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Introduction

Chairman Manchin, Ranking Member Barrasso, and members of the committee, thank you for the opportunity to testify before you today. My name is Sunita Satyapal, and I am the Director for the Hydrogen and Fuel Cell Technologies Office in the Department of Energy's (DOE's) Office of Energy Efficiency and Renewable Energy (EERE). As the Director, I direct applied research, development, demonstration, and deployment (RDD&D) activities for EERE's Hydrogen and Fuel Cell Technologies Office (HFTO).

I also serve as the coordinator for DOE's Hydrogen Program which encompasses multiple DOE offices—EERE, Fossil Energy and Carbon Management (FECM), Nuclear Energy (NE), Electricity (OE), and Science (SC), and coordinates with the Advanced Research Program Agency – Energy (ARPA-E), the Loan Programs Office (LPO), the Office of Technology Transitions (OTT), and the new Office of Clean Energy Demonstrations (OCED). With over two and a half decades dedicated to advancing hydrogen and fuel cell technologies, both in government and industry, this is truly a historic time for hydrogen and a unique opportunity for the United States, and I am honored to be invited to testify today.

Clean hydrogen is one part of DOE's comprehensive energy strategy to enable a clean, secure, and equitable energy future for all Americans. Hydrogen is an essential feedstock and fuel already used in current industries, including fertilizer production and oil refining. It is an energy carrier that offers versatility, as we strive to use all our nation's energy resources including renewables, nuclear power, or fossil and other carbon-based feedstocks with carbon sequestration and storage (CCS), to produce low-greenhouse gas (GHG) hydrogen. It can be stored in the form of a gas, liquid, or chemical carrier, and it can be used in a fuel cell or turbine to provide electricity. It also has the potential to provide flexibility in terms of applications across sectors, particularly for hard to decarbonize sectors such as heavy-duty transportation and industrial applications including ammonia production and steel manufacturing.

Status of Hydrogen Technologies Today

The U.S. currently produces more than 10 million metric tons (tonnes)[1] of hydrogen annually primarily for oil refining and fertilizer production, compared to approximately 90 million tonnes produced per year globally.[2] Infrastructure in the U.S. includes approximately 1,600 miles of dedicated hydrogen pipelines, largely in the southwest region to support oil refining,[3] and three geological hydrogen storage caverns including the world's largest.[4] [5] Outside of petroleum and

[1] DOE, "Hydrogen Program Plan," 2020. Page 9. https://www.hydrogen.energy.gov/pdfs/hydrogen-program-plan-2020.pdf
[2] IEA, "Global Hydrogen Review 2021," 2021. Page 5. https://www.iea.org/reports/global-hydrogen-review-2021
[3] DOE, "Hydrogen Program Plan," 2020. Page 13. https://www.hydrogen.energy.gov/pdfs/hydrogen-program-plan-2020.pdf
[4] DOE, "Hydrogen Program Plan," 2020. Page 13. https://www.hydrogen.energy.gov/pdfs/hydrogen-program-plan-2020.pdf
[5] Air Liquide "USA: Air Liquide operates the world's largest

fertilizer production, hydrogen use is making its way in other end use applications. These include more than 50,000 fuel cell forklifts,[6] 48 open retail fueling stations,[7] approximately 70 buses, more than 12,000 fuel cell vehicles, and over 550 MW of fuel cells for stationary and backup power (e.g., for telecommunications).[8] Based on industry input, heavy duty transportation, industrial applications such as ammonia production, and hydrogen blending appear to be primary growth opportunities over the next decade, with other uses coming later.

While most of today's hydrogen is produced from natural gas (through steam methane reforming), there were approximately 172 MW of electrolyzers[9] in the U.S as of June 2021, which could allow for the production of hydrogen using clean electricity. Although that number is growing, it is substantially behind the multiple gigawatts (GW) reported globally, including at least 9 renewable hydrogen projects larger than 10 GW each[10] and 40 GW targeted in Europe by 2030.[11] In addition to growth in electrolysis, plans were announced for a large-scale natural gas to hydrogen plant in the U.S. with 95% carbon dioxide capture producing 750 million standard cubic feet per day of hydrogen for ammonia and both domestic and global hydrogen markets. The project will also be the world's largest carbon capture for sequestration operation, sequestering more than 5 million tonnes per day of carbon dioxide.[12] Besides growth in hydrogen projects, annual shipments of fuel cells have increased 15-fold since 2015, now at over 1 GW, but still a small fraction of the potential global fuel cell market across sectors.[13] Industry has announced more than 520 large scale global hydrogen projects representing $160 billion of funding projects.[14]

Key Challenges Remain to be Addressed

While hydrogen technology has come a long way as a clean energy fuel, it is still very much in its early stages of commercial deployment and some significant challenges remain. These include lack of hydrogen infrastructure, lack of manufacturing at scale, as well as cost,

hydrogen storage facility," 2017. Accessed on January 27, 2022. https://www.airliquide.com/sites/airliquide.com/files/2017/01/03/usa-air-liquide-operates-the_world-s-largest-hydrogen-storage-facility.pdf

[6] DOE. "Snapshot of Hydrogen and Fuel Cell Applications in the United States - Examples," January 2022. https://www.energy.gov/eere/fuelcells/articles/snapshot-hydrogen-and-fuel-cell-applications-united-states-examples

[7] California Fuel Cell Partnership, 2020, Hydrogen Stations List. Development Status of Hydrogen Stations in California. https://cafcp.org/sites/default/files/h2_station_list.pdf

[8] DOE. "Snapshot of Hydrogen and Fuel Cell Applications in the United States - Examples," January 2022. https://www.energy.gov/eere/fuelcells/articles/snapshot-hydrogen-and-fuel-cell-applications-united-states-examples

[9] DOE. "DOE Hydrogen Program Record 20009: Electrolyzer Capacity Installations in the United States," June 2021. https://www.hydrogen.energy.gov/pdfs/20009-electrolyzers-installed-in-united-states.pdf; for polymer electrolyte membrane electrolyzers

[10] Hydrogen Council. "Hydrogen for Net Zero," November 2021. Page 35. https://hydrogencouncil.com/wp-content/uploads/2021/11/Hydrogen-for-Net-Zero.pdf

[11] European Commission. "A hydrogen strategy for a climate-neutral Europe," July 2020. Page 6. https://ec.europa.eu/energy/sites/ener/files/hydrogen_strategy.pdf

[12] Air Products " Landmark U.S. $4.5 Billion Louisiana Clean Energy Complex," Accessed on January 27, 2022.https://www.airproducts.com/campaigns/la-blue-hydrogen-project

[13] DOE, "Hydrogen Program Plan," 2020, Page 4. https://www.hydrogen.energy.gov/pdfs/hydrogen-program-plan-2020.pdf

[14] Hydrogen Council. "Hydrogen for Net Zero," November 2021. Pages vii and 34. https://hydrogencouncil.com/wp-content/uploads/2021/11/Hydrogen-for-Net-Zero.pdf

durability, reliability, and availability challenges in the supply base across the entire value chain. To address the climate crisis, the hydrogen that is produced must be clean– i.e., low in greenhouse gas emission.[15] This will help reduce emissions immediately as we develop a trajectory towards carbon-free hydrogen production in the longer term. The cost of hydrogen from natural gas is less than $2/kg but if utilized, upstream and process emissions need to be reduced, requiring CCS or other advanced technologies and reduced methane leakage.

If using renewables or nuclear power, electrolyzer costs as well as hydrogen storage costs must be reduced. Based on analysis in 2020, the cost of clean hydrogen was more than $5/kg[16] using renewable electricity and depends heavily on the cost of that electricity. While advanced and high temperature electrolyzers, are also progressing, challenges to market adoption include cost, durability, and manufacturing at scale. In addition to hydrogen production costs, challenges in hydrogen transport, such as pipelines, tube trailers, liquefaction, siting, permitting, and materials compatibility, need to be addressed. For instance, data shows that the delivered cost of hydrogen to fueling stations, including compressing and dispensing, for fueling vehicles can be more than $13/kg[17] – more than three times higher than the cost required to be competitive.[18]

To achieve widespread deployment, hydrogen utilization technologies must enter larger markets and be able to compete with incumbent technologies in terms of life-cycle cost, performance, durability, and environmental impact. Non-technical barriers also need to be addressed, such as developing and harmonizing codes and standards, fostering best practices for safety, addressing potential supply chain and raw materials vulnerabilities, and developing a robust workforce. The lack of direct incentives for clean hydrogen production, uptake, and infrastructure investment also impedes financial investment and market growth.

A concerted, cohesive effort must be undertaken to address the aforementioned challenges. DOE, along with its partners in industry, National Laboratories, academia, States, the environmental justice (EJ) community, labor unions, and other agencies, is focused on addressing them. For example, DOE launched Hydrogen Shot, the first Energy Earthshot - an effort to set ambitious and achievable targets to make key clean hydrogen technologies affordable in the next decade and meet climate goals. The Hydrogen Energy Earthshot (or Hydrogen Shot) sets an ambitious yet achievable "1 1 1" goal to reduce the cost of hydrogen to one dollar per one kilogram of clean hydrogen in one decade.[19] Several DOE funded consortia, such as the Million Mile Fuel Cell Truck Consortium, the Hydrogen from Next-generation Electrolyzers of Water (H2NEW), the Hydrogen Materials Compatibility Consortium (H-Mat), and HyBlend, are bringing together industry, National Laboratories, and universities to address key technical

[15] The carbon intensity thresholds defining clean hydrogen will be developed with input from stakeholders as specified in the Bipartisan Infrastructure Law.
[16] DOE. "Hydrogen Shot Overview." August 2021. Slide 4. https://www.energy.gov/sites/default/files/2021-09/h2-shot-summit-plenary-doe-overview.pdf
[17] California Fuel Cell Partnership (CaFCP). "Cost to refill," Accessed on Jan 26, 2022. https://cafcp.org/content/cost-refill
[18] DOE, "Annual Merit Review and Peer Evaluation Plenary: Hydrogen Program Overview," June 2021. Slide 14. https://www.energy.gov/sites/default/files/2021-06/hfto-amr-plenary-satyapal-2021.pdf
[19] DOE, "Hydrogen Shot," 2021. https://www.energy.gov/eere/fuelcells/hydrogen-shot.

challenges.[20] In addition, new approaches and scientific research priorities for carbon-neutral hydrogen generation were recently developed in a DOE workshop.[21] Additional efforts under the DOE Hydrogen Program include first-of-its-kind demonstrations including nuclear, renewables, integrated with electrolyzers as well as hydrogen fuel cell trucks, data centers, and marine applications.[22] [23] These DOE-funded demonstrations are critical to de-risking the technologies before the private sector will ramp up investments and deployment at scale.

Scenario Analyses on Market Potential

DOE has assessed various scenarios that show a range from approximately 20 to more than 40 million tonnes per year as the economic potential for U.S. hydrogen demand by 2040—two to four times the current demand.[24] Achieving Hydrogen Shot goals of $1/kg, along with scaling up hydrogen infrastructure, could unlock additional market growth. Hydrogen demand could also increase as new markets emerge (such as off-road transportation like marine applications, exports of clean hydrogen, and energy storage for a widespread renewable grid), and scenarios will be assessed periodically through updated analyses. In addition to DOE analysis, a group of roughly 20 industry partners projected a two-fold increase in U.S. hydrogen demand, to 20 million tonnes, by 2050 as a base case scenario, and a six-fold increase by 2050 in an ambitious scenario.[25] Given uncertainties across sectors, markets, financial investments, and technologies, these results are fairly consistent with DOE analysis. Based on these two scenarios ("base" and "ambitious"), hydrogen could account for between 1% and 14% of total energy demand in the United States.[26] Additional analysis is ongoing.

DOE's Hydrogen Program has also determined the availability of domestic resources for hydrogen production across the country, assessing locations and quantities of renewable energy and fossil feedstocks throughout the United States, along with the locations of nuclear power plants and locations where hydrogen may be produced as a by-product. The nation's energy resources are geographically widespread, and fossil, nuclear, and renewable feedstocks are each independently sufficient to support at least a doubling of domestic hydrogen consumption.[27] [28]

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[20] DOE, "Hydrogen and Fuel Cell Technologies Office Consortia," Accessed on January 27, 2022. Hydrogen and Fuel Cell Technologies Office Consortia | Department of Energy

[21] DOE, Basic Energy Sciences Roundtable: Foundational Science for Carbon-Neutral Hydrogen Technologies, summary https://science.osti.gov/-/media/bes/pdf/reports/2021/Hydrogen_Roundtable_Brochure.pdf, full report to appear (2022)

[22] DOE, "Annual Merit Review and Peer Evaluation Plenary: Hydrogen Program Overview," June 2021. Slide 12 and 20. https://www.energy.gov/sites/default/files/2021-06/hfto-amr-plenary-satyapal-2021.pdf

[23] DOE. "Energy Department Announces Approximately $64M in Funding for 18 Projects to Advance H2@Scale," July 2020. https://www.energy.gov/articles/energy-department-announces-approximately-64m-funding-18-projects-advance-h2scale

[24] DOE, "Hydrogen Program Plan," 2020. Page 10. https://www.hydrogen.energy.gov/pdfs/hydrogen-program-plan-2020.pdf

[25] Published by FCHEA. "Road Map to a U.S. Hydrogen Economy: Reducing emissions and driving growth across the nation," 2020, Page 4 and 9. https://www.fchea.org/us-hydrogen-study

[26] Published by FCHEA. "Road Map to a U.S. Hydrogen Economy: Reducing emissions and driving growth across the nation," 2020, Page 10.https://www.fchea.org/us-hydrogen-study

[27] DOE, Department of Energy Hydrogen Program Plan, 2020. Page 10, https://www.hydrogen.energy.gov/pdfs/hydrogen-program-plan-2020.pdf

[28] Connelly, E., Penev, M., Milbrandt, A., Roberts, B., Gilroy, N., Melaina, M., 2020, p. vi, available at https://www.nrel.gov/docs/fy20osti/77198.pdf

Opportunities for Hydrogen in Specific Applications

Opportunities for hydrogen exist particularly in hard to decarbonize sectors, in end uses where it is an essential chemical feedstock or the application requires large amounts of energy storage. Depending on the application, different challenges must be addressed, but markets can advance as costs decline and economies of scale are achieved. DOE's H2@Scale vision entails sector coupling in a comprehensive strategy where the bundling of applications can help drive costs down and achieve the scale required to establish a sustainable hydrogen economy.

Industrial and Chemical Applications

Several industrial and manufacturing processes already require large volumes of hydrogen, including oil refining and ammonia production, and offer opportunities to transition to the use of clean hydrogen to reduce emissions, including by retrofitting existing hydrogen plants with CCS. These processes, along with other emerging industrial and chemical uses, are driving economies of scale in the upstream hydrogen supply and associated infrastructure. Steelmaking, in particular, is receiving increasing attention as a source of demand for hydrogen. Steel is the most commonly used metal product worldwide and the conventional way to produce it involves using coal in blast furnaces to reduce iron ore to iron. Between 7% and 9% of global greenhouse gas emissions are due to steel manufacturing and by using hydrogen instead of coal those emissions can be dramatically reduced.[29] A number of demonstrations using hydrogen in steelmaking are currently underway, including operational facilities in Austria and Sweden. DOE is funding two projects in this area to demonstrate the feasibility and help address challenges.[30]

Additional emerging industrial and chemical uses of hydrogen include: cement production, which is an energy intensive process responsible for about 8% of global carbon dioxide emissions, where the use of hydrogen in place of coal could reduce both carbon dioxide and NOx emissions; synthetic fuel (or "e-fuel") production, which involves reacting carbon dioxide with clean hydrogen, offering an option for versatile low-carbon fuels such as methanol or renewable natural gas; and other industrial processes that use hydrogen as a reducing agent, such as glass manufacturing, or as a hydrogenating agent, such as industrial food processes.[31] Hydrogen in the form of ammonia or other chemicals (as a gas or liquid) can also be used to export energy. In all these cases, application-specific hydrogen requirements can strongly affect commercial viability and cost reductions are required in all these areas.

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[29] DOE, "Hydrogen Program Plan," 2020. Page 29. https://www.hydrogen.energy.gov/pdfs/hydrogen-program-plan-2020.pdf
[30] DOE. "Fiscal Year 2020 H2@Scale Funding Opportunity Announcement Selections," July 2020. Fiscal Year 2020 H2@Scale Funding Opportunity Announcement Selections | Department of Energy
[31] DOE, "Hydrogen Program Plan," 2020. Pages 29-30. https://www.hydrogen.energy.gov/pdfs/hydrogen-program-plan-2020.pdf

Transportation

Transportation accounts for approximately a third of U.S. GHG emissions[32] and can be a key contributor to localized air pollution. Hydrogen and fuel cells are an important part of a portfolio of options to reduce transportation-related emissions because they can be used in specific applications that are hard to decarbonize, such as long-haul heavy-duty trucks. Additional examples include other medium- and heavy-duty vehicles that require longer driving ranges, involve heavy loads, or demand faster refueling times than may be available with battery electric vehicles alone. With increased urgency to reduce emissions and energy-related expenses, significant opportunities exist as the medium- and heavy-duty sector accounts for 25% of annual vehicle fuel use even though it is only 4% of the vehicle fleet.[33] In addition to its use in fuel cells, hydrogen can also be used for generating biofuels and combined with carbon dioxide to produce synthetic fuels (e.g., sustainable aviation fuels), offering even more ways to meet the needs of various transportation applications. These synthetic fuels could allow certain applications or regions to continue using internal combustion engines and the vast existing liquid fuel infrastructure for hard-to-decarbonize end uses such as long-distance commercial aircraft.[34]

Transportation applications face challenges related to fuel cell cost and durability, as well as hydrogen storage, delivery, and dispensing. The type of infrastructure and associated barriers will be dictated by how hydrogen is stored on the vehicle (or aircraft, or vessel)—either as a high-pressure gas, a liquid, or in a liquid or solid carrier. Additional challenges include the establishment of necessary supply chains for storage and dispensing components and systems as well as developing widely accepted refueling protocols covering the full range of transportation options. The strategic buildout of a reliable and safe hydrogen infrastructure and fueling stations will be critical to ensure the transportation market develops in a sustainable manner, particularly in clusters where we see the most growth and potential for impact.

Stationary Power Generation and Energy Storage

Hydrogen can be used in a broad range of stationary power-generation applications—including large scale power generation, distributed power, combined heat and power (CHP), and backup power. Hydrogen can provide power through fuel cells or through combustion in turbines. Critical loads such as data centers are a notable example of an end use more recently turning to hydrogen-based options for reliable and resilient primary and backup power, attracted to benefits such as high efficiency and quiet, emissions-free operation. Combustion is also a viable approach for using hydrogen or hydrogen-rich blends (e.g., blended with natural gas) in a number of stationary applications, including commercial and residential applications.

Using hydrogen or hydrogen blends in existing distribution infrastructure and combustion equipment poses a number of challenges related to materials compatibility and combustion

[32] EPA, Fast Facts: U.S. Transportation Sector Greenhouse Gas Emissions, 1990-2019, 2021, Page 1, https://www.epa.gov/system/files/documents/2021-12/420f21076.pdf

[33] DOE, Vehicle Technologies Fact#951, 2016, https://www.energy.gov/eere/vehicles/fact-951-november-14-2016-medium-and-heavy-trucks-account-about-quarter-highway

[34] DOE, "Hydrogen Program Plan," 2020. Page 28. https://www.hydrogen.energy.gov/pdfs/hydrogen-program-plan-2020.pdf

characteristics. Progress has been made in the modification of natural gas burners in commercially available combustion turbines to accommodate high hydrogen blends (up to 100% hydrogen), but continued RD&D is needed for qualification in utility-scale power generation and to assess the compatibility of hydrogen blends with equipment designed for natural gas (e.g., building appliances).

Hydrogen can be used as a "responsive load" to enable grid stability and seasonal, long-duration energy storage. DOE hydrogen activities have validated, for the first time, the ability of hydrogen electrolyzers to dynamically respond to voltage disturbances.[35] This flexibility allows energy storage systems to adapt to the variability of renewable energy sources while meeting energy demands. Electrolyzers can also make use of available renewable electricity during times of low demand, ultimately increasing renewable energy utilization and lowering the cost of hydrogen. And hydrogen can be used as a form of energy storage for variable renewables, either feeding power back to the grid or using hydrogen as a fuel or feedstock for other applications. However, if electrolyzers are used only intermittently, the low utilization results in a stranded asset and hence higher hydrogen costs. Thus, system optimization and integration, hybrid approaches, and coupling more than one resource, including clean baseload power, can help drive costs down and create resiliency.

Jobs

Growth in the hydrogen and fuel cell industry can generate jobs in diverse sectors including manufacturing, distribution, operation and maintenance, engineering, sales, and more – many of them well paying union jobs. The types of jobs will be associated with both the hydrogen industry itself as well as indirect industries, such as upstream energy resources (e.g., deployment of and integration with renewables and other domestic energy resources), downstream infrastructure development (e.g., building and operating fueling stations and infrastructure), and production of fuel cells, electrolyzers, hydrogen storage and delivery equipment, turbines, and fuel cell systems across transportation and stationary applications.

DOE is currently funding a project that includes a consortium of industry stakeholders (H2EDGE) to conduct a gap analysis of skills related to jobs in the hydrogen and fuel cell sector and to develop curricula and training programs to train an emerging workforce.[36] Global industry coalitions have projected the potential for 30 million jobs and $2.5 trillion in revenues by 2050 as a result of a successful hydrogen industry.[37] A U.S. industry roadmap on hydrogen projected the potential for 700,000 jobs in the U.S. and $140 billion in revenue by 2030 due to the successful ramp up of hydrogen technologies.[38]

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[35] DOE, "Hydrogen Program Plan," 2020. Page 31. https://www.hydrogen.energy.gov/pdfs/hydrogen-program-plan-2020.pdf

[36] DOE. "Hydrogen and Fuel Cell Day Remarks," October 2021. Slide 15. https://www.energy.gov/sites/default/files/2021-10/hfto-satyapal-hydrogen-online-conference-october-2021.pdf

[37] Published by Hydrogen Council, "Hydrogen Scaling Up: A sustainable pathway for the global energy transition," November 2017, Page 9. https://hydrogencouncil.com/wp-content/uploads/2017/11/Hydrogen-scaling-up-Hydrogen-Council.pdf

[38] Published by FCHEA . "Road Map to a U.S. Hydrogen Economy: Reducing emissions and driving growth across the nation," 2020, Page 7. https://www.fchea.org/us-hydrogen-study

Additional efforts on modeling and validating the economic and jobs potential for hydrogen and fuel cells are planned as the industry ramps up.

Opportunities Ahead

The Bipartisan Infrastructure Law (BIL) hydrogen provisions, in addition to sustained annual appropriations, provide a tremendous opportunity for the United States to address many of these challenges and accelerate the manufacturing and roll out of hydrogen technologies and enable a competitive, sustainable market. DOE's funding has already led to more than 1,100 U.S. patents in hydrogen and fuel cells and over 30 commercial technologies in the market, along with more than 65 technologies[39] that could be commercial in the next several years.[40]

We look forward to implementing the BIL provisions as well as the core DOE Hydrogen Programs to address the challenges listed above and ensure the United States is not just a technical leader in Hydrogen but also a leader in its deployment and use. I am pleased to share that the DOE will release a Request for Information regarding the Hydrogen Hubs as well as the Electrolyzer and Clean Hydrogen Manufacturing and Recycling provisions in the coming weeks. In addition, DOE has a strong commitment to continuing support for hydrogen, including through $400 million in the President's Fiscal Year (FY) 2022 Budget Request that encompasses both scientific and technological research, as well as demonstration and deployment activities, across DOE Hydrogen Program offices. We will continue to develop measures of effectiveness to ensure success of our programs, including concrete targets and milestones, rigorous competitive merit-based selection processes, independent peer reviews, and down-selection or go/no go decision points defined by performance-based criteria for large scale projects. Stakeholder engagement will be key as we define the BIL activities and develop effective strategies. Coordination and collaboration not only within DOE, but with other Federal Agencies, States, industry, the investment community, the EJ community, labor unions, academia, national laboratories, and coalitions, as well as international partners, will play a key role in ensuring the most effective, cohesive, and efficient implementation of our programs in the United States.

Conclusion

Thank you for the opportunity to appear before the committee today. I look forward to working with you as we transition to a clean energy economy and work to reach a 100% clean electric grid by 2035, net-zero emissions by 2050, and our EJ priorities. I look forward to your questions.

[39] DOE, "Annual Merit Review and Peer Evaluation Plenary: Hydrogen Program Overview," June 2021. Slide 11. https://www.energy.gov/sites/default/files/2021-06/hfto-amr-plenary-satyapal-2021.pdf

[40] DOE, "Hydrogen Program Plan," 2020. Page 5. https://www.hydrogen.energy.gov/pdfs/hydrogen-program-plan-2020.pdf