HENRY ROYCE INSTITUTE

ADVANCED MATERIALS RESEARCH & INNOVATION

MATERIALS CHALLENGES TO ENABLE HYDROGEN DEPLOYMENT AT SCALE BY 2050

Challenge: Improving catalysts for distributed ammonia production and cracking, to realise ammonia's potential as a hydrogen storage and distribution vector.

CONTEXT

One of the benefits of hydrogen is the potential it offers for long-term storage of energy at scale. However, the physical and chemical properties of hydrogen lead to higher storage and transportation costs relative to other energy carriers such as liquid hydrocarbon fuels (diesel, bioethanol, etc.). For practical applications it is necessary to find ways of storing sufficient quantities in manageable volumes by increasing the density of hydrogen. The principal hydrogen storage methods used to date are physical-based solutions in which hydrogen is compressed and/or cooled. Various materials-based storage technologies are also under development and being investigated by the academic community. The main options are summarised in the figure below.

Large-scale hydrogen storage options

Physical-based storage		Materials-based storage	
Compressed gaseous hydrogen	Liquefied hydrogen	Ammonia	Chemical Hydrides, inc. LOHC's
Cryo-compressed hydrogen	Slush hydrogen*	Adsorbent (MOFs, zeolites, etc.)	Metal hydrides

LOHC: liquid organic hydrogen carrier, MOF: metal organic frameworks
**Slush hydrogen is a combination of liquid and solid hydrogen at the triple point (primarily investigated as a fuel for space travel).*

The relatively high density, efficiency of conversion, and moderate liquefaction temperature of ammonia has made it a key hydrogen carrier candidate. Given ammonia is already transported around the globe as an industrial feedstock, existing logistics and engineering know-how can be exploited to optimise the distribution of ammonia. Ammonia can be liquefied at a higher temperature than hydrogen, and liquid ammonia has a hydrogen volumetric density of 107 kg/m^3, and gravimetric density of 17.6 wt.%. This high energy density has made ammonia of interest for applications where large quantities of hydrogen would be required, such as in shipping.

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MATERIALS RESEARCH CHALLENGE

To support the use of ammonia as a hydrogen carrier at scale requires the development of efficient catalysts that allow ammonia to be produced on a distributed scale, and to enable ammonia be cracked more efficiently into hydrogen and nitrogen.

A significant proportion of hydrogen produced today is used in ammonia manufacture through the Haber-Bosch process. While this process has been established in industry for many years, work continues to improve catalyst performance. A less common research topic is the development of solutions to allow smaller-scale, distributed ammonia production with a lower carbon footprint. One option would be to produce ammonia directly from electrolysis. This will require the development of new electrolyser systems, including electrolytes, anode, and cathode materials. Production of ammonia from electrolysis was recently achieved by researchers at the University of Illinois at Chicago and the University of Minnesota, where 300mg of ammonia was produced from a nitrogen reduction reaction. This technology is currently at an early stage and significant work will be required to optimise and scale up the process, requiring new materials developments.

In applications where ammonia is used as a storage mechanism for hydrogen, the ammonia will need to be 'cracked' back into hydrogen and nitrogen. Catalysts for this reaction have not been developed to the same extent as those for the Haber-Bosch process.

UK CREDENTIALS AND WAY FORWARD

While ruthenium, and nickel and iron-based systems are expected to be beneficial for ammonia cracking, recently the UK Science and Technology Facilities Council (STFC) developed a new family of catalysts that may be suitable, comprised of metal amides and imides. These catalysts were able to reduce the cracking temperature by 50°C, offered improved performance under thermal cycling, and are expected to have significantly lower cost than ruthenium-based catalysts. While research is ongoing to scale up systems based on these catalysts, it remains a promising discovery for the UK. The UK has word leading capabilities in catalysis development, manufacture and wide scale deployment which can be utilised to drive advances in this field.

A cross industry/academic group is currently developing a more detailed proposal outlining the research challenges, resources and capabilities required to achieve a breakthrough in this area to enable widescale hydrogen deployment by 2050. This proposal will be available by the end of July for consideration for inclusion in the November spending review.

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