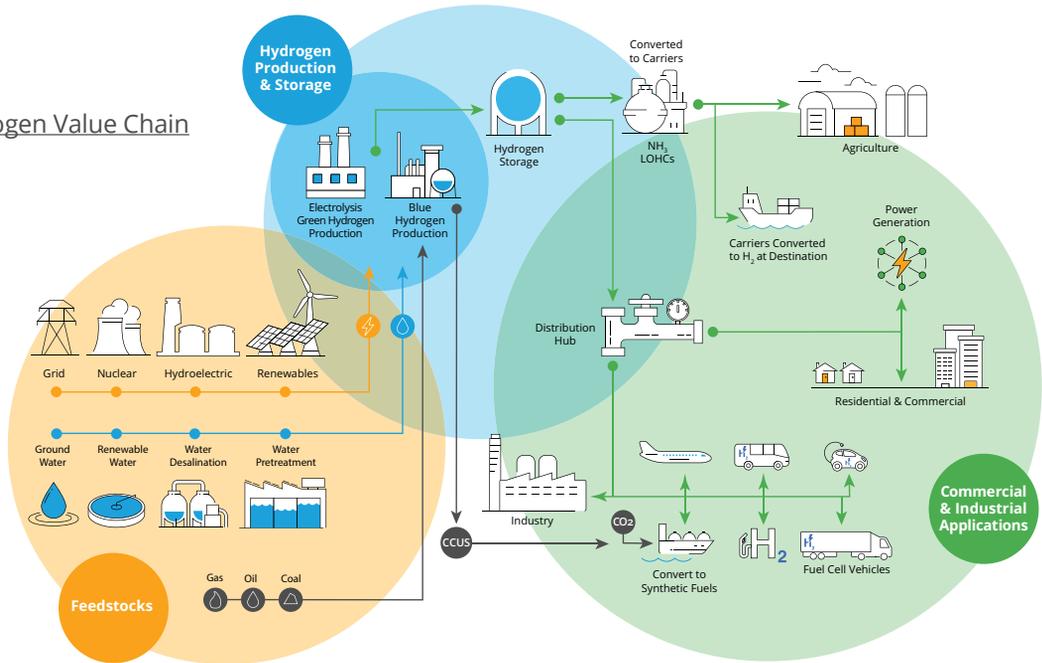


## Hydrogen Value Chain



# Hydrogen

## Production, Storage, Transportation, and Utilization

Hydrogen is a versatile low-carbon fuel used across numerous industries globally and is being considered as a leading alternative to enable scalable, long-duration renewable energy storage while re-purposing some of the existing infrastructure. However, it is also being used in a growing number of projects to accelerate applications in the energy industry, such as a transportation fuel in fuel cell electric vehicles or for long-duration energy storage.

Over the past few years, an increasing number of demonstration and commercial-scale projects have been proposed across the globe to develop hydrogen as a technology to facilitate decarbonization across numerous industries. The full hydrogen value chain is depicted above to demonstrate the wide variety of feedstocks, production processes, and end uses for hydrogen.

### Top 5 Uses of Hydrogen

#### Transport: Land, Air and Sea

- Hydrogen fuel cell electric vehicles (FCEVs) are gaining traction, particularly for commercial use. Benefits such as fast refueling time, long-range performance and lighter weight make FCEVs an attractive zero emission option.

#### Green Chemicals

- Ammonia can help facilitate the widespread use of hydrogen. "Green" ammonia, which is produced from renewable energy, can serve as an energy storage medium as liquid ammonia. It can be decomposed to produce hydrogen and nitrogen and serve as a desired hydrogen carrier.

#### Energy Storage

- Hydrogen could be stored in a tank or cavern before being funneled into a fuel cell or used to create electricity.

#### Power Generation

- Clean-burning and energy-dense, hydrogen can be a gateway to decarbonizing the world's energy systems, supply chains and heavy industries.

#### Residential and Industrial Heating

- Depending on the blending percentage as well as the age and current state of the natural gas grid, blending hydrogen into the system may require minimal or potentially no modifications to grid infrastructure or to domestic end-user appliances but requires further evaluation.

## “Typical” Definitions for Colors of Hydrogen

- **Green** – Water electrolysis using renewable energy resources to produce hydrogen
- **Gray/Brown** – Hydrogen produced using fossil-based resources such as natural gas, coal, or petroleum coke
- **Blue** – Gray or brown hydrogen combined with carbon capture utilization and storage (CCUS) to produce hydrogen
- **Pink** – High-temperature water electrolysis using nuclear energy resources

## Low-Carbon Hydrogen Production

- Electrolysis is the process of splitting water into hydrogen and oxygen using electricity
- Instead of using carbon as an energy carrier which produces carbon dioxide, electrolysis-derived hydrogen produces water when it burns
- More recently, CCUS technologies have advanced and become more efficient, making CCUS integration with gray/brown hydrogen plants less expensive and more economically competitive relative to green hydrogen

## Hydrogen Storage and Transportation

- Hydrogen can be challenging to store in large quantities in geographies that do not have access to suitable underground reservoirs
- Hydrogen can be stored as a gas using compression or as a liquid using liquefaction
- Compressed hydrogen storage is the most common method of storage including in small, high-pressure cylinders used in the fuel cell vehicles and large bulk tanks for industrial users
- Hydrogen liquefaction is more energy intensive and requires far more complex auxiliary equipment, but is better for storage of large volumes and transportation over long distances for domestic use

## Hydrogen Storage and Transportation cont.

- Geological formations such as salt caverns present an opportunity to store large volumes of hydrogen
- Pipelines are the most cost-efficient way to store/transport large quantities of hydrogen over long distances for domestic applications
- Blending hydrogen in the existing natural gas pipeline network presents an attractive option

## Performance for Power Generation

- Hydrogen can be utilized directly in fuel cell power generation equipment and is currently being developed for 100 percent firing in reciprocating engine/combustion turbine equipment
- Some of the technical challenges in hydrogen firing and/or co-firing in traditional power plants include rate of change in fuel gas properties, maintaining combustion stability, increased nitrogen oxide production, hazardous gas detection, and hazardous area classification

## Opportunities, Challenges, and Risks

- Hydrogen fuel shows significant promise to achieve long-term decarbonization goals
- Most utilities are examining opportunities for sector-coupling (e.g., power generation and transportation) to take advantage of economies of scale for hydrogen projects
- There are numerous safety/compatibility challenges with hydrogen due to its flammability and reactivity that can drive high costs in its production, storage, transportation, and utilization
- Hydrogen can be used at large scales and is expected to be feasible in 100 percent hydrogen fueled power generation stations beyond the 2030 timeframe



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For more information please contact:

**Jonathan Cristiani, Bioenergy and Hydrogen Technology Manager, Black & Veatch Corporation**  
P +1 919-463-3043 | E [CristianijM@bv.com](mailto:CristianijM@bv.com)

