HOLISTIC HYDROGEN STRATEGIES

Brandy Johnson, Babcock & Wilcox (B&W), posits how embracing diverse hydrogen generation technologies and feedstocks can help adapt to emerging energy pressures.

Hydrogen is a versatile energy carrier that is recognised as a critical component in the transition to a low-carbon economy. It offers a means to decarbonise industries ranging from transportation to heavy manufacturing. The main energy sources for hydrogen production (natural gas and electricity) are projected to experience growing demand largely due to data centres and decarbonisation efforts. As artificial intelligence (AI) and digital infrastructure expand, they place significant pressure on already strained energy grids and natural gas systems. This competition can constrain energy availability and slow down decarbonisation efforts. An 'all of the above' approach to hydrogen production that embraces a broad range of fuels, feedstocks, and novel technologies will be essential to achieving climate and energy security goals.

The energy squeeze

Global electrical demand is expected to continue to rise with the International Energy Agency (IEA) reporting a 4.3% year-over-year increase in electricity use for 2024, up from a 2.5% increase in 2023, and the agency is now predicting a 3.9% annual growth rate through 2027.[1] Much of this growth is projected to come from developing nations, but the rapid growth of data centres in more-developed nations is also starting to have a significant impact on overall electricity consumption. This amounts to an overall 15% increase in energy demand due to a combination of electrification of transport, heating, and data centres through 2027. Deloitte echoes these estimates and predicts that global electricity demand for data centres could grow to 1065 TWh by 2030,[2] which is roughly equivalent to Japan's current total annual electricity consumption. These are just a few examples that demonstrate projected increases in energy demand, but electrification and buildout of data centres are not occurring in a vacuum.

For decades, the world has been pursuing the decarbonisation of difficult-to-abate industries. Electrolysis, steam methane reforming (SMR), and autothermal reforming (ATR) with carbon capture are currently the most commonly employed methods of generating clean hydrogen. McKinsey's 2024 Global Energy Perspective reported that by 2050, hydrogen production is projected to be two to four times greater than what it is today, with 50 - 70% of total hydrogen generation expected to come from electrolysis.[3] This alone would amount to an increased demand of 4125 - 5775 TWh.

Projections for these scenarios may change significantly over time as new technologies are developed or policy changes occur. However, it is clear that rapid growth in electricity and hydrogen production could be limited by undersized and ageing energy infrastructure systems that

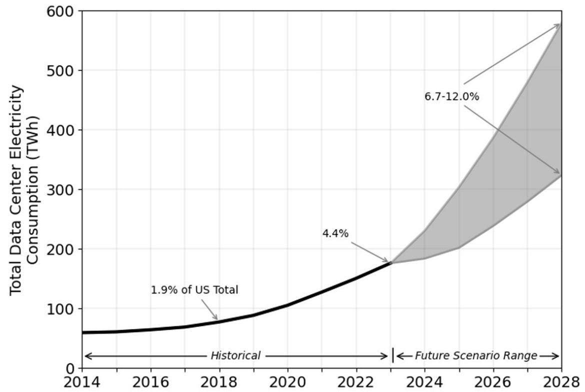

Figure 1. Data centre electricity consumption from 2014 through 2028.[5]

increase costs for both fossil fuels and renewable power. The impact of energy price fluctuations has significant implications for industry and society as a whole. In the early 2000s, US natural gas prices reached all-time highs and shut down many gas-turbine based power plants until technological breakthroughs and rapid deployment of fracking came about.[4] Fuel switching and the existence of a robust fleet of power generation assets that utilised coal helped mitigate and dampen the impact of the price surge on rate payers. To circumvent these issues in the hydrogen industry, utilisation of alternative hydrogen production methods and feedstocks should be explored.

Expanding feedstock options

The use of additional feedstocks such as biomass, waste, and coal to generate hydrogen may help relieve pressure on electricity and natural gas resources. There are technologies at various readiness levels that can gasify or pyrolyse these feedstocks to create syngas, which can then be separated and purified into hydrogen and carbon dioxide (CO_2) using traditional methods. For instance, biomass gasification presents a unique opportunity to create carbon-negative hydrogen, particularly when paired with carbon capture and storage (CCS). The availability of biomass as a feedstock has been assessed by multiple entities, including the US Department of Energy (DOE). The DOE's 2023 'Billion-Ton Report'[7] demonstrates that agricultural residues, forestry waste, and dedicated energy crops can serve as feedstock for a variety of energy technologies, offering a renewable and widely distributed energy resource. Biomass-derived hydrogen aligns well with many decarbonisation goals, particularly in regions with significant agricultural and forestry industries, such as in the Southern US, Northern Europe, and Asia. While gasification is considered to be a mature technology, it relies on capital-intensive processes and faces technical challenges associated with its performance at scale. The main challenges to cost-competitive hydrogen-from-biomass production include technology maturity, feedstock variability, tar formation, and a secure and consistent supply of feedstock, but ongoing research and demonstration projects are advancing the feasibility of biomass-to-hydrogen pathways.

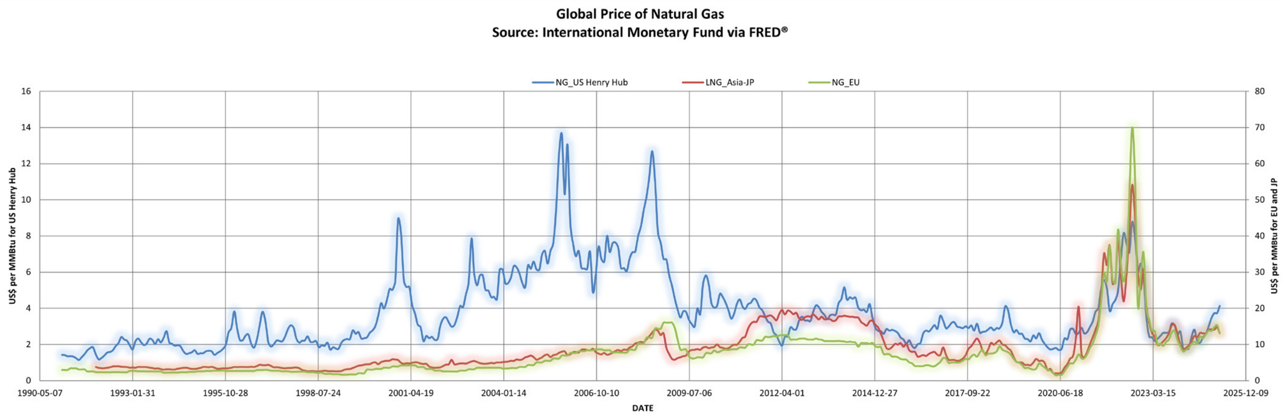

Figure 2. Global price of natural gas.[6]

Waste-derived fuels provide another viable option for hydrogen production by leveraging municipal solid waste, industrial byproducts, tail gases, and other residue materials. While the need to recycle these materials has been identified and acknowledged, waste continues to gather in landfills in many regions, emitting methane, a potent greenhouse gas (GHG). Gasification and pyrolysis technologies can convert these waste streams into hydrogen while contributing to waste reduction and circular economy goals. Like biomass gasification, technologies that can utilise waste often struggle with technical challenges, feedstock variability, and securing consistent supply chains. Further research and development is required to make use of abundant waste materials globally.

Coal, though historically associated with high carbon emissions, remains a significant global energy resource. Gasification technologies that integrate CCS can transform coal into low-carbon hydrogen. The world has vast, underutilised coal reserves, making this a secure and reliable option, particularly in regions with existing infrastructure. These technologies exist today in various forms; however, negative public perception remains a key challenge for coal-derived hydrogen.

Alternative feedstocks can provide resilience against fluctuations in energy costs and supply chain constraints while also leveraging existing infrastructure in waste management, forest management, and mining. Advanced hydrogen production technologies must be deployed to leverage these feedstocks. This is where technologies that utilise a process called chemical looping emerge as a transformative solution that can enable feedstock diversity.

Chemical looping

Chemical looping is an advanced technology that the DOE has recognised as one of the most promising carbon capture solutions for the future.[8] The process utilises oxygen carriers, typically metal oxides, that react with various gaseous and solid feedstocks while inherently isolating CO_2. This eliminates the need for costly and energy-intensive post-combustion capture systems.

Babcock & Wilcox (B&W) developed its BrightLoop™ chemical looping technology through extensive laboratory, bench scale, and pilot scale testing, and has made significant investments to advance this platform, particularly in configurations that convert water into hydrogen utilising various process inputs. Unlike SMR and gasification processes, which require separate CO_2 separation systems, and ATR, which also needs air separation systems, this chemical looping process integrates air separation, fuel conversion, and hydrogen generation into a single core reactor system.[9] The system inherently isolates a concentrated stream of CO_2, eliminating the need for a separate, costly, and energy-intensive CO_2 capture system or a front-end air separation unit. This integrated approach leads to significant reductions in capital and operational costs.

The process involves the oxidation and reduction of a particle that moves through two moving bed reactors and a fluidised bed reactor, sequentially interacting with feedstock, steam, and air. The feedstock is introduced into

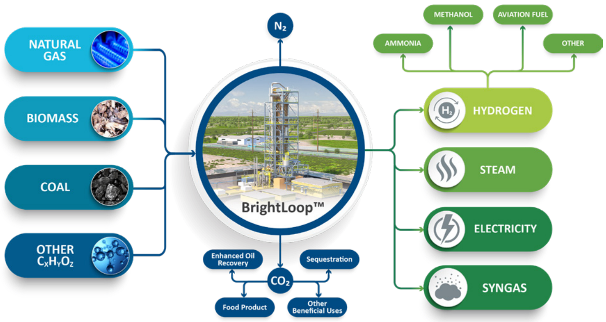

Figure 3. Feedstock diversity.

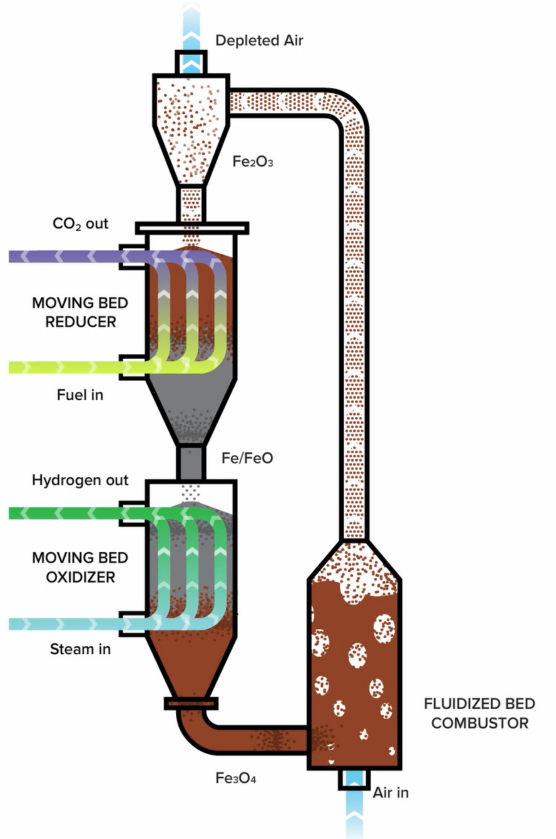

Figure 4. Chemical looping system for hydrogen generation.

the reducer, where it rapidly reacts with particles. The particles provide the necessary oxygen, and the reaction is assisted by carrier gases that move between the fuel and the particle, continuing to convert the fuel while reducing the particles. Due to the counter-current contact between the final feedstock conversion process and the particle, the reducer yields a stream composed of CO_2 and steam with trace contaminants, and the reduced particles which then flow to the oxidiser. Concentrated CO_2 flows from the reducer through treatment systems to remove minor contaminants, as required, for final CO_2 use or to meet environmental regulations.

Heat is recovered from product streams to generate the required steam for the oxidiser. The steam is introduced into the reactor, where it reacts with the particles in their reduced oxidation state. This reaction partially oxidises the particles and yields a product stream of wet hydrogen. The particles are then sent to the combustor where preheated air is introduced to fluidise and lift them while re-oxidising them to their highest oxidation state, completing the loop. The exothermic oxidation reaction provides the heat needed to sustain the process at the desired reactor temperatures. The products of the process are separate streams of H_2, CO_2, and O_2-depleted air that have undergone required purification to meet specifications.

Facilities that are capable of producing 3 - 20 tpd of hydrogen are currently under development across the US in Ohio, Wyoming, West Virginia, and Louisiana. These facilities will utilise natural gas, coal, or biomass, showcasing the flexibility and scalability of the process. Unlike challenges posed by the intermittency of renewable energy sources, the chemical looping process relies on a controllable supply of alternative feedstocks to consistently produce low-carbon hydrogen. These systems are being designed to meet regulatory compliance and provide greater energy security while supporting the transition to a net zero emissions future.

Public perception and government policy: enabling feedstock diversity

As the hydrogen economy evolves, it will be increasingly important for the hydrogen industry to support a wide range of production pathways and advocate for equal treatment in policy. While electrolysis and natural gas reforming are central to current strategies, they may not be sufficient on their own, especially as electricity and natural gas resources come under pressure from other growing sectors, like data centres. In this context, alternative feedstocks could offer regionally appropriate and low-carbon hydrogen solutions. However, these pathways often face uneven policy support and public hesitation, particularly due to concerns about the environmental impact or their connection to legacy energy systems.

To address these challenges, consideration should be given to updating policy frameworks that focus more on carbon intensity and lifecycle emissions rather than prescribing specific technologies or hydrogen colours. A comprehensive life cycle analysis of a particular project or technology would be the most important factor when determining its value to stakeholders. The hydrogen industry will also need to bolster its communication efforts around these approaches to help build broader understanding and trust.

Figure 5. Biomass to hydrogen chemical looping plant.

Governments worldwide offer various incentives to promote the development and adoption of hydrogen generation technologies tailored to their resources and strategies. However, they often attempt to pick the winning technology rather than incentivising outcomes and allowing innovation to determine the best solution. While feedstock-diverse technology development efforts have not received the same level of support, they have garnered backing from smaller institutions focused on regional development, such as states, provinces, and non-governmental organisations. To scale up and mitigate risks associated with breakthrough technologies, continued support from federal and regional governments alongside industrial stakeholders, inclusive of alternate production pathways, remains essential.

Conclusion

Hydrogen is poised to play a central role in the global transition to a low-carbon economy, yet growing demand for electricity and natural gas, driven by sectors like data centres and widespread electrification, risks creating energy constraints that could slow progress. To navigate this challenge, the hydrogen industry can benefit from embracing feedstock diversity, especially when paired with technologies that enable efficient carbon management. Innovations like chemical looping demonstrate how alternative pathways can produce low-carbon hydrogen while reducing pressure on energy systems. By taking an 'all of the above' approach to feedstocks and technologies, the hydrogen industry can adapt to emerging energy pressures, support hard-to-decarbonise sectors, and secure its role as a cornerstone of the global low-carbon economy.

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