Keeping Safety Grounded in the Hydrogen Takeoff: Revisiting Risk in Pig Launching and Receiving Operations

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ABSTRACT

Hydrogen will increasingly be present in our gas pipelines and distribution networks in the coming years. As nations seek to reduce carbon emissions to net zero, hydrogen will be a critical medium to store and transport energy harvested by renewable and other sources. The pipeline and energy industry's focus has been directed to the challenges that hydrogen, either blended with methane or transported in its pure form, will pose to existing infrastructure and production processes.

To optimize the useful life span of any pipeline system and prevent integrity failures, the ability to introduce and remove mechanical, intelligent or isolation pigs rapidly and safely is of great importance. The pigging industry is actively engaged in overcoming technical challenges and identifying suitable advances in pig design and material selection to ensure necessary operations can continue in the presence of hydrogen.

While responses to the technical challenges are timely and necessary, as pipeliner's we must also make sure that the safety of our operational teams is given the same focus. In any pigging operation, but particularly in gas lines, the launching and receiving of pigs is the most safety critical aspect. The properties of hydrogen exacerbate these risks significantly due to the molecule size, increased flammability range, volatility of the fuel blend in the presence of air and material property degradation.

This paper highlights the elevated risk profile that hydrogen poses during the launching and receiving process and identifies the mitigation actions operating teams should be made aware of through training with revised worksite procedures and risk assessments.

1. THE SIGNIFICANCE OF HYDROGEN

With the move to hydrogen service, it must be acknowledged that the properties of hydrogen pose an increased risk to those involved at the front line. The greatest risk and exposure comes when breaking containment to load or retrieve tools. The action of opening the door, also known as a quick actuating closure (QAC) [1] is the point at which

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potentially explosive atmospheres can be created and operators can be exposed to sudden pressure releases and projectiles.

The compressibility and dryness of the hydrogen means maintaining a steady tool run speed is more challenging as the tools require more abrasion resistant sealing elements. Hydrogen also poses a greater risk in the launching and retrieval process as methane between 5% and 17% mixed with air will support combustion compared to hydrogen at 4% to 75%. Hydrogen-air mixtures are extremely easy to ignite requiring only 0.017 mJ ignition energy compared to 0.25 mJ for hydrocarbons [2].

The multiple risks associated with hydrogen are summarized in the European Industrial Gases Association (EIGA) 2004 report [2], "Hydrogen is lighter than air, highly flammable, easily ignited, heats up when reduced in pressure, does not support breathing and is one of the most difficult gases to prevent from leaking." To compound these concerns is the fact that pipeline materials, designed and maintained to prevent loss of containment are themselves under threat: "In the pure state, it presents some unique corrosion mechanisms and when combined with even small impurities (ppm), the corrosion concerns can multiply." Also, the tendency towards autoignition of leaks and atmospheric vents combined with the difficulty in seeing the flame make small leaks a serious potential personal injury risk.

2. PIPELINE PIGGING REQUIREMENTS

As with all new pipelines, one that has been constructed for the purpose of hydrogen service, will require pigging to sweep out mill scale, debris and construction materials. The modular cleaning pigs and foam pigs shown in Figure 1 can be used to form a cleaning program to prepare the line for the introduction of hydrogen and avoid product and system contamination. Pigs will also be needed to water fill for hydrotesting and to displace, dry and swab the testing medium once complete. Urethane batching pigs as shown in Figure 1 or modular pigs with high sealing ability will be used along with foam pigs for their swabbing action. The effectiveness of the drying program will influence the likelihood of future corrosion and product contamination once in service. This is the same for methane service but the constraints on cleanliness and dryness will be more onerous for hydrogen.

In the case of an existing pipeline being repurposed for hydrogen service, a more involved pigging program may be needed to achieve the standards of cleanliness expected for a new line. The pipeline may already have active corrosion and contamination with debris and flow restricting deposits. Before an existing pipeline can be approved for hydrogen service, it will be necessary to inspect and evaluate integrity threats with inline inspection (ILI) tools. Cleaning and proving pigs (Figure 1) will be required to prepare the line for the safe transit of these tools as well as to optimize data acquisition.

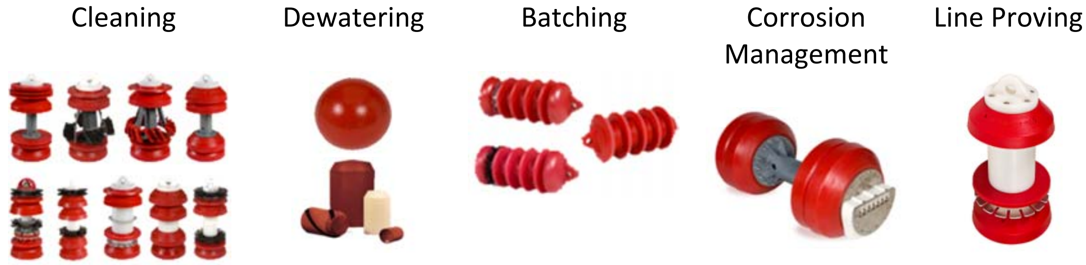

Figure 1 - Examples of commonly used mechanical / cleaning pigs

It is important that before conversion, all defects that are susceptible to hydrogen attack or degradation are sought out and removed or inactivated. EIGA suggests ILI of requalified existing pipelines for hydrogen service in the following circumstances:

- Cathodic protection records are missing or show protection as inadequate.
- Service history or material data reports are missing
- They have carried fluids such as crude oil or wet natural gas

Examples of ILI tools are shown in Figure 2 below. Further details on inspection technologies and prioritisation of integrity threats can be found in [4].

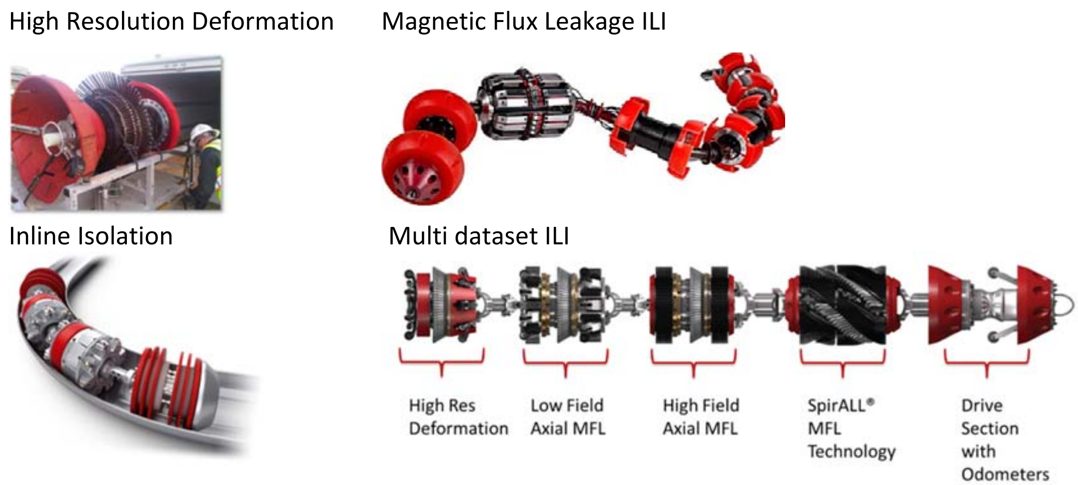

Figure 2 - Inspection and Isolation tools

Inline isolation tools may also be deployed to isolate and then retrofit or replace valves, and other equipment; as an alternative to through fitting isolations, while minimizing downtime and loss of product (see Figure 2).

PIGGING IN THE PRESENCE OF HYDROGEN

Once the hydrogen line is in service, certain material selection and safety considerations will apply. In the most optimal scenario, lines will be naturally clean and there may be no expectation of corrosion and cleaning with pigs will not be a primary management tool.

However, for pipelines transporting hydrogen-methane blends, or in repurposed lines, cleaning pigs may be more regularly called upon. One such course of remediation would be the "removal of corrosive agents. If the piping system can effectively launch, pass, and receive cleaning pigs, a cleaning program may be implemented, or existing pigging frequencies increased. Careful consideration shall be given when choosing the type of cleaning pig to ensure that a thorough cleaning is achieved and to prevent damage to the piping system, and if applicable, to the internal coating system" [3]. Cleaning will also be required to prepare for ILI or isolation tools.

Once the line is in service, the frequency and nature of integrity inspection will be determined by the operating conditions and composition of the product, as well as by the history of the asset. The material selection, design and operational considerations discussed in the following sections will determine the success of inspections in the presence of hydrogen. These requirements were covered in more detail in [5].

3. HOW ARE PIPELINE TOOLS SAFELY INSERTED AND RETRIEVED?

It is essential that pipelines are pigged to ensure safe and optimal operation, however this must not come at the cost of operational downtime, equipment damage, pollution, severe injury or worse. Tools must be launched and retrieved with suitable equipment, competent personnel and robust procedures to eliminate or mitigate risks. It is advantageous to have equipment installed on the line at suitable intervals to ensure that pigging operations can be conducted with minimal line intervention. This flexibility allows operators to conduct both planned periodic operations as well as responding to situations as they arise without having to undertake costly disruptive construction.

Vertical Launcher | Subsea Launcher | Automated Batch System | General Purpose

Figure 3 - Examples of different launch and receive designs

Tragically, there are many examples of severe injuries and fatalities caused by projected pigs and poorly designed and operated pig receivers [6] [7]. This is a point echoed by EIGA, with safety being a primary concern at the termination point of the pig run: "The pig catcher shall prevent the pigs from becoming airborne and endangering personnel" [2].

There are many different types of launching and receiving equipment (Figure 3) in operation, the variations are a result of a wide range of influencing factors including the location and primary intended function [8]. Available space can determine size and orientation, and the purpose of the anticipated pigging activity will dictate the design and functional requirements.

If valves are not opened and closed in the correct sequence, damage to pigs and piping systems may occur as well as risks of injury to personnel from a range of associated hazards. Therefore, a proven operating procedure must be followed in each launch operation and be established for each unique system design and operating conditions. More details on the typical launch and receive sequence and critical steps are available in [9].

4. MITIGATING HYDROGEN RISK BY DESIGN AND MATERIAL SELECTION

To mitigate the elevated risk profile of hydrogen, engineered controls such as compatible design and material selection for pigging equipment can reduce risk ahead of a specific operation being planned. Modifications are required to prevent damage of metallic components of the pig (brushes, fasteners, magnets etc.) and to ensure it remains intact in a hydrogen line [5]. In addition, some elastomers and polymetric materials will exhibit swelling with the ingress of hydrogen molecules [10]. It is therefore necessary to develop new sealing approaches to protect electronics and battery cannisters as well as critical sealing elements within the closure.

Polyurethane is the go-to material for pig cups and discs, but some enhancement is necessary to sustain function and ensure safety in hydrogen:

- Resistance to hydrogen permeability. If not mitigated this has the potential to cause rapid expansion when pressure is bled off as hydrogen attempts to leave the polymer structures.
- Prioritizing urethane properties to resist wear and hydrogen attack. Conventional solutions such as using “studs” in the urethane will not be available due to the spark risk and potential to damage internal coating.
- Urethane serves as a capacitor as it moves along the pipeline, the charge gained can be discharged when being retrieved. Additives in the urethane formula to allow charge to dissipate may be necessary.
- Certain regions and customers also require tools to be Appareils destinés à être utilisés en ATmosphères EXplosives (ATEX) compliant [11]. This need is set to become a minimal requirement in areas where hydrogen pipelines are operated.

5. SAFE WORKSITE DESIGN AND PREPARATION

Operational risks can be further reduced if it is possible to optimize the location, layout and design of the pigging station. For pre-existing locations, options may be limited but some basic principles should be applied where practicable.

The most comprehensive hydrogen standards available [3] [12] [2] make no direct reference to requirements for pigging station design and layout but there are detailed recommendations for other locations that may bring operators or contractors into proximity with the hydrogen line.

In reference to metering stations, EIGA provides the following guidance for ventilation, which could reasonably be applied to launch and receive locations as a minimum:

- Preferrable to locate a station outdoors.
- Design shall be such that the natural ventilation is well provided and that hydrogen cannot accumulate at the top.
- In instances where location is enclosed or in a pit, special consideration is required covering safe access and egress, ventilation systems, atmospheric monitoring and hazardous electrical designs.

ASME B31.12 [3] more specifically refers to "normal practice being to provide ventilation rates high enough to dilute hydrogen leaks of 25% of the lower flammability limit (LFL), i.e., about 1% by volume air."

For both operational and safety reasons it is essential that adequate space is provided around the launcher and receiver. Inspection tools can be several meters long, which will influence the length of the nominal and oversized barrels and must also be replicated immediately in front of the closure to allow manual or mechanically assisted insertion and retrieval. In reference to metering stations EIGA [2] recommends that "hydrogen piping may be installed on a concrete slab and the station surrounded by a fence….of a height of at least 2m". The ability to secure the pigging site when personnel are not present must be balanced against having clear and unobstructed emergency exit points during operations.

Regarding suitable ground cover, a ballast or gravel type covering can often be used around the pigging location to provide surface water drainage and avoid water logging or flooding. Some aggregates such as flints, can pose a spark risk so should be selected appropriately.

As pigging operations may be required any time in a 24-hour period and at any time of year it is beneficial to have lighting installed at the site so that work can continue safely in low light conditions, as per metering stations "lighting fixtures and installation shall conform to the code requirements for the hazardous electrical area" [2].

Any equipment permanently or temporarily installed at the pigging station will need appropriate grounding to prevent spark potential. Signage should be clear to alert anyone entering the site as to the prohibition of smoking, open flames or spark inducing equipment. Local regulations may be in place that define the requirements for intrinsically safe tools and explosive atmospheres such as the zoning system provided by ATEX.

6. OPERATIONAL PLANNING AND PROCEDURES

Once a safe worksite is established, sound procedures need to be implemented to provide control and appropriate use. ASME B31.12 requires a written plan with detailed instructions for employees covering operating and maintenance procedures for hydrogen. EIGA states that a management system shall be in place that includes the following, which can be directly applied to pigging operations:

- Safe operation of the pipeline system.
- Safe and effective execution of maintenance, modifications.
- Identification of personnel responsible for the management, operation and maintenance of the pipeline, with an appropriate organisation chart.
- A written work permit system, management of change (MOC) process and written operator and qualification program.
- Smoking and other sources of ignition are forbidden.
- Personal protective equipment including flame retardant clothing.
- Use of non-sparking tools and work permit for maintenance and/or repairs.
- Positive isolation is required prior to performing maintenance and or repairs
- Proper purging and inerting required prior to any welding or cutting.
- Temporary grounding is recommended during maintenance and/or repair.
- Plan covering facility failure, accidents, leakage, and other emergencies.

7. PERSONNEL, THIRD PARTIES AND SIMULATANEOUS OPERATIONS

The main objective of this paper is to recognise the role of field personnel in the hydrogen transition. Therefore, when measures are defined and captured in revised risk assessments and working procedures, it is paramount that a program of training and communication will allow operational personnel to adapt and plan accordingly to the new requirements [2][3].

Pigging operations can be complex and may require the personnel of multiple different companies to be onsite at the same time. This creates the potential for poor controls, lack of planning or miscommunication to increase the likelihood of an incident. Having work permit systems in place will reduce the potential for simultaneous or adjacent activities impacting the overall site safety. Ensuring all parties are aware of the heightened risks will help the transition to hydrogen progress without an increase in avoidable incidents. Rehearsed contingency plans with resources on site to respond to any incident should be in place.

8. CONTROL OF PIGGING VELOCITY AND RECEIPT

The velocity of a pigging run should be controlled to ensure the operational goals are achieved and “to avoid any potential mechanical damage to the pipeline and also for safety reasons.” [2]. ILI tools need to run below a stated maximum velocity and ideally at a steady and constant rate to acquire data at the desired resolution and avoid damage. Similarly, for cleaning pigs, running too fast may damage the urethane sealing and scraping elements leading to debris being passed over and not removed. Inspection tools and large diameter cleaning pigs can weigh several thousand kilograms so can deliver significant forces at high velocities. Lack of control when entering receivers can damage valves or closures that are not designed with high energy impacts in mind.

When pigging online with the pipeline product, compressibility of the medium makes velocity harder to control in a gas line than in liquid. When the pig encounters a restriction such as a wall thickness change or debris build up, it may stall until sufficient pressure builds to release it. Unfortunately, the release of stored energy can propel the pig for a period at velocities significantly above the upper tolerance for data acquisition before returning to a steadier profile. These “speed excursions” can result in insufficient data being collected, as well as risks associated with the forces generated.

As hydrogen is lower density than methane, these speed excursions will be exacerbated. In a modelling study [13] it was found that not only the peak velocity of the speed excursions increased significantly, but also the recovery curve to the normal flow rate was extended (Figure 4.) Due to the low density of the gas, when the pig stalls after encountering a restriction it takes longer for the required pressure to build, the peak velocity increases and there is a reduction in the medium’s dampening ability to slow the pig back to the base velocity. These effects are magnified as the hydrogen percentage increased within the blend.

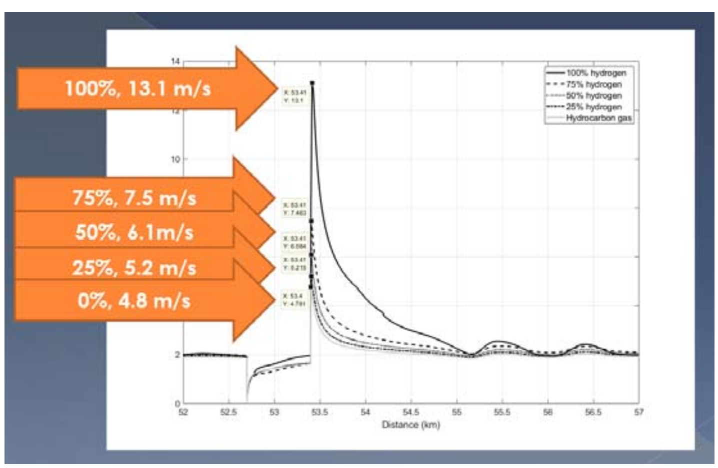

Figure 4 - Graph showing impact of increasing hydrogen content on speed excursions [13]

Furthermore, as hydrogen has a lower calorific value by volume than methane, “piping and pipelines may be operated with possible cyclic pressure loading in excess of current operating regimes for transport pipelines e.g., 20MPa (3000 psig)” [3]. This will increase the potential energy available in the system.

The small molecule size will further reduce the effectiveness of engineered mitigation measures such as the use of low drag sealing elements and passive bypass, as too much bypass will stop motion altogether. It is possible to batch pigs within a liquid medium to provide lubrication and achieve more consistent transit speeds. This however brings additional project costs, downtime and the need to remove any residual liquid from the line.

In a recent case study [5] a successful hydrogen inspection required appropriate tool modifications, detailed pre-engineering with competent and experienced pigging specialists, and fine flow control and monitoring with Coriolis meters. Receiving the tool at a steady and controlled velocity will protect the line’s mechanical integrity. Managing back pressure requires coordination, communication and a detailed understanding of the receiving process.

9. OPERATIONAL SOURCES OF IGNITION AND PRESSURE RELEASE

Engineering controls and operational planning can reduce risks, but there are some variables emanating from within the pipeline that can further complicate the receiving process. Debris from cleaning can vary greatly in volume and composition and can potentially result in undetected pressure being present in the receiver and present a source of ignition. The receiving process includes steps to verify the vessel is depressurized before the closure door is opened. However, if large quantities of debris are brought into the receiver with the pig, the tool may not fully pass into the oversized barrel leaving potential for pressure to be trapped behind the seals still engaged in the nominal section. If pressure gauges are not suitably positioned, or pressure warning devices are blocked with debris, the closure may be opened under the false impression that it is safe to do so with potentially catastrophic outcomes [7] [14] [15].

To further escalate this hazard, in repurposed or blended hydrogen – methane pipelines, “black powder” corrosion byproducts, including iron oxides and iron sulphates, may be present which can be pyrophoric (autoigniting in the presence of oxygen). Eliminating these kinds of corrosion byproducts if present will be a priority for repurposed lines, requiring pigging and potentially chemical cleaning. The combination of potential trapped hydrogen in a vessel that contains an auto igniting debris is a risk that pigging teams must be aware of and have mitigating measure in place. These can include verified and monitored inerting of all zones of the vessel, correct positioning of pressure gauges and pig signalers and measures to prevent debris from igniting during removal and disposal. A case study [15] demonstrates how this scenario in an LPG pipeline regrettably resulted in tragic outcomes.

10. VERIFIED ISOLATIONS

To isolate the launcher and receiver effectively and safely from the main pipeline it is essential that critical valves are fit for purpose and not bypassing. For new hydrogen pipelines, compatible valves and connections are selected and requirements can be found in ASME B31.12 [3]. For repurposed pipelines there are further requirements to verify that valves and joints are suitable before hydrogen is introduced "All valves shall be refurbished and valve flanges shall be refaced. In the case of any recommissioned pipeline, all flanged joints shall be tested for fugitive emissions." [2].

Launchers and receivers can be permanent or temporary, it should be noted however that in the case of hydrogen service that "flanged joints will preferably be replaced with welded joints. Any flanged joints that are present in the system shall meet the requirements for new pipelines…..any flange older than 20 years shall be refaced or replaced." [2]. Leak testing on all joints of temporary equipment must be carried out with a verified procedure to a defined criterion.

Pig launchers and receivers commonly operate with a single isolation valve. Whilst there is no specific requirement in ASME B31.12 for double isolation or other secondary measures for pigging operations, such practices are required to permit any gas or electric welding and cutting with cutting torches during construction activities where hydrogen – air mixtures may result. This includes removal of a pipe spool, double block and bleed valve configurations, installation of a blind flange or use of venturi air movers [3]. The pig launch and receive process is not technically "hot" work. However, with the spark potential as described throughout this paper it is clearly essential that isolating valves are tested and verified as not bypassing with hydrogen. To achieve double block and bleed isolations, permitting assessment and repair, inline isolation tools or hot tapping may be deployed. There are examples of failing valves allowing pressure to build in front of loaded pigs in the trap which result in pigs ejecting backwards and striking personnel carrying out the launching operation [16].

11. INERTING

The difference in densities of the transported hydrogen (or hydrogen methane mix) with air means that air ingression into open chambers is a significant risk. The heavier air will freely sink into quiescent chambers, and as this happens the explosive limits will change quickly, allowing volatile gas mixtures to form. This is especially important at the entrances to the pipeline, vents and flares. When the closure is actuated, sources of ignition can result in an explosion that directly impacts personnel, and can eject projectiles at high velocity. As such, launchers and receivers should be inerted with nitrogen as part of the venting process to ensure flammability limits are never met. The use of nitrogen does carry risks that need to be mitigated as large volumes have the potential for anoxia or asphyxiation [2].

Purging methodology should be carefully planned and executed with competent supervision. The relative densities of the gases increase the chance of formation of regions of stratified 100% concentrations of hydrogen, such as in short vertical risers, vertical legs or tees and dead legs [3]. Active monitoring of the effectiveness of the inerting process prior to breaking containment is essential.

Over-pressurization protection should also be used in case venting pathways to atmosphere are shut and catastrophic over-pressurization results. This was demonstrated in a case study describing an incident in which pressure relief valves were not in place and the nitrogen pumping unit quickly exceeded the launchers maximum pressure rating resulting in a critical failure and fatalities [14].

12. VENTING

It is essential to plan appropriate venting pathways to safely remove the hydrogen or hydrogen mix from the work area. Venting to atmosphere can become dangerous due to the volatility of the hydrogen which can easily ignite and increases in temperature when depressurizing. Elimination of spark sources alone is insufficient; high ambient temperatures can heat surfaces, or proximity to heat generating processes can increase the chance of autoignition. For permanent pigging stations, considerations for extended venting pathways should be incorporated if absent with evaluation of impact on surrounding facilities and activities.

For temporary arrangements, venting should no longer be accomplished through short pipe sections close to the pipe barrel. Longer pipe segments with a check valve will better isolate any potential flame from the vessel and operating team. A spark arrestor is also recommended.

The preferred solution, however, is flaring of purged gases, integrating with the facility’s system if available. Even flaring can pose risks if not appropriately designed and managed. Due to the relative gas densities, there is a possibility of air sinking into the flare and piping if positive pressure and flow is not sustained in the purge. This can create an explosive mixture that, upon detonation, will damage the flare and its piping, while also sending active flames backwards into the launcher or receiver to ignite gases in the vessel. Flash back suppressors would therefore also be advisable.

CONCLUSIONS

In the coming years the industry anticipates a rapid increase in the transportation of hydrogen in pipelines. In Europe, projections show 1,600km in 2020, reaching 6,800km by the end of this decade, and exceeding 39,000km by the end of 2040 [18]. Currently, hydrogen pipelines are in in the hands of specialist industrial gas manufacturers and pigging operations can be carefully planned and managed, safely leveraging available expertise. However, the growth projections suggest that hydrogen will become present in a significant portion of the energy network. It will become commonplace for field operators and contractors to be called on to launch and receive tools in the presence of hydrogen.

The pipeline industry has responded to the emergence of hydrogen with a surge in innovation, including defining requirements around the upgrade and installation of pipeline networks that can deliver hydrogen. It is imperative to focus on those involved in executing pigging operations, which deliver the diagnostic and remediation solutions that will continue to keep these networks healthy.

The variables that shape the risks encountered are numerous, and as discussed in this paper are elevated by the properties of hydrogen. In addition, as 70% of the projected European hydrogen lines will be re-purposed, there is further potential that legacy integrity and flow assurance issues will be brought forward bringing further operational challenges and risks.

It should be a collective aspiration that the successful transition to hydrogen can progress without critical incidents involving launching and receiving of pigs. To achieve this will require knowledge sharing, collaboration and vigilance from all parties. This will ensure the benefits of hydrogen are delivered whilst safeguarding not just assets, but personnel and communities.

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