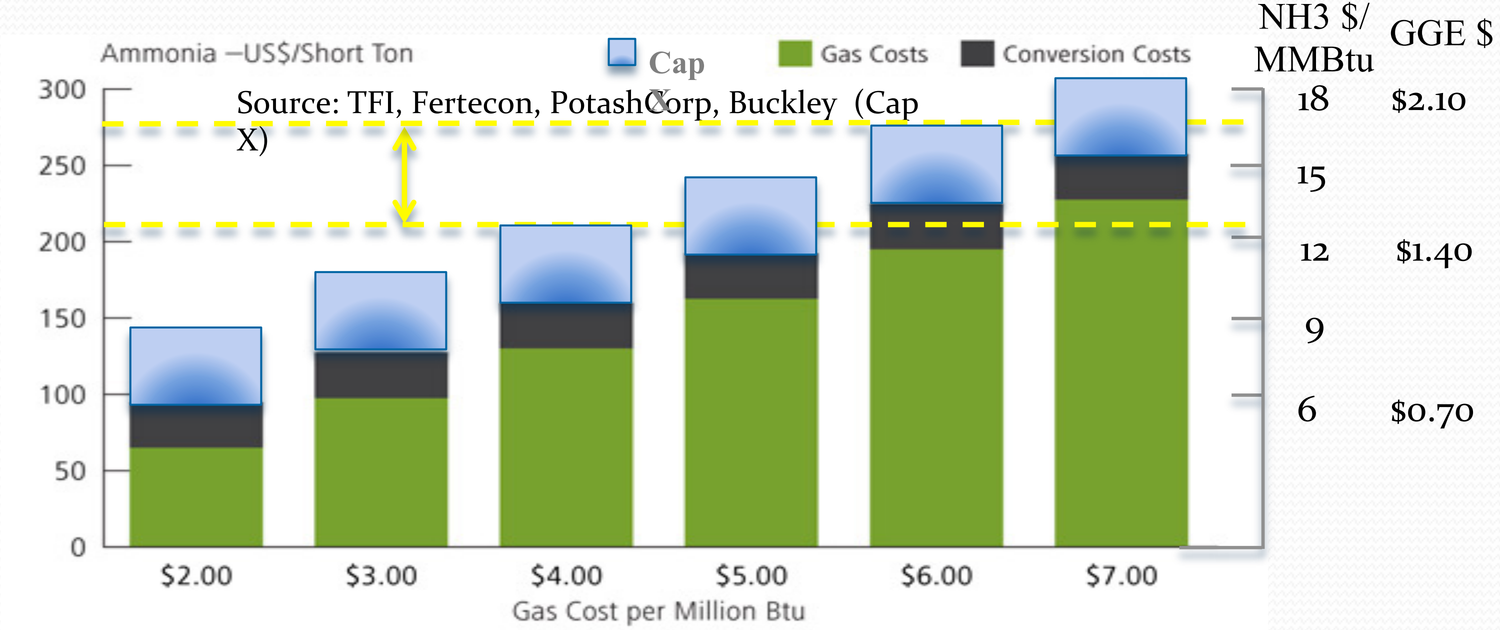
2016 World NH3 Production: 180 million tonne = ~80 Billion Gallon = ~40 Billion GGE

~3.5x

NH_3 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)

NH_3 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

NH3 vs Hydrogen Storage Costs

	NH3 (250 psi)	CNG (3200 psi)	H2 (10k psi)	Cryo NH3 (-28 F)	Cryo H2 (-423 F)
Application					
On-board vehicle [1]	$700	$1500	$6000		
Filling station	$68,000[2]		$2,643840[3]		
Large storage facility				$20 million[4]	$81.6 million[3]

[1]Phone 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.

[2]1Phone 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.

[3]"Hybrid Hydrogen Energy Storage", Michael Penev, May 22, 2013. 10k psi H2: $459/kg x 5760 kg = $2,643,840. Cryo H2 Storage: $25.5/kg x 3.2 million kg= $81.6 million.

[4]Rentech 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

	kWh/kg H2	%LHV
NH3 via Haber-Bosch	2.26[1]	6.8%
700 bar H2 Refueling (880 bar)	2.85[2]	8.5%
Liquid H2	10[2]	30.1%
Liquid H2 (advanced)	7[2]	21.1%

[1] "Efficient Ammonia Production" Power Point presentation, page 63. Jim Gosnell, KBR. 2005 NH3 Fuel Association Meeting. Argonne National Laboratory.

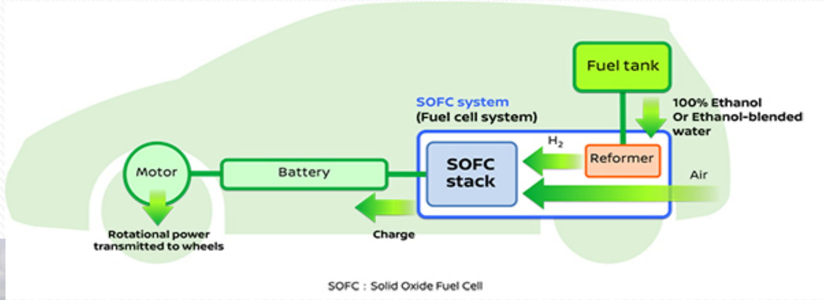
[2]Source H2 Data: "Energy requirements for hydrogen gas compression and liquefaction as related to vehicle storage needs." DOE Hydrogen and Fuel Cells Program Record. Record #: 9013. July 7, 2009. Air Products and Chemicals Inc. (APCI). 2.67 + 0.18 = 2.85. Page 3 of resource above.

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

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Safety

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 NH_3, -265F LNG, -420F H_2
Chemical storage – Too safe? Amminex, ammonium carbonate (solids)

Safety LC50

	Table 1: Toxicity Classes: Hodge and Sterner Scale (CCOHS)					
			Routes of Administration			
			Oral LD50	Inhalation LC50	Dermal LD50	
Corresponding NFPA Ratings (LC50)	Toxicity Rating	Commonly Used Term	(Single dose to rats) mg/kg	(Exposure of rats for 4 hours) ppm	(Single application to skin of rabbits) mg/kg	Probable Lethal Dose for Man
	1	Extremely Toxic	1 or less	10 or less	5 or less	1 grain (a taste, a drop)
4 (0-100)	2	Highly Toxic	1-50	10-100	5-43	4 ml (1 tsp)
3 (100-500)	3	Moderately Toxic	50-500	100-1000	44-340	30 ml (1 fl. oz.)
2 (500-2500)	4	Slightly Toxic	500-5000	1000-10,000	350-2810	600 ml (1 pint)
1 (2500-20,000)	5	Practically Non-toxic	5000-15,000	10,000-100,000	2820-22,590	1 litre (or 1 quart)
0 (>20,000)	6	Relatively Harmless	15,000 or more	100,000	22,600 or more	1 litre (or 1 quart)

Source: Canadian Centre for Occupational Health and Safety (CCOHS). NFPA data addition by Norm Olson, NH3 FA.

LC50/4hour (ppm): NH_3 - 2000; Chlorine – 146.5; Methyl Isocyanate – 5 (**Source**: Praxair, other)

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Cleaner Than Hydrogen?!

No carbon
NH_3 used to clean up NO_x
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....

NH3 will be sustainable on planet earth!

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- **Production Flexibility**
- End-Use Flexibility
- County Building

Production Flexibility

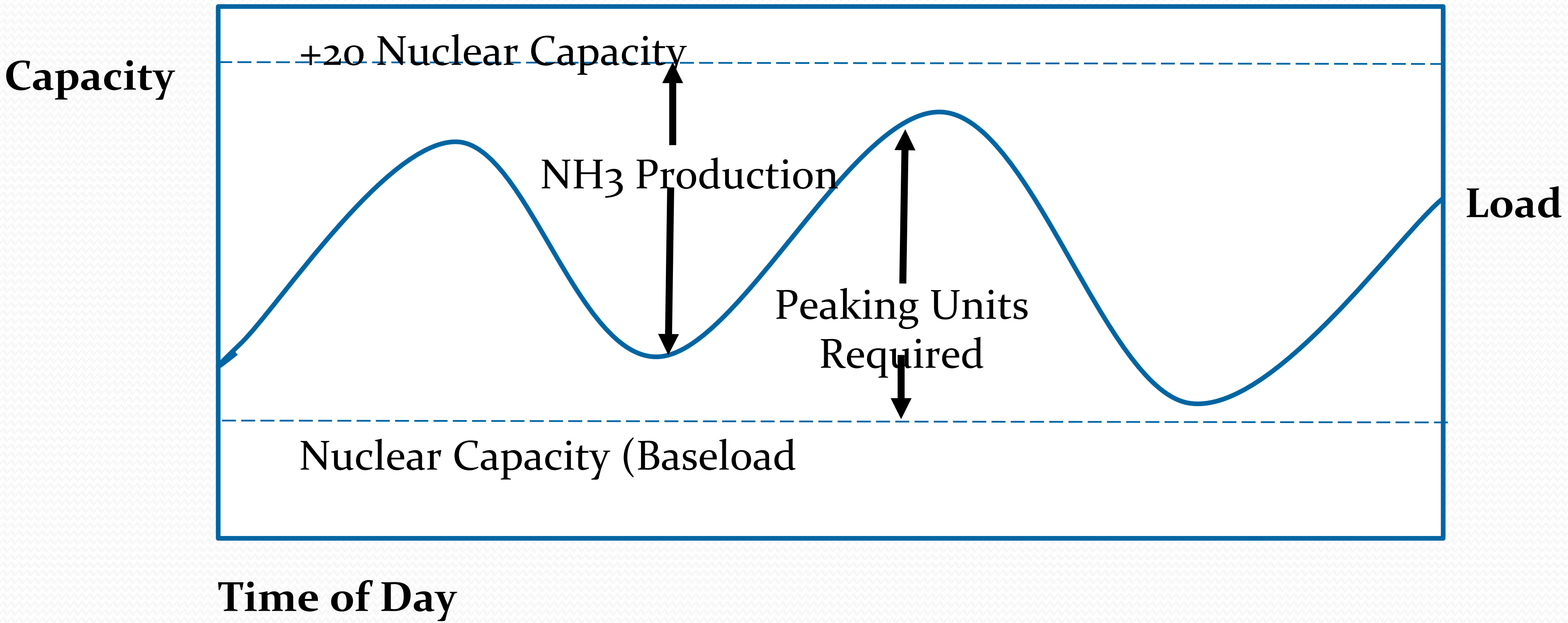
NH3 can be produced using any and all primary energy sources including but not limited to …. Solar, natural gas, wind, nuclear, OTEC, coal, hydro, etc.

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?



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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 <u>huge</u> benefits. An engine designed to use both gasoline and ethanol severely compromises the efficiency potential of ethanol, another very-high octane fuel.

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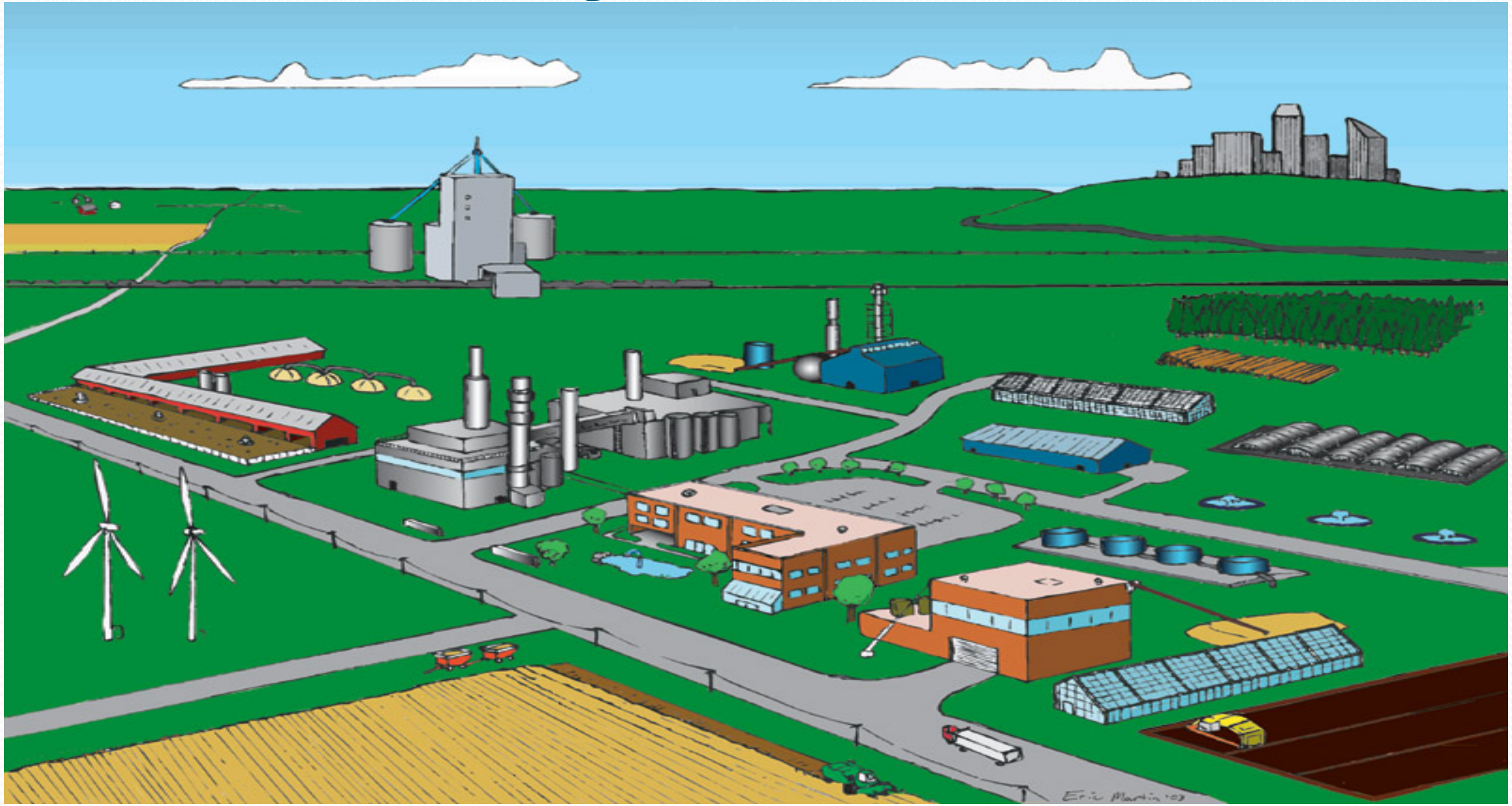
Sustainable, Self-Sufficient Community

NH_3 allows a country to develop a <u>local</u>:

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

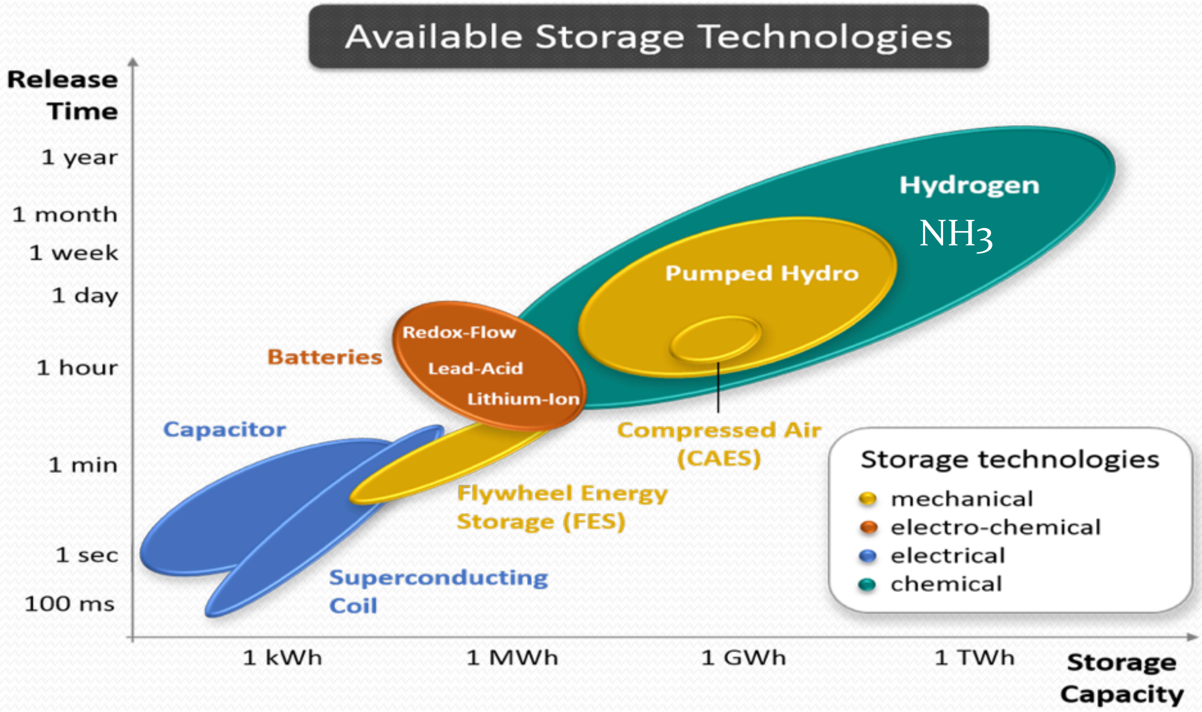


Renewable Energy: Stranded and Long-term Storage

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

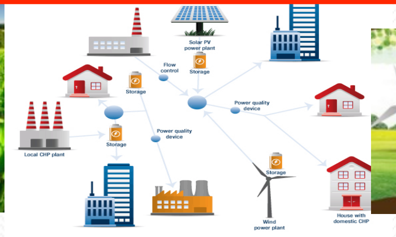


Source: Hydrogenius Technologies. NH3 addition by NKO.

NH_3 Big Picture

NH3 NH3 NH3 NH3 NH3 NH3 NH3 NH3

Agriculture



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

Prodigious business opportunities and tremendous world-wide benefits.

Top Technology Developments

Vaccines

Synthetic Ammonia Fertilizer (Haber-Bosch)

Personal Computer

Internet

NH3 Energy?

NH_3 – The Optimal Alternative Fuel

Thank You!

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https://nh3fuelassociation.org/