Ammonia

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Ammonia is more cost-effective in transporting and storing Hydrogen.

Cecilia Li

Storing

For large-scale storage of ammonia or hydrogen, **low-temperature storage** is typically used based on cost considerations.

The low-temperature storage system consists of a large insulated tank and a refrigeration system to maintain the fuel as a liquid at the low temperature.

Each process for the ammonia system uses much less energy than the corresponding process for the hydrogen system

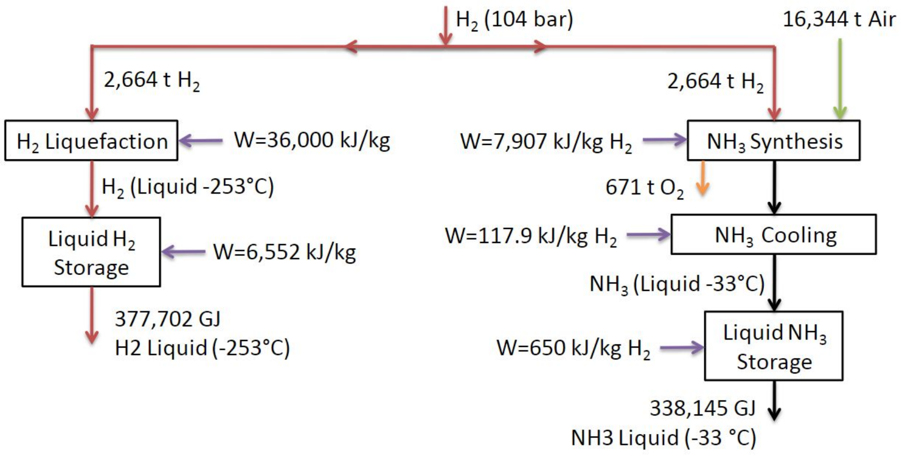


Figure 10: Hydrogen and ammonia low-temperature storage system diagram

The efficiency calculated for ammonia is 93.6% and for the hydrogen system it is 76.9%.

Low-Temperature Storage System Costs : Ammonia is more than 3 times cost effective

The low-temperature **ammonia** facility, including a 25,000 t storage vessel, refrigeration system, and all ammonia handling and plant facilities, was estimated to cost **20.2 M$**. It would be capable of holding 564 Terajoules

hydrogen sphere would contain 506 t of at a cost of **9.7 M$**, which does not include the cost of the plant facilities or the refrigeration system. the hydrogen system would only be able to store 72 TJ.

For about double the cost, ammonia offers about 7.5 times larger capacity.

3 times more cost effective

Cost- effective

The efficiency of the ammonia storage system is 93.6% whereas the hydrogen system has an efficiency of 76.9%.

The ammonia system also uses nearly five times less energy to store a given quantity of hydrogen than the hydrogen storage system

The capital and operating cost of the ammonia facility was also found to be cheaper than for the hydrogen system with a cost of 20.2M$and 63.2 M$, respectively.

Table 15: Comparison between hydrogen and ammonia low-temperature storage

	H_2 Refrig. Storage	NH_3 Refrig. Storage
Total Energy Input (kJ/kg H_2)	42,552	8,673*
Total Mass (kg H_2)	2,664,000	2,664,000*
Work Input (GJ)	113,358	23,104
Energy Out HHV (GJ)	377,702	338,145
Storage Temperature (°C)	-253	-33
Efficiency HHV	76.9%	93.6%
Energy Density (MJ/L)	9.98	15.37

*Ammonia values normalized to hydrogen

Long distance transport of ammonia is done by using pipeline.

There are 4,830 km (3,075 miles) of ammonia pipeline operating in the U.S. today.

The United States has 719 km of hydrogen pipelines. which is much smaller than the 4,830 km ammonia pipeline and miniscule compared to the 289,680 km of the natural gas pipeline

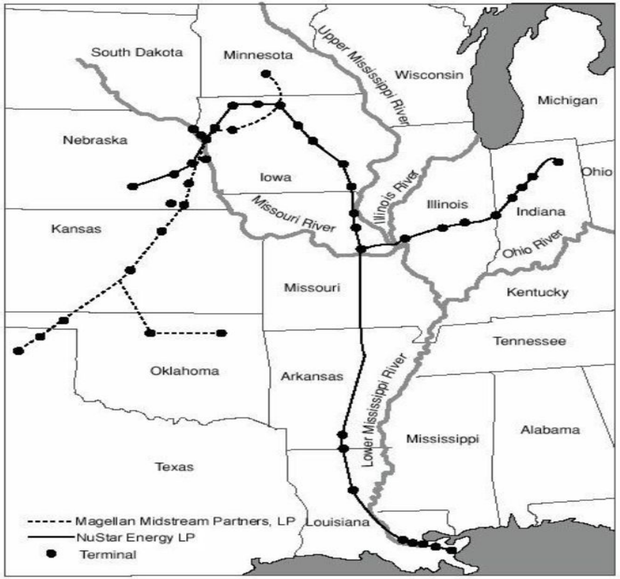


Figure 11: Ammonia pipelines in the United States [72]

Ammonia is the most efficient transportation fuel when moved through a pipeline compared to both hydrogen and natural gas

PIpeline: Hydrogen and Ammonia

Hydrogen

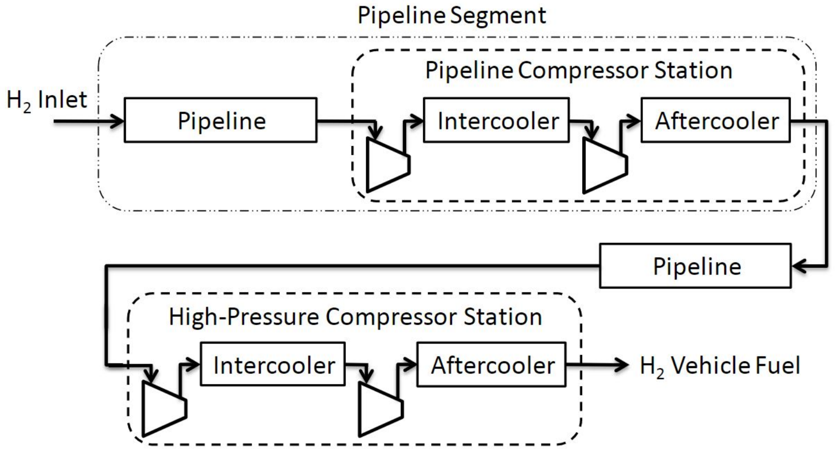
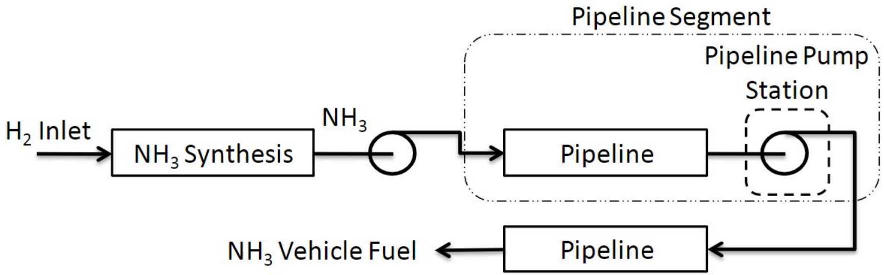


Figure 13: Diagram of hydrogen pipeline system

Ammonia



PIpeline: Hydrogen and Ammonia

Both systems obtain hydrogen from the same hydrogen supply at 104 bar.
Ammonia pipeline system energy use is only **9,028 kJ/kg-H2** while the hydrogen pipeline energy use is significantly more at **21,402 kJ/kg-H2**.

The ammonia system also had a higher efficiency than the hydrogen system with calculated efficiency of 93.4% and 86.9%, respectively.-

Double hydrogen flow (Mass Flow) and energy carrying capacity(Energy Out HHV)

Table 17: Comparison between hydrogen and ammonia pipeline system

	H_2 Pipeline	NH_3 Pipeline
Total Energy Input (kJ/kg H_2)	21,402	9,028
Mass Flow (kg/s H_2)	8.52	17.73
Work Input (MW)	182	160
Energy Out HHV (MW)	1,207	2,251
Operational Velocity (%)	50.00	45.00
Max Pipeline Velocity (m/s)	31.9	2.2
Min Pipeline Velocity (m/s)	14.0	2.2
Efficiency HHV	86.9%	93.4%
Energy Density (MJ/L)	5.57	14.09

*Ammonia values normalized to hydrogen

Ammonia has the highest energy density than hydrogen and natural gas.

The energy density of a fuel is important since it affects the quantity that can be stored in a given space on a vehicle

- Ammonia: **14.09** MJ/L (Megajoules per liter),
- Natural gas : **9.73** MJ/L.
- Hydrogen at 690 bar with an energy density of **5.57** MJ/L
- Gasoline **34.8** MJ/L

Therefore, the energy carrying capacity of the pipelines was also much higher with ammonia

Pipeline: Ammonia & compressed natural gas

The efficiency of the methane system is 97.0%. The ammonia pipeline efficiency is even higher at 99.2%

Using the same pipeline and same number of compression stations, the ammonia pipeline is able to transport **54%** more energy than the natural gas pipeline

A 12 inch nominal ammonia pipeline is capable of transporting 2,251 MW of energy, whereas the natural gas and hydrogen pipeline can only transport 1,464 MW and 1,207 MW, respectively for the same pipe.

Table 18: Energy use in the methane and ammonia pipeline systems

	CH_4 Pipeline	NH_3 Pipeline
Total Energy Input (kJ/kg)	1,704	185
Mass Flow (kg/s)	26.37	99.87
Work Input (MW)	45	18
Energy Out HHV (MW)	1,464	2,251
Operational Velocity (%)	50.00	45.00
Max Pipeline Velocity (m/s)	10.3	2.2
Min Pipeline Velocity (m/s)	4.2	2.2
Efficiency HHV	97.0%	99.2%
Energy Density (MJ/L)	9.73	14.09

Cost-effective

The commercial price to transport ammonia between Donaldsonville, Louisiana and Marshalltown, Iowa via pipeline, a distance of approximately 1,610 km, is 31.22 $/short ton or **0.0344$/kg-NH3**[77].

Adjusting this cost to hydrogen gives a cost of **0.194 $/kg-H2** for existing pipelines.

Ammonis is 5.6 times less expensive to transport.

The efficiency of a 1,610 km ammonia pipeline is 93.4% including the synthesis of ammonia from a hydrogen source. Without considering synthesis, the ammonia efficiency is **99.2**%.

Ammonia is more cost-effective in transporting and storing Hydrogen.

It uses significantly less energy, operates more efficiently, and has a lower cost than the hydrogen storage and transporting system

Sources:

https://www.energy.gov/sites/prod/files/2015/01/f19/fcto_nh3_h2_storage_white_paper_2006.pdf

https://www.sciencemag.org/news/2018/07/ammonia-renewable-fuel-made-sun-air-and-water-could-power-globe-without-carbon

https://www.ammoniaenergy.org/ammonias-role-in-the-hydrogen-society/

https://lib.dr.iastate.edu/etd/11132/A feasibility study of implementing an Ammonia Economy Iowa Energy Center Project Title: Implementing the Ammonia Economy

Large Scale Ammonia Production

The cheapest and most efficient way of producing ammonia in large amounts is through the Haber Process.

Jacob Borison

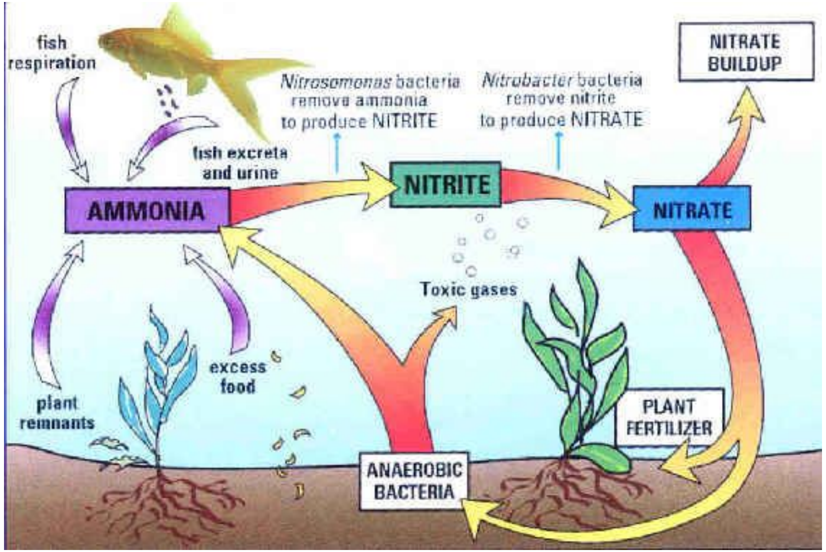
Ammonia is made naturally in various ways, though it is not harvestable for mass human use.

Lightning

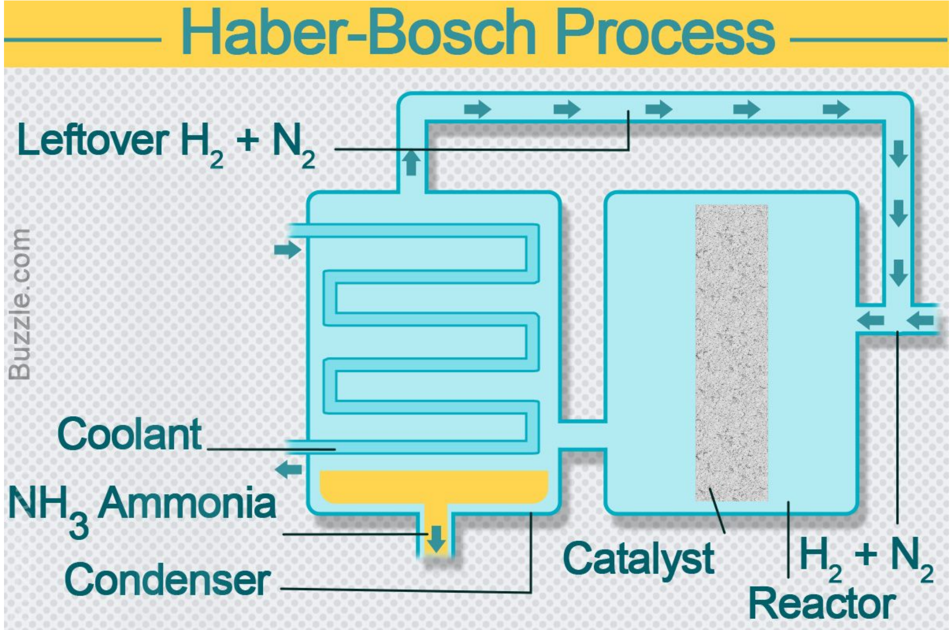
- Lighting kickstarts the reaction between Hydrogen and Nitrogen from the air.

Bacteria

- Release ammonia when metabolizing decomposed organic matter.



The Haber Process allows for ammonia to be made in large quantities.



- Combines Nitrogen from the air and a supply of hydrogen in a pressurized reaction vessel.
- Resulting product is ammonia gas, which is then cooled and stored as liquid ammonia.
- Leftover reactants are recycled to be used again

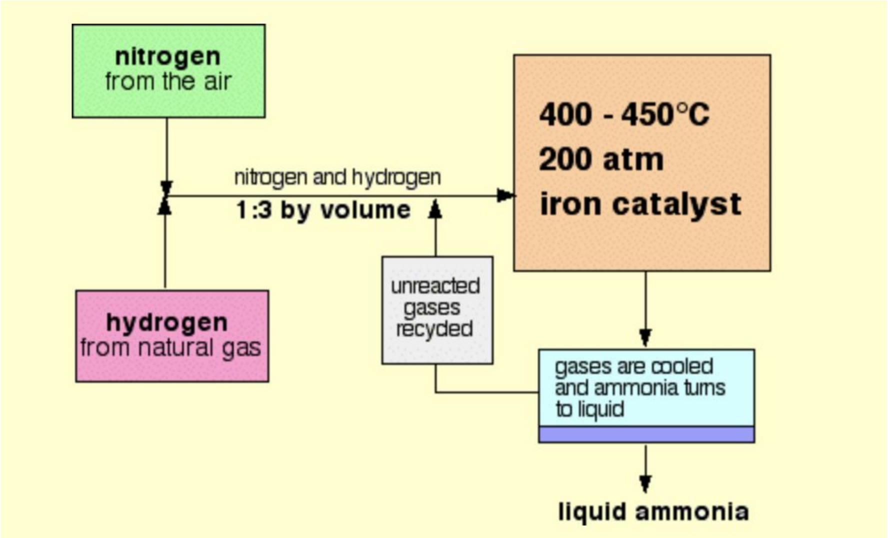
By manipulating Le Chatelier's principle, the Haber Process minimizes cost during production.

- Adding pressure makes the reaction favor the side with fewer moles
- More pressure requires more expensive equipment
- Cost benefit analysis states optimal conditions to run the Haber Process
- Optimal conditions (200 atm) only yields 10-20%
    - Unreacted Nitrogen and Hydrogen is reused

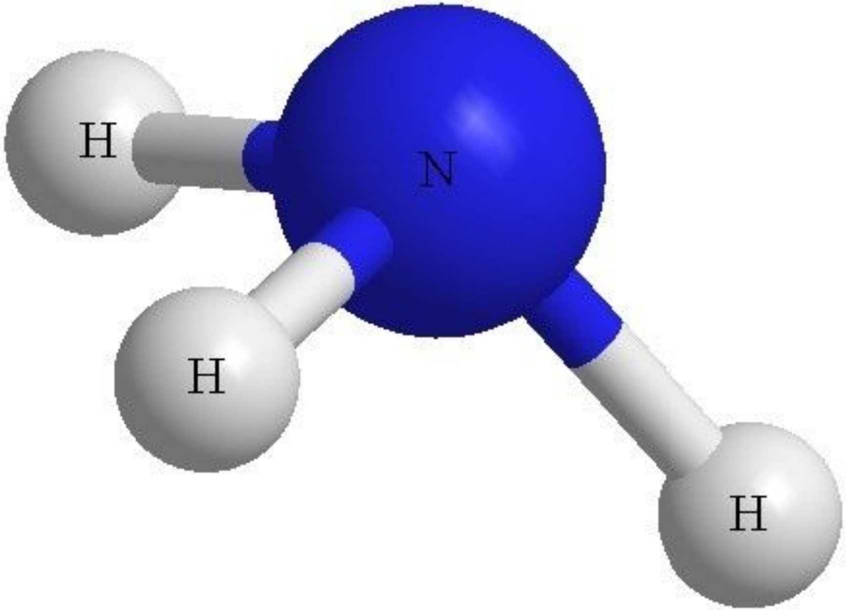
$$N_2 + 3H_2 \rightleftharpoons 2NH_3$$

The Haber Process costs more to operate than mass hydrogen production.

- Cost of .36-1.83 $/kg to make Hydrogen
- .80$/kg conversion cost for making ammonia out of hydrogen
- The price to make ammonia directly relies on the price of making hydrogen



In conclusion, the only economical and practical way of mass producing ammonia is through the Haber Process



Sources:

https://lib.dr.iastate.edu/cgi/viewcontent.cgi?article=2119&context=etd

https://docs.google.com/document/d/1PuUpJ-ICtLGXbcqMMWKnNGDxUyBCuqNpkJ6RcxX5Th4/edit

https://apps.sepa.org.uk/spripa/Pages/SubstanceInformation.aspx?pid=1

Ammonia can be a potential fuel for the engine in the future.

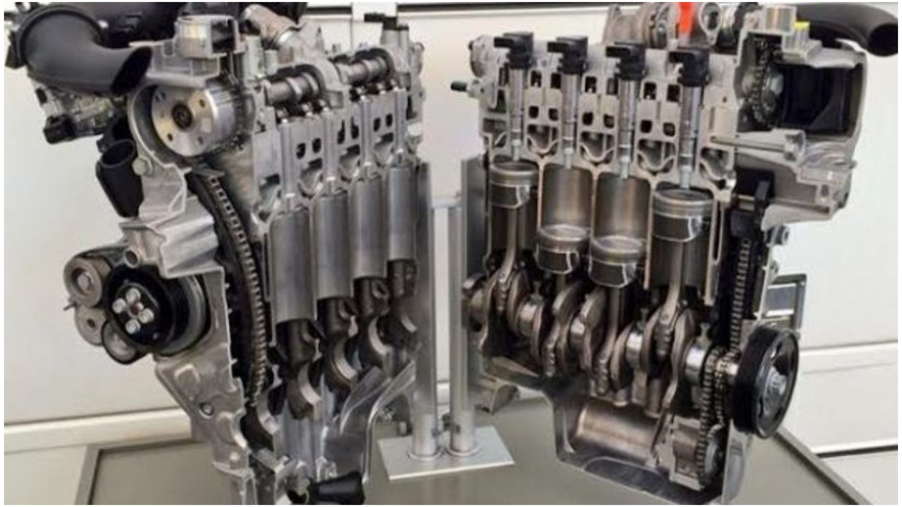
Bell Chen

Ammonia is hard to be used as the only fuel of internal combustion engine, because of its high flash point.

Flash point:
Diesel fuel 52 - 96 °C
Petrol −43 °C
Ammonia 132 °C

Auto-flammable point:
Ammonia 650 °C vs Diesel 210 °C

Only can be used along with other energy source, gasoline and battery



Ammonia can potentially be used as the fuel for constant-output engine, like marine transportation.

Due to the instability of ammonia’s flame, It is hard to operate in a small scale.

If we run the combustion engine in large scale with constant output, it is possible, but not cost efficient right now.

Ammonia 44 MJ/USD vs Gasoline 225 MJ/USD

The efficiency of direct ammonia combustion engine is also lower than gasoline engine.

Catalytic combustion can increase the efficiency and decrease Nitrogen oxide emission.

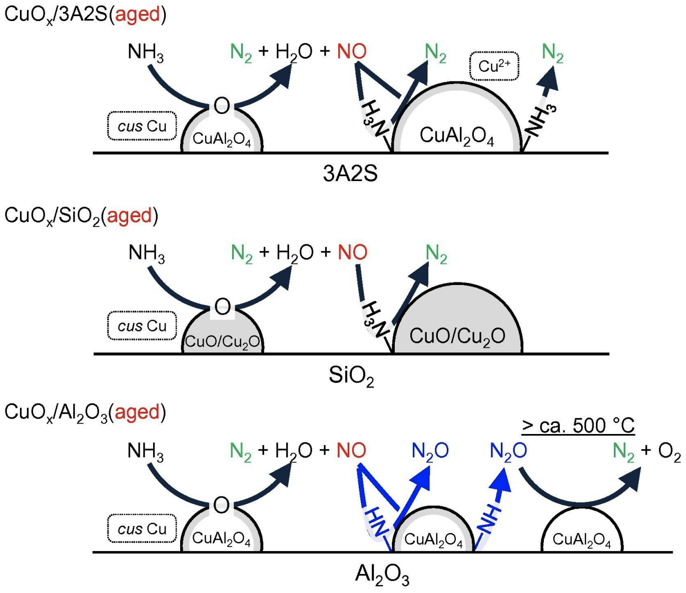
Make the combustion more stable, easier to happen, and without Nitrogen oxide potentially.

The dehydrogenation happens along with combustion.

Problem

Expensive

Still need high temperature to operate (>200°C)

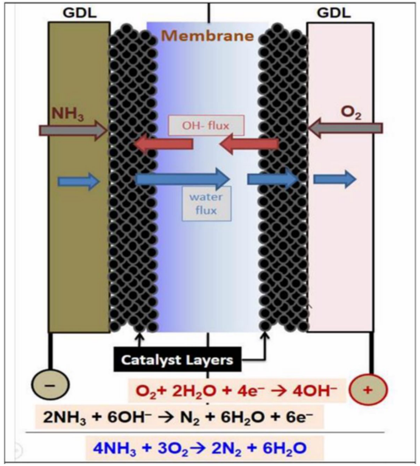


Ammonia fuel cell is a highly potential way to use ammonia, with high efficiency and stable electric output.

Most recent work reaches a peak power density of 135 mW/cm2 near 80 °C, so that

An car needs approx. 1m-1m-30cm box of fuel cell to power.

where electric car's battery need 1.5m-1m-30cm space.



Ammonia fuel tank is much more lighter than battery, good for electric cars.

One fourth of weight of electric car is li-ion battery.

The use of ammonia fuel tank along with fuel cell will decrease the weight of electric car.

Ammonia - 22.87 MJ/KG - 44 MJ/USD

Gasoline - 45 MJ/KG - 225 MJ/USD

Li-ion Cell - 0.914 MJ/KG - 9.3 MJ/USD (Storage)

In conclusion, Ammonia is a potential fuel for powering transportation, but not cost-efficient right now.

Reference

https://www.cell.com/joule/pdfExtended/S2542-4351(19)30321-6

https://www.sciencedirect.com/science/article/pii/S0021951718301052?via%3Dihub

https://pubchem.ncbi.nlm.nih.gov/compound/Ammonia#section=Melting-Point

https://www.engineeringtoolbox.com/flash-point-fuels-d_937.html