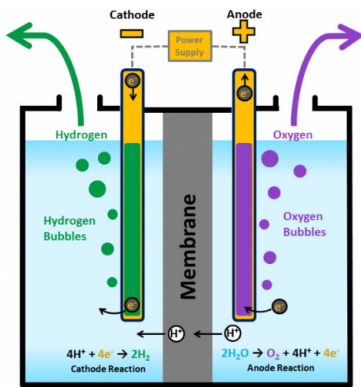
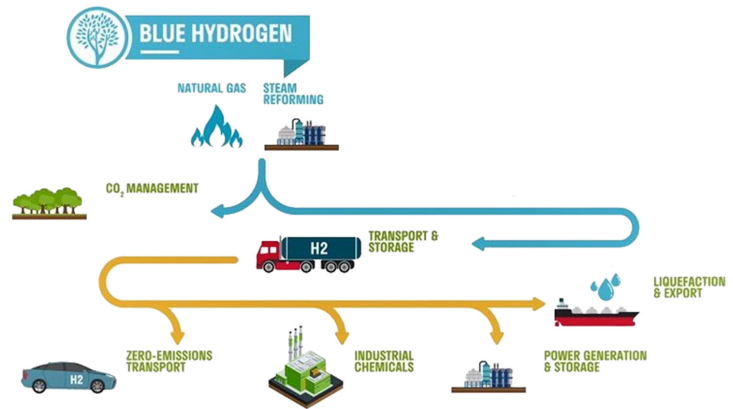


## CLEAN HYDROGEN PRODUCTION

Currently, 95% of hydrogen produced in the U.S. comes from natural gas through a process known as steam methane reforming (SMR). Hydrogen can also be produced using electricity in water electrolysis or as a byproduct in chemical processing facilities such as ethylene cracking. The widespread availability of a mix of energy resources throughout the United States, renewables (wind, solar, hydro, biomass), fossil fuels with carbon dioxide capture and storage (CCS), and nuclear offer opportunities to produce clean hydrogen in many regions of the country.

### Production Methods:

Steam methane reforming accounts for nearly all commercially produced hydrogen in the U.S. This process involves using steam reforming to separate hydrogen atoms from carbon atoms in methane. High-temperature steam under pressure reacts with methane in the presence of a catalyst to produce hydrogen, carbon monoxide, and carbon dioxide. Natural gas is the primary source of methane for hydrogen production by industrial facilities and petroleum refineries. Other sources include biofuels and petroleum fuels. Steam methane reforming that utilizes fossil fuels with CCS can produce clean hydrogen with a very low carbon intensity.

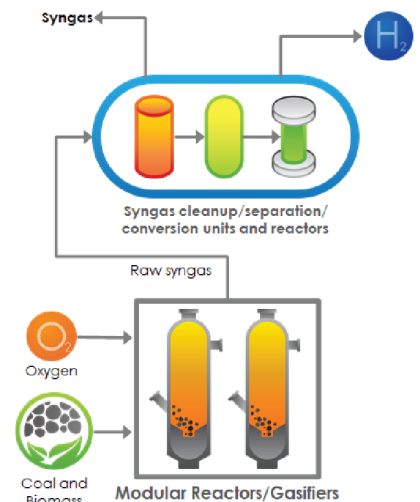


Another clean hydrogen production pathway is through electrolysis, a process that uses an electric current to split hydrogen from water. The process takes place in an electrolyzer, which is the equipment or unit where the process splits the hydrogen from the oxygen, and can be powered by electricity generated from renewable resources, nuclear, or fossil fuels with CCS.

Clean hydrogen can also be produced via a process called gasification. Using high temperatures and pressures in a vessel with a controlled amount of oxygen, gasification converts organic and/or fossil fuel materials into carbon monoxide, hydrogen, and carbon dioxide. The carbon monoxide then reacts with water in a gas clean up system to form carbon dioxide and more hydrogen using a water-gas shift reaction. Adsorbers or

special membranes can separate the hydrogen from this gas stream. Gasification utilizing fossil fuel, biomass and CCS can produce a net-negative carbon intensity clean hydrogen.

PROCESS INTENSIFICATION FOR SYNGAS & HYDROGEN



### Production Needs and Challenges:

- Lower-cost, more-efficient, and more-durable electrolyzers
- Advanced designs for reforming, gasification, and pyrolysis
- Advanced and innovative hydrogen production techniques from renewable, fossil fuel with CCS, and nuclear energy resources, including hybrid and fuel-flexible approaches
- Lower-cost CCS technologies and project deployment