INTERNATIONAL CENTRE FOR SUSTAINABLE CARBON

EXECUTIVE SUMMARY
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THE POTENTIAL ROLE OF AMMONIA IN A CLEAN ENERGY TRANSITION

AMMONIA AS A CARBON-FREE FUEL

Ammonia (NH_3) has certain properties that make it suitable for use as an energy storage medium, a hydrogen carrier and as a fuel. As it is carbon free, ammonia combustion does not emit CO_2. Ammonia is currently the second most produced chemical; around 180 Mt/y of ammonia is manufactured worldwide for use as a feedstock for fertiliser and other chemicals. Nearly 90% of ammonia is produced and consumed locally while the remaining 10%, around 20 Mt, is traded globally. Therefore, technologies for its production, safe handling, transport and storage are mature and global supply and distribution infrastructure already exists, although not on a massive scale. These factors mean that ammonia could form the basis of an integrated energy storage and distribution solution, and be a low-carbon fuel for power generation, transport and industrial processes. Ammonia combustion as an alternative approach to decarbonising power generation, may be particularly important for countries that depend on thermal power plants to provide key flexibility and other system services.

There are three main commercial technological routes for ammonia production: steam methane reforming (SMR) accounting for 72% of global ammonia production, coal gasification accounting for 26%, and the water electrolysis-based Haber-Bosch process produces less than 1%. Ammonia production processes are energy intensive and create emissions of large volumes of CO_2 as almost all ammonia is currently produced from unabated fossil fuels. When using ammonia as a fuel for decarbonisation the options include producing *renewable ammonia* via electrolysis using renewable energy to power the entire production process. However, this is a nascent commercial activity and currently not competitive with the other two options of ammonia production. The alternative is to produce *low-carbon ammonia* by combining a fossil fuel-based process with carbon capture and storage (CCS).

Ammonia can be directly burnt with minor modifications in internal combustion engines (ICE), gas turbines, and coal-fired boilers, or be fed to a fuel cell (FC) to produce electricity. There are technical challenges to burning ammonia in existing combustion systems due to its relatively low energy content and low reactivity, and the likely increase in emissions of nitrogen oxides (NOx) and nitrous oxide (N_2O); they can be overcome using existing technologies, improved engineering designs and system optimisation. Extensive R&D on ammonia combustion technologies is progressing fast. Several projects are developing ammonia-coal cofiring technologies for power generation; commercial demonstration of 20% ammonia-coal cofiring at a 1000 MW coal power unit is scheduled for 2023-24 at the Hekinan plant in Japan. Ammonia-gas cofiring technologies for gas power generation are in development and could be commercialised by 2025.

Projects are underway to demonstrate that ammonia can deliver power to shipboard systems safely and effectively. The first commercial vessels propelled by ammonia fuel or using large FCs running on ammonia are expected to launch in 2024-25. Road vehicles driven by ammonia-fuelled ICE and FC systems are in development and some have been demonstrated. However, they are not competitive with rival technologies such as batteries and hydrogen-fuelled FC, so there is less progress. Ammonia as a fuel in industrial furnaces has been explored with some positive results.

CHALLENGES AND OPPORTUNITIES

A major barrier to using clean ammonia as a fuel is its high cost. In general, renewable ammonia costs more than double conventional ammonia and it is likely to remain expensive for some years. Low-carbon ammonia costs around 25% more than conventional ammonia due to the additional cost of carbon capture.

Another serious challenge is the future demand for clean ammonia. The increased use of ammonia as an energy source could create a market many times larger than current global total production capacity. This would require a massive scale-up of ammonia production, port, storage, and distribution facilities. However, the low production rate of renewable ammonia constrains its use as a clean fuel. Low-carbon ammonia could offer a quicker and cheaper route to a low-carbon energy transition.

In addition, ammonia is a toxic gas and can damage human health. Large-scale combustion of ammonia could have a negative environmental impact due to the likely increase in emissions of N_2O, NOx, and ammonia. New safety protocols and regulations, emission standards and clean fuel standards are needed to extend the use of ammonia as fuel.

Appropriate policies need to be established to kick-start the use of ammonia as a clean fuel. For example, policies in the form of development strategies, roadmaps, action plans and mandates with targets for clean fuel uptake and/or carbon emissions reduction can inspire companies and investors to capitalise in the clean energy business. Policy support such as emission charges and tax credits, and incentives and financial support are also important to overcome the high cost of clean ammonia fuel. More R&D is needed to lower the cost of clean ammonia.

The expansion of ammonia production, transport and distribution infrastructure to enable the extended use of ammonia as a fuel requires large capital investment, which poses another challenge but also provides opportunities for investors as the market may be huge.

AMMONIA TO FUEL FUTURE CLEAN ENERGY

Substituting fossil fuels with clean ammonia in existing combustion systems can reduce CO_2 emissions over the life cycle of the fuel. For coal power generation, substituting coal with clean ammonia could reduce CO_2 emissions by 80–95%. Ammonia combustion/cocombustion and ammonia FC technologies may be commercially available within 5–10 years; it is likely that power generation and maritime transport will be early deployers of clean ammonia fuel. The first large-scale uptake of ammonia fuel use is likely to be based on lower-cost low-carbon ammonia, which can offer a quicker and cheaper start to decarbonisation than renewable ammonia. Appropriate policies are key to the successful deployment and use of clean ammonia fuel. Overall, ammonia has the potential to become a key element of a net zero emissions energy mix, especially in energy-intensive sectors such as power generation, transport and some industrial processes.

Each executive summary is based on a detailed study which is available separately from: www.sustainable-carbon.org. This is a summary of the report: Potential role of ammonia in a clean energy transition by Dr Qian Zhu, ICSC/323, ISBN 978-92-9029-646-1, 75 pp, August 2022.