Accufacts Inc.
"Clear Knowledge in the Over Information Age"

Report:
Safety of Hydrogen Transportation by Gas Pipelines

Accufacts Inc. Final 11/28/2022

About Accufacts Inc.

Accufacts Inc ("Accufacts") has an extensive chemical engineering and process safety management background, involving direct operational and engineering experience in refining, pipelines, and production. This experience includes handling, processing, and moving high pressure high purity hydrogen, including gas mixtures, and too many first-hand experiences with hydrogen releases, many resulting in explosions, given the unique "reactive" properties of hydrogen as compared to methane. Accufacts also brings several decades of involvement in pipeline safety regulatory development at the federal and various state levels, as well as numerous pipeline failure incident investigations in North America.

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prepared for the

Pipeline Safety TRUST
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This report is developed from information clearly in the public domain. The views expressed in this document represent the opinions of the author.

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I. Executive Summary

Accufacts' key positions concerning hydrogen transportation in pipelines as discussed in this report are summarized in Table 1.

Table 1 Accufacts key positions on hydrogen introduction into transportation pipelines to address global warming

Scenario	Accufacts' Position
Hydrogen blending into gas distribution systems	Should not be permitted at any level because of hydrogen's ability to explode especially in buildings, and the weaker downstream gas pipeline systems within public buildings not intended for hydrogen.
Gas transmission systems	As most gas transmission pipelines feed into distribution systems, hydrogen blending should not be allowed in such existing gas transmission pipelines feeding distribution systems.
Limited existing gas transmission not supplying gas distribution systems	May be suitable for hydrogen blends that only service major industrial gas users, if knowledge gaps can be resolved and pipeline integrity can be demonstrated for hydrogen service.
New gas transmission pipelines designed for hydrogen service	New smaller diameter gas transmission pipelines may be suitable for hydrogen service.

II. Introduction

The Pipeline Safety Trust asked Accufacts Inc. ("Accufacts") to review and comment on various aspects related to hydrogen pipeline safety. Depending on the source of hydrogen production, some applications of hydrogen may be considered a greenhouse gas reducer, as governments and the private sector attempt to meet commitments toward reducing greenhouse gas emissions that contribute to climate change. One application of hydrogen under consideration is to blend gaseous hydrogen into existing natural gas (methane) pipeline systems for combustion by end users. As this report explains, pipelines containing hydrogen pose significantly increased dangers and risks compared to conventional natural gas pipelines.

This report identifies serious concerns about the pursuit of hydrogen blending options for existing gas transmission or gas distribution pipelines given the increased danger and small impact that such blending would have on emissions contributing to climate change. Hydrogen blending in most existing U.S. gas pipeline systems may not prove viable, given such factors as:

1. the interplay between gas transmission and distribution pipeline systems as most transmission systems supply distribution systems which should not receive hydrogen even as blends,
2. the many information gaps that must be resolved to demonstrate integrity of existing gas pipeline systems to transport hydrogen, even as lower concentration blends,
3. the significant natural gas leakage on many gas distribution pipeline systems across the U.S., and the slipperiness of hydrogen indicates that leakage would be worse when carrying hydrogen and demonstrates a need for pipe replacement that will take time and be expensive,
4. moving hydrogen from traditional industrial settings, such as more open-air refineries and chemical plants, to commercial/residential confined buildings never designed nor intended for such efforts, and
5. the limited benefit, and possible drawbacks, of hydrogen blending to reduce greenhouse gas emissions contributing to climate change.

There may be some unique transmission and distribution systems that may be able to safely accept hydrogen blending, but Accufacts investigations spanning many systems across the country show such opportunities will be rare. Transportation of higher purity hydrogen in some selective gas transmission pipelines may be the most likely near-term approach for the use of hydrogen to reduce greenhouse gas emissions that contribute to climate change.

Transportation of hydrogen by pipeline should be approached with caution and limited to facilities capable of transporting it without leaks or failures. Adding hydrogen to existing pipelines introduces significant additional threats into neighborhoods because of hydrogen's unique properties. This paper intends to advance discussions regarding best applications of hydrogen by assessing options and risks concerning hydrogen transportation by pipeline and by providing recommendations to prudently address additional dangers associated with hydrogen in pipelines.

III. Key Background

Governments and oil and gas companies are looking to hydrogen as a means to decarbonize segments of the energy and industrial sectors. The 2021 Infrastructure Investment and Jobs Act appropriated $9.5 billion for clean hydrogen and the 2022 Inflation Reduction Act provides additional policies and incentives for hydrogen. The U.S. Department of Energy ("DOE") launched the Hydrogen Shot in 2021, seeking to reduce the cost of clean hydrogen by 80% to $1 per 1 kilogram in 1 decade,[1] and the DOE opened applications for its regional clean hydrogen hub program in September

[1] https://www.energy.gov/eere/fuelcells/hydrogen-shot

2022.[2] How hydrogen will be integrated as a fuel and energy storage mechanism is still being determined, but whichever applications are prioritized, hydrogen transportation pathways will be necessary to facilitate deployment. It is generally expected that the best use of hydrogen will be for high-heat, hard-to-electrify sectors such as certain industrial processes, and that it is preferable for hydrogen production and end-use to be in close proximity.[3]

As these opportunities take shape, the concept of blending hydrogen into natural gas pipelines is under discussion. The Draft DOE National Clean Hydrogen Strategy and Roadmap proposes the following future activities: "development of injection standards for blending hydrogen into natural gas pipelines," "assessing opportunities to repurpose natural gas infrastructure for hydrogen," and "identifying conditions under which deployment of new infrastructure would be necessary."[4] Oil and gas industry stakeholders are offering proposals involving the movement of hydrogen via new or converted pipelines, or as blends of hydrogen into existing natural gas transmission or distribution pipelines. For example, a recent gas industry sponsored report suggests blending of hydrogen up to 20% by volume into existing gas utility distribution systems as a solution to get to "Net-Zero."[5]

A recent UC Riverside Report for the California Public Utilities Commission ("Blending Report") identifies many, but not all, major relevant safety issues related to hydrogen movement by pipelines.[6] This Blending Report also documents over six pages of technical questions or "knowledge gaps" needing further assessment and prudent resolution.[7] In addition to the gaps identified by UC Riverside, Accufacts, recommends three further key technical knowledge gaps where additional assessment and information is needed (see page 14).

The Pipeline and Hazardous Materials Safety Administration, or PHMSA, the federal office responsible for minimum pipeline safety at the federal level, is also advancing important safety research in some related technical pipeline safety matters concerning hydrogen movement in pipelines.[8] These above-mentioned efforts will take many

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[2] https://www.energy.gov/articles/biden-harris-administration-announces-historic-7-billion-funding-opportunity-jump-start

[3] See pp. 40 &41, https://www.hydrogen.energy.gov/pdfs/clean-hydrogen-strategy-roadmap.pdf.

[4] *Ibid.,* p. 45.

[5] American Gas Association ("AGA") Study prepared by ICF, "Net-ZERO Emissions Opportunities for Gas Utilities," February 8, 2022, p. 104.

[6] Prepared by the University of California, Riverside with subcontractor Gas Technology Institute, for the California Public Utilities Commission, "Final Report - Hydrogen Blending Impacts Study," filed 7/18/2022, R1302908.

[7] *Ibid.,* pp. 111 – 116.

[8] See the Pipeline and Hazardous Materials Safety Administration ("PHMSA") Research Announcement #693JK322RA0001 at:

years to reach appropriate technical resolution, understanding, and acceptance by various regulators, decisionmakers, pipeline operators, and the public.

When compared to methane (i.e., natural gas), hydrogen (H_2) has several unique physical properties, identified in this report, that make movement by pipeline especially dangerous. Natural gas, once processed for end use, is about 95% methane (CH_4), and thus gas transmission and distribution pipelines are designed to transport gas comprised primarily of methane. Hydrogen, or gas mixtures containing hydrogen, are more prone to leak out of a containment vessel such as a pipeline. Such hydrogen driven releases are not only more likely to migrate and are easier to explode, burning hotter than methane natural gas streams, but also contribute to climate change as an indirect greenhouse gas. In layman's terms, hydrogen is more "slippery" when compared to natural gas. Important modifications to minimum federal and state pipeline safety regulations are warranted, whether attempting to use new hydrogen pipelines, or converting existing pipelines to hydrogen gas service, including blending options.

IV. Hydrogen has unique physical properties making it significantly more reactive when compared to methane

Hydrogen transported in pipelines is a clear, odorless gas that, when released, can burn with a very light blue flame that may not be visible in daylight. It is not unusual for hydrogen releases to explode and then burn. Hydrogen has some unique properties that in chemical engineering terms make hydrogen more "reactive" as compared to other hazardous hydrocarbons moved in transportation pipelines, such as methane as natural gas. These hydrogen properties make movement by transportation pipeline, whether via gas transmission or gas distribution, substantially more dangerous than conventional natural gas pipeline operations. Based on hydrogen release events, many with explosion, the following are major points for discussion to help in understanding these important property differences when it comes to hydrogen transportation by pipeline, even as gas mixtures, as compared to conventional natural gas:

1. Hydrogen has a much greater flammability range (4.0 – 75.6 vol%) as compared to methane (5.0 – 15 vol%), so it is more susceptible to combustion.
2. Hydrogen has a much lower autoignition temperature that favors ignition and resulting detonation/explosion as compared to natural gas when ignition sources are not present.
3. The combustion characteristics of hydrogen are quicker and more efficient (i.e., faster burn velocity), producing a more rapid/efficient combustion than natural gas, often with explosive outcomes, either outside or in structures.
4. Hydrogen on a per pound basis has slightly greater than 2.5 times the energy density of methane.
5. Being a much smaller atom/molecule, hydrogen or hydrogen gas mixtures can more easily leak out of a pipeline, and once released migrate more easily into

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https://primis.phmsa.dot.gov/matrix/RfpInfo.rdm?rfp=90&s=280E4A9F749B439AA5FC1923F6C29803&c=1.

soils and nearby buildings where such contained releases involving hydrogen are more likely to explode as compared to methane.

6. Hydrogen is an indirect greenhouse gas, with potentially thirty-three times the warming power of carbon dioxide in the first 20 years.

***Flammability*:** Flammability range describes the minimum and maximum concentrations at which a given vaporous substance will ignite or combust when mixed with air. The significantly greater range of flammability for hydrogen over methane clearly indicates that hydrogen releases have a much wider range of concentrations favoring combustion as compared to natural gas.[9]

Autoignition: Autoignition temperature is the lowest temperature required to ignite a gas or vapor in air spontaneously (without a spark or flame being present). Hydrogen has a lower autoignition temperature (1040 °F) than methane (1103 °F).[10] This lower autoignition temperature contributes to a higher likelihood that pipeline releases will explode and then burn for some time, fueled by pipeline inventory.

Combustion: Hydrogen burns faster than methane and once ignited, has faster flame speeds coupled with a higher combustion efficiency. Such factors contribute to hydrogen releases tending to detonate/explode with extreme energy release from pipeline fed fires generating very high temperatures. Higher purity hydrogen fed fires generate very high and fatal heat radiation densities that tend to shift toward the ultraviolet rather than the more conventional infrared heat radiation spectrum associated with methane fires. Such burning releases are hard to see in daylight but are still very destructive/fatal to receptors, such as the public, who may not be aware of such unique heat radiation and thus remain too close to such events.[11]

Density: On a per pound basis hydrogen is one of the highest energy density gases, especially when compared to methane. The Blending Report appears to focus on much lower pressure (at the end use) burner tip combustion, citing combustion by volume density associated with appliances. Such comparisons miss the much greater consequences of energy release of hydrogen using density by pound associated with pipeline releases. Hydrogen releases from pipelines are easier to explode and then continue to burn depending on the fuel supply, which for pipelines can be considerable tonnage spanning significant time. Because of pipeline inventory increased from pressure, pipeline releases do not shut off quickly, even when valves are closed as the system depressures. Such pipeline-fed flames result in very high heat releases (think of a powerful blowtorch). The tremendous amount of energy release capable from

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[9] American Institute of Chemical Engineers, "Guidelines for Evaluating the Characteristics of Vapor Cloud Explosions, Flash Fires, and BLEVEs," 1994, p. 48.
[10] *Ibid.*
[11] Hydrogen Tool, "Hydrogen Compared with Other Fuels," at https://h2tools.org/hydrogen-compared-other-fuels.

pipelines should be using energy density per pound as the appropriate parameter to capture hydrogen related pipeline release consequences.[12]

Leakage: Hydrogen, being the smallest atom, makes containment challenging for pressurized pipelines, even as a H_2 molecule. Such releases underground will be prone to migrate considerable distances, especially if the earth above the pipeline is capped, with asphalt or concrete for example, as is often the case with gas distribution systems. While not a defined technical property, in layman's terms think of hydrogen or hydrogen/natural gas blends as being more "slippery" than natural gas. Hydrogen or hydrogen natural gas mixtures will likely have not only a greater propensity to leak, but such releases will more easily migrate laterally underground from pipelines and eventually accumulate if confined in structures to dangerous concentrations.[13]

Indirect Greenhouse Gas: Hydrogen is an indirect greenhouse gas which, through a series of chemical reactions, increases the amount of greenhouse gases like methane in the atmosphere. A recent study estimated that hydrogen emissions could have about 30 times the warming power of carbon dioxide, pound for pound, over the first 20 years after being emitted.[14] The study also found that depending on the leak rates of methane and hydrogen, the development of "blue hydrogen," where hydrogen is produced from natural gas and the CO_2 emissions are captured and sequestered, could actually increase warming in the next few decades. This is an especially important consideration given hydrogen's propensity to leak as well as its potential ability to increase leakage rates in hydrogen/natural gas blends.

Accufacts finds it odd that the cited papers discussing and driving the hydrogen economy and hydrogen's possible use in transportation pipelines fail to prudently address the many unique properties of hydrogen that make it significantly more dangerous compared to methane transported in such natural gas pipelines. Especially disingenuous is the failure of hydrogen release discussions to outline the differences in such releases in more industrial facilities (such as refineries, chemical plants, or major electric power plants) where releases are outdoors and away from the public, versus the consequences of such releases in buildings containing the public, where explosions forces are seriously magnified. Such deficiencies demonstrate a lack of experience concerning the dangers in hydrogen release events, especially explosions.

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[12] See Energy Density of Hydrogen - The Physics Factbook, "Energy Density of Hydrogen," at https://hypertextbook.com/facts/2005/MichelleFung.shtml.

[13] Many states have imposed leak classification and leak grading requirements for their intrastate natural gas pipelines that are based on methane.

[14] Ilissa B. Ocko and Steven P. Hamburg, article in Atmospheric Chemistry and Physics, "Climate consequences of hydrogen emissions," Volume 22, Issue 14, published July 20, 2022, p. 9359, Figure 3 at https://acp.copernicus.org/articles/22/9349/2022/acp-22-9349-2022.pdf.

V. Additional factors that influence decisions to utilize hydrogen in natural gas transportation pipelines

Beyond hydrogen's additional reactivity, there are features of existing gas pipelines that make introduction of hydrogen into natural gas transportation pipelines concerning. Currently there are slightly less than 300,000 miles of onshore gas transmission and slightly more than 2,300,000 miles of natural gas distribution pipeline, consisting of mains and services lines.[15] A third category of gas transportation pipeline, gas gathering, that mostly evolved from the advancement of gas production from shale formation fracking, also exists, but this category of pipeline is not likely to involve hydrogen. It is important to recognize some of the general differences between natural gas transmission and distribution systems that can affect safe pipeline operation and public safety regarding the possible addition of hydrogen in such existing pipelines:

A. For Natural Gas Transmission Pipelines

Transmission pipelines are usually large-diameter, high-pressure pipelines designed to move large volumes of gas per day with diameters ranging from 4-42 inches. Gas transmission pipelines mainly serve other pipelines, electric power plants, large industrial facility fuel consumers, local distribution center systems, and large liquified natural gas (LNG) facilities. Most gas transmission pipelines are composed of steel with some minor mileage consisting of composites. The majority of transmission pipelines operate at much higher pressures and Specified Minimum Yield Strength levels, or SMYS, as defined in federal pipeline safety regulations, that place them into the rupture consequence regime if certain anomalies in the pipeline grow to defects.[16] Ruptures are the pipeline failures that fracture, usually in microseconds, generating big craters ejecting tons of steel pipe, and upon ignition generate fireballs, releasing extremely high heat fluxes that burn for considerable time. Leaks are gas releases where the pipe failure usually doesn't quickly grow with time, such as a puncture or corrosion through wall pitting. Thus, gas transmission pipelines can release gas as either leaks or ruptures. Not all natural gas leaks are immediately dangerous, but all gas pipeline ruptures are dangerous, given the over-pressure forces and pipe shrapnel generated from pipe rupture, and extremely high heat radiation if ignition occurs.

Gas transmission pipelines are usually located in well-defined pipeline rights-of-way ("ROW") of varying widths, that by federal regulation are required to be posted to indicate that a gas transmission pipeline ROW is in the area. Most gas transmission pipeline ROWs are controlled by easement contracts that usually limit landowner activity such as no buildings on such pipeline ROWs by contract. The result is that structures are not usually too exposed to transmission pipeline gas leaks, though pipeline ruptures of high-pressure gas transmission pipelines can

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[15] PHMSA website Annual Report Mileage Summary Statistics, at: https://www.phmsa.dot.gov/data-and-statistics/pipeline/data-and-statistics-overview.

[16] 49CFR§192.3 Definitions.

easily impact structures well beyond the ROW. Such easement ROWs for transmission pipelines are not always the case. Recent Accufacts investigations and a new definition in PHMSA's proposed gas transmission pipeline regulation have made public that a small minority of gas transmission pipelines do not have a defined easement nor ROW.[17] A small group of gas pipelines can become transmission if a pipeline operator voluntarily designates so to PHMSA. This PHMSA change in transmission pipeline definition can lead to situations where some transmission pipelines are not on ROWs, placing them near structures.

B. For Natural Gas Distribution Pipelines

Gas distribution pipelines are generally smaller diameter, lower pressure mains and service lines operating at less than 20% SMYS. Gas distribution pipelines range on the order of ½-inch to 24-inch in diameter, though cast iron pipelines, which operate at very low pressures, can be larger in diameter. These gas distribution systems consist of a network of pipe "grids" of mains in towns, cities, and neighborhoods which then feed into service lines running to homes, businesses, as well as some power plants and smaller LNG peaking facilities. Gas distribution systems operate at less than 20% SMYS at MAOP. By their nature gas distribution systems are close to structures. In some cases, usually associated with older installations, part of the gas distribution system is inside structures, such as basements.

For various reasons plastic has taken over gas distribution in many new installations as well as pipe replacement projects, with current mileage in this country consisting of slightly over two-thirds consisting of a wide range of plastics, and the remaining about one-third of the gas distribution mileage consisting of steel or iron-based materials, such as cast iron.[18] A smattering of distribution pipeline miles are of other materials, such as copper. From a pipe failure/fracture mechanics point of view, by nature of their lower stress levels, gas distribution pipelines don't rupture or fracture like higher pressure gas transmission pipelines, they leak. While many gas distribution system leaks are not dangerous, some methane gas leaks can be quite dangerous if the leaked gas reach structures. Some gas distribution systems are over one-hundred years old with much of these older systems constructed of cast iron, wrought iron, and earlier forms of carbon steel. These older iron-based pipelines are prone to brittle cracking failures that release gas as leaks.

[17] PHMSA Final Rule for 49CFR Part 192, "Pipeline Safety: Safety of Gas Transmission Pipelines: Repair Criteria, Integrity Management Improvements, Cathodic Protection, Management of Change, and Other Related Amendments," issued August 4, 2022, § 192.3 Definitions vii, Transmission line.

[18] PHMSA, Pipeline Mileage and Facilities, 2010+ Pipeline Miles and Facilities, "Gas Distribution Pipeline Miles by Material," at website: https://www.phmsa.dot.gov/data-and-statistics/pipeline/data-and-statistics-overview.

It has also been well known for many decades that specific types of early plastic gas distribution pipe, such as Adyl A, Century, ABS, and certain other plastics, are also prone to cracking that favors gas leakage.[19] In some parts of the country, gas distribution systems may also exhibit various forms of plastic or metal "connection" failures that can be another source of leakage. It is currently not illegal to leak natural gas. None of these gas distribution systems containing such crack threats, connection threats, or proximity issues within or near a building should be permitted to allow blended hydrogen in their operation. Such gas distribution systems dramatically increase the dangers from hydrogen driven pipeline leakage near/in structures with very little benefit from hydrogen blending to reduce carbon emissions.

1. **The internal piping in buildings is the weakest link that should prevent hydrogen blending in gas distribution systems**

   While some distribution systems have spent considerable efforts trying to tighten their systems to reduce methane leakage, the weakest link in this process is the downstream lower pressure internal gas systems within structures that are fed by the gas distribution systems. Such lower pressure internal systems are not governed by pipeline safety regulations for transportation pipelines but are usually addressed by other organizations (such as local fire or building codes that vary considerably across the country). Adding a new substance like hydrogen, with its greater ability to leak and explode, to the wide range of internal piping used in structures intended for methane, will have serious public safety consequences. Hydrogen is a very unforgiving gas, that can easily explode in the open, but is especially destructive when explosion occurs in the confinement of buildings, such as residences. It is this final factor that leads Accufacts to conclude that hydrogen, even as blends, should never be allowed in gas distribution systems.

VI. Can pipelines be a critical link to a hydrogen economy?

A listing of possible production sources of hydrogen, compared to the possible consumers of such hydrogen to effectively reduce greenhouse gases, demonstrates that pipelines may be needed to connect supply to demand. One important question regarding the emerging hydrogen economy is to what extent, if at all, existing natural gas pipelines should be utilized for such efforts and when new, specially built pipelines designed for hydrogen service are warranted.

[19] Report of Phase I Investigations prepared by joint work/study groups, identifying some types of plastic pipe susceptible to cracking and used to help develop the Distribution Integrity Management Program, or DIMP, federal pipeline safety regulations that became effective in August 2011, "Integrity Management for Gas Distribution," December 2005, Risk Control Practices Report – Exhibit E, p. 43.

A. Current hydrogen pipeline miles in the U.S. are not typical

U.S. pipeline developers, owners, operators, and regulators have limited experience with hydrogen pipelines, and even less experience with natural gas/hydrogen blended pipelines. Currently there are slightly under 300,000 miles of onshore natural gas transmission pipelines and slightly over 2,300,000 miles of natural gas distribution (mains and services lines) pipelines in the U.S.[20] A review and analysis of the public database from PHMSA indicates, that as of the end of 2021, the U.S. had slightly more than 1,500 miles of hydrogen transmission pipeline.[21] The bulk of this limited hydrogen transmission pipeline mileage, about 85%, is in three major transmission pipelines. These three lines consist of hydrogen pipelines no greater than 18 to 20-inches in diameter at their largest diameter of high-pressure pipeline with the preponderance of their mileage consisting of much smaller diameter pipe of 12-inches or less. Pipe diameter plays a controlling factor in the tonnage of gas that can be released from a pipeline in the event of a leak or a pipeline rupture. These three major pipelines are mainly located in the Gulf Coast region with over 80% of the pipeline mileage in areas of lower building density, defined as a class location unit 1 under current federal pipeline safety regulations.[22]

The movement of hydrogen by very limited mileage of pipelines in the U.S. is mainly in rural areas. Transporting hydrogen in pipelines is very uncommon, representing 0.5% of gas transmission pipelines. It is very important to understand and clearly communicate how hydrogen, even blended, can affect not only new but existing gas transmission and distribution systems as it relates to public safety.

B. Most existing gas transportation pipeline systems are not suited for hydrogen, even as blends

Current minimum federal pipeline safety regulations do not prevent the blending of hydrogen into existing natural gas transportation pipelines. In the past decade after the implementation of Distribution Integrity Management Program, or DIMP, regulation, many billions of dollars have been invested across the U.S., with the

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[20] See Pipeline and Hazardous Materials and Safety Administration, or PHMSA, websites for year 2021 at: https://www.phmsa.dot.gov/data-and-statistics/pipeline/data-and-statistics-overview.

[21] PHMSA Gas Transmission & Gathering Annual Data – 2010 to present (ZIP) at: https://www.phmsa.dot.gov/data-and-statistics/pipeline/gas-distribution-gas-gathering-gas-transmission-hazardous-liquids.

[22] As a cost reduction effort, some in the gas pipeline industry have been trying to get area classification regulations that apply only to gas transmission pipelines removed from federal minimum pipeline safety regulations. Such removal would significantly increase the risks associated with hydrogen transportation by transmission pipeline. Class location requirements basically prescribe thicker pipe or lower MAOP to be imposed, increasing pressure related safety margins within a certain time period, as building density and other factors increase around a gas transmission pipeline.

primary focus on pipe replacement to reduce hazardous natural gas leaks. Even this leak focus has not prepared gas systems for the additional risks associated with hydrogen blending.

Further studies and discussions are warranted to identify necessary changes in federal pipeline safety and siting regulations to prudently address the dangers of transporting hydrogen in existing pipelines, especially given the many unique properties that make hydrogen more dangerous than natural gas in gas transmission or distribution systems. PHMSA's federal pipeline safety regulations do not address pipeline siting issues, as siting is usually, but not always, handled by other agencies, like the Federal Energy Regulatory Commission, or FERC, whose charters are not pipeline safety. But FERC does not have jurisdiction to determine siting or routing or whether there is a need for a hydrogen pipeline, so none of the risks of transporting hydrogen in an existing line have been considered by FERC or any other permitting agency.

Hydrogen pipelines fall into two main categories: 1) movement of purer hydrogen in a gaseous state via new construction or conversion of existing pipelines to hydrogen service, and 2) blending hydrogen to form a mix with existing natural gas pipelines as essentially gas transmission and/or distribution pipelines. As efforts to reduce the impacts of climate change drive some fossil fuel gas pipelines into underutilization or obsolescence, there is great temptation to try to convert this existing pipeline infrastructure to extend its lifecycle. While possible hydrogen/methane blending discussions are understandable, these proposals frequently ignore the dynamics and interplay between transmission and distribution systems, and where hydrogen use might be best used to timely address climate change. It is also important to recognize how hydrogen can affect gas transmission and gas distribution as well as the public differently. Some existing gas transmission pipeline systems (most likely the smaller diameter intrastate pipelines) may be capable of moving higher purity hydrogen specifically targeted to major fossil fuel consumers (i.e., electric power plants and large industry fuel consumers). Many of the gas distribution systems across the country contain materials that are not compatible with hydrogen, even in blends. There are existing gas transmission and distribution pipelines that should not be considered for hydrogen service, even limited blended service.

For example, numerous intrastate gas transmission pipelines cannot be inspected by highly specialized inline inspection ("ILI" or "smart pigs") tools. Such multi-ton tools might possibly help in identifying cracking threats, though this advancing technology and its prudent application, are still evolving, leaving much room for misuse as too many rupture failures have occurred after ILI tool runs have failed to identify threats. In addition, a substantial portion of transmission pipelines are of a vintage that is more susceptible to cracking threats related to manufacturing. These same transmission pipelines also may contain various factors that can lead to hydrogen deterioration of the steel and failure.

Likewise, there are many gas distribution pipelines, such as those constructed of cast iron, wrought iron, and earlier forms of carbon steel, where such iron-based pipelines tend to exhibit brittle cracking failures that are prone to leakage. As previously mentioned, it has also been well known for many decades that specific types of plastic gas distribution pipe are prone to cracking. In some parts of the country gas distribution systems also contain "connection" risks, either for steel or plastic pipe. One of the benefits of over a decade of DIMP pipeline safety regulation is that not only have many pipeline operators gained a better understanding of their distribution systems, but the public has the ability to gain a better appreciation of distribution systems in their area. It is worth noting that DIMP's focus is on pipeline safety, usually the reduction of grade 1 leaks designated as hazardous, and not on methane leak reduction, which historically is not illegal.

C. Is transporting hydrogen, especially in existing systems, a dangerous experiment?

It is easy to be lulled into the temptation that hydrogen blending into existing natural gas systems should start with lower concentrations that may eventually be increased as time and experience is gained. The fact is that the rush to utilize hydrogen could be a very dangerous experiment:

1. Few existing gas transmission systems may be suitable for conversion to hydrogen

Only certain users of natural gas are expected to transition to hydrogen combustion in a decarbonized economy. Most existing natural gas transmission pipelines transport and deliver gas to many sources that cannot or should not receive hydrogen, either as higher purity or lower purity streams. Comingling gas transmission systems with hydrogen blends would make it impossible to selectively target power plants and large industrial consumers with hydrogen without imposing blended hydrogen streams on distribution systems they also serve. These likely candidates for hydrogen conversion, however, are going to be in a rare minority of the total transmission pipeline miles in the U.S. given the requirement to service their distribution clients. The few existing gas transmission pipelines that may be suitable to move hydrogen, if they can meet the challenges of hydrogen compatibility that needs to be demonstrated, are most likely going to drive to higher purity hydrogen to favor the economics of decarbonization at such large industrial consumers.

2. Hydrogen blending for natural gas distribution systems ignores the very real dangers of introducing hydrogen into confined buildings while overstating climate change emission benefits

With regard to gas distribution systems servicing residential, commercial, and industrial customers, there are both safety and climate reasons not to pursue blending. Most decarbonization analyses conclude that building electrification is the most cost-effective decarbonization pathway, accompanied by generation shifting. But proposals to instead continue to use gas distribution infrastructure to transport hydrogen continue to proliferate, raising numerous questions regarding the potential climate benefit and safety risks concerning the reactive nature of hydrogen in such public structures. Furthermore, hydrogen itself is an indirect greenhouse gas and recent research indicates that hydrogen use may not yield climate benefits depending on such factors as: 1) how much hydrogen is ultimately emitted from various production sources (i.e., blue or green) and the fossil fuels it replaces, 2) the leakage rate across the hydrogen supply/delivery chain, and 3) the time period utilized to evaluate global warming impacts associated with hydrogen.[23] It is clear that whenever possible, electrification with renewable energy sources would achieve a much better emissions reduction, and more efficiently, without imposing hydrogen dangers on residents. It is important not to overstate the benefits of hydrogen to mitigate climate change, while understating the very real dangers to the public of hydrogen transportation in pipelines.

VII. Why is California rushing forward on hydrogen?

California merits special mention as this state has established several ambitious climate goals and timelines to reduce greenhouse gas emissions (e.g., a 2016 California law requiring dramatic cuts in emissions by 2030, and a mandated objective of carbon neutrality by 2045). The use of hydrogen as previously explained may play an important role in trying to reach these goals, but a detailed plan going forward has not been agreed upon.

A. Observations on a recent hydrogen Blending Report for California

A 2022 report, Hydrogen Blending Impacts Study, prepared for the California Public Utilities Commission, raises many questions concerning the possible impacts of hydrogen pipeline safety, for both new and existing gas transmission and distribution systems within the state.[24] This report is an important step and will require much time and money to address the many knowledge gaps it identifies. The proposed three-year timeline presented in the Blending Report may be overly optimistic about the effort necessary to resolve these information gaps given the extensive specialized knowledge and experience needed.[25] Before any significant

[23] Ilissa B. Ocko and Steven P. Hamburg, article in Atmospheric Chemistry and Physics, "Climate consequences of hydrogen emissions," Volume 22, Issue 14, published July 20, 2022, pp. 9350 – 9352 at https://acp.copernicus.org/articles/22/9349/2022/acp-22-9349-2022.pdf.

[24] Prepared by: University of California, Riverside with subcontractor: Gas Technology Institute, for the California Public Utilities Commission, "Final Report - Hydrogen Blending Impacts Study," filed 7/18/2022, R1302908.

[25] *Ibid.,* Summary and Recommendations, pp. 111 – 116.

hydrogen blending option or consideration is moved forward, these issues need to be clearly addressed and made public, especially concerning existing pipeline infrastructure in California.

In addition to the knowledge gaps identified in the Blending Report, there are other considerations that will significantly impact any informed safety decisions and related timing involving hydrogen transportation via pipeline:

1) The extreme heat and temperatures generated by burning hydrogen supplied from a pressurized pipeline release (leak or rupture) as compared to a methane natural gas release must be explicitly accounted for in considering the risks imposed on communities by transporting hydrogen by pipeline.
2) While identifying the potential of crack risk in plastic distribution pipelines, the Blending Report fails to adequately explore crack threat dangers in steel transmission pipelines. Crack threats greatly increase the risks to communities from transporting hydrogen by pipeline.
3) Of the two basic types of energy density, gravimetric (per unit mass) and volumetric (per unit volume), the Blending Report focused on volumetric. This misses the unique capability of pipelines to release incredible amounts of gas tonnage, whether via leak, or the much more insidious pipeline ruptures as defined by pipeline fracture mechanics.[26] No other form of onshore transportation is capable of the tonnage release capability as that from pipelines. Lower pressure gas distribution systems can leak many tons of gas, especially if such releases contain hydrogen. Because of its unique properties, hydrogen influenced pipeline releases will most likely explode, and then burn incredibly hot, fed by pipeline inventory for considerable periods of time. The gravimetric parameter should play a critical role in hydrogen pipeline evaluations and decisions.

Over the past several decades the majority of new or replacement pipe installed in gas distribution systems in the U.S. has been various forms of plastic, largely because of cost considerations. The report properly points out the need for further detailed follow-up before hydrogen is even considered for introduction into existing gas distribution systems within California.

Cracking threats are a bona fide threat to steel transmission pipelines, both vintage and new gas transmission pipelines. Despite all the advances in fracture mechanics used to estimate time to failure of transmission pipeline steel cracking threats, the real issue remains assessment techniques to reliably identify and properly characterize the pipeline crack threat well before its failure, as too many recent pipeline ruptures after ILI tool runs across the U.S. have demonstrated. The Blending Report identifies certain cracking issues but fails to describe how to reliably identify and avoid such threats, especially in gas transmission pipelines.

[26] *Ibid.,* Conclusions, p. 109.

The Blending Report, however, states many important observations:

> "Further research and development is required that considers the system integrity and durability at all levels of steels (low-, medium-, high-strength), distribution-level polymer pipes, and all components, valves & sealants used throughout the different network levels. The impact of integrity and durability on safety as the blending percent and pressure increase requires an in-depth study of leak detection, odorization, gas build-up, dispersion dynamics, and safety zones to account for changes in flammability, ignition, and explosivity."[27]

Crack identification in gas transmission pipelines, even with current ILI technologies are challenging, especially if the pipelines are moving hydrogen. Given the many miles and wide disparity in types, grades, and vintages of gas transmission and distribution pipe, there are pipeline systems within California that should never receive hydrogen, even in mixtures because of cracking release potential that will allow hydrogen release.

Hydrogen blending into natural gas pipelines presents increased safety risks across complex pipeline networks, such as an increased risk of explosion and fire that could harm people. To protect the public, hydrogen blending should not be pursued without additional research, clear standards to safeguard people and the environment, and investigations to resolve outstanding questions of risk.

VIII. Recommended areas needing additional safety focus to advance the hydrogen economy with pipelines

Given the discussions in this report, Accufacts recommends the following additional efforts concerning the possible use of pipelines to try and address climate change with hydrogen:

A. Gas utilities should not pursue hydrogen blending into their systems and regulators should prohibit the blending of hydrogen in gas distribution systems.

Given the dangers that hydrogen introduces into gas distribution systems, the propensity of such systems even now to leak methane, the close proximity to structures for these gas systems, as well as the ability of hydrogen to release within structure "weakest link" internal piping not regulated as transportation pipelines, hydrogen addition into gas distribution pipelines should be prohibited. The benefits of adding hydrogen to such systems to address global warming are questionable and do not warrant the many dangers placed on the public. Hydrogen is clearly not methane.

[27] *Ibid.,* Recommendations, p. 109.

B. PHMSA should update reporting requirements to include any percentage of hydrogen blended into a transportation pipeline.
For pipeline operators contemplating blending hydrogen into their system, PHMSA should require that such operators report their blending efforts and concentrations, prior to such efforts, to assure that the public is also timely notified of such increased dangers from hydrogen activities. This should not include streams where hydrogen is relatively low or "trace" concentrations which should be defined in regulations. An acceptable level of hydrogen concentration releases in structures should be scientifically developed and demonstrated.

C. Existing transmission pipelines <u>that should not be candidates for hydrogen transportation</u> should be clearly identified.
As discussed in this report, certain pipeline systems should not be candidates for hydrogen transportation, even in blended mixtures, because of their material incompatibility with hydrogen, the propensity to leak or possibly rupture and inability to properly assess certain pipeline threats. Inability to run advancing/developing technology ILI tools within a gas transmission pipeline would be one characteristic that removes a pipeline from transporting hydrogen.

D. PHMSA should require gas transmission pipelines converting to transport hydrogen, either blends or higher purity, to conduct spike hydrotests.
Federal regulations governing the transportation of gas must be amended to insure that before conversion to hydrogen service, pipelines possibly containing manufacturing cracking threats, must be subject to a spike hydrostatic pressure test as defined in federal pipeline safety regulations.[28] Because of the unique properties and dangers associated with hydrogen, "Other technology or other technical evaluation process" further outlined in federal pipeline safety regulation must not be permitted. If traceable, verifiable, and complete records of the pipeline needed to verify manufacturing cracking threats cannot be provided, the pipeline must not be allowed to be placed into hydrogen service.

E. Pipeline safety leakage survey regulations should be specifically enhanced for pipelines transporting hydrogen.
Given the propensity of hydrogen or hydrogen/methane mixtures to increase gas leakage that works against the goal of reducing emissions contributing to climate change, enhanced pipeline safety regulations are warranted in the area of leak surveys. Such additional regulations should include advanced gas leak detection surveys methods (especially using remote detection technologies) and increased frequency on systems moving hydrogen over current natural gas regulations. Historically, it has not been illegal to leak natural gas from gas pipelines, either transmission or distribution. Some states have imposed more frequent leak surveys more stringent than federal minimums, but even these

[28] 49CFR§192.506(a) Transmission lines: Spike hydrostatic pressure test.

state regulations apply only to intrastate pipelines and may not be sufficient for all systems that might move hydrogen or hydrogen blends.

F. **Foster research advances on hydrogen compatibility of steel transmission pipelines and their components.**
It is well known that hydrogen can deteriorate certain forms of steel pipelines and their components. While the pipeline industry has been aware of such threats, further research in this area is needed to identify specific conditions where hydrogen threatens transmission pipeline operations. Such important information needs to be made public before a rush into an ill prepared real-world pipeline experiment.

G. **The knowledge gaps identified in the recent Blending Report for California should be addressed and the results made public.**
If hydrogen blending options for existing pipelines are pursued, the information knowledge gaps identified in the Blending Report need to be completed and made public before such efforts are attempted. Specifically, as identified in the Blending Report, additional studies are needed regarding the safety impact on pipeline integrity and durability as concentration of hydrogen and operating pressure increase on existing gas systems. These studies should address design criteria, leak detection, odorization, gas build-up, dispersion dynamics, and increased safety zones to account for changes in flammability, ignition, and explosivity of natural gas systems blending hydrogen. Such important research efforts will take time.

H. **For California, the CPUC should fully explore and confirm the heat release capability and combustion dynamics from pipelines containing hydrogen, both as leaks and ruptures.**
Given the CPUC's jurisdiction over intrastate gas pipeline safety, this organization should require that the hydrogen heat release and combustion dynamics be affirmed and made public before any decision regarding the use of hydrogen be allowed into existing intrastate gas pipeline systems within California. The gravimetric energy density of hydrogen should be the controlling parameter for pipelines moving hydrogen.

IX. Conclusions

The above hydrogen discussions work to undermine arguments that hydrogen and methane should be treated the same with respect to movement by pipeline. Informed transparent public discussions are warranted, especially given the additional risks associated with hydrogen's unique properties that make movement in pipelines, especially in neighborhoods, more dangerous than conventional natural gas fossil fuel movements in such pipeline infrastructure. Since pipelines are easily capable of placing more tonnage of hazardous material in a neighborhood than other forms of transportation, caution is advised in such matters as it relates to the introduction of hydrogen in such infrastructure. Clearly, because of its unique physical properties, hydrogen is more dangerous than natural gas.

Many questions remain on the effects of hydrogen in pipelines before we race forward with attempts to shift to a hydrogen economy to try and address climate change. Specific prescriptive pipeline safety regulations setting clear minimum enforcement standards targeted at various attempts to move hydrogen via pipeline are required before we try to convince the public that such transportation can be safely performed.

In addition, certain types of gas transmission and gas distribution pipeline systems are woefully inadequate to move hydrogen safely, even as blends, and these pipelines should not be allowed to perform such a task. It should become evident that blending options mixing hydrogen into many existing natural gas pipeline systems significantly increase the dangers to the public with little material benefit in reducing emissions that significantly contribute to climate change.

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