HYDROGEN FOR THE ENERGY TRANSITION

For more information, please contact Dr Martin Lawrence, CEng, MIMechE, Combustion Development Specialist at Air Products PLC.
Mobile: +44 (0) 7887624893. Email: lawrenm1@airproducts.com. Or visit: https://www.airproducts.com/ applications/melting-non-ferrous

Climate change is being accelerated by greenhouse gas emissions. The UK is looking to become leaders in the Energy Transition from fossil fuels to using sustainable energy sources. Following the Climate Change Act, published in 2008 and a series of Carbon Budgets, the UK government are setting into law the world's most ambitious climate change target to map out how to cut emissions to net-zero by 2050. There are a number of potential routes towards net-zero carbon emissions, including electrification, biofuels, gasification, carbon capture, and hydrogen.

Some industrial processes are suitable for electrification, whereby fossil fuel powered furnaces and boilers can be replaced with equipment powered by green electricity. However, hard-to-abate industries and processes may have to switch to low carbon fuels, such as hydrogen. Carbon capture may be an alternative solution to fuel switching if the carbon dioxide (CO_2) can be stored or used effectively and economically. Hydrogen has been identified as one of the leading candidates for low carbon fuel switching to enable the transition towards net-zero carbon emissions in transport and heavy industry. This is due to its properties and its potential to become a clean alternative to fossil fuels, such as natural gas, oil, and coal. A transition from fossil fuels to low carbon hydrogen is likely to become the best route to net-zero for the aluminium industry, where electrification and carbon capture may not be possible or economical.

Hydrogen production

Hydrogen is the most abundant element in the universe, and it is used for a number of industrial processes, including petroleum refining, fertiliser production, and metal treatment. However, on Earth, it only occurs naturally as part of compounds, such as water and organic molecules. Therefore, in order to produce pure hydrogen, the hydrogen must be extracted from these compounds and this needs to be done in an efficient and environmentally friendly way for the hydrogen to be considered low carbon. Most industrial hydrogen is considered grey hydrogen as it is produced from the steam reformation of methane and its production has similar CO_2 emissions to the combustion of coal.

Zero and low-carbon hydrogen can be produced from electrolysis using renewable energy (green hydrogen) or by applying carbon capture to steam methane reforming plants to reduce the amount of CO_2 emitted into the atmosphere (blue hydrogen). There are a number of certification and "guarantee of origin" schemes for low-carbon and/or renewable hydrogen. These include or derive from CertifHy, TÜV SÜD, and the Renewable Transport Fuel Obligation and define varying thresholds for hydrogen to be considered low carbon and/or renewable. Carbon intensity thresholds are generally calculated as a percentage of CO_2 emissions saving based on a fossil fuel equivalent benchmark, type and age of the hydrogen production facility, and use of hydrogen. The threshold is typically between 33 - 38 gCO_2e/MJ_{LHV} of hydrogen produced by steam reformation of methane (blue hydrogen) and can be below 30 $gCO2e/MJ_{LHV}$ for electrolysis (green hydrogen). It is expected that the thresholds will become more stringent as we approach key net-zero milestones. Figure 1 shows a comparison of different types of hydrogen, with respect to CO2 emissions and shows examples of best available technology (BAT) benchmarks, with low carbon thresholds from CertifHy and RTFC UK.

Hydrogen supply chain

Hydrogen is an industrial gas that has been supplied to industries around the world for many years and as such there are several solutions when considering the supply of hydrogen. Air Products offers liquid hydrogen and compressed hydrogen gas in a variety of purities and various modes of supply around the world, with an extensive network of pipelines, hydrogen manufacturing plants and transfill facilities. Hydrogen can be generated at a large plant and supplied via pipeline locally to the end use point. Large plants can be designed to include a liquefier, which can produce liquid hydrogen for remote supply. This can be decanted into transportable tankers and delivered by truck or train and then used to fill cryogenic storage tanks, located on the site of the end user. It is also possible to provide high pressure gaseous hydrogen via tube trailer to a remote location in a similar manner. Figure 2 *(overleaf)* shows a photograph of a liquid hydrogen tanker for hydrogen deliveries. Gaseous or liquid bulk deliveries are great for supplying processes that are not local to a large plant and can be suitable for varied hydrogen usage. Hydrogen can also be transported and stored safely as ammonia, which can be liquified under milder conditions and therefore it can be stored in inexpensive pressure vessels, rather than cryogenic containers. Furthermore, liquid ammonia contains about 1.7 times more hydrogen by weight than liquid hydrogen; liquid hydrogen contains 71 kg-H_2/m^3 and liquid ammonia contains 120 kg-H_2/m^3.

On-site generation is another option for remote processes that require a consistent supply of hydrogen, whereby

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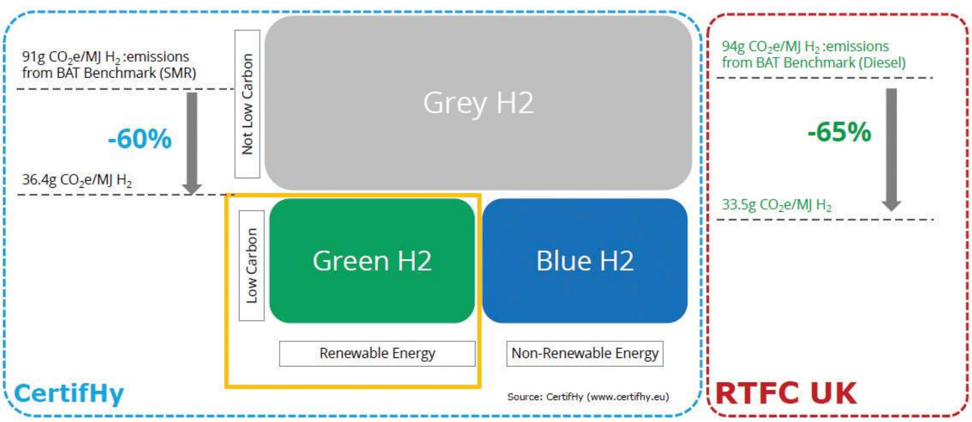

Figure 1. Different types of hydrogen and CO2 emissions thresholds from CertifHy and RTFC UK.

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Figure 2. Air Products liquid hydrogen tanker for hydrogen bulk deliveries.

a relatively small hydrogen plant can be installed on the site of the end user to produce hydrogen to be directly used in the process. The hydrogen generator can be either an electrolyser or a small methane reformer that can be designed to output the amount of hydrogen required for the process. On-site generators are better suited for continuous processes that require a steady amount of hydrogen during operation. For an on-site generator to be certified as low carbon hydrogen, the end user would be required to purchase either renewable energy or natural gas. End users in the aluminium industry that are not located in the vicinity of a large plant could consider bulk deliveries or on-site generation, depending on their particular circumstances.

Creating a low-carbon hydrogen infrastructure

The scale of change required for switching from fossil fuels to low carbon alternatives is of the same order of magnitude as that of previous industrial revolutions. It follows that a hydrogen economy will drive innovation and ideals, leading to new legislation and working practices. The creation of a hydrogen infrastructure will allow the market to begin to form and grow.

There are a number of potential hydrogen clusters currently in consideration for the UK, including HyNet and Humber Zero, which would produce low carbon hydrogen to be introduced into the UK natural gas grid for those areas. These projects will introduce low carbon hydrogen into the market. The supply of renewable and low-carbon hydrogen at large scale is at an early stage of development; production and distribution – by pipeline and road - will require substantial investment by the private sector and take a number of years, with substantial support from the UK government. It is likely that UK hydrogen production will be complemented by imports from parts of the world well-served with renewable energy resources.

Hydrogen for mobility

Air Products provides hydrogen fuelling solutions for a variety of markets and has more than 60 years' experience in hydrogen production, handling, and distribution. Air Products deployed their first hydrogen fuelling station in 1993 and have developed an extensive patent portfolio related to hydrogen supply and dispensing technology based on performing millions of safe fills. Significant advances have been, and continue to be, made in the use of hydrogen, both as a transportation fuel and a fuel for power generation. With more than 60 years of hydrogen experience, Air Products is at the forefront of hydrogen energy technology development. With a multi-billion dollar investment, Air Products have partnered with NEOM and ACWA Power to build the world's largest green hydrogen plant in Saudi Arabia, which will be on stream in a few years' time. The joint venture project will produce 650 tons per day of hydrogen from wind and solar energy, which will be transported in the form of 1.2 million tons per year of renewable ammonia. The renewable hydrogen will be used to power buses and trucks around the world, eliminating 3 million tons per year of CO_2 emissions, equivalent to the emissions from over 700,000 cars.

Hydrogen for combustion

Hydrogen is being considered as a replacement for today's fossil fuels because it is abundant, efficient, and unlike other alternatives, it offers the potential to be renewable and it produces no CO_2 emissions when combusted. It can be utilised as the energy carrier for generating electrical power with hydrogen fuel cells and for hydrogen combustion.

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Figure 3. Air Products' long standing blue hydrogen facility in Port Arthur, Texas.`

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A wide range of industrial applications currently use natural gas and can be considered for switching to using hydrogen to achieve their net-zero carbon emissions targets. The calorific value of hydrogen is about 12.7 MJ/m3 and the average calorific value of natural gas in the UK is about 39 MJ/m^3, which means that approximately three times the volumetric flow rate of hydrogen is required to produce the same energy as natural gas. This is important when considering retrofit applications to switch from natural gas to hydrogen, as the burners and pipework must be sized appropriately to allow the increased volumetric flow rate of fuel.

As the concentration of hydrogen in the fuel is increased, the composition of the furnace atmosphere changes; increasing the water content and the potential for free hydrogen molecules to escape the flame and come into contact with the charge material inside the furnace. Therefore, it is necessary to understand how these changes in furnace atmosphere could impact on the final product. For some secondary aluminium melting operations, hydrogen absorption can be a challenge, whereby hydrogen can be absorbed by the aluminium, creating porosity in the final product and potentially causing defects. Pilot studies and the implementation of hydrogen combustion systems onto early-adopter production furnaces are essential to provide an understanding of how to operate the process to minimise any potential risks. Furthermore, the effects on the furnace and downstream equipment, such as the baghouse, must also be understood.

Air Products has more than 50 years' experience in combustion technology and industrial furnace applications and has world-class research and development facilities that have produced best in class technology for the secondary aluminium industry. Combining a history of proven technology with decades of operational know-how and experience across the range of metals production operations, allows Air Products to work with customers to effectively understand and overcome challenges, bringing improvements in efficiency, productivity, and yield. With a change in focus from the industry towards reducing CO_2 emissions, Air Products have developed burner technology capable of using hydrogen as a fuel, either blended with natural gas or as 100% hydrogen. An example of a hydrogen burner operating at varying amounts of hydrogen blended into natural gas can be seen in Figure 4. The technologies are currently being deployed on a number of trial projects to demonstrate how hydrogen can be used in heavy industry and the learnings from these studies can address the above potential issues and give end users confidence to switch to hydrogen.

Traditionally, oxygen enhanced combustion has been used throughout heavy industry to provide increased combustion efficiency to reduce fuel usage and increase productivity. When comparing air-fuel combustion (20.9% oxygen) to oxy-fuel combustion (100% oxygen), the removal of nitrogen from the process allows the fuel and oxygen to react much faster, creating a significantly hotter flame, in the region of 1000°C. Furthermore, there is no energy wasted heating nitrogen, which would otherwise be exhausted, unnecessarily removing heat from the furnace. This results in a significant reduction in fuel consumption of up to 40%, when compared with air-fuel combustion, which can be directly translated as up to 40% CO_2 reduction. When considering the relatively high cost of hydrogen compared with natural gas, oxy-hydrogen combustion systems can be implemented during the energy transition to reduce the overall cost of switching to hydrogen by reducing the amount of fuel required.

The increased combustion efficiency can also provide a significant increase in productivity when compared with air-fuel combustion systems. The significant increase in flame temperature of oxy-fuel flames can increase the melt rate by up to 100%. This is particularly interesting when considering using an on-site electrolyser to generate hydrogen, as the oxygen 'waste' stream can be used in the combustion process. electricity produced by renewable energy sources is used to power the electrolyser, then low-carbon oxy-hydrogen combustion can be used to eliminate CO2 emissions, whilst also providing significant fuel savings and increased productivity.

Conclusion

Hydrogen will play a pivotal role in generating a cleaner future for heavy industrial processes, such as the secondary aluminium industry. Hydrogen has been used as an industrial gas for decades and Air Products has more than 60 years' experience in producing, distributing, and handling hydrogen. There are also commercially available technologies to facilitate the use of hydrogen for the heating and energy applications to support the transition to a low-carbon economy.

Research and development work is ongoing, and further work needs to be done to prepare industry for using hydrogen, in terms of how it may affect processes, equipment, and final product quality. Governments around the world are already releasing funding calls for industry preparation projects and this will likely continue as we progress towards 2050. Low carbon hydrogen infrastructure needs to be put in place for hydrogen for the energy transition and this has already begun with a number of ground-breaking projects. By working together, we can decarbonise the hard-to-abate sectors.

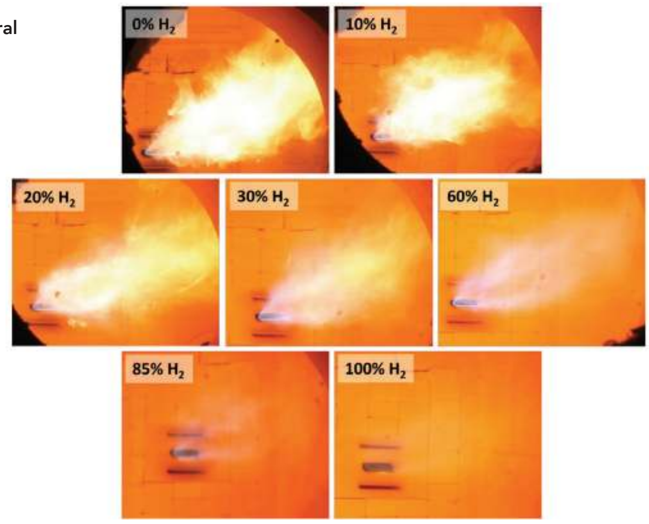

Figure 4. Hydrogen blended with oxy-natural gas flames from 0% H_2 (100% natural gas) to 100% H_2 (0% natural gas).