EXECUTIVE SUMMARY

MATERIALS COMPATIBILITY OF EXISTING NATURAL GAS INFRASTRUCTURE FOR HYDROGEN, CARBON DIOXIDE, AND AMMONIA

The transition to a low-carbon world will require alternative energy carriers (AECs) and carbon dioxide (CO_2) to be stored and transported using engineering materials from the point of production to the final end use. The need for safe, reliable, and affordable energy has prompted interest in repurposing the existing oil and gas infrastructure for moving and storing AECs and CO_2. In the United States, the oil and gas infrastructure consists of nearly 3 million mi (4.8 million km) of pipelines (and associated pumping, compression, and regulator stations) and over 400 underground storage facilities. The overwhelming majority of these assets were built-for-purpose and installed over several decades. While repurposing may offer the potential for significant cost and time savings, it is critical that detailed assessment of all materials within the system be performed to ensure they are compatible with the fluid being transported.

Materials used in the delivery and storage infrastructure generally include polymers (elastomers and thermoplastics) and metals/alloys. Due to the limitations in acceptable materials for pipeline applications, guidance for metals and alloys provided in the full report primarily focuses on carbon and low alloy steels; however, where applicable other relevant metals and alloys are discussed. Thermoplastic and elastomeric materials used throughout the natural gas infrastructure are generally found in valves, compressor and regulator station components, liners, and piping for distribution systems. When repurposing the infrastructure for new fluid service, it is important to consider not only the materials compatibility of all system components, but also how changes in operational conditions will impact system integrity. Based on a comprehensive review of technical literature, the full report is intended to provide:

- An overview of predominant failure modes and key material properties that affect potential materials compatibility issues.
- Identification of compatible elastomers, thermoplastics, and metals/alloys for delivery and storage infrastructure within the existing NG infrastructure and potential cross-functionality in terms of compatibility with hydrogen, carbon dioxide and ammonia.
- Analysis of the technical information, gaps, and inconsistencies on the subject to narrow down the materials considered suitable/compatible and to advise on testing and qualification following standardized practices, original equipment manufacturer (OEM) recommendations, and high-quality references.
- A source of key reference documents for materials compatibility.

It is important to recognize that while many materials exhibit acceptable short-term compatibility under standardized or simulated laboratory test conditions, long-term in-service performance needs to be established. Key findings from the full report include:

- Polymeric materials are not generally standardized so their properties and performance can vary based on synthesis routes and processing history. To ensure polymers have the requisite materials compatibility for the intended application, it is recommended that they are assessed and qualified using standard test methods and procedures.
- Nitrile rubber (NBR), hydrogenated nitrile butadiene rubber (HNBR), tetrafluoroethylene propylene (TFEP), fluoroelastomer (FKM), and perfluoroelastomer (FFKM) are the most common elastomers used in NG service for sealing and gasket components.

- For pipeline applications in gaseous hydrogen service, NBR/HNBR, EPDM, and FKM are typically specified as sealing materials. For higher pressure applications or cyclic service, rapid gas decompression (RGD)-resistant ethylene propylene diene monomer (EPDM) and FKM should be specified.
- Supercritical CO_2 (sCO_2) is a strong solvent to many elastomers, including FKM and NBR, which are commonly used in natural gas service. However, research suggests that RGD-resistant EPDM and FFKM, and some HNBR seals may be suitable for sCO_2 service.
- EPDM, FFKM and certain HNBRs are suitable for liquid ammonia service. FKM is not recommended.
- Polyethylene (PE) is primarily used in NG distribution piping and liner materials. For gaseous hydrogen service, PE and polyamide (PA) may be suitable for use in low pressure gas distribution pipelines.
- Thermoplastics do not have the requisite strength for transmission pipelines; however, multi-layered thermoplastic composite piping (TCP) systems that rely on a thermoplastic liner for compatibility and fiber reinforced structural layer for pressure containment are promising. For high pressure hydrogen piping applications (up to 2500 psig [17 MPa]) a code case for composite piping with an HDPE liner (code case 200) has been incorporated into the ASME B31 Code for Pressure Piping.
- For dense phase or sCO_2 applications, traditional single-layer thermoplastic pipes lack the structural stability and integrity, but development of TCPs is on-going.
- For ammonia service, PE and epoxies are both suitable materials, suggesting that existing PE distribution pipelines are suitable for ammonia transport.
- Within the oil and gas infrastructure, most of the piping and structural components are constructed of carbon or low alloy steels. Cast, ductile and malleable irons may be used in valve bodies or lower pressure applications, such as distribution piping.
- Prior to transitioning an existing pipeline to hydrogen service, a detailed engineering assessment should be performed to determine the potential impacts of hydrogen on system integrity.
- 300-series stainless steels (especially 316L), copper and copper-based alloys are generally recommended for hydrogen service.
- For compression systems, wholesale replacement will be required for 100% hydrogen service; however, the blend ratio where wholesale replacement becomes necessary is dependent on compressor type.
- Commercial CO_2 pipelines operate at pressures above the design pressure limits of most natural gas pipeline systems. Considering the reduced pressure rating, it may be impractical to repurpose natural gas pipelines for CO_2 transport.
- Dry CO_2 is non-corrosive to carbon and low alloy pipeline steels; however, the presence of moisture can cause significant issues with corrosion.
- Transport of liquid ammonia through pipelines has been performed for many decades and while carbon and low-alloy steels are susceptible to ammonia stress corrosion cracking the cause and mitigation strategies are well known.
- Copper-containing alloys, galvanized steels and cast irons are not recommended ammonia service

The Low-Carbon Resources Initiative

This report was published under the Low-Carbon Resources Initiative (LCRI), a joint effort of EPRI and GTI Energy addressing the need to accelerate development and deployment of low- and zero-carbon energy technologies. The LCRI is targeting advances in the production, distribution, and application of low-carbon energy carriers and the cross-cutting technologies that enable their integration at scale. These energy carriers, which include hydrogen, ammonia, synthetic fuels, and biofuels, are needed to enable affordable pathways to economy-wide decarbonization by mid-century. For more information, visit www.LowCarbonLCRI.com.

Technical Contacts:

Michael Gagliano, Technical Executive, 704.595.2134, mgagliano@epri.com

Vinicio Ynciarte Leiva, Engineer/Scientist V, 972.556.6517, vynciarteLeiva@epri.com

3002027449 October 2023

EPRI
3420 Hillview Avenue, Palo Alto, California 94304-1338
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com