NEW ENERGY

# Your Guide to Hydrogen Generation and Lowering Carbon Emissions

# Hydrogen is Poised to Accelerate the Decarbonization Revolution

As climate change, carbon emissions and environmental issues take center stage, industries around the world are looking at their operations with an eye for sustainability. Amid the array of pathways available for decarbonization, hydrogen has emerged as one key lever for reducing global emissions.

Hydrogen is an abundant element, energy dense and emits no carbon dioxide when combusted; it can be stored and transported with existing methods. The energy industry already has four decades of experience handling and producing hydrogen. Despite these advantages, employing hydrogen as a fuel is not widespread. However, with today's focus on curbing carbon emissions, hydrogen is gaining attention as one fossil fuel alternative. It is especially promising for sectors where lowering emissions has historically presented challenges, such as long-haul transportation, chemicals production and steel manufacturing.

Developing, deploying and scaling this new hydrogen ecosystem isn't easy; it requires a robust value chain including production, compression, liquefaction, storage and distribution and transportation. To realize hydrogen's potential as a lever for decarbonization, every link in the value chain must be keyed for zero- to low-emissions operations.

At John Crane, we're leveraging our legacy of technology leadership, innovative solutions and service excellence to accelerate progress at a time when industries are increasingly looking to hydrogen to meet their sustainability goals.

Hydrogen is one key lever for reducing global emissions


# A Brief Review of Hydrogen's Potential

Hydrogen is of great interest as the world seeks to bring global energy-related carbon dioxide ($CO_2$) emissions to net zero by 2050. Hydrogen is one of the International Energy Agency's (IEA) five pillars in the pathway to net zero, and hydrogen energy is receiving attention from governments and industry alike. Amid the complexities of decarbonization, there is a clear consensus among experts: Hydrogen has an essential role in the new energy transition.

The political drive for low-emission hydrogen is strong as countries strive to develop the means for meeting decarbonization commitments. Many governments directly support investment in hydrogen technologies with strategic policies such as carbon taxes and clean-energy incentives. For example, the UK has its "Industrial Hydrogen Accelerator Programme," India has a "National Green Hydrogen Mission" and Canada has created the "Low-carbon and Zero-emissions Fuels Fund," which includes hydrogen.

While natural gas and coal are today's primary sources of hydrogen production, there is growing momentum behind clean, electrolytic hydrogen. Using wind or solar power to produce hydrogen energy, or hydrogen as a fuel, will aid with decarbonizing vital yet emission-tied sectors that traditionally rely on fossil fuels.

However, the world must act faster to make a renewable hydrogen economy more affordable, safe and efficient. The IEA has identified numerous near-term actions to support the hydrogen value chain. Government-level recommendations include actively stimulating commercial demand for clean hydrogen, rejecting cumbersome regulatory barriers and addressing the financial investment risk of first-movers and hydrogen newcomers.

Additional recommendations for accelerating the overall shift to a low-emission hydrogen future include scaling up supply and demand, and building on existing industries, infrastructure and policies. Advancing technology and innovation is fundamental to supporting these efforts, and the growing number of patents for hydrogen-related technology indicates that a shift toward low-emissions solutions is already in progress.

For industries like petrochemical refining, where hydrogen is already in use, there is an opportunity to decarbonize by switching from unabated fossil fuel-based hydrogen to low-carbon hydrogen. However, a significant impact on carbon emissions can be made by leveraging hydrogen for non-traditional applications, such as heavy industry, transport and power generation.

# Today's Methods of Hydrogen Production

Hydrogen is an abundant element throughout the universe but does not exist freely in nature; it must be extracted from other compounds during production. This extraction is possible using various technologies, some of which are employed today. There are additional methods in the research and development stage, which may prove to be cleaner, more efficient pathways for scaling up future production.

## Electrolysis

As the name suggests, electrolysis uses electricity to split a substance. In the case of hydrogen, electrolysis separates water into its constituent elements — oxygen and hydrogen — without producing harmful byproducts or emissions.

The electrolysis process itself takes place in an "electrolyzer," consisting of an anode and a cathode with an electrolyte substance separating the two. As electricity passes through the electrolyzer, water splits into hydrogen and oxygen. Hydrogen can then be captured for storage or immediate use.

The three main types of electrolyzers differ by the electrolyte material used. They are polymer electrolyte membrane (PEM), alkaline and solid oxide.

## Steam Methane Reforming (SMR)

Steam methane reforming is the energy sector's most widely used hydrogen production method. It creates a chemical reaction with high-pressure steam, methane and a catalyst to produce hydrogen. SMR can be used with natural gas, ethanol, propane and gasoline. While SMR is a carbon-emitting process, it's possible to capture the CO2, leaving pure hydrogen as the product.

## Autothermal Reforming (ATR)

Autothermal reforming is similar to SMR, although it is not as mature a technology; it produces hydrogen through partial oxidation and steam reforming of methane. The two most distinctive differences between SMR and ATR are that autothermal reactions occur in a methane combustion chamber and require pure oxygen, whereas SMR uses oxygen via air.

## Thermochemical Water Splitting Cycle (TWSC)

Like electrolysis, a thermochemical water splitting cycle process separates water to produce hydrogen. However, in the case of TWSC, high-temperature heat is used instead of electricity. An emerging method currently being investigated for viability at scale, this pathway consumes only water while producing hydrogen and oxygen.

## Biological Hydrogen Production

Capturing the hydrogen that microorganisms produce, or biological production, is in its early research stages. There are two general types of biological processes: photolytic and photofermentative. Microorganisms that use sunlight to separate water into hydrogen and oxygen are photolytic. In a photofermentative system, microbes use sunlight to break down organic matter, releasing hydrogen in the process.

With their low environmental impact, biological methods are an attractive option for low-carbon hydrogen production, and research efforts are focused on improving process efficiency and hydrogen yields.

The technology for producing clean hydrogen is expected to develop and mature along with the hydrogen economy, enabling efficient, cost-effective methods for reaching our decarbonization goals.

# The Importance of Renewable Hydrogen

While low-emission hydrogen production — using carbon capture, utilization and storage, for example — is a near-term step toward net zero, renewable hydrogen is the vital end goal. Renewable hydrogen, produced from energy sources such as solar, wind or geothermal, will significantly impact emissions reductions, particularly for sectors traditionally regarded as hard to abate. However, there are still challenges to overcome as the world aims to hasten renewable hydrogen production.

## Making Renewable Hydrogen Cost Effective

Producing renewable hydrogen comes at a higher cost than producing low-emissions hydrogen. The capital to purchase renewable hydrogen technology, such as electrolyzers, also creates a significant barrier.

Auspiciously, developments are pointing to the cost of electrolyzers decreasing by as much as 40% to 80% by 2030.

## Improving Production Efficiencies

Increasing the efficiency of electrolysis technology will help scale up clean hydrogen production to meet future demands and positively contribute to the overall hydrogen value chain. Researchers are also working toward maximizing yields from nascent renewable pathways, such as biological methods.

## Creating Hydrogen Policies

Supporting renewable hydrogen production with strategic governmental policies and regulations will stimulate demand and accelerate the growth of the hydrogen economy. This support may come in the form of grants, loans or tax incentives for hydrogen-related projects, in addition to creating roadmaps for achieving hydrogen deployment targets.

John Crane is committed to developing solutions that support a wide range of technologies involved in low-carbon and renewable hydrogen. Our market-ready renewable hydrogen solutions deliver both reliability and sustainability. Through our involvement in international efforts to advance hydrogen technology, such as Hydrogen Europe, we are actively working to accelerate progress across every link of the hydrogen value chain.

**40% to 80%**

Estimated cost decrease of electrolyzers by 2030

# Challenges and Opportunities for Hydrogen Storage and Transportation

A heavy investment in hydrogen storage and transportation infrastructure is needed to transition to a low-carbon future. Currently, the end-to-end efficiency of the hydrogen value chain, from production to storage to transportation to end use, is not optimal. Exploring new, low-carbon pathways that increase efficiency for each link along the value chain will accelerate the adoption of hydrogen energy and overall movement toward net zero.

At the moment, there is no single solution for hydrogen storage or distribution, which is why evaluating existing methods and developing new options is essential. Also critical is improving the availability of storage at key locations and addressing hydrogen transportation without gaining a carbon footprint from inefficiencies. While challenging, this scaling up is vital to smoothing the transition to, and speeding up the adoption of, low-carbon hydrogen for industries.


## Hydrogen Storage

Hydrogen storage can enable flexible access to energy, which is required for industrial applications. Strategic deployment of stored hydrogen also has the potential to fulfill production needs when paired with an intermittent method such as renewable water electrolysis. Storing hydrogen as a compressed gas or a liquid involves established technologies well-understood by industry. Newer approaches, currently in the research stage, could eliminate some of the challenges inherent in conventional methods.

### Compressed Gas Storage

Storing hydrogen as a compressed gas is simple, reliable and the most prevalent method used in industry today. However, when compared to the same volume of an incumbent fossil fuel, such as natural gas, it does not deliver as much energy. To compensate, the storage needed to accommodate the anticipated global demand for hydrogen could manifest as sprawling tank farms and significant capital investments.

### Liquid Storage

Cooling hydrogen below its boiling point (-252.8° C) changes it from gaseous to liquid. Stored liquified hydrogen has a higher energy density than gaseous hydrogen; however, maintaining hydrogen in a liquid state requires specialized equipment to withstand cryogenic conditions.

### Materials-Based Storage

Nascent approaches for hydrogen storage may aid with transcending the challenges with current storage methods. Researchers are currently exploring hydrogen chemical storage that uses a reaction to "attach" hydrogen to another material. A promising approach for storing large quantities of hydrogen is materials-based and involves chemically binding hydrogen with a metal to form a solid metal hydride. The metal absorbs hydrogen, much like a sponge, and when it is heated, the hydrogen is freed. This simple method is an attractive option for storing hydrogen as it foregoes the need for managing pressurized tanks or complex cryogenic systems.

## Hydrogen Transportation

Safe, reliable infrastructure for hydrogen transport is mission-critical for the new hydrogen value chain. It is an underpinning for the widespread adoption of hydrogen as a new energy. Currently, the hydrogen industry uses established transportation options; however, there may be innovative methods to transcend the challenges inherent in conventional transportation.

The physical state of hydrogen plays a deciding role in selecting a transportation method.

### Compressed and Liquid Hydrogen

Options for moving gaseous hydrogen include pipeline and truck transport. Pipeline networks are an established method for transporting gaseous materials under pressure, but existing pipeline networks — typically used for fossil fuels — are not hydrogen-ready. While trucking compressed hydrogen cylinders is a simple alternative to pipeline transport, this method may not significantly impact an overall goal of net zero unless trucking is decarbonized.

Liquifying hydrogen enables the transportation of a larger energy mass than compressed gas. However, as liquefaction requires cryogenic conditions, pipelines cannot maintain hydrogen in its liquified state. The use of tanker trucks also requires cryogenic support. These challenges make for cumbersome infrastructure requirements, and a significant investment would be needed for liquid transportation to fulfill the future demand for hydrogen.

### Liquid Organic Hydrogen Carriers (LOHC)

An emerging method for transporting hydrogen over long distances uses a liquid organic hydrogen carrier (LOHC). By bonding hydrogen to a stable organic liquid, transportation can be accomplished using conventional means. The LOHC would undergo a hydrogenation reaction prior to transport, and then when an LOHC reaches the end user, a dehydrogenation process would separate the hydrogen for use.

Transporting via LOHC is an attractive option as there's no need for managing high-pressure cylinders or cryogenic systems. In addition, by using existing pipeline infrastructure, LOHCs have the potential to become a breakthrough pathway to low-carbon hydrogen transportation.

### Liquid Ammonia

Ammonia (created in a reaction combining hydrogen and nitrogen to produce $NH_3$) is another promising solution for hydrogen transportation. Ammonia is already a globally traded commodity, so transport networks are in place. Using ammonia allows for hydrogen separation via "ammonia cracking" or, for some industries such as fertilizer production, the ammonia itself may be employed in the end-use process.

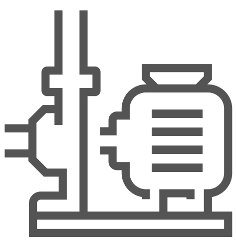
# John Crane's Hydrogen Storage and Transportation Solutions

Rotating equipment is critical across every link, and supporting reliable delivery at scale requires a range of technologies to enable compression, expansion, pumping and filtration, as well as secondary processes, such as those that maintain cryogenic conditions.

John Crane takes a comprehensive approach to creating a foundation for the new hydrogen economy, with innovative technologies, solutions and services that enable both conventional and emerging transportation methods.

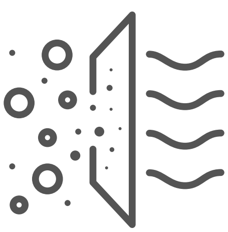
## Compression

Dry gas seals, high-performance couplings and seal gas recovery systems for reciprocating compressors and turboexpanders in hydrogen applications



## Pumping

Mechanical seals, seal support systems, couplings and filtration solutions for ammonia and LOHCs and cryogenic liquid hydrogen storage



## Filtration

Seal gas and fuel gas conditioning, lube oil filtration and process filtration for critical equipment and end users, as well as practical solutions for supporting pre-filtrations and modular systems

# Sectors to Fast-Track for a Net Zero Future

Renewable and low-carbon hydrogen is poised to play an important role in decarbonizing applications such as power generation, heavy industry and transport, where processes currently rely on fossil fuels and limiting carbon emissions has proven challenging.

## Decarbonization of Power Generation

Large-scale renewable energy generation inherently supports a carbon-free future; however, energy sources like solar and wind are intermittent. Today's power generation industry relies on fossil fuels to maintain a consistent, reliable energy output to meet demand. Hydrogen is a promising candidate for clean power generation, as it can be produced using renewable methods and then stored for on-demand access.

## Decarbonization of Transportation

According to the IEA, "$CO_2$ emissions from the transport sector must fall by more than 3% per year to 2030" to achieve its Net Zero by 2050 Roadmap. The uptake of hydrogen fuel cells and hydrogen combustion engines will be vital in achieving this reduction.

Current fuel cell electric vehicle (FCEV) technology is efficient and produces no emissions aside from heat and water vapor. However, hydrogen fuel cells are complex, expensive and under-supported by infrastructure. Hydrogen combustion engines, conversely, are a more straightforward technology. Infrastructure already exists, but these engines are comparatively heavy and produce emissions in the form of nitrogen oxide.

Today, hydrogen FCEV applications include long-haul vehicles, such as public buses and drayage (freight) trucking, while hydrogen combustion is utilized in heavy transportation, such as locomotives and ocean shipping. With a more robust hydrogen supply infrastructure in place, the decarbonization potential of hydrogen-powered vehicles is significant.

"$CO_2$ emissions from the transport sector must fall by more than 3% per year to 2030"

to achieve the IEA's Net Zero by 2050 Roadmap.

## Decarbonization of Heavy Industry

Among the heavy industries, targets for decarbonization include iron and steel, which ranks first for $CO_2$ emissions, as well as fossil-fuel-reliant ammonia production, which emits twice as much $CO_2$ as crude steel manufacturing.

Within the steel industry, there is potential to replace coal fuel with renewable hydrogen to accelerate decarbonization. For ammonia, which relies on gas-based steam reforming and coal gasification, future production methods could decarbonize through hydrogen from electrolysis.

## Accelerating Decarbonization with John Crane

With favorable regulations on the horizon, many industry leaders have established objectives to decarbonize their plants and processes. Initiatives for achieving this end include adding clean hydrogen energy sources or decarbonization technologies. Whether an established enterprise or a new player in the industrial space, aligning hydrogen technology with operations to maximize reliability and efficiency is vital.

John Crane has the experience to work alongside industries as a partner to optimize new energy operations. Our expertise and innovative technology in sealing systems, filtration and couplings place us at the forefront of clean hydrogen, where we support customers, the industry and the planet.


# The Future of Renewable Hydrogen and Its Role in a Sustainable World

A key lever to achieving the IEA's Net Zero Scenario, renewable hydrogen has the potential to decarbonize a range of industries worldwide, thus accelerating the path to a low-carbon future, mitigating climate change and promoting environmental sustainability. By leveraging clean hydrogen, hard-to-abate sectors such as power generation, transportation and heavy industry are poised to become carbon-reduction success stories.

John Crane is at the forefront of the energy transition, helping to bridge the gap between current capabilities and future needs of customers aiming to scale up renewable hydrogen initiatives. Every day, our market-ready sealing, filtration and pumping technologies are enabling customers to achieve their sustainability goals, supporting every link along the hydrogen value chain from production to storage to transportation.

Shape your new energy reality today with John Crane.

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