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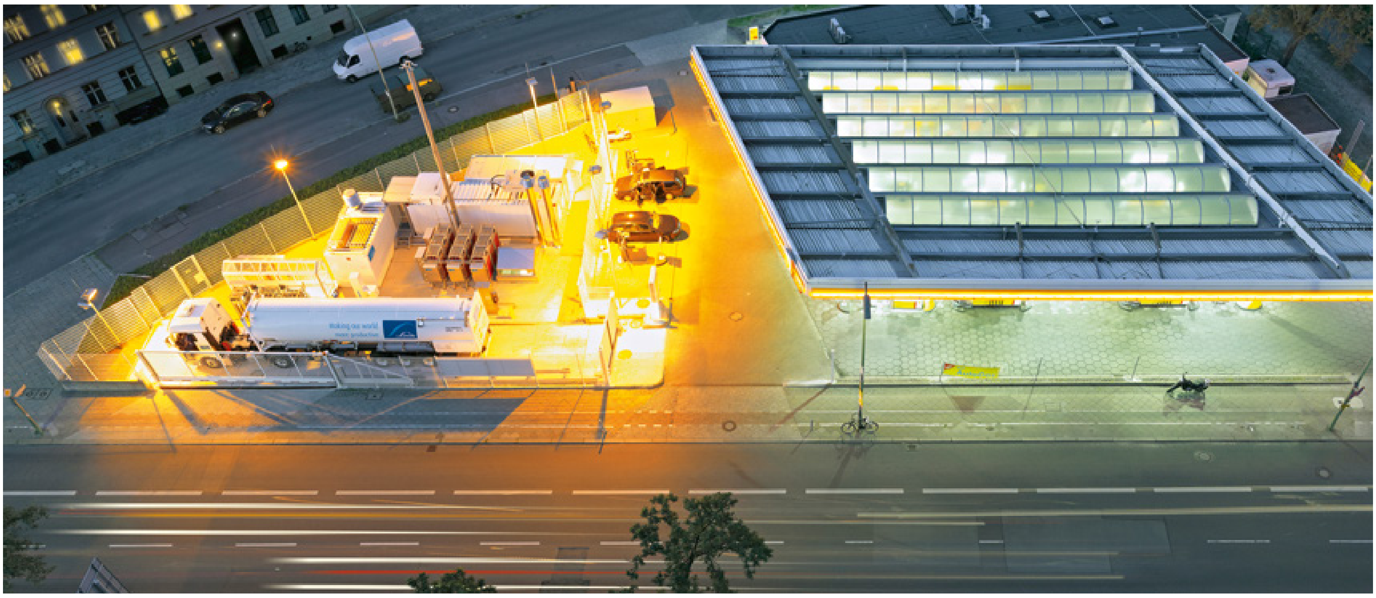
Energy transition and the power of hydrogen to achieve net zero

A white paper in conjunction with

Linde



Introduction

Few energy topics are as hyped today as the potential for 'clean' hydrogen—hydrogen produced with low or no carbon emissions—to contribute to global climate goals. Barely a day goes by without a new statement from a government or industry regarding progress towards a hydrogen economy. However, the reality at present is that clean hydrogen, whether 'blue' (produced by steam methane reforming with carbon capture and storage or CCS) or 'green' (produced with renewable energy via electrolysis), is still rare and expensive.

Given the wide range of potential applications—from heating to energy storage—that clean hydrogen could potentially address, it is reasonable to ask whether the gas really can live up to expectations or if it will remain a side note in the race to a low-carbon future. This paper, produced in association with the leading industrial gases and engineering company Linde, aims to provide an overview of hydrogen's likely role as an enabler in the journey to a cleaner energy system. It covers:

- How hydrogen could complement renewable electricity in a zero-carbon energy system.
- What needs to happen for clean hydrogen to be competitive on cost.
- Which elements of fossil-fuel infrastructure need to change to accommodate hydrogen.
- Which applications are most likely to be early adopters of clean hydrogen.
- What types of clean hydrogen are most likely to emerge in different markets.
- How one community is already moving along the path toward a hydrogen economy.

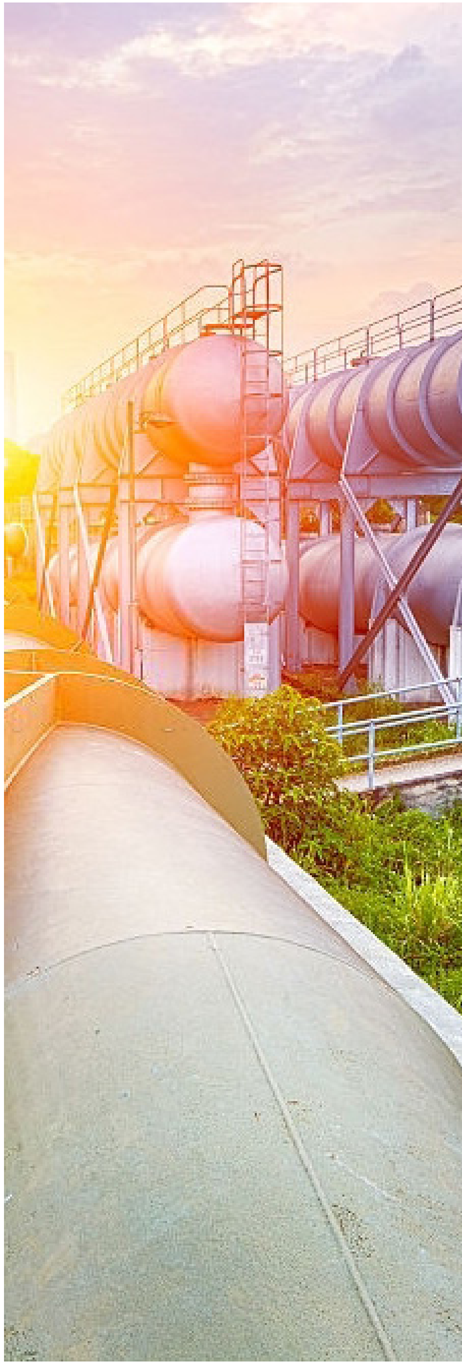
The role of hydrogen as an enabler

There is general consensus that the decarbonized energy system of the future will be mostly electric. The primary sources of energy will be renewable, such as wind and solar, which are already mature technologies and are cost competitive with fossil fuels in a growing number of markets worldwide.

This renewable electricity will feed the grid, supplementing and eventually replacing conventional power, and can also supply the energy needed for battery electric vehicles (BEV). In our homes, it could power electric hobs and electric heaters. But there are many activities today that cannot be undertaken simply by substituting hydrocarbon molecules for electrons.

They include industrial processes such as steelmaking and ammonia production; long-distance travel via land, sea and air; and energy storage when renewables fail to meet electricity demand for days or weeks, just to name three examples. For these hard-to-abate sectors, what is needed is a fuel that does not generate a carbon footprint. There are several options that could be used, but perhaps the most promising, not least because it is required as a feedstock for more complex carbon-neutral fuels, is clean hydrogen. This could in theory be used in practically all the world's hard-to-abate sectors, complementing renewable electricity and allowing society to progress to a completely sustainable—and thus almost limitless—energy model.

The journey from gray to green hydrogen



The main challenge facing wide-spread clean hydrogen adoption today is cost. Hydrogen is already produced cheaply on a global scale for industrial use, but it doesn't live up to its full potential of low-carbon fuel. Almost all production today involves steam methane reforming of natural gas, in which case the product is 'gray' or the gasification of coal or lignite, which yields 'brown' hydrogen. The latter is associated with significant levels of carbon emissions.

Reducing those emissions is challenging from a cost perspective. Producing blue hydrogen involves adding Carbon Capture and Storage (CCS) to a steam methane reforming system, which makes it more expensive, and sequestration is not always a viable solution as acceptable sequestration sites may not be available. And green hydrogen depends on having an abundant supply of low-cost renewable energy plus cheap electrolysis technology. While renewable electricity and electrolyzers are getting cheaper, there is still some way to go.

The result is that blue hydrogen can currently cost one and a half to two times more than gray hydrogen, according to Krish Krishnamurthy, director of clean hydrogen technologies R&D at Linde. And green hydrogen can cost up to three to five times more than gray, at current renewable energy and electrolysis system costs. For clean hydrogen right now, "the economics are challenging," Krishnamurthy says.

But that could change. In particular, higher carbon pricing could make gray hydrogen more expensive and at the same time provide a financial incentive to add CCS to steam methane reforming. For this to happen, carbon prices would have to rise to around USD$100 per ton, Krishnamurthy says. Furthermore, widespread adoption, increase in scale and further efficiency improvements will be critical in driving costs down over the next decade.

But in regions such as Europe, where natural gas prices are already high, renewable electricity costs are dropping and there is upwards pressure on carbon pricing, "we think that the transition to green can happen sooner," he says.

Working across the value chain

Production is only part of the clean hydrogen cost equation. Once it has been made, the hydrogen needs to be taken to where it will be used and this can add significant expense, says Andreas Rupieper, managing director of ITM Linde Electrolysis.

Traditionally, he says, "you have a complex value chain after the molecule is produced. It needs to be conditioned to certain pressure levels or liquefied to be filled into a trailer."

Trailers can transport the hydrogen by road over long distances, but once the hydrogen is delivered to a customer site, it still needs to be stored and then processed via vaporization or pressure reduction before it can be used. All this adds to the cost of the fuel. But there are two ways these costs can be reduced. One is by producing the hydrogen on-site. The other is to distribute it via pipeline and using existing natural gas networks might be a way to do this.

Concerns are frequently voiced about injecting hydrogen into existing natural gas networks, namely around compatibility and the impact on natural gas combustion characteristics. However, says Krishnamurthy, "this should not be an issue for hydrogen concentrations of up to 10-15%. There is past experience and recent pilot validations in injecting hydrogen at low concentrations into natural gas pipeline supply. Furthermore, high-pressure transportation of pure hydrogen by pipeline is done safely and efficiently today – we are well-versed at this, since we've been operating roughly 1,000km of hydrogen pipeline for quite some time."

The potential for cost-effective, long-distance clean hydrogen transport in Europe, at least, was discussed at length in April 2021 when 12 European gas transmission system operators revealed plans for a 39,700 km European Hydrogen Backbone (EHB) to be completed by 2040. Around 69% of the network would come from repurposing existing natural gas grids.

"Transporting hydrogen over 1,000 km would on average cost €0.11-0.21 per kg of hydrogen, making the EHB a cost-effective option for long-distance hydrogen transportation," says industry consortium Gas for Climate in a press release.[1]

Another consequence of the cost of transporting pressurized or liquified hydrogen is that in places where there is no pipeline access, such as Australia, it may pay to use the fuel as an industrial feedstock rather than exporting it abroad. Australia is currently studying the production of clean hydrogen for export markets but could find it more financially rewarding to use it instead for the manufacture of other low-carbon products, such as steel or ammonia, if they could command a premium overseas.

Reducing supply chain costs: hydrogen liquefiers

Pipelines notwithstanding, the transport of liquified hydrogen is likely to be a major feature of future low-carbon energy systems. And Linde is showing how hydrogen liquefaction can be achieved at scale. While small liquefaction plants use a closed helium circuit for refrigeration, once capacities rise above 1,000 liters per hour other technologies are needed, especially to manage the turbo expansion requirements.

Linde has perfected the use of hydrogen Claude processes for large-capacity liquefaction, and separate cold boxes for even larger scale systems. These technologies have enabled the company to achieve liquefaction capacities of more than 30 metric tons per day [ii]—and the upper limit is rising.

Clean hydrogen applications

David Burns, vice president of clean energy at Linde, sees half a dozen potential applications for clean hydrogen, in descending order of adoption, starting with the ones that are already viable today. These are:

- Transportation and mobility: hydrogen is already vying with batteries for decarbonization of the automotive sector, and when it comes to segments such as long-haul road transport or shipping the fuel has a clear advantage.
- Secondary industry on-site users: because of the costs of transport (see above), there is a strong financial incentive for industries that require relatively low volumes of hydrogen, such as semiconductor manufacturers, to make clean hydrogen on site.
- Regulation-driven use cases: in regions such as Europe, large carbon emitters such as oil refineries are under growing pressure to cut emissions and could start adopting clean hydrogen to help meet regulations such as Europe's Renewable Energy Directive II.
- Power-driven use cases: an increasing penetration of renewable energy generation sources is creating a demand for buffering and storage options on grids in Europe, Australia and parts of the US. Clean hydrogen can replace gas for these applications.
- Chemical processes: many chemical industries rely on hydrogen, but these are highly commoditized and thus may take longer than other segments to embrace higher-priced clean supplies of the gas.
- Steelmaking: we see steelmaking becoming a much bigger user of hydrogen in the future, as the steelmaking sector has committed to cutting its carbon footprint. We expect more widespread use of the Direct Reduction of Iron (DRI) technology in this sector, which uses hydrogen as a feedstock. But the commoditized nature of the industry and the long-time horizon for decarbonization mean it could be one of the last sectors to realize its full potential.
- Building heating: replacing natural gas with hydrogen could result in a significant decarbonization of this sector and goes hand-in-hand with conversion of natural gas grids.

Pathways to profitability

As noted above, green hydrogen can currently be two or three times more expensive than blue. Michael Schäffer, head of hydrogen and syngas plants at Linde Engineering, says "That does not necessarily mean, however, that blue hydrogen will always take precedence over green as the world moves towards low-carbon energy systems." Rather, the choice of whether to develop blue or green hydrogen in a given market will likely depend on a range of factors, including:

- Availability of carbon sequestration options.
- Renewable energy costs and capacity.
- Cost and availability of natural gas.
- Carbon pricing.

In markets where there is an excess of cheap natural gas and plenty of space for carbon storage, it may make sense to produce blue hydrogen. Conversely, if a market has plentiful, cheap renewable energy and high carbon pricing but little natural gas, then green hydrogen production would be a better option. These factors suggest that clean hydrogen production may be strongly tinged by regional markets.

Blue hydrogen, for example, is likely to be the best choice for markets such as the Middle East, Russia and the US Gulf Coast, while green could be favored in Australasia, Europe or Latin America.

Case study: a hydrogen economy in the making

While for the most part the debate about clean hydrogen is focused on future opportunities, in Aberdeen, Scotland, a transition to the fuel has been underway for more than half a decade. The city council commissioned industrial gas leader BOC, a Linde company, to install and operate a hydrogen bus refueling station at Kittybrewster as part of the government's Road to Zero vehicle emissions reduction strategy.

The refueling station produces 360 kg of hydrogen a day using on-site electrolysis[iii] and now serves various fleets in addition to the buses. But for Aberdeen local government councilor Philip Bell, who oversees the project, the move to hydrogen in public transportation is just the first step in an ambitious plan for the future.

"The initial motivation for this was the oil and gas industry, which has sustained Aberdeen but is now declining," Bell says. "What's the next wave that we can jump on? Hydrogen, clearly. I think many skills could be transferred. This is the go-to place for hydrogen."

Outlook and conclusions

The economics of clean hydrogen today mean that its practical use is limited. But the picture is changing rapidly as nations and organizations quicken the pace to achieve net-zero emissions. At the same time, hydrogen is one of several low-carbon assets and so it is likely "there will be applications for specific cases, for specific regions," says Michael Schäffer, head of hydrogen and syngas plants at Linde Engineering.

Graham Cooley, CEO of ITM Power, believes clean hydrogen will be key to global decarbonization efforts. For example, he says: "The building block for the whole of chemistry is methanol. Traditionally you make that from natural gas. But if you capture carbon dioxide and combine it with renewable hydrogen you have a route to renewable chemistry."

The heavy-duty transportation sector, including trucks, buses, trains and ferries, is already primed to use hydrogen as an alternative fuel, according to David Burns, vice president of clean energy at Linde. "Cars make a lot of sense with batteries," he says, "but when you get to the heavy commercial sector you want range—800 to 1,000 km—and when you fuel it you want to do it in 15-20 minutes, just the same as you do with diesel today."

With all this, it is safe to say that even if clean hydrogen ends up achieving a fraction of its overall potential it will have still gone a long way towards achieving energy decarbonization. Rather than being over-hyped, it is possible clean hydrogen is not being hyped enough.

References

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