Low Carbon-Intensity Hydrogen Production Pathways, Distribution, and Use in Secondary Aluminum Melting

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Greenhouse gas (GHG) levels have been rising over the past 150 years as the world becomes ever more industrialized.[1] Climate change, which is attributed to increasing levels of GHGs in the earth's atmosphere, can have a significant impact on humans and wildlife due to changes in the earth's surface temperature, ocean temperature, precipitation, and sea level.[2] Most of these GHG emissions are anthropogenic carbon dioxide (CO_2) emissions from the burning of fossil fuels for heat, electricity, and transportation.[3] For the sustainability of the planet, it is essential that humanity embrace the energy transition and identify ways to reduce reliance on fossil fuels by turning to cleaner and low- or zero-carbon alternative energy sources, such as hydrogen.

To achieve the significant reduction in GHG emissions needed to mitigate climate change, multiple solutions will be required to replace fossil fuels. Electrification with renewable power will have a key role to play, particularly for things that are easy to electrify like passenger cars and home cooking/heating; however, in hard to abate sectors, such as long-distance road transport and heavy industry, electrification will not be feasible, or in some cases, possible. In these cases, hydrogen is the best solution. Hydrogen is a versatile energy carrier that could contribute to 20% of the needed global emissions reduction.[4]

Hydrogen Production

Hydrogen has been produced at large scale for decades, particularly for refineries that use it in several processes, including hydrodesulfurization units to meet low sulfur fuel standards. Hydrogen is produced using a process called steam methane reforming (SMR), where natural gas is combined with steam to convert it into syngas (a combination of hydrogen and carbon monoxide). This stream is further processed in a water gas shift (WGS) reactor to convert excess steam and carbon monoxide into additional hydrogen and CO_2. Excess heat is recovered from this stream for use elsewhere in the process before the cooled stream is sent to the final purification step, typically a pressure swing adsorption (PSA) unit. Any remaining methane, carbon monoxide, CO_2, nitrogen, and water vapor are removed in the PSA and used as fuel in the SMR furnace. Hydrogen from the PSA is typically delivered at high purity (up to 99.999+%).

Although hydrogen is readily available today, the hydrogen produced via the SMR process has a relatively high carbon intensity (kg $CO_2e/MJ\ H_2$). This is because all the carbon entering the process as natural gas is usually emitted to the atmosphere as CO_2. Hydrogen produced using this process is referred to as "gray" hydrogen (Figure 1). To successfully reduce GHG emissions via hydrogen, it is important that the hydrogen itself has low carbon intensity. There are two primary paths for doing this, which are commonly referred to as "blue" hydrogen and "green" hydrogen. Blue hydrogen is made from fossil fuels, such as natural gas, but most of the CO_2 from the process is captured, sequestered, or utilized. Air Products has already been successfully capturing approximately one million tons per year of CO_2 for over a decade from two SMRs in Texas. Green hydrogen is produced from water electrolysis that is powered by renewable energy. The process itself inherently has no GHG emissions.

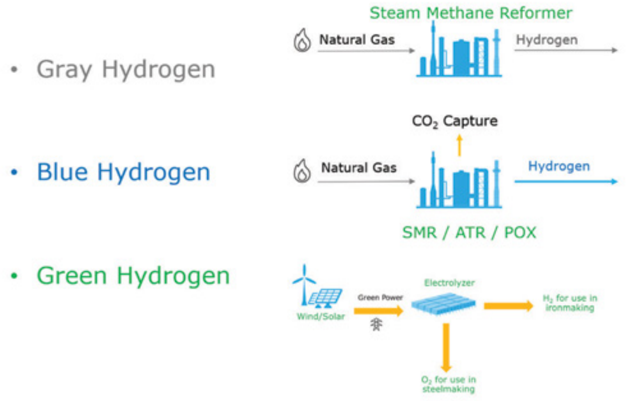

Figure 1. Gray, blue, and green hydrogen production processes.

There are many large-scale blue and green hydrogen projects that have been announced around the world. Air Products has initiated two blue hydrogen projects in Edmonton, Alberta, Canada and in Louisiana. The Edmonton project (Figure 2) is a net-zero hydrogen energy complex designed to use natural gas and oxygen (from an ASU) to produce syngas in an autothermal reformer (ATR). More than 90% of the CO_2 produced in this process is captured and sequestered. A portion of the hydrogen that is produced is used to make power for use by the facility in a gas turbine and for export, which achieves the net-zero facility designation. The remainder of the hydrogen is for delivery to customers as gaseous hydrogen via pipeline or liquid hydrogen via tanker trucks.

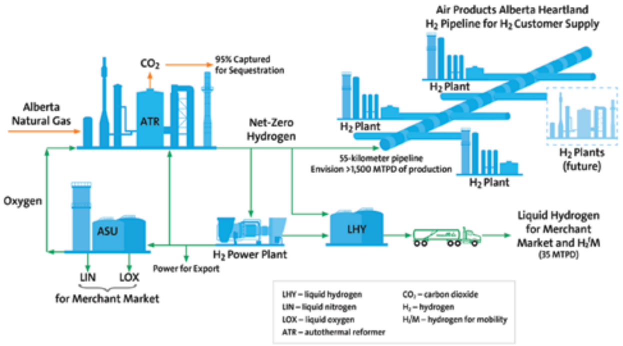

Figure 2. Net-zero hydrogen energy complex in Edmonton, Alberta, Canada.

The Louisiana clean energy complex (Figure 3) will produce more than 1,800 tonnes/day (>750 million SCFD) of blue hydrogen from natural gas and oxygen using the partial oxidation process (POX). The CO_2 that is generated in this process will be permanently sequestered in a dedicated underground pore space leased from the State of Louisiana. A portion of the hydrogen that is produced will be used to make blue ammonia and the remainder will be injected into Air Products' existing 700-mile hydrogen

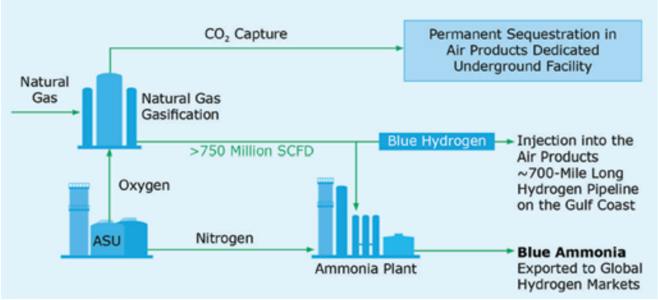

Figure 3. Blue hydrogen clean energy facility in Louisiana.

pipeline on the U.S. Gulf Coast, currently the world's largest such pipeline.

Several near-term green hydrogen projects have also been initiated by Air Products in the U.S., including in New York, Texas, and Arizona. However, the world's largest green hydrogen plant (Figure 4) is being built as part of the NEOM project in Saudi Arabia by the NEOM Green Hydrogen Company (NGHC), an equal joint venture of ACWA Power, Air Products, and NEOM. This is a multibillion-dollar project that will integrate up to 4 GW of solar and wind power to produce up to 600 tonnes/day of carbon-free hydrogen in the form of green ammonia. Air Products is the exclusive offtaker of the green ammonia, which will be shipped globally and converted back to hydrogen for use in the transportation and industrial sectors.

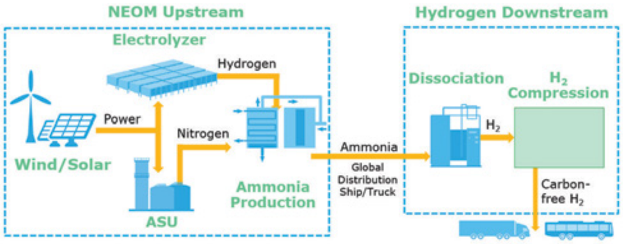

Figure 4. World's largest green hydrogen production complex as part of the NEOM project in Saudi Arabia.

Once hydrogen is produced through one of the means described, it can be supplied to industrial processes in several ways, depending on the volume required by the process and the distance to the hydrogen production site. Small quantities of hydrogen (<0.25 tonnes/day) are typically supplied as a compressed gas in cylinders or tube trailers. Moderate quantities of hydrogen (up to ~10 tonnes/day) can be shipped as liquid hydrogen or can be produced locally by a small on-site generator. Large quantities of hydrogen (>10 tonnes/day) can be supplied via pipeline or from a large on-site dedicated plant.

Hydrogen in Secondary Aluminum Melting

CO_2 is a major source of GHG emissions from secondary melting furnace operations. Combustion of hydrocarbon fuels generates CO_2. Therefore, the most direct way to reduce CO_2 emissions is to reduce the amount of fuel used per ton of material processed. The use of oxy-fuel combustion helps to improve the thermal efficiency of the process as compared to cold air-fuel combustion systems.[5] Improved thermal efficiency can help reduce fuel usage per ton of material processed and, therefore, CO_2 emissions by as much as 40%. The use of oxy-fuel, in addition to next-generation smart burners can, thus, help achieve partial decarbonization goals.

To further reduce CO_2 emissions, manufacturers can switch the fuel type from hydrocarbon fuels to biofuels or alternative fuels like hydrogen (H_2) or ammonia (NH_3).[6] The combustion of H_2 or NH_3 will not produce any CO_2. However, it is important to consider the carbon intensity of the production pathways of the fuels themselves, as described previously.

Smart oxy-fuel burners are fuel-flexible and can operate safely with natural gas, hydrogen, or mixtures of hydrogen and natural gas.[7] Figure 5 shows the operation of the Air Products' Transient Heating smart oxy-fuel burner using natural gas and hydrogen as a fuel in a combustion laboratory test furnace at 5 MMBtu/hr. The field results show that the fuel usage per ton of material processed with oxy-fuel burners can be reduced by as much as 45%.[8] This reduced fuel usage can provide an added economical advantage as compared to air-fuel systems, while low-carbon intensity hydrogen infrastructure continues to expand and become more cost effective (as compared to natural gas). How the use of hydrogen can impact melt quality and refractory remains an open question, and long-term field studies are being carried out to address it.

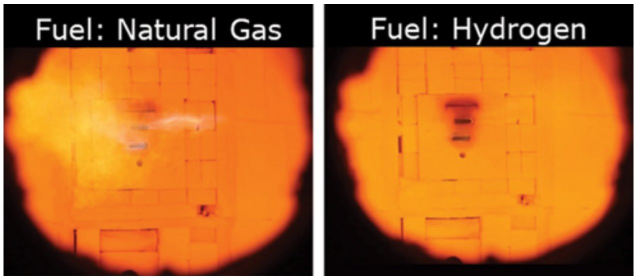

Figure 5. Transient Heating smart oxy-fuel burner operation using natural gas and hydrogen as a fuel at 5 MMBtu/h at the Combustion Test Laboratory.

Hydrogen Safety Considerations

Hydrogen is considered an important molecule to drive the energy transition and decarbonization of the global industrial sector. While hydrogen has primarily been used in industries like refining, ammonia production, etc., it is now developing in short-term trials in the aluminum industry. Due to the specific chemical and physical properties of hydrogen and because it is a relatively new molecule for the aluminum industry, it is important to address safety considerations for use of hydrogen.

The production, supply, and distribution of hydrogen can be achieved in a safe manner. Gas manufacturing companies have been producing and supplying hydrogen in large quantities for several decades. Hydrogen is a lighter molecule with low viscosity and a wider flammability limit than natural gas. These properties of hydrogen necessitate the consideration of specific design features to address three critical challenges.

First, hydrogen gas has a very low viscosity, so special attention must be paid to prevent leaks from developing in hydrogen systems. Valves and fittings must be designed specifically for operation using hydrogen.

Second, hydrogen can cause hydrogen-assisted cracking or hydrogen-induced cracking (HIC). High-quality stainless steels are used to address this issue. Hydrogen supply systems, which include piping and distribution skid systems, from the storage tank or onsite hydrogen generation to the burners are designed for the pressures and temperatures of interest by following appropriate industry codes. The National Fire Protection Association (NFPA) has several standards that are followed in hydrogen application design and operation. These codes include NFPA 2, NFPA 55, NFPA 68, and NFPA 69. In addition, the Compressed Gas Association (CGA), the Asia Industrial Gases Association (AIGA), the European Industrial Gases Association (EIGA), and the Japan Industrial and Medical Gases Association (JIMGA) have numerous standards related to hydrogen.

Third, hydrogen has wider flammability limits as compared to natural gas. Burner systems are designed to work with hydrogen and produce stable flames.

Industrial gas companies take these parameters into consideration when developing and manufacturing their products. They actively work to develop safety best practices to ensure that hydrogen is produced and delivered safely and reliably.

Conclusion

The use of low-carbon intensity hydrogen as a fuel provides a viable path for the decarbonization of secondary melting furnaces. Three main considerations for the use of hydrogen in an industrial application are the production of low-carbon intensity hydrogen, the distribution channel to bring hydrogen onsite, and the supply of hydrogen from onsite storage or production to the burner system using appropriate skids and piping. All three of these activities are currently executed safely in many applications and can be implemented to enable the use of hydrogen in an aluminum plant.

Currently, hydrogen is primarily produced by the SMR process; however, several large-scale blue and green hydrogen projects that can supply low-carbon intensity hydrogen are being executed. The technology required to distribute hydrogen is well established. Finally, smart fuel-flexible oxy-fuel burner technology is already available that can provide partial or full transition of fuel from natural gas to hydrogen. The use of oxy-hydrogen burner systems vs. cold hydrogen-air systems can provide an added advantage to reduce the fuel usage per ton of material processed and thereby, provide economic benefit by using less fuel (in particular, low-carbon intensity hydrogen).

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