GREAT PLAINS INSTITUTE

Hydrogen 101

HYDROGEN PRIMER AND POTENTIAL FOR DECARBONIZATION

KEY TAKEAWAYS

- Hydrogen is a clean energy solution to help decarbonize critical sectors of the economy such as transportation, power generation, and manufacturing.
- Hydrogen's versatility as an energy carrier distinguishes its long-term potential to contribute to meeting midcentury climate goals.
- Hydrogen production is flexible, with some production pathways capable of achieving low, zero, or net-negative emissions.

KEY ADVANTAGES

Hydrogen has three key advantages that distinguish it from other zero-carbon energy options:

1. It generates high heat when burned, resulting in zero-carbon emissions.
2. It is suitable for seasonal energy storage, improving grid reliability.
3. It can be flexibly produced with available resources, supporting an affordable and scalable clean energy transition.

WHAT IS HYDROGEN?

Hydrogen is a colorless, odorless gas that does not produce carbon emissions when burned making it poised to play a substantial role in decarbonization. Hydrogen is an energy carrier, meaning it can deliver and store energy from other sources. This quality makes it an ideal alternative to burning fossil fuels such as coal or natural gas.

Hydrogen can be produced from a variety of resources, such as natural gas, nuclear power, biogas, and renewable power like solar and wind. While hydrogen releases no emissions when burned as fuel, hydrogen production methods have varying emissions intensity levels.

WHAT MAKES HYDROGEN CLEAN?

The production pathway is what determines whether hydrogen is “clean” or not. Clean, in this context, refers to whether the production pathway results in significantly large amount of carbon emissions compared to other methods.

Each of hydrogen’s production stages and end-uses need to be measured to determine its total emissions. This evaluation is often called a lifecycle greenhouse gas analysis and can help ensure that the production method creates low- or zero-carbon hydrogen across pathways. Accounting methods like this one are critical to ensuring that carbon dioxide (CO_2) emissions are not overlooked during the production process and the eventual use of hydrogen. Hydrogen is considered "clean" for the purposes of funding opportunities if the entire production process creates two kilograms or less of CO_2 for every kilogram of hydrogen produced.

HOW CAN HYDROGEN HELP DECARBONIZE OUR ECONOMY?

Hydrogen has the potential to meet various needs in our economy including three of the most energy-intensive sectors:

Transportation sector

For transportation, hydrogen can power zero-emissions vehicles through fuel cell technology. Unlike a traditional internal combustion engine used in most cars today, fuel cell vehicles use hydrogen and oxygen to emit water as exhaust, producing no CO_2, particulate, or sulfur emissions.

Manufacturing and industrial sectors

Hydrogen can be used in the manufacturing and industrial sectors for either power generation or industrial applications. Notably, hydrogen can reach the high temperatures required for industrial heating processes, such as cement and steel manufacturing. For example, high heat is needed to chemically modify the ingredients for cement production. Reaching such high temperatures can be hard to achieve through other low-carbon strategies, such as electrification. Hydrogen can also serve as a feedstock for many chemical processes inherent to industrial production.

Power sector

Hydrogen allows the use of existing assets in the power sector for the energy transition, avoiding the high capital costs of new development. In some cases, it can be blended with natural gas and distributed through existing natural gas transport infrastructure.

Hydrogen can also play a key role in enabling electric grid stability. It is particularly suitable for long-duration storage (meaning ten or more hours in this context). When energy demand is low and electricity generation is high, hydrogen can conserve electricity until demand increases. This quality is particularly useful as more seasonal and variable generation, such as renewable generation, increases. Hydrogen can offer the complementary capacity to efficiently store excess energy when energy production is high and exceeds demand.

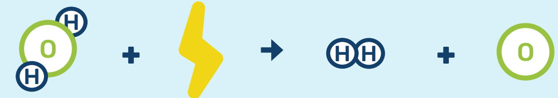
HOW IS HYDROGEN PRODUCED?

Just as there are many opportunities to utilize hydrogen, there are also many production methods. Each pathway uses different inputs to produce hydrogen, with a wide range of carbon emission-reduction options.

Flexible production allows for the best use of surrounding resources. For instance, in areas with an abundance of natural gas production, methane reformers can be used to produce hydrogen. The carbon emissions from those facilities can be captured and used or stored, resulting in low-carbon hydrogen. Electrolyzer plants offer opportunities in areas with abundant renewable and zero-carbon energy. And, areas with biomass waste feedstocks can combine gasification with carbon capture to produce hydrogen. That combination has the potential to produce hydrogen with net-negative emissions. Although there are many ways to produce hydrogen, here are a few of the more common ways:

Electrolysis

Hydrogen can be produced by using water electrolysis, which uses electricity to split water into oxygen and hydrogen gas. The potential for emissions reductions from electrolysis is dependent on the electricity source, such as renewables, fossil fuels, or nuclear power.

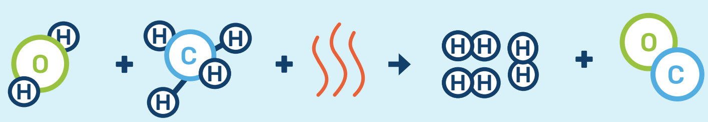


H_2O (water) + ELECTRICITY = H_2 (hydrogen) + O (oxygen)

Steam-methane and autothermal reforming

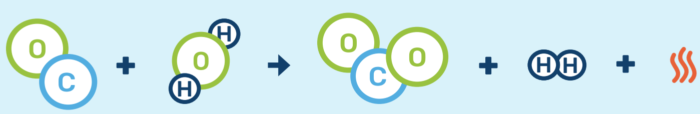
Hydrogen can also be produced when natural gas is split into hydrogen and CO_2 using steam-methane reforming or autothermal reforming. During steam-methane reforming, methane and water are heated and react to create carbon monoxide and hydrogen. Water is added to the system, reacting with the carbon monoxide to form CO_2 and hydrogen.

Step 1: Steam-methane reforming reaction



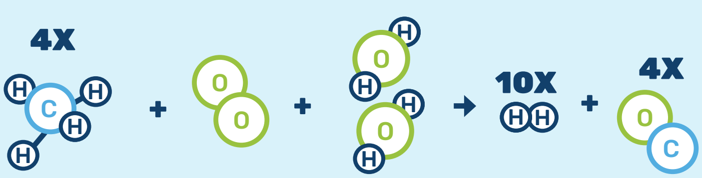
H_2O (water) + CH_4 (methane) + (HEAT) → $3H_2$ (hydrogen) + CO (carbon monoxide)

Step 2: Water-gas shift reaction



CO (carbon monoxide) + H_2O (water) → CO_2 (carbon dioxide) + H_2 (hydrogen) + (A LITTLE HEAT)

Autothermal reforming uses oxygen and CO_2 or steam in a reaction with methane to form synthesis gas. Synthesis gas is a fuel gas mixture consisting primarily of hydrogen, carbon monoxide, and very often CO_2.



$4CH_4$ (methane) + O_2 (oxygen) + $2H_2O$ (water) → $10H_2$ (hydrogen) + 4CO (carbon monoxide)

The carbon oxides created from both processes, steam-methane reforming or autothermal reforming, can be captured and utilized or stored to create a zero- or low-carbon production pathway.

Other production types

- Methane pyrolysis produces hydrogen through the thermal splitting of methane. This process is still experimental and removes the carbon in a solid form instead of CO_2 gas.
- Coal gasification uses steam and oxygen to break molecular bonds in coal and form a gaseous mixture of hydrogen and CO_2.
- Hydrogen also occurs naturally.

WHAT IS NEXT FOR HYDROGEN?

The Federal Government has recognized the importance of reaching cost-effective hydrogen production by 2030 and has awarded $9.5 billion through the Bipartisan Infrastructure Law to support clean hydrogen deployment. Eight billion dollars of that funding will go towards developing areas across the nation where hydrogen producers and consumers are closely located and connected, also known as hydrogen hubs.

To bring clean hydrogen production to scale, the Inflation Reduction Act includes a scaled Clean Hydrogen Production Tax Credit to defray the upfront and operating costs associated with production. The credit is technology neutral and awarded based on carbon intensity, such that the lower the carbon intensity of the hydrogen produced, the greater the credit value. The Bipartisan Infrastructure Law provides a consistent measure of evaluating how clean hydrogen is.

Applicable percentage as determined by lifecycle greenhouse gas rates

Carbon Intensity (kg-CO_2e/kg H_2)	Max Hydrogen PTC Credit ($/kg H_2)
4kg – 2.5	20%
2.5kg – 1.5	25%
1.5kg – 0.45	33.4%
<0.45kg	100%

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