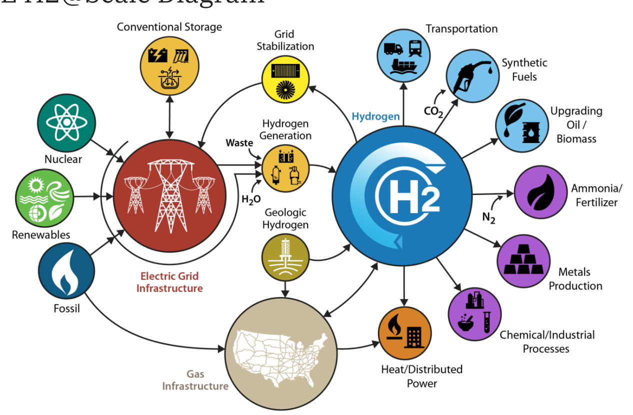
Hydrogen

Hydrogen (H_2) is a feedstock and energy carrier used in multiple sectors. Global hydrogen demand reached 100 Mt in 2025,[1] with 14 Mt in the U.S.[2] Hydrogen is the most abundant element in the universe, but is present in limited amounts in elemental form on Earth. The primary production method (globally and in the U.S.) is steam methane reforming (SMR) of natural gas (NG), which produces CO_2 emissions. Electrolysis, another method, uses electricity to split water into hydrogen and oxygen, offering a decarbonization pathway when powered by zero- or low-carbon sources like renewables or nuclear power. Hydrogen can play a key role in decarbonizing end-use applications where alternatives like electrification are problematic.[3]

- Hydrogen has the highest energy per mass of any fuel at 120 MJ/kg H_2 on a lower heating value basis,[4] but very low volumetric energy density of 8.5 MJ/L for liquid hydrogen and 4.7 MJ/L for compressed hydrogen gas at 700 bar pressure, compared to 31.3 MJ/L for gasoline.[5]
- H_2 is stored as high-pressure gas or low-temperature liquid.[4]
- Demand for low-GHG hydrogen grew almost 20% in 2025 but remains below 1% of global H_2 demand.[1] Global production of low-GHG hydrogen is estimated to reach 27 Mt by 2030.[1]

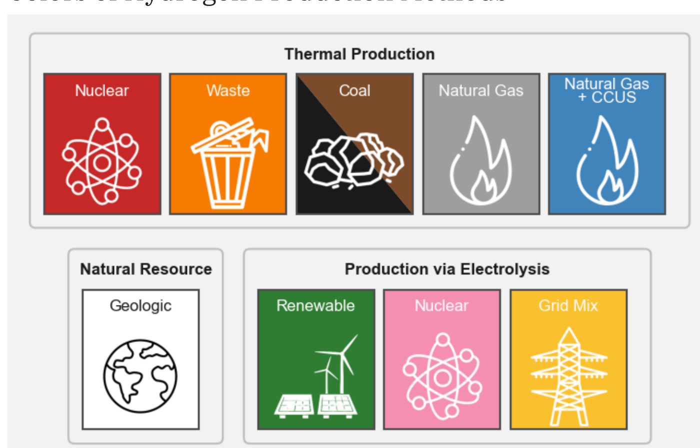
DOE H2@Scale Diagram[6]



Production

- Announced capacity from new production projects for low-emission H_2 by 2030 would increase production by 24x. Production of just the projects that are almost certain to begin production by 2030 would increase production by 3.8x.[7]
- Hydrogen can be extracted from geologic sources[8] or produced via SMR, electrolysis of water, and gasification of coal or biomass.[9] Hydrogen is also produces as a co-product of other industrial processes.[10] Hydrogen production via coal gasification is primarily used in China.[1]
- There has been a recent surge in exploration for geologic hydrogen: subsurface hydrogen trapped in rocks similar to fossil fuels.[8,11] The number of geologic hydrogen exploration companies grew 4x from 2020 to 2024.[11] Analysis indicates that geologic hydrogen resources may be greater than proven NG reserves.[12]
- In SMR, NG reacts with high-temperature steam to produce hydrogen and synthesis gas containing CO and CO_2. The "water-gas shift reaction" converts CO and steam over a catalyst to produce additional hydrogen and CO_2.[13]
- SMR is the least expensive ($0.9-4.4/kg H_2) and most widely used method,[7,9] accounting for 70.6% of total H_2 production in the U.S.[14] SMR emits 7-19 kg CO_2/kg H_2.[11,15,16]
- SMR can be paired with carbon capture, utilization, and storage (CCUS) to decrease carbon intensity to 1-4 kg CO_2/kg H_2.[16] In 2025, the U.S. produced 400 kt of low emission H_2 via SMR with CCUS.[1] This was >40% of globally produced low-emission H_2 in 2025.[1]
- Alkaline and proton exchange membrane electrolyzers are commercially available, while solid oxide electrolyzer cell and anion exchange membrane electrolyzers are maturing.[11]
- The market price for hydrogen via SMR in the U.S. was $1.04 / kg H_2 in 2025, and is expected to stay relatively stable.[1,4,12]
- Green hydrogen production cost $7.5/kg H_2 in 2020[6] and $4.33-6.05/kg H_2 in 2024.[41] The U.S. Department of Energy (DOE) had targeted $2/kg H_2 by 2026 and $1/kg H_2 by 2031.[6] Low-emission H_2 costs remain higher than SMR, in part due to slowdowns in deployment and high inflation.[1] Refitting SMR processes to include CCUS increases costs by 150%.[1]
- The current grid mix is not ideal for electrolysis as 58% of U.S. electricity comes from fossil fuels, resulting in a CO_2 intensity of 20-25 kg CO_2/kg H_2.[18,19]

Colors of Hydrogen Production Methods[16,44]



Click here to view definitions of each production method.

Distribution and Storage

- H_2 in the U.S. is produced at or near where it will be used, reflecting transportation challenges.[9] H_2 can be transported via pipeline, liquid tanker, or tube trailer trucks.[20]
- Pipelines are the least expensive method to transport large amounts of H_2 at $0.2-0.5/kg H_2, with ~1,600 mi of pipeline

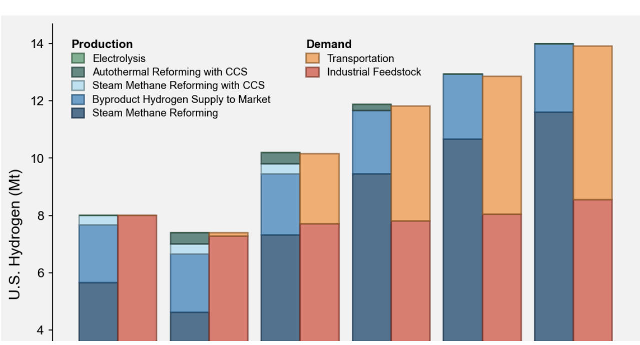
in the U.S.[9,21] Tube trailers transport compressed H_2, typically used for distances under 200 mi, but cost \$0.9-1.9/kg H_2.[9,21]

- Liquid tankers are better suited for transporting larger amounts over longer distances but cost \$2.7-3.2/kg H_2 due to energy and equipment requirements for liquefaction.[9,21]
- Typical storage of H_2 as a compressed gas requires high-pressure tanks >350 bar (atmospheric pressure is ~1 bar).[4]
- Liquid storage achieves greater densities but uses more energy to achieve extremely low temperatures as the boiling point of H_2 is –253 °C (–423 °F).[4,22]
- Hydrogen delivered via pipeline leaks the least, 1.2%, while compressed and trucked supply chains have a leakage rate of 4.2%. Liquid hydrogen has the highest leakage rate of 10-20% due to boil-off: H_2 that converts to a gas and is discarded.[43]
- Underground hydrogen storage options are expanding: salt cavern storage has been in use since 1983 and new facilities are being constructed in the U.S. and Europe,[23] while other proposed sites include abandoned coal mines and refrigerated mined caverns.[24]

End-Uses

- Bulk chemical production is the largest U.S. end use of hydrogen at 4.3 Mt in 2025, followed by fossil fuel refining at 3.7 Mt.[14] Other uses include methanol production and direct reduction of iron (DRI) in steelmaking,[6] which requires 47-68 kg H_2/ t steel.[25]
- A potential application for hydrogen is synfuel production through reacting hydrogen with CO_2. When atmospheric CO_2 is used, the carbon in fuel is considered net zero in emissions, though CO_2 capture process emissions may still occur.[26]
- Blending hydrogen with NG could result in rapid demand increase.[26] Preliminary estimates say hydrogen can be injected into NG pipelines up to 20% by volume, though co-firing with NG reduces GHG emissions only 6-7%.[26,27]
- Hydrogen burners are currently under development to replace NG and other fossil fuels for industrial heating.[1,42]
- Hydrogen can be used in residential buildings to power fuel cell combined heat and power (CHP) systems, direct flame combustion boilers, catalytic boilers, and gas-powered heat pumps. Larger district heat and CHP devices using NG could be redesigned for hydrogen.[28]
- Transportation uses include direct or indirect application in conventional and synthetic fuels across all transport modes. Global refining used 44 Mt H_2 in 2025, over 250 times the direct use as transportation fuel.[1]
- U.S. hydrogen transportation includes about 50k fuel cell forklifts, nearly 50 retail fueling stations, about 80 fuel cell buses, and more than 15k fuel cell vehicles.[5]
- Hydrogen is not well suited for light-duty vehicles, but may find a use to decarbonize heavy-duty transport where storing large amounts of energy and rapid refueling are challenging for electric vehicles.[3,5]

U.S. Projected Hydrogen Supply and Demand[14]



Environmental Impacts

- Total H_2 production generated 1,000 Mt of CO_2 in 2025, more than the combined emissions of Indonesia and France.[1]
- Environmental concerns include NOx emissions from high-temperature combustion,[29] methane leakage from SMR production,[30,31,32] and atmospheric reactions with greenhouse gases (CH_4, O_3, H_2O) leading to increased radiative forcing.[33,34]
- Climate benefits depend on the specific use case, production method, hydrogen and methane emission rates, renewable electricity availability, and time scale.[30]
- Global warming potential for hydrogen ranges from 4x - 12.8x the potential of CO_2.[33]
- Green hydrogen production using renewable electricity is estimated to reduce warming by 66-95% relative to displaced fossil fuel technologies.[30]
- Electrolysis represents less than 5% of worldwide hydrogen production but offers a pathway to zero-carbon emissions.[35]
- Water requirements for electrolysis are 9 kg H_2O/kg H_2 on a stoichiometric basis,[36] increasing to 15-20 kg H_2O/kg H_2 when accounting for electricity generation.[37]
- The water required to produce 800 Mt of hydrogen for a net zero economy in 2050 would be much less than current fossil fuel extraction and processing needs, accounting for 0.7% of global freshwater use. Desalination would add approximately \$0.02/kg to hydrogen prices from salt water.[37]

U.S. Hydrogen Policy

- The Infrastructure Investment and Jobs Act provided \$9.5B for hydrogen,[38] including \$7B to the Regional Clean Hydrogen Hubs Program to form the foundation of a national clean hydrogen network.[39]
- The Inflation Reduction Act offers up to 30% Investment Tax Credit and \$3/kg H_2 Production Tax Credit for clean hydrogen production through 2027, plus up to \$85/ton for low-carbon hydrogen through 2032 in spite of recent legislation that restricted clean energy credits.[38,40]

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Sources for this factsheet are online, help with units and abbreviations is here. See css.umich.edu/publications/factsheets for other factsheets.