HYDROGEN

De-risking hydrogen pipelines

Decarbonising gas infrastructure will lead to greater use of hydrogen in the drive to net zero. *Neil Gallon*, Principal Engineer, Rosen, explains the challenges.

The global energy transition faces many challenges to ensure a sustainable, reliable and affordable energy supply – and gas will continue to play an important role. However, looking forward, decarbonising existing gas infrastructure will lead to greater utilisation of greener fuels, such as hydrogen.

The potential of hydrogen has been recognised globally, with initiatives such as the 'European Hydrogen Backbone' – which envisages some 23,000 km of hydrogen pipeline within nine European countries by 2040, some 75% of which will be converted from natural gas and 25% will be newbuild (see *Petroleum Review*, September 2020, p5).

There are two major challenges associated with the transition to hydrogen – the first is how to generate the hydrogen, and the second is whether the existing pipeline infrastructure can cope with the change in duty from natural gas to hydrogen. If not, what needs to be done to convert existing, often aged pipelines?

There are several options for the generation of hydrogen, ranging from 'green' hydrogen generated entirely by renewable energy sources to 'grey' hydrogen, which uses natural gas as the primary energy source. Interestingly, 'blue' hydrogen – where natural gas is used as a source, together with carbon capture and storage (CCS) to minimise greenhouse gas (GHG) emissions, is increasingly considered a viable solution. There are many issues to resolve in terms of hydrogen generation – whatever the 'colour'. Nevertheless, regardless of the source of the hydrogen, the challenges associated with transport remain the same.

Pipeline conversion

The challenges associated with converting an existing natural gas pipeline infrastructure can be summarised in two simple questions for pipeline operators:

- Can existing natural gas pipelines be converted to transport hydrogen?
- How can the integrity of a hydrogen pipeline be managed?

As with so many simple questions, there are no simple answers. The effects of hydrogen are still being extensively researched. Pipeline inspection expert Rosen, for example, is currently engaged in European Pipeline Research Group (EPRG) and Pipeline Research Council International (PRCI) activities and has joined various partners in the Hyready joint industry project (JIP), which aims to provide guidelines for the transition to hydrogen. In parallel with this work, Rosen is developing a 'Hydrogen Integrity Framework' aimed at providing a systematic approach for the safe and economic conversion of existing pipelines to hydrogen (see later in this article).

History of hydrogen

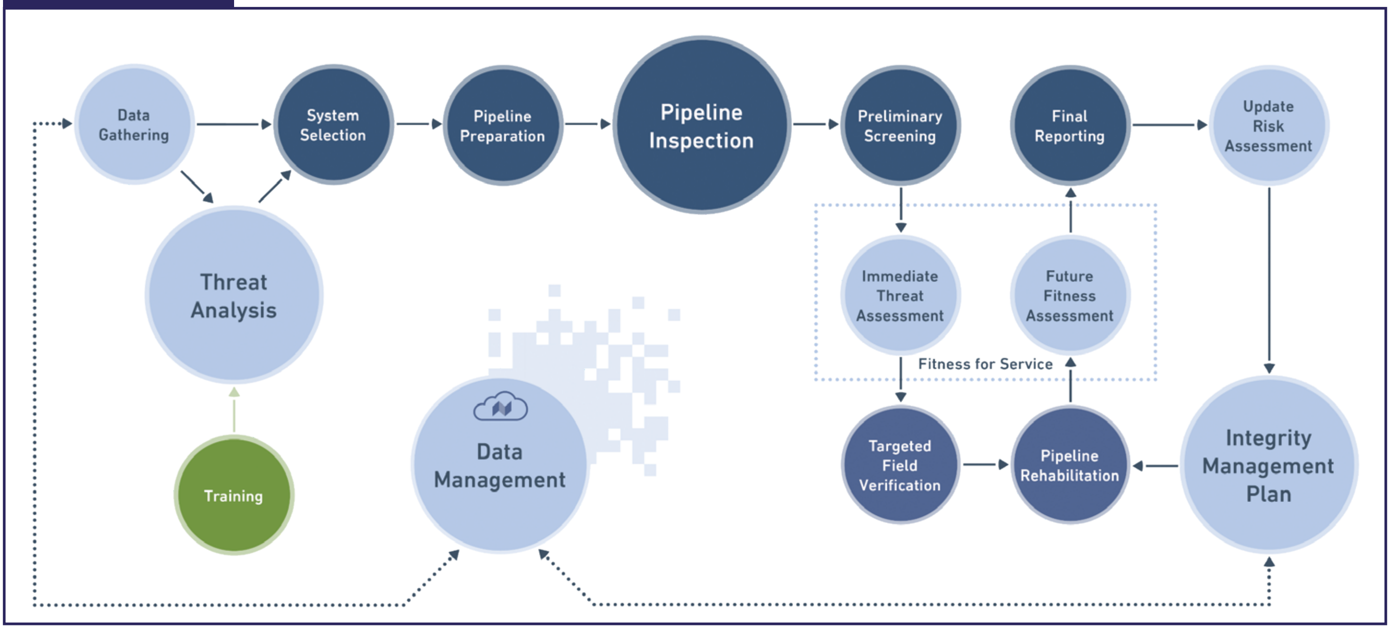
It is often thought that hydrogen is 'new' and that the concept of using hydrogen as an energy source and transporting hydrogen in pipelines are 'novel'. However, while the conversion of the natural gas infrastructure to hydrogen is new, hydrogen is anything but.

There are currently over 4,500 km of hydrogen pipelines in operation throughout the world, almost all made out of carbon steel, which transport gaseous hydrogen. For the most part, these pipelines were designed and built for hydrogen transport, with only one exception. At a broader level, hydrogen has been industrially manufactured, stored and transported using carbon steel vessels, pipework and storage bottles for over 100 years. For many years, 'town gas', which contained roughly 50% hydrogen, was widely used for domestic heating and lighting in the UK prior to the introduction of natural gas. Indeed, some of today's UK urban gas distribution infrastructure was originally designed for town gas.

While the replacement of natural gas with hydrogen and

Figure 1: A systematic approach for de-risking the introduction of hydrogen in existing natural gas pipelines

Source: Rosen



the introduction of hydrogen into modern natural gas transmission and distribution networks introduces challenges, there is nothing 'new' or inherently 'impossible' about the concept of hydrogen pipelines.

Hydrogen challenges

The integrity challenges and damage mechanisms involved in hydrogen transport can be split into two main areas. Hydrogen can directly cause defects (eg cracking) or can act in a more insidious manner affecting the mechanical properties of the material. Both damage mechanisms result from the dissociation of gaseous hydrogen at the internal surface of the pipeline via Sieverts' Law, leading to the adsorption of hydrogen into the pipe wall.

The amount of dissociation and adsorption will largely depend on hydrogen's partial pressure and temperature, while the susceptibility to damage will depend on the amount of absorbed hydrogen, the material microstructure and the stress present.

Existing hydrogen codes control these factors and are generally more restrictive than their natural gas equivalents in terms of allowable pipeline materials (often restricting to grade X52 or below) and operate at lower pressures to reduce the stresses present. These restrictions can be difficult to follow if converting an existing pipeline. In this case, the construction materials are already present, and the existing operating pressure can be higher than allowable under hydrogen-specific codes.

It is, therefore, necessary to understand the challenges and damage mechanisms, and the rationale behind hydrogen-specific restrictions, to identify how to convert pipelines. It is generally understood that direct hydrogen cracking is unlikely, as there is simply not enough hydrogen present. That said, the effects on mechanical properties can be significant.

The most important mechanical properties of line pipe steel are the strength (yield strength/Rt0.5 and ultimate tensile strength/UTS), ductility, fracture toughness and resistance to fatigue cracking. The effect of hydrogen on these properties can be summarised as shown in **Table 1**.

The magnitude of these effects and their implications for pipeline operation, will depend on various factors. Some of these factors will be operational (eg the applied stress). However, some will be microstructure dependent. When converting existing pipelines, which can often be 40 or 50 years old, understanding the microstructures involved (both parent and weld) is both challenging and critically important.

The introduction of hydrogen, while undoubtedly an integrity challenge, is one that can and should be managed within an integrity framework. As with all pipeline anomaly management activities, the first step should be focused on understanding the pipeline; then the damage mechanism(s), their morphologies and the associated susceptibility of the pipeline system to them should be thoroughly classified.

Only then can effective inspection and monitoring regimes be specified to target the threat(s) accurately. While in-line inspection of hydrogen pipelines is challenging, with hydrogen ingress into the tool sensors' electronics being an elevated risk, it is possible to successfully inspect hydrogen pipelines.

Hydrogen integrity management

Rosen believes that the best approach to addressing the transition to hydrogen is in the form of a Hydrogen Integrity Framework. This approach has been proven in related fields – in the company's Crack Management Framework, for example – and in addressing related threats such as sour gas or CO_2. The approach is based on extensive research that has already been completed on issues such as material susceptibility to hydrogen-induced embrittlement or accelerated fatigue cracking, and technologies that are available to map microstructures, material properties, geometry and deformation features where stress levels are elevated, and to detect features that may be the starting points for fatigue cracks.(See **Figure 1**.)

Current conversion feasibility studies and initiatives are primarily focused on identifying threats, material compatibility, code compliance or code amendment, and operational compatibility. However, a holistic approach adds more value – integrity management is an on-going process that needs constant attention and management.

Mechanical property	Effect of hydrogen compared to natural gas
Strength (yield or ultimate tensile strength)	Minimal effect
Ductility	Significant decrease
Fracture toughness	Significant decrease
Fatigue crack growth rate	Significant increase

Table 1: Mechanical properties of pipelines carrying hydrogen versus natural gas

A robust knowledge of material properties forms the basis of any 'fitness for hydrogen' assessment. In recent years, the Rosen Group has introduced a holistic approach to pipeline material verification, incorporating review and alignment of existing records, in-line inspection (ILI) data, in-situ field examinations, material testing and industry expertise in order to establish a complete and thorough knowledge of pipeline material properties.

At the core of this service are the company's RoMat technologies and the Pipeline DNA process, which provides a comprehensive view of the pipeline makeup. The process combines multiple ILI datasets, such as magnetic flux leakage (MFL), geometry, mapping, material properties and other pertinent information to establish 'populations' of pipe within a pipeline. Traditionally, ILI has not been able to provide strength data, but with the addition of Rosen's pipe grade sensor (PGS) technology, a strength grade can be assigned to each pipe population.

For pipeline systems that already contain hydrogen, Rosen has tools tested and approved up to 100% hydrogen and 100 bar at ambient temperature, using a special tool set-up for sealing, material of discs and cups, and hydrogen-proofed electronic components, alloys and magnets.

Looking ahead

Although the use and transport of hydrogen has been around for many decades, there are some specific areas and integrity challenges involved in transitioning pipelines from natural gas to hydrogen that will require further research. This might lead to changes or additions to current integrity management and operating practices that are needed to monitor and mitigate potential new threats.

A holistic approach, like the Hydrogen Integrity Framework, involves identification and quantification of the threats, together with appropriate mitigation and management, and will enable the safe, economic and successful introduction of hydrogen into the natural gas network. ●