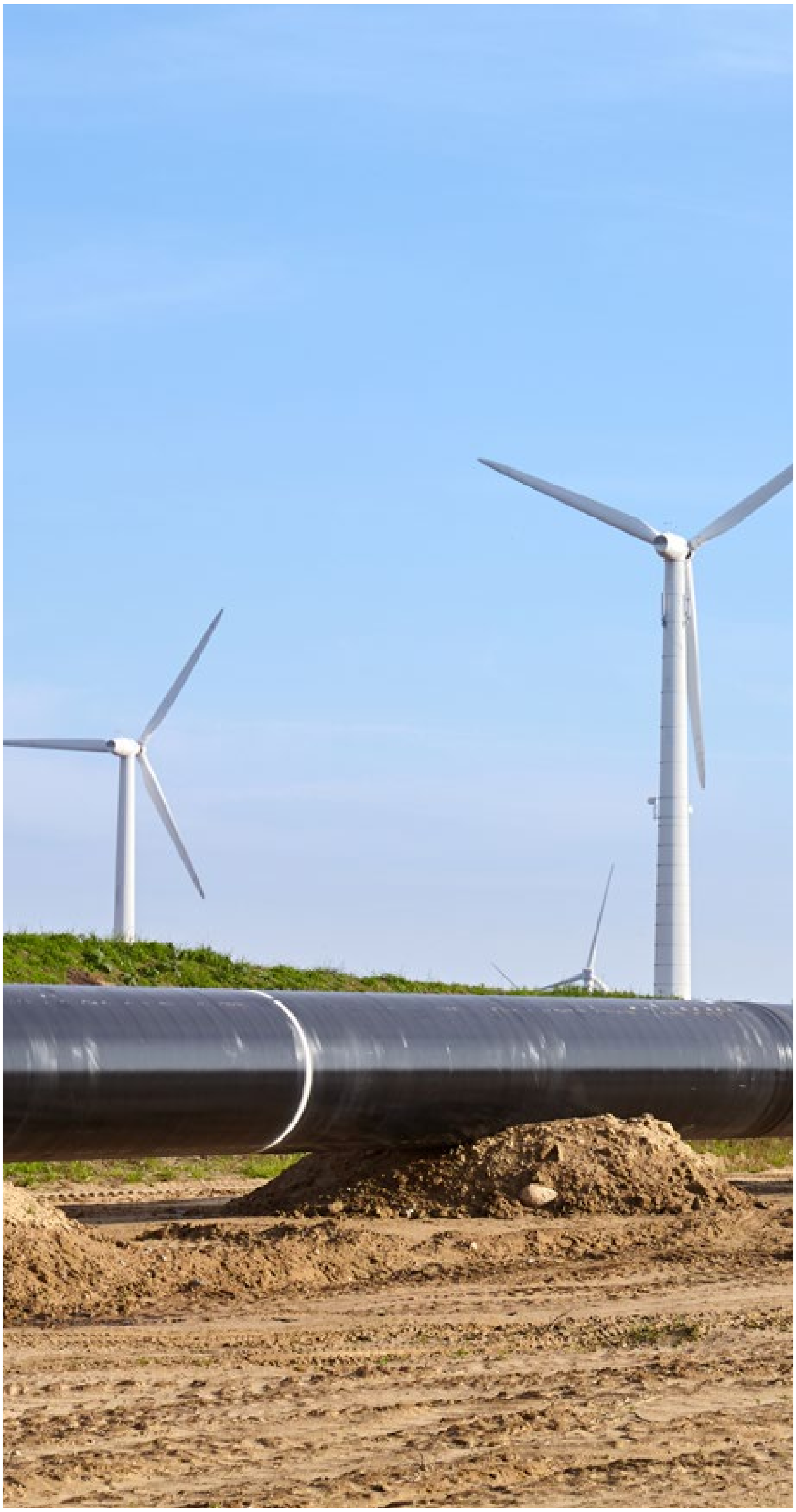
2/2024

Pipeline Technology Journal



Future Fuels & CO_2

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e-ISSN 2196-4300 / p-ISSN 2751-1189

The Pipeline Industry in a Changing Energy Landscape

Marion Erdelen-Peppler
President
European Pipeline Research Group - EPRG

Welcome to the 2nd issue of the Pipeline Technology Journal in 2024 which is addressing aspects of the climate emergency and the role the pipeline industry can play. As an integral part of the advancing global energy transition, it is expected to supply cleaner, more sustainable yet affordable energy in the near future. An emphasis on decarbonizing the existing gas infrastructure will lead to greater penetration of greener fuels, ultimately produced from renewable energy. The pipeline industry has safely managed to transport these emerging fuels for decades. While this does constitute a solid foundation, there is a common understanding that emerging fuels pipelines of the future, transporting energy rather than feedstock, will be operated differently from their present-day equivalents, thus needing dedicated assessment. Existing gaps have been carefully identified and are addressed by ongoing research.

As resources are limited, it is more important than ever to bundle the existing capacity to achieve reliable results in the shortest possible time. Collaboration in research groups can be an effective measure to achieve this goal. The European Pipeline Research Group EPRG is working on pipeline safety for more than 40 years. It was founded to address the global challenges related to the then emerging gas pipeline industry – an analogy to the situation the industry is in today. As in the days of the foundation of EPRG, it faces new challenges which need to be mastered globally and at a speed that necessitates collaboration on a wider scale. EPRG has responded to this situation by building a network of companies and international partnerships. The value of the group is reflected by the growth in membership it has experienced in the last years, clearly also driven by the focus it gives emerging fuels research. The current programme on hydrogen and CO_2 have been tailored to the needs of the wider industry, to address and close the most important gaps. This will contribute to ensure economical operation of the new pipelines at the highest levels of safety.

Sincerely,

Marion Erdelen-Peppler
President
European Pipeline Research Group - EPRG

This Issue's

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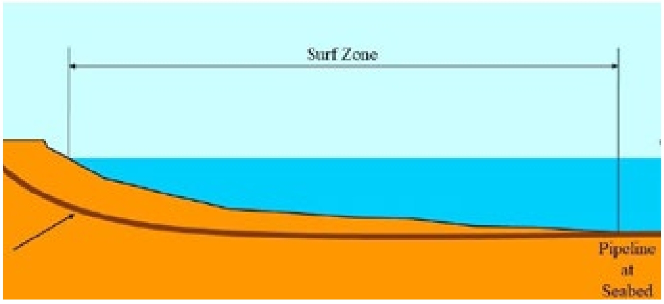

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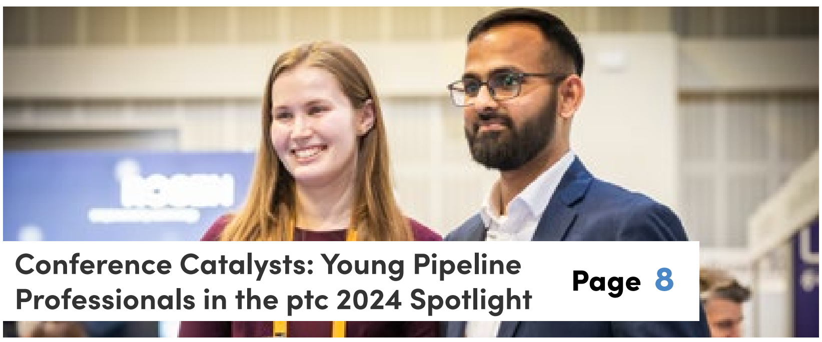

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30177 Hannover, Germany
Tel: +49 511 90992-10
URL: www.eitep.de

ISSN
e-ISSN: 2196-4300
p-ISSN: 2751-1189

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Conference Catalysts: Young Pipeline Professionals in the ptc 2024 Spotlight

In the dynamic and ever-evolving world of pipeline engineering, young professionals play a crucial role in shaping the industry's future. One of the effective ways to engage the young professionals in the pipeline industry is the pipeline conferences that serve as essential platforms for young professionals to learn, connect, and grow. By actively participating in these events, young pipeline professionals can propel their careers forward, gain valuable insights, and contribute to the industry's innovation. With this mind, the pipeline technology conference (ptc) established the Young Pipeliners Engagement Committee (YPEC) in 2022. The committee did a phenomenal job in engaging young pipeline professionals at the ptc 2023 and is working hard to creating more engagement in the ptc 2024.

The YPEC is made up of a diverse group of young pipeline professionals from around the world who are passionate about the future of the pipeline industry. With four founding members, Dr. Kshama Roy, Mr. Danny Molyneaux, Ms. Marguerite Forde and Mr. Anish Goswami, the committee is now comprised of total six members with Ms. Lauren Jackson and Dr. Sameera Naib joining the team in 2024. The committee's primary mission is to engage, inspire, and empower young pipeline professionals to succeed and drive innovation in the industry. Members of the YPEC meet regularly online to share ideas and collaborate on initiatives aimed at promoting young talent at the ptc 2024.

Read the full article here:
https://www.pipeline-journal.net/news/conference-catalysts-young-pipeline-professionals-ptc-2024-spotlight

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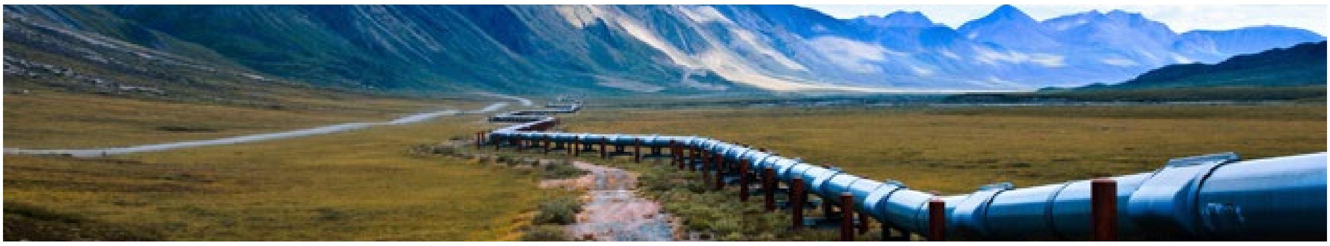

Crucial Challenges in the Design of CO_2 Pipeline Clusters

S. STOKES, C. PEACE, D. CAMPBELL, Y. TKACH > WOOD PLC

Abstract

Carbon capture and storage (CCS) plays a critical role in meeting global net-zero targets. Pipeline clusters are under development to transport carbon dioxide (CO_2) from disparate emitters to a common injection site. Design requirements vary depending on system configuration and transport phase (gas versus dense). Examples are:

- Diverse industries result in varying impurities in the CO_2 and the mechanical pipeline design must consider the impact on fluid behaviour. Associated design challenges are highlighted in the paper.
- Appropriate pipeline material selection is critical, including adequate control of running ductile fracture. The paper discusses limitations with the current industry approach associated with Charpy V-notch toughness, notably for legacy pipelines repurposed for CO_2.
- Technical safety requirements are based on code but also industry best practice considering dispersion modelling. The paper discusses the influence that CO_2 release behaviour has on the pipeline network design.
- The paper recommends careful planning for early operations. Pre-commissioning seeks to lower the pipeline water content prior to CO_2 service. Commissioning must consider integrity assurance during first introduction of pressurised CO_2.

Wood's CO_2 pipelines, flow assurance and materials team discuss CO_2 transportation challenges, design approaches and thought leadership they are undertaking along with the wider industry.

1. Introduction

The global CCS market is experiencing exponential growth buoyed by government incentives and carbon pricing schemes deployed to align with net-zero targets. Planned CO_2 capture capacity has increased from approximately 40mtpa in 2020 to a forecast value of approximately 420mtpa in 2030 (Figure 1). This momentum in capacity growth is accompanied by a significant diversification in CO_2 source. Natural gas processing constituted >60% of captured CO_2 in 2020, however this is forecast to reduce to <20% in 2030. CO_2 derived from power generation and ammonia/hydrogen sources are in fact dominant in the 2030 forecast.

There is, therefore, growing recognition that deploying CCS to meet decarbonisation goals hinges on the timely rollout of CO_2 infrastructure which can manage a diversified source of CO_2. A multi-user CCS cluster or hub configuration business model is emerging to enable decarbonisation of remote and smaller-scale hard-to-abate industry. An industrial cluster offers economies of scale to emitters who can send emissions (CO_2) to common transport and injection infrastructure through an entry tariff.

A key challenge in developing CCS clusters is the design of the common pipeline. There is a misconception that capture and storage costs dominate CCS capital expenditure (CAPEX). In fact, for a CCS cluster project (such as Summit's North Dakota CCS scheme, USA), the transport component (onshore pipeline in the case of Summit), may dominate the project costs (Figure 2). The CO_2 pipeline for a CCS cluster project is a complex and costly element requiring specialist engineering. There are numerous examples of front-end project phase recycle and/or cost growth due to a lack of appreciation of the transport technical risks. Common factors in mitigating CCS cluster pipeline techno-economic risks are:

- A detailed understanding of the impact of impurities from the diverse range of industries in the commingled CO_2 stream.
- Appropriate material selection that accounts for additional toughness requirements for CO_2 service.
- Acknowledging CO_2 is not hydrocarbon and will behave very differently on release and when dispersing.
- Accounting for CO_2 phase behaviour and physical properties early in the project for key operations such as commissioning and first fill.

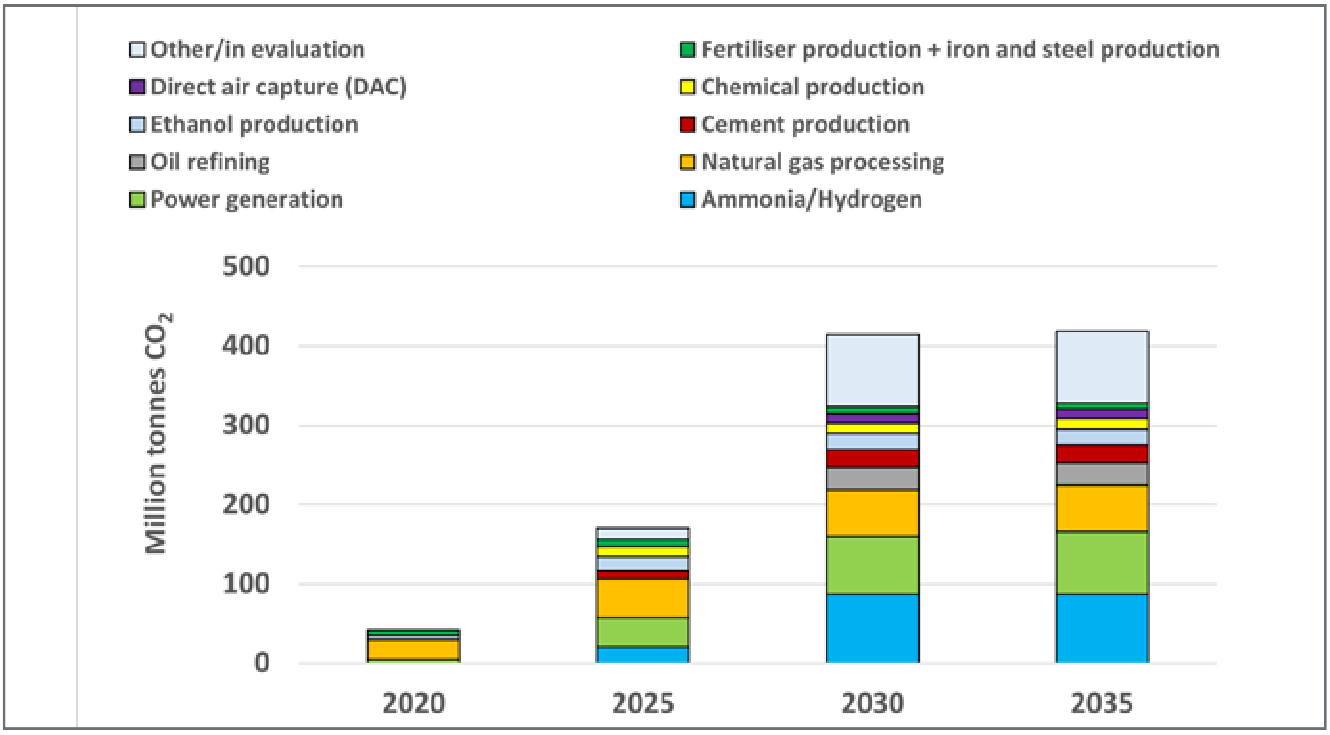

Figure 1: Global Capture Capacity by Point Source, Historical and Announced (Cumulative) - Ref data sourced from BloombergNEF[1]

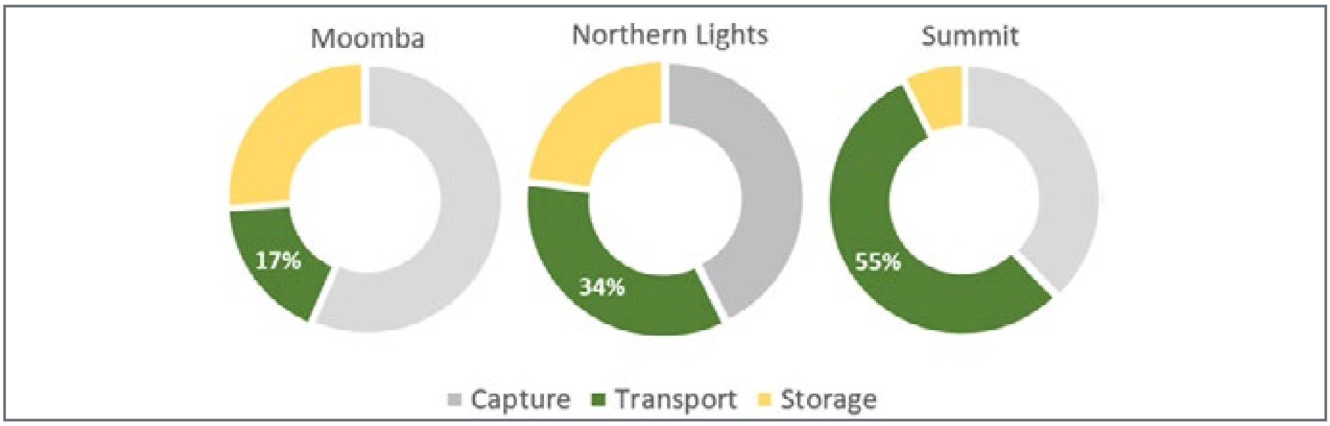

Figure 2: CCS Value Chain Cost Breakdown - Ref data sourced from Wood Mackenzie Lens CCUS Valuations[2]

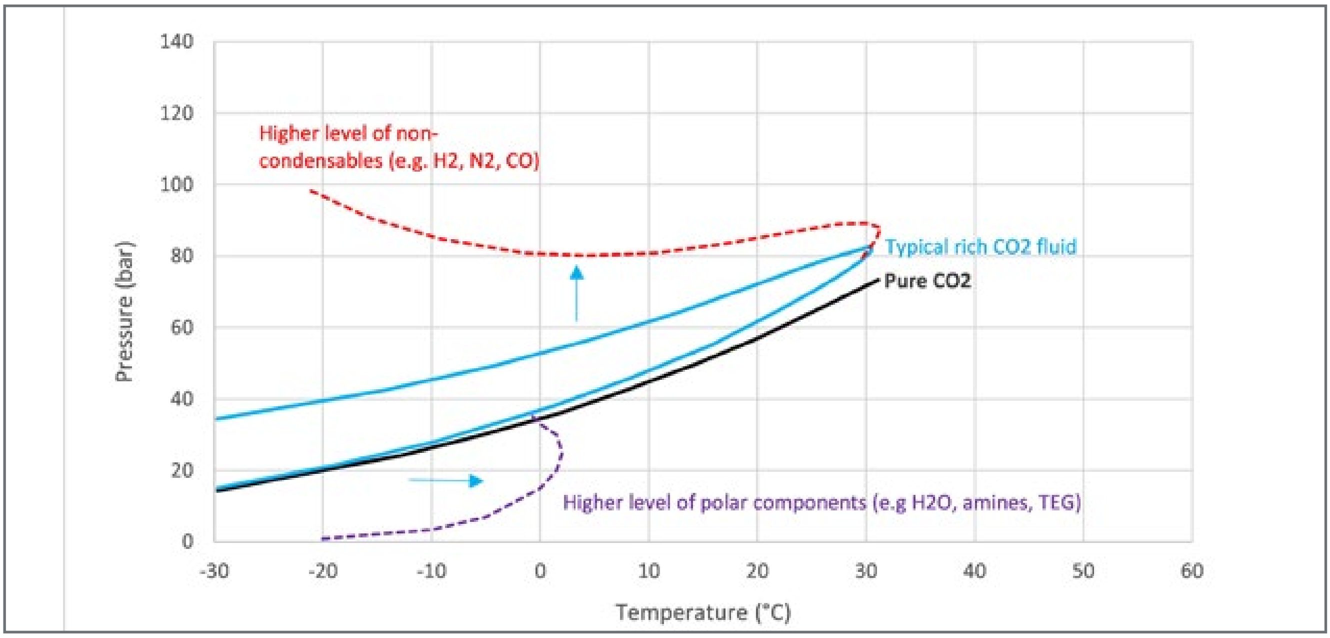

Figure 3: Impurity impact on the CO_2-rich Fluid Phase Envelope

2. It is not Pure CO_2

Depending on the industry type and capture process, each emitter feeds a cocktail of impurities to the CO_2 pipeline, the concentration of which changes with rate and over time. Non-condensable impurities such as hydrogen, nitrogen, carbon monoxide, methane, and argon increase the bubble point of the fluid, whereas heavier components like pentane, hexane, methanol and ethanol all decrease the dew point. Polar components like water, amines and glycols result in a separate aqueous phase due to low solubility in the bulk CO_2-rich phase (Figure 3).

The presence of impurities and/or trace components within the CO_2 can cause a significant change to the phase envelope and behaviour of the stream. This in turn impacts the pressure window within which the dense or gaseous phase pipeline can operate, as well as the fluid density, the pipeline capacity and compression power requirements. The composition and impurities of the CO_2 can also cause significant risk to the pipeline infrastructure and design life. The impurity levels also impact the reservoir storage site capacity and geochemical response.

There are numerous aspects of CCS cluster pipeline design which require a thorough understanding of the fluid impurity levels and hence behaviour. The following examples highlight the need for close interface between the flow assurance, pipeline and materials engineering disciplines.

- Example 1 – pipeline fracture assessment

The fracture control of pipelines transporting dense phase CO_2 depends on the pipeline steel capability to adequately resist both brittle and ductile failure mechanisms. This is discussed further in Section 4. Simply put, if a failure occurs, we want the fracture to arrest within a short distance of the initiation. The arrest pressure (pressure below which a propagating ductile fracture cannot be sustained) must be greater than the saturation pressure (pressure at which the fluid crosses the two-phase boundary). The saturation pressure (Psat in Figure 4) is a direct function of the impurities concentration, namely non-condensables such as methane and hydrogen. A 95mol% CO_2 fluid with 5mol% inerts will require tougher pipe than a 99mol% CO_2 pipeline (Figure 4). A detailed understanding of the CO_2 source, capture process and fluid conditioning is essential to avoid either an under-designed (risk penalty) or over-designed (CAPEX penalty) pipeline.

- Example 2 – hydrogen embrittlement

The concentration of hydrogen can be limited in a dense phase CO_2 pipeline. However, during certain operations, i.e. shutdown, there may be a risk of crossing the bubble point line and gaseous CO_2 break-out. In this scenario, the concentration of hydrogen in the first bubbles of gas forming within a system can be far greater than the bulk concentration. Gaseous hydrogen can enter the metal matrix and the accumulation of atomic or molecular hydrogen at lattice defects can result in embrittlement and subsequent reduction of materials fracture toughness[3].

- Example 3 – acid phase formation

Recent studies have reported that noticeable, and potentially severe, corrosion occurs at water-undersaturated conditions in dense phase CO_2 with the presence of impurities, such as oxygen, hydrogen sulphide, sulphur dioxide, nitrogen dioxide, etc. due to synergistic interactions between chemical species that can form nitric acid (HNO_3) and sulphuric acid (H_2SO_4). Even low concentrations of sulphur oxides and nitrogen oxides in the presence of sufficient oxygen can form corrosive acids, hence tight control of impurities tolerance levels is necessary. Reference is made to the recently revised Northern Lights specification[4] which has reduced the nitrogen oxides tolerance to ≤1.5ppmv due to new insights obtained through testing on the impact of corrosive fluids.

In the CCS cluster situation where diverse industries (cement, fertiliser, steel, power, etc.) dispose of their captured CO_2 to shared transport infrastructure, the usual approach is that the operator of the common transport/storage system will set a fluid specification to which all the emitters will have to meet. Each emitter will then be required to condition its CO_2 accordingly. The operator of the network will only accept any CO_2 if it meets the entry specification.

Developing a fluid entry specification for a CCS hub network is, however, a complex process as consideration must be given to multiple potential source proponents each with their unique CO_2 composition. The fluid entry specification development should follow a risk-based approach in order to:

- Minimise barriers for potential sources connecting to the network due to an overly restrictive specification.
- Minimise project costs from a whole of project perspective, not just the transport and storage components.
- Understand the risk associated from out of specification CO_2 and any consequential infrastructure damage.

Each of the impurity components should be considered in isolation, with consideration of the primary drivers for limiting the component, the guidance from a storage site and health and safety perspective and what was considered technically achievable as part of ‘business as usual' at the source and capture end.

The risk assessment for impurities in a CO_2 pipeline cluster, and particularly the interaction of impurities from different sources, is an ongoing field of research. Evolving insights may result in a re-visit of the risks associated with a particular impurity or combination of impurities, and hence a review of the system integrity risks and required fluid entry specification.

Wood, Equinor, TotalEnergies and Gassco have initiated a joint industrial project (JIP) with the aim of providing industry guidelines for how the CO_2 specification can be set in specific projects, taking into account current available knowledge[6].

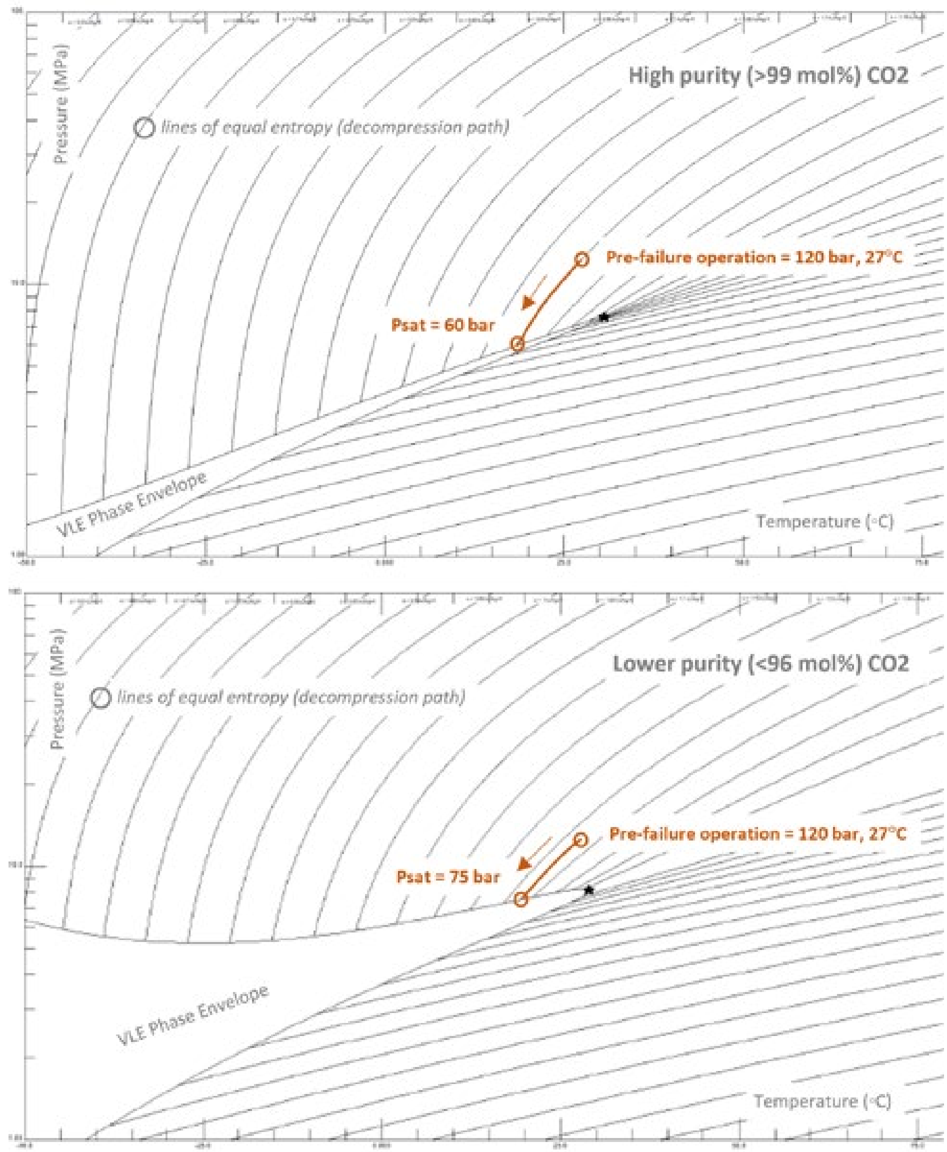

Figure 4: Fracture Assessment-Sensitivity in Saturation Pressure due to Impurity Concentration[5]

3. It is not hydrocarbon

From a safety perspective, the impure CO_2 fluid transport in the pipeline cluster behaves quite differently to hydrocarbon in the event of a release:

- CO_2 has a molecular weight approximately 50% heavier than air; this has implications on how CO_2 disperses when released into the environment. Accidental release of CO_2 may result in cold gaseous phase pools forming at surface level and potentially drifting significant distances to inhabited areas, posing a threat to life through asphyxiation. The potential for low-risk exposure at extended distances due to hazardous cloud drifting in unfavourable weather/topography may lead to high societal risk at extended distances, far greater than for typical natural gas systems.
- On first release to atmosphere, dense phase CO_2 will flash to a mixture of vapour and solid (dry ice). These solid effects are not present in flashing releases of hydrocarbons, and hence they present new challenges for industry dispersion and consequence models.
- The temperature of the released mixture will also drop significantly due to high Joule-Thomson effects (relative to hydrocarbon). The temperature can be theoretically as low as -78°C at the release point. Therefore, in addition to asphyxiation,

cryogenic burn risks due to exposure or inhalation of solid particles must be considered.

- CO_2 is a significantly more efficient solvent in dense phase than gaseous. Upon phase change any impurities in solvent within the CO_2 are likely to be released potentially posing additional hazards. Hydrogen sulphide, carbon monoxide and nitrogen oxides are all toxic compounds found within typical CCS fluid streams.

A key mechanism to reduce risk exposure is to minimise inventory by sectionalising the CO_2 pipeline. Selection of isolation valve spacing will involve a trade-off between the cost to install and maintain the valves on the one hand, and the consequences of pipeline failure on the other. Based on assessment of code requirements by Wood of AS/NZS 2885.1, ASME B31.8, CSA Z662, IGEM/TD/1 and PD 8010: Part 1, a nominal spacing of block valves for CO_2 service will typically be in the range of 18km to 20 km, but is likely to be adjusted based on issues such as site accessibility, topography, environment, availability of land etc. The exact suitability of block valve spacing requires risk assessment and detailed CO_2 dispersion modelling.

Dispersion modelling will typically utilise gaussian-based software for screening. However, once a reduced number of scenarios are defined, Wood recommends computational fluid dynamics (CFD) analysis for rigorous dispersion modelling accounting for complex terrain, physical features, and meteorological effects.

4. We need to toughen up

As per code and standards requirements, a fracture control plan (FCP) shall be developed for pipelines transporting dense phase CO_2. The FCP provides critical information on the materials specification and testing requirements for:

- Avoidance of brittle fracture initiation.
- Prevention of ductile fracture initiation.
- Avoidance of brittle fracture propagation.
- Arrest of ductile fracture propagation.

Due to the excessively low temperature CO_2 can experience during a potential release (as discussed in Section 3), brittle fracture initiation and brittle fracture propagation must be avoided. Brittle fracture initiation is avoided through conducting Charpy V-notch specimen testing to achieve a minimum individual Charpy energy at or below the minimum design temperature. Avoidance of brittle fracture propagation is conducted by achieving and specifying 85% shear area[7] in the drop weight tear tests (DWTTs) through a temperature transition curve.

The initiation of ductile failure is mitigated by ensuring that the pipeline steel has sufficient fracture toughness to prevent a through wall defect of a certain length from initiating a fracture, which is shorter than the critical defect length (CDL) at which infinite toughness would be required to prevent fracture initiation. A value of 85% CDL is typically employed as a defect length to demonstrate that crack initiation can be resisted.

Without doubt, determination of the Charpy impact energy of the pipe body material required to arrest ductile fracture propagation is the most challenging part of the FCP for a pipeline intended for the transportation of the dense phase CO_2. Running ductile fracture occurs if a defect exceeds the critical size for the material and stress level and a crack may propagate along the pipeline driven by the hoop stress and internal pressure. Ductile crack propagation is slower than that of brittle cracks, and the driving force for cracking may be reduced by decompression of the fluid, resulting in lower hoop stress at the crack tip. When the crack driving force becomes less than the material resistance to fracture, the fracture propagation arrest occurs.

Historically, the most used design method to assess ductile fracture propagation in pipeline transporting highly pressurised compressible fluids is the Battelle two curve method (BTCM) developed for natural gas pipelines in the 1970s. However, it is well known within the industry that CO_2 exhibits very different decompression characteristics to that of hydrocarbon gases. These differing characteristics lead to a sustained pressure plateau during decompression which means that the BTCM developed for ideal gases and hydrocarbons does not apply without major modification. It should also be noted that decompression behaviour of CO_2 is very sensitive to the presence of other components (impurities) as discussed in Section 2. An alternative methodology is presented in

DNV-RP-F104[8] which denotes "propagation expected", "evaluation based on special assessments" and "evaluation based on small-scale testing" segments on the domain diagram. Essentially, "evaluation based on small-scale testing" region is the region where the ductile fracture propagation arrest is expected if the Charpy energy requirement is met. At the same time, "evaluation based on special assessments" indicates that a full-scale fracture propagation test is required to confirm that a long ductile fracture propagation in the pipeline can be prevented. Based on the saturation pressure of the dense phase CO_2, the minimum toughness value required to arrest running ductile fracture also increases. DNV applies limits to the applicability of the arrest method, one notably being a minimum required Charpy impact energy of 250J.

Much work is ongoing within the industry (notably DNV JIP CO_2SafePipe[9]) to revisit the domain diagram presented in DNV-RP-F104 and relax some of the restrictions, for example the minimum toughness value. This will be of particular importance for the repurposing pipeline projects which would not have set such stringent specification and testing during original service.

5."CO_2mmissioning" – the first step is the hardest

The pre-commissioning and commissioning of a CO_2 pipeline has a crucial role in the long-term integrity of the pipeline system. After pipeline systems have been flooded and hydrotested, the challenging activity of dewatering and drying commences. Water left in the pipeline will cause severe carbonic corrosion when in contact with the CO_2 process fluid. Since any water remaining within the pipeline or facilities after testing could have serious integrity consequences, attention should be given to minimise the presence of dead legs and crevices. Options available to dry the pipeline including vacuum drying, Super-Dry air and nitrogen drying, each has advantages and disadvantages.

One of the key aspects to consider with drying the pipeline is achieving the required dew point, which typically ranges from -40°C to -45°C based on ISO 27913:2016[10] and DNV-RP-F104. For this reason, nitrogen drying is often considered due to its ability to achieve significantly lower dew points, however this comes with additional complexity and costs associated with nitrogen drying skids. Wood market research indicates several suppliers are available to provide the required nitrogen dew point and target pressure.

An alternative which many subsea (and some onshore) CO_2 pipeline projects are investigating is the ability to dry commission a pipeline by removing the necessity to flood and hydrotest through additional quality assurance steps. Removing the flooding and hydrotest steps will help to mitigate against any residual water within the pipeline. Dry commissioning requires careful consideration of the entire pipeline procurement and construction quality assurance and quality control procedures. Wood has supported clients in securing hydrotest waivers.

A further consideration is the subsequent pipeline commissioning (first fill with CO_2). The initial pressure drop from a source of higher-pressure CO_2 to an initially lower pipeline pressure can result in very low transient operating temperatures as the CO_2 phase changes and expands to lower pressure gas, giving rise to risks to mechanical integrity of the pipeline and risk of water dropout leading to wet CO_2 corrosion risks. As the pipeline is then subsequently pressurised, the conversion of lower density gaseous CO_2 to higher density liquid CO_2 can be an unexpected constraint to commissioning schedule estimates, taking an order of magnitude longer than simple linear predictions might estimate.

The magnitude of the pressure drop during commissioning can be reduced by pre-pressurising the pipeline with dry air or nitrogen. This is a common procedure for moderate length/diameter pipelines to manage low temperatures, and for repurposed pipeline that may have a high minimum design temperature e.g., 0°C. However, pre-pressurisation can be excessively costly for longer distance/larger diameter pipelines due to the large inventory involved. The first fill strategy requires a techno-economic assessment of the alternative methodologies on a case-by-case basis.

6. Summary

The emergence of CCS hubs that will collect emissions from multiple industries presents new challenges for the pipeline industry. Close interface between key discipline teams is required to ensure optimal design outcomes, including (but not limited to): pipeline engineering, flow assurance, technical safety, materials science, fracture specialists and dispersion modellers. A deep domain understanding of CO_2 phase behaviour and the impact of a wide range of impurities is essential. An appreciation of the limitations in current codes and standards which have not been drafted with CO_2 in mind is also a necessity. Conditions during onerous operations, such as depressurisation and first startup, must be understood and addressed at the earliest possible opportunity.

A thorough multi-discipline appreciation for the technical challenges posed by CO_2 pipeline clusters will de-risk projects and avoid costly design recycle late in the pipeline project.

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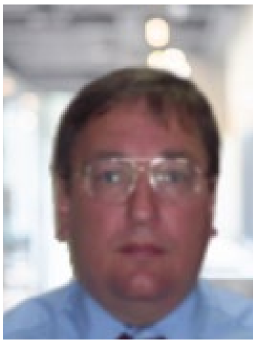

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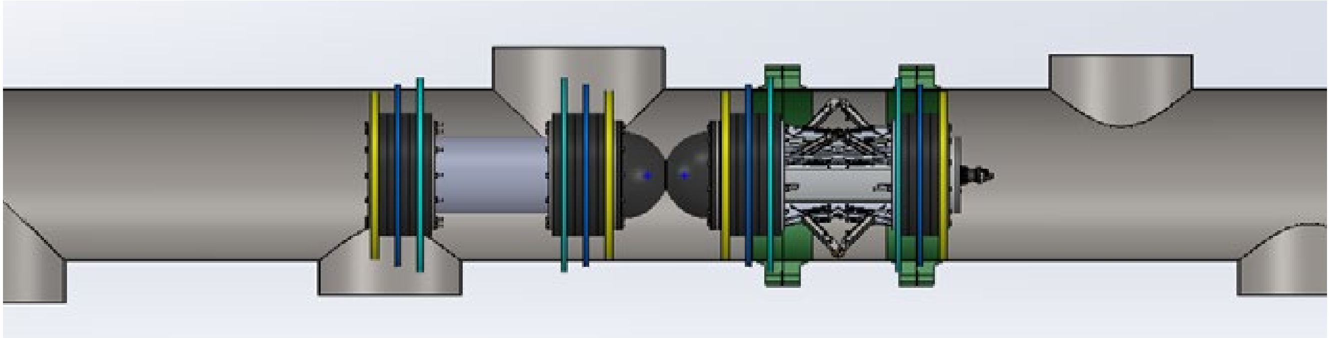


Innovative Pipeline Inspection Technique: Tackling Complex Manifold Challenges with a Dual-Tool Assembly

M. ALONSO & H. OVERDIJKINK > INTERO INTEGRITY SERVICES

Abstract

Intero Integrity Services was tasked by a prominent energy company with inspecting a 36" pipeline in 2023, which included a challenging manifold inspection. The challenge stemmed from a manifold featuring six large-diameter take-offs, posing a significant obstacle for standard bidirectional pigs and inspection tools.

Following successful simulations, comprehensive engineering plans, including 3D and 2D designs, were developed. These plans prioritized durability against push-pull forces and protection for the interconnecting cable.

Prior to field implementation, a proof-of-concept test was conducted at the service provider's facility. This test involved simulating the pipeline conditions using a unique 36" spool with 10" take-offs and modifying existing pig traps to accommodate the dual-tool assembly.

The test results were positive, requiring only minor on-site adjustments. Furthermore, a specialized "rescue pig" was procured as a contingency measure for cable breakage scenarios.

In summary, the service provider's ground-breaking solution successfully met the energy company's pipeline inspection challenge, highlighting a blend of inventive engineering and proactive risk management.

1. Introduction

Addressing the challanges and to assure that the 36" single body Pipeline Surveyor would pass the 6 T-pieces of the pipeline section during inspection, Intero Integrity Services proposed a multi stages project plan which includes the following:

- Paper / digital Feasibility assessment.
- Proof of concept at Intero's base in The Netherlands.
- Actual inspection of the pipeline including the manifold.

1.1 Background

In August 2017, Intero conducted an inspection of a segment of the pipeline, stretching from the launching point to the manifold area. Initially, it was assumed that the inspection wouldn't extend beyond this point, covering approximately 800 meters. Nevertheless, this limited inspection yielded valuable data, offering essential insights for our client.

Recognizing the significance of this data and looking ahead to the future, the client presented Intero with a challenge: to carry out a comprehensive inspection of the entire pipeline during the next scheduled shutdown. With a commitment to excellence and the right team in place, along with the necessary investments, Intero took on the challenge, embarking on the design of the tool and operation.

1.2 Pipeline Surveyor

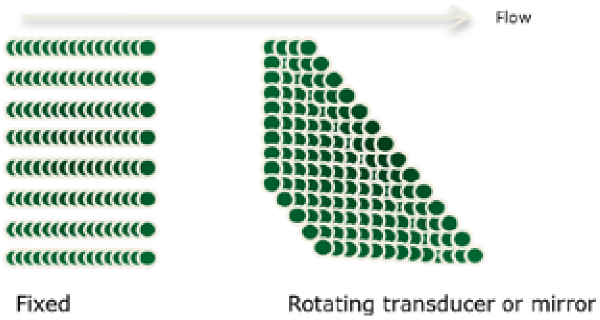
The system employs a contact-free ultrasonic measuring head for maximum flexibility, capable of scanning the entire pipe wall surface. It can handle various pipeline features such as dual diameters, mitered bends, full-bore unbarred tee pieces, and single entry configurations using regular, high, and ultra-high resolutions. The Pipeline Surveyor is designed for inspecting "unpiggable" or challenging pipelines ranging from 3" to 64", located anywhere in the world, from subsea offshore to remote areas.

Matrix

- Multiple transducers evenly distributed over the tool's circumference
- High-speed operation

Helix

- Rotating mirror covering the entire pipe wall
- Flexibility to increase resolution and measurement grid



2. Paper / Digital Feasability Test

The project's challenge involved customizing an inspection solution capable of navigating 1.5D bends and varying distances between take-offs. After brainstorming, the optimal solution involved creating a linkage between a bidirectional pig and the inspection tool. This design ensures that if one of them loses traction, the other can provide the necessary traction for the dual-body system.

2.1 Simulation

To start the process a 3D model of the manifold and take off's was drawn.

In that 3D model a bidi and inspection tool assembly were placed to simulate a run and observe in which scenarios a bypass would be created.

Distance between bidi and inspection tool was carefully adjusted to create a situation which bypass would never occur on both pigs at the same time.

2.2 Detailed engineering: 3D design + 2D drawings

After a successful simulation, the next step involved detailed engineering of the inspection tool and bidirectional pig. Key considerations included ensuring all components could withstand the pushing and pulling forces and safeguarding the steel cable from damage.

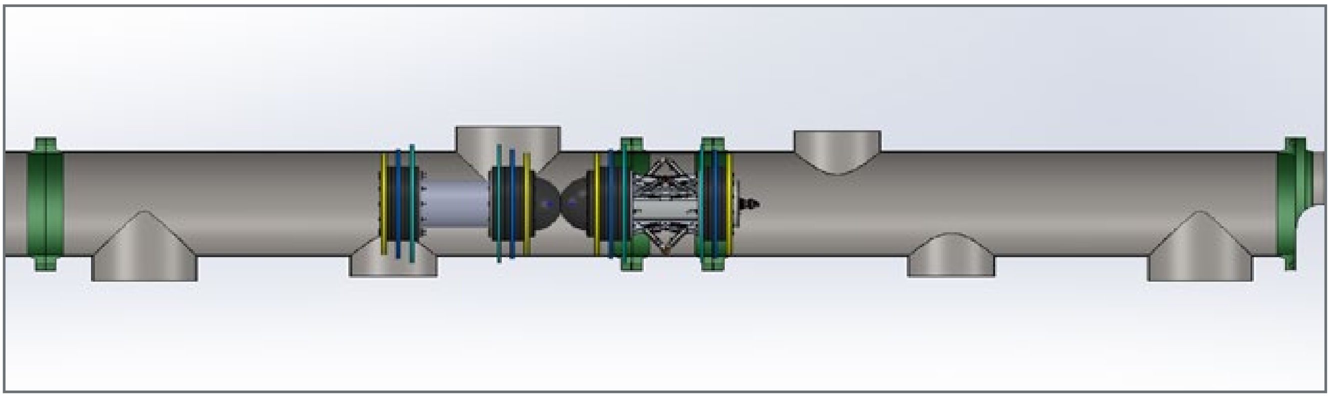


Figure 1: Bidi and inspection tool assembly inside the manifold

Figure 2: The test spool piece and extended pig traps.

3. Proof of Concept

3.1 Test

To minimize the risk of a successful inspection, a test was conducted at Intero's facilities in Tricht, the Netherlands. A custom 36" spool with 10" take-offs was fabricated to partially replicate the site conditions. Additionally, the existing 36" pig traps were extended to accommodate the launch and reception of two pigs simultaneously.

3.2 Results of the test

The concept proved successful, requiring only minor adjustments for on-site assembly. Furthermore, a specialized "rescue pig" was procured to address cable breakage scenarios.

To have a solution prepared just in case, the abovespecial foam pig was ordered.

4. Execution

The project commenced in August 2023 at the customer's site, beginning with safety training and site access. This section outlines the on-site execution and the project's results.

4.1 Purpose of the Inspection

The inspection's primary purpose was to assess the pipeline's integrity. The pipeline, with a diameter of 36" and a length of 4020m, was previously inspected, and the customer requested a fitness for purpose (FFP) assessment and corrosion growth evaluation.

Key pipeline characteristics:

Diameter: 36"

Length: 4020m

Wall Thicknesses: 12.7, 14.3, 15.9, 19.1 mm

4.2 Mechanical Preparation & Set Up

Days before the work onsite was executed the needed materials for the job were prepared (Ili tool, launcher / receiver, hoses etc.) and transported to the customers site.

Arrived onsite, after the safety training & Risk assessment the equipment was unloaded and connected to the customers system.

Figure3: Loading of the bidi & inspection tool during the test

Figure 4: Special foam pig

Figure 5: The transport with Ili tool, launcher / receiver, hoses etc.

Figure 6: A brush pig being removed

Figure 7: The inspection tool being prepared

4.3 Determining Markers / GPS Coordinates

To ensure accurate GPS coordinates of pipeline features and anomalies, the inspection tool was equipped with a gyroscope. The GPS coordinates of markers were precisely measured to enhance the accuracy of GPS data.

4.4 Cleaning / Gauging

A progressive cleaning program, developed through collaboration between the customer and Intero, was implemented. The challenge involved removing debris from the pipeline without getting stuck in the T-pieces. After several brush pigs were run, two runs with the dual-body system were executed to confirm the line's cleanliness.

4.5 Inspection

During the cleaning process, a sample of the product was taken for calibration of the high-resolution ultrasonic measuring head, which was conducted to prepare for inspections in crude. Once the pipeline was deemed clean, the inspection tool was assembled and made ready for the inspection. Just before launching the inspection tool,

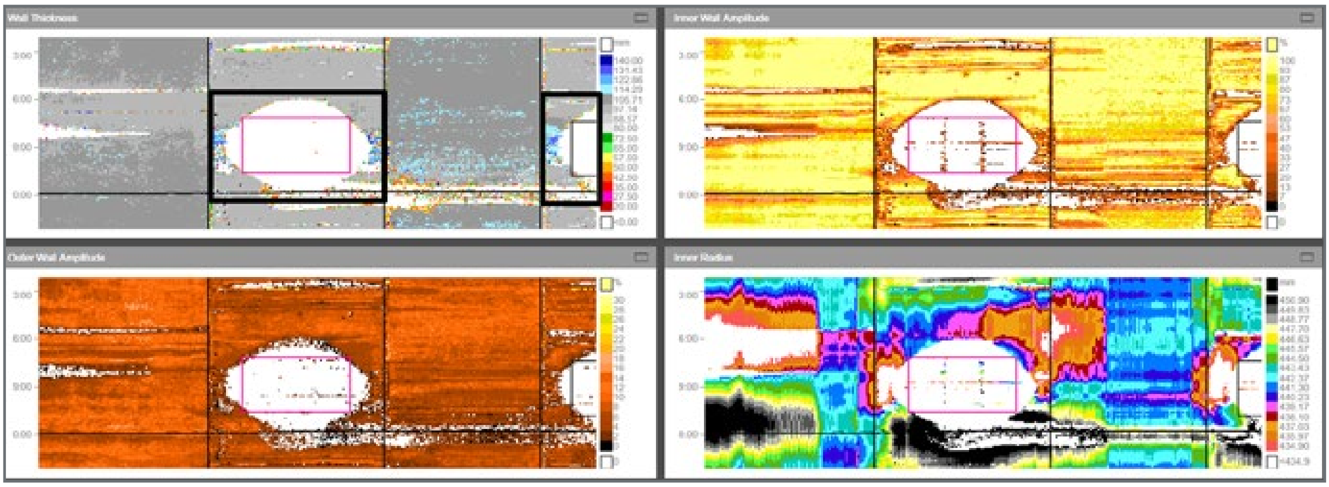


Figure 8: UT data presentation showing 2 T-pieces

the fiber optic connection for online data was established. The high-resolution inspection, including passage through the T-pieces, was completed within 20 hours (average 262 m/h), and data collection was successful.

4.6 Ultrasonice results

No major anomalies were detected, and the pipeline was found to be in good condition.

5. Conclusion

In July 2023, Intero successfully executed the anticipated inspection, meeting the client's expectations and garnering their full satisfaction. This accomplishment not only ensured the integrity of their critical pipeline but also provided a robust solution for its future maintenance and safety.

Inspecting "non -piggable" or challenging pipelines is possible with the correct approach and technical Expertise to reduce the risk. It is critical to follow a multi-step approach which includes: a paper exercise, engineering, mechanical testing of the engineered solution and finally the work onsite.

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Faster Realization of Infrastructure Projects

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Abstract

Shortly after the war in Ukraine had begun, it became clear that Germany needed to diversify its sources of natural gas supply to reduce its dependency and ensure its national energy security. The import of liquefied natural gas (LNG) through the Wilhelmshaven port required a strong connection to the national gas transmission network. OGE had to establish a link between Wilhelmshaven and the network (WAL) and furthermore expand the German long-distance gas transmission network. These challenges had to be addressed at the time of a global pandemic, which presented managers with a multitude of issues that required an innovative approach in management. In this paper, we will look at the difficulties faced by managers during the post-COVID era, specifically addressing the emerging challenges of remote working and home office. Furthermore, we will highlight how OGE has dealt with these issues during a period of increasing projects needs and shorter realization times.

1. Introduction

By the end of 2022, the existing Voslapper Groden (UVG) transshipment facility in Wilhelmshaven was intended to be used for importing LNG to Germany. The Floating Storage and Regasification Unit (FSRU) "Höegh Esperanza" was supposed to dock at this location. OGE had to build a gas pressure control and metering facility (GPCM facility) and a connection pipeline (WAL) starting at this point and reaching almost 26 km running towards Friedeburg. Furthermore, additional pipelines and GPCMs were necessary to strengthen the German transmission network.

The WAL project entailed a planning and construction time of nine months, requiring less than one hundred days of actual construction.

The WAL project operated ten times faster than traditional projects of this scale, making it a significant milestone in ensuring a reliable supply of natural gas in Germany.

At the same time, during the post-COVID era, managers had to face new hurdles such as experiencing difficulties in communication with their employees working from home. Due to the COVID-19 pandemic, the use of digital tools (e.g. e-mail, phone, video) for managers (and employees) gained importance in everyday work.

The contact restrictions imposed during the COVID-19 pandemic accelerated the adoption of digital management tools in many organizations since 2020 as employees were forced to conduct their work from home. The shift towards digitization and increased remote working promoted the establishment of new forms of communication methods and tools.

However, they also lead to a restructuring of engagement and work processes, which are perceived as a challenge by many employees (Krämer and Pfizenmayer, 2020; Statista Research Department, 2020).

Due to these changes, managers are required not only to have considerable competence regarding digital communication tools, but also to possess strong emotional skills to guide their employees through this transformation process and to continue to fulfill their management responsibilities effectively.

2. Success Factors for a successful WAL Project

2.1 OGE's Project Organization

OGE operates approximately 12,000 km of pipeline network in Germany, making it the leading long-distance gas transmission network operator in the country. In addition to technical operations, OGE has a project organization that focuses on the planning, approval and construction of pipelines and facilities for gas transmission. Through the successful implementation of Gas Network Development Plan projects in recent years, OGE has gained experience with investment programs ranging from 250 to 500 million euros annually. The continuous development of OGE as a project organization has led to the expansion of knowledge in assessment, planning, and construction management. Without this capability, implementation of the WAL project under the existing conditions would not have been possible.

Figure 1: WAL pipes

2.2 Success Factors in a Post-COVID World

Reducing the planning and construction time from the usual five to seven years to just nine months posed a significant challenge, as no comparable examples existed before. There was no suitable framework of experience, even for a well-organized project organization. All parties involved agreed that implementing such an accelerated project was a significant risk. In a project with a short duration, even minor risks had to be carefully considered, as any delays could have a direct and irreversible impact on the completion date.

A strong, united project team was necessary. Given the circumstances, there was an early awareness of the importance of active risk management. Due to the tight schedule, the project had no room for delays, making it crucial to identify and capitalize on potential opportunities to mitigate the impact of occurring risks.

At the project's outset, existing success factors were identified and immediately utilized, along with those that needed to be developed. Uniper's existing route planning played a crucial role in speeding up the planning and approval process.

By adopting these planning documents, the period until submission of the plan approval application was significantly shortened. The documents only needed minor adjustments and additions. The approval application could be submitted on time by April 29, 2022, six weeks after the project had begun.

OGE's experience with the execution of large projects enabled the development of a robust awareness of the importance of an effective project organization. In addition to the required skills and experience of the team members, human interaction and proper prioritization were key factors for the project's success.

As a result, it was decided to consolidate the project participants into a task force with concentration at one location. This organizational structure shortened decision-making processes and reduced the impact of external disruptions, improving the project team's ability to act. The formation of OGE as a project organization proved to be a great strength, allowing the individual selection of project members. Consequently, the project's initiation phase was reduced, and commitment to the shared goal was achieved much earlier than usual.

The importance of the WAL pipeline was recognized at both state and federal levels. Olaf Lies, the Minister of Environment and Energy of Lower Saxony, supported the project as a patron and facilitated collaboration between OGE and the relevant offices and authorities. Political support was also extended at the district and municipal levels, forming a crucial foundation for the "new German speed".

In addition, the WAL project was included in the LNG Acceleration Act, leading to adjusted requirements in the planning process. As a result, the plan approval decision and construction start-up were possible within just 3.5 months, starting in mid-August 2022. Significant preparations for construction, such as the design of construction roads and the provision of pressure pits, were started in July. The Federal Ministry of Economics and Climate Protection (BMWK) and the Federal Network Agency (BNetzA) quickly recognized the importance of the project. This was a crucial condition for the investment security of the project. As a result, OGE could initiate binding material orders in April, just two weeks after inception of the project.

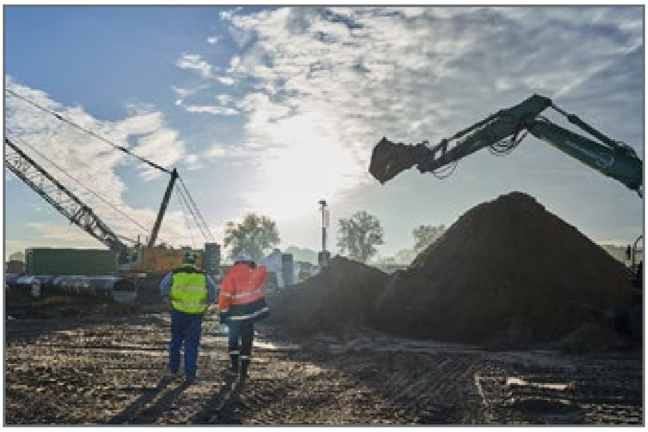

Figure 2: Ambitious schedule

2.3 Construction Organization

Normally, a project such as the WAL, with a length of approximately 26 km, would be executed in a single construction spread.

However, the project team decided to divide it into two independent construction spreads and assigned each of them to two different construction companies. The short construction time required a high deployment of construction teams and machinery. Indeed, it was evident that weather conditions would present a challenge because construction took place during autumn and winter. There were significant concerns that the construction site, characterized by low-bearing capacity soil, would be weakened due to heavy or prolonged rainfall.

Consequently, a construction concept was developed, which involved using construction roads to maximize drivability. Effective cooperation with authorities allowed an early start of construction by mid-July. The time until the plan approval decision was used to build construction roads. During the construction process, the weather conditions were mostly favorable, allowing the pipeline laying schedule to be optimized by approximately two weeks.

Figure 3: The short construction time required considerable machinery.

2.4 WAL Project Results

The WAL project faced high-level demands and expectations both internally within OGE and externally, especially from the political sphere. Project execution was exceptional due to the short planning and construction time of only nine months.

Risk and opportunity assessment were conducted very carefully during project planning. Success factors included a cooperative relationship with political entities, authorities, and the local community, as well as the development of a construction concept tailored to minimize risks, featuring the extensive use of construction roads. The formation of a task force within OGE proved to be an effective organizational structure for achieving rapid project completion.

The WAL project not only met but also exceeded the high requirements in several areas. Suppliers, service providers, and construction companies proved themselves as reliable partners to politics and society, showing that "new German speed" is possible. This remarkable pace was achievable because all parties were fully aware of their responsibilities and willing to fully commit themselves to the common goal.

3. Additional Pipelines and subsequent projects to strengthen the German Transmission System and Challanges of a Post-COVID Work Environment

In addition to the WAL project, further infrastructure to strengthen the German transmission system proved necessary. These projects could not be executed as a task force, because of their number. Thus, various

Figure 4: WAL

challenges had to be faced in digitally supported communication with employees and realize interpersonal aspects such as team building, the expression of support and feedback, as well as the build-up trust.

3.1 Challanges of Digital Communication for Employee-Oriented Management

To achieve project goals, employees must be committed to the cause. A strong connection to both managers and team members is crucial. However, actual isolation and diminishing attachment are fostered by reduced contact between supervisors and employees, weakened mutual emotional perception and limited opportunities to give and receive feedback. Relying solely on digital management carries the risk of facilitating less frequent or less intense exchange between supervisors and employees.

This reduced contact between supervisors and employees contributes to employees feeling left alone in their home office and to a diminishing attachment to their manager. In addition, diary studies with employees reveal that the loss of informal communication channels with colleagues intensifies the perceived isolation experienced by employees in their home office (Kellner et al., 2020). Despite the enhanced use of digital tools, most managers report experiencing difficulties in communication with their employees working from home (Statista Research Department, 2020).

Little research has been conducted on the effects of working from home on employees' attachment to their managers and the role that digital media-based management communication plays in this context. Initial long-term studies indicate that the transition to home office working during the pandemic led to an increased sense of isolation among employees (Van Zoonen & Sivunen, 2022).

Regular communication using various media and employer-provided support can alleviate this perceived isolation (Bentley et al., 2016), leading to improved well-being and job performance. In addition, the lack of contact with colleagues in their home office exacerbates employees' sense of loneliness (Bansmann, 2021; Kellner et al., 2020).

The absence of informal conversations (e.g. in the hallway) hinders the building of collegial relationships and team formation (Jämsen et al., 2022; Kellner et al., 2020), limits networking opportunities, and diminishes employees' sense of organizational belonging (Felfe, 2008).

3.2 Success Factors and Risks in a Post-COVID and "Post" Gas Crisis World

Reducing the planning and construction time from the usual five to seven years to three to four years continues to be a challenge. Implementing such accelerated projects carries major risks. In projects with a short duration, even minor risks must be carefully considered, as any delays will have a direct and irreversible impact on the completion date.

A strong and united project team is necessary. Political support is still necessary at the district and municipal levels, to form the "new German speed." Consequently, these projects were included in the LNG Acceleration Act, leading to adjusted requirements in the planning process.

However, this inclusion took time and triggered a discussion about the necessity of the speed involved and the projects. The significance of the project is recognized by the Federal Ministry of Economics and Climate Protection (BMWK) and the Federal Network Agency (BNetzA), but the effect is weakened.

3.3 OGE's approach to enhance Employee Engagement using Digital Management

OGE's approach to strengthen employee engagement and foster a sense of connection, commitment and loyalty among team members in the digital work environment includes the following main pillars:

- Real contact and team days

All OGE employees can work from home up to three days a week. Two days must be used for either office work or being present on the construction site. Each team has at least one team day per week.

- Effective communication

Clear and regular communication with remote employees has to be prioritized. Various digital communication tools have to be utilized to maintain regular contact, provide updates and offer support. It has to be ensured that communication goes both ways, allowing employees to voice their concerns, ask questions, and provide feedback.

- Virtual and non-virtual team building

Activities and initiatives have to be implemented that promote team bonding and a sense of solidarity among remote team members. This can include virtual team-building exercises, online social events, and informal video conference meetings to foster a positive team culture as well as classic team building events.

- Individual support and recognition

Individual support has to be provided to employees by regularly checking in with them, addressing their concerns, and offering guidance. Their contributions and achievements have to be recognized and appreciated through acknowledgments, e.g. during team meetings.

- Promotion of work-life balance

The importance of a work-life balance has to be emphasized and remote employees have to be encouraged to establish boundaries between work and personal life. Flexible work arrangements have to be provided and employees' well-being has to be supported by promoting self-care practices and mental health resources.

- Fostering of a sense of belonging

Opportunities for collaboration, team projects and cross-functional interactions have to be created. Remote employees have to be encouraged to actively participate in discussions, share ideas, and contribute to the overall goals and objectives of the team and organization.

- Supportive management

Managers have to be empowered to be accessible, approachable, and supportive to remote employees. Managers have to be trained in digital management skills, including effective virtual communication, active listening, and empathy, in order to build strong relationships with their teams.

4. Conclusion

In conclusion, our journey through the intricacies of energy security, project management, and organizational adaptation has revealed a multifaceted landscape. The WAL project stands as a testament in overcoming challenges, setting new benchmarks, and ensuring Germany's energy security. Beyond the WAL project, we continue to navigate through ongoing projects, where the intricacies of planning, execution, and political support continue to shape the trajectory of Germany's energy landscape.

Furthermore, OGE as a company continuously deals with the hurdles rising from increased working from home. The digital shift demands not just efficient project management but also adept leadership in fostering a connected workforce. In summary, this overview captures not just a successful project but an ongoing journey of adaptation and resilience. It provides guidance for energy leaders, project managers, and organizations dealing with the challenges of energy security, complex projects, and the impact of remote working.

As we move forward, the lessons from the WAL project and our ongoing efforts to embrace the digital era underpin our commitment to ensuring a sustainable and secure energy future for Germany. We shape energy supply, today and in the energy mix of the future.

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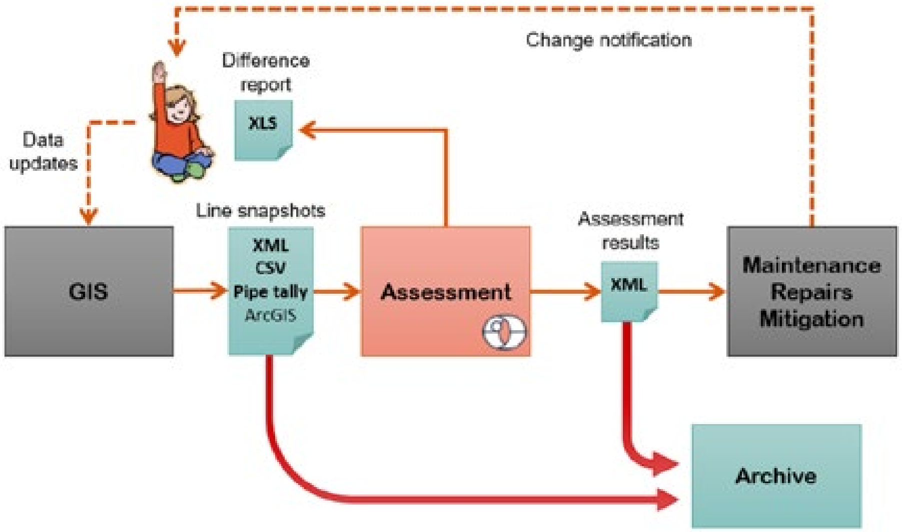


Software-based assessment of hydrogen-readiness of pipelines supported by GIS data

R. MENNICKE[1] & H. BRÜGGEMANN[2] > [1]GEOMAGIC GMBH & [2]VEENKER INGENIEURE

Abstract

This article describes an approach to the assessment of steel pipelines regarding their potential suitability for hydrogen transportation. The assessment is made based on pipeline inventory data available in georeferenced form in a GIS, as well as in supplementary databases, and uses the software platform trascue.PIMS by GEOMAGIC GmbH, combined with an assessment configuration by Veenker-Ingenieure. The assessment configuration is based on the current DVGW (German Technical and Scientific Association for Gas and Water) worksheet G 464, helps determine hydrogen suitability, and provides a useful life forecast. In this way, an overview of hydrogen suitability can be obtained with relatively little effort.

Suitability assessment of steel pipelines for the transportation of up to 100 % hydrogen can be largely automated if geo-referenced pipeline inventory data is available in a geographic information system (GIS) and supplementary databases. Specialized software for pipeline assessment can be adapted to this new requirement.

To support pipeline assessment, GEOMAGIC GmbH has developed the software framework trascue.PIMS, which serves as the central element in data collection and preparation for assessment, the assessment process proper, as well as result analysis and presentation (Figure 1).

Different assessment configurations can be created within this same platform to model different algorithms for assessments and analyses. A "white-box" approach is used, i.e., the assessment algorithms are fully disclosed and can be viewed (Figure 2). The system is self-documenting, as the assessment algorithms can be output as a PDF document and the principles according to which the assessment is carried out are thus presented transparently.

Assessment algorithms are configured in the program interface and can range from simple scoring rules to complex formula systems and recursive calculation processes. Existing assessment configurations can be modified by users with the appropriate expertise to reflect changes in regulations, new findings, or additional requirements.

This platform has been used by Veenker-Ingenieure to develop an assessment configuration based on the regulations of the current DVGW worksheet G 464. The algorithms given in this document can be used to evaluate the basic suitability for hydrogen of a steel pipeline (Figure 3), as well as provide a useful life prediction under the influence of hydrogen. The assessment uses detailed materials data, information on existing damage, and known load-cycle profiles. If this data is not known, conservative assumed values can be used. To get the best results, it makes sense to keep detailed pipe tally and materials data available in a database for digital analysis, i.e., not as linked PDF documents, but as numerical values. By linking the assessment process to the GIS database, secondary

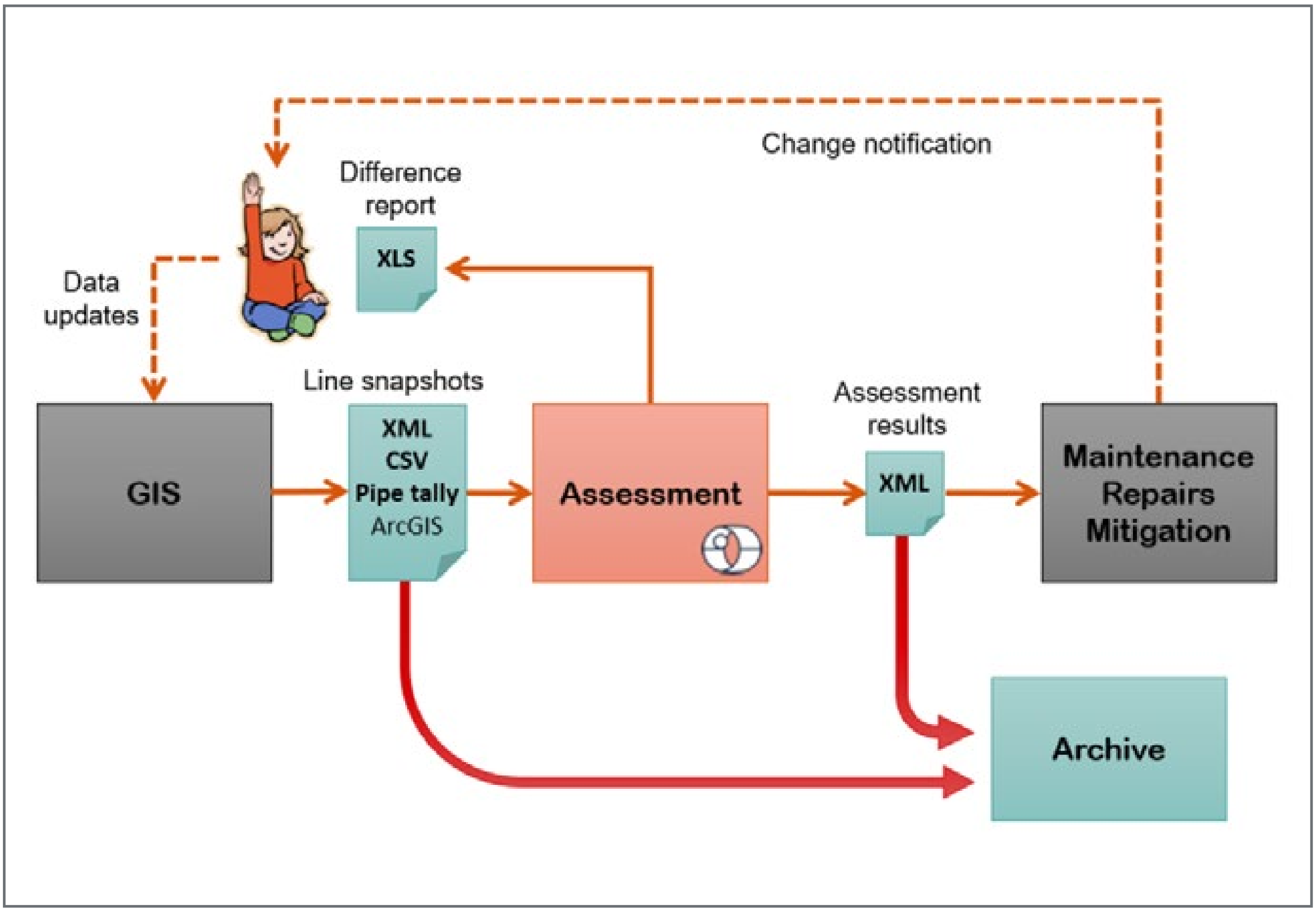


Figure 1: trascue.PIMS in the assessment workflow

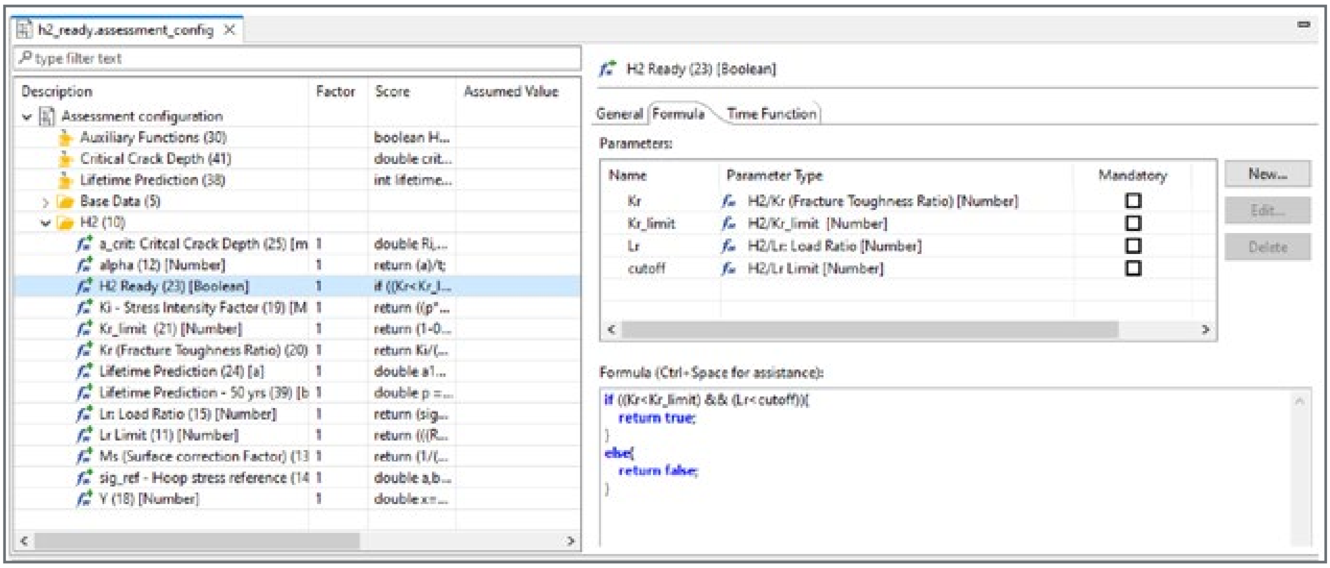


Figure 2: Assessment configuration

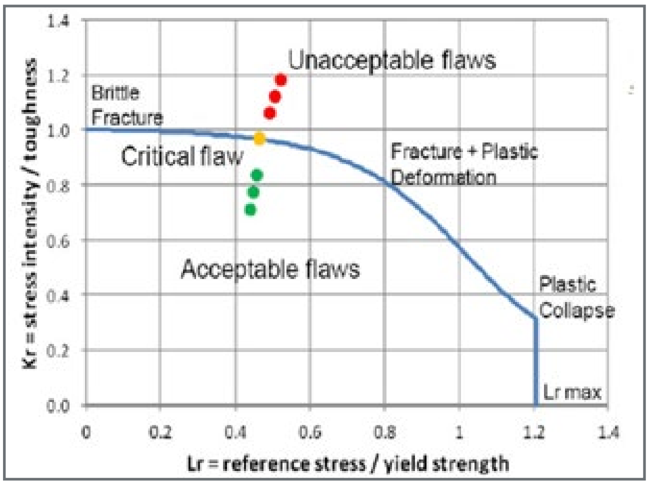
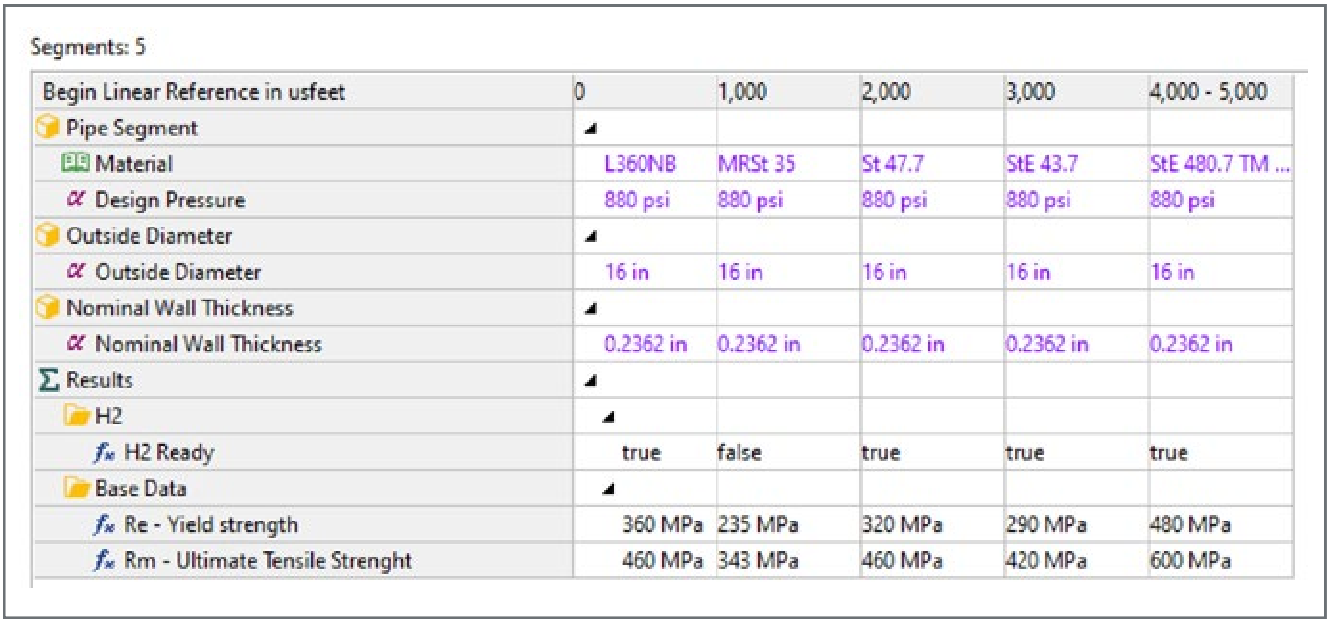


Figure 3: Assessment of suitability for hydrogen use
(source: Rishi Sharma / www.researchgate.net)

information such as environmental influences, inspection results, additional loads, etc. can also be easily incorporated into the suitability assessment.

The assessment result provides a general yes/no vote on the pipeline's potential for hydrogen use. If a pipeline is potentially suitable, a useful life prognosis is made based on the allowable number of full load cycles (DP <-> 0) (Figure 4).

The assessment results can be viewed with fine-grained geographic resolution in maps, charts, and tables, as well as in pre-defined reports (Figure 5). Results can be aggregated to get overall values for the segment or line level.


Segments: 5

Begin Linear Reference in usfeet	0	1,000	2,000	3,000	4,000 - 5,000
Pipe Segment					
Material	L360NB	MRSt 35	St 47.7	StE 43.7	StE 480.7 TM ...
Design Pressure	880 psi	880 psi	880 psi	880 psi	880 psi
Outside Diameter					
Outside Diameter	16 in	16 in	16 in	16 in	16 in
Nominal Wall Thickness					
Nominal Wall Thickness	0.2362 in	0.2362 in	0.2362 in	0.2362 in	0.2362 in
Results					
H2					
H2 Ready	true	false	true	true	true
Base Data					
Re - Yield strength	360 MPa	235 MPa	320 MPa	290 MPa	480 MPa
Rm - Ultimate Tensile Strenght	460 MPa	343 MPa	460 MPa	420 MPa	600 MPa

Figure 4: Assessment result

Figure 5: Examples for result presentation

Pipeline components made of materials other than steel (e.g., valve seals, insulated couplings) can be identified and listed. If manufacturer information on these components is available and stored in the GIS, a suitability assessment can also be carried out for these elements. Otherwise, a list of the components to be assessed manually may be created, depending on the required process.

In this way, an overview of the potential suitability of complex networks for hydrogen use can be gained with relatively little effort.

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Overcoming data access challenges to provide an effective leak detection system

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Abstract

As pipeline industry challenges continue to grow, it's never been more important to make maximum use of the data available for leak detection. Crucial to this is the deployment of hardware that allows pipeline operators to access more data, resulting in a more effective leak detection system.

In this article, Sales and Senior Research Engineer Harry Smith discusses a range of hardware and software that can support a data driven approach to leak detection, from non-intrusive instrumentation to upgraded algorithms.

1. Prioritizing data for leak detection

As pipeline industry challenges continue to grow, it's never been more important to make maximum use of the data available for leak detection. Crucial to this is the deployment of hardware that allows pipeline operators to access more data, resulting in a more effective leak detection system. However, there are a range of challenges that can prevent operators from accessing the data they need. This article discusses those challenges and how they can be overcome with the right hardware and software.

2. Areas with no power or communications

To minimize risk, it's not uncommon for a significant length of pipeline to pass through a remote location to avoid areas of significance, such as a high (HCA) or moderate (MCA) consequence area.[1] In some cases, passing through remote locations is the only option too, such as in the Middle East where over 80% of the region's topography is desert.[2]

A problem with pipeline sections in remote locations is that they're typically off grid, meaning data can be difficult to access due to the lack of power or communication in the area. This can cause additional challenges, such as a rise in pipeline theft. In Latin America, opportunists are known for stealing product from pipelines in remote locations, as the risk of getting caught is lower due to the logistics involved with getting pipeline operators on site in a remote location. For this reason, accessing data in areas with no power or communications is vital.

Advancements in leak and theft detection hardware mean that instrumentation can now be powered by wind and solar energy. For example, Atmos Eclipse is built to detect leaks and thefts in real-time through its ability to measure at a 60 Hz data acquisition rate. For remote locations with limited power or communications, Atmos Eclipse can function as an integrated solution in a networked environment or be powered by solar and wind energy.

Other opportunities to access data in remote locations with limited power and communications can be found in battery powered data acquisition units.

Atmos Odin facilitates the remote location of leaks and thefts. It continually logs data from its internal pressure sensor to identify product loss on a pipeline. It's small and inconspicuous so it's difficult for thieves to see. Used alongside the human element of offline analysis by engineers, Atmos Odin has been used to detect and identify the location of illegal tapping points in Africa recently.

Figure 1: Atmos Eclipse powered by wind and solar

3. Case study 1: SEP Congo

SEP Congo have been the established oil logistics experts in the Democratic Republic of Congo since 1910, playing a crucial role in the supply of oil products throughout the country.

Critical to the continued success of their operations has been the installation of hardware in remote locations with limited power and communications.

Using Atmos Odin, SEP Congo was able to collect pressure data in remote areas of the pipeline. Critical changes in the data could then be analyzed offline by Atmos engineers using proprietary data analysis techniques and any leaks or thefts be reported.[1]

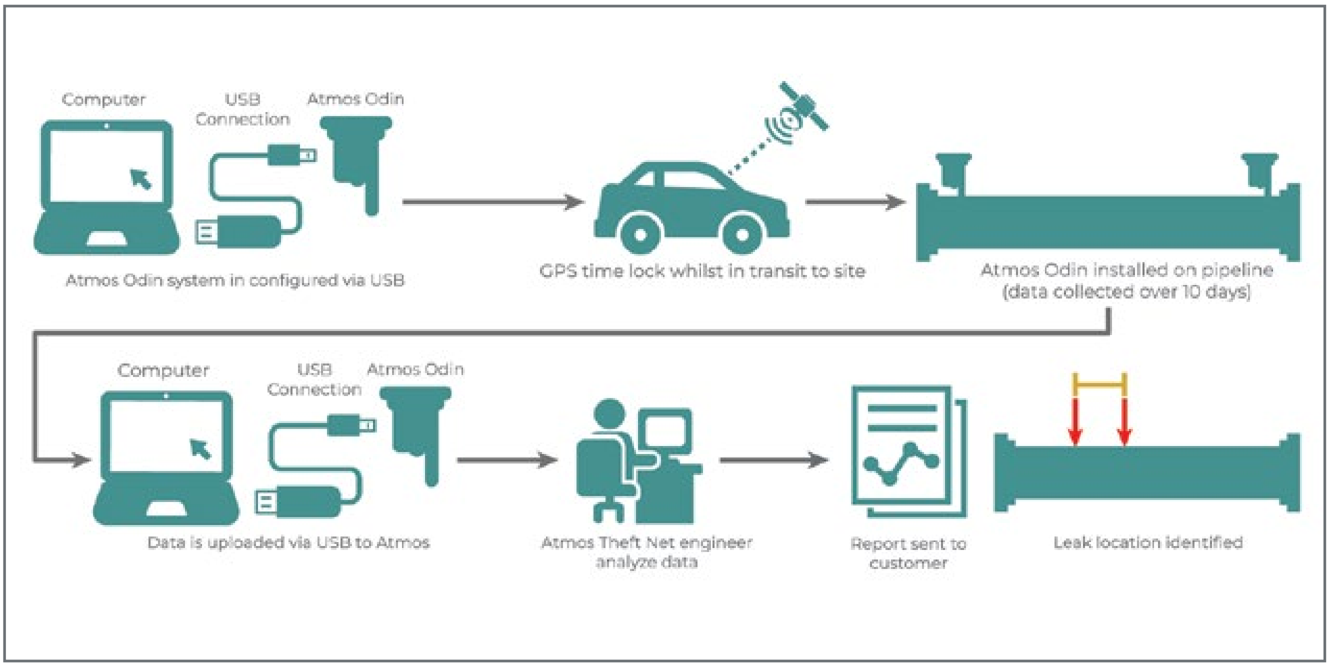

Figure 2: The process involved in Atmos Odin's leak and theft detection

4. Case study 2: TotalEnergies Marketing Belgium

As a major provider in refining and retail sectors in Belgium, TotalEnergies Marketing Belgium produces and distributes fuels, natural gas and electricity. On one of its multiproduct pipelines transporting a mix of diesel, gasoline, heating oil and jet fuel, TotalEnergies Marketing Belgium required a theft detection solution that minimized risk to the pipeline integrity, while detecting theft events in line with its commitment to safe operations.

In conjunction with Atmos' software, Atmos Eclipse was installed to collect data for changes in the pressure and flow on the pipeline. One tapping point was detected with a 40 meter location accuracy (0.3% of the pipeline section).[2]

5. Pipeline sections with limited space

Some pipeline sections have limited space to install instrumentation, such as pipelines in tank farms. This can make it difficult for operators to access the leak and theft data they need.

Atmos Eclipse can be installed in tight spaces, which allows for more opportunities to access leak and theft detection data along a pipeline.

Figure 3: A tapping point located on TotalEnergies Marketing Belgium's pipeline

Figure 4: Atmos Eclipse installed on a section of the pipeline

6. High consequence areas

Many pipelines running through HCAs and MCAs are often also exposed to geohazards. For example, Latin America's topography is highly variable, including mountains and highlands, river basins and coastal plains so it's highly likely that a pipeline will cross at least one of these terrains. For pipeline routes close to mountains and highlands there is a risk of landslides, lahars and volcanic activity and for river-crossing pipelines there is a risk of riverbed scour and underground erosion.

All geohazards can pose a risk to pipeline integrity and the ability to access valuable leak and theft data. Fortunately, robust hardware like Atmos Eclipse can be installed for remote monitoring in challenging climates, such as the ability to operate and continue to collect data even in -20 C to 60+ C temperatures.

Pipeline operators can be further supported by training software which can expose them to abnormal operating conditions specific to the region in which the pipeline operates, so that if a leak does emerge as a result of the conditions of operating in a HCA, operators can continue to make maximum use of the data available to identify the leak and take effective actions.

7. Cyber security restrictions

Cyber security can present many restrictions that interfere with accessing data in a leak detection system. It's crucial that operators can access leak detection data quickly.

Atmos uses data diodes that allow the flow of data in one direction securely. This facilitates a timely data transfer as an alternative to remote access, data diodes can provide faster, secure support through the easy access of leak detection system data and push data out to

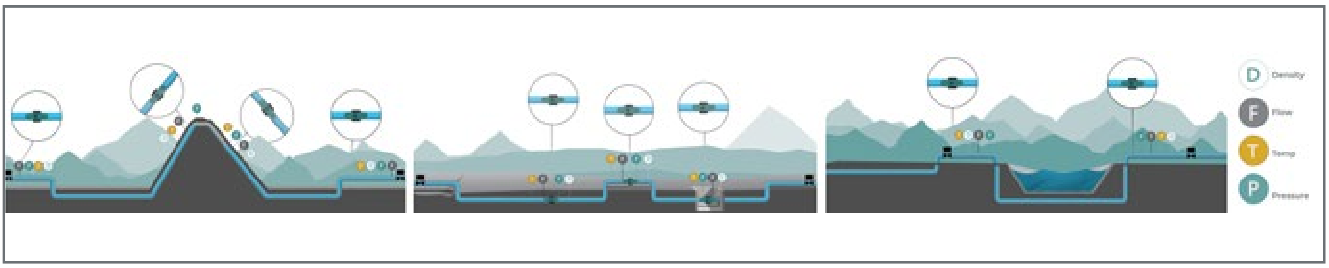

Figure 5: A selection of Atmos Eclipse's installations in high consequence areas

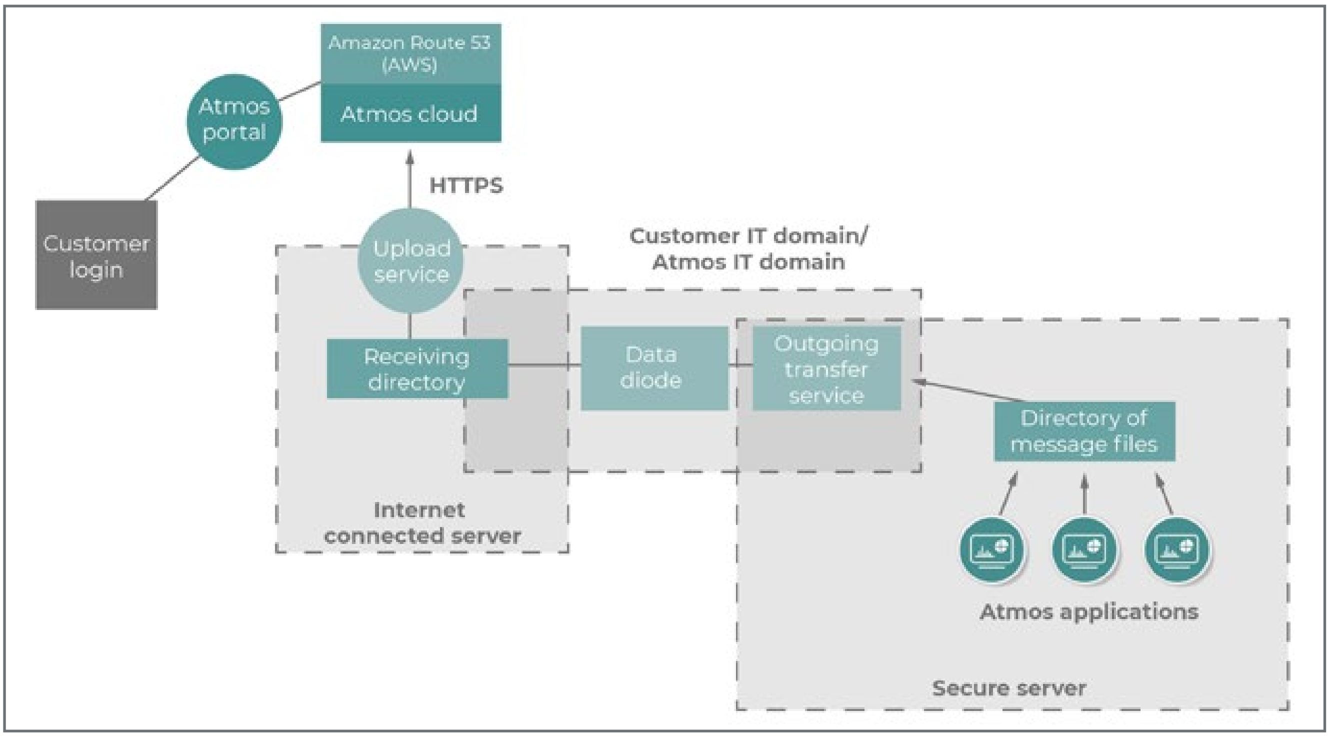

Figure 6: Data transfer options

Atmos servers when required eg when a leak alarm is generated.

Data diodes remove complex remote logins, ensure timely monitoring of pipeline conditions and are easy to retrofit on existing systems.

By allowing access to the system's data, the data diode avoids putting operators' cyber security at risk and increases efficiency in responding to pipeline events.

8. Upgraded algorithms

In areas of high risk like high consequence areas (HCAs) and moderate consequence areas (MCAs), ensuring leak detection continuously optimizes sensitivity should remain a priority, so upgraded algorithms remain crucial.

A new algorithm from Atmos specializes in single ended leak detection, utilizing flow and pressure data at a single end of the pipeline eg the onshore end of an offshore pipeline. This allows for onset leak and rupture detection (via the negative pressure wave principle) to be provided for tanker loading and unloading offshore pipelines and onshore pipelines where instrumentation is only feasible at one end.

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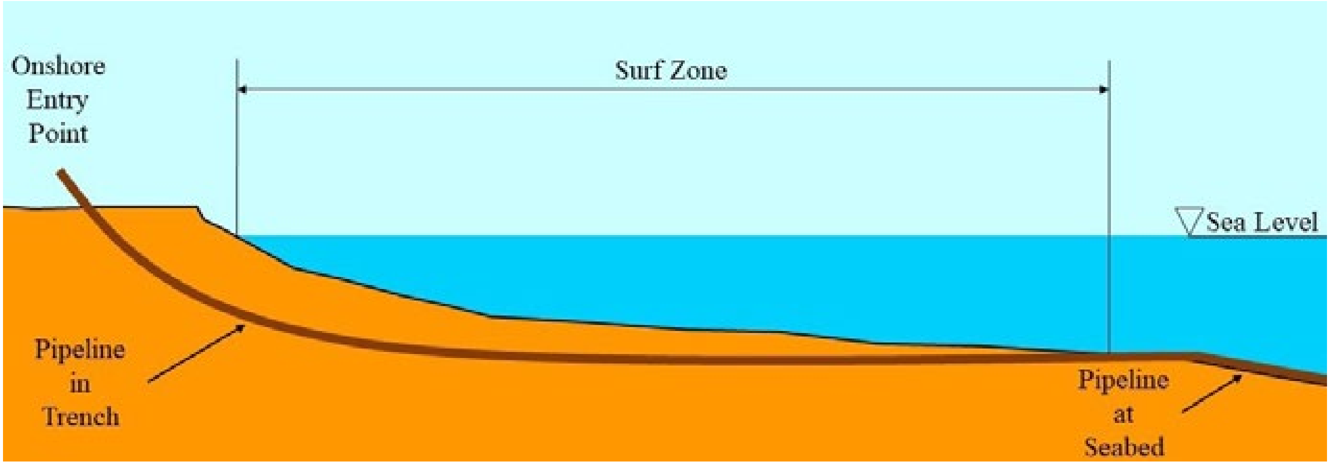

An Innovative Approach to Optimize Near Shore Burial Requirements of Subsea Pipelines Based on Field Experience

Q. SALEEM, R. AL-SHIBAN & F. AL-FOSAIL > SAUDI ARAMCO

Abstract

Subsea pipelines originating from offshore fields and approaching land are required to be buried in near shore area to provide protection against environmental loading, marine activity, instability and unfavourable soil conditions.

This paper presents an innovative approach to optimize near shore burial requirements of subsea pipelines. This approach involves use of accurate metocean and bathymetry data to identify true extent of splash zone as well as the use of actual field experience to determine the optimum near shore burial length. The presence of hard/rocky seabed further supports the optimization of burial length which can be challenging and can pose the risk of a major schedule delay.

The proposed approach was successfully applied to reduce the near shore burial length of a number of subsea pipelines by at least 25% which resulted in significant reduction of capex/opex costs, less environmental impact and project schedule improvement leading to early start up.

1. Introduction

Subsea pipelines such as in-field flowlines, trunklines, test lines etc. are an integral part of all offshore field developments. The production from the offshore fields are transported to land via subsea trunklines or export lines, which are required to be buried in the near shore area to provide protection against environmental loading, marine activity, instability and unfavourable soil conditions (as applicable).

The external environmental loading in the form of waves and currents is significantly high in shallow waters and surf zone associated with pipeline shore approach. The waves break in the surf zone and the shallow water causes the waves to become unstable. The wave slamming action in surf zone can affect the integrity and safe operation of the submarine pipelines.

Subsea pipelines are externally concrete weight coated to ensure vertical and lateral stability on seabed [1-5]. The stability in shore approach areas can be challenging due to shallow waters, large hydrodynamic forces and hard/rocky seabed conditions. These conditions in conjunction with large pipeline diameters may lead to a very high concrete coating thickness which may not be able to be applied in the available coating yards.

The marine activities in the shore approach area is a key consideration while establishing the pipeline burial requirements. This involves consideration of vessel movement in the area, marine channels and determining the minimum clearance required for marine activities.

The geotechnical data in the shore approach area plays a vital role in determining the extent of near shore burial of subsea pipelines. The hard/rocky seabed conditions can lead to pipeline instability which can dictate pipeline burial, however, hard seabed conditions can lead to trenching difficulties which can significantly impact the project schedule. On the other hand, for soft soils having low shear strength or likely to be liquified, if the depth of sinking cannot be limited to a satisfactory value then the pipeline burial becomes necessary.

The guidance available in the industry standards for the near shore burial requirements of subsea pipelines is somewhat limited. For example, ASME B31.4 [6] requires special considerations for protecting the pipeline in surf zone whereas ASME B31.8 [7] calls for burial depth to be sufficient to prevent scouring, spanning and stability issues. Neither of these standards provide any guidance on the extent of surf zone and the corresponding burial length. However, DNV-OS-F101 [8] states that the need for burying the pipeline should be evaluated based on environmental loading, requirements intended for a clean beach for recreation and shipping activity. Furthermore, DNV-RP-C205 [9] defines the shallow water wave breaking limit (water depth which corresponds to 1.28 times the 100-year maximum wave height) which can potentially be used to establish the extent of surf zone and the equivalent burial length.

The near shore burial length of the replacement subsea pipelines, as per the guidance provided in industry codes and standards, was found to be significantly higher than the actual burial length of the existing subsea pipelines (section 3). There were no issues with the shore approach section of the subsea pipelines over 40-45 years operational life. The mismatch between the standards and the actual field experience in terms of burial length in shore approach zone led to an alternative approach to optimize near shore burial requirements of subsea pipelines, as outlined in the following sections.

Another important consideration is that subsea burial costs are very high especially for large diameter pipelines, therefore, the reduction of the burial length offers less environmental impact and economic benefits as well as significant schedule improvement both for construction stage and for subsea repairs during operation.

2. Alternative Approach for Near Shore Burial Length

This paper presents an alternative approach to optimize near shore burial length requirements of subsea pipelines. This approach utilizes additional means in terms of the below key parameters driving the pipeline burial length in shore approach area:

- Extent of surf zone
- On-bottom stability
- Marine activities
- Field Experience

Extent of Surf Zone: The extent of surf zone is typically defined as per shallow water wave breaking limit outlined in DNV-RP-C205 [9] as shown in Figure 1.

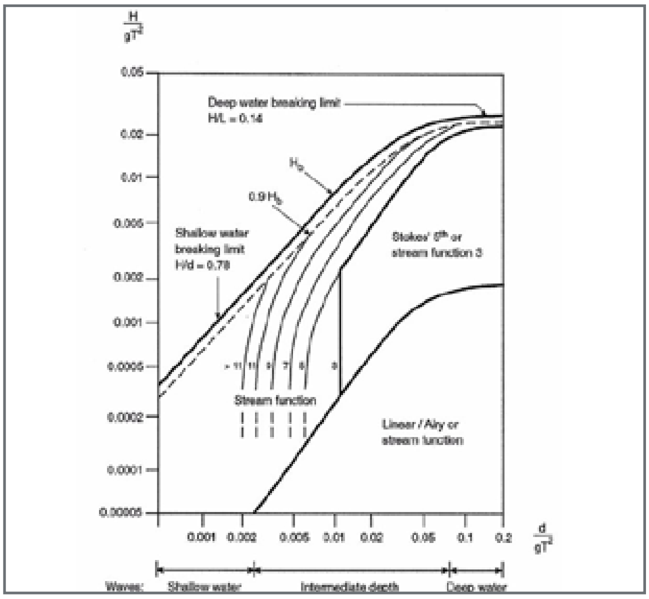

Figure 1: Shallow water breaking limit as per DNV-RP-C205 [9]

The shallow water wave breaking limit, as per Figure 1, is the water depth which corresponds to 1.28 times the 100-year maximum wave height and is the theoretical limit. As part of the alternative approach, the true extent of surf zone is determined based on numerical wave propagation simulations which may be as part of shallow water metocean study. The key input for wave modelling is the bathymetry and available metocean data which can be used to transform offshore wave conditions to various locations along the pipeline route using a SWAN wave model. This approach predicts surf zone's extent more accurately which can lead to reduction in shore approach burial length.

On-bottom Stability in Shore Approach: The on-bottom stability in shore approach section is governed by metocean data and/or seabed soil conditions. It is common to conservatively use available wave and current data at nearby locations along with assumed or limited available soil data. As part of the alternative approach, a detailed shallow water metocean study is required to provide the accurate wave/current data to be used for on-bottom stability analysis in shore approach area. Furthermore, the geotechnical data should be based on a comprehensive offshore survey with boreholes and PCPT (Piezocone Cone Penetration Test) carried out every 0.25km. The minimum depth for boreholes and PCPT should be trench depth plus 1m.

Marine Activities: Marine activities in the shore approach area are an important parameter for determining the burial requirements. However, in the majority of the cases the marine activities were found not to be governing in shore approach area, therefore, the burial length was often found to be governing by the extent of surf zone. As part of the alternative approach, it is recommended to use shallow water markers or other suitable means to protect the pipeline in shore approach area. Furthermore, strict monitoring and access permission for vessels should be used to ensure the integrity of the pipeline.

Offshore Field Experience: The field experience can be an invaluable tool for optimizing the near shore burial requirements of subsea pipelines. For replacement subsea pipelines, the actual near shore burial length of existing subsea pipelines can be used to corelate with and to optimize the burial length requirements. Also, for new subsea pipelines, the same approach can be used provided there are existing subsea pipelines nearby which can be considered to calibrate based on their operational experience. The case studies with different subsea pipelines are covered in the following section.

3. Application of Alternative Approach

The alternative approach for optimizing the near shore burial length of subsea pipelines can be applied using the following steps:

Step1: Acquire well defined bathymetry and geotechnical data in shore approach area. The seabed contours at 1m depth interval are recommended to ensure that the bathymetrical conditions are adequately captured along the intended pipeline route.

Step 2: Use Company metocean database to extract the wave, current and wind (environmental) data at nearby locations where accurate metocean data is available.

Step 3: Perform numerical wave propagation simulations using a suitable wave model accounting for depth-induced wave breaking phenomenon to establish the true extent of the surf zone.

Step 4: Conduct detailed metocean study to determine extreme waves, extreme currents and extreme joint wave and current conditions in shore approach area.

Step 5: Carry out shore approach on-bottom stability analysis, based on the refined input data obtained from steps 1-4, in compliance with DNV-RP-F109 "On-Bottom Stability Design of Submarine Pipelines" [10].

Step 6: Establish the near shore burial requirements based on vessel movement in the area, marine channels and determining the minimum clearance required for marine activities.

Step 7: Correlate the calculated near shore burial lengths from steps 3, 5 and 6 with burial length of existing subsea pipelines to achieve optimization.

The alternative approach for near shore burial length has been successfully applied for both replacement and new subsea pipelines. A number of case studies, where near shore burial length has been optimized based on field experience, are presented below and the associated benefits are also highlighted.

Case Study 1: The first case study is a 48" diameter subsea replacement pipeline with wall thickness of 0.875" (22.22mm). The pipeline is bare carbon steel and externally coated with FBE and concrete weight coat. The maximum water depth along the route length of 6.35km is 95.1ft (29m). The initial near shore burial lengths proposed for 48" subsea pipeline based on different criteria are outlined in Table 1.

Burial Length Criteria	Trench to Water Depth LAT (m)	Trench Length (m)
Surf zone	7	4,600
Marine Activities	5.3	3,900
On-Bottom Stability	7	4,600

Table 1: Near Shore Burial Lengths for 48" Subsea Pipeline

The near shore burial length of existing 48" subsea pipeline was found to be 650m corresponding to a water depth of 3m. The required burial length for the new pipeline was calculated to be 1.5 km corresponding to a water depth of 3m. The root cause for the mismatch between burial lengths was found to be the use of approximate/available bathymetry and metocean data as well as the lack of numerical wave propagation simulations to determine the true extent of surf zone. By using the alternative approach outlined in section 2 and following the steps presented earlier in this section, the revised near shore burial length was found to be 2.2 km as shown in Table 2.

Subsea Pipeline	Initial Proposed Burial Length (m)	Optimized Burial Length (m)	Reduction (%)
48"	4,600	2,200	52

Table 2: Optimized Near Shore Burial Length for 48" Subsea Pipeline

Case Study 2: The second case study involves two 24" and 36" diameter subsea replacement pipelines with wall thickness of 0.938" (23.8mm) and 1.25" (31.75mm) this respectively. The pipelines are carbon steel internally FBE coated and externally coated with FBE and concrete weight coat. The maximum water depth for 24" pipeline along the route length of 6.9km is 108.3ft (33m). The maximum water depth for 36" pipeline along the route length of 7.6km is 101.7ft (31m). The initial near shore burial length proposed for 24" and 36" new subsea pipelines were 3.94km and 3.99 km respectively corresponding to water depth of 7.5m. This was in line with the near shore burial length of existing 24" and 36" subsea pipelines which were also buried up to 7.5m water depth from the shore line.

It was found that the requirement to bury the existing subsea pipelines up to 7.5m water depth was governed by the anticipated marine activities. The need to bury both subsea pipelines up to 7.5m water depth was re-evaluated using the alternative approach outlined in section 2 and following the steps presented earlier in this section. The numerical wave propagation simulations based on refined/accurate bathymetry and metocean data indicated that surf zone for both pipelines extends up to 5m water depth from the shore line. The revised near shore burial lengths for 24" and 36" subsea pipelines based on different criteria are outlined in Table 3.

Burial Length Criteria	Trench to Water Depth LAT (m)	Trench Length (m)
	24" Pipeline	
Surf zone	5	1,588
Marine Activities	6.1	2,950
On-Bottom Stability	6.1	2,950
	36" Pipeline	
Surf zone	5	1,357
Marine Activities	5	1,357
On-Bottom Stability	5	1,357

Table 3: Revised Near Shore Burial Lengths for 24" and 36" Subsea Pipelines

The optimized near shore burial lengths for 24" and 36" pipelines are presented in Table 4.

Subsea Pipeline	Initial Proposed Burial Length (m)	Optimized Burial Length (m)	Reduction (%)
24"	3,941	2,950	25.1
36"	3,985	1,357	65.9

Table 4: Optimized Near Shore Burial Length for 24" and 36" Subsea Pipelines

Case Study 3: The third case study involves four subsea pipelines comprising of two 42" diameter and two 48" diameter sizes. The wall thickness of 42" and 48" subsea pipelines is 0.938" and 1.575" respectively. The pipelines are carbon steel internally FBE coated and externally coated with FBE and concrete weight coat. The maximum water depth along the route length of 65.8km is 156ft (47.5m). The initial near shore burial lengths proposed for the subsea pipelines based on different criteria are outlined in Table 5.

Burial Length Criteria	Trench to Water Depth LAT (m)	Trench Length (m)
Surf zone	7.5	29,000
Marine Activities	5.2	17,800
On-Bottom Stability	7.5	29,000

Table 5: Initial Near Shore Burial Lengths of Subsea Pipelines

The near shore burial length of nearby existing subsea pipelines in the same field was found to be 9,500m corresponding to a water depth of 4.5m. The required burial length for the new pipelines was calculated to be 10.75 km corresponding to a water depth of 4.5m. The root cause for the mismatch between burial lengths was found to be the use of approximate/available bathymetry and metocean data as well as the lack of numerical wave propagation simulations to determine the extent of surf zone. By using the alternative approach outlined in section 2 and following the steps presented earlier in this section, the revised near shore burial length was found to be 13.8 km as shown in Table 6.

Subsea Pipelines	Initial Proposed Burial Length (m)	Optimized Burial Length (m)	Reduction (%)
42" and 48"	29,000	13,800	52.4

Table 6: Optimized Near Shore Burial Length of Subsea Pipelines

4. Implementation

The alternative approach for optimizing near shore burial length was implemented in company standards and procedures by mandating the methodology presented in this paper to be employed. This ensured that accurate bathymetry and metocean data are used in determining the true extent of surf zone through numerical wave propagation simulations. Furthermore, a detailed metocean study and comprehensive geotechnical data is required to be availed for use in on-bottom stability analyses and approval should be obtained from engineering department. As a final step, the calculated near shore burial lengths from different criteria should be correlated with burial length of existing subsea pipelines to achieve desired optimization of near shore burial length. As demonstrated by a number of case studies in section 3, the alternative approach for optimizing the near shore burial length significantly reduced the final burial requirements of subsea pipelines which resulted in:

- Less environmental impact
- Uncomplicated maintenance
- Reduced downtime
- Significant cost savings
- Schedule improvement

5. Concluding Remarks

This paper presents an innovative approach to optimize near shore burial requirements of subsea pipelines approaching land from offshore fields. This approach involves the use of accurate metocean and bathymetry data to identify the true extent of splash zone as well as the use of actual field experience to determine the optimum near shore burial length. The presence of hard/rocky seabed further supports the optimization of burial length which can be challenging and can pose the risk of a major schedule delay. The approach presented in this paper has been successfully applied to reduce the near shore burial length of a number of replacement and new subsea pipelines. A number of case studies are included, where near shore burial length has been optimized based on field experience, and the associated benefits are also highlighted. The innovative approach presented in this paper can be used to significantly reduce the near shore burial requirements of subsea pipelines. This optimization will result in less environmental impact, reduction of capex and opex costs as well as schedule improvement will lead to early start up.

Acknowledgement

The authors would like to thank Saudi Aramco management for permission to publish this paper.

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The LTS Futures Project – a UK Operator's (SGN) Experience of Assessing the Feasibility of Repurposing Their Natural Gas Transmission System to Transport Hydrogen

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Abstract

The Local Transmission System (LTS) is the backbone of the United Kingdom (UK) energy network, delivering natural gas from the National Transmission System (NTS) to towns and cities across the country.

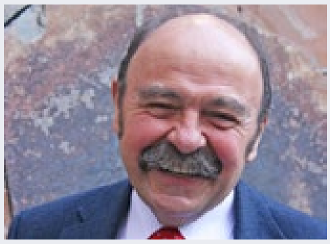
The four Gas Distribution Networks (GDNs) operate approximately 11,000 km of high-pressure pipelines, operating at pressures above 7 barg. The pipelines were originally designed to transport and store natural gas.

The UK Hydrogen Strategy states that: "Low carbon hydrogen will be critical for meeting the UK's legally binding commitment to achieve net zero by 2050". Hydrogen behaves differently to natural gas, therefore it is necessary to assess how it affects the existing LTS infrastructure.

The LTS Futures Project is a first of a kind, £30 million, joint funded project between SGN, the UK energy market regulator OFGEM, and the other UK GDNs. The project is led by SGN and looks to repurpose a 30 km natural gas transmission pipeline to hydrogen for a live demonstration trial, which will inform the development of a Blueprint methodology for repurposing the LTS. The LTS Futures Project is researching, testing and collating evidence to understand the compatibility of LTS assets, pipelines, associated plant and ancillary fittings in hydrogen, which will all be captured in the Blueprint.

The aim of the Blueprint is to provide a methodology to determine if a natural gas LTS asset is fit for hydrogen service and identify any data gaps, or further work needed for repurposing for hydrogen service.

THE J.N.H. TIRATSOO COMMEMORATIVE WHITEPAPER



For readers who may not be so familiar with that name: John Tiratsoo was an eminent member and pillar of our industry. He is perhaps best known as the former editor of Pipelines International magazine and the Journal of Pipeline Engineering. John was also co-founder and co-organizer of the Pipeline Pigging and Integrity Management conference and exhibition (PPIM). He made major contributions to our industry and has been a driving force in the professional sharing of information.

The following paper by Gemma Simpson, Nancy Thomson, Courtney West, Jane Haswell, Andrew Cosham & Gary Senior was chosen by the PPIM organizer, Clarion, and made available for reprint in this edition of the PTJ as a commemorative tribute to John Tiratsoo. The paper was presented at the recent PPIM held in Houston February 12-16, 2024. Special thanks to BJ Lowe and Ben Stroman of Clarion for making this possible.

1. Introduction

Hydrogen has a growing interest from a variety of sectors and stakeholders for blending / replacement of natural gas and so as a potentially valuable decarbonisation tool for governments, industries and consumers.

Hydrogen can be produced in several ways, both with fossil fuels and renewable energy. Currently, 95% of global hydrogen is produced through a process of steam methane reforming (SMR) of fossil fuels, either coal or natural gas – referred to as 'grey' hydrogen, or 'blue' hydrogen if the carbon emissions are captured and stored or reused. The most widely discussed and proposed alternative to SMR is to produce hydrogen through electrolysis – referred to as 'green' hydrogen, generally using renewable energy produced during off-peak times.

The move to decarbonisation in the UK has generated major interest in initiatives exploring the use of existing natural gas networks (pipelines and installations) for the transportation and distribution of hydrogen. SGN's 'Future of the LTS' project is one of the most advanced projects relating to above 7 barg pipelines. The project is investigating the requirements for repurposing the Local Transmission System, (LTS) to transport hydrogen. This project includes a live trial of the Grangemouth to Granton (GG) pipeline, which is currently decommissioned and held under low pressure nitrogen.

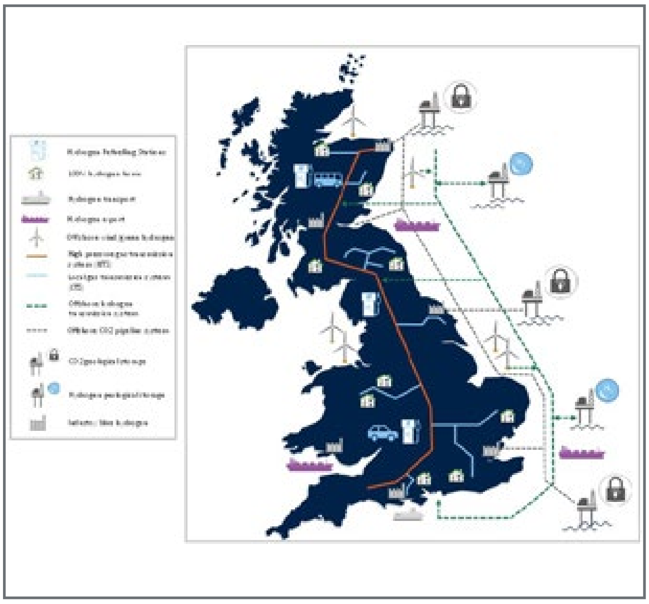


Figure 1: Potential future UK hydrogen system transformation

2. Pre project studies

SGN carried out pre project studies to consider the repurposing of the LTS for the transportation and storage of hydrogen or carbon dioxide. The Hytechnical project was a scientific and regulatory feasibility study which considered the requirements of standards to ensure compliance with safety legislation, the compatibility of the materials to ensure that the materials of existing natural gas networks are appropriate for safe transportation of hydrogen, and the risks posed to people by a pipeline failure. A detailed assessment of LTS pipelines confirmed that a significant percentage of the LTS network consists of relatively low-strength pipeline grades that operate at low stresses. Both factors are conducive to the pipeline's suitability for hydrogen transportation and storage as the use of higher strength steels and higher pressures leads to potential increased susceptibility to hydrogen degradation and an increased demand on the pipeline steels in terms of stresses.

Pipeline case studies were used to identify pipeline sections which were suitable to be repurposed for hydrogen use. These case studies included the decommissioned pipeline from Grangemouth to Granton, which was identified as having potential to be repurposed for hydrogen transportation. The requirements for LTS repurposing were considered in the Hytechnical programme, which comprised of:

1. Desktop exercises to understand the impact hydrogen has on:

    a. Inspection, Maintenance and Repair (IMR);

    b. Repurposing Pressure Reduction Installations (PRI); and,

    c. Building Proximity Distance (BPD) and separation distances to parallel pipelines.

2. Development of hydrogen supplements to gas industry standards (TD1, TD3, TD4 and TD13)

3. Updating of IGEM1/SR/25 hazardous area standard for hydrogen.

The Hytechnical programme concentrated on identifying the gaps that needed to be addressed in the development of approved industry standards and to ensure safe best practice. This work ensured consistency in repurposing existing natural gas networks and construction of new assets, which complied with legislation. The desktop studies carried out by Hytechnical aimed at closing gaps identified in studies addressing the inspection, maintenance and repair, requirements for pressure reduction installation performance and quantitative risk assessment (QRA) gaps. The results of the desktop studies provide the evidence-based research that will feed into the IGEM documents hydrogen supplements. Specifically, the IGEM TD document supplements were aimed at allowing new hydrogen pipelines to be installed (allowing industrial clusters to be decarbonised) and provide the re-qualification process (including material testing) for repurposing pipelines.

In parallel with this, SGN shared the findings of the work to identify any further gaps, and chaired an IGEM group called 'LTS Futures' which comprised membership from all the gas distribution networks, HSE, BEIS and other industry bodies. This group worked collaboratively to identify knowledge gaps which were then addressed in the LTS Futures Research Programme. These included:

1. Evaluation and specification of materials requirements

2. A live trial to provide results for the development of a procedure, terms the Blueprint for repurposing LTS pipelines for hydrogen service.

3. Laboratory and offsite testing to ensure the performance of old or vintage materials is adequate for transporting hydrogen, that existing defects can be tolerated and that available modification and repair methods are acceptable, and the consequences of unplanned releases and failure are understood and can be evaluated.

The above knowledge gaps were developed into a research programme with 6 Elements, described in this paper.

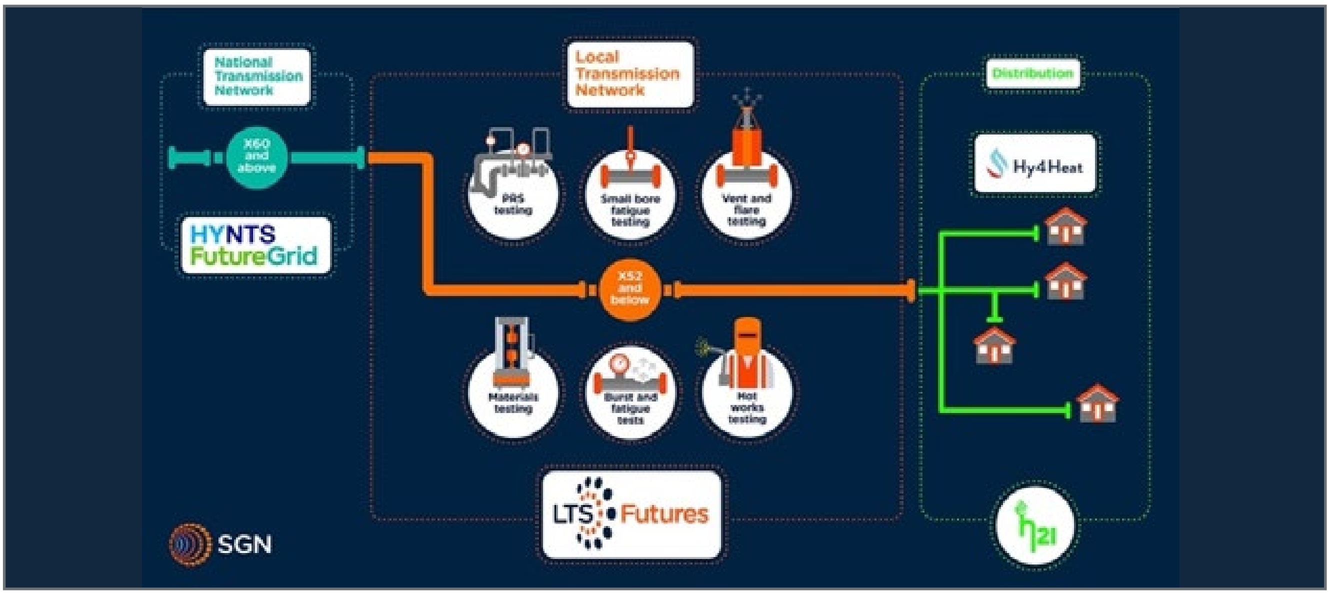


Figure 2: Interaction of LTS Futures project with other UK projects

Figure 3: LTS Futures project – six key Elements

3. Project scope and timeline

SGN are undertaking the LTS Futures Project, which forms part of the United Kingdom's (UK's) national hydrogen research programme to deliver a net zero decarbonisation solution for customers.

The project seeks to research, develop, test and evidence the compatibility of the LTS assets, pipelines, associated plant and ancillary fittings for hydrogen service. The aim of the project is to demonstrate that the LTS can be repurposed to transport hydrogen, providing options for the decarbonisation of power, industry, heat and transport by delivering a safe supply of energy to all customers both during, and after, the energy transition.

The project was launched in April 2022 and will run until 2025 after the completion of the live trial of the LTS pipeline in 2024/25. Delivery of the LTS Futures project will support critical future heat policy decisions, providing understanding on the role of our extensive LTS in achieving net zero for the SGN networks in Scotland and the south of England, and beyond.

The pipeline includes:

- 25.163 km of 457 mm diameter x 6.35 mm wt x X52 grade spiral welded pipe

- 3.845 km of 457 mm dia x 9.52 mm wt x X52 grade seamless pipe
- Internal coating – epoxy resin
- 1 x 457 mm Class 300 ball valve in 610 mm x 610 mm concrete pit
- 2 x 150 mm Class 300 ball valves
- 762 mm dia sleeves (grouted and forged end seals)
- Cold bends, forges bends, sweepolet connection
- Local concrete protection
- 100% radiography of welds
- External coating – coal tar enamel
- Hydrotest pressures – 6.35 mm spiral weld section – 84.7 barg, 9.52 seamless sections 127 barg

A decommissioned pipeline section for the live trial was selected to avoid the need take an operational natural gas pipeline section out of service, which would require the construction and installation of a diversion to maintain security of supply. To identify a relevant pipeline section for the trial, sections of decommissioned LTS pipelines were assessed against a number of factors to determine whether they provide a reasonable representation of typical LTS pipelines. This assessment identified that the SGN decommissioned Grangemouth to Granton pipeline provided the best representation for the LTS Futures Live Trial. This pipeline represents a bounding case in terms of material grade (X52 is the bounding case above which material performance factors or material qualification is required), pipe type (spiral welded pipe presents the greatest technical challenge) and diameter and wall thickness, which represent respectively the maximum hazard and the highest probability of failure.

The pipeline has been mothballed since the 90s, so its use in the live trial requires a comprehensive assessment of the pipeline integrity and condition in order to bring it back into service, as well as to repurpose it from natural gas to hydrogen service.

The Grangemouth to Granton pipeline provides the upper bound case material for the LTS. The material (vintage X52) is upper bound case of 93% of the population of LTS pipeline assets, and the pipeline's construction includes key components which are typically included in LTS pipelines, such as block valves, cold bends, forged components and sleeves. The controlled demonstration will validate the interactions of these features together and with hydrogen.

The route includes:

- 35 road crossings
- 11 crossings of other services
- 4 rail crossings
- 1 river (Almond) crossing

The route passes through rural and suburban areas. In the rural farm land areas, typical land drains are installed to maintain the quality of the land. In the suburban areas, the pipeline route passes close to occupied properties, which will require that the risk posed by the pipeline to people be assessed, and the need for risk mitigation measures, including the installation of slabbing over the pipeline to provide protection against potential damage caused by third parties working close to the pipeline. In addition, the route is close to Edinburgh airport, which will require operational and emergency procedures to take account of potential interference with flight paths.

4. The UK transmission system

The UK natural gas network is comprised of the National Transmission System (NTS) and the Local Transmission Systems (LTS) which are connected to the NTS. The NTS provides the capability for the transportation of natural gas from UK system entry points which are mainly located at coastal locations where gas arrives in the UK from offshore fields, interconnectors or by LNG ships. The NTS transports the gas from these location to the 8 distribution gas networks. The LTS is connected to the NTS network and transports the gas from the NTS Offtakes to the towns and cities within the distribution network where the pressure is reduced further to supply commercial and domestic users. The combination of the NTS and the

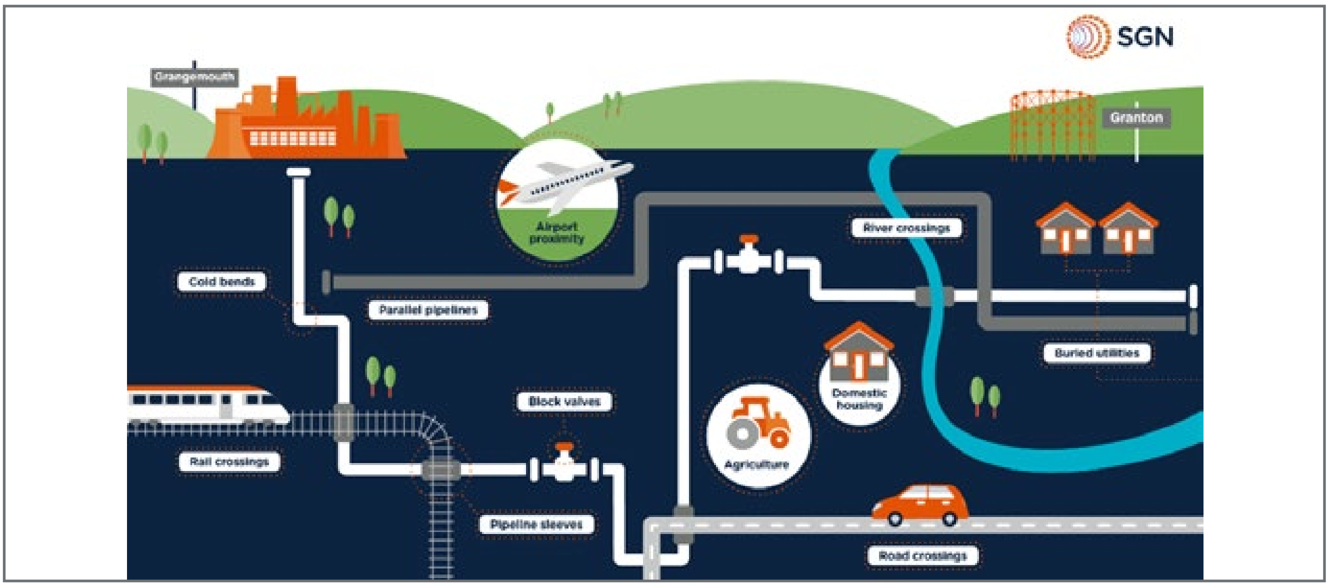


Figure 4: Schematic of the Grangemouth to Granton pipeline

LTS provides a fully integrated gas network for energy supply within the UK from the Entry Points to the medium and low pressure networks. The NTS comprises 7,600 kms and the LTS comprises over 11,000 kms of pipelines.

SGN owns and operates over 3,000 kms of HP (>7barg) pipelines, 75,000km of distribution main (<7 barg) and 8,000 pressure reduction installations (PRI's) - supplying 5.9 million homes and businesses.

The key parameters of the NTS and LTS pipeline populations have been analysed using the UKOPA (United Kingdom Operators' Pipeline Association) data which are summarised and compared in Table 1.

The NTS and LTS are maintained and operated to the UK standard IGEM/TD/1 [1]. The development of IGE/TD/1 commenced in 1964, with the construction of the UK NTS. The development of TD/1 was based on a detailed review of the ASME B31.8 standards, identification of the key principles and application of these to the UK environment, with particular attention to the higher population density. The development of gas industry specifications commenced with the development of the IGE/TD/1 standard.

A high level review of the UK pipeline population carried out for the HyTechnical Project confirmed that, on average, the LTS population is older than the NTS population. The LTS population is also a lower grade and operates at lower design factors. The chemistry and microstructure of older pipelines is likely to more susceptible to hydrogen embrittlement than that of newer pipelines of equivalent strength.

65% of the NTS and 81% of the LTS was designed and constructed during the development of IGE/TD/1 principles in Editions 1 and 2, and 35% of the NTS and 19% of the LTS meets the current design, construction and

Parameter	NTS	LTS
Diameter	95%≥ 610 mm	90% ≤ 610 mm
Material Grade	78% ≥equal to or greater than X52	89% equal to or lower than X52
Design Pressure	70 - 94 bar	49% ≤ 40 bar
Design Factor	≥ 0.68	49% ≤ 0.3
Commission Date	31% before 1973	71% before 1973
Hydrotest	High level (105% SMYS)	Typical - 1.5 x Design Pressure
Pressure cycling	Pressure cycled	Pressure cycled
Odour	Gas not odourised	Gas odourised

Table 1: Comparison of NTS and LTS Pipeline Populations

testing requirements in IGEM/TD/1 Edition 5 or 6. The LTS is constructed using older material and therefore incorporates a wider range of material manufacturing quality.

5. Risk

In the UK Pipeline Land Use Planning (LUP) zones are set by HSE based on calculated pipeline individual risk transects, and societal risk is used to carry out ALARP assessments when risk reduction must be considered. The risks posed by hydrogen pipelines depend upon the probability and consequences of failure. The probability of failure may be affected by the degradation of material properties, and the consequences of failure are influenced by the higher flame speed and flame temperature for hydrogen. The higher flame speed results in higher explosion overpressures for delayed ignition, the higher flame temperature affects objects engulfed in the flame, but as the radiative heat flux is lower the thermal hazard zone is not increased.

Risks posed are dominated by rupture, and so will increase if the rupture rate due to fatigue, external interference and/or ground movement is increased as a result of material degradation, and if the consequences are more severe because of the increase in overpressure due to delayed ignition.

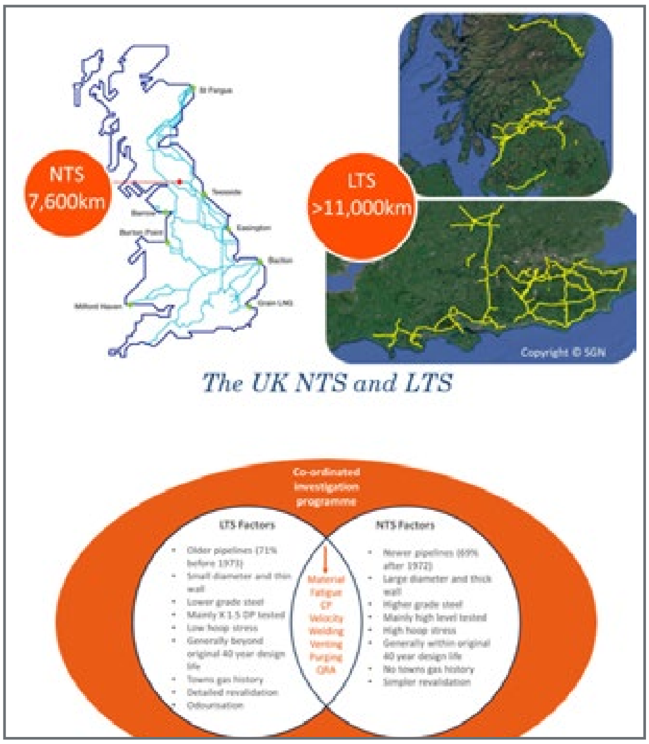


Figure 5: NTS vs LTS differences

Overpressure is a hydrogen specific consideration which could potentially affect the pipeline Building Proximity Distances (BPD). An initial evaluation of BPDs for hydrogen pipelines was carried out in the Hytechnical work programme. LTS Futures will use the results of delayed ignition rupture tests of a 6" pipeline section which are being carried out as part of the FutureGrid project to determine the overpressure and thermal consequences of a pipeline rupture. The results of these tests will allow validation of the LTS Futures BPD estimates and assess whether the overpressure hazard can be addressed within the thermal consequence distances.

6. UK Code requirements for hydrogen transmission pipelines (new build and repurposing)

UK pipelines are subject to legislative control under the Pipelines Safety Regulations 1996 (PSR 96) [2]. The Regulations cover general duties for the safe management of all pipelines in the UK relating to design, construction, operation, maintenance and decommissioning. In addition, the Regulations specifically define Major Accident Hazard Pipelines (MAHPs), which are pipelines that convey 'dangerous fluids' and for which the consequences of failure would present a major accident resulting in significant danger to people. Additional duties are defined for these pipelines, including notification, preparation of a Major Accident Prevention Document (MAPD), emergency procedures and arrangements, and provision of information to Local Planning Authorities for inclusion in the Emergency Response Plan for the area. High pressure gaseous hydrogen is classed as a dangerous fluid, as per natural gas.

Pipeline design requirements for high pressure steel transmission pipelines are specified in the standard IGEM/TD/1 [1] for natural gas pipelines. The Hytechnical research programme has developed a supplement to TD/1 for hydrogen pipelines.

The UK design requirements are integrity based in that design principles and requirements prescribe design parameters to be applied to ensure pipeline integrity and therefore consequently safety. However, where requirements are not definitive or conditions which fall outside the prescribed requirements are being addressed, the use of QRA as a decision tool is

allowed. IGEM/TD/1 allows the use of individual and societal risk levels calculated using Quantified Risk Assessment (QRA) to be used to route pipelines and to carry out site specific risk assessments.

IGEM/TD/1 was originally developed by the UK gas industry to support the development of the National Transmission System (NTS) for natural gas. The principles of the American pipeline code ASME B31.8 were revised for application in the UK. The key principles identified were the requirement to assess the infrastructure within a fixed corridor along the proposed route of a pipeline, classify the area according to the infrastructure, and limit the pipeline operating stress in areas of high levels of infrastructure development. These principles were accepted and modified for application in the higher populated areas in the UK. The modifications involved replacing the fixed corridor width with a multiple of the building proximity distance (BPD), which defines the minimum required separation between the pipeline and existing normally occupied buildings, and limiting the operating stress in highly populated areas to 30% of the pipe material's Specified Minimum Yield Stress (SMYS).

The BPD is derived as the distance to a thermal radiation level of 32 kW/m2 from a steady state fire, and its definition takes account of the low probability of pipeline failures and the possibility, due to the linear nature of the hazard, of escape or to take cover from the effects of thermal radiation. The BPD is calculated according to the diameter and pressure of the pipeline. The BPD is based on thermal consequences, and work to include the effects of overpressure were identified as a gap and are being carried out in LTS Futures.

Since the adoption of the ASME standard principles for application in the UK, major research programmes have been undertaken in the USA (Battelle Memorial Institute, Pipeline Research Council International (PRCI)), Europe (directed by the European Pipeline Research Group (EPRG)) and UK (Gas Council, British Gas) to evaluate the failure behaviour of and consequences of failure for high pressure gas pipelines. In addition, the USA experience of material manufacture and fabrication problems was accepted and applied in the UK IGEM standards, specifically in terms of design factor and wall thickness, proximity requirements, hydrotest requirements and fatigue. The aim of the ASME and IGEM standards are to minimise risks (posed by gas transmission pipelines) to the public, by:

- Recognising pipeline failure modes and consequences
- Minimising effects of consequences of failure (proximity distances)
- Minimising frequency of failure:
- resistance to damage (wall thickness requirements)
- control of failure mode (material properties, Design Factor)

The development of the IGEM UK standards for hydrogen pipelines builds on the history of the UK standards development through requirements to take account of:

- The physical, chemical, thermodynamic and energy properties of hydrogen compared to natural gas The impact of hydrogen on the properties of steel, including the impact on defect limits and repair techniques
- The hazards associated with releases of hydrogen, and the impact on safety management requirements
- The increase in flowrate required to account for the reduced energy density, and the consequent increase in gas velocity on vibration, noise and acoustic fatigue
- Changes to inspection, maintenance and repair requirements

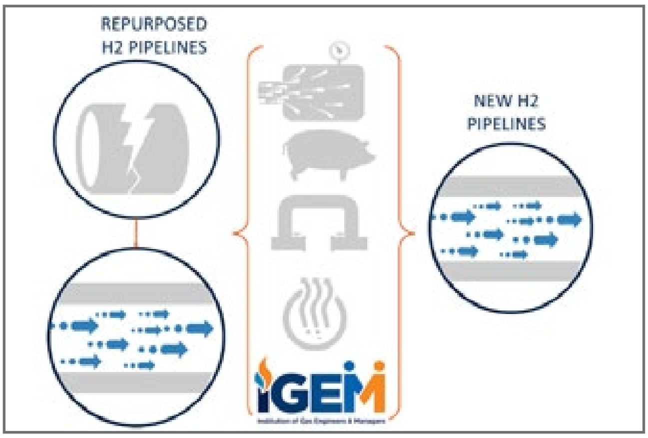


Figure 6: IGEM – Supplements for hydrogen (repurposing and new build)

7. Project Elements

There are six integrated elements of the project which are summarised below.

7.1 Element 1 - Design of live trial and pipeline modifications

Objective

Provide formal confirmation that the condition and integrity of the proposed pipeline are acceptable for safe operation, and that the risk posed by the pipeline are acceptable for hydrogen service.

Key aspects

To be able to repurpose the Grangemouth to Granton pipeline for hydrogen service in accordance with IGEM/TD/1, a design and operability assessment is required. This assessment includes an evaluation of the material properties and condition of the pipeline e.g.

- *A hydrotest, an inline inspection or equivalent*
- *A cut out of a small section for material testing (not a pre-requisite for repurposing)*
- *Detailed line walks*
- *Above ground survey (e.g. Close Interval Potential Survey (CIPS))*
- *Building proximity surveys*
- *etc*

The above activities require co-ordination and liaison with landowners. The results of these activities are analysed to identify modifications or repairs required for repurposing.

Key learnings to date

- *Demonstration of pipeline integrity by a successful hydrotest to a minimum pressure of x1.5 MOP*
- *CIPS and DCVG surveys completed and follow up digs as required*
- *Completion of IGEM/TD/1 report, acting as a technical audit of the pipeline*
- *Development of an outline blueprint for repurposing the LTS*
- *Defining pipeline integrity management requirements (IMR) prior and during live trial*
- *Drafting Major Accident Prevention Document (MAPD) for hydrogen operation*
- *Development of project specific welding procedures for hydrogen pipeline / pipework*

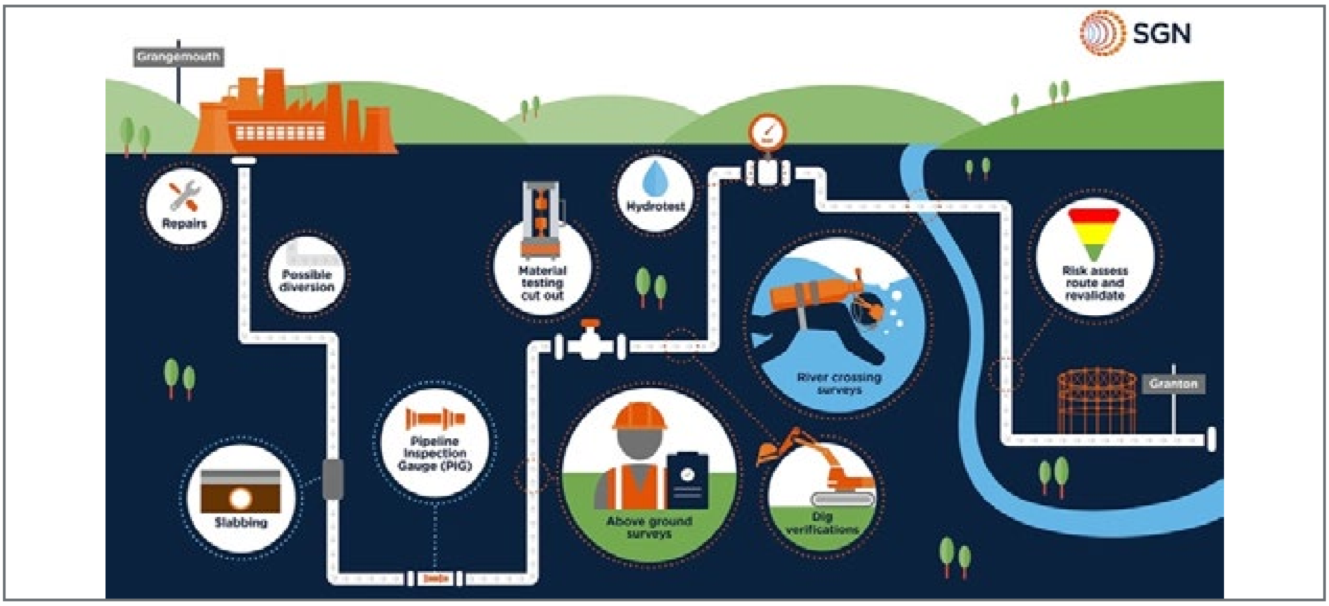


Figure 7: Live trial design considerations

- Design feasibility study completed for hydrogen supply
- Purging requirements analysed by modelling
- Pipeline section removed for material testing (Element 2) and full scale testing (Element 3)

Figure 8: Marker Posts

Looking forward

- *Detailed design of hydrogen supply / entry unit / flare stack*
- *Conduct all construction works for hydrogen supply / entry unit / flare stack*
- *Update blueprint*
- *Update MAPD*

7.2 Element 2 - Laboratory material testing

Objective

To determine the effect of pressurized, gaseous hydrogen on the material properties of vintage steel currently used to transport natural gas.

Key aspects

The material properties (such as strength, ductility and toughness) of the pipeline are key characteristics that affect how the pipeline responds to loads and its tolerance to defects. Coupon scale testing provides an opportunity to perform a large volume of testing to evaluate the effect of hydrogen on such material properties.

Material tests will provide a comparison between failure in air and hydrogen. This will influence the acceptability of defects (acceptable, or repair, or replace) and will inform the QRA and Blueprint.

The Grangemouth to Granton pipeline is considered a good example of pipelines in the LTS due to its vintage, grade, and geometry. Line pipe from the Grangemouth to Granton pipeline and from other pipelines in the LTS will be tested to provide a risk profile of all the LTS materials to understand the likely extent to which LTS pipelines can be repurposed and an assessment of cost. This will include options for intervention, ranging from increased inspection and survey to repair and replacement. The outcome of the testing will also inform industry standards.

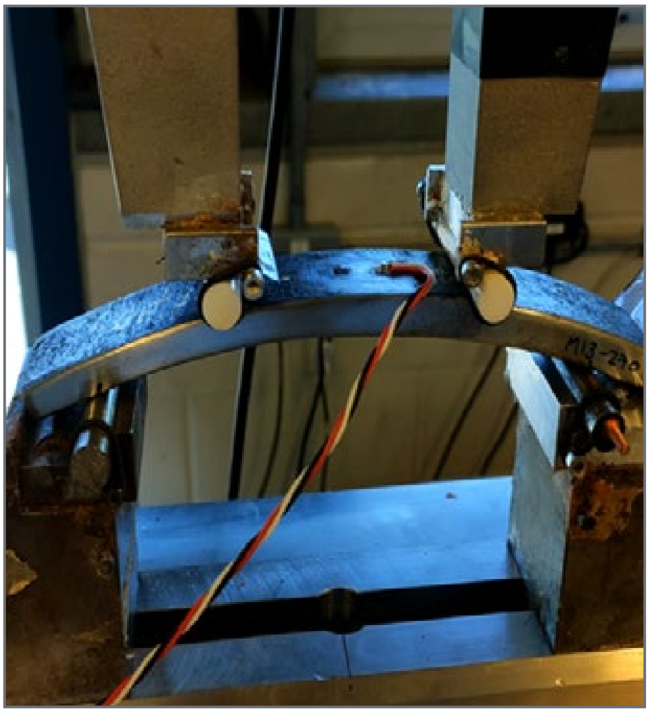


Figure 9: Fatigue Endurance Testing in Air

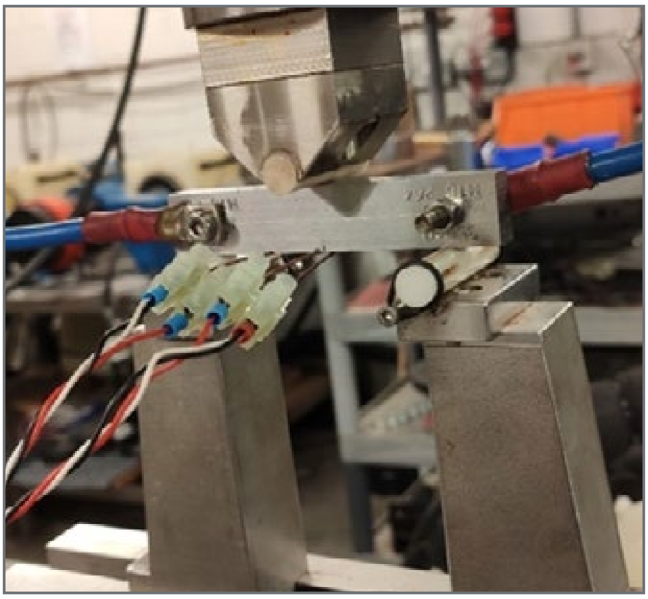


Figure 10: Fracture Toughness Testing in Air (SENB Specimen)

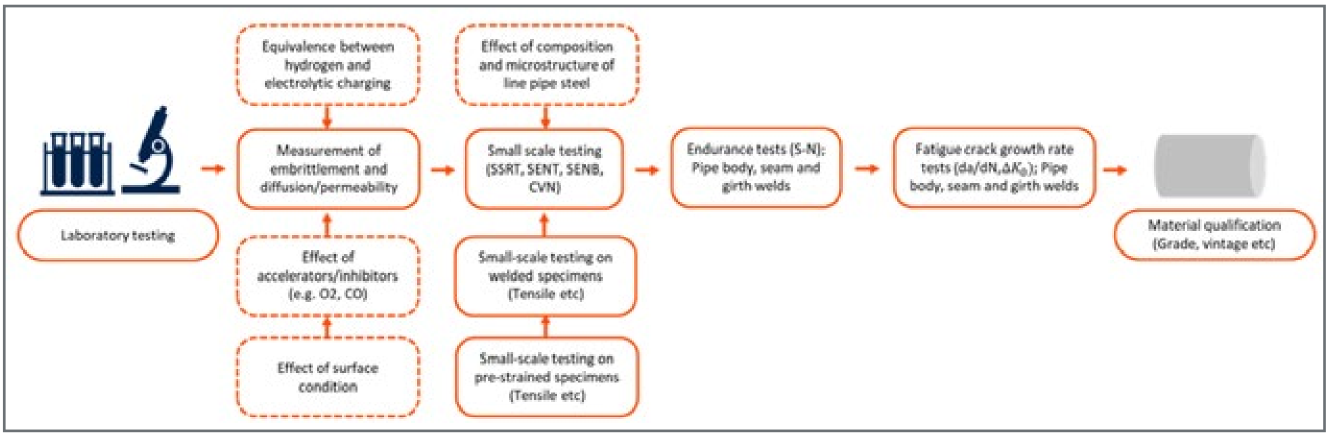


Figure 11: Material testing flow chart

Key learnings to date

- *The pipe body, girth welds and seam welds have been characterised through microscopy, hardness and chemical composition testing to inform on the baseline properties.*
- *Transverse strip tensile and Charpy V-notch Impact tests have been performed on the material as would typically be carried out as a quality control test on line pipe for a new pipeline.*
- *Tensile tests and Slow Strain Rate Tensile (SSRT) tests have been carried out in air and gaseous pressurised hydrogen. Tests on the pipe body, girth welds and seam welds have been conducted. The testing demonstrates a consistent, reduction in the ductility in hydrogen.*

Looking forward

- *Constant load, threshold stress intensity factor (K1H) tests are to be performed in a gaseous hydrogen environment, as per Option 2 of ASME B31.12.*
- *Fracture toughness testing is to be conducted using both Single Edge Notch Bend (SENB) and Single Edge Notch Tension (SENT) specimens in both air and pressurised, gaseous hydrogen. Initial results will inform if there is a favoured specimen type for testing material used in pipeline applications.*
- *Fatigue Crack Growth Rate (FCGR) tests and Endurance tests are to be conducted in both air and pressurised, gaseous hydrogen. Frequency Scanning tests are also to be conducted to determine the effect of loading frequency on crack growth rate within a hydrogen environment.*

7.3 Element 3 - Off-site testing

Six work packages are to be undertaken by DNV at their Spadeadam Test Facility, Cumbria. The testing programme includes: hot work testing, ignited releases with overpressure and thermal radiation measurements, fatigue testing of branch connections in hydrogen service, pressure reduction station performance testing, and burst tests and fatigue tests of pipeline defects.

Work Package 1 – Hot works

Objective

To investigate whether it is possible to safely carry out live welding on a hydrogen pipeline and determine whether the weld properties and fatigue performance are degraded because of hydrogen.

Key aspects

The aim of the hot works package is to demonstrate the following:

- *That live welding can be conducted on a hydrogen pipeline safely under a defined procedure.*
- *Determine if standard SGN welding specifications are applicable to hydrogen pipelines.*
- *Develop a weld procedure qualification record (WPQR) and establish weld quality.*
- *Heat decay trials*
- *Investigate weld fatigue performance in a hydrogen environment.*

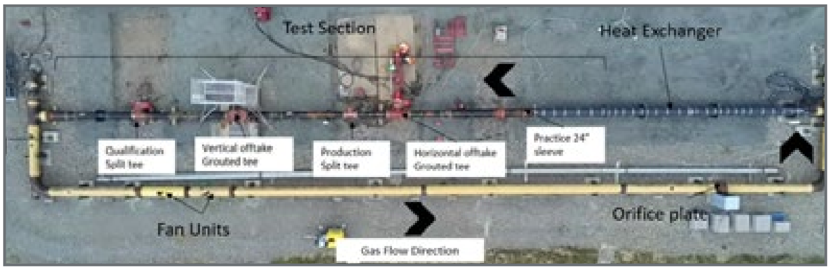


Figure 12: Test loop at DNV Spadeadam

Figure 13: Test loop at DNV Spadeadam

Figure 14: Setting up slit tee for welding at DNV Spadeadam

Key learnings to date

- *Heat decay trials under flowing hydrogen conditions to understand heat transfer rates*
- *Successful welding x3 split tees under flowing hydrogen conditions*
- *Successful grouting of an epoxy tee under flowing hydrogen conditions*
- *Drill x4 split tees under flowing hydrogen conditions*
- *Development of Welding Procedure Specifications (WPS's) for live welding to a hydrogen pipeline*

Looking forward

- *To weld an 18in split to the Grangemouth to Granton pipeline whilst under hydrogen operation (Element 4)*

Work Package 2 – Burst and Fatigue Tests

Objective

The aim of the burst and fatigue tests is to provide data which can be compared to baseline tests which also form part of the programme to see if the effect of hydrogen exposure reduces the burst pressure and fatigue life of pipeline defects. This information can then further inform hydrogen pipeline defect assessments.

Key aspects

The burst and fatigue work package will produce data on the effects of hydrogen exposure on pipeline defects. Nine burst tests will be carried out on samples with dents, dent and gouges and crack-like defects. Fourteen fatigue tests will be carried out on samples with crack like defects, dents in the pipe wall, dents on the seam welds, and dents on the girth welds. An epoxy tee and split welded tee will also be fatigue tested as part of WP1. The vessels to be tested in hydrogen will be soaked in hydrogen for approximately 90 days prior to the start of the tests.

Figure 15: Hydrostatic Burst Test

Figure 16: Heating of defect on hydrogen burst test vessel

Figure 17: Hydrostatic Burst Test Defects (before and after test)

Figure 18: WP1 Tee Fatigue Test Vessel

Key learnings to date

- *Finite element analysis conducted during the design of the tests has provided information on the minimum length of a test vessel, to avoid interaction between the defect and the domed ends.*
- *Hydrostatic burst testing completed and provided baseline values for defect failure pressures.*
- *Pre-heating of defects on hydrogen burst vessels to attempt the break down surface oxide layer.*
- *Hydrostatic fatigue pre-test to evaluate instrumentation suitability and cycle time.*

Looking forward

- *Hydrogen burst testing of five vessels currently undergoing extended soaking period.*
- *Hydrostatic fatigue testing of purpose made defects and vintage welds.*
- *Hydrogen fatigue testing of purpose made defects and vintage welds.*
- *Hydrogen fatigue testing of grouted epoxy and welded tee from live application in WP1.*
- *The effect of hydrogen on the burst and fatigue strength of defects in pipelines.*
- *The relevance of material properties (fracture toughness, etc.) measured in small-scale tests to the behaviour of defects observed in full-scale tests.*

Work Package 3 – Fatigue testing of small-bore branch connections

Objective

To determine the fatigue performance (vibration-induced) of small-bore attachments and to obtain data to assess if the performance is reduced as a result of hydrogen exposure.

Key aspects

The work package will produce data on the effects of hydrogen exposure on small-bore branch connections when subject to a high frequency excitation force to simulate pipework vibration loading. A 610mm OD x 11m long test vessel will be fabricated. The test vessel will include ten welded attachments with a range of sizes, onto which a typical pipe configuration.

When the test vessel has been hydrogen saturated the internal hydrogen pressure will be increased to test pressure and then vibration generators attached to each branch connection to produce the required high frequency vibration loading. By monitoring strain gauges attached to the branch pipes the frequency and amplitude of the vibration will be measured.

The test will run until a branch connection fails, this will then be repaired, and the test continued until all the branches have failed or representative number of cycles have been achieved.

Figure 19: WP1 Tee Fatigue Test Vessel

Key learnings to date

- *Natural frequency calculations for different connection types / geometries*
- *Design of complex external loading system*

Looking forward

- *Completion of fatigue testing programme*

Figure 20: Venting / flaring trials

Work Package 4 – Vent and flaring trials

Objective

The vent and flaring work package will investigate the thermal radiation, noise and overpressures generated when hydrogen is vented and flared under pressure. This data will enable direct comparisons to be made with natural gas venting and flaring data and provide information for QRA's.

Key aspects

The aim of the vent and flaring work package is to collect data on the following:

- *The noise spectrum and noise level at 100 m distance for hydrogen vent and flaring operations.*
- *The overpressure generated when delayed ignition is experienced with venting and flaring operations.*
- *The thermal radiation generated from hydrogen flaring operations.*
- *Good quality normal and high speed video of unignited and ignited plumes.*

Key learnings to date

- *Noise and overpressure measurements were recorded and subsequently analysed*

Looking forward

- *Technical reporting of tests conducted*

Work Package 5 – Performance testing of pressure regulator equipment

Objective

The aim of this work package is to establish if existing pressure reduction units can function correctly when operating with hydrogen and if the units can accommodate the higher flow / velocity required to transmit the same amount of energy as natural gas. The testing will establish if there are any instabilities in the sensing instrumentation and whether the units experience vibration or noise issues as a result.

Key aspects

To perform these tests an experimental arrangement is currently being designed, which though not finalised, will be based on Figure 21.

Key learnings to date

- *Design feasibility for test rig complete.*

Looking forward

- *Detailed design of test rig, then construction and commissioning*
- *Implement test programme*

7.4 Element 4 – Live trial

The key characteristics and deliverables of the live trial are illustrated in Figure 22.

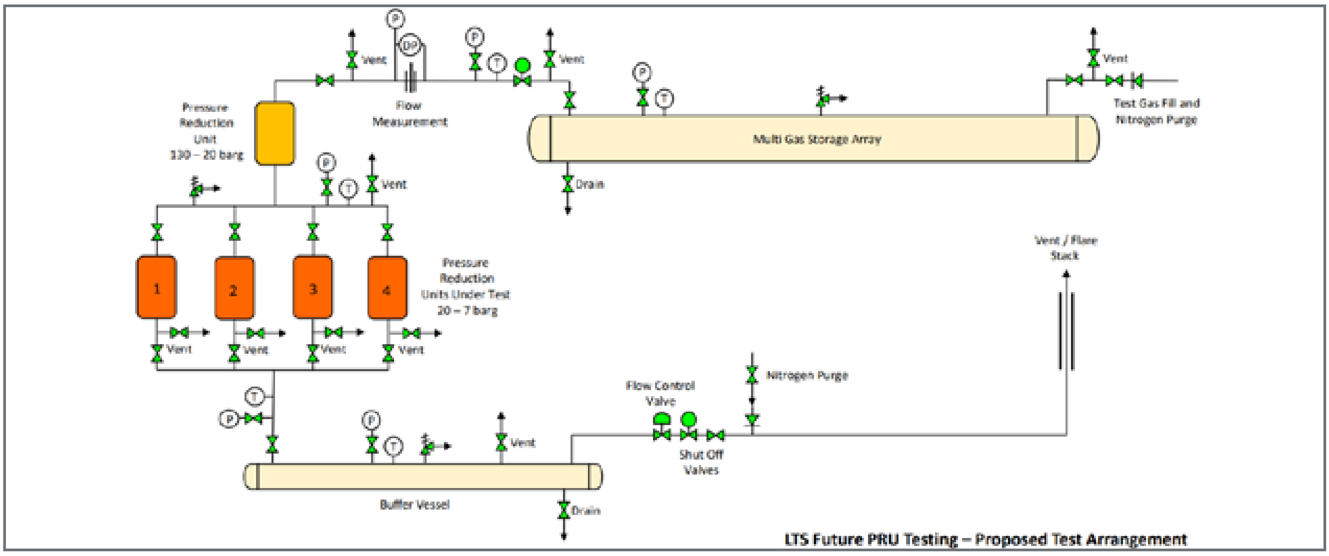


Figure 21: Example of pressure regulator experimental arrangement

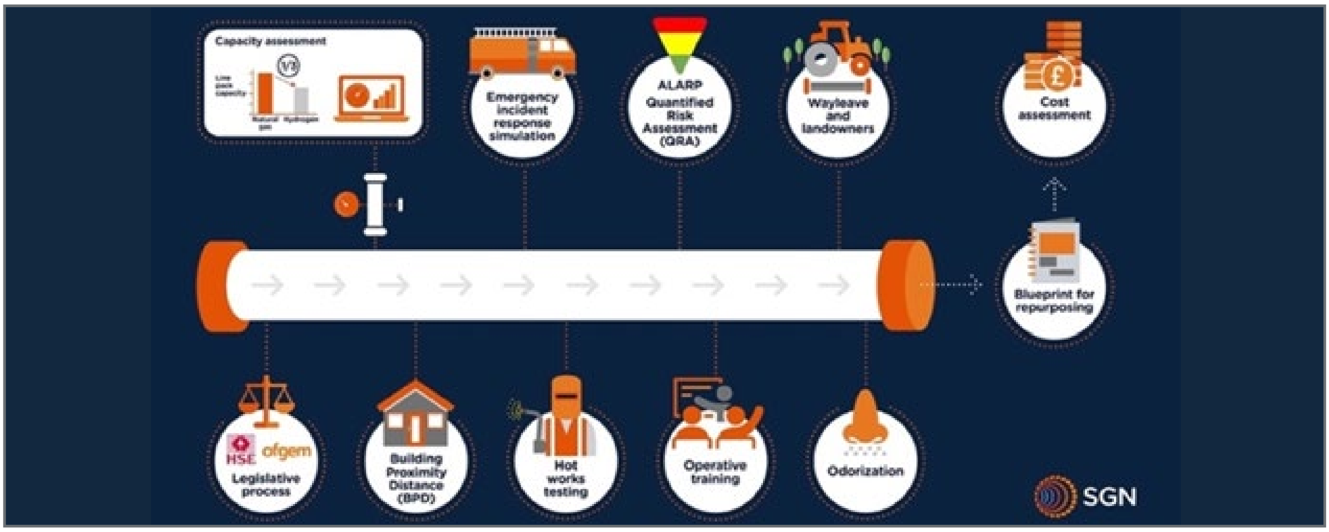


Figure 22: Live trial – key characteristics

Objective

To address the following:

- *Purging / Commissioning*
- *Venting/Flaring,*
- *Maintenance/Operations (i.e. split tee and drilling / stoppling)*
- *Emergency Response*
- *Decommissioning.*

Key aspects

In order to carry out the live trial, the capability, competence and resilience of the systems, organization and people involved in the proposed repurposing must be confirmed as acceptable. Operational, maintenance and emergency procedures are required to ensure safe management. These procedures must be applied to actual features on real pipelines by people who need to be trained.

The live trial will validate a number of the previous findings and conduct various simulations, training and exercises. The three main exercises carried out on the demonstration pipeline will be: an emergency response simulation, line pack tests and hot working onto the live hydrogen pipeline.

Key learnings to date

- *Not yet commenced.*

Looking forward

- *Live trial to be conducted Q4 2024 / Q1 2025*

7.5 Element 5 - QRA and Case for Safety

Objective

To develop a quantified risk assessment (QRA) and Case for Safety, for regulatory review.

Key aspects

Pipeline Safety Regulations (PSR 1996) & Gas Safety and Management Regulations (GSMR 2015)

[3] require gas transporters have a fully defined 'safety case' to ensure the safe operations of pipelines that are kept well maintained and good state of repair. These regulations set the required principles for safe operation of pipelines which filter down into a hierarchy of further detailed and defined sets of standards and specifications (such as BS, ASME, IGEM etc.) which cover a wide range of engineering and safety parameters to be compliant with. These standards fundamentally require that any change in service or operating conditions of high pressure pipelines must have a safety evaluation carried out.

Key learnings to date

- *QRA of the 3" supply line and the 3 most populated locations along the Grangemouth to Granton pipeline has shown that risk levels are broadly acceptable despite using conservative factors on failure frequency and conservative assumptions on ignition probability.*
- *A draft Case for Safety has been developed in accordance with the framework agreed with the UK safety regulator (HSE) that incorporates key information from the other elements of the project.*

Looking forward

- *The QRA conservatisms are expected to be reduced following the conclusion of material and full-scale test programs.*
- *The Case for Safety is a living document that will be updated as required.*
- *Any existing procedures referred to in the Case for Safety will be reviewed and amended for hydrogen use as required prior to the live trial.*

7.6 Element 6 – Knowledge dissemination

Objective

Sharing knowledge with stakeholders, e.g. other operators, government agencies and wider industry.

Key aspects

LTS Futures will liaise with associated projects including FutureGrid, H100 Fife, H21 and Hy- Deploy, ensuring that knowledge dissemination, continuity of learning, complementary scopes and co-ordinated timelines are achieved across the projects. Engagement with key stakeholders on a site- specific, regional and national level will cover disciplines of statutory consultees, local authority, political, industry, regulatory bodies, local community, public and customers, and other project stakeholders.

Key learnings to date

- *Several stakeholder (internal and external) engagement exercises have been conducted which have encouraged a two-way communication process, giving SGN the opportunity to explain the project purpose and its objectives, whilst enabling feedback and challenge / review*
- *Several conference papers are being prepared to provide shared learning.*

Looking forward

- *Further stakeholder engagement exercises are to be conducted prior and post the live trial.*

8. Development of the LTS Futures Blueprint

The key requirements for the Blueprint are:

1. Capacity Assessment – Determine whether the required capacity for future energy delivery is sufficient at the current pipeline maximum operating pressure (MOP).
2. Data Assessment – Identify the data required to complete the application of the Blueprint, including route survey, availability of original design and construction records and operations and maintenance records required by pipeline standards. In particular, the records which are essential to completing the assessment.
3. Integrity Assessment – Perform fitness for service assessments for the impact of hydrogen on materials, based on material test results (to be developed under LTS Futures Elements 2 and 3); and for all existing damage and defects, taking account of degradation of material parameters due to hydrogen embrittlement.
4. Quantified Risk Assessment – Calculate the individual and societal risks posed by operation in hydrogen service, and confirmation that the risk levels are As Low As Reasonably Practicable (ALARP). Where risks are not ALARP, identify the required mitigation actions to reduce risk levels.
5. Safety Justification – Taking into account the outcome of previous steps, detail all modifications required to justify that the assets will be acceptable for future operation in hydrogen service from a safety perspective.
6. HSE Liaison – Follow the notification procedure required by HSE, develop and agree the Blueprint methodology with the HSE, and HSE review and comment on documentation produced as part of the Blueprint application process.

Key learnings to date

- *The majority of the data required for pipeline repurposing should be referenced in the TD/1 MOP Affirmation audit. Availability and accessibility of records has been variable.*
- *There is not a requirement for installations to be formally audited and assessed under IGEM/TD/13 (as it is for pipelines under IGEM/TD/1). This can result in fragmented records.*
- *Good quality TD/1 reports are an important element in demonstrating that a pipeline can be repurposed.*

Looking forward

- *The LTS Futures Blueprint will be further updated at key project stages.*

9. Conclusions and final remarks

The key outcome of the LTS Futures programme will be the development of a Blueprint for repurposing, and in developing the Blueprint the project will demonstrate the safety, technical, commercial, regulatory and operational requirements for repurposing an LTS transmission pipeline. These outcomes are essential for demonstrating the compatibility of the LTS in a hydrogen environment and provide political and investor confidence in decarbonising industrial clusters and the potential for LTS networks to play a role in the future energy systems.

This project aims to generate learning for industry, government, regulatory bodies, stakeholders and the public, on both a national and international level to help inform the UK energy transition. While the LTS Futures project is not exhaustive, the programme covers an extensive (breadth and depth) scope of works that will be transformational in validating the evidence base for hydrogen in the UK gas networks. Of primary importance will be the demonstration that the Grangemouth to Granton pipeline can be repurposed safely, securely and cost effectively to transport 100% hydrogen in the same way that natural gas is transported in the LTS by gas distribution networks today.

The live trial of the Grangemouth to Granton pipeline will provide the majority of this learning, as this trial represents typical LTS operating conditions in terms of the route, and operation and maintenance activities.

The programme seeks to:

1. Provide evidence to determine the safety and suitability of LTS network assets for hydrogen culminating in a live trial to prove the practical and operational aspects.

   a. Develop a methodology (blueprint) for future repurposing projects, ensuring safety, efficiency and applicability throughout the Great Britain

   b. Determine the suitability of LTS materials for 100% hydrogen

   c. Validate the operational strategy for operating a hydrogen network, identifying any differences from operating a natural gas network

   d. Develop the skills and competencies for managing, operating and maintaining assets in the hydrogen economy, with the procedures required to support it

2. Provide the technical foundation and investor confidence to support delivery of industrial cluster decarbonisation in:

   a. Development of knowledge and acceptance of hydrogen within the public, industry, standards bodies and regulatory agencies

   b. Development of an optimised and validated cost model for future repurposing projects

   c. Provision of visibility of the commercial and regulatory aspects for future operation of repurposing hydrogen networks, this insight will support future regulatory models

   d. Commencing the understanding of the interface and commercial arrangements with hydrogen suppliers

3. Defining the role of LTS in system transformation and facilitate industrial clusters by:

   a. Identifying the requirements the regulatory (safety, commercial and environmental) framework required for the GB Hydrogen network in terms of

      i. Compliance with Pipelines Safety Regulations

      ii. Compliance with Pressure Systems Safety Regulations

      iii. Identify any modifications required to the Gas Safety (Management)

      iv. Regulations or other legislation

      v. The Land Use Planning and Planning consent process

   b. Confirming whether a repurposed LTS will deliver the required operating pressures, flowrates and linepack to facilitate the green recovery

Acknowledgements

The authors would like to acknowledge the contribution of the following to this complex project:-

- **SGN:** Antony Green, Max Koronka, Sophie Bladon, David Wylie, Craig Henderson, Craig Keating, Steve Howells
- **PIE:** Nikki Barker, Tony Stonehewer, Graham Goodfellow, Chris Lyons, Chris Hughes, Peter Boothby
- **DNV:** Clara Huéscar Medina, Adam Robinson, David Hall, Sarah Kimpton
- **ROSEN:** Mark Atkinson
- **TWI:** Jonathan Wilson
- **NGS:** Ashley Burnhope TDW: Jamie Bull
- **Stats Group:** Neil Mackay
- **Steer Energy:** Nick Ryan Premtech; Martin Nicholson

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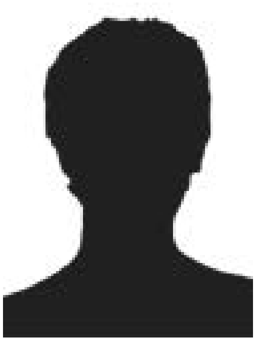

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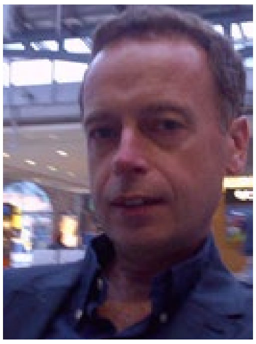

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Ask the Experts

Future Fuels & CO_2

Q1) What are the primary challenges in establishing a regulatory and technical framework for hydrogen pipelines?

Victoria Monsma: The worldwide ambition is to shift to clean energy sources to reduce CO_2 footprint. However, national safety regulators will require evidence to demonstrate that the operators are "hydrogen-ready". To achieve "hydrogen readiness," a pipeline operator must guarantee that their infrastructure, operations, and personnel are fully equipped to manage hydrogen transportation with the same target safety level as natural gas . This involves a few key elements:

- *Technical Compatibility:* The operator's pipeline infrastructure, including pipelines and equipment, must be compatible with hydrogen transportation.
- *Regulatory Compliance:* Pipeline operators must comply with regulatory and code requirements related to hydrogen transportation, including safety, environmental, and operational standards.

Handling hydrogen comes with some challenges that are different from natural gas. This requires adapting existing operations, practices, and organizations, and developing new strategies to ensure safe and efficient transportation. For many years, pipeline operators have effectively operated and managed high-pressure, long-distance oil and natural gas pipelines, relying on their experience and comprehensive safety and integrity data. However, the transportation of hydrogen through similar pipelines poses new challenges in terms of design and operation, integrity, and risk management.

The lack of extensive historical data and operational experience with hydrogen pipelines poses a significant challenge in establishing regulatory standards and technical requirements. Current industry codes and standards for repurposing existing pipelines for hydrogen transport are prescriptive and generally not practical for conversion of pipelines built to natural gas standards. Multiple ongoing efforts are under development by Codes and Standards organizations to provide updates to these requirements.

Additionally, the legal and regulatory framework for H_2 transportation is still evolving in most nations. This is one of the greatest challenges faced by the energy sector, the lack of a clear legal and regulatory framework for hydrogen transportation. The safety of such pipelines is regulated using approaches developed for natural gas, which is being debated by industry and regulators.

Q2) What are the challenges for integrating Hydrogen into existing pipeline operations, and how can these challenges be addressed?

Tim Illson: For most regions, it will be challenging to manufacture enough hydrogen to operate an entire pipeline system with 100% hydrogen, and there may be insufficient widespread demand initially for a pure hydrogen network to be required. Pipeline network operators have to plan for operating with blends of hydrogen and natural gas or running a hydrogen network in parallel with a natural gas network. These options have different challenges; for blends, the main issue is that not all gas users will require hydrogen but still need natural gas. This may be mitigated by the use of deblending technology, which separates the hydrogen and natural gas after offtake from the pipeline.

A UK deblending test has been approved as part of the FutureGrid programme. The main challenge with operating parallel hydrogen and natural gas networks is that many facilities would be shared (e.g., compression). The mitigation is careful network planning so that the hydrogen network uses spare capacity in the facilities; for example, a site with multiple compressors could dedicate some to hydrogen and the rest to natural gas. Then, as demand for hydrogen increases, more facilities can be dedicated to the hydrogen network. In addition, the integrity management system for hydrogen will be different than for natural gas and needs to be suitable for hydrogen.

Kevin Hemingway: Operators encounter significant challenges when integrating alternative gases, such as hydrogen, into existing gas infrastructure. One of the primary challenges stems from the inherent differences in calorific value and thermal content between these alternative gases and traditional natural gas. Hydrogen has a significantly lower thermal content volumetrically, necessitating the combustion of larger volumes to meet the same energy requirements.

Furthermore, most existing equipment and appliances within the gas distribution network and end-user facilities are optimized for natural gas, posing compatibility issues with alternative gases. Gas operators must ensure blended gases, including those containing hydrogen, remain safe for transport and compatible with various customer appliances such as stoves, heaters, and boilers. This requires comprehensive risk assessments, compatibility studies, potential retrofitting of equipment, and the utilization of robust gas quality tracking systems supported by advanced analytical techniques. By addressing these challenges, gas operators can facilitate the successful integration of hydrogen while maintaining reliable service for customers amidst the transition to decarbonized energy sources.

Q3) We are looking to accurately measure and monitor the flow of hydrogen in pipelines. Are there technologies we can rely on to improve this?

Kevin Hemingway: Hydrogen has a low density and high diffusivity, which can complicate traditional measurement methods designed for denser gases like natural gas. As a result, accurately quantifying hydrogen flow rates becomes more challenging, potentially leading to inaccuracies in measurement data.

To address these challenges, various technologies, such as ultrasonic flow meters, advanced computational fluid dynamics (CFD) simulations, and hydraulic modelling software solutions, are being developed to improve the accuracy and reliability of hydrogen flow measurements.

While ultrasonic flow meters utilize sound waves to measure the velocity of hydrogen flowing through the pipeline, advanced computational fluid dynamics (CFD) simulations model the behaviour of hydrogen within the pipeline, considering factors such as pressure, temperature, and flow dynamics. By simulating different scenarios, operators can better understand hydrogen flow behaviour and optimize pipeline performance.

Advanced hydraulic modelling software solutions are another important tool for improving hydrogen flow measurement accuracy. A powerful tool, such as Synergi Gas, is great for system planning and can be used to size main extensions and replacements for economy and performance, and create long-term strategic plans that maximize gas network infrastructure. It can also help make daily operating decisions for load approval, compressor operations, and other operational support challenges. Hydraulic models help monitor pipeline conditions, including flow rates, pressures, and temperatures and provide feedback to operators where SCADA may not be available. Furthermore, by integrating data from sensors with hydraulic models, operators can detect anomalies promptly and validate measurement data through virtual simulations.

Q4) What are the key factors we should consider when repurposing existing infrastructure for carbon capture and storage (CCS) initiatives?

Kevin Heminway: Repurposing existing infrastructure for carbon capture and storage (CCS) initiatives requires careful consideration of various factors to ensure the safety, reliability, and efficiency of CCS systems. One critical aspect is assessing the structural integrity and suitability of the existing infrastructure for CO_2 transportation. This involves conducting thorough evaluations of pipelines and facilities to determine their capacity to safely transport CO_2 and implementing necessary upgrades or retrofits as needed to meet CCS requirements.

Managing the potential risks associated with CO_2 transportation is another key consideration. Challenges such as fracture control, corrosion, and impurity control must be effectively managed to mitigate risks and ensure the long-term integrity of the CCS system. Implementing strategies to prevent system overpressurization and equipment damage is essential for maintaining safe and reliable operations.

Sophisticated modelling techniques also play a crucial role in addressing challenges associated with repurposing existing infrastructure for CCS initiatives. By utilizing advanced hydraulic modelling solutions, operators can assess the dynamic behaviour of CO_2 flow and predict and mitigate transient pressure surges effectively. Designing surge mitigation measures based on these simulations is critical to ensuring system reliability and preventing equipment damage.

Furthermore, implementing robust leak detection solutions is essential for maintaining the integrity and safety of CCS systems. Continuous monitoring of pressures, inventories, and flows enables early detection of leaks or anomalies, allowing prompt response and mitigation measures to prevent environmental risks.

Victoria Monsma: Carbon dioxide (CO_2) can be transported via pipelines in different states, such as gaseous, liquid, or dense phase, depending on temperature and pressure. Gaseous CO_2 provides less transport capacity because of the lower density of the product and associated frictional pressure drop. Transporting gaseous CO_2 would typically be limited to moderate pipeline lengths and transfer rates. Liquid CO_2 can provide higher transfer capacity; however, for the existing natural gas pipeline, there might be some potential process and operating challenges. For example, in the case of liquid CO_2, one of the key considerations is a ductile running fracture. To prevent ductile running fractures, the decompression speed of the fluid needs to be higher than the fracture propagation speed of the pipeline wall. This shall be considered when assessing the existing pipelines for CO_2 transport. If pipe properties cannot arrest cracks, then the operator will need to consider the installation of crack arrestors.

Furthermore, when repurposing existing pipelines for CO_2 transport, the topography of the pipeline route becomes crucial. It can present significant challenges, particularly with varying elevations along the route. The transportation of CO_2 demands careful consideration to address the complexities imposed by diverse topographical conditions. Additionally, in the event of a CO_2 release, the topographical features pose an additional concern. Due to its density, CO_2 has a tendency to flow downhill from elevated areas such as hillsides to lower-lying regions like valleys, where populations often reside.

Q5) How can we optimize the integration of renewable natural gas (RNG) into existing natural gas systems?

Kevin Hemingway: Renewable natural gas (RNG), also known as biomethane, is produced by upgrading biogas to remove contaminants like CO_2 and N_2, resulting in a high-BTU gas predominantly composed of methane. RNG sources are characterized by small but consistent flow rates, necessitating flow control rather than pressure regulation. The thermal (energy) value of RNG may vary but is often slightly lower than that of natural gas, although it can occasionally be enriched with propane to align with customary gas energy values.

The proposed thermal value of RNG compared to natural gas is a critical consideration, as a lower value means a larger volume of RNG is required to provide the same energy output. Enforced specifications for RNG system entry are advantageous in ensuring compatibility with existing natural gas infrastructure and operations.

Modelling the integration of RNG into natural gas systems involves assessing whether there is sufficient pipe capacity to accommodate RNG during peak load periods, which is typically the biggest challenge. Conversely, ensuring the system can absorb RNG throughout the year, particularly during periods of low demand, presents another significant challenge. By addressing these differences and challenges comprehensively, integrating RNG into existing natural gas systems can contribute to a more sustainable and diversified energy supply.

Q6) When blending hydrogen or any other future fuel, how can we prepare for variations in energy supply and demand?

Kevin Hemingway: Modeling variations in energy supply and demand plays a pivotal role in facilitating the integration of hydrogen blending into existing energy systems. Using advanced modelling techniques, energy planners can analyze the dynamic interactions between hydrogen production, storage, distribution, and consumption alongside traditional energy sources. This enables the identification of optimal blending ratios and operational strategies to maximize the benefits of hydrogen integration while ensuring system stability and reliability.

Moreover, sophisticated modelling tools such as Synergi Gas allow for the simulation of different scenarios, including variations in hydrogen availability, demand patterns, and renewable energy generation. By forecasting future trends and assessing potential challenges, stakeholders can proactively design infrastructure upgrades, grid reinforcements, and market mechanisms to effectively accommodate hydrogen blending.

Additionally, modeling enables the evaluation of hydrogen blending's impact on overall energy system performance, including factors such as grid flexibility, emissions reduction, and cost-effectiveness. This holistic approach aids in developing policies and regulations that incentivize hydrogen adoption and support its role in achieving decarbonization goals.

With each issue of the journal, the "Ask the Experts" section focuses on a new topic of particular relevance to the pipeline industry. People from the international pipeline community are invited to send in their questions which will afterwards be answered publicly by selected experts from the respective field.

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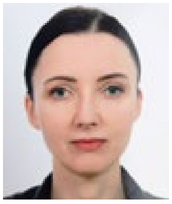
This issue's experts

Kevin Hemingway, Product Manager – Synergi Gas and Synergi Liquid, DNV

Kevin holds business and engineering degrees from Drexel University and Temple University, respectively. He has served the international natural gas and water utility industries for over 20 years by providing computer-based modelling tools, consulting services, client support, and professional training.

Kevin joined DNV in 1996 and has served in client-facing roles focused on gas and liquid hydraulic modelling throughout his tenure. Currently, he is the Product Manager for Synergi Gas and Synergi Liquid, where he continues to collaborate with customers and help DNV better meet its clients' needs through software and service offerings. When not evangelizing for DNV's modellers or modelling software, he can be found hiking the trails of Pennsylvania with his family, both two-legged and four-legged.



Victoria Monsma, Principal Integrity Specialist, DNV

Victoria Monsma, a Principal Pipeline Specialist at DNV with more than 15 years of experience. She is currently engaged in consulting on a broad spectrum of Energy Transition projects. Victoria is a Subject Matter Expert in a field of reuse of existing natural gas network for transport hydrogen. As a SME she is involved in the developing of the company hydrogen service portfolio, methodology, guidelines, service specification. Using her expertise, she is supporting different clients such as gas TSO's and DSO's, authorities and other in making them an informed decision with regards to the conversion of their assets to hydrogen.

Tim Illson, Principal Integrity Specialist – Hydrogen and Carbon Transport, DNV

Tim Illson has worked in industrial corrosion control for more than 35 years and is presently involved in consultancy for a wide range of hydrogen and CCUS activities, and renewables infrastructure. Specific areas of technical expertise include pipeline repurposing studies (H_2/CO_2), corrosion control and materials selection for hydrogen and CO_2 pipelines, test programme development for validating hydrogen materials, corrosion of wind turbine structures, cathodic protection of monopile interiors, and offshore and onshore coating systems.

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