AMMONIA

Future energy storage solution

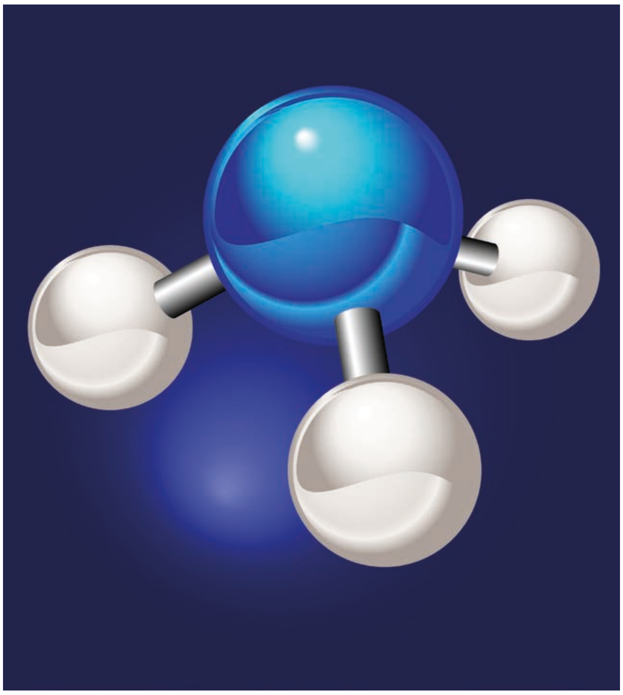
Can ammonia be viewed as an economically efficient and technologically suitable solution to address large-scale, long-duration storage in the decarbonised energy systems of the future? ask *Aliaksei Patonia* and *Rahmatallah Poudineh* of the Oxford Institute for Energy Studies (OIES).*

Ammonia (NH_3) and hydrogen (H_2) are currently considered to be among the two most promising solutions available for long-term storage in a low carbon economy. We believe that ammonia, as an energy vector of hydrogen, is preferable to pure hydrogen from economic, environmental and technological perspectives. Various ammonia generation techniques are analysed here, as well as the conditions under which zero carbon ammonia makes sense economically.

Renewables-dominated energy systems are characterised by high levels of variability and uncertainty. In addition, in many places, peak demand for heating and/or cooling does not coincide with peak renewable generation. There are also studies arguing that climate change itself may increase the likelihood of long periods of low wind generation, leading to increased seasonal variability or intensified fluctuations of wind power generation from year-to-year. These all mean that, in a renewable energy dominated power system, storing large volumes of energy for a long period of time is likely to be crucial in addressing the challenge of meeting peak demand.

While there are multiple technologies allowing for the large-scale preservation of energy (ie electrical, electrochemical, mechanical and chemical), the future of energy storage is more often associated with either electrochemical storage (eg batteries) or chemical storage (eg hydrogen or ammonia). Despite the gradually decreasing production cost of electrochemical storage, the cost of storing energy per kWh for a chemical storage such as hydrogen is significantly lower in comparison with most long-lasting batteries. On the other hand, despite often being viewed as an option to address the challenge of long-term, large-scale energy storage, pure hydrogen poses a number of challenges associated with the way in which it is kept and delivered. This has resulted in a growing interest in exploring ammonia as a more advantageous storage option.

Although ammonia has the potential to be used as a fuel in a direct combustion process or in ammonia-fuelled fuel cells for land and marine transport or power generation purposes, its highest product value can be achieved when used as a hydrogen carrier. Ammonia could thus be appropriate for most power and energy systems.



Ammonia best fits in the energy system as an energy vector of hydrogen, representing a more economical way of delivering hydrogen over long distances than the conventional way of transporting it in compressed or liquefied forms

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In places with intermittent energy resources, such as wind and solar, ammonia can help to balance the energy system, while sporadically augmenting a country's energy exports if there is excess generation.

A matter of cost and safety

Hydrogen and ammonia have roughly the same energy intensity and costs. However, as liquid ammonia has over 50% more volumetric energy than liquid hydrogen – more than twice the volumetric energy of hydrogen gas at 700 bar – it seems to be more economically advantageous, according to a study by the US Department of Energy (2010). In addition, in comparison to hydrogen, ammonia is easier and less dangerous to handle. Specifically, its vapour pressure is much lower (10 bar at 25°C), which to a great extent simplifies the design of storage tanks for transportation purposes. Therefore, if it is generated through a carbon-free process, ammonia can be used for storing large amounts of energy for a long time in a transportable form because of its specific physical features – this is essential for achieving a low carbon future.

Siemens, a company which is working on the extended integration of renewables and energy storage, says: 'For big-capacity, long-duration storage, chemical fuels are hard to beat.' And among chemical storage solutions, ammonia takes a special place due to its unique features.

As mentioned, ammonia is relatively easy to handle. Of all the chemical storage options, ammonia produced by means of electrolytic hydrogen generation stands out as a 'green' solution that is easier to handle than hydrogen, being less flammable. In addition, with a boiling point of 33.36°C, ammonia is easily liquefied and requires less energy for storage and transportation than hydrogen, whose boiling point is –252.9°C. Finally, its characteristic smell, though offensive in higher concentrations, provides an invaluable early warning of potential lethal emission – a feature not found in hydrogen.

Furthermore, ammonia is rapidly deployable. Being one of the most important commodity chemicals in the world, it also represents one of the most widely generated chemical products. That is why ammonia's handling and shipping infrastructure, including regulations for transportation, are already in place. Traditionally, ammonia is transported and contained in tanks under a modest pressure, which means it could be rapidly deployed to the part of the energy system where it is needed, via pipelines, railroads, barges, ships, road trailers and storage depots. Thus, scaling up ammonia production and distribution does not need extensive investment in infrastructure development.

In addition, ammonia bonds

together one nitrogen atom and three hydrogen atoms, which means a litre of liquid ammonia carries a greater mass of hydrogen than a litre of liquid hydrogen itself. As a result, liquid ammonia is a more efficient hydrogen carrier than liquid hydrogen, as more energy can be delivered within the same volume of storage vessel.

Finally, ammonia potentially produces no carbon emissions and can be produced carbon-free. Although the traditional process of producing ammonia – steam reforming – normally utilises either natural gas or coal as the main fuel, if it is produced from green hydrogen there would be no CO_2 emissions. However, in order to gain wider use, the zero carbon process of ammonia production needs to be proven economically efficient.

Disadvantages

Ammonia also has a number of disadvantages. For instance, the direct burning of ammonia is technically impeded by its low flammability and radiation intensity. These characteristics hamper ammonia's self-sustained burning and heat transfer in a combustion process and turn it into a challenging fuel to rely on. At the same time, even with successful ammonia incineration, there is high fuel NO_x (nitrous oxides) emission, (whereas hydrogen combustion simply produces water). That is why, to abate NO_x emissions, some more advanced technologies, such as selective catalytic reduction, are needed. This will lead to additional cost. Therefore, with the currently available ammonia incineration technologies, this fuel is unlikely to represent a first-choice option for a combustion process.

Another disadvantage is that green ammonia production is not yet fully established. As of 2018, pilot plants for the production of green ammonia had just started in the UK and Japan. New demonstration plants have more recently been announced in Australia, Denmark, Morocco and the Netherlands. This reflects the limited popularisation of unconventional ammonia production to date, and its generation based on electrolysis is yet to be well established.

Furthermore, despite being less flammable than hydrogen, ammonia is a highly toxic chemical associated with coma and convulsions at a blood ammonium concentration of 200 µmol/l. This toxicity factor appears to be one of the major impediments to deploy these technologies, as public perception is very formative. That is why, despite its highly identifiable odour making leakage detection easier, proper storage of ammonia and prevention of its leakage should be viewed as a priority – not only by ammonia producers, but also by its storage operators, transporters and end users. This is particularly important as ammonia has a tendency to concentrate near the ground and quickly dissolve in water, which would pose a significant threat to public health.

Companies organising ammonia transportation and storage in tanks also need to take measures to avoid 'ammonia stress corrosion cracking'. In addition, due to the tendency of an ammonia-air mixture to explode when exposed to high heat, preserving the right temperature is crucial.

In this context, with a broader use of ammonia in the future and an increased number of actors involved in its handling, undertaking the required safety measures will not only presuppose additional indirect costs but also require a more comprehensive approach to safety training, public education and policymaking.

Uses of ammonia and future potential

Currently, global production and trade of ammonia is driven by the fertiliser industry, and accounts for roughly 80% of globally generated ammonia. Ammonia is also widely used in the chemical and other related industries as a precursor to nitrogen-containing substances; as a precursor for explosives; softening cotton in synthetic fibres; in antibacterial drugs and more complex commodities. In addition, it is used in industrial refrigeration processes.

The application of ammonia in the energy sector is currently very insignificant. Such a low level of penetration of ammonia into the energy sector could be viewed as an opportunity for further progress, especially as ammonia's physical properties could offer significant room for energy-based applications. For instance, with a significant further improvement of ammonia combustion technologies, pure ammonia can potentially serve as an alternative to fossil fuels in internal combustion engines and generators. Due to the absence of carbon in its chemical structure, the incineration of ammonia does not generate CO_2, carbon monoxide, hydrocarbons or soot, but only nitrogen and water.

Nevertheless, further technological improvement of the existing combustion engines is needed to increase their efficiency, to deal with ammonia's narrower flammability range, higher ignition temperature and lower combustion efficiency when compared to common hydrocarbons. More important, however, ammonia combustion technologies need to be improved in order to enable a complete elimination or minimisation of NO_x emissions (caused in all forms of air combustion).

Looking forward

With further technological progress, ammonia could become an attractive propellant for land transportation and a sustainable alternative to bunker fuel which is currently used in maritime transport. However, new vessels will have to adjust to this type of marine fuel, as ammonia occupies substantially more volume than diesel for the same propulsion amount. Furthermore, although the direct consumption of ammonia is less complex from a technical perspective, measures still need to be taken to address NO_x emissions. At the moment, the issue of using ammonia for carbon-free shipping appears to be at an early stage of development.

The use of ammonia in fuel cells rather than in internal combustion engines could effectively address the NO_x pollution challenge and provide better overall performance – but there's a greater level of technical challenges to overcome.

Ammonia best fits in the energy system as an energy vector of hydrogen. As a hydrogen carrier, ammonia represents a more economical way of delivering hydrogen over long distances than the conventional way of transporting hydrogen in compressed or liquefied forms. In this sense, green ammonia producers could also benefit from the integration of their product into the hydrogen energy economy of the future. Apart from the intra-sectoral alignment of different elements of the energy industry across territories and geographic areas, spreading the use of ammonia as a means of long-term large-scale energy storage could allow for cross-sectoral integration, which would offer new benefits to other sectors (such as transport). ●

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