Ammonia, an unexpected energy source.

Nate Hoskin, CFP®
Chief Investment Officer

Mina Girgis
Research Analyst

HOSKINCAPITAL
Investment & Market Research

WHAT IS AMMONIA?

Ammonia is one of the most widely produced chemicals in the United States. In pure form it is known as “anhydrous ammonia”. Ammonia is also produced in the human body and is commonly found in nature. It is essential in the body as a building block for making proteins and other complex molecules. In nature, ammonia occurs in soil from bacterial processes. It is also produced when plants, animals and animal wastes decay. At room temperature, ammonia is a colorless, highly irritating gas composed of one nitrogen and three hydrogen molecules (NH_3). It dissolves easily in water to form ammonium hydroxide solution which can cause irritation and burns. Ammonia gas is easily compressed and forms a clear, colorless liquid under pressure. It is usually shipped as a compressed liquid in steel cylinders. Ammonia is not highly flammable, but containers of ammonia may explode when exposed to high heat.

About 80% of the ammonia produced in industry is used in agriculture as fertilizer. Ammonia is also used as a refrigerant gas, to purify water supplies, and in the manufacture of plastics, explosives, fabrics, pesticides, dyes and other chemicals. It is found in many household and industrial-strength cleaning solutions. Cleaning solutions for industrial use contain higher concentrations of ammonia and can quickly cause irritation and burns.

AMMONIA AS A RENEWABLE FUEL

Benefits	**Drawbacks**
● Efficient hydrogen carrier with three hydrogen atoms per molecule ● Transportation of ammonia is much safer than pure hydrogen ● No carbon is emitted during combustion ● When liquified, ammonia carries 48% more hydrogen by volume than compressed or cryogenic H_2 ● Leaks are easily detectable due to its sharp odor ● Ammonia is already produced and transported on an industrial scale (176 million tonnes per year)	● High ignition temperature and low flame velocity make pure ammonia a less effective accelerant vs hydrocarbons ● When used in a fuel mix, ammonia combustion creates NO_x gases which can contribute to acid rain and ground-level ozone accumulation ● Ammonia is considered a high health hazard because it is corrosive to eyes, skin, and lungs ●

AMMONIA AS A HYDROGEN CARRIER

Ammonia is, in many ways, a perfect commodity for a hydrogen-driven economy. According to a report by ammonia production technology firm Haldor Topsoe, Ammonia has a higher energy density, at 12.7 MJ/L, than even liquid hydrogen, at 8.5 MJ/L. Unlike pure hydrogen, which needs to be stored at -253 °C, ammonia becomes liquid at a more sustainable -33 °C. Ammonia is hazardous to handle, but is less flammable than hydrogen.

Furthermore, thanks to a century of ammonia use in agriculture, ammonia production and transportation infrastructure already exists. Nearly 180 million metric tons (t) of ammonia are produced annually and 120 ports are equipped with ammonia terminals.

THE AMMONIA COLOR SPECTRUM

BROWN AMMONIA, also called "grey ammonia", is currently the most commonly used type of ammonia. The Haber-Bosch process directly combines hydrogen and nitrogen using high heat and extreme pressure. Haber-Bosch is also energy intensive, using about 1% of the world's total energy production. The hydrogen used is usually obtained from steam methane reformation, which involves removing hydrogen from natural gas molecules and releasing carbon dioxide as a waste product. The aggregate production of grey ammonia is responsible for nearly 1% of the world's total CO_2 emissions.

BLUE AMMONIA is conventionally produced ammonia (grey ammonia) for which the carbon by-product has been captured. The carbon is captured via direct storage (injecting it into the ground), cement curing, or enhanced oil recovery. While this method has notably lower environmental impact when compared to grey ammonia, it is in need of regulation to homogenize environmental impact across different methods. A sub-category of blue hydrogen is "white hydrogen", which is naturally occurring pure hydrogen found in underground traps and harvested via fracking.

TURQUOISE AMMONIA uses a method called "methane pyrolysis" to convert methane into hydrogen and solid carbon. Solid carbon, also called carbon black, is a form of paracrystalline carbon similar to activated carbon. This process does create carbon as a byproduct but, due to its solid form, the carbon by-product does not degrade the atmosphere or air quality.

GREEN AMMONIA comes from water electrolysis powered by renewable electricity. Separating hydrogen from oxygen is a zero-carbon reaction, but the production of the electricity used must also be produced in a clean way. Projects abound, but many have not exceeded ten thousand tons, only 1% the capacity of a normal ammonia plant. That said, a project led by Air Products, Inc. in Saudi Arabia aims to produce one million tons per year. The project would consume four gigawatts of renewably generated electricity. Within green ammonia are yellow ammonia, which is produced using solar power, pink ammonia, produced using nuclear power.

AMMONIA FUEL CELLS

The Department of Energy provides a great primer on how fuel cells work:

“Fuel cells work like batteries, but they do not run down or need recharging. They produce electricity and heat as long as fuel is supplied. A fuel cell consists of two electrodes—a negative electrode (or anode) and a positive electrode (or cathode)—sandwiched around an electrolyte. A fuel, such as hydrogen, is fed to the anode, and air is fed to the cathode. In a hydrogen fuel cell, a catalyst at the anode separates hydrogen molecules into protons and electrons, which take different paths to the cathode. The electrons go through an external circuit, creating a flow of electricity. The protons migrate through the electrolyte to the cathode, where they unite with oxygen and the electrons to produce water and heat.”

Ammonia is a contender for use in fuel cells alongside methanol and ethanol because it’s easy to liquify (similar to propane at 1-2 atmospheres) and does not contain carbon. Ammonia is more energy dense than pure hydrogen, but toxicity to humans is a major concern. Anhydrous ammonia is lighter than air and quickly disperses into the atmosphere, but may cause problems in a car or other vehicle accident. That said, ammonia would be as safe as gasoline when used as a transportation fuel or in a fuel cell (Olson and Holbrook, 2007). This danger can be abated through the use of metal amines (Klerke et al., 2008).

Ammonia fuel cells have existed since the 1960s and ammonia has been proven to work in almost all fuel cell models, specifically alkaline, alkaline membrane, proton exchange membrane, and molten hydroxide fuel cells.

The general drawbacks and challenges of using ammonia in a fuel cell center around temperature and energy density. In general, it’s quite hard to separate the hydrogen from the nitrogen atom at low temperatures and when it can be performed the energy density is low. The most effective ammonia fuel cells operate above 200 °C, more than twice the average operating temperature of a normal car (~93 °C).

To conclude, ammonia is a low-cost, carbon free chemical that is already produced at scale. As such, it is an ideal energy vector in a hydrogen-powered economy, but the ammonia must be produced sustainably and though the fuel cell technology exists it is not yet ready to be scaled or commercialized.

CURRENT AMMONIA PROJECTS

Ammonia is currently be scrutinized as a possible savior of the carbon-intensive maritime shipping industry. According to the International Maritime Organization (IMO), the United Nations body that regulates the industry, commercial shipping contributes more than 3% of the world's carbon emissions. The delegates of the IMO have agreed to reduce those levels to 50% of 2005 levels by 2050, but this task involved immediate implementation of diesel alternatives.

Finland's Wärtsilä, a power source manufacturer for maritime companies, tested a prototype ammonia combustion engine in June of 2021. Of the prototypes, a fuel-mix motor containing 70% ammonia is operating smoothly and tests have proven successful on a pure hydrogen version with ammonia as the feedstock.

Equinor and Man Energy Solutions are working on similar projects under the moniker Demo2000. Target delivery dates range from 2023 to 2025, with Wärtsilä aiming for field tests by 2022 and Man Energy Solutions expects to have a two-stroke engine ready for delivery by 2024. In a related project, Wärtsilä is also working to install ammonia fuel cells on Eidesvik Offshore's Viking Energy vessel by 2023. After its conversion Viking Energy would be the first carbon-free maritime vessel in the world.

Other projects are in process by Japan's Green Ammonia Consortium, an industry body building a value chain "from supply to use of CO2-free ammonia".

WRAP UP

Ammonia is far from being starship fuel, but it offers a new opportunity for the use of renewable energy that hasn't been tapped yet. It carries with it the added benefit that humans are really really good at transporting and storing ammonia because of the scale at which we do so for fertilizer. In a hydrogen-powered world, ammonia has the potential to play a crucial role and investors who gain exposure to this theme stand to benefit from a blue-water opportunity.

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