DOE Hydrogen Program 2022 Annual Merit Review and Peer Evaluation Meeting

Hydrogen Blending into Natural Gas Pipelines

Project ID: H2060
WBS 8.6.4.2

Chris San Marchi (SNL)
Austin Glover (SNL)
Kevin Simmons (PNNL)
Mark Chung (NREL)
Amagad Elgowainy (ANL)

Project Goal: provide high-level assessment of hydrogen blending in distribution gas networks

Vision

Develop general understanding of important variables in hydrogen blending scenarios for distribution gas networks

What	• **Model the economic impact and lifecycle emissions** associated with blending hydrogen into an exemplar natural gas distribution system • Assess **hydrogen-induced degradation** of distribution piping for service with hydrogen blends and assess gaps in **codes and standards**
How	• **Leverage DOE/lab tools** to estimate value proposition of blending using Atlantic Gas and Light Company distribution network as an exemplar • **Evaluate piping materials** in gaseous hydrogen environments using core laboratory capabilities
Why	• **Quantify the value proposition** of hydrogen blending to accelerate early-market hydrogen technology adoption and achieve short-term emissions reduction • **Ensure safety of decarbonized energy distribution infrastructure,** especially materials degradation due to gaseous hydrogen exposure

Overview: H_2 Blending into NG Pipelines CRADA

Timeline

Start: August 2020
End: March 2022

100% complete

Budget

Total project: $800K
- DOE Share: $600K
- Cost Share: $200K

Total DOE funds received to date: $600K

Partners

National Labs

Argonne National Laboratory – Amgad Elgowainy, PI
National Renewable Energy Laboratory - Mark Chung, PI
Pacific Northwest National Laboratory – Kevin Simmons, PI
Sandia National Laboratories – Chris San Marchi, PI

Industry Stakeholder

- Southern Company Services

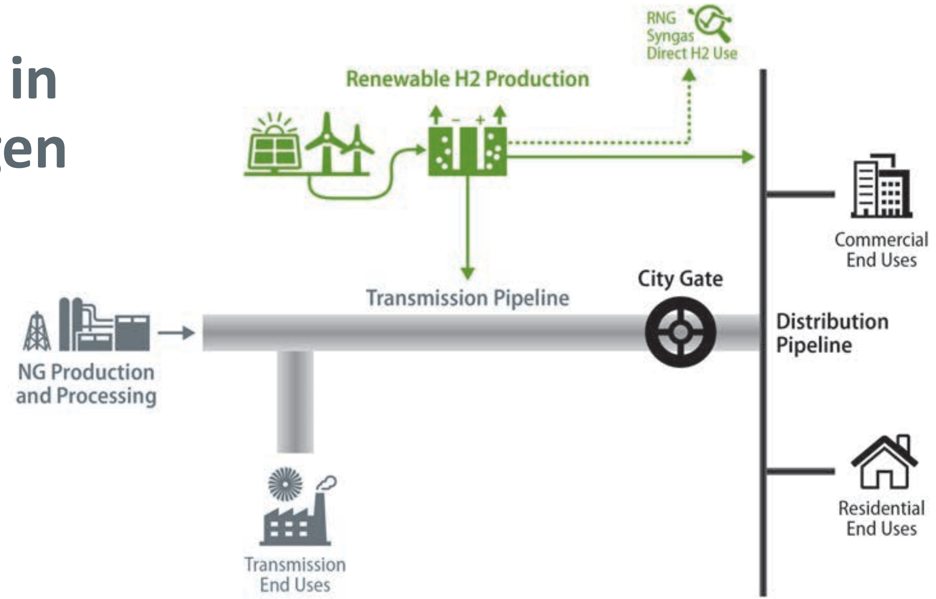
Relevance: Pipeline Blending Benefits

- The U.S. possesses an extensive natural gas pipeline system comprising of **2.44 million miles** of pipe
- Converting networks for hydrogen blending within the U.S. natural gas pipeline system **may offer a low-cost pathway** to distribute green hydrogen
- Blending low-carbon hydrogen into the U.S. natural gas pipeline systems furthers national decarbonization objectives by:
  - Offering a pathway with incremental steps towards cost-efficient pure hydrogen transportation
  - Promoting *early-market access* for hydrogen technology adoption
  - Enable *short-term carbon emissions reductions* with the potential for long-term emissions reductions for hard-to-decarbonize sectors

H_2 Blending into NG Pipelines CRADA

This project addresses 5 topics in the context of blending hydrogen in a distribution gas network

- Codes and Standards
- Technoeconomic Analysis
- Life Cycle Analysis
- Hydrogen compatibility of polyethylene piping
- Hydrogen compatibility of metallic piping



The Atlantic Gas and Light Company (AGLC) natural gas distribution network is used as an exemplar system

Objectives

Task 1 Assess materials of interest, design criteria, operating conditions, and failure modes for natural gas distribution systems (NGDS)

Task 2 Assess the behavior of PE pipe materials in hydrogen environments

Task 3 Develop baseline understanding of hydrogen effects on fatigue and fracture of structural metals in low-pressure NGDS

Task 4 Calculate the levelized cost of hydrogen (LCOH) for production of low-carbon hydrogen to meet demand under various blending concentration scenarios; Estimate the carbon emissions impact of adding hydrogen to AGLC infrastructure

Task 5 Generate a list of relevant codes and standards for hydrogen blending and pure hydrogen service on existing, upgraded, or new pipelines

Approach

Task 1 Conduct fracture mechanics experiments to evaluate the potential for growth of defects in metal piping

Task 2 Characterize PE base materials and develop a framework to assess life of PE pipe using standard practices

Task 3 Survey literature of fatigue/fracture resistance of metals in NGDS
Write white paper identifying technical gaps in material behavior in gaseous hydrogen, including test plans to address these gaps

Task 4 Estimate LCOH and carbon emissions for various permutations of hydrogen blended with NG

Task 5 Write white paper identifying relevant codes and standards that affect the distribution of hydrogen or H_2- NG blends in NGDS

Approach: Milestones

Due Date	Lab	Description	Status
Mar 2021	**SNL**	Codes and standards assessment	**Complete**
Sept 2021	**NREL**	Economic and emissions analysis: Hydrogen service costs	**Draft**
Sept 2021	**ANL**	Economic and emissions analysis: Emissions reductions from hydrogen service	**Draft**
Mar 2022	**SNL**	Fatigue and fracture of structural metals in natural gas distribution systems	**Draft**
Mar 2022	**PNNL**	Hydrogen effects on physical and mechanical properties of polyethylene pipe for natural gas distribution systems	**Complete**

Accomplishment: Codes and Standards

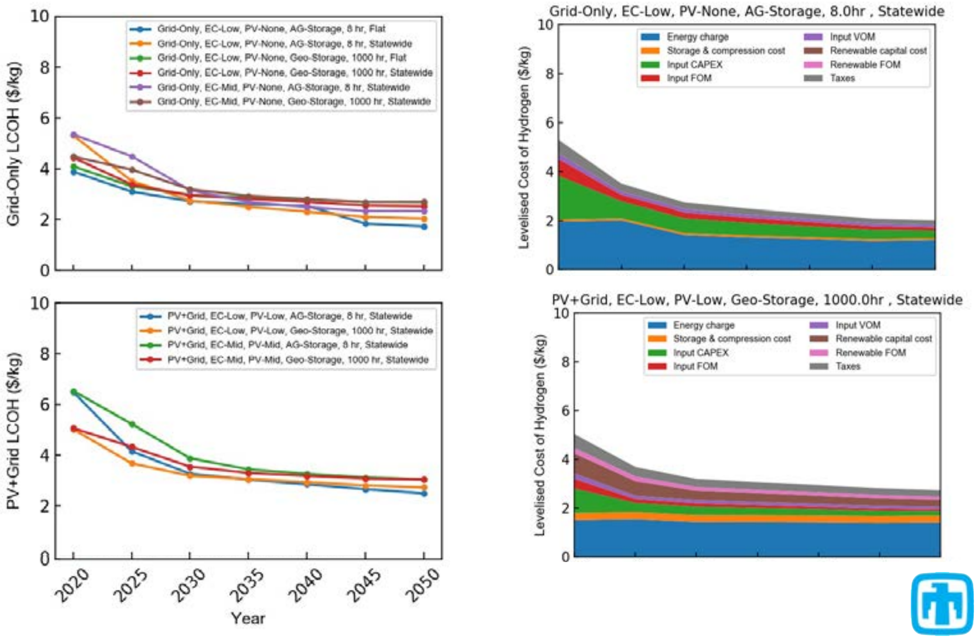
- Codes and standards for hydrogen blending were reviewed and summarized in report no. SAND2021-12479
- The principal conclusions are:
  - ASME B31.12 for pipelines specified hydrogen content >10% H_2
  - NFPA 2 hydrogen technologies (building) code applies to <95% H_2
  - Guidance on pipeline conversion is inadequate
  - NFPA 54 for residential fuel gas does not consider hydrogen or blended hydrogen
  - Gas leak detection is not adequately addressed

Accomplishment: TEA/LCA

<u>Goal</u>: Quantify the levelized cost of hydrogen production for injection into the Atlantic Gas and Light Company (AGLC) natural gas network

For electrolysis using grid electricity and/or photovoltaic (PV)-derived electricity the following conclusions can be drawn:

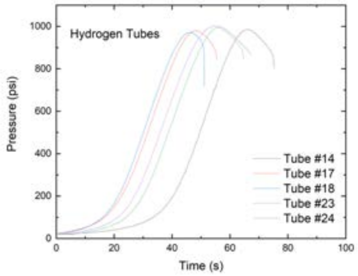
- Grid-Only cases achieve lower LCOH
- Electricity cost is primary driver
- Capacity factor is a strong function of storage duration
- Long-duration geologic storage enable high capacity factors and lower PV curtailment without dramatically increasing LCOH

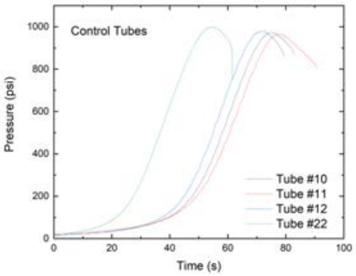


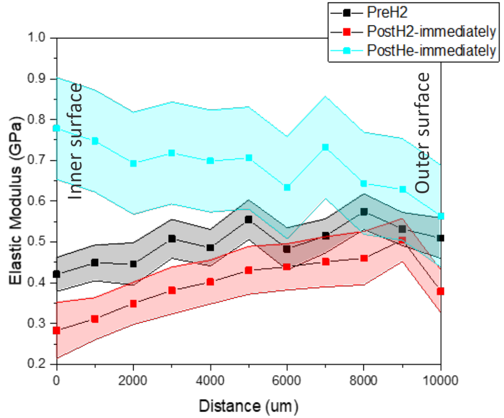
Accomplishment: Polyethylene piping

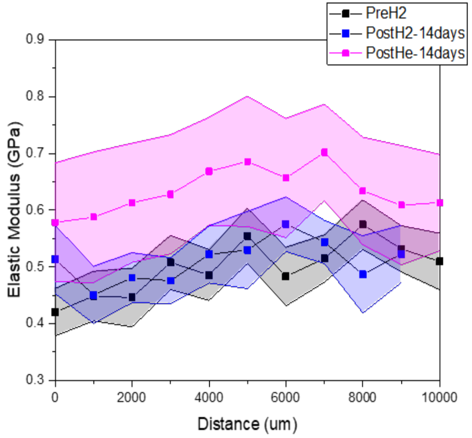
Medium-density polyethylene (MDPE)

Burst testing confirms no significant hydrogen effect on burst pressure or strain around failure









- **Helium exposure (left) resulted in modulus increase that does not return to original value**
- **Subtle hydrogen effects (right) on are not permanent**

Impact: **Subtle changes in elastic properties of polyethylene when exposed to gases are not unique to hydrogen; hydrogen promotes plasticization, whereas helium induces densification**

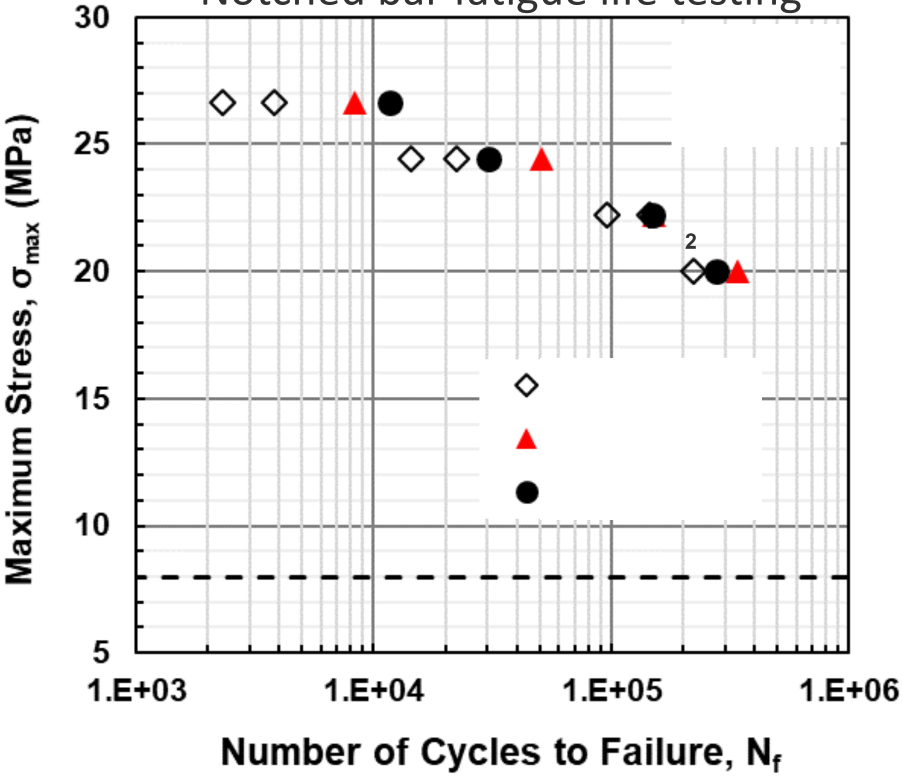
Accomplishment: Polymers R&D

- Fatigue life of MDPE is improved when tested in high-pressure hydrogen compared to in air

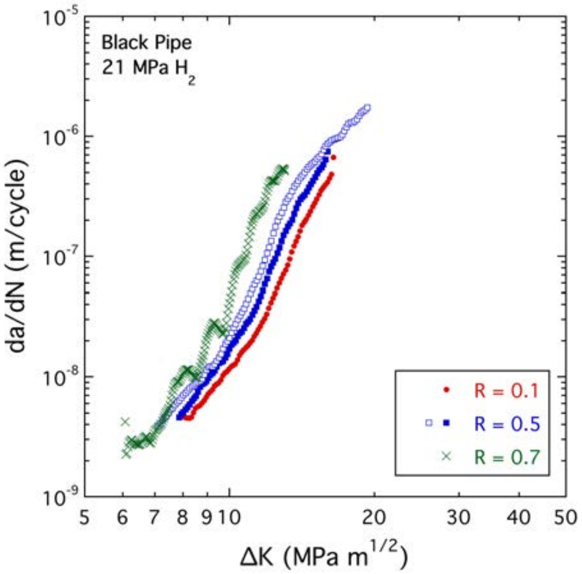
- Fracture resistance in gaseous H_2 is approximately the same as in air

<u>Impact</u>: ***In situ* testing suggests H_2 does not affect basic fatigue and fracture properties**

Notched bar fatigue life testing



Accomplishment: Steel piping



- Black pipe is a common material of construction for natural gas distribution
  - Fatigue and fracture properties of black pipe are degraded by gaseous hydrogen
    - Behavior is similar to line pipe steels used for gas transmission
  - The pressure stresses in distribution systems are exceptionally low, suggesting degraded properties will only be relevant in exceptional cases

Impact: These results combined with structural analysis show distribution piping is not compromised by hydrogen at any blending ratio

Accomplishments and Progress

Response to Previous Year Reviewers' Comments

- This is a project was not been reviewed before at AMR

Collaboration and Coordination

- **U.S. DOE National Laboratories**
  - **ANL**: Life cycle assessment and emissions analysis
  - **NREL**: Techno-economic analysis
  - **PNNL**: Polymeric material testing and analysis
  - **SNL**: Project lead; Metallic material testing and analysis; supporting polymeric material testing
- **Industry stakeholder**
  - **Southern Company Services**: project motivation and guidance on the Atlanta Gas Light Company (AGLC) Natural Gas Distribution Lines (the exemplar for this activity)

Remaining Challenges and Barriers

- **This activity is complete**
- **However, many questions remain about blending scenarios and concepts** (below is a few open questions on structural integrity)
  - Polymers:
    - Tests methods to accelerate testing of the influence of hydrogen on long-term aging of polyethylene remain inadequate
    - Long-term aging of soft seals (gaskets, o-rings) in low-pressure hydrogen is relatively unknown
  - Metals:
    - Whereas pressure stresses in pipes are relatively low and very unlikely to induce failures, stresses in ancillary components can be high and certain materials could be problematic
    - The threat of external loads is difficult to quantify and relatively unknown

Proposed Future Work

- This activity is complete
- Outcomes have been rolled into **HyBlend: Pipeline CRADA (IN035 & IN036)** for continuation in a more general context.

Summary

- Important gaps in existing **codes and standards** were outlined in report no. SAND2021-12479
- **Electricity costs dominate LCOH** (from electrolysis) with long-duration storage being an important cost mitigator
- **Carbon reductions** are nonlinear with blending concentration, only nominal reductions can be achieved at low blending concentration
- **Polyethylene piping** displays transient elastic properties after exposure to gaseous hydrogen; however fatigue life and fracture properties are not degraded in hydrogen
- Fatigue and fracture properties of **steels in distribution piping** are degraded by hydrogen, but the pressure stresses in distribution piping mitigate hydrogen embrittlement concerns from pressure

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC., a wholly owned subsidiary of Honeywell International, Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA-0003525.

This work was authored in part by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308.

Thank You

Chris San Marchi <cwsanma@sandia.gov>

Kevin Simmons <kl.simmons@pnnl.gov>

Mark Chung <Mark.Chung@nrel.gov>

Amagad Elgowainy <aelgowainy@anl.gov>

Technical Backup and Additional Information

Technology Transfer Activities

- **Outcomes are intended to be published in the open scientific literature or as unlimited release laboratory authored reports.**
  – Content is often available through https://osti.gov/
    - Or for NREL reports: https://nrel.gov/publications/
  – Hydrogen-assisted fatigue and fracture data is available through an online materials property database: https://granta-mi.sandia.gov/
  – Additional materials content is available at https://h-mat.org/

Special Recognitions and Awards

- none

Publications and Presentations

1. R. Shrestha, J.A. Ronevich, L. Fring, K. Simmons, N.D. Meeks, Z.E. Lowe, T.J. Harris Jr, C. San Marchi; “Compatibility of medium density polyethylene (MDPE) for distribution of gaseous hydrogen” (PVP2022-84791), ASME 2022 Pressure Vessels and Piping Conference, 17-22 July 2022, Las Vegas NV (partly funded under HyBlend: Pipeline CRADA).
2. A.M. Glover, J.T. Mohr, A.R. Baird, “Codes and standards assessment for hydrogen blends into the natural gas infrastructure”, SAND2021-12479, Sandia National Laboratories, Albuquerque, NM.
3. Evan Reznicek, Kevin Topolski, Mark Chung, Amgad Egowainy, Adarsh Bafana, “Techno-economic and lifecycle analysis of electrolytic hydrogen production for injection into Atlanta Gas Light Company natural gas distribution lines“, draft report, National Renewable Energy Laboratory, Golden CO.
4. Kevin Simmons, Lisa Fring, Wenbin Kuang, Yongsoon Shin, Yelin Ni, Yao Qiao, Chris San Marchi, Joseph A. Ronevich, Rakish Shrestha, “Hydrogen Infrastructure Assessment for Injection of Gaseous Hydrogen in Atlanta Gas Light Company (AGLC) Natural Gas Distribution Lines”, PNNL-32690, Pacific Northwest National Laboratory, Richland WA.
5. Chris San Marchi, Joseph A. Ronevich, Rakish Shrestha, Noah D. Meeks, Zachary E. Lowe, Timothy J. Harris Jr. , “Hydrogen Infrastructure Assessment for Injection of Gaseous Hydrogen in Atlanta Gas Light Company (AGLC) Natural Gas Distribution Lines: Effects of Hydrogen Environments on Fatigue and Fracture Properties of Metals”, draft report, Sandia National Laboratories, Livermore CA.

Contributors

National Renewable Energy Laboratory
- Amgad Elgowaiy(Pi)
- Adarsh Bafana (analyst)

National Renewable Energy Laboratory
- Mark Chung (Pi)
- Chad Hunter (former PI)
- Jeff Mohr (codes and standards)
- Evan Reznicek (analyst)
- Kevin Topolski (postdoc)

Southern Company Services
- Noah Meeks
- Tim Harris
- Zach Lowe

Pacific Northwest National Laboratories
- Kevin Simmons (PI)
- Lisa Fring (polymer scientist)
- Wenbin Kuang (polymer scientist)
- Yongsoon Shin (polymer scientist)
- Yelin Ni (polymer scientist)
- Yao Qiao (polymer scientist)

Sandia National Laboratories
- Chris San Marchi (PI)
- Joe Ronevich (fatigue and fracture)
- Austin Glover (codes and standards)
- Rakish Shrestha (post-doc)
- James McNair (testing)
- Brendan Davis (testing)