ELECTRIC POWER RESEARCH INSTITUTE

Quick Insights

Safety Considerations of Blending Hydrogen in Existing Natural Gas Networks

RESEARCH QUESTION

What are the safety implications of repurposing natural gas networks for delivering hydrogen blended with natural gas for domestic appliance and industrial consumption?

KEY TAKEAWAY

Blending hydrogen with natural gas in existing delivery networks could offer a number of potential energy benefits, and recent feasibility studies have found that blends of approximately 5-20% hydrogen can be accommodated by most existing natural gas networks with little increased risk. But safety/risk assessments need to be conducted on a case-by-case basis due to the widely varying characteristics of local/regional gas infrastructure and end-use systems.

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KEY POINTS

- The addition of less than 20% hydrogen is not expected to increase the risk of explosion in the distribution system (lower pressure), in which risks are dominated by leakage.
- A variety of materials are used in the equipment and pipelines of today's natural gas networks and some are more tolerant of hydrogen than others.
- Natural gas network components such as compressors, valves, and meters need to be tested in the presence of hydrogen to understand and mitigate risks.
- Trials and lab testing are required to verify the safety and impacts on performance of appliances and assess possible risks associated with gas leaks at the point of end use.

INTRODUCTION

Activity around the use of hydrogen as a sustainable energy carrier has accelerated in recent years, due in part to ambitious CO_2 reduction targets in many countries that require deep, economy-wide decarbonization. The concept of blending hydrogen in existing natural gas pipeline networks is being explored as a hydrogen delivery/transmission method. For this reason, research is under way to analyze the safety implications of hydrogen blending for existing pipeline infrastructure.

Several recent studies analyze the technical and safety implications of hydrogen blending in pipelines, most of which look at concentrations of up to approximately 20%. Rigorous risk/safety assessments from upcoming and recently commissioned field trials will provide insights into the safety case for hydrogen blending in pipelines. A summary of planned and in-progress blending demonstrations is included here, illustrating the potential range of safe levels of hydrogen blending.

SAFETY ACTIVITIES

Detailed safety assessments of hydrogen blends in existing natural gas pipelines are ongoing. Major initiatives include:

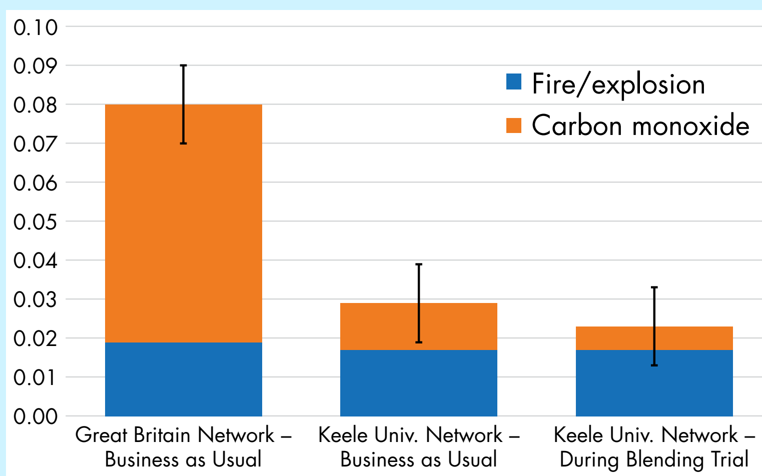
- The independent structured risk assessment process the UK's Health and Safety Executive (HSE) conducted for approval of the 2019 HyDeploy Project included lab tests, pre-trial work, equipment specification review, and an extensive literature search of previous studies (see sidebar).[1,2]
- The recently launched Center for Hydrogen Safety, under the auspices of the American Institute of Chemical Engineers (AIChE) and cosponsored by the U.S. Department of Energy (DOE), along with other national agencies.[3]
- The Fuel Cell & Hydrogen Energy Association (FCHEA) has robust work on codifying technical knowledge around safety.[4]
- The U.S. Department of Energy and national labs are working on steel and weld compatibility, and are actively engaged in the development of technical standards.[5,6]

Safety Approval of HyDeploy Project

HyDeploy @ Keele will inject a blend of up to 20% hydrogen in a private gas network at Keele University. Overall system risk during the field trial is expected to be low, and a slight decrease from business as usual (see bar chart). Due to these findings, the HSE granted its first-ever approval for injection of hydrogen in a natural gas network. Key findings:

- *There was no substantial effect on the short-term operation of **appliances**. A small-scale study demonstrated that unmodified appliances could tolerate hydrogen levels up to 20% without adversely affecting safety due to operational performance or gas leakage.*
- ***Metals and polymers** were evaluated for the effects of deterioration, embrittlement, cracking elasticity, and seal integrity. Largely based on a literature review of existing safety studies and some soaking tests, all materials at the Keele campus were found to be satisfactory.*
- *The specification of the Hydrogen Grid Entry Unit (H2GEU) that will be used at Keele was assessed and found to be suitable for safe operation in the UK, therefore the risk of **blending** issues—maintaining the desired hydrogen blend—was found to be acceptably low.*
- *Gas **measurement and detection** equipment was found to perform satisfactorily through testing.*

This objective of this project-specific safety review was to help build the overall case for hydrogen blending, and to increase public acceptance of this blending project.



Risk, in fatalities per millions of people, associated with conveyance and use of gas for the UK's HyDeploy Project at Keele University compared to "business as usual" and the Great Britain system as a whole (GB).[7]

1 HyDeploy Project: https://academic.oup.com/ce/article/3/2/114/5487479#136074492
2 HSE injecting hydrogen into the gas network – a literature search: http://www.hse.gov.uk/research/rrhtm/rr1047.htm
3 AICHE: https://www.aiche.org/CHS
4 FCHEA Codes and Standards Support: https://www.hydrogen.energy.gov/pdfs/review19/scs022_quackenbush_2019_p.pdf
5 US DOE H2 Safety Subprogram: https://www.hydrogen.energy.gov/pdfs/review19/scs000_hill_2019_p.pdf
6 Materials work at Sandia National Lab: https://www.hydrogen.energy.gov/pdfs/review19/scs005_sanmarchi_2019_p.pdf
7 HyDeploy, Project evidence base: https://www.hsl.gov.uk/media/1298396/03.%20catherine%20spriggs.pdf

KEY SAFETY ASPECTS OF BLENDING PROJECTS

1. **Pipelines**: The likelihood and severity of explosion/fire can increase with higher hydrogen levels, due in part to the larger flammability range of hydrogen. At lower concentrations of hydrogen the failure frequency of pipelines due to materials issues (discussed in next section), or ignition events is largely unchanged.
    - The addition of less than 20% hydrogen is not expected to increase the risk of explosion in the distribution system (lower pressure), in which risks are dominated by leakage.[8]
    - Due to the more rapid dispersion of hydrogen relative to natural gas, the safety risks associated with transmission pipeline explosions shift spatially, and therefore are highly dependent on the population distributions near the pipeline.[8]
2. **Materials**: Various materials are used in the equipment and pipelines of today's natural gas networks (for instance, stainless steel, cast iron, copper, and polymers), and some of these are more tolerant of hydrogen than others. The integrity of pipeline materials in the presence of hydrogen (for instance, any degradation, embrittlement, or cracking) must be understood to evaluate risks associated with potential component failure, permeation through pipe walls, or general system leakage. In general, hydrogen-induced cracking in pipes is a limiting factor in increasing hydrogen concentration. Adaptations of existing integrity management programs likely would be needed to address any resulting risk/safety-related concerns.[8] Material-specific risks of hydrogen blending include:
    - **Carbon and low-alloy steel piping**: Alloys are susceptible to hydrogen embrittlement and fatigue crack growth due to low ductility and fluctuation of the operating pressures. Although carbon and low-alloy steels often are used in high-pressure transmission systems that require high strength, this group of materials would be susceptible to embrittlement and cracking from hydrogen-blended compressed natural gas (CNG), potentially even at relatively low pressures.
    - **Ductile iron, cast and wrought iron and copper piping**: These pipeline materials typically are used in low-pressure distribution systems and generally have not been of concern for hydrogen blend damage in distribution systems.
    - **Stainless steel piping**: Stainless steels are more ductile than carbon steels and might do well in low-pressure distribution systems for hydrogen blends. However, this group of alloys typically is not used in natural gas transmission due to higher cost.
    - **Plastic piping**: No major concern with hydrogen aging is expected for plastic piping, such as polyvinyl chloride (PVC), used in low-pressure distribution systems. However, diffusion of hydrogen in plastics is relatively high compared to that in alloys, which may present a higher safety risk.
    - **Polyethylene piping**: No degradation has been reported with polyethylene piping used in low-pressure distribution systems. No adverse interaction is expected between hydrogen and polyethylene. However, diffusion of hydrogen in polyethylene is relatively high compared to that in alloys, which may present a safety risk.
3. **Components**: Many components are used throughout existing natural gas networks (e.g., compressor stations, regulators, valves, meters, and gas detection equipment). It is imperative that the operational characteristics of these components in the presence of hydrogen are well understood, so that the associated risks such as premature failure, reduced efficiency, leakage, and accuracy of gas detection can be appropriately mitigated.
    - **Leakage and gas accumulation**: Relative to natural gas, hydrogen has a greater tendency to leak through valves, gaskets, seals, and pipes,[8] and risks associated with accumulation of hydrogen in confined spaces from those leaks could require additional monitoring/detection devices.
    - **Meters**: Not expected to need recalibration for measurement of gas mixtures containing less than 50% hydrogen.[8]

8 NREL report: https://www.energy.gov/sites/prod/files/2014/03/f11/blending_h2_nat_gas_pipeline.pdf

4. **Point of Use**: Trials and lab testing are required to verify that the safety of appliances is not compromised, and to assess the effect on performance characteristics for customers. Risks associated with gas leaks at the point of end use also must be assessed.[9]

- **Home appliances**
  - The NATURALHY[10] study found that for properly adjusted appliances and favorable local natural gas quality, conventional domestic appliances could accommodate up to 20% H_2. However, long-term material compatibility of domestic appliances is not well understood, and no level of hydrogen may be acceptable for poorly adjusted appliances.
  - The following table summarizes hazards which may be increased, decreased, or remain relatively unchanged with hydrogen blended into the gas supply, from the International Energy Agency Greenhouse Gas R&D Programme (IEA GHG) study.[11]

Causes	Main Household Hazardous Phenomena					
	Rapture*	Explosion	Fire	Burns	Suffocation	Poisoning
High pressure of gas (or heated medium) and chemical properties of gas	x					
Unburned gas in air		--	++		--	
Use of gas and open fire in a device or heating appliance	x	x	x	++		
The appliance itself				x		
Flue gas system			x	x	--	--
Heated media	x	x	x			

* Rupture is inclusive of harmful chemical effects on materials used.
x Hazard exists but unchanged by presence of hydrogen up to 15%[12]
++ Hazard increased by presence of hydrogen
– Hazard reduced by presence of hydrogen

- **Residential leaks, gas buildup, and risk of explosion**
  - HyHouse study findings:[13]
    - When residential gas leaks occur, the risks associated with hydrogen are comparable to that of natural gas. Generally, a low leak rate of hydrogen gas will easily disperse before dangerous concentrations are reached.
    - For blends of up to 30% hydrogen, the increase in the severity of explosions in confined, vented building environments was small relative to natural gas.[10]
    - Gas buildup behavior in building environments was found to be similar to that of natural gas.[8]

9 *An end-use level summary of considerations and possible impacts of hydrogen blending on home and commercial appliances is provided in http://www.hse.gov.uk/research/rrpdf/rr1047.pdf*
10 *NATURALHY study: http://www.gerg.eu/public/uploads/files/publications/academic_network/2010/1b_Florisson.pdf*
11 *IEA GHG Study: https://ieaghg.org/docs/General_Docs/Reports/Ph4-24%20Hydrogen%20in%20nat%20gas.pdf*
12 *The study analyzed the impacts of up to 25% blends.*
13 *HyHouse study: https://www.kiwa.com/gb/en/products/hy-house-kiwa-gastec/*

Name (Location)	Project Lead	Project Term	Blending Level	Distributed To	Hydrogen Source	Funding
Project H2GO (Sydney, Australia)[14]	Jemena	2020 planned; 5-year trial	Up to 10%	1. Municipal gas customers (250 homes); 2. Hydrogen vehicle fueling station; 3. Onsite H_2-powered generator	0.5 MW electrolyzer (from grid)	$10.5M
Clean Energy Innovation Hub – Hydrogen microgrid (Perth, Australia)[15]	ATCO	July 2019	Up to 100%	Local	Electrolyzer using onsite photovoltaic	$2.5M
HyP SA (Tonsley Innovation Park, Adelaide, Australia)[16]	AGIG	5-year initial project period, starting in 2019	5%	Municipal gas customers (710 homes). Potential to add refueling station.	1.25 MW electrolyzer (Siemens) (from grid)	$8M
HyDeploy (Newcastle, UK)[7]	Cadent and Northern Gas Networks	Summer 2019, trial to conclude Spring 2020	Up to 20%	Private gas network at Keele University (38 commercial buildings and 98 homes)	0.5 MW electrolyzer (ITM Power)	$9.4M
GRHYD Demo Project (Cappelle-la-Grand, France)[17]	ENGIE	June 2018, 5-year span	Up to 20%, variable	1. VNG bus fueling station (fleet of ~50 buses); 2. Residential neighborhood (~200 homes)	10 m^3/hour PEM electrolyzer (from wind), and 5 kg storage module)	–

NEAR-TERM HYDROGEN BLENDING PROJECTS

In addition to studies assessing hydrogen blending capabilities and risks, planned and in-progress blending demonstration projects tie a hydrogen source to a point of distribution. The projects are summarized in the following table, including the level of hydrogen blending. Note that the ATCO hydrogen microgrid in Perth, Australia is planned to carry 100% hydrogen using a dedicated distribution system, in addition to hydrogen/natural gas blends.

Australia,[18] California,[19] Japan,[20] France,[21] and Korea[22] have released hydrogen-focused vision reports, roadmaps, or strategies primarily aimed at decarbonization of specific end-use applications, depending on local and regional opportunities. These plans include evaluation of use of existing natural gas pipelines for delivery of hydrogen to reduce the carbon footprint of space heating, cooking, vehicle fueling, and industrial process heating. Demonstrations such as the hydrogen microgrid in Perth Australia, (part of the Clean Energy Innovation Hub) and the H21 North of England proposal[23] in the UK that aims to convert an existing gas distribution network for 100% hydrogen delivery.

14 ARENA Jemena demonstration: https://arena.gov.au/assets/2018/10/power-to-gas-infographic.pdf; https://arena.gov.au/projects/jemena-power-to-gas-demonstration/; https://www.energynetworks.com.au/renewable-gas-australia-2019

15 Clean Energy Innovation Hub: https://www.atco.com/en-au/projects/clean-energy-innovation-hub.html

16 Hydrogen Park of South Australia: http://www.renewablessa.sa.gov.au/topic/hydrogen/hydrogen-projects/hydrogen-park-south-australia

17 GRHYD demonstration project: https://www.engie.com/en/businesses/gas/hydrogen/power-to-gas/the-grhyd-demonstration-project/

18 Australia's National Hydrogen Roadmap: https://www.csiro.au/en/Do-business/Futures/Reports/Hydrogen-Roadmap

19 The California Fuel Cell Revolution: https://cafcp.org/sites/default/files/CAFCR.pdf

20 Japan's New Strategic Roadmap for Hydrogen and Fuel Cells: https://www.meti.go.jp/english/press/2019/0312_002.html

21 France's Hydrogen Deployment Plan for Energy Transition: https://docs.wixstatic.com/ugd/45185a_5674644ba353434392a8d80bf755eb32.pdf

22 Korea's announcement of hydrogen economy roadmap: http://english1.president.go.kr/BriefingSpeeches/Speeches/110

23 H21 North of England: https://www.northerngasnetworks.co.uk/event/h21-launches-national/

CONCLUSION

Safety/risk assessments of hydrogen blending must be conducted on a case-by-case basis due to a large dependence on the characteristics of local/regional gas infrastructure and end-use systems. The UK's Health and Safety Executive (HSE) risk assessment, highlighted here, for approval of the HyDeploy project demonstrated how modern regulatory approval for hydrogen blending in gas networks may be attained. The evidence base built by early demonstration projects will inform the safety case for broader commercial deployment of hydrogen blending.

RELATED EPRI WORK

In addition to the following in-progress initiatives, EPRI continues to engage with strategic collaborators, exploring opportunities for collaborative research assessing hydrogen technology and applications:

- Prospects for Large-Scale Production of Hydrogen by Water Electrolysis[24]
- Stationary Fuel Cells in Europe
- Hydrogen Technology Assessment with integrated energy-economics modeling in US-REGEN
- Valuation of hydrogen technology on the electric grid using production cost modeling, in partnership with the U.S. Department of Energy (DOE)

24 *Program on Technology Innovation: Prospects for Large-Scale Production of Hydrogen by Water Electrolysis*. EPRI, Palo Alto, CA: Feb 2019. 3002014766. https://www.epri.com/#/pages/product/3002014766/

Quick Insights: Hydrogen's Role in Decarbonizing Heat in the United Kingdom. EPRI, Palo Alto, CA: May 2019. 3002016650.

Program on Technology Innovation: Review of the Uniper Energy Storage GmbH Power-To-Gas (P2G) Demonstration Projects. EPRI, Palo Alto, CA: Aug 2017. 3002011519.

Power-To-Gas (P2G): Generating Hydrogen Fuel and Using Natural Gas Infrastructure for Energy Storage. EPRI, Palo Alto, CA: Aug 2014. 3002004285.

CONTACT INFORMATION

Principal Investigator:
Neil Hughes, Sr. Regional Manager, EPRI International, Inc.
nhughes@epri.com, +44 797.970.8360

For inquiries regarding the technical content of this brief or for general inquiries about EPRI's Quick Insight Briefs, please send an email to QuickInsights@epri.com.

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Electric Power Research Institute
3420 Hillview Avenue, Palo Alto, California 94304-1338 • PO Box 10412, Palo Alto, California 94303-0813 USA • 800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com