Hydrogen as an Energy Source

This brief is intended as a short introduction to hydrogen as an energy source. It will briefly discuss the various types of hydrogen and a variety of hydrogen use-cases that are nearing market readiness. Finally, this brief will discuss recent federal support for hydrogen through the Infrastructure Investment and Jobs Act of 2021 and the Inflation Reduction Act of 2022.

Key Takeaways

- Hydrogen is a versatile energy-carrying element that can be deployed to assist with a variety of energy sector goals.
- Historically, most commercial hydrogen has been produced through oil refining and other chemical production processes.[1]
- Clean hydrogen -- produced from renewable energy, nuclear power, or fossil fuels with carbon capture technologies -- can allow for the decarbonization of a range of key sectors such as long-haul transportation, iron and steel production, and energy production.
- The Infrastructure Investment and Jobs Act of 2021 contains $9.5 billion to support hydrogen across three programs administered by the U.S. Department of Energy (DOE).
- The Inflation Reduction Act of 2022 contains two major tax credit programs related to hydrogen production.

Executive Summary

Hydrogen is the simplest and most abundant element in the universe.[2] While highly combustible and energy-dense, hydrogen only naturally occurs on earth in compounds formed with other elements such as with oxygen to form water (H_2O) and carbon to form hydrocarbons. These hydrocarbons are found in fossil fuels among other resources. Although chemical and industrial uses for hydrogen have been broadly deployed for more than a century, recent market and government investment in hydrogen as an energy source has broadened interest in hydrogen production.[3] Combusted hydrogen primarily emits water vapor, and hydrogen is viewed as a key method to reduce greenhouse gas emissions and store energy from more traditional energy sources like renewable energy, natural gas, and nuclear.

Hydrogen Production

Though abundant throughout the environment, hydrogen must be separated from other elements where it occurs. There are many different methods to produce hydrogen for fuel use.[4] Each method carries varying levels of complexity, cost, and carbon consequences. The two most common methods for producing hydrogen are steam-methane reforming and electrolysis.[5]

Steam-methane reforming is the most widely used commercial method of producing hydrogen. Commercial hydrogen producers and petroleum refineries use this process to separate hydrogen atoms from carbon atoms in methane. High temperature steam is placed under pressure in the presence of a catalyst to produce hydrogen, carbon monoxide, and carbon dioxide. While natural gas is the main source of methane for hydrogen production, landfill gas (also called biogas) can be substituted in this method.

Electrolysis uses an electric current to split hydrogen atoms from water. This process can be utilized at commercial scale to convert electricity to hydrogen gas, often referred to as "power-to-gas." Electrolysis itself does not produce any byproducts other than hydrogen and oxygen. While electricity derived from any source can be used to create hydrogen through electrolysis, hydrogen created from electricity from low or non-carbon emitting technologies -- such as solar, wind, and nuclear, or fossil fuels paired with robust carbon capture -- is referred to as "clean hydrogen." Electrolysis allows energy from these sources to be converted into hydrogen gas where it can be stored, stockpiled, and transported before use. Put another way, electrolysis allows excess electricity generation, including from intermittent sources of energy such as wind, solar and nuclear power, to be converted into hydrogen for longer-term storage and future use, without the need for batteries. It is important to note that it takes more energy to produce hydrogen through electrolysis than hydrogen produces when converted to useful energy. However, in some contexts, such as to achieve decarbonization goals and/or for long-term storage of intermittent energy sources, this loss of efficiency may be acceptable.

Color Categories of Hydrogen

Hydrogen itself is an invisible and colorless gas. However, producers, marketers, government agencies, and other stakeholders often refer to hydrogen in color categories (e.g. pink hydrogen vs brown hydrogen).[6] Three of the most common color categories for hydrogen are green, pink, and blue. "Green" refers to hydrogen that was created through electrolysis with electricity from renewable sources. "Pink" refers to hydrogen that was derived through electricity produced by nuclear energy, while "blue" refers to hydrogen created by energy from fossil fuels that have carbon capture processes in place. It is important to note that, while some consensus around the definition of these color categories is forming, there is not a strict statutory or regulatory definition behind this system. Currently, the color system plays more of an informal marketing role.

Hydrogen Use-Cases

Much of the current promise of hydrogen stems from its potential to decarbonize difficult industrial sectors such as long-distance transportation, electricity production, and heavy metal production.

Industrial Uses

Hydrogen is used by refineries to lower the sulfur content of diesel fuel. As such, refinery demand for hydrogen has increased in parallel with demand for diesel fuel. This is true both domestically and on the international market. As discussed above, there are two primary types of hydrogen production for industrial purposes; 1) steam-methane reforming, and 2) by-product hydrogen production. Since steam-methane reforming requires the use of valuable natural gas feedstock to power the process, refineries have increasingly purchased hydrogen from third-party chemical suppliers in lieu of ramping up production of hydrogen in-house. Comparing 2008 and 2014, on-site refinery hydrogen production changed very little (less than 1%), while hydrogen supplied by merchant producers increased by 135%.[7]

Transport

Hydrogen is considered an alternative vehicle fuel under the Energy Policy Act of 1992.[8] Both light duty vehicles and heavy-duty commercial vehicles can use hydrogen either through internal fuel cells or by burning hydrogen in an internal combustion engine. Fuel cells can be as much as 2-3 times more efficient than traditional internal combustion engines but carry a high unit cost. Hydrogen burned in internal combustion engines emits less than traditional internal combustion engines but also produces nitrogen oxide. Both technologies are limited by the lack of dedicated hydrogen fueling infrastructure.

Electricity Production

Like the transportation use-case discussed above, electricity can be created from hydrogen either through fuel cells or by igniting the gas itself. Hydrogen fuel cells combine hydrogen and oxygen atoms to produce electricity. As of the end of October 2021, there were approximately 166 operating fuel cell electric power generators at 113 facilities in the United States with a total of about 260 megawatts (MW) of electric generation capacity.[9] Interest in directly burning hydrogen for electricity generation is growing. Currently, most facilities mix hydrogen with natural gas at various ratios before burning. However, a growing number of power plants have announced plans to burn 100% green hydrogen in their combustion gas turbines.[10]

Federal Investment

The Infrastructure Investment and Jobs Act of 2021 (IIJA) contains $9.5 billion to support hydrogen across three programs administered by the U.S. Department of Energy (DOE). These programs are detailed below.

By far the largest of these programs is the Regional Clean Hydrogen Hubs. This program is intended to create networks of hydrogen producers, consumers, and local connective infrastructure to accelerate the use of hydrogen as a clean energy carrier that can deliver or store substantial amounts of energy. These competitive funds are open to projects that demonstrate production, processing, delivery, storage, and end-uses for clean hydrogen. There are expected to be between six and ten awards for regional hydrogen hubs. DOE has publicly stated that they received 79 applications from 48 states for these funds. The final application date for regional hydrogen hubs is April 7, 2023.

Hydrogen Funding Programs in the Infrastructure Investment and Jobs Act (IIJA)			
Program Name	**Program Funds**	**Program Type**	**Program Status**
Regional Clean Hydrogen Hubs	$8 billion	Competitive	Applications due 4/7/2023
Recycling Clean Hydrogen Manufacturing Recycling, Research, Development and Demonstration Program	$500 million	Competitive	• Concept Papers due 4/19/2023 • Applications due 7/19/2023
Clean Hydrogen Electrolysis Manufacturing and Recycling Program	$1 billion	Competitive	• Concept Papers due 4/19/2023 • Applications due 7/19/2023

The Inflation Reduction Act of 2022 contains two major tax credit programs related to hydrogen production. The Clean Hydrogen Production Tax Credit is a new tax credit program open to all hydrogen producers in the United States. The base tax credit amount is expected to be $0.60/kg multiplied by the applicable percentage. The applicable percentage ranges from 20% to 100% depending on lifecycle greenhouse gas emissions. The $0.60/kg is adjusted for inflation. An additional bonus credit amount of five times the base credit is expected to be available, provided the production facility meets certain labor requirements, such as prevailing wages and registered apprenticeships. In addition, the Inflation Reduction Act also extends and expands the Credit for Carbon Oxide Sequestration. The Carbon Oxide Sequestration program extension includes a substantial increase in the value of the previous tax credit. This extension is expected to have an impact on the production of “blue” hydrogen.

Hydrogen Tax Credit Programs in the Inflation Reduction Act (IRA)			
Program Name	**Period of Availability**	**New or Existing**	**Eligible Recipients**
Clean Hydrogen Production Tax Credit	Credit is for hydrogen produced after 12/31/22. Credit is available for facilities placed in service before 1/1/33 for their first 10 years in service.	New Tax Credit	Producers of hydrogen in the United States.
Credit for Carbon Oxide Sequestration	Credit can be claimed for 12 years after a facility is placed in service. Facilities must be placed in service before 1/1/33.	Extended and modified	U.S. facilities within minimum volumes: 1,000 metric tons of CO2 per year for DAC facilities; 18,750 metric tons for electricity generating facilities (with carbon capture capacity of 75% of baseline CO2 production); 12,500 metric tons for other facilities.

Conclusion

Hydrogen is a simple, versatile, and abundant element. Hydrogen has been used in industrial processes for more than a century. However, recent technological improvements, coupled with significant federal funding opportunities, have renewed commercial interest in hydrogen. While hydrogen presents certain challenges to widespread adoption, the potential upsides of hydrogen are significant. In transportation, hydrogen can provide a zero-emission alternative to fossil fuel internal combustion engines. Hydrogen, either mixed with natural gas or burned alone, offers a less carbon intensive method to produce electricity. Electrolysis allows electricity to be converted to hydrogen gas for long- term storage, transportation, and use as a dispatchable fuel source. At present, each of these use-cases for hydrogen have accompanying challenges. However, the potential upsides of these approaches, if widely adopted, are significant. Paired with $9.5 billion in federal funding from the IIJA and substantial tax credit opportunities from the IRA, hydrogen is well-positioned for broader research, development, and deployment.

This brief was developed by Chris Fletcher, Senior Policy Analyst, NGA Center for Best Practices.

[1] https://www.iea.org/fuels-and-technologies/hydrogen
[2] https://www.eia.gov/energyexplained/hydrogen/
[3] The Future of Hydrogen: Seizing Today's Opportunities. Report Prepared by the International Energy Agency (IEA)
[4] https://www.eia.gov/energyexplained/hydrogen/production-of-hydrogen.php
[5] https://www.eia.gov/energyexplained/hydrogen/production-of-hydrogen.php
[6] ibid
[7] https://www.eia.gov/todayinenergy/detail.php?id=24612
[8] https://www.eia.gov/energyexplained/hydrogen/use-of-hydrogen.php
[9] https://www.eia.gov/energyexplained/hydrogen/use-of-hydrogen.php
[10] ibid