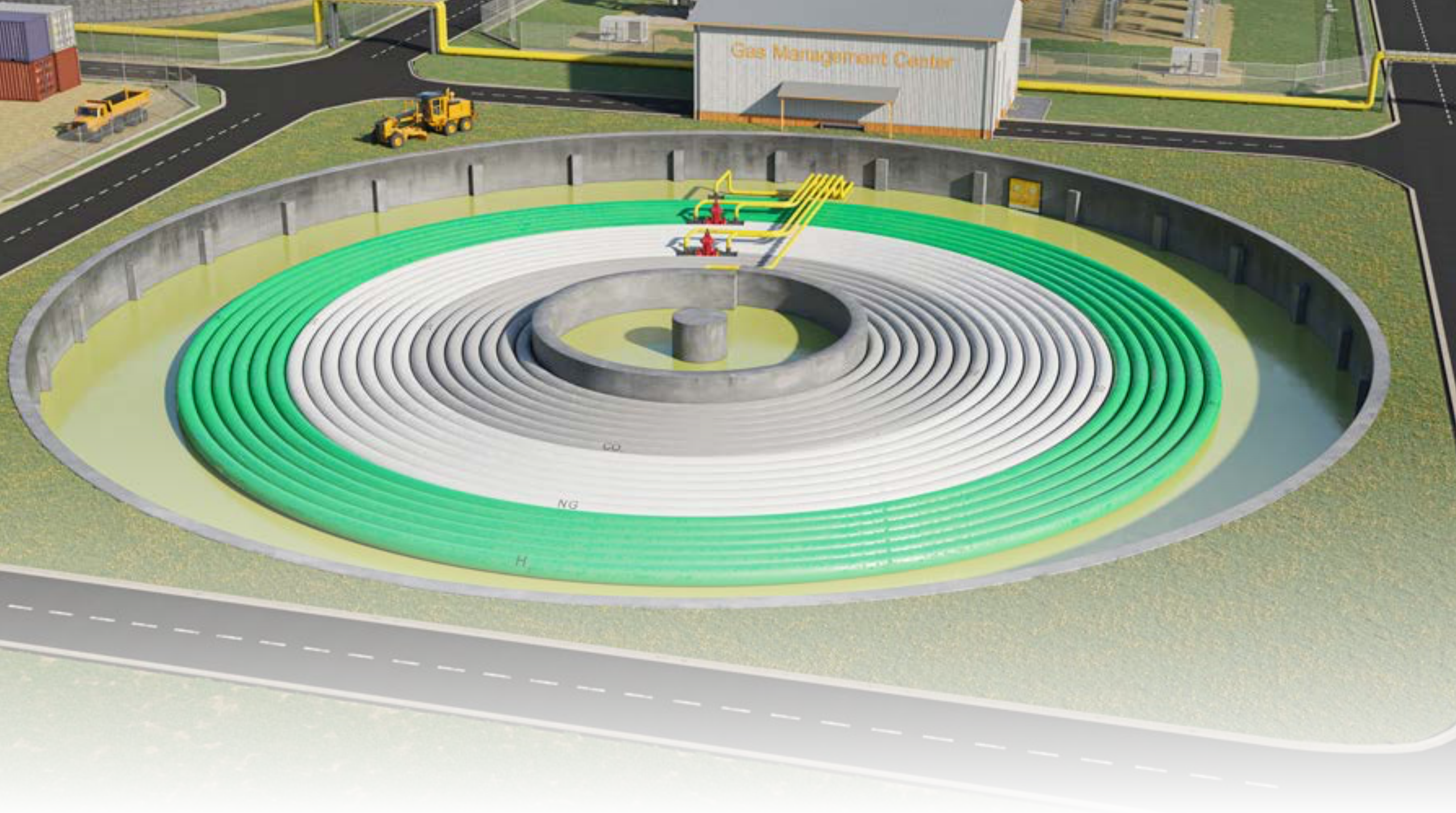


HYDROGEN – MANAGING THE TRANSITION OF PIPELINE ASSETS

Interest in the use of hydrogen as an energy vector has increased significantly in the past few years. Hydrogen is planned to play a significant role in the deep decarbonization of the energy sector — transportation, industrial processes, ammonia production, natural gas supplementation, seasonal energy storage, and other difficult areas to decarbonize lead the end-use applications for hydrogen. The U.S. Department of Energy (DOE) H2@SCALE initiative predicts a serviceable consumption potential of over 100 million metric tons of hydrogen per year in the U.S. if it were to replace existing fossil fuels. There are aggressive initiatives coming out of the U.S. DOE that include $8B U.S. dedicated to hydrogen hubs across the United States and additional tax and carbon credits via the Inflation Reduction Act passed in 2022.

Most of the hydrogen produced and consumed today is in the industrial market with industrial gas companies leading the initiatives. Most of the hydrogen is produced through steam methane reforming of natural gas (SMR) which has some carbon emissions associated with it. The true promise of hydrogen comes in the form of low carbon intensity (CI) processes like green hydrogen production (renewable electricity powering electrolysis), SMR with carbon capture, or other emerging production methods with low carbon intensity (autothermal reforming with CC, biomass, etc.). With the low CI potential, there has been a paradigm shift in the past few years where utilities, transportation companies, and even technology companies are making one hundred billion dollar plus investments in producing and consuming hydrogen for their energy needs.

The momentum in the hydrogen market leads to the need to develop comprehensive production, distribution, and end-use equipment manufacturing and supply chains. Many of the on-going product designs in the hydrogen market simply take a product that was created for the natural gas market and slightly tweak it to fit hydrogen applications — upgrading materials of construction, volumes, etc.

this approach is the customer is often left with a system that isn't optimized for hydrogen use and often has issues with reliability. Early commercialization efforts have resulted in many lessons learned in creating hydrogen specific products from the ground-up, with hydrogen use at the forefront of the design.

Distribution of Hydrogen

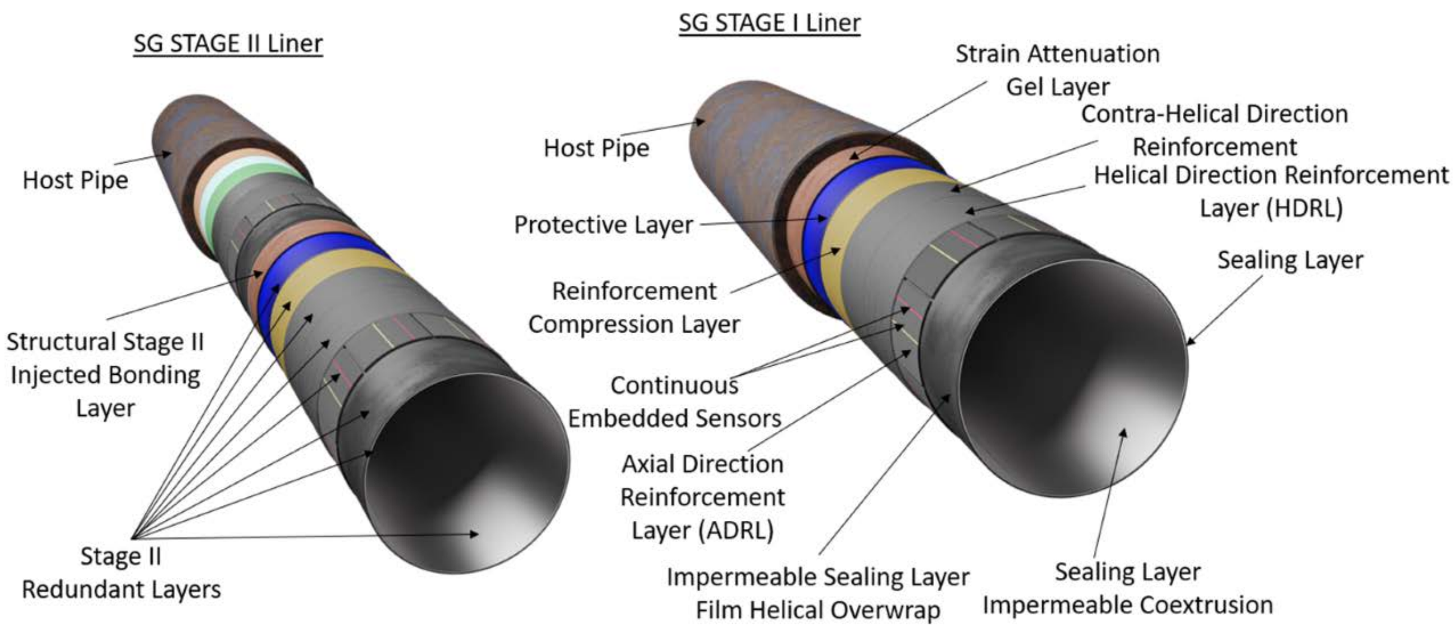
One of the key areas of interest for the hydrogen market is the distribution of hydrogen throughout the U.S. The distribution topic is often met with complacency or brushed off as "easy" when performing project planning for hydrogen initiatives. This complacency is twofold: 1) people can take for granted existing energy infrastructure in the U.S. and how long that took to build out (e.g., vast natural gas pipeline network across the U.S.) and 2) people underestimate the logistics of transporting hydrogen with regards to the value proposition to the distribution company.

Currently, most of the hydrogen is moved over the road by gaseous tube trailers or liquid tankers. Gaseous tube trailers are cost competitive over relatively short distances — typically less than 20 miles. Liquid tankers are used when needing to move the hydrogen across multiple states, however, they come with their own complications as liquid hydrogen needs to be maintained at -253oC. With ambitious growth targets for hydrogen over the next decade, considerations for transitioning the existing energy pipeline infrastructure to safe and resilient hydrogen transmission across the U.S. need to be adapted. There is only about 1,600 miles of hydrogen pipelines in the U.S. today, almost exclusively in the gulf coast region. Most of these pipelines are considered low-pressure, < 1,000 psig, and are used for industrial processes throughout the gulf. The value proposition of installing hydrogen pipeline transitioning technologies across the U.S. will depend on supply and demand and how quickly the hydrogen economy scales; however, there are technical issues that need to be addressed today to ensure the safe deployment of hydrogen ready pipelines soon.

Considerations for Hydrogen Pipeline Asset Management

One of the biggest areas of R&D interest in hydrogen pipelines is in material compatibility. There are many initiatives across the world that explore hydrogen compatibility of materials — in the U.S. the DOE's H-Mat consortium is a great resource to further understand hydrogen material compatibility. In addition, the U.S. DOE has funded hydrogen blending initiatives that look at existing natural gas infrastructure and the use of hydrogen or hydrogen/natural gas blends with existing materials. Some of the main issues with hydrogen compared to natural gas pipelines include hydrogen embrittlement, hydrogen permeation, hydrogen reducing the strength of the pipeline, and even the molecule size of hydrogen which may make it more prone to leaking.

Equally, the capability for owners and operators to secure the required right of way, local and federal permitting and regulatory approval for new steel or composite open trench pipeline installations is limited at best. This regulatory barrier is to a great extent based on public perceptions of catastrophic



environmental and or human tragedy events from pipeline failures in the past. These perceptions are exacerbated by the fact that hydrogen is a new and to a great extent a misunderstood energy source, resulting in both warranted and unwarranted fears about the environment and public safety in the event of a pipeline leak. The regulatory and social incompatibility with installing new hydrogen pipelines only bolsters the need for new, resilient, and safe liner technologies to transition existing energy pipeline infrastructure for hydrogen transmission and distribution.

Hydrogen has a low volumetric energy density when compared to something like methane (main component of natural gas) — depending on pressure and temperature conditions methane would be 8x — 10x the volumetric density of hydrogen. This leads to a need for higher pressures when exploring hydrogen applications and the current steel pipeline infrastructure is not rated for this increased compression. In addition to the higher pressures, pipeline systems may need to flow at higher flow rates to accommodate the differential in energy content that needs to be delivered to end-use equipment. Innovative, ultra-high pressure transitioning liners that are purposely built for hydrogen applications are a necessity to the future success of the hydrogen market.

A major goal in the asset management of hydrogen capable pipelines will be leak detection and localization. Leak detection for all types of pipelines has come under scrutiny in recent years. There has been a significant push from regulatory bodies to eliminate hazardous leaks and minimize releases from pipelines and pipeline facilities — the latest major requirements coming from the PIPES Act of 2020. Hydrogen won't be exempt from these requirements and, complicating things further, hydrogen is much more difficult to detect than something like natural gas. There is a need for unique ways to monitor the health of existing and future pipelines, especially for hydrogen applications, in any asset management plan. Companies are exploring leak detection monitoring and drone technologies that could fly pipelines as part of their operations plans. One of the more promising technologies is an innervated tubular composite liner system with integrated fiber optics that are coupled with AI/ML fusion interrogators to actively monitor the integrity of the composite liner, detect and localize leaks within a few inches, and provide significant remote monitoring and reassurances to pipeline operators.

Although there are some lower pressure hydrogen pipelines already in operation, the need for higher pressure and higher flow, liner modified pipelines in the future will lead to special regulatory considerations when commercializing products. Fortunately, the Pipeline and Hazardous Materials Safety Administration (PHMSA) has an entire office dedicated to new technologies and special waivers. The process for both a new technology and special waivers are relatively the same, a company needs to lay out what exemptions they need from applicable regulations and test procedures, typically 49 CFR Part 192 for hydrogen pipelines, and submit those to PHMSA for review and approval. New technology considerations will have a higher level of scrutiny but will lead to special waivers for future installations. With hydrogen still being in the "emerging" phase, companies should budget plenty of time to interface with PHMSA on these efforts as they can be considerable.

Final Thoughts

The hydrogen economy has a significant amount of hype behind it and in a lot of regards, appears to be moving full steam ahead based on the current enormous global investment in hydrogen technologies. Today's distribution methods through tube trailers or liquid tankers won't hold up with the volumes needed to make hydrogen a reality — pipeline transition technologies need to be developed. Key areas to consider when taking on a hydrogen pipeline asset development include material compatibility, pressure rating, and flow rate capability. Designing pipeline systems for leak detection is a major (regulatory) advantage on projects and a monumental advantage to proper asset management. Engaging PHMSA early and often will be a necessity for any hydrogen pipeline transitioning project.

ABOUT THE AUTHORS

Michael Peters has been working in hydrogen systems R&D and commercialization for over a decade, specializing in renewable electrolysis and hydrogen infrastructure. He has worked on projects from production to end-use and everything in-between. He joined EnServ in January of 2022, previously he was at the National Renewable Energy Laboratory based out of Golden, Colorado. During his time at NREL, he led many multi-million-dollar R&D projects, including the $15M hydrogen blending CRADA project from DOE's HyBlend initiative. Mike joined EnServ as the Lead Hydrogen Consultant and Business Development Manager — looking to grow EnServ's portfolio in conventional and renewable fuels.

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