Hydrogen Pipeline Transport Issue Brief

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BACKGROUND

Hydrogen transportation will be key to connecting hydrogen produced in rural areas or from centralized industrial facilities to areas of high demand, such as industrial clusters or shipyards. Hydrogen can be transported in liquid or gaseous form via pipelines, rail, trucks, or ships. Other transportation alternatives include creating a hydrogen carrier, such as ammonia or methanol, for easier transport and storage.

Pipeline transportation is the most economical method for long-distance transportation and delivering liquid and gaseous bulk fuels to end uses. However, the regulatory authority for dedicated hydrogen pipelines and for natural gas pipelines carrying hydrogen admixtures is divided among different federal and state agencies that oversee siting, commercial access and rates, safety, and security.[1]

Distinguishing between federal-state jurisdiction and navigating the multiple regulatory authorities adds to the complexity of facilitating the development of hydrogen pipeline infrastructure.

To support the growth of a US hydrogen economy, the hydrogen pipeline transportation network will need to expand its geographic reach beyond the existing 1,600 miles of hydrogen pipelines; however, this buildout will require clarity over the regulatory oversight of hydrogen pipelines and the technical and non-technical challenges related to hydrogen pipeline safety, siting, and content.

Key technical and regulatory questions

This issue brief seeks to address the key technical and regulatory questions for hydrogen pipeline transportation:

- What is considered the current maximum amount of hydrogen that can be blended into natural gas pipelines (percent by volume) from a technology and safety perspective?
- Which regulatory authorities have jurisdiction over siting, safety, and blending?
- What are the technology challenges and the potential fact-based solutions to transporting hydrogen via pipelines?
- What are the cost considerations for the construction, operation, and maintenance of hydrogen pipelines?

Solutions to these lingering questions can inform the development of cost-effective hydrogen transportation options and the alternatives to transporting hydrogen, such as producing clean hydrogen close to demand centers.

This issue brief was prepared for the Policy, Education, and Outreach work group of the Hydrogen Economy Collaborative (HEC).

The HEC aims to coordinate national efforts, especially those in the Midwest, with emerging hydrogen industries to synchronize new supply chains. Focus areas include research and development, production, infrastructure, distribution, education, outreach, and market development to help meet consumer preferences for low-carbon energy solutions.

The HEC is administered by the Great Plains Institute. Learn more at https://betterenergy.org/hydrogen-economy-collaborative/.

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Hydrogen transportation options

Options for transporting hydrogen via pipeline include transporting it as an admixture (a blend of natural gas and hydrogen) in existing natural gas pipelines or as pure hydrogen in dedicated purpose-built hydrogen pipelines. Existing natural gas pipeline infrastructure systems around the globe use admixtures of up to 10 percent hydrogen concentration (with some pilot projects testing up to 20 percent admixtures by volume[2]), but many concerns have been raised about the long-term impacts of hydrogen admixtures on pipeline materials.

Laboratories and research institutions are now modeling and evaluating the lifecycle emissions, pipeline impacts, and costs of hydrogen blends and their transportation within the existing natural gas pipeline network.

Transporting a hydrogen blend or admixture via existing natural gas transportation infrastructure can have significant benefits for developing the nascent hydrogen economy. It could also avoid or delay the construction and permitting of new pipelines. However, the impacts of hydrogen and hydrogen admixtures on existing natural gas transportation infrastructure, infrastructure materials, and end-use equipment are not well understood and are being studied in pilot projects around the world.

Introduction

Transporting hydrogen in pipelines has two major hurdles—one of these is technological, and the other is regulatory. As the hydrogen economy develops in the US and Europe, there have been proposals to deliver hydrogen admixtures through existing natural gas transmission and distribution infrastructure to take advantage of economic and market development opportunities.

There are over 300,000 miles of natural gas transmission pipelines in the US and 2,300,000 natural gas distribution pipelines,[3] which may be able to deliver hydrogen admixtures or be repurposed to deliver pure hydrogen. In contrast, there are a little over 1,600 miles of dedicated hydrogen transportation pipelines in the US carrying pure hydrogen. Compared to natural gas transmission pipelines, these are relatively short and located mainly on the Gulf Coast, where they deliver gas to refineries and ammonia plants.[4]

US and European utilities have been testing hydrogen admixture concentrations in natural gas distribution systems as part of pilot or demonstration projects to test the concentrations' impacts on pipeline integrity and safety, as well as on the system's end uses (e.g., home heating).[5]

From a technological perspective, transporting hydrogen has several safety risks due to hydrogen's natural properties and the condition of existing physical infrastructure. As the smallest molecule, hydrogen can leak through pipeline joints and compressors and diffuse through plastic pipeline membranes. It is also highly flammable. If hydrogen atoms dissociate from one another, the single (atomic) hydrogen can bond with steel pipes, joints, welds, etc., and cause embrittlement. This is especially true in high-pressure systems like natural gas distribution networks.

Regulatory authority for the siting, safety, and commercial regulation (rate setting) of hydrogen pipelines (both hydrogen pipelines and natural gas pipelines carrying hydrogen admixtures) in the US is divided among the federal government and the states and, in some cases, is still under development. Different agencies oversee siting, commercial access and rates, security, and safety.

Regulatory authority can be difficult to navigate as the authority also differs for dedicated hydrogen pipelines versus natural gas pipelines carrying hydrogen admixtures. Whereas interstate natural gas pipelines must seek siting approval from the Federal Energy Regulatory Commission (FERC), interstate dedicated hydrogen pipelines do not fall under federal regulatory authority.[6] These pipelines must seek siting approval from regulatory authorities in individual states. However, while a state may grant siting approval, the project may trigger federal laws and thus be subject to federal regulation under, for example, the National Environmental Policy Act or the Endangered Species Act.

Furthermore, regulatory provisions for rate regulation will vary from state to state for both hydrogen and natural gas-hydrogen admixtures. Rates for interstate natural gas pipelines are regulated by federal authorities (FERC), whereas for dedicated interstate hydrogen pipelines, rates are regulated by the Surface Transportation Board.

In addition to jurisdiction over rates, FERC has the authority to require that natural gas pipeline operators adopt quality standards, including hydrogen content, developed by the North American Energy Standards Board.

Pipeline safety and security are overseen by different regulatory authorities. The Department of Transportation has regulatory authority over interstate and intrastate pipelines (both natural gas and hydrogen pipelines), administered by its Pipeline and Hazardous Materials Safety Administration (PHMSA). However, PHMSA relies on state regulators in most states to oversee the intrastate pipeline safety administration, inspection, and enforcement.

Why do we need long-distance hydrogen pipeline transportation?
Hydrogen pipelines are needed to connect hydrogen production sites with demand centers and storage sites. Hydrogen production is frequently sited at locations with hydrogen inputs (e.g., renewable energy, natural gas, carbon storage resources), which are distant from the hydrogen end uses.

How many miles of hydrogen pipelines (designed for and currently used for hydrogen) are currently operating in the US?
Currently, there are 1,600 miles of dedicated hydrogen pipelines in the US; these are owned by merchant hydrogen producers and located near end-use demand (e.g., petroleum refineries and chemical plants).[7] Most of these pipelines transport hydrogen at constant and low pressure.

REGULATORY AUTHORITY

Who regulates the safety of hydrogen pipelines?
The US Department of Transportation (DOT) regulates the safety of interstate and intrastate energy commodity pipelines, including hydrogen pipelines. Under the DOT's PHMSA authority, it has regulated hydrogen pipelines since 1970 under the Natural Gas Pipeline Safety Act. Pipeline safety rules are found in the code of federal regulations 49 CFR Part 192. In 2003, gas pipeline integrity management requirements were added to the safety standard.[8]

PHSMA is partnering with other agencies to study hydrogen delivery through distribution infrastructure and any challenges for stationary power generators.[9] PHMSA is also studying lower-cost pipeline material alternatives and lighter-weight materials and structures for hydrogen storage and transport.

The safety of approximately 1,500 miles of long-distance hydrogen pipelines is under the regulatory jurisdiction of the US Department of Transportation's PHMSA.[10]

What entity is responsible for setting and enforcing safety standards of hydrogen transport via pipeline?
As the hydrogen economy develops and grows, additional standards are needed to ensure confidence in hydrogen infrastructure's design, performance, and safety. PHMSA has published minimum safety requirements through standards for pipeline facilities, pipelines, and the transportation of gas or hazardous liquids within the limits of the Outer Continental Shelf in 49 CFR Part 192, 195.[11]

Who regulates the percent admixture allowed?
No agency or department regulates the percent admixture per se. Instead, different agencies or departments regulate standards for things like safety and quality, which have an impact on blending. For example, the Office of Pipeline Safety (within PHMSA) enforces pipeline safety standards for blended fuels, but where the blending occurs will dictate regulatory oversight. Blending with natural gas at the city gate of a gas distribution utility will be regulated by the state authority. The *U.S. National Clean Hydrogen Strategy and Roadmap*, a document whose development was called for in the Infrastructure Investment and Jobs Act, establishes targets and identifies action items, including developing national guidance for hydrogen blending limits by 2026-2029.[12]

FERC also plays an indirect role in regulating hydrogen admixtures. The commission regulates gas quality and interchangeability standards under its rate authority, but only when standards or specifications are included in pipeline tariffs. However, hydrogen specifications are not required in FERC-regulated tariffs, and most interstate natural gas pipeline operators do not have specifications for hydrogen content in their tariffs.[13] FERC's authority to regulate quality and interchangeability standards for hydrogen admixtures becomes increasingly nebulous as the amount of hydrogen in the admixture increases. This raises the question of whether a natural gas pipeline undergoing a transition to hydrogen would still be a natural gas pipeline and still subject to FERC jurisdiction under the Natural Gas Act.

Who regulates construction, tariffs, and siting?
The siting of dedicated intrastate hydrogen pipelines is regulated by the states, similar to natural gas pipelines. Interstate hydrogen pipelines also must seek regulatory siting approval from each state through which it passes, in contrast to natural gas pipelines.

Regulation of pipeline construction and tariffs for transportation of natural gas and hydrogen admixtures are regulated by FERC (18 CFR PART 153, 157, and 284) and cover the construction and operation of natural gas facilities, the issuance of certificates of public need for natural gas facilities, and the regulation of interstate natural gas transportation.[14]

Interstate hydrogen pipeline rates are regulated by the Surface Transportation Board , an independent federal regulatory agency, which does not require pipeline companies to file rate tariffs but rather acts as an arbiter in rate disputes.[15]

What admixture or blend percentage is currently allowed in the US?
The allowed admixture varies by jurisdiction. Public utility commissions typically oversee pipeline safety and reliability standards (set by PHMSA) for intrastate pipelines, including the allowed admixture in natural gas pipelines.[16]

Are there any US jurisdictions currently carrying a natural gas/hydrogen admixture?
As of May 2023, approximately 22 pipeline blending projects had been announced in the US.[17]

The following examples of pilots and research in the US are testing different admixture amounts:

- CenterPoint Energy is delivering a 5 percent hydrogen blend to its customers in Minneapolis as part of the utility's pilot project. Residents are heating their homes and cooking with the blend.[18]
- Dominion Energy's research concluded that a 5 percent admixture is safe and compatible with current end-use residential appliances.[19]

Pipeline transportation

What are the options for transporting hydrogen via the existing natural gas system?
One option is injecting hydrogen/natural gas admixture into existing natural gas infrastructure. The allowable hydrogen concentration that can be blended with and transported via an existing natural gas pipeline depends on the pressure fluctuation, structure, and existing pipeline condition. Admixtures of 2 to 10 percent by volume are generally considered technically feasible, with some grid operators contending that 20 percent admixtures are feasible.[20]

Another option is converting existing natural gas infrastructure to transport higher admixtures (retrofitting).

Converting an existing natural gas pipeline into a dedicated hydrogen pipeline (repurposing) is another option.

Hydrogen blending/admixture

What is hydrogen blending and deblending/ extraction?
Hydrogen blending is an injection of a certain volume of hydrogen into the existing gas infrastructure, either to create a new lower-carbon fuel or to enable hydrogen transportation through existing infrastructure, which would then require deblending.

Hydrogen deblending or extraction is a point-of-use separation of the hydrogen from its gas carrier. Deblending enables the end-use customer to receive pure hydrogen.

What percent of admixture or hydrogen blending is considered technically sound to transport in existing gas infrastructure?
Different authorities have recommended varying safety limits. In the US, the range of accepted blends runs from 2 to 15 percent (by volume) as being technically sound and avoiding embrittlement issues.[21] However, some transmission operators are conducting pilots using 20 percent as the upper limit.[22] Some blending studies show that admixtures greater than 5 percent increase the possibility of pipeline embrittlement.[23]

Technology challenges

Why is the hydrogen blending range 2–20 percent? Why can some existing infrastructure only handle a 2 percent admixture while others may be able to handle a 20 percent admixture (by volume)?

Pressure range. Steel natural gas pipelines are fitted with compressors to compensate for the pressure losses within a pipeline. However, these compressors are not optimized to handle hydrogen blends because hydrogen is a lower-mass gas.[24]

Pipeline structure and material. Plastic pipelines do not have the same embrittlement risk as steel pipelines but, for other reasons, may not be able to support higher than a 20 percent admixture as hydrogen may be able to permeate the plastic walls.

Existing pipeline. Hydrogen embrittlement occurs with existing cracks, fractures, or corrosion of metal pipelines. The metal absorbs hydrogen atoms and embrittles the metal. Hydrogen blends above 5 percent may cause leaks and steel pipeline embrittlement, although the alloy and construction of the pipe change the embrittlement risk.[25]

End uses. Pipelines deliver gas to various end uses, including power generation, residential appliances, vehicles, and industrial equipment. More data are needed to understand end-use equipment impacts of hydrogen admixtures and the acceptable blend percentages for end-use equipment. Blends above 5 percent could require modifications for appliances, such as stoves and water heaters, to avoid leaks and equipment malfunction and failure.

What is embrittlement?

Embrittlement occurs when a metal pipeline already has fractures or defects and is subject to fluctuating pressure changes. Under these conditions, hydrogen embrittlement can occur if hydrogen diffuses into pre-existing cracks or fractures, accelerating their propagation. This pitting can reduce the metal's load-bearing capability. However, hydrogen embrittlement appears unlikely at low hydrogen blends.[26]

PHMSA's research and development arm focuses on addressing hydrogen's impact on steel pipelines.

What are the options for reducing/eliminating embrittlement?

Retrofitting. Solutions depend on the pipeline and include coating the inner steel wall, more sophisticated monitoring, and purpose-built pipes.[27]

What are the technical challenges to repurposing natural gas infrastructure for carrying 100 percent hydrogen?

Existing natural gas infrastructure may need to be substantially retrofitted to accommodate 100 percent hydrogen, and each pipeline's technical state and chemical composition needs to be considered separately to account for the integrity of the metal and the structure of the pipeline components. Components such as valves, seals, fittings, pressure regulators, metering equipment, and safety equipment may need to be replaced to be suitable for operation with pure hydrogen due to hydrogen's higher permeability than natural gas.[28] Pipelines and joints may require improved sealing to reduce hydrogen leakage. Similarly, pipeline meters and leakage monitoring equipment would need to be replaced with sensor equipment to detect hydrogen leaks. Current monitoring equipment cannot detect hydrogen leaks because hydrogen is eight times smaller than methane.

Cost implications

What are the estimated costs of repurposing natural gas pipelines to carry 100 percent hydrogen?

The cost of repurposing natural gas pipelines may be 10–35 percent of new purpose-built hydrogen pipelines.[29] Hydrogen transport in purpose-built pipelines is estimated at $0.12–0.22/kilogram of hydrogen (kgH2)/621 miles, including compressor stations. This cost estimate includes pipeline upgrades, compressors, and operating expenses, such as the energy for compression.

The International Energy Agency (IEA) suggests that the cost of delivering hydrogen will depend on infrastructure availability and material quality, and the transmission and distribution distances. However, the costs increase linearly with distances beyond 1,500 kilometers (km) (930 miles). Beyond the 1,500 km distance, IEA estimates that it becomes more cost-effective to convert hydrogen into ammonia or a liquid organic hydrogen carrier and to transport ammonia or liquid hydrogen via ships, even when accounting for the energy expenditure of converting ammonia or liquid hydrogen back into hydrogen.[30]

Bloomberg New Energy Finance estimates pipeline transport costs between $0.10/kgH2 to $0.58/kgH2 for distances between 100 km (62 miles) and up to 1,000 km (621 miles).[31]

California operational data show that the delivered cost of hydrogen to vehicle fueling stations can be more than $13/kilogram, which is estimated by the US DOE's Offices of Fuel Cell Technologies to be more than three times higher than the cost required to be competitive.[32] (These costs include compressing and dispensing.)[33]

Solutions

What are some potential solutions for the risks of transporting hydrogen via existing gas pipelines or dedicated hydrogen pipelines?
Retrofitting existing gas pipelines is a potential solution. Retrofits would require installing new compressors (and potentially new end-use equipment and appliances, depending on the blend volume) to capture 80–90 percent of pure hydrogen's energy. In addition, the potential for leaks would need to be addressed. Hydrogen leakage can occur around the welded joints and compression fittings in high-pressure transmission pipelines. In lower-pressure distribution pipelines, hydrogen leakage can occur if hydrogen needs to be transported at higher pressure than just with natural gas.[34]

Repurposed or new pipelines are another potential solution. The following materials may be options:

- Fiber-reinforced polymer pipelines. The installation costs for these polymer pipes are approximately 20 percent less than steel pipeline installation.
- Polyethylene and other plastic pipeline material with reduced permeability may be an option for transporting low-pressure hydrogen.
- Dedicated pure hydrogen pipelines made of low-strength grade carbon steel , steel without impurities, or micro-alloyed steel.

The first hydrogen fueling station in the U.S. fed directly from an active industrial hydrogen pipeline. Photo by Michael Penev, NREL 19212

Notes

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[16] Parfomak, *Pipeline Transportation of Hydrogen: Regulation, Research, and Policy*. PHMSA delegates authority over the administration of its safety standards to state regulators.

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