Hydrogen on tap: Supporting decarbonization by pipelining H_2 to the point of use

O. PURRUCKER, Linde Engineering, Pullach, Germany and **J. BALSTER,** Evonik Fibres, Schörfling, Austria

H_2 is set to play an increasingly important role in the world's energy mix. As an industry feedstock, a source of heat and power or a transportation fuel, H_2 has the potential to gradually decarbonize large sectors of industry. As an energy vector, it is increasingly being heralded as a way to unlock the potential of renewable energy.

The appeal of H_2 is being fueled not only by the promise of "clean energy" during the transition to a more sustainable energy economy. What makes this gas so compelling is its flexibility. The multitude of H_2 production technologies has the potential to support more rapid scale-up and market development, as this variability can accommodate regional differences in energy resources like natural gas, coal or wind and solar power. Therefore, H_2 supports everything from conventional (gray) production methods, through evolving lower-carbon (blue) models leveraging carbon capture and storage (CCS) technologies, to low-/no-emissions (green) options based on the electrolysis of water powered by renewable energy.

Moving toward lower-carbon pathways. Today, most H_2 is still produced by reforming natural gas and water (steam methane reforming). This accounts for about 42%[1] of all H_2 produced.

A similar share (around 41%[1]) is attributable to byproducts or coproducts of chemical processes. In fact, the chemical industry goes on to use this H_2 in many other production processes. Around 16%[1] is made from the gasification or partial oxidation (POX) of coal. The remaining 1%[1] is attributable to renewable or low-carbon sources of energy, such as electrolysis of water and biomass gasification. This share is set to rise dramatically.

In the transition from gray through blue and toward green H_2, the energy economy needs gas generation and processing companies that are capable of supporting the full production spectrum. These companies must be able to produce and recover H_2 from a vast variety of feedstocks such as natural gas, liquid petroleum gas (LPG) and naphtha. Drawing on CCS technologies, they can then convert this gray H_2 into blue H_2.

Recovering H_2 from a broad selection of H_2-rich offgases from refineries, ethylene plants or chlorine alkaline electrolysis facilities, these companies should also be able to tap into new H_2 sources that were previously utilized mainly for heat generation. In addition, such companies should offer green H_2, made by electrolyzing water using electricity from solar or wind power. This diversity of choice is essential for the widespread adoption of low-carbon H_2.

Getting H_2 to the point of use. Looking beyond the growing diversity of production methods, H_2 storage and transport are equally important for cost viability and availability at the point of consumption. Bulk trailer and cylinder deliveries are already well established. As demand rises, however, more efficient high-volume solutions will be required to deliver H_2 safely and quickly to different end users.

A dedicated H_2 pipeline or delivery infrastructure would be ideal. To date, however, the market has been deterred by the high costs that would be involved in building such a pipeline from scratch. So far, very few pure H_2 pipelines have been realized globally. Here, also, the answer lies in flexibility. The existing natural gas infrastructure—disused pipelines, in particular—could be repurposed to carry H_2. This effort, complemented by newbuilds, could provide an innovative answer to the need for a high-volume pipeline distribution infrastructure for H_2.

Blending H_2 with natural gas. With this delivery scheme, H_2 would be simply injected into the existing natural gas pipeline, typically at concentrations between 5% and 30%, and delivered to a wide range of endpoint applications. The idea is not new, but it was previously hampered by the difficulty involved in separating H_2 from natural gas at the point of use. Now that challenge has also been resolved. The separation and purification technologies required downstream to extract H_2 from the pipeline or natural gas blend are available and mature.

This solution to separate and extract the H_2 was developed collaboratively by the authors' companies. The fully integrated system combines pressure swing adsorption (PSA) technologies with a custom-designed gas separation membrane technology.

How do gas separation membranes work? Essentially, gas separation membranes consist of asymmetric hollow fibers made of polyimide with a nanometer-scale selective layer on the fiber outer shell (FIG. 1). Polyimide is known for its excellent chemical and mechanical properties, making it an ideal material for membrane-based gas separation. When the H_2/natural gas blend is applied to the membrane from the outside, the small H_2 molecule permeates quickly through the wall of the membrane to the pressure-less side. By contrast, methane (the major component of natural gas) is a large molecule, so it stays outside the membrane and is retained on the high-pressure side.

For H_2 separation applications, the fibers are coiled in a cross-counter winding pattern, forming a structured packing

FIG. 1. Bundle of polyimide hollow fibers that will be woven into a membrane cartridge and packaged.

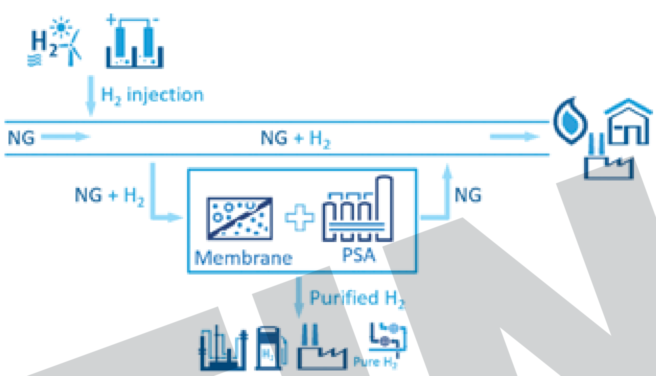

FIG. 2. Ready-to-run solution for efficient extraction of H_2 from a natural gas pipeline blend.

for optimal flow distribution. Furthermore, the hollow fiber design allows for robust operation under high pressures and harsh pressure fluctuations. This makes these modules more forgiving of pressure shocks and reversal of transmembrane pressure than conventional flat-sheet modules.

One key advantage of this membrane technology is its efficiency. The pressure inherent in the natural gas blend is sufficient to separate the H_2 from the natural gas. No electricity or additional resources, such as chemicals or water, are required.

How does PSA work? PSA technology takes advantage of the fact that different gas molecules attach with different strengths to the inner surface of porous solid materials, known as adsorbents. In this case, methane attaches to the small adsorbent particles, and the H_2 remains more or less in the free volume around this solid. The H_2 is then extracted as a pure gas stream from the top of the vessel.

At some point, the various adsorbents are saturated with methane and other components of the natural gas, and the process is halted. The vessel on the bottom is opened, relieving the pressure and withdrawing the adsorbed species from the bottom of this vessel. The system then switches to the next pressurized vessel with the regenerated adsorbent, and the process begins again.

Membranes and PSA in a hybrid system. The hybrid solution for H_2 extraction is designed with one or more membrane stages and one PSA step to maximize H_2 recovery rates. The feed gas is evenly distributed to the available fiber surface to maximize capacity and selectivity. Once the H_2 concentration exceeds 30%, this enriched stream is sent to a PSA, where this gas is further purified and the concentration is increased up to 99.9999%.

This technology is mature and market-ready. The first real-scale demo showcase is already under construction at Linde's Dormagen plant near Düsseldorf in Germany, due to go onstream in 2021, and the first-reference customer is already up and running.

More than a pipe dream. The first projects to advance the H_2 pipeline network are already underway. For example, in Europe, 11 transmission system operators (TSOs) launched a plan to collectively create the European Hydrogen Backbone (EHB). The aim is to build and expand a functional H_2 network in Europe. The group, which has expanded to include 23 TSOs from 21 countries, published an updated report in 2021[2] outlining a more ambitious H_2 pipeline network plan.

According to the EHB, the H_2 infrastructure could grow to become a pan-European network, with a length of 39,700 km by 2040, encompassing 69% repurposed natural gas pipelines and 31% newbuild H_2 pipelines. Further network development would be expected after 2040.

As movement is made toward these ambitious targets, a transitional phase with interim solutions can be expected over the next few decades. At this early stage in the H_2 journey, it is highly unlikely that any country or region will be able to produce sufficient H_2 from renewable sources to fill entire pipelines—especially considering that typical international transmission pipelines have a capacity in excess of 1 MM Nm^3/hr. Blending H_2 into natural gas will be the technology of choice in enabling a smooth transition toward a "greener" future. Over time, it is expected that the share of H_2 in these blends will increase.

As these figures illustrate, blending coupled with appropriate extraction and purification technologies adds to the flexibility of H_2. It could be economically viable to blend conventional or low-carbon H_2 into existing natural gas infrastructure at concentrations of 5% to 30%, and unused lines can be repurposed to carry pure H_2.

Looking ahead. It can be said that H_2 has the flexibility and potential to speed the transition to a low- or zero-carbon economy and, on the way there, to help decarbonize hard-to-abate sectors like iron and steel, chemicals, oil refining and heavy transport (e.g., trucks, ships, trains and aircraft).

Companies that cover every step in the value chain can contribute to the accelerated adoption of H_2. This starts with diverse production methods and extends through state-of-the-art gas conditioning and purification technologies. The value chain also encompasses secure storage capabilities including high-volume caverns and flexible delivery models such as cylinders and bulk supplies. Now, leveraging innovative point-of-use extraction and recovery technologies, innovative companies are bringing greater flexibility and scale to the delivery space by paving the way for "H_2 on tap." H2T

NOTES

[a] Commercialized by Linde and Evonik under the name HISELECT® powered by Evonik.

LITERATURE CITED

Complete literature cited available online at www.H2-Tech.com.

ONLINE ONLY

LITERATURE CITED

1. International Energy Agency, "The future of hydrogen," June 2019.
2. Gas for Climate, "Extending the European Hydrogen Backbone: A European hydrogen infrastructure vision covering 21 countries," April 2021, online: https://gasforclimate2050.eu/wp-content/uploads/2021/06/European-Hydrogen-Backbone_April-2021_V3.pdf

OLIVER PURRUCKER heads the business development and sales department of the Adsorption and Membrane Plants product line, part of the engineering business of Linde. This business area plays a significant role in the H_2 value chain by providing solutions for extraction and purification of H_2 from various gas streams like synthesis gases and offgases. Furthermore, it provides sound solutions for carbon capture from manifold sources. Since joining Linde in 2007, Dr. Purrucker has held various positions in sales, business development and innovation management.

JÖRG BALSTER initially worked as a Researcher at the European Membrane Institute, after studying chemical process engineering at the University of Applied Sciences Münster and earning a PhD in the field of membrane electrodialysis at the University of Twente in the Netherlands in 2006. In 2007, he moved to Parker Hannifin in the Netherlands as R&D Leader for gas separation membranes. In 2010, Dr. Balster became Manager of the membrane technology group in Evonik's process engineering department. In 2012, he moved to Schörfling, Austria, where he was responsible for managing the global application technology for all SEPURAN gas separation products. Since 2016, Dr. Balster has been responsible for the market launch of further developed SEPURAN products for the helium, hydrogen, oxygen and nitrogen markets.