For example, in areas where renewable energy is abundant, electrolytic hydrogen/ammonia could be drivers. On the other hand, in areas with traditional energy sources, carbon capture may be a better option. Any of these technologies can be developed safely, if properly designed and operated.

**CCBJ: What notable hydrogen projects has BakerRisk been involved in over the last couple of years?**

- Hydrogen tests and internal research projects.
- Working with different electrolyzer manufacturers and OEMs.

BakerRisk has conducted internal and client research with hydrogen, including dispersion, gas detection, jet fire, and explosion. Those research projects have enhanced our modeling capabilities as well as an understanding of what type of mitigations can work in different environments. This knowledge has helped us support our clients as they scale their operations.

BakerRisk has been involved with most major electrolyzer manufacturers and OEMs. We have conducted hazard and risk identification projects, detailed quantitative modeling with steady state and CFD models, performed hazardous area classification (HAC), gas detection, building design, and various other studies related to this topic.

BakerRisk is proud to have supported many types of hydrogen projects including grey, blue, and green hydrogen production, transport through pipelines and trucks, fueling facilities for bus and heavy duty vehicles, and end use at industries, warehouses, storage facilities, and beyond.

Our global portfolio of these projects with our focus on enhancing safety has made for a very satisfactory contribution to this energy transition. We are not stopping here, we understand this will be a long journey and are ready to do our part in helping this energy transition occur smoothly and safely. ☼

# Stantec Reflects on State of Play in Hydrogen Infrastructure, Production and Transportation

**Stantec** (Edmonton, Ontario) is a global sustainable design and engineering services company with more than 28,000 employees and 400 offices worldwide. Stantec's consultancy services span the entire built environment and utilities sectors. Stantec's Energy business combines sustainable and economic solutions with a strategic mindset focused on the low-carbon energy transition.

***Nathan Ashcroft, Strategic Business Developer, Energy****, has 25 years of experience in a wide range of leadership roles. His career has spanned the development of energy, chemical, and infrastructure studies and projects across different parts of the globe. In recent years, Nathan has strategically formed initiatives and become a leader in energy transition and clean technology as it applies to the changing energy world.*

***Steve McManamon, Sector Leader, Environmental Services, Energy,*** *is the U.S. Energy sector leader of Stantec's Environmental Services business line. His job is to grow Stantec's oil and gas business throughout North America. After 30 years in the business, his background spans environmental regulations, environmental risk management, large capital project permitting, and Fortune 500 company account management.*

***Michel Johnson, Vice President, Power Sector, Environmental Services United States****, has spent over 20 years of his career in strategic planning, environmental engineering, and business consulting for global energy infrastructure projects. He is people-oriented and data-driven with a proven track record in profitable growth, financial management, and consulting for Stantec's Energy Transition client portfolios.*

**CCBJ: How is Stantec prioritizing decarbonization solutions within its overall business strategy?**

Johnson: Decarbonization solutions are a critical investment opportunity for Stantec and included in our Global Energy Transition Initiative. As we continue to partner with targeted energy clients, ranging from mining and investor-owned utilities companies to manufacturing and oil and gas organizations, our focus is to map a viable, low-carbon path forward. We do this via upfront business planning, energy advisory services, and managing the execution of the resulting plans from project development through construction and operations.

**CCBJ: Can you describe how the clean energy market has evolved over the past five years? What changes can we expect over the next couple of years?**

Johnson & McManamon: The energy transition is growing exponentially and, according to the US DOE and UNESCO, by 2030 it will be a $32 trillion global business. This huge level of growth is largely driven by three factors: regulation, shareholder pressures, and profitability.

In more detail:

- **Regulation:** Tax incentives, grants, political will, streamlining permitting processes, Enterprise Risk Management, and litigation are all factors that impact investment.
- **Shareholder pressure:** Investors have choices and are more often requiring Fortune 500 companies to invest more in clean energy and ESG.
- **Profitability:** Technology and operational efficiency are improving profitable investment in renewable and clean energy development.

Over the past five years, there has been rapid growth in what might now be considered traditional renewables (wind and solar) and associated electrical transmission.

Ongoing government subsidy programs are supporting this growth. With the advent of the Inflation Reduction Act (IRA), subsidies for other alternative forms of clean energy such as hydrogen and carbon mitigation technologies like carbon capture and sequestration (CCS) are now also in play.

While there are threats to some of these programs with the pending outcome of the 45V carbon credit "definition," we anticipate the next two years will include continued strong investment in traditional renewables in tandem with rapid high investment in hydrogen, CCS, and other clean energy, carbon reduction technologies, and markets.

**CCBJ: What does this mean for the energy transition in the future?**

We should expect to see:

- Greater levels of investment from VCs and Fortune 500 companies.
- New investments in alternative low carbon energy sources like hydrogen, biofuels et al., and associated carbon mitigation via carbon sequestration, direct air capture (DAC), and other advancing technologies.
- Continued evaluation and development of the "all of the above" model for low carbon energy sources.
- Greater demand for local control potentially shifting power distribution from a traditional IOU model to Public Utility Districts.
- AI and technology advances will aid in greater certainty for investors and reliability for power users.
- Advancement of microgrids, EV, and home battery storage will change the utility cost model.

**CCBJ: How is money being allocated, and which types of clean energy are attracting additional investment?**

Stantec: In the United States, there's both the Inflation Reduction Act providing tax incentives as well as associated DOE grant funding. Grid modernization, large transmission, and offshore wind have been big benefactors of IRA tax incentives, whereas hydrogen hubs and carbon sequestration via the DOE will see significant hub and individual project grants.

In Canada, energy demand is flat, and because of the political drivers there's uncertainty on renewable development as it relates to solar and wind. However, green hydrogen is the big focus, and the government is providing large tax incentives in this area.

In the UK, approximately 45% of the UK's electricity stems from renewables, and a large driver of that is the UK's government tax incentives encouraging both renewable and transition development.

In the Netherlands, the SDE++ is an operating grant that aims to help in achieving the government's goal of reducing greenhouse gas emissions in the Netherlands by at least 55% by 2030 compared to 1990.

Considering global investment in renewable energy capacity from 2010 to 2019, it is clear that China (US$758B), the United States (US$356B), Japan (US$202B), Germany (US$179B) and the UK (US$122B) are leading the race.

**CCBJ: How do you view key advances in 1. hydrogen fueling infrastructure, 2. hydrogen production, and 3. hydrogen transportation?**

Ashcroft:

## 1. Hydrogen-fueling infrastructure

Hydrogen fueling infratstructure has evolved to allow for a wide variety of storage and operating modes, including trucked-in gas commodity, gas that is produced onsite in various methods, and trucked-in liquid commodity. The simplest and least-costly facilities use gaseous hydrogen (GH2) that is remotely produced and delivered to the site.

In one approach, 'tube trailers' containing GH2 at up to 3600 PSI are delivered and dropped at the facility and then connected to a compressor that increases the gases pressure to the dispensing pressure of 350 bar or 700 bar (about 5,000 PSI or 10,000 PSI respectively). Once the tube trailer is exhausted, it is replaced with a fresh trailer. This is sometimes called a 'drop and swap' configuration.

In another GH2 configuration, the hydrogen gas is offloaded to fixed ground-storage vessels. This is done by drawing and recompressing the GH2 from the delivery trailer and pushing into the storage vessels at 10,000+ PSI. This increased pressure improves space efficiency but requires multiple hours to achieve, with the delivery trailer often occupying part of the station and occupying a compressor that would otherwise be available for dispensing.

The last available arrangement for GH2-based hydrogen fueling is to produce some or all the station's fuel onsite. This can be done most economically using steam-methane reforming of natural gas, which uses very high-pressure and high-temperature steam to 'reform' the CH4 methane molecule to GH2 + CO2 and CO byproducts.

When conventional natural gas is used, the resulting carbon byproducts increase the hydrogen's carbon intensity (CI), but this can be mitigated by using bio or renewable natural gas as the feedstock, thus reducing the resulting overall CI. The CI is reduced by redirecting the biomethane that would otherwise migrate to the atmosphere, and is a very 'strong' greenhouse gas, to become GH2 and CO2 + CO, with the resulting CO2 + CO being roughly one seventh of the CI of the source methane.

GH2 can be also generated onsite from other steam-methane reforming-like processes that similarly break down other hydrocarbons, alcohols, and even wood pulp.

GH2 can also be generated onsite, extracting pure hydrogen from water using the electrolysis method. In this approach, the only inputs are water and electricity, and the only outputs are GH2 and oxygen.

But while the carbon output of the onsite system is zero, this does not account for the CI associated with the input electrical power, which varies significantly by region and even time of day.

Additionally, electrical-power requirements for electrolyzer systems can be fairly large. For example, even a small electrolyzer from a Nel (model MC250) that produces 531 kg per 24 hours requires 1.25 MW of 480V power.

The GH2 generated from any of the processes described above are discharged from their respective generation systems at low pressures ranging from 15 to 300 PSI. But since the dispensing pressure of GH2 is 5,000 or 10,000 PSI, a significant gas-compression and intermediate-storage process is needed, which is typically done by diaphragm-type compressors, as these prevent introduction of contaminants and preserve high gas purity.

Intermediate high-pressure GH2 storage may also be fairly substantial, as it is needed to accumulate the gas that is produced during the hours when fueling is not occurring. (If possible, steam-methane reformers and electrolyzers should run 24 hours per day, in order to maximize utility and efficiency.)

In a paradigm shift from using gaseous hydrogen as the feedstock for a fueling system, liquified hydrogen (LH2) can alternately be the storage medium for the fuel. This has the advantages of being much denser than even high-pressure gas (LH2 is more than 3x denser than GH2 at 5000 PSI) and can be offloaded at the facility within 45-60 minutes. It requires modest electrical power to operate (i.e., 200-800 amps at 480V, depending on amount of concurrent and ongoing dispensing). However, since LH2 needs to be maintained at very low temperature of -423F and it boils at any higher pressure, commodity losses need to be considered. Such losses occur when LH2 commodity is delivered, when pumps startup as well as during extended periods of nonuse (though this loss rate is less). Additionally, since LH2 is stored at low pressures of less than 150 PSI, it needs to pressurized as well as warmed to ambient temperature.

This is done using reciprocating pumps that push high-pressure LH2 to ambient-air vaporizers, which essentially absorb ambient heat and transfer it to the LH2, resulting in GH2 at ambient temperature. The GH2 is then routed to the priority-valve panel that automatically directs the flow to either intermediate storage or directly to the dispensers, depending on available storage and dispenser demand.

Finally, hydrogen-fueling systems that utilize various combinations of the above commodity formats are feasible. For example, an LH2 system that provides the majority of the hydrogen via pumps and vaporizers as described above could be augmented by an onsite production system (either electrolyzer or steam-methane reformer), which could provide some degree of backup resiliency in case of LH2-supply interruption. Or, a facility that is sized to provide most or all of the needed hydrogen via an onsite system (again, either steam-methane reformer or electrolysis) could have a connection to receive gas from drop-and-swap tube trailers in the case of elevated demand or failure of the onsite system.

## 2. Hydrogen production

Over 95% of global hydrogen production is from either natural gas reforming or electrolysis. Natural gas reforming for hydrogen production has been around for over 75 years. This hydrogen production is termed grey hydrogen. This process requires significant energy to reform the hydrocarbon molecule to produce hydrogen.

The significant energy results in large greenhouse gas emissions (GHG) produced in the process. Capturing these GHG from the process, significantly reducing the GHG emissions in the process. When the GHG's are captured (for subsurface sequestration) the hydrogen is termed 'blue'.

To reduce emissions from current grey hydrogen production, there are significant advancements to capture GHG from existing hydrogen facilities. Additionally, new hydrogen facilities built utilizing gas from the feedstock will be blue hydrogen. Given the significant growth projected for hydrogen, there is significant effort being deployed to make the GHG capture part of the process more energy and operationally efficient.

Electrolyzing water for hydrogen production is not a new concept. However, it has not been the chosen method to produce hydrogen as it has not been scalable or cost-effective to this point. With the advent of net-zero aspirations and the desire for a lower emissions hydrogen, there are significant advancements sourcing lower costs of electricity to power the electrolyzer process, mainly from ever increasing solar and wind power.

Green hydrogen production is set to grow very significantly over the next 25 years and beyond. This will require much larger-scale and more efficient electrolyzers. Currently, the two main technologies are alkaline and PEM (Proton Exchange Membrane). Given the 'size' of the prize for electrolyzer manufacturers, there is tremendous research being done and trialed to increase the size and overall efficiency of electrolyzers. This includes a wide range of companies, in established global companies along with well funded start-up companies, seeking to advance a more efficient machine that can be a market leader and bestseller effectively.

## 3. Hydrogen transportation

Hydrogen pipelines and trucks are the best solutions for transport over smaller distances. However, when quantities or distances become greater, other techniques are needed. With increasing hydrogen production globally, moving hydrogen in larger quantities over further distances is driving advancement in hydrogen transportation solutions.

Three energy carriers that can make this transport possible are:

- **Ammonia** – Ammonia is a combination of hydrogen and nitrogen; Ammonia is moved around the world globally safely.
- **Liquid Organic Hydrocarbon Carriers** (LOHC) – Liquid organic hydrogen carriers are organic compounds that can absorb and release hydrogen through chemical reactions. LOHCs can therefore be used as storage media for hydrogen.
- **Liquified hydrogen** Gaseous hydrogen is liquefied by cooling it – to below −253°C (−423°F). Once hydrogen is liquefied it can be stored at the liquefaction plant in large insulated tanks. It takes energy to liquefy hydrogen—using today's technology, liquefaction consumes more than 30% of the energy content of the hydrogen and is expensive. Hydrogen's expansion ratio of 1:848 means that hydrogen in its gaseous state at atmospheric conditions occupies 848 times more volume than it does in its liquid state.

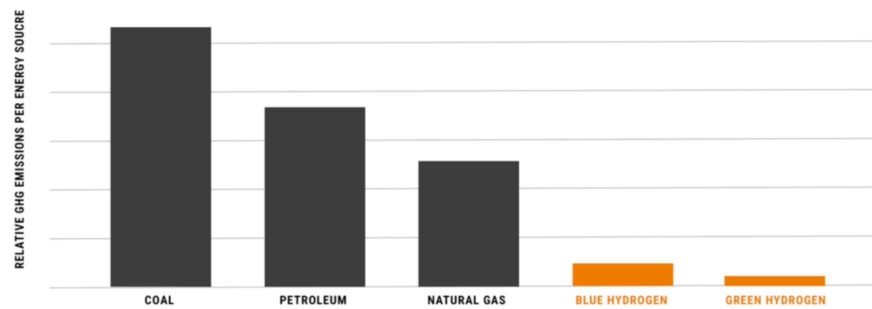
**CCBJ: What are the most notable hydrogen energy or hydrogen hub projects in which Stantec has participated?**

Ashcroft & McManamon: We have been involved in a wide range of hydrogen projects, from production and storage, conveyance, transportation, conversion to ammonia, sustainable fuels and fueling stations. Specific to the DOE's Clean Hydrogen Hubs Program, Stantec has been providing early technical services on projects within three of the seven hubs selected for potential DOE grant award.

**CCBJ: What are the anticipated outcomes of the DOE's Regional Clean Hydrogen Hubs Program?**

Ashcroft: The Hydrogen Hubs are a generational incentive that will accelerate the commercial-scale deployment of clean hydrogen helping to generate clean, dispatchable power, create a new form of energy storage, and decarbonize heavy industry and transportation. Together, the seven Hydrogen Hubs will eliminate 25 million metric tons of carbon dioxide emissions from end uses each year—an amount roughly equivalent to combined annual emissions of over 5.5 million gasoline-powered cars.

## How Does Blue & Green Hydrogen Stack Up Against Fossil Sources?




**CCBJ: Has Stantec collaborated with other companies to enhance the success of its hydrogen solutions?**

Ashcroft: We are working with a wide range of cutting-edge hydrogen solutions. We have collaborated with a new bio-hydrogen technology pathway that is using much less energy for hydrogen production. We have:

- Completed numerous studies into how hydrogen can be blended safely into existing natural gas pipelines.
- Hosted numerous webinars, articles and created general thought leadership pieces to advocate for hydrogen as a practical solution to reducing emissions globally.
- Completed feasibility work to assess hydrogen usage in what is termed 'hard to abate' industries such as steel manufacturing and aviation fuel, and worked with the World Bank to assess hydrogen production for economic development in less developed countries.

**CCBJ: What is Stantec's approach to scaling up hydrogen production and distribution?**

Ashcroft: At Stantec, we have built a fully capable Hydrogen team, from advisory services through to engineering and construction management. We see ourselves as being able to work with hydrogen developers from Day One and see any project through to completion. Hydrogen is a new vector for many clients. We have worked with our clients to develop a robust and practical hydrogen project selection, from selecting the right technology, project size, siting location, and a project execution plan. We have also worked with emerging technologies to help guide them to commercial realization.

**CCBJ: How is Stantec planning to engage with potential users?**

Ashcroft: Hydrogen isn't new to people in the oil, gas, and petrochemical industry. However, hydrogen projects are now being developed for a far wider range of use, with hydrogen effectively coming into wider society and communities in a much larger way. Hydrogen is highly combustible and does present some risks. Our role at Stantec is to work with relevant bodies, be they hydrogen developers or different levels of government, to provide expert opinion and advice informing people that are new to hydrogen, so that the risks are known and understood as not radically different to those of natural gas.

We always say: In the right hands, using the right technical and safety-first approach, there is nothing that we cannot resolve that would prevent from us from utilizing hydrogen in a much broader societal sense, as part of our climate solutions. ☼