Introduction to Clean Hydrogen

The potential roles, benefits, and challenges of clean hydrogen

Why clean hydrogen?

Clean hydrogen is part of a comprehensive portfolio of solutions to achieve the Biden-Harris Administration's goal of net-zero greenhouse-gas (GHG) emissions by 2050. Hydrogen is complementary to other decarbonization efforts such as electrification, and it has a particularly important role to play in addressing the hardest-to-decarbonize sectors of our economy. Clean hydrogen can also provide cleaner air and economic opportunities for communities across America.

What is hydrogen and where does it come from?

Hydrogen is the most abundant element in the universe; it is also the simplest and the lightest. While hydrogen constitutes nearly 75% of all the universe's matter, only a small fraction of the hydrogen accessible on earth exists in a pure state (not bonded to other elements). Producing hydrogen typically involves extracting it from other materials—such as water, biomass, or fossil fuels—using an external source of energy. In addition, "geologic" (or "natural") hydrogen—which forms underground through geologic processes—is receiving growing interest, with its potential for extraction and use being examined by industry and governments all over the world.

What makes hydrogen clean?

Hydrogen can be considered clean when its production process results in low or zero GHG emissions, including upstream emissions from inputs like methane-based feedstocks or electricity production. It can be produced from renewable or nuclear energy or using fossil energy with carbon capture. Ensuring low or zero local air pollution due to the production of clean hydrogen is also a high priority.

Advantages of clean hydrogen

- **Reduced GHG emissions and air pollution:** Clean hydrogen can be *produced* with low or zero GHG emissions; it can also be *used* in many applications (e.g., when converted to electricity in a fuel cell) with no GHG emissions or air pollution.
- **Versatility of sources:** Unlike traditional energy resources, which are typically geographically constrained, clean hydrogen can be produced virtually anywhere, using a wide range of energy resources—including renewables, nuclear, and fossil energy with carbon capture.
- **Versatility of uses:** Clean hydrogen has been described as the "Swiss Army knife" of clean energy because it can be used in multiple applications across many sectors of the economy. For example, it can be used in fuel cells to produce electricity and heat with no direct emissions (emitting only water vapor) across a wide range of transportation and stationary-power applications, including energy storage, and it can be used in a number of industrial and chemical processes.

Clean hydrogen's role in a low-carbon future

- **Addressing our hardest-to-decarbonize sectors:** Clean hydrogen has a key role to play in several sectors where there are limited or no viable alternatives (including in applications where electrification is particularly challenging or costly). These include key drivers of our economy that are essential to American prosperity and a modern quality of life, such as medium- and heavy-duty transportation (trucks, buses, trains, ships, aircraft, and offroad equipment) and industrial and chemical processes like cement and steelmaking, and the production of fertilizers and liquid fuels (including low-GHG fuels such as biofuels and synthetic fuels).
- **Enabling clean power generation:** Clean hydrogen can support the expansion of low- or zero-GHG electricity by providing a means for long-duration energy storage and offering improved flexibility and revenue for clean power generation—including renewable and nuclear power. In addition to providing an option for bulk energy storage (where electricity is used to produce hydrogen, which can later be converted back to electricity using a fuel cell or combustion turbine), hydrogen can also provide options for generators to produce and sell hydrogen into other markets (industrial, heavy transportation, etc.) when integrating surplus electricity into the grid may be challenging.
- **Complementing electrification efforts:** Hydrogen can play an especially valuable role in complementing electrification approaches because it can be stored, transported, and used in locations or applications where electrification may be challenging—for example, when transporting energy over long distances or to remote locations.

Key barriers and challenges facing clean hydrogen

The main barrier to large-scale deployment of clean hydrogen is its high cost, which can be addressed through ongoing technical advances as well as achieving economies of scale across the entire hydrogen value chain—from hydrogen production to delivery and storage, to technologies for hydrogen utilization (e.g., fuel cells).

Additional challenges include increasing public support; improving the durability and reliability of the technologies; expanding hydrogen infrastructure; addressing potential supply chain bottlenecks; developing and supporting a well-trained workforce; adopting the necessary codes and standards; and improving safety knowledge and safety practices. It will also be important to advance methods for hydrogen production, storage, transmission and use that reduce potential negative impacts such as leakage of input gases (e.g., methane) and leakage of hydrogen to the atmosphere.

Environmental and other community concerns about clean hydrogen

Communities have expressed concerns about potentially harmful impacts from clean hydrogen, including concerns about hydrogen safety; air pollution resulting from the production and combustion of hydrogen; water consumption during hydrogen production; the potential indirect impacts of unintentional hydrogen releases on climate change; concerns that producing hydrogen via steam methane reforming will hinder a transition away from fossil fuels; and a lack of trust in companies with ties to the fossil fuel industry.

Concerns have also been raised by some community leaders around the use of carbon capture technology applied to fossil-based hydrogen production technologies and the siting of hydrogen production facilities. The U.S. government's Hydrogen Interagency Task Force understands and takes seriously the public's concerns around hydrogen and is undertaking diverse efforts to improve the public safety and benefits of hydrogen—such as funding projects that improve leak detection and research that investigates hydrogen's indirect global warming potential. For example, see a new clean hydrogen and environmental justice resource released by the Department of Energy (DOE).

Uses for hydrogen and the scale of demand

- **Current uses:** Most of the hydrogen consumed in the United States today is used as a ***chemical input*** for processes such as petroleum refining, fertilizer production, and the production of chemicals, such as methanol. These and other uses drive a demand for roughly **10 million metric tons** (MMT) per year in the United States and roughly 100 MMT globally. It is also used in limited quantities today as a ***fuel*** (e.g., for lift trucks and transit buses).
- **Emerging and future uses:** Future uses of clean hydrogen touch on many sectors of the economy, including steel and cement production; industrial heat; as a transportation fuel for medium- and heavy-duty vehicles, trains, ships, aircraft, and offroad equipment; for producing biofuels and synthetic fuels; for backup power; and for long-duration energy storage. Analysis in the *U.S. National Clean Hydrogen Strategy and Roadmap* identifies opportunities for a demand of **10 MMT** of clean hydrogen by 2030, **20 MMT** by 2040, and **50 MMT** by 2050.

How hydrogen is produced

Currently, 95% of the hydrogen produced in the United States comes from natural gas, using steam methane reforming (SMR). While SMR produces carbon dioxide emissions and other air pollutants, there is a small but rapidly growing industry producing clean hydrogen from electrolysis, where renewable or nuclear electricity is used to break the chemical bonds of water molecules to produce hydrogen and oxygen gas.

Emerging and future production methods include advanced ***electrolysis*** technologies; ***thermal production*** of hydrogen from fossil resources (with carbon capture), biomass, or waste streams; ***advanced approaches***, such as the use of sunlight to directly split water; and may also include ***extraction of geologic hydrogen***, including potential methods for stimulating generation of geologic hydrogen.

Expected positive outcomes from increased production and use of clean hydrogen

- **Reduced GHG emissions:** Achieving the estimated potential of 50 MMT of clean hydrogen production domestically by 2050 could reduce GHG emissions economy-wide by 10% and will be critical to achieving a net-zero emissions economy. Global emissions reductions from large-scale use of clean hydrogen are expected to be even higher—up to 20%.
- **Improved air quality:** The sectors where clean hydrogen will play the largest role are also some of the most polluting sectors of our economy. Replacing conventional fuels with clean hydrogen in many of these applications (e.g., heavy trucking, industrial heat) can significantly reduce local air pollution, especially in disadvantaged communities that are marginalized by underinvestment and overburdened by pollution.
- **Economic opportunities:** The domestic hydrogen and fuel cell industry is a rapidly growing high-tech sector, with the potential to help strengthen the domestic economy and provide high-skilled jobs in manufacturing, installation, maintenance, and service. According to one estimate, by 2030, the domestic hydrogen industry is expected to create 100,000 new jobs.
- **Energy security:** Because it can be produced from diverse resources in virtually every part of the world, clean hydrogen has the potential to reduce market vulnerabilities and redraw the international energy landscape in ways that are beneficial to the United States, our partners, and our allies.

What is the U.S. government doing to support the use of clean hydrogen?

The U.S. government is committing unprecedented resources and attention to developing the clean hydrogen economy for the benefit of all Americans as well as the broader global community—including through historic investments in the Bipartisan Infrastructure Law and the Inflation Reduction Act. Read more about:

- The overarching plan for hydrogen in the *U.S. National Clean Hydrogen Strategy and Roadmap*.
- The U.S. government's Hydrogen Interagency Task Force and its all-of-government approach to clean hydrogen.
- Historic investments in the Hydrogen Hubs, which will form the foundation of a national clean hydrogen network.
- The economy-wide vision for clean hydrogen in H2@Scale.
- DOE's ambitious Hydrogen Shot goal.