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Pipeline Transportation of Hydrogen: Regulation, Research, and Policy

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SUMMARY

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Some in Congress have proposed hydrogen as an environmentally superior alternative to conventional fossil fuels for vehicles and power generation, among other applications. Delivering hydrogen to scattered facilities—such as power plants, industrial sites, and fuel distribution hubs—would require an expansive hydrogen pipeline network. Accordingly, the House Select Committee on the Climate Crisis 2020 majority staff report recommended that Congress draft legislation to facilitate the development of hydrogen infrastructure, and that federal agencies create an associated plan and change their regulatory framework to support it. The House Appropriations Committee report on the Energy and Water Development Appropriations Bill, 2021 (H.Rept. 116-449) calls for additional hydrogen pipeline research at the Department of Energy (DOE).

Hydrogen gas is colorless and odorless, with the highest energy content by weight of any fuel. When used in a fuel cell, hydrogen can generate electricity with only heat and water vapor as by-products. Hydrogen gas poses an overall safety risk comparable to that of methane, the principal component of natural gas, although specific risks may differ due to hydrogen's distinct properties. Hydrogen rises and disperses faster than methane when released into the air. Because hydrogen molecules are the smallest of all molecules, it is more prone than methane to leaking through joints, cracks, and seals in infrastructure. It can also permeate directly through materials used for natural gas distribution faster than methane. Hydrogen can deteriorate steel pipe, pipe welds, valves, and fittings through embrittlement and other mechanisms.

As of December 2020, there were 1,608 miles of hydrogen pipeline in the United States, located primarily along the Gulf Coast. Although nearly all hydrogen pipeline shipment occurs in dedicated hydrogen infrastructure, some U.S. operators have initiated projects to blend hydrogen and methane in natural gas pipelines. Analysts assert that 20% hydrogen concentrations by volume may be the maximum blend before significant pipeline upgrades are required. In addition, the end-use equipment in power plants and industrial facilities may not tolerate higher hydrogen concentrations without modification. Converting natural gas pipelines to carry pure hydrogen is technically feasible, and may offer economic and development advantages over building new pipelines. Both converted and new hydrogen pipelines would face significant market uncertainty and logistical challenges related to hydrogen demand. Regulatory authorities differ for dedicated hydrogen pipelines and for natural gas pipes carrying hydrogen-methane blends. Currently, regulation of their siting, commercial service, security, and safety is divided among federal agencies and the states. Federal jurisdiction resides variously with the Surface Transportation Board (STB), the Federal Energy Regulatory Commission (FERC), the Transportation Security Administration (TSA), and the Pipeline and Hazardous Materials Safety Administration (PHMSA) within the Department of Transportation (DOT).

The pipeline industry has long identified technological challenges to developing a national network of dedicated hydrogen pipelines. To address these challenges, many experts favor a significant federal role in hydrogen pipeline research and development (R&D). Consistent with this view, under a series of agency initiatives and energy statutes the federal government has funded hydrogen pipeline-related R&D since the 1960s supported by the National Aeronautics and Space Administration, DOE, DOT, and the National Institute of Standards and Technology (NIST). At various times, their research has examined basic materials science, hydrogen pipeline safety, pipeline economics, hydrogen markets, and pipeline network modeling, among other topics. Sector experts have identified numerous potential areas for additional R&D which may be a priority to support the development of a widespread hydrogen pipeline network sometime in the future.

Congress has acted to facilitate the development of hydrogen pipelines through various measures over the last 30 years, including provisions in the Spark M. Matsunaga Hydrogen Research, Development, and Demonstration Act of 1990; the Hydrogen Future Act of 1996; the Energy Policy Act of 2005; and periodic appropriations to agency and program offices. If Congress supports a policy requiring a national network of dedicated hydrogen pipelines, it may encounter both technical and nontechnical challenges. Key policy issues which Congress may examine include the regulation of pipeline siting, including potential federal-state jurisdictional conflicts, and the regulation of pipeline rates and terms of service. The application of PHMSA's existing pipeline safety regulations to a large national network of dedicated hydrogen pipelines also may garner consideration. Understanding ongoing needs for pipeline-related R&D under any national hydrogen strategy, and determining what federal support may be required for it is likely to be a factor in budgeting and oversight of federal agency programs. How hydrogen pipelines fit into broader federal oversight of energy pipeline security also may be an issue. Congress faces mapping the relationship between hydrogen pipelines and other federal (or state) energy initiatives; overseeing related activities among different federal agencies; and prioritizing federal efforts to develop hydrogen pipelines.

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Introduction

Some in Congress have proposed hydrogen as an environmentally superior alternative to conventional fossil fuels for vehicles and electric power generation, among other applications.[1] Delivering hydrogen to widely scattered facilities—such as power plants, industrial sites, and vehicular fuel distribution hubs—could require the development of an expansive hydrogen pipeline network.[2] As the House Science Committee reported in 2002, "new energy sources such as hydrogen will require a new generation of pipelines."[3] Likewise, a 2021 National Academy of Sciences report concluded that, among other actions to meet a net-zero carbon emissions goal, "a hydrogen pipeline network will ultimately also be needed."[4] Environmental and other stakeholders similarly have identified hydrogen shipment by pipeline as essential to a national hydrogen fuel strategy.[5] The House Appropriations Committee report on the Energy and Water Development Appropriations Bill, 2021 (H.Rept. 116-449) calls for hydrogen pipeline research at the Department of Energy.[6]

Shipping hydrogen by dedicated pipeline is not new in the United States, but the existing hydrogen pipeline infrastructure is small compared to that of the nation's natural gas and oil pipeline systems. The hydrogen pipeline network required to support a hydrogen-based U.S. energy strategy would need to be much larger and with much broader geographic reach than that in place today. Hydrogen also historically has been blended with natural gas in some U.S. natural gas pipelines, and currently is being shipped this way in significant volumes overseas, but there currently are barriers and limitations to the blending approach. Establishing a national network of dedicated hydrogen pipeline infrastructure, or reconfiguring existing natural gas systems to carry hydrogen, poses numerous challenges related to technology, regulation, siting, and economics.

This report discusses the physical characteristics of hydrogen, including its safety and how it is commercially produced. The report reviews the current status of hydrogen transportation in pipelines and options for expanding U.S. hydrogen pipeline infrastructure. The report examines relevant federal regulation of hydrogen pipeline siting, safety, commercial service, and security. It reviews federal support of hydrogen pipeline-related research programs since the 1960s and summarizes congressional actions to support U.S. hydrogen pipeline development. The report concludes with a discussion of selected policy issues for Congress.

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[1] See for example, S.Res. 720, Designating October 8, 2020, as "National Hydrogen and Fuel Cell Day," 116th Congress, 2nd Session, September 24, 2020.

[2] Argonne National Laboratory (ANL), *Overview of Interstate Hydrogen Pipeline Systems*, November 2007, p. 1.

[3] U.S. Congress, House Committee on Science, *Energy Pipeline, Research, Development, and Demonstration Act*, 107th Cong., 2nd sess., May 16, 2002, H.Rept. 104-475 (Washington: GPO, 2002), p. 2.

[4] National Academy of Sciences, *Accelerating Decarbonization of the U.S. Energy System*, 2021, p. 23.

[5] See for example: Energy and Environmental Economics, Inc. and The Energy Futures Initiative, Inc., *Net-Zero New England: Ensuring Electric Reliability in a Low-Carbon Future*, November 16, 2020, p. 71; Clean Air Task Force, "CATF Comments on the Revision of the TEN-E Regulation," July 13, 2020, p. 3, https://www.catf.us/wp-content/uploads/2020/06/CATF_Response_TEN-E-1.pdf. "At each stage of the Hydrogen Strategy, success is inextricably tied to robust, integrated development of key infrastructure. This infrastructure includes ... pipelines."

[6] H.Rept. 116-449, "Energy and Water Development and Related Agencies Appropriations Bill, 2021," July 15, 2020. The House-passed energy and water bill was included in negotiations over drafting the enacted Consolidated Appropriations Act, 2021 (P.L. 116-260).

Physical Characteristics of Hydrogen

Hydrogen (H) is the simplest element, consisting of a single proton and electron. One of the most abundant elements on Earth, it can bond with oxygen to form water (H_2O) and with carbon to form methane (CH_4)—the primary constituent of natural gas—and other hydrocarbons. Hydrogen also can combine with different elements to form other commercially important chemical compounds, such as ammonia, hydrogen peroxide, and hydrochloric acid. Pure hydrogen is generally found bonded in pairs of hydrogen atoms, so the standard symbol for molecular hydrogen is H_2.

In its pure form (at standard atmospheric pressure and temperature), hydrogen is a colorless and odorless gas, although it can be liquefied at temperatures below −423°F. Hydrogen has the highest energy content by weight of any fuel, but has comparatively low density, so it requires a greater physical volume for the same energy as other fuels. For example, a kilogram of hydrogen contains almost three times as much energy as a kilogram of gasoline, but it takes four liters of liquid hydrogen to provide the same amount of energy as one liter of gasoline.[7] Compared to natural gas, hydrogen has over twice the energy content per kilogram, but hydrogen gas contains less than one-third of the energy as the same volume of natural gas at the same pressure.

When used in a fuel cell, hydrogen can generate electricity with only heat and water vapor as by-products.[8] Thus, hydrogen fuel cells do not generate greenhouse gases or other atmospheric emissions—such as carbon dioxide, sulfur dioxide, and nitrogen oxides—associated with burning conventional fossil fuels. Burning hydrogen in a conventional combustion turbine to generate electricity, or in a vehicle engine, may generate nitrogen oxides due to the heat of combustion and the presence of nitrogen in air.[9] Producing and transporting hydrogen (discussed below) also may generate some of these kinds of emissions, depending upon the processes used. The overall emissions profile of a particular hydrogen fuel supply must take its entire lifecycle into account.

Safety Characteristics

As is the case for fossil fuels, there are safety risks associated with hydrogen production and transportation. In its gaseous state, hydrogen in transmission pipelines poses an overall risk comparable to that of methane shipped in natural gas pipelines; specific risks may be greater or lesser due to hydrogen's distinct physical properties and the infrastructure involved.

Hydrogen is 93% lighter than air and 88% lighter than methane, so it rises and disperses faster than methane when released into the atmosphere. Hydrogen's flammability range in air (hydrogen-air ratio) is between 4% and 75%, which is a much wider range than that of methane (5% to 15%), so hydrogen needs much less air to burn.[10] If a hydrogen gas cloud in an open area encounters a source of ignition (e.g., a spark) it will quickly burn its way back to its source. A hydrogen fire radiates significantly less heat than a comparable natural gas or gasoline fire, so it

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[7] Department of Energy (DOE), Office of Energy Efficiency and Renewable Energy, "Hydrogen Storage," online article, 2020, https://www.energy.gov/eere/fuelcells/hydrogen-storage.

[8] Fuel cells do not burn their fuel, but use an efficient electrochemical reaction to produce electricity. For further discussion, see CRS Report R46436, *Hydrogen in Electricity's Future*, by Richard J. Campbell.

[9] Mike Menzies, "Hydrogen: The Burning Question," *The Chemical Engineer*, Institution of Chemical Engineers, September 23, 2019.

[10] Pacific Northwest National Laboratory (PNNL), "Hydrogen Compared with Other Fuels," Hydrogen Tools Portal, 2020, https://h2tools.org/bestpractices/hydrogen-compared-other-fuels.

poses less risk of thermal damage or secondary fires away from the point of combustion.[11] However, unlike fires involving methane or other fossil fuels, hydrogen fires are so pale that they are almost imperceptible in daylight or artificial light, so visible detection can be a challenge.[12]

In confined spaces, due its high energy content and high flammability range, hydrogen may pose significant explosion risks to structures and equipment.

> If hydrogen gas mixtures enter confined regions, ignition is very likely and can result in flame acceleration and generation of high pressures capable of exploding buildings and throwing shrapnel. Flammable mixtures of hydrogen in confinements such as pipes or ducts, if ignited, will readily result in accelerated flames and conditions that can lead to transition to detonation.[13]

Methane poses similar explosion risks if released in confined spaces, with similar potential for damage to buildings and throwing debris from damaged infrastructure or structures.

Because hydrogen molecules are the smallest of all molecules—about 25% smaller than methane molecules—hydrogen is more prone than methane to leaking through joints, microscopic cracks, and seals in the infrastructure meant to contain it.[14] Hydrogen can also permeate directly through polymer (plastic) materials, such as those typically used to make natural gas distribution pipes, four to five times faster than methane does.[15] Both hydrogen and methane are odorless and colorless gases. To reduce the safety risks of methane leaks, odorants are generally added to natural gas in distribution systems to aid in leak detection. Due to differences in end use (e.g., in fuel cells) odorization of hydrogen has distinct chemical requirements and can require costly separation equipment. Research is underway on potential odorants that can be added to hydrogen transportation systems.[16]

The presence of hydrogen can deteriorate steel pipe, pipe welds, valves, and fittings through a variety of mechanisms. In particular, atomic (unpaired) hydrogen can diffuse into the material and cause "hydrogen embrittlement," which can lead to cracking, blistering, and weakness under tension. These effects potentially can lead to acute pipeline failure or may generally reduce the service life of a pipeline or other container.[17] Hydrogen embrittlement is a greater risk in the types of high-pressure, high-strength steel typically used for natural gas transmission than in low-pressure, low-strength distribution pipes. The susceptibility of particular pipelines depends upon many factors, including hydrogen pressure, concentration, and temperature, as well as the specific properties of the type of materials used and other operating conditions.[18] Where embrittlement may be a concern, pipeline companies may use specialty steels or may modify their infrastructure and put other measures in place (such as restricting hydrogen concentration in methane mixtures

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[11] International Association for Hydrogen Safety (HySafe), *Biennial Report on Hydrogen Safety*, June 2007, p. 1-9, http://www.hysafe.org/BRHS. The lower heat radiation of a hydrogen fire is largely due to heat absorption by the water vapor generated by the hydrogen fire itself.

[12] HySafe, June 2007, p. 84.

[13] Ibid.

[14] The kinetic diameters of molecular hydrogen and methane, respectively, are 289 and 380 picometers.

[15] National Renewable Energy Laboratory (NREL), *Blending Hydrogen into Natural Gas Pipeline Networks: A Review of Key Issues*, NREL/TP-5600-51995, March 2013, p. x.

[16] See, for example, Scotland Gas Networks, *Project Closure Report. Hydrogen Odorant and Leak Detection Part 1, Hydrogen Odorant,* October 2019, https://sgn.co.uk/sites/default/files/media-entities/documents/2020-09/Hydrogen_Odorant_and_Leak_Detection_Project_Closure_Report_SGN.pdf.

[17] Peter Adam, et al., "Hydrogen Infrastructure—The Pillar of Energy Transition," white paper, Siemens Energy, September 15, 2020, pp. 14-15, https://assets.siemens-energy.com/siemens/assets/api/uuid:3d4339dc-434e-4692-81a0-a55adbcaa92e/200915-whitepaper-h2-infrastructure-en.pdf.

[18] NREL, March 2013, pp. 21-22.

when transporting hydrogen with natural gas) to manage embrittlement risks. Nonetheless, the potential for hydrogen embrittlement is an important safety parameter in the design and operation of hydrogen pipelines.

When hydrogen is introduced into pipelines originally designed to transport natural gas or other commodities, its distinct chemical characteristics can create greater safety risks than those in dedicated hydrogen pipelines. In particular, studies suggest that safety risks in natural gas distribution systems increase with higher hydrogen concentrations and may pose much greater risks than existing methane distribution.

> If less than 20% hydrogen is introduced into distribution system, the overall risk is not significant. But the service lines are more critical than distribution mains because they are mostly installed in the confined spaces. In this case, adding hydrogen in the gas increases the explosion risk in the event of a gas leak. If the hydrogen level in natural gas increases beyond 20%, the overall risk in service lines can significantly increase and the potential hazards can become severe, while the overall risk in distribution mains still can be moderate up to 50%. For hydrogen level above 50% in natural gas, the risks in both distribution mains and service lines significantly increase compared to the situation with natural gas, and the overall risk in distribution system becomes unacceptable.[19]

The variability of safety risk depending upon both the hydrogen concentration and the specific part of the pipeline system involved complicates hydrogen pipeline risk assessment and is an overarching consideration in evaluating the potential for hydrogen infrastructure development.

Hydrogen Production

Large natural reserves of hydrogen rarely occur on Earth; hydrogen is found mostly as a compound with other elements in liquids, gases, or solids. Hydrogen is also found in living organisms, and, as a result, can be found in biomass and fossil fuels originating from biological sources. Hydrogen can be extracted from these various sources using appropriate technologies.

According to the Department of Energy (DOE), over 95% of U.S. hydrogen production comes from steam-methane reforming. In this process, natural gas (which is mostly methane) reacts with high pressure, high temperature steam in the presence of a catalyst to produce a mixture of mostly hydrogen and carbon monoxide. Further processing reduces the carbon monoxide, producing a gaseous stream of mostly hydrogen.[20] Hydrogen can also be extracted from coal—another organic hydrocarbon—through gasification, among other methods. In coal gasification, oxygen (or air) and steam directly contact heated coal causing a series of chemical reactions which convert these feedstocks to a synthetic gas from which hydrogen can be separated, along with solid byproducts.[21] Coal gasification offers the capability for carbon dioxide to be separated from the gaseous stream, allowing it to be potentially sequestered (e.g., stored permanently underground) or sold commercially for enhanced oil recovery or industrial uses.[22]

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[19] Zhongquan Zhou and Daniel Ersoy, "Review Studies of Hydrogen Use in Natural Gas Distribution Systems," Gas Technology Institute, prepared for National Renewable Energy Laboratory, December 16, 2010, p. 15.

[20] Department of Energy, Office of Energy Efficiency and Renewable Energy, "Hydrogen Production: Natural Gas Reforming," online article, 2020, https://www.energy.gov/eere/fuelcells/hydrogen-production-natural-gas-reforming.

[21] National Energy Technology Laboratory, "Gasification Introduction," 2020, https://www.netl.doe.gov/research/Coal/energy-systems/gasification/gasifipedia/intro-to-gasification.

[22] For further discussion, see CRS In Focus IF11501, *Carbon Capture Versus Direct Air Capture*, by Ashley J. Lawson.

In addition to extraction from fossil fuels, hydrogen can be produced from water by electrolysis, a technique which splits water molecules into pure hydrogen and oxygen. Electrolysis can be accomplished a number of ways using electricity from conventional or renewable sources and is already commercially available at industrial scale.[23] Other techniques to produce hydrogen undergoing research and development include biomass gasification, biomass fermentation, thermolysis (which splits water atoms using very high temperatures), and photolysis (which uses solar photons in biological or electrochemical systems to produce hydrogen directly). These techniques could be employed using renewable resources, either to generate the electricity required or as the feedstock (biomass).[24] Nuclear power plants also may be used for hydrogen production, either by generating electricity for electrolysis, or by producing heat and high-quality steam for other hydrogen-producing processes.[25] All of the above techniques potentially can be employed at industrial scale to produce large volumes of hydrogen.

Pipeline Shipment of Hydrogen

Due to their high capacity and economies of scale, pipelines are the most economic transportation mode for shipping most gaseous and liquid commodities—including hydrogen—over long distances in large quantities. As a 2005 DOE Hydrogen Pipeline Working Group workshop concluded, "at very large volumes, an extensive pipeline infrastructure is currently the most cost-effective and energy efficient manner to transport hydrogen to much of the market."[26] Over a century ago, domestic pipelines commonly shipped hydrogen (blended with methane and other gases), but the advent of natural gas production from North American reserves in the 1940s generally ended this practice as the new natural gas supplies replaced hydrogen and hydrogen blends. Today, nearly all U.S. pipeline shipment of hydrogen is in dedicated hydrogen infrastructure, although there are proposals to ship hydrogen-methane blends once again in U.S. natural gas pipelines as one aspect of a national energy strategy.

Hydrogen Pipelines in the United States

As of December 2020, there were 1,608 miles of active hydrogen pipeline in the United States. Over 90% of these pipelines are located along the Gulf Coast in Texas, Louisiana, and Alabama, primarily serving refineries and ammonia plants in the region (**Figure 1**).[27] Comparatively short hydrogen pipelines are located elsewhere in Texas, Louisiana, and in 9 other states. California has 16 miles of hydrogen pipeline, Indiana has 14 miles, and the remaining 7 states have fewer than 10 miles each.[28] By comparison, there are over 300,000 miles of U.S. natural gas transmission pipeline (not counting distribution mains) located in the 48 contiguous states and Alaska.

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[23] Department of Energy, *Department of Energy Hydrogen Program Plan*, November 2020, p. 17.

[24] Dale Gardner, "Hydrogen Production from Renewables," *Renewable Energy Focus*, web publication, January 1, 2009, http://www.renewableenergyfocus.com/view/3157/hydrogen-production-from-renewables/.

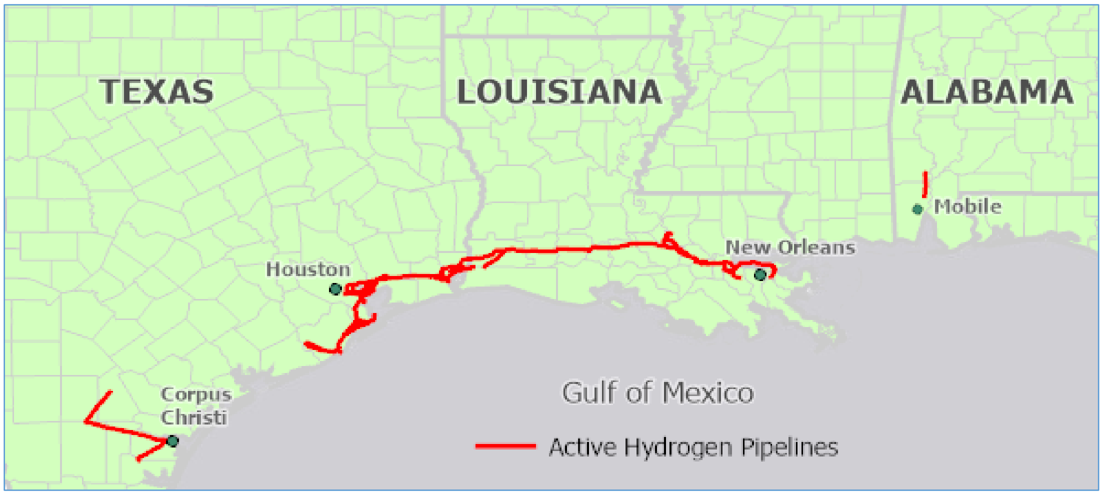
[25] Department of Energy, Office of Nuclear Energy, "Could Hydrogen Help Save Nuclear?," online article, November 26, 2018, https://www.energy.gov/ne/articles/could-hydrogen-help-save-nuclear.

[26] Department of Energy (DOE), *Hydrogen Pipeline Working Group Workshop: Workshop Proceedings*, September 2005, p. 3.

[27] Pipeline and Hazardous Materials Safety Administration (PHMSA), "Gas Distribution, Gas Gathering, Gas Transmission, Hazardous Liquids, Liquefied Natural Gas (LNG), and Underground Natural Gas Storage (UNGS) Annual Report Data," Form 7100.2-1 operator filings database, 2020, available at https://www.phmsa.dot.gov/data-and-statistics/pipeline/gas-distribution-gas-gathering-gas-transmission-hazardous-liquids. The other states with hydrogen pipelines are Kansas, Michigan, New York, Ohio, Oklahoma, Utah, and Washington.

[28] Ibid.

Figure 1. U.S. Gulf Coast Hydrogen Pipelines in 2020



Source: CRS using data from Texas Railroad Commission, Public GIS Viewer, 2020, https://www.rrc.state.tx.us/about-us/resource-center/research/gis-viewers/; PHMSA, National Pipeline Mapping System, Public Map Viewer, 2020, https://pvnpms.phmsa.dot.gov/PublicViewer/; PHMSA, Gas Transmission and Gathering Annual, online database, 2020, https://www.phmsa.dot.gov/data-and-statistics/pipeline/gas-distribution-gas-gathering-gas-transmission-hazardous-liquids; and Esri Data and Map, 2019.

Notes: The map includes pipelines designated by PHMSA as carrying hydrogen, "other gas" including hydrogen, and synthetic gas known from company references to include high hydrogen concentration. The Texas and Louisiana pipelines do not comprise a single, integrated system, but rather, several systems owned by different companies with limited interconnections. Pipeline locations are approximate.

Hydrogen Shipment in Natural Gas Pipelines

Beginning in the 1800s, gas used for lighting streets and buildings was manufactured from coal (primarily), pitch, petroleum products, and even whale oil.[29] Commonly referred to as "town gas" or "water gas," it typically consisted of hydrogen, methane, carbon monoxide, and small amounts of carbon dioxide and nitrogen. The hydrogen content of town gas ranged from 10% to 50%.[30] This gas was transported in nascent pipeline networks which became the foundation of large gas distribution systems operating in many U.S. cities. However, the increasing availability of lower cost natural gas from domestic reserves starting in the 1940s eventually supplanted town gas in these distribution systems, although town gas was still used in some communities until the 1950s.[31] Today, Hawaii Gas is the only natural gas utility in the United States distributing manufactured (synthetic) gas with a significant hydrogen concentration. The "syngas" in its Oahu pipeline system, which is derived from naphtha, contains approximately 12% hydrogen.[32]

Although nearly all pipeline shipment of hydrogen in the United States and overseas occurs in dedicated hydrogen (or syngas) infrastructure, some pipeline operators have initiated projects to evaluate blending significant hydrogen volumes in natural gas pipelines. Demonstration projects

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[29] M. W. Melaina, O. Antonia, and M. Penev, *Blending Hydrogen into Natural Gas Pipeline Networks: A Review of Key Issues*, National Renewable Energy Laboratory (NREL), NREL/TP-5600-51995, March 2013, p. v.

[30] National Grid and Atlantic Hydrogen Inc., *Hydrogen-Enriched Natural Gas: Bridge to an Ultra-Low Carbon World*, 2009, p. 4, https://www.osti.gov/etdeweb/servlets/purl/21396875.

[31] M. W. Melaina, O. Antonia, and M. Penev, March 2013, p. v.

[32] Hawaii Gas, "Hydrogen," web page, accessed December 15, 2020, https://www.hawaiigas.com/clean-energy/hydrogen/.

in Europe, for example, have been blending up to 20% by volume of hydrogen into isolated portions of their natural gas distribution systems.[33] In November 2020, Southern California Gas Company and San Diego Gas & Electric Company filed a joint application with state regulators to initiate a similar hydrogen blending demonstration project in their respective gas distribution systems in California.[34] Several other U.S. utilities have proposed or initiated early efforts to test hydrogen blending in natural gas pipeline systems, but they have not announced plans to ship significant hydrogen volumes in commercial service.[35] None of the above projects appear to directly involve hydrogen-methane blending in transmission pipelines, but one operator in Italy has demonstrated 10% hydrogen blending in a segment of its natural gas transmission network serving several large industrial customers.[36] Higher percentages of hydrogen content in hydrogen-methane blends are anticipated in both natural gas distribution and transmission pipelines; however, analysts assert that 20% hydrogen concentrations by volume may be the maximum allowable blend before significant pipeline upgrade costs are required due to potential impacts on pipeline materials.[37] In addition, the end-use equipment in power plants and industrial facilities served by natural gas transmission pipelines may not tolerate higher hydrogen concentrations without modification.

Conversion of Existing Natural Gas and Oil Pipelines

Another means of hydrogen shipment by pipeline is converting natural gas, crude oil, or refined product pipelines to carry pure hydrogen. Pipeline conversion typically would involve measures such as modifying compressors, valves, seals, meters, and other components; replacing pipeline segments or reworking welds with compatible materials; modifying leak detection systems; and installing new controls to monitor and manage hydrogen flows. There are at least two examples of such conversion in the United States. In the 1990s, Air Liquide (one of the Gulf Coast operators) purchased two crude oil pipelines in Texas and successfully converted them to hydrogen service.[38] While such conversions have been uncommon in the past, converting natural gas pipelines, in particular, to carry pure hydrogen is emerging as a potentially effective strategy for increasing hydrogen shipment capability. As a 2020 DOE report stated, "natural gas networks are well developed in the United States and represent infrastructure that could be adopted for conveyance of hydrogen," although "converting natural gas infrastructure to hydrogen

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[33] International Energy Agency, *Hydrogen*, web publication, June 2020, https://www.iea.org/reports/hydrogen.

[34] Southern California Gas Company, San Diego Gas & Electric Company, Pacific Gas and Electric Company, and Southwest Gas Corporation, *Joint Application Regarding Hydrogen-Related Additions or Revisions to the Standard Renewable Gas Interconnection Tariff*, Before the Public Utilities Commission of the State of California, November 20, 2020, https://www.socalgas.com/sites/default/files/2020-11/Utilities_Joint_Application_Prelim_H2_Injection_Standard_11-20-20.pdf.

[35] Yannic Rack and Tom DiChristopher, "Facing Uncertain Future, Gas Operators Look to Hydrogen Lifeline," *S&P Global Market Intelligence*, online article, December 2, 2020, https://www.spglobal.com/marketintelligence/en/news-insights/latest-news-headlines/facing-uncertain-future-gas-operators-look-to-hydrogen-lifeline-61190436; David Iaconangelo, "Hydrogen: 3 Things to Watch in 2021," *E&E News*, January 4, 2021.

[36] Snam S.p.A, "Snam and Hydrogen," web page, updated September 8, 2020, https://www.snam.it/en/energy_transition/hydrogen/snam_and_hydrogen/.

[37] Energy and Environmental Economics, Inc. and The Energy Futures Initiative, Inc., *Net-Zero New England: Ensuring Electric Reliability in a Low-Carbon Future*, November 2020, p. 24. 20% hydrogen by volume is equivalent to 7% by energy content.

[38] Jim Campbell, Air Liquide, "Questions and Issues on Hydrogen Pipelines," Presentation to the DOE Hydrogen Pipeline Working Group Meeting, August 31, 2005, https://www.energy.gov/sites/prod/files/2014/03/f10/hpwgw_questissues_campbell.pdf.

infrastructure is a long-term proposition."[39] Likewise a group of major natural gas transmission companies in Europe has proposed converting much of the continental natural gas transmission system to establish "a dedicated European Hydrogen Backbone."[40] Although such proposals may have long time frames, one German utility announced a demonstration project in 2021 to convert a medium-pressure natural gas distribution pipeline to carry pure hydrogen to a small group of industrial customers for space heating (using modified boilers).[41]

Studies of converting natural gas pipelines to carry hydrogen cite potential economic and development advantages. An analysis of the German national pipeline network concluded that converting existing natural gas pipelines into dedicated hydrogen pipelines could reduce hydrogen transmission costs by 20% to 60% compared to constructing new hydrogen pipelines.[42] Such conversions could facilitate hydrogen market development by providing high-volume, networked transportation capability for hydrogen with limited additional capital investment, thereby avoiding a "chicken and egg" problem wherein initial hydrogen demand cannot financially support large pipeline construction projects. Converting natural gas pipelines to hydrogen also could reduce the risk that those existing pipelines could become devalued or "stranded" assets due the reduced demand for natural gas transportation resulting from hydrogen and renewable energy policies.[43] Finally, converting pipelines in existing rights-of-way could be preferable to establishing new pipeline routes, a potentially lengthy process which has faced increasing regulatory and legal challenges in the United States and elsewhere over the last decade.

The potential to preserve the value of existing pipeline assets while reducing methane emissions are among the reasons that domestic pipeline operators are examining the potential for natural gas pipeline conversion in the United States. For example, the head of the American Gas Association, which represents U.S. natural gas distribution companies, stated in 2021, "you're going to be hearing a lot about hydrogen in the coming days ... and the industry is at the table."[44] Notwithstanding potential advantages, apart from technical issues that would need to be addressed for extant natural gas pipelines to ship hydrogen, such an initiative would still face significant market uncertainty and logistical challenges related to hydrogen demand.

U.S. Regulation of Hydrogen Pipelines

A key factor in the development of U.S. hydrogen pipelines is regulation of their siting, commercial service (e.g., rates), safety, and security. Some regulatory authorities differ for dedicated hydrogen pipelines and for natural gas pipelines carrying hydrogen mixed with methane. Currently, these authorities are divided among federal agencies and the states.

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[39] Department of Energy, *Hydrogen Strategy: Enabling a Low-Carbon Economy*, July 2020, p. 14.

[40] Enagás et al., *European Hydrogen Backbone*, July 2020, p. 4.

[41] E.ON SE, "Unique Project in Germany: Natural Gas Pipeline is Converted to Pure Hydrogen," press release, November 10, 2020.

[42] Simonas Cerniauskas et al., "Options of Natural Gas Pipeline Reassignment for Hydrogen: Cost Assessment for a Germany Case Study," *International Journal of Hydrogen Energy*, vol. 45, no. 21, April 17, 2020.

[43] Environmental Defense Fund, *Managing the Transition Proactive Solutions for Stranded Gas Asset Risk in California*, 2019.

[44] Karen Harbert, President and CEO, American Gas Association, remarks at the United States Energy Association State of the Energy Industry Forum, January 28, 2021, video recording available at https://youtu.be/e2fZrEyMJC0.

Siting Approval

There is no federal authority to approve the siting of dedicated hydrogen pipelines, although federal approvals may be required for siting of specific pipeline segments (discussed below). In this respect, hydrogen pipelines are similar to oil pipelines and intrastate natural gas pipelines, which also are under state jurisdiction. Developers seeking to construct hydrogen pipelines must seek separate approvals from the individual states through which the pipeline would pass, with each state having its own distinct statutory requirements for such approval. This approach is in contrast to the siting of interstate natural gas pipelines, the siting of which must be approved by the Federal Energy Regulatory Commission (FERC) under Section 7(c) of the Natural Gas Act.[45]

Although a state may authorize the construction of a hydrogen pipeline within its borders under state law, the developer must also comply with any federal laws that may apply to the project—such as the Endangered Species Act, the National Historic Preservation Act, the Coastal Zone Management Act (CZMA), or the Clean Water Act (CWA). Requirements under these statutes may include, for example, authorization for water crossings from the Army Corps of Engineers, permission for a route that crosses federal lands from the Bureau of Land Management, consultation with Native American tribes to identify historic or cultural sites, and other mandatory federal consultations and approvals.[46] Some federal statutes provide for state roles or state administration of approval authorities (e.g., CZMA, CWA); therefore, states entities also may be reviewing and approving segments of pipelines. Other approvals must be granted from federal agencies directly. Review of pipeline permit applications by federal agencies also requires them to examine environmental impacts in compliance with the National Environmental Policy Act (NEPA).[47]

Regulation of Pipeline Service

The terms of commercial service of commodity pipelines may include provisions for access to pipeline capacity, rates for transportation service, requirements for commodity quality, and other commercial requirements. Some pipelines may be designated as “common carriers,” a legal classification which requires them to serve all shippers at all times and typically makes their rates subject to economic regulation through regulated tariffs. Other pipelines may be “contract carriers,” serving only a specific group of shippers, usually under long-term pipeline capacity agreements, but also subject to rate regulation.[48] Rates for intrastate utility pipelines are under state jurisdiction, whereas rates for interstate pipelines are under federal jurisdiction. Common carrier provisions and associated rate regulation may apply to both hydrogen pipelines and natural gas pipelines carrying a methane-hydrogen blend, although overall regulatory provisions differ

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[45] As codified at 15 U.S.C. §717f(c), “No natural-gas company or person ... shall engage in the transportation or sale of natural gas, subject to the jurisdiction of the Commission, or undertake the construction or extension of any facilities therefor ... unless there is in force with respect to such natural-gas company a certificate of public convenience and necessity issued by the Commission.”

[46] For more background on federal water crossing permits, see CRS Report R44880, *Oil and Natural Gas Pipelines: Role of the U.S. Army Corps of Engineers*, by Nicole T. Carter et al.

[47] For more background on NEPA, see CRS In Focus IF11549, *The Legal Framework of the National Environmental Policy Act*, by Nina M. Hart and Linda Tsang.

[48] For further discussion of common and contract carriage see William A. Mogel and John P. Gregg, “Appropriateness of Imposing Common Carrier Status on Interstate Natural Gas Pipelines,” *Energy Law Journal*, vol. 4, no. 2, 1983, pp. 155-187. Being subject to rate regulation is often a requirement to be granted eminent domain authority by a state or federal agency for pipeline construction.

from state to state.[49] Pipelines carrying only natural gas typically are regulated as contract carriers. Transportation rates for either common or contract carrier pipelines are specific to individual pipelines, typically based on negotiated agreements with shippers or on cost of service plus an allowed rate of return.

Jurisdiction over rates for interstate hydrogen pipelines resides with the Surface Transportation Board (STB). The STB is an independent federal regulatory agency (administratively affiliated with the Department of Transportation) with the primary mission of resolving railroad disputes pursuant to the Interstate Commerce Act (ICA). The STB is the successor agency to the Interstate Commerce Commission (ICC). Because pipelines, like railroads, can be common carriers used by more than one company for the transportation of goods, the ICA also assigned the ICC (and thus the STB) oversight authority over pipelines transporting a commodity other than "water, gas or oil." However, the STB does not require pipeline companies to file tariffs and justify their rates. Instead, the STB acts as a forum to resolve disputes related to pipelines within its jurisdiction. Parties who wish to challenge whether a rate or another aspect of a pipeline's common carrier service is "just and reasonable" may petition the STB for a hearing, but "the STB may not on its own initiative investigate and alter rates charged by a hydrogen pipeline."[50]

FERC Rate Regulation

In addition to siting authority, the Natural Gas Act (NGA) vests in FERC extensive regulatory authority over the rates for interstate natural gas pipelines, which could also apply if hydrogen-methane blends are carried in such pipelines.[51] Like the ICA, the NGA mandates a "just and reasonable" standard for pipeline rates and terms of service.[52] For most interstate natural gas pipelines, FERC uses a cost-of-service methodology which allows for a reasonable rate of return on investment by the pipeline owner. The commission may set "initial" rates for newly certificated pipelines under Section 7 of the NGA, may approve general rates and rate changes under Section 4, and may require prospective rate changes when rates are seen as no longer just and reasonable under Section 5. The commission may initiate an NGA Section 5 rate proceeding on its own or upon complaint from an interested party.[53]

Pipeline operators incorporate their FERC-approved rates and other conditions for transportation in publicly-posted tariffs available to prospective shippers. Tariff conditions may be related to the allocation of pipeline capacity to shippers, description of the pipeline services offered, financial and transactional requirements, and specification of commodity characteristics (quality). Among other provisions, FERC requires gas pipeline tariffs to incorporate business practice standards

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[49] For example, Texas Natural Resources Code, Section 111.002, states that "A person is a common carrier" if it "owns, operates, or manages, wholly or partially, pipelines for the transportation of carbon dioxide or hydrogen in whatever form to or for the public for hire, but only if such person files with the commission a written acceptance of the provisions of this chapter expressly agreeing that, in consideration of the rights acquired, it becomes a common carrier subject to the duties and obligations conferred or imposed by this chapter."

[50] U.S. Department of Transportation, Research and Innovative Technology Administration, "Statement Regarding a Coordinated Framework for Regulation of a Hydrogen Economy," 72 *Federal Register* 609, January 5, 2007.

[51] FERC also has jurisdiction over rates and certain other activities related to interstate oil pipelines under the ICA, although that jurisdiction is not as extensive as its jurisdiction over natural gas pipelines. 49 App. U.S.C. §1.

[52] "All rates and charges made, demanded, or received by any natural-gas company for or in connection with the transportation or sale of natural gas subject to the jurisdiction of the Commission, and all rules and regulations affecting or pertaining to such rates or charges, shall be just and reasonable." 15 U.S.C. §717c.

[53] Federal Energy Regulatory Commission, "Cost-of-Service Rate Filings," web page, updated August 14, 2020, https://www.ferc.gov/industries-data/natural-gas/overview/general-information/cost-service-rate-filings.

developed by the North American Energy Standards Board (NAESB).[54] Hydrogen content is among the natural gas quality attributes which may be limited by a pipeline operator under the NAESB standards.[55]

Safety Regulation[56]

Under the Natural Gas Pipeline Safety Act of 1968 (P.L. 90-481) and the Hazardous Liquid Pipeline Act of 1979 (P.L. 96-129), the Department of Transportation (DOT) has primary authority to regulate the safety of interstate and intrastate energy commodity pipelines. The department administers this authority through its Pipeline and Hazardous Materials Safety Administration (PHMSA). DOT's pipeline safety authority extends to hydrogen pipelines, which PHMSA has regulated since 1970 as a "flammable gas" under its safety requirements at 49 C.F.R. Part 192, *Transportation of Natural and Other Gas by Pipeline: Minimum Federal Safety Standards*.

The federal pipeline safety regulations are comprehensive, covering pipeline design, construction, operation and maintenance, and spill response planning.[57] PHMSA uses a variety of strategies to promote compliance. The agency conducts programmatic inspections of management systems, procedures, and processes; conducts physical inspections of facilities and construction projects; investigates safety incidents; and maintains a dialogue with pipeline operators. The agency clarifies its regulatory expectations through published protocols and regulatory orders, guidance manuals, and public meetings. PHMSA relies upon a range of enforcement actions, including administrative actions, such as corrective action orders and civil penalties, to ensure that operators correct safety violations and take measures to preclude future safety problems.

PHMSA's enabling legislation allows the agency to delegate authority over intrastate pipeline safety program administration, inspection, and enforcement to state regulators, and allows state offices to act as "agents" (excluding enforcement) for those sections of interstate pipelines within their boundaries. To support its state partners, PHMSA may reimburse states for up to 80% of their pipeline safety expenditures.[58] PHMSA relies heavily on state agencies, with over 70% of inspectors being state employees. PHMSA also provides grants for pipeline safety research and development, including hydrogen-related research, to inform its regulatory activities.[59]

Pipeline Security

The federal program for U.S. pipeline security began immediately after the terror attacks of September 11, 2001. The Aviation and Transportation Security Act of 2001 (P.L. 107-71) established the Transportation Security Administration (TSA) within the DOT, authorizing the agency "to issue, rescind, and revise such regulations as are necessary" to carry out its functions

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[54] Federal Energy Regulatory Commission, "Standards for Business Practices of Interstate Natural Gas Pipelines," 83 *Federal Register* 170, August 31, 2018.

[55] North American Energy Standards Board, Wholesale Gas Quadrant, *Business Practice Standards,* Version 1.8, September 30, 2006, p. 65.

[56] For further detail about federal pipeline safety regulation, see CRS Report R44201, *DOT's Federal Pipeline Safety Program: Background and Key Issues for Congress*, by Paul W. Parfomak.

[57] 49 C.F.R. Part 192, "Transportation of Natural and Other Gas by Pipeline: Minimum Federal Safety Standards."

[58] 49 U.S.C. §60107.

[59] See, for example: Andrew J Slifka, et al., "Measurements of Fatigue Crack Growth Rates of the Heat-Affected Zones of Welds of Pipeline Steels," Proceedings of the ASME 2015 Pressure Vessels and Piping Conference, Boston, MA, July 19-23, 2015.

(§101). Because pipelines are considered a mode of transportation, pipeline security falls under this provision. TSA subsequently was transferred to the Department of Homeland Security, newly created under the Homeland Security Act of 2002 (P.L. 107-296). The Implementing Recommendations of the 9/11 Commission Act of 2007 (P.L. 110-53) directs TSA to promulgate pipeline security regulations and carry out necessary inspection and enforcement if the agency determines that regulations are appropriate (§1557(d)). However, to date, TSA has not issued such regulations, relying instead upon industry compliance with voluntary guidelines for pipeline security.[60] The pipeline industry maintains that regulations are unnecessary because pipeline operators have voluntarily implemented effective physical and cybersecurity programs.[61]

In fulfilling its responsibilities, TSA cooperates with PHMSA under the terms of a 2004 memorandum of understanding and a 2020 annex to facilitate transportation security collaboration.[62] TSA also cooperates with DOE's Office of Cybersecurity, Energy Security, and Emergency Response, whose mission is to "enhance the security of U.S. critical energy infrastructure to all hazards, mitigate the impacts of disruptive events and risk to the sector overall through preparedness and innovation, and respond to and facilitate recovery from energy disruptions."[63] TSA also collaborates with FERC's Office of Energy Infrastructure Security, which regulates the security of the bulk power electric grid.

Federal Hydrogen Pipeline R&D

The pipeline industry has long identified technological challenges to developing a national network of dedicated hydrogen pipelines.[64] To address these challenges, pipeline researchers and industry experts favor a significant federal role in hydrogen pipeline research and development (R&D). Consistent with this view, under a series of agency initiatives and energy statutes (discussed in the next section), the federal government has supported hydrogen pipeline-related R&D since the 1960s. This research has been supported by the National Aeronautics and Space Administration (NASA), DOE, DOT, and the National Institute of Standards and Technology (NIST). At various times, these agencies have acted independently or in coordination. Their research has examined a range of topics including basic materials science, hydrogen pipeline safety, pipeline economics, hydrogen markets, and pipeline network modeling, among other topics.

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[60] Transportation Security Administration, *Pipeline Security Guidelines*, April 2011, and *Pipeline Security Smart Practice Observations*, September 19, 2011.

[61] Interstate Natural Gas Association of America, "Pipeline Cyber and Physical Security," fact sheet, https://www.ingaa.org/File.aspx?id=34999&v=5c0904b.

[62] Transportation Security Administration and Pipeline and Hazardous Materials Safety Administration, "Transportation Security Administration and Pipeline and Hazardous Materials Safety Administration Cooperation on Pipeline Transportation Safety and Security," memorandum, February 26, 2020, https://www.phmsa.dot.gov/sites/phmsa.dot.gov/files/2020-03/PHMSA-TSA%20MOU%20Annex_executed.pdf.

[63] Office of Cybersecurity, Energy Security, and Emergency Response (CESER), "CESER Mission," web page, https://www.energy.gov/ceser/ceser-mission.

[64] See, for example, American Petroleum Institute, prepared statement for the House Committee of Energy and Commerce, Subcommittee on Energy and Air Quality hearing on the Hydrogen Energy Economy, Serial No. 108-21, May 20, 2003. "Regardless of whether hydrogen is distributed via retrofitted pipelines or new dedicated pipelines, technological issues need to be addressed."

National Aeronautics and Space Administration

Some of the earliest federal activities in hydrogen pipeline-related R&D were initiated by NASA as an outgrowth of the agency's aerospace programs. For example, in the late 1960s, NASA sponsored research at Rocketdyne on the effects of pressurized hydrogen on metals, work which became an important reference for subsequent research on hydrogen pipeline embrittlement.[65] NASA's Office of Energy Programs funded a 1975 Hydrogen Energy Systems Technology Study performed by the Jet Propulsion Laboratory which included a specific focus on bulk hydrogen shipment by pipeline, among other topics.[66] The agency continued supporting research related to hydrogen pipelines through the 1980s.[67] In 1990, NASA began funding a technology assessment by the National Hydrogen Association (NHA, a nongovernment membership association), DOE, and DOT "to develop information on current and emerging hydrogen-related technologies," including pipeline technology, and to "define the context in which policy discussions about commercialization and infrastructure change can begin."[68] In 1997, NASA published safety standards for hydrogen systems "facility design, design of components, materials compatibility, detection, and transportation" as well as "operational issues and emergency procedures."[69] Although these standards were developed specifically for NASA activities, many aspects could be applicable to hydrogen pipelines.

Department of Energy

An official of the federal Energy Research and Development Administration (a predecessor to the DOE) testified in 1975 that the agency had "an ongoing program to investigate hydrogen compatibility with structural materials such as those used in pipelines."[70] Concluded in 1981, this research investigated "the hydrogen compatibility of structural materials for energy storage and transportation, a program which focused on the feasibility of using the natural gas pipeline network for hydrogen gas transmission."[71] DOE supported subsequent hydrogen pipeline material research in the 1980s.[72] In 1991, DOE joined NASA in the NHA's hydrogen technology assessment through the newly designated National Renewable Energy Laboratory. DOE funded

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[65] R. J. Walter and W.T. Chandler, *Effects of High-Pressure Hydrogen in Metals at Ambient Temperature: Final Report*, Report No. R-7780-1, 2, 3 (NASA Contract NAS 8-19), Rocketdyne, Canoga Park, CA, February 28, 1969.

[66] Jet Propulsion Laboratory, *Hydrogen Tomorrow: Demands & Technology Requirements*, NASA-CR-146416, December 1975.

[67] See, for example: Ali K. Kashani, *Assessment of Potential Future Hydrogen Markets in the U.S.*, prepared by Jet Propulsion Laboratory through an agreement with NASA, JPL Pub. 80-68, September 1980.

[68] National Hydrogen Association, *The Hydrogen Technology Assessment, Opportunities for Industry and Research, Phase I*, prepared for the National Aeronautics and Space Administration, NASA-CR-190969, January 1, 1991, p. i.

[69] NASA, "Safety Standard for Hydrogen and Hydrogen Systems: Guidelines for Hydrogen System Design, Materials Selection, Operations, Storage and Transportation," NASA-TM-112540, January 1, 1997, p. 1-1.

[70] James S. Kane, Deputy Assistant Administrator for Conservation, Energy Research and Development Administration, Statement before the House Committee on Science and Technology, Subcommittee on Energy Research, Development, and Demonstration hearing on Hydrogen, June 10 and 12, 1975.

[71] W.R. Hoover et al., *Hydrogen Compatibility of Structural Materials for Energy Storage and Transmission: Final Report*, Sandia National Laboratories, SAND-81-8006, May 1, 1981.

[72] See, for example: H. J. Cialone and J. H. Holbrook, "Effects of Gaseous Hydrogen on Fatigue Crack Growth in Pipeline Steel," *Metallurgical Transactions A*, vol. 16A, January 1985, pp. 115-122. This research was performed at Brookhaven National Laboratory under DOE Contract No. 55072-S.

other hydrogen pipeline-related R&D in the1990s within the agency's hydrogen program, although pipelines do not appear to have been a major focus.[73]

DOE's hydrogen pipeline R&D efforts expanded in 2003 under President George W. Bush's Hydrogen Fuel Initiative. Among other objectives, this five-year initiative increased funding "to develop the technologies and infrastructure to produce, store, and distribute hydrogen for use in fuel cell vehicles and electricity generation."[74] A 2005 merit review and peer evaluation for the DOE Hydrogen Program cited several pipeline projects underway that time, including research on hydrogen pipeline permeability and embrittlement.[75] As part of its 2006 Hydrogen Posture Plan, DOE outlined research in specific categories of technology intended "to lower the cost of the hydrogen delivery infrastructure," including lower-cost hydrogen compression, better pipeline materials to prevent embrittlement, and (in coordination with DOT) hydrogen delivery safety technologies such as seals, valves, sensors, and controls.[76] DOE's 2007 update to its multi-year research, development, and demonstration plan for its Hydrogen, Fuel Cells & Infrastructure Technologies Program outlined 10 ongoing projects focused on hydrogen pipelines.[77] In 2008, a DOE-sponsored consortium published a study examining "the cost effective mechanism for the transport and delivery of hydrogen from the central production facilities to the point of use."[78] The results of this research were incorporated into hydrogen delivery models developed for the DOE's Hydrogen Analysis (H2A) Project, part of the Hydrogen Fuel Initiative.[79]

DOE has continued to sponsor hydrogen pipeline-related R&D over the last decade. For example, in 2013, DOE published a study examining hydrogen blending in natural gas pipelines.[80] DOE's Hydrogen and Fuel Cell Technologies Office's multi-year R&D plan for hydrogen delivery, updated in 2015, focused on "developing innovative process technologies that can reduce hydrogen transport and fueling costs" and modeling to support analysis and optimization of hydrogen delivery pathways, including pipeline delivery.[81] In 2017, the DOE-supported U.S. DRIVE partnership published the *Hydrogen Delivery Technical Team Roadmap*, "to address the technical goals and milestones for hydrogen delivery systems, to assess technologies and early stage R&D that could help meet these goals, and to identify the barriers to achieving these goals."[82] In 2018, DOE established the Hydrogen Materials Compatibility Consortium (H-Mat),

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[73] National Renewable Energy Laboratory, *Proceedings of the 1992 DOE/NREL Hydrogen Program Review*, May 6-7, 1992, Honolulu, Hawaii, NREL/CP-450-4972, published July 1992.

[74] Executive Office of the President, Office of the Press Secretary, press release, "Fact Sheet: Hydrogen Fuel: A Clean and Secure Energy Future," February 6, 2003, https://georgewbush-whitehouse.archives.gov/news/releases/2003/02/20030206-2.html.

[75] Department of Energy, *DOE Hydrogen Program: 2005 Annual Merit Review and Peer Evaluation Report*, DOE/GO-102005-2187, September 2005.

[76] Department of Energy and Department of Transportation, *Hydrogen Posture Plan Hydrogen Posture Plan: An Integrated Research, Development Plan*, December 2006, p. 18.

[77] Department of Energy, *Hydrogen, Fuel Cells & Infrastructure Technologies Program: Multi-Year Research, Development and Demonstration Plan*, October 2007, Table 3.2.1.

[78] Nexant, *Final Report: Hydrogen Delivery Infrastructure Options Analysis*, Section 1, DE-FG36-05GO15032, 2008.

[79] Department of Energy, "The Hydrogen Analysis (H2A) Project," web page, accessed January 12, 2021, https://www.hydrogen.energy.gov/h2a_analysis.html#h2a_project.

[80] NREL, March 2013.

[81] Department of Energy, Fuel Cell Technologies Office, *Multi-Year Research, Development, and Demonstration Plan*, Section 3.2 "Hydrogen Delivery," August 2015, pp. 8-9, https://www.energy.gov/sites/prod/files/2015/08/f25/fcto_myrdd_delivery.pdf.

[82] U.S. DRIVE, *Hydrogen Delivery Technical Team Roadmap*, July 2017, p. 4. More information on U.S. DRIVE is available at https://www.energy.gov/eere/vehicles/us-drive.

involving five national laboratories, to research the effects of hydrogen on the performance of materials used in hydrogen infrastructure and storage.[83] DOE also has established cost and performance targets for key aspects of pipeline transportation including capital cost per mile, compressor energy, pipeline pressure, leakage, maintenance cost, and pipeline operating life.[84]

In July 2020, a DOE Office of Oil and Natural Gas (ONG) presentation stated that DOE has pursued pipeline R&D related to metal fatigue and fracture resistance due to hydrogen embrittlement in natural gas pipelines; developing new components, configurations, and sensors for hydrogen transportation; and conducting hydrogen transportation infrastructure assessments. The presentation also states "ONG is in an ideal position to conduct R&D initiatives that would lead to more efficient and cost-effective technologies for transporting hydrogen."[85] DOE's 2020 Hydrogen Program Merit Review did not report any active R&D projects specifically focused on pipelines, although it did include updates for three projects that could apply to pipelines: two investigating hydrogen infrastructure steel, and one investigating hydrogen compressor seals.[86] The department's FY2021 budget request included R&D funds for "turbines fueled with hydrogen produced from coal gasification with CCUS" potentially "mixed through the natural gas pipeline infrastructure."[87] It also requested R&D funds for advanced materials operating in "aggressive service environments" including environments subject to "hydrogen attack," noting that "these aggressive environments, and the associated materials durability challenges are common across multiple applications."[88]

In November, 2020, the National Renewable Energy Laboratory announced plans to lead a two-year, collaborative R&D project (HyBlend), involving six national laboratories and 20 industry and academic participants "to address the technical barriers to blending hydrogen in natural gas pipelines."[89] The project anticipated $10 million in DOE funding and an additional $4 to $5 million of funding from other participants. A $160 million DOE Funding Opportunity Announcement (FOA) for hydrogen program R&D published in January 2021 included an objective "to develop technologies that improve the cost and performance (e.g., resiliency, reliability, safety, and integrity) of hydrogen transportation infrastructure, including pipelines," although it did not include funding for pipeline-specific areas of interest. The FOA anticipated that it would be amended in the future as funding becomes available to incorporate additional areas of interest.[90]

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[83] Hydrogen Materials Compatibility Consortium, "About H-Mat," web page, accessed January 19, 2021, https://h-mat.org/.

[84] Department of Energy, DOE Technical Targets for Hydrogen Delivery, web page, accessed January 12, 2021, https://www.energy.gov/eere/fuelcells/doe-technical-targets-hydrogen-delivery.

[85] Department of Energy, Office of Oil and Natural Gas, "Oil and Gas Economy-wide Production, Transport and Storage of Hydrogen," presentation at the United States Energy Association Hydrogen Workshop, July 23, 2020, pp. 11-12, https://usea.org/sites/default/files/event-/US_DOE_FE_30_H2_Workshop_07_23_2020_public.pdf.

[86] Department of Energy, Hydrogen Program, "2020 Annual Merit Review: Progress Updates," web page, accessed January 12, 2021, https://www.hydrogen.energy.gov/annual_review20_proceedings.html.

[87] Department of Energy, *FY2021 Congressional Budget Request*, Vol. 3 Part 2, DOE/CF-0164, February 2020, p. 219.

[88] Ibid., p. 221.

[89] National Renewable Energy Laboratory, "HyBlend Project to Accelerate Potential for Blending Hydrogen in Natural Gas Pipelines," press release, November 18, 2020.

[90] Department of Energy, *Financial Assistance Funding Opportunity Announcement: Fossil Energy Based Production, Storage, Transport and Utilization of Hydrogen Approaching Net-Zero or Net-Negative Carbon Emissions*, DE-FOA-0002400, January 15, 2021, p. 10.

Department of Transportation

As the federal regulator of pipeline safety, DOT has funded R&D related to hydrogen pipelines through PHMSA, the Research and Innovative Technology Administration (RITA), and their predecessor, the Research and Special Programs Administration (RSPA)—although the scope of this research has been limited. In particular, PHMSA has stated that its "hydrogen-related expenditures, particularly for research and development, are expected to be small relative to those made by other organizations," with a "need to focus on supporting activities to ensure that hydrogen is transported safely."[91] In 1983, RSPA commissioned a technical review of safety criteria for hydrogen transportation by pipeline.[92] In 2006, RITA published a technical assessment and research gap analysis of hydrogen infrastructure safety.[93] PHMSA's database of R&D projects lists a handful of additional studies over the last 20 years, including research on the impact radius of hydrogen pipeline leaks, and the effects of hydrogen on pipeline steel, metal fatigue, and welds, with the most recent work reported in 2015.[94] In July 2020, DOT announced $10 million in funding to establish a pipeline research, development, and testing facility at the Transportation Technology Center (TTC) in Pueblo, CO, to "support development of new technologies and advance stakeholder knowledge related to pipeline safety issues" including remote sensing, leak detection, damage prevention, and construction.[95] Although the announcement does not provide details on specific research projects anticipated, PHMSA's new testing facility potentially could be employed to support hydrogen pipeline safety R&D.

National Institute of Standards and Technology

The involvement of NIST (part of the Department of Commerce) in hydrogen pipeline R&D stems from its mission to provide measurement, calibration, and quality assurance techniques that underpin U.S. commerce, technological progress, and public safety. In the context of hydrogen pipelines, specifically, the laboratory stated in 2007 that its role was addressing standards issues surrounding their commercial use, filling data gaps for the codes and standards community, and testing components.[96] In 2008, NIST announced the construction of a new laboratory to "evaluate tests, materials, mechanical properties and standards for hydrogen pipelines."[97] NIST has an ongoing program of laboratory research involving hydrogen pipeline materials in areas such as

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[91] Pipeline and Hazardous Materials Safety Administration, "Hydrogen," web page, accessed January 12, 2021, https://primis.phmsa.dot.gov/comm/hydrogen.htm.

[92] Wyle Laboratories, *Safety Criteria for the Operation of Gaseous Hydrogen Pipelines*, prepared for the U.S. Department of Transportation, Report No. DOT.RSPA/DMT-10-85-1, 1985.

[93] Research and Innovative Technology Administration, *Hydrogen Infrastructure Safety Technical Assessment and Research Results Gap Analysis*, DOT-T-06-01, April 2006.

[94] Michael Baker Jr., Inc. *Potential Impact Radius Formulae for Flammable Gases Other Than Natural Gas Subject to 49 CFR 192*, DTRS56-02-D-70036, June 2005; Pipeline and Hazardous Materials Safety Administration, Research and Development Program, "Research Project Query," online database, https://primis.phmsa.dot.gov/matrix/prjQuery.rdm?nocache=1860, accessed January 12, 2021.

[95] Pipeline and Hazardous Materials Safety Administration, "PHMSA Announces $10 Million Award for Engineering Services for a New Pipeline Research, Development, and Testing Center," press release, PHMSA 06-20, July 22, 2020.

[96] Hydrogen Delivery Pipeline Working Group, "Workshop Summary," Center for Hydrogen Research, Aiken, GA, September 25-26, 2007, https://www.energy.gov/sites/prod/files/2014/03/f9/pipeline_group_summary_ms.pdf.

[97] National Institute of Standards and Technology, "NIST Building Facility for Hydrogen Pipeline Testing," press release, January 23, 2008.

pipeline steel fatigue under hydrogen exposure and the cost of hydrogen pipelines under different design standards.[98]

> NIST's unique laboratories measure steel properties in ways that mimic actual service situations such as mechanical fatigue in a high-pressure hydrogen gas environment ... paving the way for the safe use of thinner-walled pipes that are more cost-effective than pipes made of older steel. The stronger steel means that pipelines can be larger in diameter and move hydrogen at higher pressures, so more hydrogen can be transported faster and safer. NIST tests on hydrogen-transporting pipes led to a code change that allowed pipeline owners to switch to the thinner-walled pipes without increased cost.[99]

NIST has collaborated with PHMSA on some of its hydrogen pipeline steel research.

Congressional Action on Hydrogen Pipelines

Congress has acted to support the development of hydrogen pipelines specifically through various measures over the last 30 years. Section 104 of the Spark M. Matsunaga Hydrogen Research, Development, and Demonstration Act of 1990 directed the Secretary of Energy to "initiate research or accelerate existing research in critical technical issues ... including ... transmission, distribution, storage, and use" of hydrogen.[100] The Hydrogen Future Act of 1996, which amended Section 104, retained the language supporting hydrogen transmission and distribution research.[101]

The Energy Policy Act of 2005 mandated that relevant federal agencies, in consultation with FERC and other stakeholders, designate corridors for hydrogen pipelines and other energy infrastructure on federal lands in the 11 contiguous Western States and (later) in the other 39 states; perform associated environmental reviews; and incorporate the designated corridors into their land use and resource management plans.[102] The act also required the agencies to "expedite applications" to construct or modify hydrogen pipelines or other energy infrastructure within such corridors.[103] The act mandated that the Secretary of Energy, in consultation with other federal agencies and the private sector, conduct a research and development program on hydrogen technologies, including infrastructure to deliver and distribute hydrogen.[104] The act explicitly required the secretary to conduct a program in partnership with the private sector to address "safe

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[98] See for example, N. Nanninga et al., "A Review of Fatigue Crack Growth for Pipeline Steels Exposed to Hydrogen," *Journal of Research of the National Institute of Standards and Technology*, vol. 115, no. 6, 2010, pp. 437-452; Robert L. Amaro et al., "Modeling the Fatigue Crack Growth of X100 Pipeline Steel in Gaseous Hydrogen," *International Journal of Fatigue*, vol. 59, 2014, pp. 262–271; and J.W. Sowards et al., "Economic Impact of Applying High Strength Steels in Hydrogen Gas Pipelines," *International Journal of Hydrogen Energy*, vol. 40, no. 33, 2015, pp. 10547-10558.

[99] National Institute of Standards and Technology, "Industry Impacts: Pipeline Safety," web page, accessed February 2, 2021, https://www.nist.gov/industry-impacts/pipeline-safety.

[100] P.L. 101-566 §104(b).

[101] P.L. 104-271 §103(a).

[102] P.L. 109-58 §§368 (a) and (b). The statute names the Secretaries of Agriculture, Commerce, Defense, Energy, and the Interior, in consultation with the Federal Energy Regulatory Commission, states, tribal or local units of governments, affected utility industries, and other interested persons. The 11 contiguous Western States are Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, and Wyoming.

[103] P.L. 109-58 §368(c). In 2009, the Secretaries of the Interior and Agriculture issued Records of Decision (RODs) designating the Western States energy corridors. On November 20, 2020, pursuant to a settlement agreement, the agencies requested stakeholder input on revisions to these corridors. In 2011, the Departments of Energy, Agriculture, the Interior and Defense issued a report on the potential for energy corridors in the other 39 states, but have not designated any such corridors to date.

[104] P.L. 109-58 §805(a).

delivery of hydrogen or hydrogen-carrier fuels, including ... transmission by pipeline."[105] The stated goals included enabling "a commitment not later than 2015 that will lead to infrastructure by 2020 that will provide ... widespread availability of hydrogen from domestic energy sources through ... delivery, including transmission by pipeline."[106] The act also required the creation of an interagency task force chaired by the Secretary of Energy to "work toward ... a safe, economical, and environmentally sound fuel infrastructure for hydrogen," and "uniform hydrogen codes, standards, and safety protocols," among other objectives.[107]

The House Select Committee on the Climate Crisis stated in its 2020 majority staff report, "to achieve wide use of hydrogen at a reasonable cost ... one option is to generate hydrogen at a small number of large-scale facilities and then distribute it through a pipeline network."[108] The majority staff report recommended that Congress draft legislation to facilitate the development of hydrogen transportation and related infrastructure, that federal agencies create a hydrogen infrastructure development plan, and that the agencies review and change their regulatory framework to support the plan.[109]

Congress historically has funded hydrogen pipeline R&D through periodic appropriations to agency and program offices, although not typically through a hydrogen pipeline R&D line item. Continuing this approach, the Consolidated Appropriations Act, 2021, provides funding for the Department of Energy's Office of Hydrogen and Fuel Cell Technologies which may be used to support hydrogen pipeline research.[110] However, the accompanying House Report specifically encourages the department "to pursue research on ... equipment for the delivery of hydrogen, including pipelines."[111] The accompanying House Rules Committee Joint Explanatory Statement encourages the Secretary of Energy "to work with the Department of Transportation and industry on coordinating efforts to deploy hydrogen fueling infrastructure," which may include hydrogen pipelines.[112]

Policy Issues

Building out a national network of dedicated hydrogen pipelines, or adapting the existing natural gas system to carry hydrogen, face both technical and nontechnical challenges. Key policy issues which Congress may examine include development of new pipelines, regulation of existing pipelines, hydrogen pipeline safety regulation, and federal support of hydrogen pipeline R&D.

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[105] P.L. 109-58 §805(e).

[106] P.L. 109-58 §805(f).

[107] P.L. 109-58 §806(b).

[108] House Select Committee on the Climate Crisis, Majority Staff, *Solving the Climate Crisis*, June 2020, p. 257.

[109] Ibid.

[110] P.L. 116-260 §9009.

[111] H.Rept. 116-449, "Energy and Water Development and Related Agencies Appropriations Bill, 2021," July 15, 2020.

[112] House Rules Committee, Joint Explanatory Statement, "Division D, Energy and Water Development and Related Agencies Appropriations Act, 2021." The statement incorporates the House Report language by reference: "Unless otherwise noted, the language set forth in H.Rept. 116-449 carries the same weight as the language included in this explanatory statement and should be complied with unless specifically addressed to the contrary in this explanatory statement."

Development of New Hydrogen Pipelines

As discussed above, some stakeholders have posited that a national hydrogen strategy would require building an expansive network of new pipelines to carry pure hydrogen. Constructing such pipelines would require significant private capital investment—in excess of $1.0 million per mile—with sufficient financial returns to attract the private capital required.[113] However, in an initial period of hydrogen market development, there might not be enough hydrogen demand to secure financing for the type of large-diameter, long-distance pipelines which could ultimately be needed to transport hydrogen most efficiently (and cost-effectively). This situation would be similar to that facing new carbon dioxide (CO_2) pipelines needed under a national strategy of carbon capture and sequestration. In the latter case, advocates have proposed federal financial support—such as a federal loan or grant program, or loan guarantees—to subsidize CO_2 pipeline construction and reduce developers' investment risks.[114] Similar economic arguments for federal financial support could be made for hydrogen pipelines, although there are important differences between H_2 and CO_2 with respect to sources, uses, and design considerations. Whether federal financial support is involved or not, because hydrogen pipeline construction would be costly and likely driven by the private sector, addressing private investment needs and associated financial risks would be key factors in hydrogen pipeline development.

In circumstances where new hydrogen pipelines could be economically viable, they might still face significant siting challenges for other reasons. Over the last decade, numerous fossil fuel pipeline projects in various parts of the United States have encountered regulatory and legal barriers to siting and, in some cases, to continued operation. These challenges have been primarily on the grounds that the pipeline projects might harm the environment—directly or indirectly—or might pose unacceptable risks to public safety. Environmental justice, which involves concerns of disproportionate risks to health and safety across communities with differing demographics (e.g., race, national origin, or income), also has become an important factor.[115] Prominent examples of contested pipelines include the Keystone XL Pipeline, the Constitution Pipeline, and the Atlantic Cost Pipeline—all of which were major interstate pipeline projects cancelled by their developers after protracted permit review and litigation—and the Dakota Access Pipeline, which was constructed following a contentious permitting process but still faces litigation and permit challenges.[116]

It is an open question to what extent hydrogen pipelines would be viewed by regulators or other stakeholders in the same light as fossil fuel pipelines and thus face similar siting challenges. Some of the arguments against fossil fuel pipelines, for example, that they produce fugitive methane emissions or promote fossil fuel production, may not apply. Nonetheless, DOE's 2020 *Hydrogen Program Plan* identified rights-of-way and permitting as needs and challenges to overcome for hydrogen delivery infrastructure.[117] Anticipating such challenges, as noted above, in 2020, the majority staff of the House Select Committee on the Climate Crisis called for

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[113] U.S. DRIVE, July 2017, p. 12. This cost per mile is for a relatively small diameter, 8-inch pipeline, including right-of-way costs, which may vary by location. Hydrogen pipeline construction costs generally are higher than those for natural gas pipelines due to requirements for thicker pipeline walls at larger diameters.

[114] See, for example, State CO_2-EOR Deployment Work Group, *21st Century Energy Infrastructure: Policy Recommendations for Development of American CO_2 Pipeline Networks*, February 2017, p. 21.

[115] For further discussion of the concept of environmental justice, see CRS In Focus IF10529, *Role of the U.S. Environmental Protection Agency in Environmental Justice*, by David M. Bearden and Angela C. Jones.

[116] For further background on the Keystone XL Pipeline, see CRS Insight IN11445, *Keystone XL Pipeline: The End of the Road?*, by Paul W. Parfomak.

[117] Department of Energy, November 2020, p. 6.

legislation to facilitate hydrogen infrastructure development. Likewise, some hydrogen proponents have suggested that Congress could establish federal siting authority for interstate hydrogen pipelines analogous to FERC's natural gas siting authority under the Natural Gas Act.[118] Preempting state authority in this way could simplify the siting process, however it would not necessarily ensure such pipelines would be constructed; the Constitution and Atlantic Coast natural gas pipeline projects were cancelled even though they were under FERC's jurisdiction and had been approved by the commission. Seeking to establish federal siting authority could also create conflicts with states that wish to retain infrastructure siting authority within their borders.

Regulation of Hydrogen in Natural Gas Pipelines

Reconfiguring existing natural gas pipelines is seen by many as the most feasible and economic means to develop a national infrastructure for transporting hydrogen. As the DOE asserted in its 2021 FOA, from a technical perspective, "there is little doubt that the existing infrastructure ... can be retrofitted and redeveloped to carry hydrogen gas, whether blended with natural gas or pure."[119] However, as the FOA also points out, the quantities of blended or pure hydrogen that will be needed, where, and when have not been assessed and "the dynamics of increasing hydrogen production, transport, and storage as part of future decarbonization efforts are still unclear."[120] Consequently, even if the technical issues are addressed, the FOA states that "the uncertainties that remain in transforming the existing natural gas supply chain are daunting."[121]

Among the uncertainties facing the conversion of natural gas pipelines to carry hydrogen are a number of regulatory issues. One overarching issue would be FERC's regulation of gas quality for blended methane and hydrogen carried in natural gas transmission pipelines during a hydrogen transition. FERC has asserted its authority to regulate gas quality and interchangeability standards under its general rate authority when such specifications are included in pipeline tariffs. As the commission has stated, "where gas quality and interchangeability issues are of concern to the transporting pipeline, tariff standards are essential terms and conditions of service."[122] However, most interstate natural gas pipeline operators do not have specifications for hydrogen content in their tariffs; conversely, most tariffs likely give operators the discretion to exclude significant hydrogen concentrations from their systems.[123] Furthermore, FERC has not established an overall ratemaking policy specifically to support shipping large volumes of hydrogen in the interstate natural gas pipeline system.[124] Although the commission's policy states that "pipelines and their customers should develop gas quality and interchangeability specifications," hydrogen specifications are not required in FERC-regulated tariffs. In addition, while FERC expects such specifications, when included, to be "based upon sound technical, engineering and scientific considerations," they could vary from operator to operator depending

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[118] James Bowe and William Rice, "Building the Hydrogen Sector Will Require New Laws, Regs," *Law360*, January 13, 2021.

[119] Department of Energy, January 15, 2021, p. 98.

[120] Ibid.

[121] Ibid.

[122] Federal Energy Regulatory Commission, *Policy Statement on Provisions Governing Natural Gas Quality and Interchangeability in Interstate Natural Gas Pipeline Company Tariffs*, Docket No. PL04-3-000, June 15, 2006, p. 12.

[123] K&L Gates LLC, *The H_2 Handbook*, online publication, 2020, pp. 57-58, https://www.klgates.com/epubs/h2-handbook/index.html.

[124] Alastair O'Dell, "PE Live: Regulation Needs to Catch Up with Hydrogen Development," *Petroleum Economist*, June 24, 2020.

upon pipeline-specific considerations.[125] In January 2021, FERC Commissioner Neil Chatterjee commented that "there are gas quality standards ... that may need to be developed to help foster these changes" and that the commission needed "to be open to changing [its] regulations to incorporate" hydrogen into natural gas pipelines.[126]

A lack of consistent quality and interchangeability standards for hydrogen-methane blends across interstate natural gas pipelines would impede a hydrogen blending strategy. As one analysis has stated, "for any business interested in utilizing a FERC-regulated interstate natural gas pipeline for hydrogen, there will be a threshold issue of whether they are even able to put hydrogen on the pipeline."[127] To address such concerns, some analysts have suggested that "FERC could create a national interconnection policy to establish common standards" for blending hydrogen in interstate natural gas pipeline systems.[128] Some advocates have further suggested that the federal government could require natural gas pipelines to blend hydrogen into their systems.[129] Similar concerns about gas quality standards exist among the states with respect to intrastate transmission pipelines and natural gas distribution systems, although state pipeline tariffs are not subject to federal authority. How, and to what extent, FERC could or should establish new hydrogen policies for interstate pipelines under its existing NGA authority, or whether additional legislative authority or direction would be required, may be questions for Congress. The recovery of pipeline conversion costs (to accept hydrogen) under FERC-regulated tariffs under any hydrogen blending mandates would also need to be resolved.[130] Aligning such a federal policy with independent natural gas quality initiatives among various states could also require federal oversight and coordination.

If increasing concentrations of hydrogen were introduced into the interstate natural gas pipeline system, it also could raise jurisdictional issues among the federal agencies. Presuming, as some legal analysts have concluded, that FERC "likely ... would have jurisdiction under the NGA to regulate the introduction of hydrogen into interstate natural gas pipelines to supplement or displace natural gas," questions may arise as to what point a pipeline undergoing such a transition would no longer be a "natural gas" pipeline and, therefore, no longer under FERC's jurisdiction.[131] If a pipeline planned to leave FERC's jurisdiction (likely through an "abandonment" proceeding) and presumably come under the ICC's jurisdiction, how this proceeding would be conducted, and how it might affect the pipeline's rates, permits, or conditions of operation imposed under the NGA could require congressional attention. There are examples of interstate natural gas to crude oil pipeline conversion under FERC, such as the 2012 Pony Express Pipeline conversion, but this case involved the outright switch from one commodity to another, with rates for both under FERC's regulatory jurisdiction.[132] The gradual conversion of

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[125] Ibid.

[126] Commissioner Neil Chatterjee, FERC, Remarks for the K&L Gates Distinguished Speaker Series, January 26, 2021, https://www.klgates.com/Distinguished-Speaker-Series-with-FERC-Commissioner-Neil-Chatterjee-1-26-2021-1.

[127] K&L Gates, 2020, p. 53.

[128] Yannic Rack and Tom DiChristopher, "Facing Uncertain Future, Gas Operators Look to Hydrogen Lifeline," *S&P Global Market Intelligence*, December 2, 2020.

[129] David Iaconangelo, "Hydrogen: 3 Things to Watch in 2021," *E&E News*, January 4, 2021.

[130] David L. Wochner, et al., "Blending Hydrogen into U.S. Natural Gas Pipelines: Three Issues to Resolve," *Bloomberg Law*, November 16, 2020.

[131] James Bowe and William Rice, January 13, 2021.

[132] Federal Energy Regulatory Commission, Order on Petition for Declaratory Order, 141 FERC ¶ 61,180, Docket No. OR12-26-000, November 30, 2012. FERC has jurisdiction over the regulation of oil pipeline rates pursuant to the Interstate Commerce Act (49 App. U.S.C. §1 et seq.).

a FERC-jurisdictional natural gas pipeline to an ICC-jurisdictional hydrogen pipeline could involve new regulatory considerations.

Hydrogen Pipeline Safety Regulation

As discussed above, the DOT's Pipeline and Hazardous Materials Safety Administration regulates the safety of hydrogen pipelines. However, because PHMSA's existing pipeline regulations are focused primarily on natural gas, they may not be adequate to address the safety risks of a widespread, dedicated hydrogen pipeline network. For example, some analysts suggest that "certain characteristics of hydrogen are not necessarily fully contemplated in some of the existing regulations' design requirements" and, therefore, may "fall short of creating a comprehensive regulatory regime that will guide the development of the entire industry."[133] Two particular areas of concern are pipeline steel and welding techniques, which may need to be specified to address potential embrittlement in new or converted hydrogen pipelines.[134] The operating conditions of natural gas pipelines carrying hydrogen-methane blends are also likely to be more variable and demanding than those of the existing U.S. hydrogen pipelines. As PHMSA has stated, almost all existing hydrogen pipelines in the United States serve industrial customers operating at constant, relatively low pressure.[135] FERC Commissioner Chatterjee has stated that "pipeline safety standards may need to be developed to help foster" hydrogen blending and "are really going to be essential."[136] Whether PHMSA should develop more hydrogen-specific pipeline safety regulations, and what such regulations could entail, may be an issue for Congress.

Support of Hydrogen Pipeline R&D

Pipeline researchers and industry experts have long supported a federal role in hydrogen pipeline research and development. As a DOE Hydrogen Pipeline Working Group report stated in 2005,

> Research is needed to resolve concerns about the possibility for hydrogen embrittlement of pipeline steels and/or to develop alternative (lower cost, durable) pipeline materials. If pipeline capital and labor costs could be substantially reduced, hydrogen pipeline transmission could be used sooner rather than later. Pipeline research requires a concerted and focused effort, including fundamental materials science. It will require strong government support.[137]

In accord with this view, various federal agencies have funded R&D efforts related to hydrogen pipeline materials, safety, and operations for many years, making fundamental contributions to support their commercialization and deployment. However, sector experts have identified numerous potential areas for additional R&D which may be a priority to support the development of a widespread hydrogen pipeline network sometime in the future. Among the technical topics are hydrogen pipeline compressor technology, leak detection and management, advanced materials, and compatibility of hydrogen-methane blends with existing infrastructure, among

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[133] Damien Lyster et al., "Federal Hydrogen Regulation in the United States: Where We Are And Where We Might Be Going," online article, Vinson & Elkins LLP, December 10, 2020, https://www.jdsupra.com/legalnews/federal-hydrogen-regulation-in-the-54947/.

[134] James Bowe and William Rice, January 13, 2021.

[135] Pipeline and Hazardous Materials Safety Administration, "Hydrogen," web page, accessed January 12, 2021, https://primis.phmsa.dot.gov/comm/hydrogen.htm.

[136] Commissioner Neil Chatterjee, January 26, 2021.

[137] DOE, September 2005, p. 3

other topics.[138] In addition to these, some analysts have identified research needs associated with pipeline network-level considerations, such as the optimal timing and siting of hydrogen pipelines under various market conditions, network risk assessment, and the relationship between pipelines and other hydrogen transportation modes (e.g., tanker trucks) during a hydrogen transition.[139]

The private sector is undertaking efforts to address some hydrogen pipeline research needs through efforts like the Low-Carbon Resources Initiative, jointly administered by the Electric Power Research Institute and the Gas Technology Institute, "to accelerate the development and demonstration of low-carbon energy technologies."[140] Likewise the Interstate Natural Gas Association of America, which represents interstate pipeline companies, has stated that its members "are committed to the further research and development of promising new technologies, such as ... renewable hydrogen."[141] However, such initiatives may not address the full range of R&D issues of potential importance to hydrogen pipeline-related policy. Understanding ongoing needs for pipeline-related R&D under any national hydrogen strategy, and determining what federal support may be required for such R&D, is likely to be a factor in congressional budgeting and oversight of federal agency programs. Ensuring coordination of hydrogen pipeline R&D efforts among different federal agencies within broader agency plans for hydrogen technology deployment, and with the private sector, also may be a challenge.

Federal Oversight of Pipeline Security

Ongoing threats against the nation's energy pipelines have heightened concerns about the security risks to these pipelines, their linkage to the electric power sector, and federal efforts to protect them. These security concerns were exacerbated in 2016 after environmental activists in the United States announced they had disrupted five pipelines transporting oil from Canada.[142] In a December 2018 study, the Government Accountability Office stated that, since the terrorist attacks of September 11, 2001, "new threats to the nation's pipeline systems have evolved to include sabotage by environmental activists and cyber attack or intrusion by nations."[143] Two FERC commissioners expressed similar concerns in a June 2018 op-ed, writing "as … natural gas has become a major part of the fuel mix, the cybersecurity threats to that supply have taken on new urgency."[144] In 2020, the TSA's Surface Security Plan identified improvised explosive devices and cyberattacks as key risks to energy pipelines, which "are vulnerable to terrorist attacks largely due to their stationary nature, the volatility of transported products, and [their]

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[138] U.S. DRIVE, July 2017, pp. 10-14; Pipeline and Hazardous Materials Safety Administration, "Hydrogen," web page, accessed January 12, 2021, https://primis.phmsa.dot.gov/comm/hydrogen.htm.

[139] See, for example: M.H. Alencar and A.T. de Almeida, "Assigning Priorities to Actions in a Pipeline Transporting Hydrogen Based on a Multicriteria Decision Model," *International Journal of Hydrogen Energy*, vol. 35, no. 8, April 2010, pp. 3610-3619; Jean Andre et al., "Design and Dimensioning of Hydrogen Transmission Distribution Pipeline Networks," *European Journal of Operational Research*, vol. 229, no. 1, August 2013.

[140] Gas Technology Institute, "EPRI and GTI Launch Initiative to Accelerate Low-Carbon Energy Technologies," press release, August 10, 2020.

[141] Interstate Natural Gas Association of America, "2021 Vision Forward: Addressing Climate Change Together," online publication, January 2021, p. 3, https://www.ingaa.org/File.aspx?id=38523&v=6553c6c8.

[142] Climate Direct Action, "To Avert Climate Catastrophe, Activists Shut Down 5 Pipelines Bringing Tar Sands Oil into the U.S," press release, October 11, 2016.

[143] Government Accountability Office, *Critical Infrastructure Protection: Actions Needed to Address Significant Weaknesses in TSA's Pipeline Security Program Management*, GAO-19-48, December 2018, p. 1.

[144] Neil Chatterjee and Richard Glick, "Cybersecurity Threats to U.S. Gas Pipelines Call for Stricter Oversight" AXIOS, June 11, 2018.

dispersed nature."[145] Existing natural gas pipelines carrying hydrogen blends presumably would be subject to the same security risks as other natural gas pipelines. The risks from environmental activists to pipelines carrying pure hydrogen might be different if such pipelines are viewed as part of a strategy to mitigate climate change, but such environmental considerations might not reduce risks from other actors.

In recent years, there has been ongoing debate about the structure and effectiveness of the federal pipeline security program. Some in Congress have suggested that TSA's current pipeline security authority and voluntary standards approach may be appropriate, but that the agency may require greater resources to more effectively carry out its mission.[146] Others stakeholders have debated whether security standards in the pipeline sector should be mandatory—as they are in the electric power sector—especially given their growing interdependency. Still others have questioned whether any of TSA's regulatory authority over pipeline security should move to another agency, such as the DOE, DOT, or FERC, which they believe could be better positioned to execute it.[147] Concern about the quality, specificity, and sharing of information about pipeline threats also has been an issue. How hydrogen pipelines fit into the broader debates about, and federal oversight of, energy pipeline security may be an issue for Congress.

Conclusion

The United States' strategy to transition away from environmentally harmful fossil fuels continues to evolve, and using hydrogen as a fuel and an industrial feedstock is considered an important element of such a strategy. Most hydrogen proponents assert that a significant national network of hydrogen pipeline would be necessary to support this strategy, and that such a network could be established through some combination of building new, dedicated hydrogen pipelines and converting existing natural gas pipelines to carry hydrogen. While there already exists a modest U.S. hydrogen pipeline network, the scale of a national hydrogen pipeline system would need to grow dramatically over time to support ambitious environmental goals, in line with what PHMSA has stated: "as the hydrogen economy moves from concept to reality, and the public grows to depend on hydrogen availability ... the ability to safely and reliably transport ... larger quantities of hydrogen will become increasingly important."[148] Although many technical, regulatory, and economic issues would still have to be resolved to grow the hydrogen pipeline system, efforts have been underway domestically and abroad to address potential barriers to future hydrogen pipeline development and gas pipeline conversion. In past decades, Congress has supported these efforts, and recent Congresses have continued to do so.

Notwithstanding hydrogen pipeline initiatives to date, the development of a national hydrogen pipeline network is only one component—albeit a critical one—of a complex energy market involving different sources of hydrogen supply and a myriad of potential end-uses. Developments in both hydrogen supply and demand will be key determinants of how much hydrogen pipeline capacity will be needed, when it will be needed, and where. Factors such as the deployment of

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[145] Transportation Security Administration, "2020 Biennial National Strategy for Transportation Security Report to Congress," May 29, 2020, p. 71.

[146] U.S. Congress, House Homeland Security, Transportation Security, *Pipelines: Securing the Veins of the Energy Economy*, 114th Cong., 2nd sess., April 19, 2016, Serial No. 114-64 (Washington: GPO, 2016).

[147] Mark Rockwell, "TSA's Role in Pipeline Cybersecurity Could Be Up for Grabs," *Federal Computer Week*, September 27, 2018.

[148] Pipeline and Hazardous Materials Safety Administration, January 12, 2021.

hydrogen-fueled electric power plants, vehicles, and industrial processes—as well as technologies to convert existing end use equipment (e.g., heating systems) to burn hydrogen—will be as important to hydrogen pipeline development as the pipeline technology itself. Congress faces mapping the relationship between hydrogen pipelines and other federal (or state) energy initiatives; oversight of related activities among different federal agencies; and prioritizing federal efforts to develop hydrogen pipelines.

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