# Feedstocks and utilities for green hydrogen

**Stephen B Harrison**

**CEO for sbh4 Consulting**

## Introduction

For several years, attention has focused on green hydrogen as a clean energy vector. When produced on electrolysers using renewable electrical power generated by wind, solar, or hydro schemes, green hydrogen has a very low carbon footprint. Ammonia is derived from hydrogen through nitrogen reaction, sourced from air, in the Haber-Bosch process. Many of the largest green hydrogen schemes proposed worldwide will convert green hydrogen to green ammonia for cost-effective shipping to international markets. Conversion of hydrogen to ammonia adds cost at the production location but means that ammonia, rather than hydrogen, can be shipped to the end-user destination.

Liquid hydrocarbon fuels are incredibly useful energy vectors due to their high energy density and ease of handling. As such, gasoline, diesel, aviation kerosene, and heavy fuel oil have become the fuels of choice for cars, trucks, planes, and shipping. A key challenge of the energy transition is replacing conventional fuels with sustainable and cost-effective alternatives. Sustainable aviation fuel (SAF) is one such option, covering fuels derived from non-fossil sources. Currently, biofuels are the main SAF source and have already been used in hundreds of thousands of commercial flights worldwide. SAF can also be produced via power-to-liquid (PtL) pathways using renewable electricity to generate green hydrogen or syngas, with captured $CO_2$ providing the carbon needed to form hydrocarbon fuels.

E-methanol burns with almost no emissions of particulates or sulphur dioxide. Methanol, like diesel and heavy fuel oil, does produce CO2 emissions during combustion. However, since e-methanol is made from CO2 captured from stack emissions or the air, its use is carbon neutral.

Whether the fuel is green hydrogen, green ammonia, e-methanol, or SAF, certification to identify the CO2 intensity of the production process will be required as a guarantee of origin. In many markets, there are clear requirements emerging that the definitions of renewable fuels must move beyond simple ‘grey’ or ‘green’ labels to a more scientifically valid and environmentally robust classification system. Certification from an independent party to validate the product claims will inevitably be required.

Water, air, nitrogen, and CO2 are the fundamental feedstocks to the above reaction pathways. Water and nitrogen also play key roles as utilities to enable safe and efficient operations (see Figure 1).

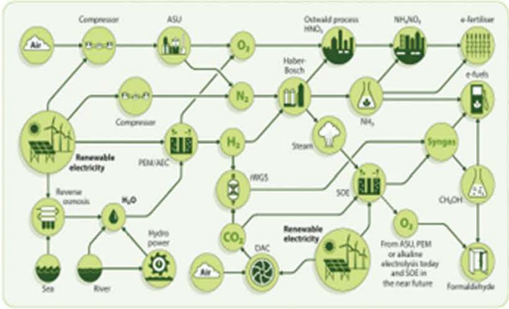

Figure 1: Air, water, and renewable electricity for integrated e-fuels, e-fertilisers, and e-chemicals production

## Crystal clear water: natural hydrogen carrier

Pure water supply to an electrolyser is essential. Electrolysis splits water molecules into oxygen and hydrogen. Supply of pure water to the electrolyser must be guaranteed. Failure to supply water means the electrolyser scheme must shut down. For a proton exchange membrane (PEM) system, that will probably not be a major issue, but for an alkaline system an unplanned shutdown may result in corrosion of the electrodes and a reduction in electrolysis efficiency during future operation (see Figure 2).

The capital and operating costs of pure water supply are low, but the costs of failure are high: reliability is key. Water supply for a typical green hydrogen scheme will generally be only 1 or 2% of the total operating cost. Impurities such as calcium ions in the water will rapidly damage a PEM electrolyser membrane due to the interaction with the catalyst coating. Alkaline electrolysers also have sensitivities to poisons in the water. The consequences of an impure water supply are unacceptable.

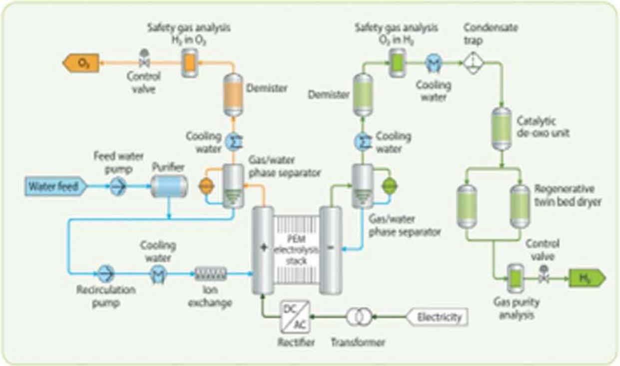

Figure 2 Pressurised PEM electrolysis process

The main quality parameter associated with the pure water supply to an electrolyser is conductivity. As a rule of thumb, a conductivity of less than 2 µS/cm (0.2 mS/m) should be the target. Ions, such as calcium or sodium, that are dissolved in the water will increase conductivity. So, measurement of this parameter will confirm that damaging dissolved salts are not present. Electrolyser manufacturers will provide a more detailed specification for the feed water, and most will provide the necessary deionisation equipment as part of a complete package.

## Purity standards for electrolyser feed water

Two internationally recognised standards refer to demineralised water purity for electrolysis. The US-based ASTM D1193-06(2018) Standard Specification for Reagent Water identifies three grades of purity. Many electrolyser producers will request supply of Type 2 water as a minimum purity. It has a maximum permissible conductivity of 1 µS/cm (0.1 mS/m).

ISO 3696:1987 is an alternative to the ASTM document. It is titled 'Specifications for Water for Analytical Laboratory Use'. As with the ASTM document, the ISO Standard also includes three grades of purity, and the typical feed for an electrolyser would be Grade 2 with a maximum conductivity of 0.1 mS/m. In addition to conductivity, the total organic content and total silica are important parameters for electrolysis feedwater.

Maximum concentrations of these impurities are also specified in the above standards. Other contaminants to be avoided include carbonate and sulphate ions, as well as silicon and aluminium oxides.

## Water desalination and purification

While hydropower offers easy access to fresh water for electrolysis, most renewable energy growth comes from wind and solar, often located offshore or in arid regions. As a result, water desalination and transport technologies, already used for potable water, will be essential to supply electrolysis projects. Inner Mongolia in China has vast solar and wind resources, with a 2025 green hydrogen. production target of 500,000 tonnes. However, in this land-locked location, seawater desalination is expensive and requires long pipelines. The most cost-effective option here is to drill deep for groundwater. For use with electrolysis for green hydrogen, the default technology for seawater desalination and brackish water purification is reverse osmosis.

This can be combined with some thermal heat from solar radiation to avoid the use of fossil fuels. When used with freshwater, the reverse osmosis plant will operate at around 15 bar to generate water of electrolyser feedstock purity. For seawater desalination, a higher operating pressure of around 80 bar is used. Water purification for electrolysis requires high-pressure pumping, but its power demand is relatively low about 1–2% of total system power for freshwater and up to 5% for seawater. Using solar-driven thermal desalination can further reduce this demand. Achieving ultra-low conductivity may require a polishing step such as electro-deionisation, while overall water treatment typically accounts for around 5% of total capital cost, compared to roughly 20% for power management systems.

## Cooling water and balance of plant power

Electrolysers are approximately 70% efficient when they convert power to hydrogen. The wasted power generates heat which is generally dissipated on a cooling tower. A typical cooling tower will need about 2% of the daily recirculated cooling water volume to be topped up due to evaporation losses (see Figure 3). The pumps that recirculate the cooling water, drive the cooling tower fans, and recirculate the electrolyte around alkaline electrolysers all consume power. However, the power demand for this balance of plant items is only 10% of the total electricity consumption for an electrolyser system.

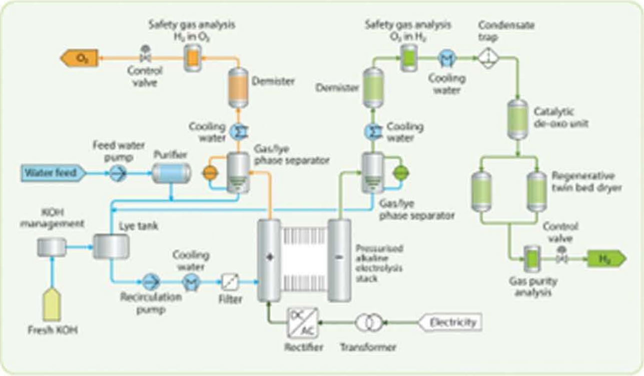

Figure 3 Pressurised alkaline electrolysis process

## CO2 feedstock purity for PtL and urea

A solid oxide electrolysis cell (SOEC), operating in co-electrolysis mode, consumes steam and CO2 to yield syngas, which can produce e-methanol or liquid hydrocarbons through established chemical pathways, such as methanol synthesis and Fischer-Tropsch conversion. Introduction of steam to the SOEC means that water molecules are delivered to the electrolyser in a highly energised state. Therefore, about 25% less electrical power is required to split them than when using low-temperature electrolysis, such as a PEM or alkaline electrolyser (see Figure 4). When e-fuels production is done in traditional refineries, waste heat or excess steam can often be fed to a SOEC. In stand-alone PtL processes for e-fuels production, exothermic reactions such as Fischer–Tropsch or methanol synthesis can provide the heat requirement of the SOEC. This integrated pathway results in high overall efficiency.

In co-electrolysis, both the steam and CO2 must comply with the purity specification required by the electrolyser. The requirement for CO2 feedstock purification varies depending on its source. CO2 captured from the combustion of fossil fuels can contain sulphur compounds that must be removed. The use of captured CO2 reduces the overall CO2 impact of SAF and introduces an element of circularity into the value chain.

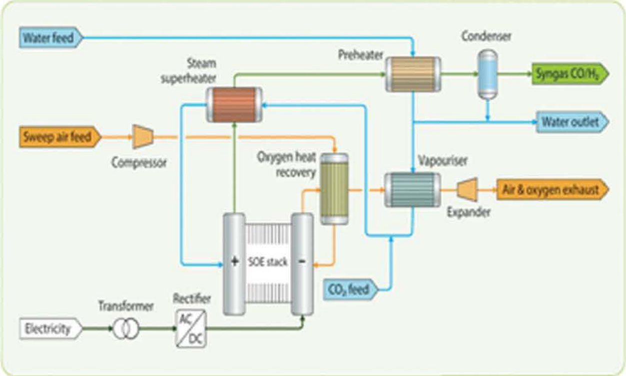

Figure 4: Solid oxide CO-electrolysis process for syngas generation

CO2 derived from direct air capture (DAC) is around three times more expensive than CO2 captured from stack emissions. However, it is generally free of any potentially harmful impurities, and the purification costs can be avoided. If waste heat is unavailable, hydrogen can be produced using an alkaline electrolyser and then reacted with captured $CO_2$ to form syngas via the reverse water gas shift reaction. Captured $CO_2$ is also a key feedstock for green urea production, enabling its circular use in creating carbon-neutral e-fuels, fertilisers, and chemical products.

## Nitrogen for safe electrolyser operations

The lower flammable limit (LFL) of hydrogen in pure oxygen at atmospheric pressure and 20°C is 4%. However, electrolysers generally operate at 80°C; at this temperature the LFL reduces to 3.8%. Pressurised alkaline and PEM electrolysers operate at between 15 and 30 bar. At 20 bar and 20°C, the LFL of hydrogen in oxygen increases to 5%. Both the operating pressure and temperature influence the flammability limit of hydrogen in pure oxygen (see Figure 5).

Electrolysis generates both hydrogen and oxygen, separated by membranes in PEM and AEM systems but coexisting in alkaline electrolysers.

Variations in renewable power can increase oxygen levels in hydrogen, activating nitrogen purge safety systems. At GW scale, frequent purging can justify on-site nitrogen generation using simplified cryogenic technology with lower energy demand and cost than full air separation units.

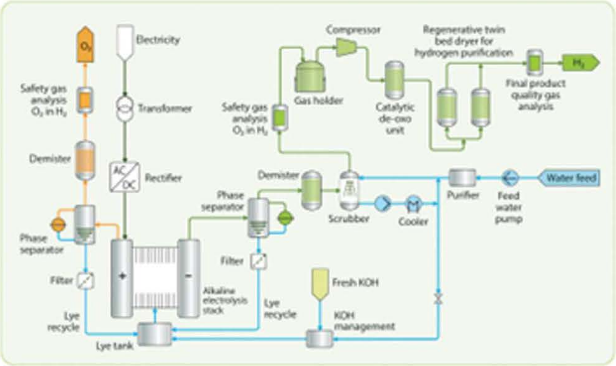

Figure 5: Low-pressure alkaline water electrolysis process

## Nitrogen feedstock for green ammonia

Ammonia is readily liquefied and, in this state, has a volumetric energy density 50% higher than liquid hydrogen. The reduced shipping costs of liquid ammonia, compared to liquid hydrogen, mean that Capex and Opex savings from shipping can be directed to the ammonia conversion facility. For long distances, such as the Australia to Europe route, liquid ammonia is the most cost-effective mode of green hydrogen transportation (see Figure 6).

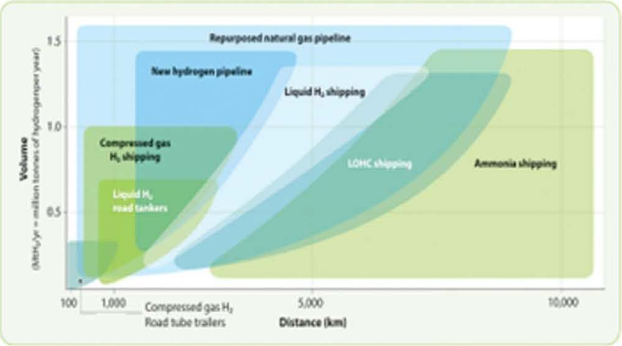

Figure 6: Hydrogen transport options when considering volume and distance

Ammonia is an attractive energy vector as a widely produced, globally traded commodity. Out of 185 million t/y of grey ammonia produced worldwide, 20 million t/y is traded internationally via mature shipping infrastructure. This established network makes green ammonia a promising, fungible energy carrier.

Grey ammonia prices depend on natural gas costs and global supply and demand dynamics. Although China has underutilised capacity, it remains landlocked, causing high utilisation of tradeable capacity. Consequently, price volatility and limited export availability strongly drive the development of new green ammonia plants.

Furthermore, using pure nitrogen instead of air in synthesis reduces energy losses, plant size, Capex, and Opex. With renewable electricity, on-site nitrogen generators provide a sustainable supply for future green ammonia production.

### Solid oxide electrolysis for Haber-Bosch process integration

Green electrons are highly valuable and result from significant infrastructure investment in wind and solar parks or hydro dams. Using them to produce green ammonia is essential to optimising project economics and reducing the cost of the energy transition. Using a solid oxide electrolyser or SOEC is highly efficient if hydrogen is to be converted to green ammonia (see Figure 7).

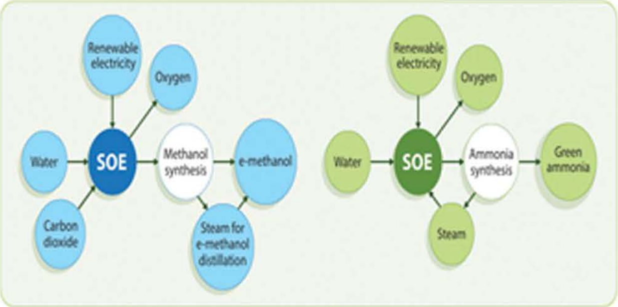

Figure 7: Solid oxide electrolysis for energy-efficient e-fuels production

Steam generated by the Haber-Bosch ammonia synthesis reactor can supply up to 70% of the steam required for solid oxide electrolysis. Methanol synthesis is also exothermic. However, the heat liberated by the reaction of syngas to form methanol is generally used to purify the methanol using distillation. Therefore, alkaline, PEM or SOEC electrolysis technologies can be equally efficient for methanol production.