Importance of Catalysis for Achieving Net Zero

Dr Yagya Regmi and Dr Laurie King, UK Catalysis Hub and Manchester Metropolitan University*

**y.regmi@mmu.ac.uk*

Abstract: It is critical to develop a broad portfolio of affordable and efficient technologies that can manage and ultimately overcome the climate crisis. The burden of developing such technologies to reverse the adverse effects of emissions without compromising the living standards lie with the scientific and engineering community in both academia and industry. In this article, we discuss some of the technologies that are either reaching commercial maturity or are currently under investigation in the scientific community. We also discuss the magnitude and scale required to achieve Net Zero targets. The accompanying video is a detailed technical case study on electrolysers used to produce hydrogen from water using renewable energy to store vast amount of renewable energy.

Meeting the energy demand: The industrial revolution and subsequent innovations have uplifted the living standards of billions around the world. Underpinning these developments is our ability to harvest and use energy – over 90% by burning fossil fuel reserves (hydrocarbons) such as coal, gas and oil.[1] Additionally, these hydrocarbons are also critical sources of raw materials for medicine, infrastructure, clothes, and chemicals. Continued hydrocarbon combustion technologies are considered unsustainable because they are finite reserves, but more critically, their combustion releases greenhouse gases such as carbon dioxide into the atmosphere. Instead, we can replace our fossil fuels with energy sourced from renewable sources such as solar, wind and hydroelectric power. However, renewable sources of energy are inherently intermittent (e.g. the sun does not always shine), and their abundance varies across the globe both geographically, as well as seasonally (e.g. winter vs summer).[2] To overcome the intermittency and unequal distribution, it is necessary to develop energy storage and transportation technologies alongside developing energy harvesting and conversion technologies such that electricity can be generated when and where renewable resources are abundant, and stored until required for end use.

Hydrogen as the energy carrier: One commonly touted option for energy storage is in the form of molecular hydrogen.[3] Globally today, >90 million metric tonnes of hydrogen is used as chemical feedstock.[4] However, >95% of this hydrogen is derived from hydrocarbon reforming, which releases carbon dioxide. Electrolytic hydrogen generation using water electrolysers has the potential to overcome the energy storage and transport challenges, provided we can make the technologies sustainable and affordable. When energy harvested from solar panels and wind turbines (electrical energy) is used to split water into hydrogen and oxygen in the electrolyser, the renewable energy is stored in the chemical bonds of hydrogen. The hydrogen can then be either transported to where it is needed or stored until required. The energy stored in the chemical bonds of hydrogen can be released either analogous to how fossil fuels are used (internal combustion engines and direct combustion) or using fuel cells to convert the stored chemical energy back as electricity. This hydrogen is also a critical chemical feedstock for fertiliser production, metal refining, food processing and oil refining amongst others. It is thus necessary to replace this existing hydrocarbon-based hydrogen feedstock with electrolytic hydrogen to enable reduction in carbon dioxide emissions associated with these technologies. The scales necessary to use hydrogen as energy carrier will be many folds higher than replacing the 90 million metric tonnes feedstock.[5]

Costs and scales: To reduce costs and to reduce strain on resources, electrolysers need to be extremely efficient at converting the captured renewable energy into hydrogen at hundreds of billion tonne scales. Additionally, the cost of electrolytic hydrogen needs to be competitive with the cost of traditional fossil fuels when used as the energy carrier and hydrogen derived from hydrocarbon as well when used as the chemical feedstock. Currently, electrolytic hydrogen (green hydrogen) is three to five times more expensive (per kg) than hydrocarbon derived hydrogen (grey hydrogen).[6] Consequently, the energy (kWh) from electrolytic hydrogen is also just as expensive (3-5 times) as the energy derived from fossil fuels. Although electrolysers have existed for decades, the scales necessary to meet Net Zero targets is currently thought to require proton exchange membrane water electrolysers which require the deployment of precious metals such as platinum and iridium-based materials.[7] There therefore exists a critical need to develop electrolyser technologies and components that either eliminate, or drastically reduce the usage of scarce precious metals reducing the cost of green hydrogen. One of the primary uses of these rare and expensive metals in electrolysers is as the active material (catalyst) that controls the efficiency of the underlying electrochemical processes.

Catalysis challenges: Catalysts are materials used in chemical processes to speed up and enable the underlying chemical reactions to proceed. There are electrolysers technologies, either commercialised or under development, that do not require platinum and iridium as catalysts. However, these technologies either cannot meet the scales necessary in the short and medium term or still need further optimisation to be commercially viable. For example, traditional alkaline electrolysers, alkaline exchange membrane electrolysers and solid oxide electrolysers operate using abundant iron, nickel and cobalt based catalysts. Alkaline electrolysers are commercially available at megawatt scales, but the need to purify and then compress hydrogen post-generation limit their suitability for the scales necessary for Net Zero. Alkaline exchange membrane and solid oxide electrolysers generate pure streams of hydrogen at elevated pressures, but various components (e.g. membranes) need further optimisation prior to scaled-up commercial deployment.[7] This renders proton exchange membrane electrolysers, which require platinum and iridium catalysts, as the leading option to meet the most immediate Net Zero goals using hydrogen as the energy carrier.[3] The technical challenge however remains, that we must design platinum and iridium catalysts that minimise their precious metal contents without compromising catalyst efficiency and durability, recycle and reuse them effectively and ultimately develop catalysts and technologies that do not require precious metals.

Outlook: Green hydrogen as both an energy carrier and a clean and sustainable chemical feedstock represents just one of the many technological transformations required to overcome the current climate crisis. Indeed, we will require multiple technologies across the energy and chemical sector to balance the effects of climate change. Similar to the hydrogen generation catalysts discussed above, at the heart of many chemical processes and technologies are the catalysts that are required to efficiently convert molecules such as water, carbon dioxide, and nitrogen into useful chemicals and materials. At the UK Catalysis Hub we uncover fundamental knowledge to understand how and why catalysts enable chemical reactions to proceed. Critically, we apply this knowledge to identify pathways to design advanced catalysts and technologies that can enable us to overcome these generational challenges reducing our dependence on fossil fuels.

References:

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