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Ammonia for power

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ABSTRACT

A potential enabler of a low carbon economy is the energy vector hydrogen. However, issues associated with hydrogen storage and distribution are currently a barrier for its implementation. Hence, other indirect storage media such as ammonia and methanol are currently being considered. Of these, ammonia is a carbon free carrier which offers high energy density; higher than compressed air. Hence, it is proposed that ammonia, with its established transportation network and high flexibility, could provide a practical next generation system for energy transportation, storage and use for power generation. Therefore, this review highlights previous influential studies and ongoing research to use this chemical as a viable energy vector for power applications, emphasizing the challenges that each of the reviewed technologies faces before implementation and commercial deployment is achieved at a larger scale. The review covers technologies such as ammonia in cycles either for power or CO_2 removal, fuel cells, reciprocating engines, gas turbines and propulsion technologies, with emphasis on the challenges of using the molecule and current understanding of the fundamental combustion patterns of ammonia blends.

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1. Introduction

Renewable energy is playing an increasingly important role in addressing some of the key challenges facing today's global society, such as the cost of energy, energy security and climate change. The exploitation of renewable energy looks set only to increase across the world as nations seek to meet their legislative and environmental obligations with respect to greenhouse gas emissions. There is broad agreement that energy storage is crucial for overcoming the inherent intermittency of renewable resources and increasing their share of generation capacity.

Thus, future energy systems require effective, affordable methods for energy storage. To date, a number of mechanical, electrical, thermal, and chemical approaches have been developed for storing electrical energy for utility-scale services. Storage solutions such as lithium batteries or redox cells [1–3] are unlikely to be able to provide the required capacity for grid-scale energy storage. Pumped hydro and methods such as compressed gas energy storage suffer from geological constraints to their deployment [4–6]. The only sufficiently flexible mechanism allowing large quantities of energy to be stored over long time periods at any location is chemical energy storage [7].

Chemical storage of energy can be considered via hydrogen or carbon-neutral hydrogen derivatives. One such example is ammonia, which has been identified as a sustainable fuel for mobile and remote applications. Similar to synthesised hydrogen, ammonia is a product that can be obtained either from fossil fuels, biomass or other renewable sources such as wind and photovoltaics, where excessive electrical supply can be converted into some non-electrical form of energy [1]. Some advantages of ammonia over hydrogen are its lower cost per unit of stored energy, i.e. over 182 days ammonia storage would cost 0.54 \$/kg-H_2 compared to 14.95 \$/kg-H_2 of pure hydrogen storage [8], higher volumetric energy density (7.1–2.9 MJ/L), easier and more widespread production, handling and distribution capacity, and better commercial viability. Ammonia produced by harvesting of renewable sources has the following properties [9–11],

1. It is itself carbon-free, has no direct greenhouse gas effect, and can be synthesized with an entirely carbon-free process from renewable power sources;
2. It has an energy density of 22.5 MJ/kg, comparable to that of fossil fuels (low-ranked coals have around 20 MJ/kg; natural gas has around 55 MJ/kg, LNG 54 MJ/kg, and hydrogen 142 MJ/kg);
3. It can easily be rendered liquid by compression to 0.8 MPa at atmospheric temperature; and,
4. An established, reliable infrastructure already exists for both ammonia storage and distribution (including pipeline, rail, road, ship); today around 180 million tons of NH_3 are produced and transported annually.

1.1. Interest in ammonia for power

Ammonia has recently started to receive attention internationally as a consequence of the primary benefits outlined in the previous section. For example, Japan has been looking for renewable alternatives for their energy consumption requirements over the last few decades, due to lack of natural energy resource. Hydrogen has been presented as an attractive solution that could meet their energy demands, accompanied by reduction in greenhouse gas emissions. However, Japan has clearly recognised the potential of ammonia to serve as the hydrogen carrying energy vector, and a 22-member consortium led by Tokyo Gas has been created to curate “Green Ammonia” promoted by the Cross-Ministerial Strategic Innovation Program (SIP) of Japan [12], seeking to demonstrate hydrogen, ammonia and hydrides as building blocks of a hydrogen economy, Fig. 1. The Japan Science and Technology Agency (JST) has announced the intentions of the consortium to develop a strategy for “forming an ammonia value chain” that promotes the leadership of the country in the production and use of the chemical worldwide. All consortium members have extensive knowledge of handling ammonia, with multimillion projects in progress or under consideration. For example, IHI Corporation and Tohoku University plan to invest \$8.8 M in 2017 to set up a duel-fuel gas turbine that co-fires one part of ammonia to five parts of methane [13]; similarly, Chugoku Electric Power Company intends to conduct co-firing experiments with coal and ammonia (at 0.6%) at one of their power plants, paying \$373,000 for the implementation of this project [14].

In the USA, the Advanced Research Project Agency-Energy (ARPA-E), subsidiary of the Department of Energy, has recently launched its “Renewable Energy to Fuels through Utilisation of Energy-Dense Liquids” (REFUEL) program, whose aim is to develop scalable technologies for converting electrical energy from renewable sources into energy-dense carbon-neutral liquid fuels (CNLFs) and back into electricity or hydrogen on demand, thereby accelerating the shift to domestically produced transportation fuels, improving American economic and energy security, and reducing energy emissions [16].

ARPA-E announced that grants totalling \$32.7 M would be awarded to 16 REFUEL projects of which 13 are focusing on ammonia. From small scale ammonia synthesis using stranded wind en-