DOE Hydrogen Program Responses to Common Questions & Concerns about Hydrogen

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Introduction

This document serves to increase transparency and provide information to address concerns about hydrogen's opportunities and limitations as a decarbonization solution, especially those raised by environmental justice (EJ) groups. These are prominent concerns that the Department of Energy (DOE) has become aware of though requests for information (RFIs), public listening sessions held by multiple DOE offices,[1] and other means via DOE's Office of Economic Impact and Diversity (ED).

The information in this document attempts to reduce the uncertainty and address misconceptions about clean hydrogen and hydrogen-based technologies and discuss how DOE-funded projects may be able to address further concerns. Responses also reference recently published "Frequently Asked Questions (FAQs) about Hydrogen and Fuel Cells."[2] These replies are informed by the knowledge of clean hydrogen experts at DOE, using the best available data.

The DOE Hydrogen Program's Energy and Environmental Justice Working Group (H2 EEJ WG)[i] plans to update and add to these responses as new questions arise and more information becomes available. For any comments or questions related to this document or the FAQs please reach out at hydrogen-FAQ@hq.doe.gov.

Common Questions

1. What is clean hydrogen?

Clean hydrogen is hydrogen that is produced with low greenhouse gas (GHG) emissions. It can be produced from electrolysis coupled to renewable and nuclear energy, or using fossil resources when the carbon emissions are captured and stored (see the FAQs for information on hydrogen production methods). To determine what qualifies as "clean" hydrogen, DOE characterizes the GHG emissions resulting from hydrogen production on a "well-to-gate" basis. This approach assesses the "upstream" emissions from the energy resources and the feedstock used, which occur prior to the point of production, and emissions at the production facility itself. Examples of upstream emissions include those resulting from electricity generation and natural gas drilling. Emissions at the production facility include those from combustion or other chemical processes (e.g., pyrolysis, etc.). Emissions are quantified using the term "carbon dioxide-equivalent" (or CO_2e). CO_2e is a unit of measurement that represents the global-warming impact of any greenhouse gas (GHG), using the global warming impact of a kilogram of carbon dioxide (or one CO_2e) as a baseline. Methane, for example, the main chemical in natural gas, is a powerful GHG and has global warming potential of roughly 30 CO_2e, or about 30 times the global warming potential of carbon dioxide.

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[i] The H2 EEJ WG includes multiple offices within the DOE Hydrogen Program (see www.hydrogen.energy.gov) and coordinated with the H2 Joint Strategy Team.

In June of 2023, DOE published the initial Clean Hydrogen Production Standard (CHPS) Guidance, establishing a well-to-gate emissions target for clean hydrogen production of 4 kilograms of CO_2e per kilogram of hydrogen produced.[ii] The CHPS guidance is consistent with a vast majority of responses from stakeholders who commented on the draft guidance, released in September 2022. This target represents a roughly 60% reduction of emissions relative to the most common way that hydrogen is currently produced—via steam methane reforming (SMR). Hydrogen production technologies that can achieve this target today include electrolysis powered by renewables or nuclear power, as well as SMR with high rates of carbon capture and storage (CCS). This target is also the threshold to qualify for the hydrogen production tax credit (45V) established by the Inflation Reduction Act.

It is important to note that the "well-to-gate" boundary does not include emissions associated with manufacturing equipment, such as electrolyzers or renewables. DOE is currently funding analysis of the emissions intensity of manufacturing and may establish targets to reduce manufacturing-related emissions in the future. DOE is also funding analysis to better understand the impact that indirect greenhouse gases, such as hydrogen itself (when it leaks and escapes into the atmosphere), can have on how clean hydrogen production is. These impacts may also be accounted for in future targets.

2. *Why has DOE shifted away from using colors (grey, blue, green, etc.) to differentiate between hydrogen production methods?*

Rather than characterizing various hydrogen production pathways by different colors, DOE and many stakeholders are shifting to the use of "clean hydrogen." This is being done to reflect the primary focus on carbon intensity, which is considered the most important metric, regardless of how the hydrogen may be produced. Using the term "clean hydrogen" helps to maintain focus on hydrogen that is made from low emissions pathways without preference for a given approach. As discussed in ***What is clean hydrogen?***, emissions are quantified using the term carbon-dioxide equivalent (or "CO_2e").

While the color-coded descriptions can be a useful way to describe the different energy resources and processes used to produce hydrogen, they are not as useful or transparent as quantitative information about total GHG emissions. Quantifying emissions rather than assigning colors will provide more clarity on the amount of emissions that may be produced and the resulting environmental impact of that clean hydrogen. Reporting values for carbon intensity will also improve transparency in DOE-funded projects, align with international standards, and help quantify emissions-mitigation opportunities for any given technology. DOE will continue to be transparent about how clean hydrogen is produced in all its projects (e.g.,

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[ii] The CHPS Guidance provides more information on this target and how it was developed to account for statutory factors within the Bipartisan Infrastructure Law.

projects involving electrolysis, steam methane reforming, biomass gasification, nuclear energy sources, etc.).

For more than 30 years, DOE has funded the *Greenhouse gases, Regulated Emissions, and Energy Use in Technologies* (or GREET) tool, which assesses the life cycle GHG emissions from all hydrogen production pathways (among many other energy-related technologies). This helps to ensure consistency and transparency in determining which hydrogen is "clean" and which isn't (see the hydrogen FAQs for more information about GREET). This tool, which was developed by DOE's Argonne National Laboratory and has been used by thousands of stakeholders for decades, enables DOE to calculate the GHG emissions from a proposed hydrogen production project. GREET requires specific knowledge about each feedstock and energy source. Feedstocks are the raw materials used to make hydrogen and can include natural gas, biomass, and water. Energy sources can include electricity (e.g., from renewables directly, or from the grid), natural gas, biomass, etc. For implementation of the Hydrogen Production Tax Credit (45V), the Inflation Reduction Act defines the life cycle boundary as "well-to-gate" (for more information on this, see ***What is Clean Hydrogen?***) and specifies that GREET must be used to determine those well-to-gate emissions. DOE will be providing ongoing training through webinars and workshops to disseminate information about the tool and encourage its use. DOE will continue to update GREET as more information becomes available, such as information about emissions from upstream manufacturing processes.

3. *What do clean hydrogen demonstrations and deployments look like?*

Hydrogen technologies can be used across a wide range of applications. While hydrogen is already widely used for chemical and industrial processes, demonstrations and deployments of clean hydrogen technologies are expanding into new operating environments, including warehouses, city transportation systems, and ports. Hydrogen fuel cells, which use hydrogen to produce electricity with no emissions other than water, are being deployed across the country in many applications, including for backup power, material-handling, and transportation. In the United States today there are more than 60,000 fuel cell forklifts, approximately 150 fuel cell buses, and more than 16,000 fuel cell cars in operation, all using hydrogen to operate and producing zero emissions.

Significant media attention lately has focused on the *Hydrogen Hubs* (officially, the "Regional Clean Hydrogen Hubs"), which will be among the largest clean hydrogen demonstration and deployment projects in the United States and the world. These commercial-scale projects will aim to illustrate the feasibility of commercial-scale clean hydrogen with co-located hydrogen production and use (see FAQs for more information about Regional Clean Hydrogen Hubs). The Bipartisan Infrastructure Law (BIL) also requires the Regional Clean Hydrogen Hubs to demonstrate a diverse array of end uses for clean hydrogen, including in the power generation, industrial, and transportation sectors. Such end-uses may include as a fuel for long-haul trucks, as a chemical feedstock for industrial applications, as a way to store energy to help variable renewable-power generation integrate with the electric grid, and others. DOE's vision for clean hydrogen demonstrations and deployments is to target hard-to-decarbonize sectors. These sectors include, but are not limited to, industrial heating, chemicals production, heavy duty transportation, aviation, maritime shipping, and energy storage to support a renewable-based grid.[3] See the FAQs for more information on clean hydrogen uses.

4. How are the workforce and first responders being trained to work safely with hydrogen?

Like any other fuel, such as gasoline, diesel, or natural gas, hydrogen must be handled appropriately (see the FAQs for more information about hydrogen safety). The safe deployment of clean hydrogen is one of DOE's highest priorities, and safety standards and training are incorporated throughout the entire value chain for clean hydrogen—from production through storage, distribution, and end use. For example, all fuel cell vehicles and hydrogen filling stations must meet the same rigorous safety standards as their gasoline and diesel counterparts. DOE's Hydrogen and Fuel Cell Technologies Office (HFTO) has funded work in Safety Codes and Standards for more than three decades, which supports the safe deployment and use of hydrogen and fuel cell technologies—including dissemination of safety-related information, trainings, and lessons learned. Over the last two decades, HFTO-supported efforts have trained more than 36,000 code officials and first responders on hydrogen technologies.[4,5]

Several tools and courses addressing hydrogen safety are currently available to the public, including the Hydrogen Tools Portal (http://h2tools.org), which includes the Hydrogen Lessons Learned database (http://h2tools.org/lessons/) and the Hydrogen Safety Best Practices online manual (https://h2tools.org/bestpractices) developed by DOE and the Hydrogen Safety Panel at Pacific Northwest National Laboratory (PNNL). These resources were compiled leveraging the expertise of industry, government, universities, and research institutions. HFTO has also prioritized training emergency response personnel through the distribution of awareness-level and operations-level classroom curricula. PNNL, with support from DOE, has collaborated with the American Institute for Chemical Engineering (AIChE) to form the Hydrogen Safety Panel and the Center for Hydrogen Safety, which provides direct access to safety training resources.[6] The Center for Hydrogen Safety has more than 100 members worldwide, including some of the largest companies and government ministries developing and deploying hydrogen technologies in the United States and worldwide. This provides stakeholders with access to both a long history of hydrogen safety information as well as the most up to date lessons learned and best practices. Other examples include national hydrogen safety training for emergency responders[7] developed through the California Fuel Cell Partnership, PNNL, and other partners.

Additional tools and trainings are currently being developed including a DOE-supported laboratory course that was made publicly available through the Center for Hydrogen Safety website (Hydrogen Laboratory Safety). HFTO also supports outreach and education activities, including the Hydrogen Education for a Decarbonized Global Economy (H2EDGE) project, which aims to develop and deliver professional training courses and university curriculum content. In collaboration with industry and university partners, H2EDGE is developing certificates, credentials, qualifications, and standards for training.

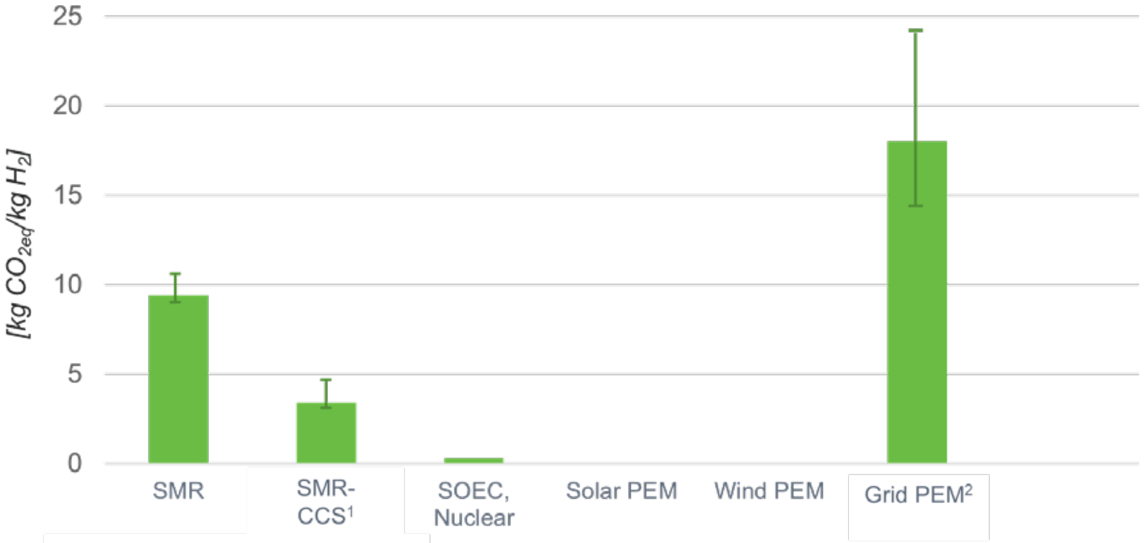
Common Concerns about Hydrogen

1. Hydrogen production via steam methane reforming (SMR) produces more greenhouse gas emissions than other hydrogen production methods.

Generally, SMR without carbon capture and storage (CCS) produces more greenhouse gas (GHG) emissions than most other production methods (Figure 1); therefore, the use of SMR without carbon mitigation methods is not supported by DOE. The overall GHG emissions of SMR and other hydrogen production methods can vary, depending on the entire system of production involved. The GHG emissions associated with a hydrogen production method depend on several factors, including the feedstock,[8] energy source, engineering controls, and carbon capture system (for production pathways using capture and storage). See the FAQs for more information on hydrogen production methods. For example, if the feedstock is methane (as for SMR), upstream methane leaks need to be considered, as does the source of the electricity used in the process, as well as emissions related to the carbon capture process. Because the feedstock for electrolysis is water, and the energy used in the process is provided by electricity, upstream methane leaks are not a factor; however, the electricity source can generate significant upstream GHG emissions if it is not renewable or nuclear based.

Argonne National Laboratory's Greenhouse Gases, Regulated Emissions, and Energy Use in Technologies (GREET) model provides a comprehensive platform for the life cycle assessment (LCA) of different hydrogen production pathways, including overall GHG emissions.[9] The following figure shows a sample of the GHG emissions associated with SMR and electrolysis calculated with the default assumptions in GREET for different scenarios.[10] GHGs are expressed here in carbon dioxide equivalents (CO_2e)—see explanation of CO_2e in ***What is clean hydrogen?***

The parameters that are input into the GREET model—such as the methane leakage rate or percentage of carbon captured—can be adjusted to reflect specific projects. This graph shows green bars that represent the average GHG emissions from different hydrogen production scenarios. The error bars indicate the range of potential methane leakage for pathways that use natural gas and the range of average grid emissions for different regions of the country for the pathways that use the grid to power an electrolyzer.



1. Assumes 96% CCS rate given state-of-the-art technologies
2. Based on average grid emissions in various regions of the country

Source: Argonne National Laboratory's GREET® model

Figure 1: Summary of calculated GHG emissions from various hydrogen production pathways. SOEC stands for solid oxide electrolyzer cell, which is a high temperature electrolyzer (700°–800°C). PEM stands for proton exchange membrane, which is a type of low-temperature electrolyzer (70°–90°C).

2. *Hydrogen combustion applications produce health-harming air pollutants such as nitrogen oxides (NOx).*

Any high-temperature combustion (e.g., combustion of diesel, gasoline, natural gas, hydrogen) can produce NOx[11] which is a hazardous air pollutant. NOx formation occurs when air (which contains nitrogen and oxygen) is exposed to very high temperatures (>1500°C). While NOx formation is a concern for hydrogen combustion, it is also a concern for the combustion of fossil fuels. There are multiple mitigation strategies to prevent emission of these pollutants. For more background information on NOx and the current mitigation strategies, please refer to the FAQs. DOE's Office of Fossil Energy and Carbon Management supports efforts to ensure low NOx and reduced air pollution for turbine technologies that may utilize clean hydrogen.

3. *Hydrogen is a less efficient option to replace fossil fuels for heating and cooking in homes and buildings and does not out-perform batteries for light-duty vehicles.*

DOE is not prioritizing clean hydrogen to replace more-efficient clean-energy options for residential use or light-duty vehicles (see ***Is hydrogen going to replace electrification efforts?*** in the FAQs). There are circumstances where using clean hydrogen is more impactful (e.g., certain applications that are hard to electrify like heavy-duty transportation, ammonia production, steelmaking, and production of liquid fuels). These high-priority applications are identified in the *U.S. National Clean Hydrogen Strategy and Roadmap*. While electrifying home appliances like heating and cooking is becoming more prevalent, there are cases in which using clean hydrogen may be considered, particularly if there is more infrastructure available for hydrogen gas than there is for electricity, or for certain legacy buildings that cannot be retrofitted easily with heat pumps. The construction of a large network of new pipelines to bring clean hydrogen specifically for residential applications is unlikely to be a priority for the U.S. Government.

For cars that most people drive, battery electric vehicles have more commercial options than hydrogen-powered vehicles. Light-duty hydrogen fuel cell electric vehicles (FCEVs) face more barriers to widespread adoption due to the lack of hydrogen stations and are only sold in certain regions of the country. Depending on the application and requirements such as driving range, fueling times, and payload capacity, medium- and heavy-duty FCEVs may be more suitable than battery electric vehicles, as discussed in the FAQs and the U.S. National Blueprint for Transportation Decarbonization.[12]

The most promising markets for clean hydrogen are primarily where electrification is difficult, impractical, or expensive—including heavy-duty vehicles, industrial applications, and other transportation applications such as marine and air. DOE's research, development, and analysis efforts will continue to help identify the most promising applications.

In some cases, relevant to buildings and industrial complexes, blending hydrogen into natural gas is an interim option that can reduce greenhouse gas emissions, help achieve decarbonization goals, and decrease the use of fossil fuels. As required in the Bipartisan Infrastructure Law, at least one Hydrogen Hub must demonstrate clean hydrogen for residential heating. Once clean hydrogen is injected into the natural gas system, it will be burned in all the connected residential combustion appliances such as gas stoves and furnaces. This exploration of clean hydrogen for residential use is intended to replace dependence on natural gas in the long-term and is not intended to replace heating and cooking in homes powered by clean electricity.

Hydrogen can also be used in stationary fuel cells to produce electricity for buildings, providing the benefit of zero emissions and resiliency. See the hydrogen FAQs for more information about fuel cells. In addition, fuel cells can provide options where grid infrastructure is limited such as for remote or island communities. Because fuel cells using hydrogen produce no carbon emissions as well as no local air pollution (e.g., NOx, SOx), they can be an attractive emerging technology in regions where air quality is a concern. By the end of 2019, there were more than 300,000 residential fuel cells in Japan providing power and hot water, with reliable, resilient operation.[13]

4. *The fossil fuel industry is the primary driver for hydrogen production, and producing hydrogen from fossil fuels will only encourage further investment in the sector.*

It is true that the fossil fuel industry has advocated for and is involved in developing hydrogen projects. However, the fossil fuel industry is only one of many drivers in the clean hydrogen ecosystem. For example, there is significant interest from developers and users of renewable resources, particularly because hydrogen can be stored and used when intermittent resources such as solar and wind are not available. A diverse coalition of parties interested in clean hydrogen, as indicated through participation in requests for information, listening sessions, and H2 Matchmaker,[14] includes states and municipalities, tribal nations, venture capital firms, utility companies, renewable energy developers, industrial manufacturers, and innovative startups. DOE is committed to advancing clean hydrogen production from renewable and nuclear energy, not just using fossil fuels as a feedstock. Historic federal investments, tax incentives, and the Clean Hydrogen Production Standard will create conditions that will change the current market for hydrogen and help ensure that clean hydrogen is produced from a number of different pathways in the future.

Clean hydrogen is one part of a comprehensive portfolio of energy technologies that can support the nation's transition to a net-zero economy while leveraging regional resources and creating equitable and sustainable growth. Clean hydrogen can enable decarbonization, particularly in industries where other methods of decarbonization (e.g., electrification) are not feasible. See the U.S. National Clean Hydrogen Strategy and Roadmap and the U.S. National Blueprint for Transportation Decarbonization for targeted high-impact uses.[**Error! Bookmark not defined.**, 15]

DOE recognizes that using a combination of clean hydrogen production methods is essential to support a clean and equitable energy economy. Hydrogen production from steam methane reforming (SMR) coupled with carbon capture and storage is an approach for producing clean hydrogen without large investments in new hydrogen infrastructure because existing SMR facilities can be retrofitted with carbon capture and storage capabilities. Sec. 813 of the Bipartisan Infrastructure Law (BIL) supports the development of Regional Clean Hydrogen Hubs, and the BIL specifies that one of these hubs must produce clean hydrogen with a fossil feedstock. However, DOE specified that BIL funds should not be used on construction of new fossil facilities, and instead must be dedicated to retrofitting existing facilities with technologies that reduce emissions.[16]

Among the many clean-hydrogen production pathways DOE is pursuing, a top priority is advancing electrolysis powered by clean sources of electricity such as renewables and nuclear energy. Although most of the hydrogen produced in the U.S. today is from SMR, recent legislation supports investment in non-fossil hydrogen production, such as electrolysis. The BIL specifically includes $1 billion for the research, development, demonstration, and deployment of electrolysis, and the Inflation Reduction Act includes a clean hydrogen production tax credit that maximizes the incentive for clean hydrogen produced with emissions below 0.45 kg CO_2e per kg of hydrogen – which can be achieved, for example, by running an electrolyzer with renewable electricity. Recent funding opportunities under the BIL (SBIR and FOA) make funding available for universities, small businesses, and industry to support electrolyzer R&D, the electrolyzer supply chain, and manufacturing.[17, 18]

In addition, President Biden announced use of the Defense Production Act as one of several mechanisms to support clean hydrogen production from electrolysis, giving DOE the authority to accelerate domestic production of five key energy technologies (including electrolyzers) that reduce demand for fossil fuels and bolster our clean energy economy.[19] The combination of the BIL, the Inflation Reduction Act, and the Defense Production Act are intended to boost non-fossil hydrogen pathways and drive investment in electrolysis from the private sector.

5. *Investments in supply chains based on fossil fuels may result in stranded assets.*

DOE is not funding the development of new steam methane reforming (SMR) facilities, but instead is focused on the development of carbon capture technologies that will enable cleaner operation of these existing facilities. By coupling carbon capture technologies to SMR facilities, the production of GHGs will be reduced in the near-term. With the long-term goal of transitioning towards cleaner forms of hydrogen and reducing dependance on fossil fuels, these fossil-based SMR facilities can be repurposed to reform methane from biological and natural sources such as municipal solid waste and landfills, thereby preventing SMR facilities from becoming stranded assets. In addition, DOE is also pursuing approaches other than SMR to convert natural gas into hydrogen—such as pyrolysis, which can convert natural gas or biomass into solid carbon and gaseous hydrogen, without the need for carbon capture and storage. Pyrolysis, as opposed to SMR, results in a valuable co-product—solid carbon—which may be used in various industries such as manufacturing tires and batteries. Such an approach may ultimately have lower GHG emissions than SMR with CCS, and therefore be a more-viable longer-term solution.

To reduce the likelihood of stranded hydrogen assets in all the Hubs and similar investments, DOE is targeting strategic, high-impact end uses in sectors such as heavy-duty transportation, industrial applications, and enabling renewables through long-duration energy storage. DOE envisions that clean hydrogen can play a key role in the future of clean energy, particularly in these difficult-to-decarbonize areas.[3,15] For more information on hard-to-decarbonize areas, see the hydrogen FAQs.

Much attention has been paid to the historic level of investment in clean hydrogen technologies in the BIL, especially for the development of Regional Clean Hydrogen Hubs. The legislative language mandates that at least one of the hubs is required to use a fossil fuel feedstock. The BIL also requires that each of the Hubs can produce hydrogen that demonstrably meets the Clean Hydrogen Production Standard. DOE expects the Hubs to employ state-of-the-art technologies and best practices to mitigate emissions (GHG and criteria pollutants) within their facilities, and the projects will be evaluated by the degree to which they reduce well-to-gate emissions (see ***What is clean hydrogen?*** for more information about the Clean Hydrogen Production Standard and well-to-gate emissions).

6. *Carbon capture and storage is a) energy-intensive, b) expensive, and c) has not been proven effective at reducing emissions.*

Carbon capture and storage (CCS) is a proven and valuable addition to reduce emissions associated with hydrogen production from fossil fuel feedstocks.[20] CCS is capable of capturing 90% of the carbon dioxide from power plants and other facilities,[21] with 35 commercial capture facilities in operation globally and over 300 facilities in development.[22] DOE is investing in research to reduce the cost of CCS and the energy penalty associated with carbon capture, investigating options to convert carbon dioxide into valuable products. DOE is also conducting R&D to enable long-term carbon dioxide storage.

The following three sections address each of the listed concerns.

a) *CCS is energy intensive.* The energy requirements of a carbon capture system depend on several factors, including the concentration of carbon dioxide in the gas stream at the facility, the carbon capture technology employed, and system engineering. For example, carbon dioxide capture at ethanol, fertilizer, or gas processing facilities is relatively efficient because these facilities tend to have higher concentrations of carbon dioxide in their gas streams. Removing carbon dioxide from a given volume of a gas stream requires about the same amount of energy, regardless of how much carbon dioxide the gas stream contains (i.e., regardless of whether if it's a stream with low- or high-concentration of carbon dioxide). Therefore, removing carbon dioxide from a higher-concentration stream is less energy intensive than removing it from a low-concentration stream, because more carbon dioxide is removed for a similar energy input. DOE is actively investing in development of carbon capture materials, such as sorbents and membranes that have the potential to further improve the rate of carbon dioxide capture and reduce the energy required to separate it from other gases.[23] Improved integration of carbon capture systems into facilities can help improve efficiency and reduce cost.

b) *CCS is expensive.* The cost of CCS is dependent upon the application. For example, CCS is generally cheaper for gas streams with higher concentrations of carbon dioxide because the capture technology is more efficient in these conditions. As noted in the *U.S. National Clean Hydrogen Strategy and Roadmap*, the cost of hydrogen produced from SMR increased by less 10% (from $2.08/kg to $2.27/kg) with addition of CCS, making SMR with CCS a viable short-term approach.[24] The cost of CCS also depends on the materials' efficiency and cost. DOE is investing in next generation capture materials, such as sorbents and membranes, that have the potential to significantly reduce cost and energy requirements while increasing capture rates.[25] The transport distances and storage conditions also impact the cost of CCS. In addition, the conversion of carbon dioxide into useful products such as fuels, plastics, chemicals, building materials, and bioproducts can help extract economic value and offset some costs.[26]

c) *CCS has not been proven effective at reducing emissions.* State-of-the-art carbon capture systems coupled with steam methane reforming (SMR) have demonstrated high carbon capture rates (>90%), and a carbon capture system powered by energy released in the hydrogen production process has the potential to reduce greenhouse gas emissions by 75%.

> Over 100 commercial-scale CCS systems are currently operable or in development worldwide. Carbon dioxide has been transported in the United States (and in other countries) for decades, and there are more than 5,000 miles of existing pipelines in the United States that transport carbon dioxide to storage locations.[27] In addition, tens of millions of tons of carbon dioxide have been safely stored over 20 years in the United States, Canada, and Norway. For example, more than 30 million tons of carbon dioxide has been stored in the United States in large-scale field projects, and 19 small-scale projects have safely injected over a million tons of carbon dioxide into different geologic settings.[28]

DOE is also actively investing in research of carbon dioxide storage technologies.[29] There are many technical factors that must be considered when siting a subsurface carbon storage complex including available storage space, depth and integrity (ability to store gases without leaks), and ability/ease of injecting gases into the geologic feature. These characteristics for a potential site are determined through a rigorous process, which includes assessing potential storage risks. The EPA also has specific regulations governing the underground storage of carbon dioxide, and any such installation must comply with these regulations as part of the permitting process. DOE's Regional Carbon Sequestration Partnership (RCSP) Initiative supports research into the best approaches for storing carbon dioxide. The RCSP has developed a number of best-practice manuals.[30]

Over the long term, DOE is investing billions of dollars to support the storage of carbon dioxide in the United States to enable net-zero emissions targets. DOE is advancing technologies to:

- Reduce the costs of carbon capture and storage
- Investigating different strategies to achieve negative emissions using CCS (e.g., by storing carbon emissions from renewables such as biomass, or by storing carbon dioxide extracted from the atmosphere through "direct air capture")
- Developing the tools for regulators and resource managers to manage CO_2 storage.

Additionally, DOE is also investing in CO_2 conversion pathways that produce useful products. The utilization of captured CO_2 is a promising approach for emissions reduction and will reduce the need for storage. Many utilization strategies include the synthesis of fuels, plastics, chemicals, and building materials. However, the markets for these products are not large enough to for these approaches to fully achieve net-zero goals on their own. Therefore, CCS will be essential to reduce GHG emissions and avoid the worst climate crisis scenarios.

7. *Existing pipeline infrastructure is not equipped to carry large volumes of hydrogen without creating safety hazards. Construction of new pipelines would further burden frontline communities and be very expensive.*

It is true that most of today's natural gas pipeline infrastructure is not equipped to transport large volumes of hydrogen. According to a study by the National Renewable Energy Laboratory,[31] existing legacy pipelines typically cannot carry blends of hydrogen beyond 5%–

15%. DOE is funding research into safely blending clean hydrogen in natural gas pipelines and development of new pipeline materials that can safely transport higher concentrations of hydrogen. For example, DOE's HyBlend and H-Mat consortia include over 30 partners committed to working together to address materials compatibility issues.[32]

As discussed in the *U.S. National Clean Hydrogen Strategy and Roadmap*, federally funded deployments of clean hydrogen technologies will target high-impact end-uses (e.g., heavy-duty vehicles, industrial applications, and long-duration energy storage), where hydrogen can be provided to the end-use application from relatively few, centralized locations. This means that the construction of a large network of new pipelines—e.g., the network that would be needed to bring clean hydrogen to residential locations or for light-duty vehicle refueling—is unlikely to be a priority for DOE. However, new pipelines will likely be built in locations with a large demand for clean hydrogen (e.g., steel plants, hydrogen hubs, and truck terminals) and in these cases, the risk to communities will be reduced with "dig-once" policies, where pipelines will be built while other infrastructure is installed to minimize disruption to the local communities.[3]

DOE is funding ongoing research into hydrogen transportation via pipelines, including blending hydrogen into existing steams of natural gas pipelines. When clean hydrogen is blended into natural gas, heat and power can be generated with lower emissions than using pure natural gas alone. This is a near-term solution for reducing carbon dioxide emissions. However, increasing the percentage of hydrogen in existing pipelines can result in increased fatigue and cracking of the pipelines depending on the type of material and operating conditions (e.g., temperatures and pressures). DOE, in collaboration with industry, has created the HyBlend initiative, which is dedicated to developing public tools that assess the risks of blending given different materials, system ages, and blend concentrations.[33] HyBlend is also developing tools for analyzing life cycle greenhouse gas emissions and costs of blending compared to other energy pathways, along with materials development and assessment for improved pipeline materials. For example, pipelines made from plastics could potentially replace metal pipelines because they are less impacted by higher hydrogen blends.

DOE is committed to mitigating the risks and costs associated with deployment of new pipelines and is funding research into pipeline materials, leak mitigation, and safety. For example, DOE will work with the U.S. Department of Transportation's Pipeline and Hazardous Materials Safety Administration (PHMSA), the EPA, and other agencies to take all necessary measures to prevent leaks and mitigate hazards of hydrogen leakage. Such measures will involve engineering controls and safety guidelines, including utilization of leak detection technology. (See **Concern 8** for more information on hydrogen leakage and detection.)

Before clean hydrogen is blended with natural gas or otherwise used in buildings, either residential or commercial, extensive safety and cost analysis are critical. Since building new pipelines could be disruptive and costly, additional costs associated with these processes must be weighed against the benefits of providing a more sustainable and low-carbon gas product to consumers. DOE will assess the costs and risks associated with demonstrating clean hydrogen use in building to develop best practices. Additionally, several natural gas utilities, in the United States and internationally, are currently evaluating hydrogen blending in in-service natural gas networks and in isolated pipeline demonstration facilities.

8. Hydrogen leakage mitigation and detection are nascent areas with limited reliable technology, and hydrogen in the atmosphere can worsen global warming.

Commercial hydrogen detection technologies are currently used in industrial and research settings to protect workers from significant leaks. However, lower-cost, more-sensitive hydrogen sensors are needed to detect smaller hydrogen leaks. DOE has ongoing R&D and open opportunities for funding R&D to develop tools to accurately measure very small hydrogen losses (measurable on the parts-per-billion scale), as well as leak-mitigation technologies.[34]

Hydrogen is not a direct greenhouse gas (GHG); however, some early research shows that hydrogen can interact with other gases in the atmosphere and subsequently extend the lifetime of certain GHGs such as methane (see the FAQs for more information). DOE is supporting research to better understand the indirect warming potential of hydrogen in the atmosphere. While further research is necessary to fully understand these impacts, there is no evidence to suggest that hydrogen leakage would significantly offset the climate benefits of using clean hydrogen. Furthermore, improvements in leak detection and prevention offer clear pathways to mitigate any negative climate impacts.

Along with partners in the European Commission, HFTO co-led the “Clean Hydrogen Joint Undertaking Expert Workshop on the Environmental Impacts of Hydrogen” in March 2022. A comprehensive report on this meeting was published, containing a thorough discussion of the technical and knowledge gaps related to atmospheric models, sensor and monitoring technology, and estimated hydrogen losses.[35] One important finding was that more research is needed to fully understand the impact of hydrogen in the atmosphere. In coordination with NOAA, DOE plans to improve existing climate models to further understand the global hydrogen cycle and the impacts of hydrogen leakage. This collaboration will also support atmospheric data collection, strengthen hydrogen measurement techniques, and update state-of-the-art life cycle assessment tools, such as Greenhouse Gases, Regulated Emissions, and Energy Use in Technologies (GREET), to fully reflect these effects.

9. Water usage for electrolysis can be devastating in water-short areas of the United States.

Water demand for electrolysis is an important concern, particularly in the context of climate change related droughts in various parts of the United States. Although electrolysis does consume water to generate hydrogen, the overall water consumption for hydrogen produced from electrolysis is comparable to the amount of water consumed in steam methane reforming, and even in the refining of petroleum products such as diesel and gasoline. Deployments of hydrogen production technologies should be optimized to mitigate water impacts in stressed regions of the country, such as through connective infrastructure to other regions. The

Greenhouse Gases, Regulated Emissions, and Energy use in Technologies (GREET) model can be used to estimate water usage for different hydrogen production methods.[36] In addition, DOE is funding research into electrolyzers that can tolerate impure water sources, which could further reduce stress on limited clean, freshwater resources.[37] The additional cost of water purification and desalination does not significantly contribute to the overall cost of hydrogen production from seawater, and this is a promising pathway for western states that have access to seawater. See the hydrogen FAQs for more information about water consumption with electrolysis.

10. Regional Clean Hydrogen Hubs and local hydrogen projects will increase residential energy prices.

There is no connection today, and unlikely to be any significant connection in the future, between large-scale hydrogen projects (such as the Regional Clean Hydrogen Hubs) and residential energy prices. DOE currently expects the use of clean hydrogen for residential purposes (heating and electricity) to be rare, since electrification is a more readily available and a less expensive option in the vast majority of cases. While there is a common perception that decarbonization of energy will result in higher costs to consumers, the rapid pace of advances in renewable energy technologies has meant that in some cases clean electricity can be cheaper than electricity from fossil resources. Furthermore, with ongoing technology advances, clean energy costs will only continue to decline. However, in the cases where clean energy currently remains more expensive, the Biden Administration is also enacting policies—such as the historic tax credits in the Inflation Reduction Act—to help lower costs and enable clean energy technologies to be competitive, particularly for those who experience energy and environmental injustice.

One of the goals of the Regional Clean Hydrogen Hubs is to demonstrate a path to achieving the Hydrogen Energy Earthshot goal of reducing the cost of producing clean hydrogen to $1/kg. If this goal is achieved, clean hydrogen will be cost competitive in many applications. The Regional Clean Hydrogen Hubs are intended to demonstrate the utility of clean hydrogen in many sectors, including in some buildings where electrification is more expensive or challenging.[38] Although one Regional Clean Hydrogen Hub will demonstrate residential clean hydrogen use, this does not necessarily mean clean prices will increase or that hydrogen adoption will be widespread within the sector.

The Hydrogen Shot, launched in June of 2021, set an ambitious goal to reduce the cost of producing clean hydrogen to $1/kg in one decade. The deployment of technology capable of meeting the Hydrogen Shot target can lower energy costs for various sectors and can improve the resilience of a renewables-based grid. As deployment of clean hydrogen technologies increases, the economies of scale will enable a continued decrease in the cost of clean hydrogen.

The Regional Clean Hydrogen Hubs will locate clean hydrogen producers and users in close proximity. These hubs will also be specialized based on the natural resources available in the region and the local industries in need of tailored decarbonization solutions. The Regional Clean Hydrogen Hubs and DOE-funded local clean hydrogen projects will be deployed with stringent Community Benefits Plans and robust community engagement strategies to help identify and address specific community concerns.

11. Could the Regional Clean Hydrogen Hubs increase emissions or pollution?

In most cases, the Regional Clean Hydrogen Hubs will significantly reduce GHG emissions, as well as local air pollution. Reductions in pollution will vary across the Hubs depending on how the hydrogen is produced and used. For example, if the hydrogen is produced from electrolysis powered by renewable energy and used in a fuel cell to displace diesel (e.g., replace diesel generators for stationary power or replace diesel engines in trucks and buses), reductions in both GHG emissions and local pollution could be quite significant. On the other hand, if hydrogen is produced from SMR with CCS, then burned in a combustion turbine, reductions in GHG emissions could be less significant and NOx mitigation technology would be necessary to achieve low levels of local air pollution. In addition to conducting life cycle assessments of hydrogen production (which cover well to gate), DOE also expects the Hubs to expand their life cycle assessments to include potential criteria pollutants from end uses (e.g., NOx).

Emissions related to hydrogen—both greenhouse gases (GHG) and other local air pollution—are determined by the methods of production, storage, transportation, and use (see the FAQs for more information about GHG and other pollutant emissions). DOE is ensuring a consistent approach to assessing any pollution from the Regional Clean Hydrogen Hubs by requiring them to conduct a detailed life cycle assessment (LCA) to determine the intensity of all emissions (e.g., carbon dioxide, methane, criteria air pollutants) over the lifetime of the Regional Clean Hydrogen Hub. DOE requires that the Regional Clean Hydrogen Hubs demonstrably reduce emissions with a clear pathway for meeting the Clean Hydrogen Production Standard; therefore, these projects will produce clean hydrogen with lower GHG emissions than existing hydrogen production methods (e.g., SMR without CCS).[39] See the hydrogen FAQs for more information about LCA and hydrogen production methods.

12. Will front-line communities be included in hydrogen-related projects, and will they have a say in how projects are sited?

The Biden Administration and DOE are prioritizing the importance of engaging communities. DOE recognizes that long-standing underlying economic inequalities, combined in many cases with structural racism, have resulted in the development of energy projects that disproportionately and inequitably harm low-income communities and communities of color. To ensure an equitable transition to clean energy, and to avoid further harm to communities with environmental justice concerns, DOE is focused on ensuring that every project that receives funding through a DOE Justice40 Covered Program adheres to the principles of environmental justice.[40] All clean hydrogen activities conducted by DOE, including the Regional Clean Hydrogen Hubs, and hydrogen activities through the Hydrogen and Fuel Cell Technologies Office and the Office of Fossil Energy and Carbon Management are covered under the

Justice40[41] initiative according to EO 14008, "Combating the Climate Crisis At Home and Abroad".[42]

Environmental justice is the fair treatment and meaningful involvement of all people—regardless of race, ethnicity, income, or education level—in environmental decision making. Environmental justice promotes the protection of human health and the environment, empowerment via public participation, and the dissemination of relevant information to inform and educate affected communities. Energy justice asks that we recalibrate our energy system to ensure that the benefits and the burdens of the new system are more equitably spread across communities in our nation.

DOE has many of the technical tools to avert catastrophic climate change and to transition to a clean energy system, but energy equity and environmental justice can help transform these technologies and tools into an energy system that is more equitable and just for all. Listening and increasing transparency are critical steps in ensuring DOE meets or exceeds its goals for energy and environmental Justice.

To help address community concerns, all applicants to DOE's funding opportunities are required to provide Community Benefits Plans. Research and development–based funding opportunities require applicants to consider how successful commercialization of their technology will impact labor, energy equity, and diversity, equity, inclusion, and accessibility (DEIA) in the future. Applicants are also required to identify how they will increase DEIA in their proposed project. Demonstration and deployment–based funding opportunities require applicants to discuss their plans to engage impacted communities and labor, determine the benefits and negative impacts of projects—and critically—where those impacts flow, and take action to mitigate negative impacts. Typically, demonstrations are smaller prototypes of a full system that would be larger and permanent in commercial use. Deployments are projects that bring mature, commercially available systems into operation.[Error! Bookmark not defined.] See the above question "**What do hydrogen demonstrations and deployments look like?"** for further information. Applicants are asked to address whether and how they will consider changing project characteristics, including siting, based on what they learn from community engagement.

For all applications related to DOE-funded projects for clean hydrogen, including the Regional Clean Hydrogen Hubs or projects funded by the Bipartisan Infrastructure Law, these community benefit plans are scored in the merit review process, just like the technical project plans. Applicants must also develop project milestones associated with these plans that are included in their scope of work. These milestones will be tracked and managed by DOE staff, similar to other technical milestones.

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