Are Hard Spots a Stable Threat in Hydrogen-blended Pipelines?

Isya Muhajirin | Quest Integrity MYS
Olivia Chung | Quest Integrity NZL
Kevin Spencer | Quest Integrity CAN
Michael Turnquist | Quest Integrity USA

Contents

Introduction

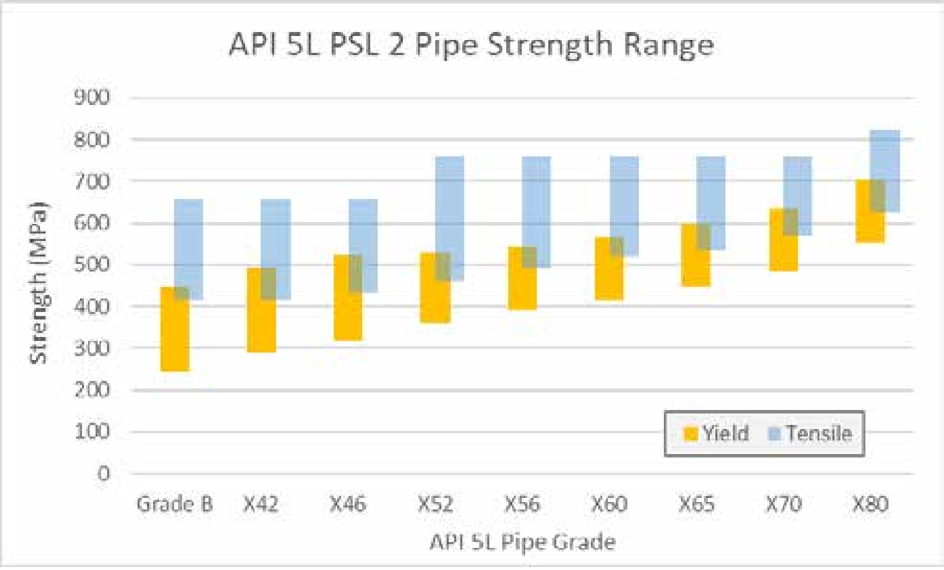
Hydrogen demand and pipeline integrity challenges

- Global hydrogen demand is expected to grow significantly by 2050.
- Blending hydrogen into existing natural gas pipelines is a practical solution for large-scale transportation.
- Introduction of hydrogen into existing pipelines introduces new risks, particularly with hard spots.
- This paper seeks to explore possible actions for managing risk of hard spots in hydrogen blend with dry natural gas.

Quest Integrity

Hard spots in pipelines

How are they created?

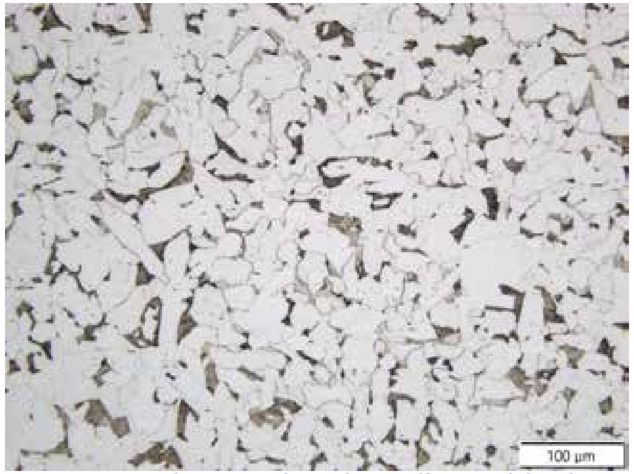


Main cause	Impact	Potential area
Uneven cooling	Undesirable microstructure	Pipe body and seam welds
Welding process	Increase local hardness	Heat affected zone (HAZ) and vicinity of arc strike
Cold working or deformation	Plastic deformation	Dent, gouges, and mechanical defects in pipe

In API 5L, any hard spot larger than 50 mm (2.0 in.) in any direction shall be classified as a defect if its hardness exceeds 35 HRC (345 HV/ 327 HBW).

Observed microstructures

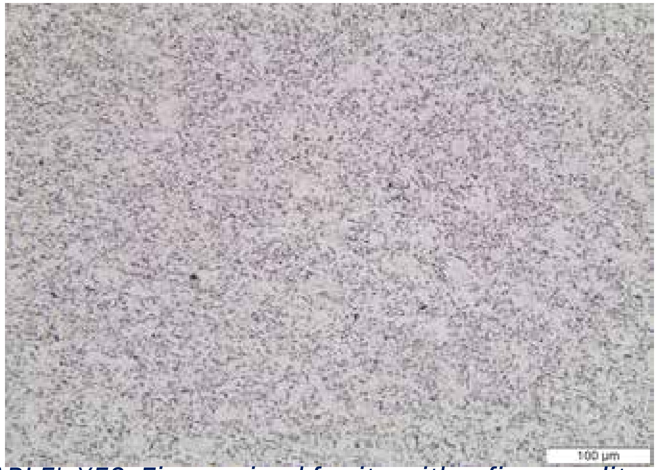
API 5L line pipe steels and untempered martensite (hard spots)



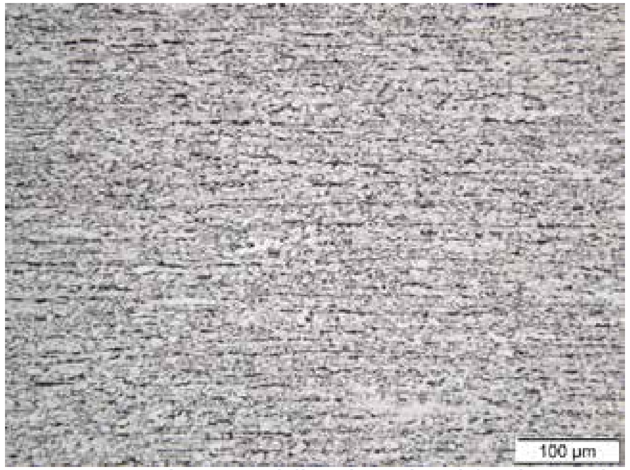
API 5L Grade B. Equiaxed pearlite and ferrite

API 5L X42. Pearlite and ferrite in a heavily banded structure

Untempered martensite



API 5L X52. Fine-grained ferrite with a fine pearlite carbide structure

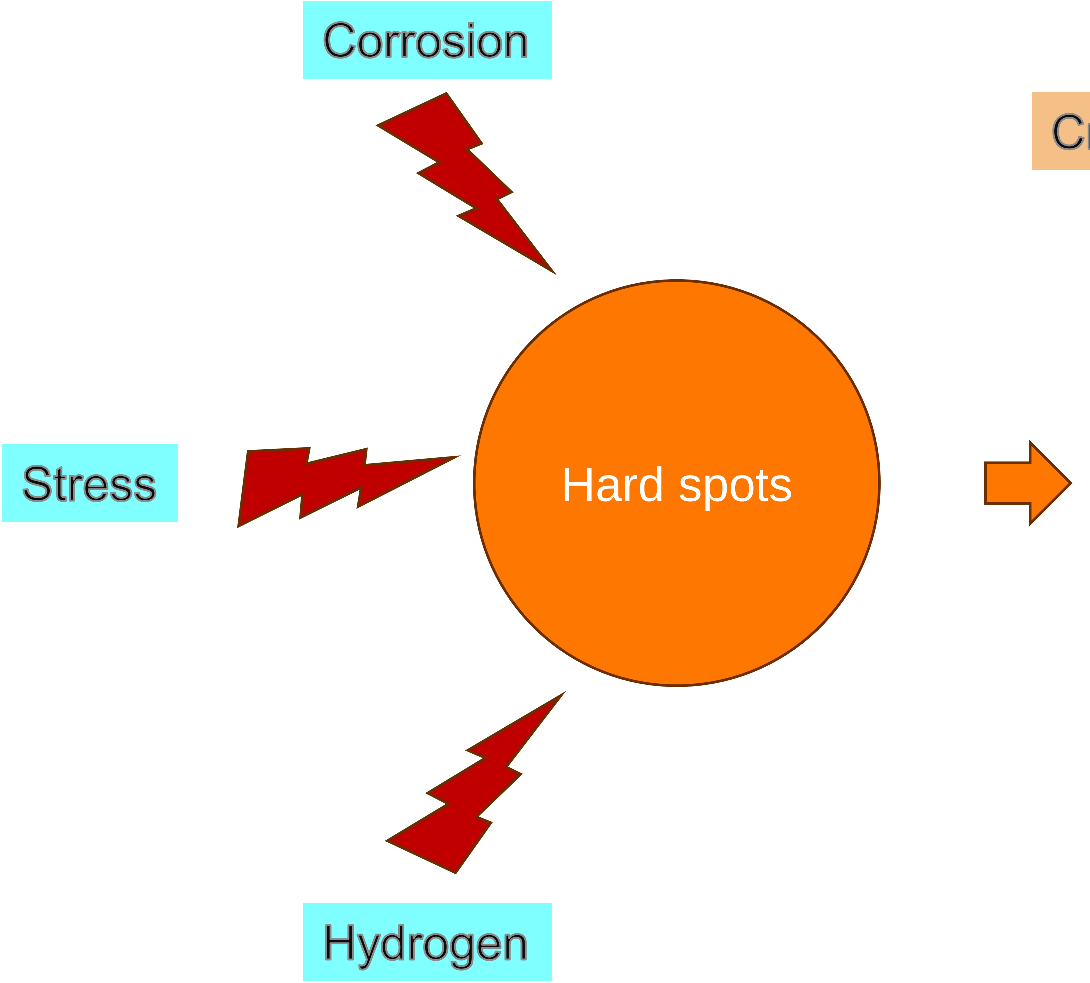


API 5L X60. Elongated fined-grained ferrite and pearlite

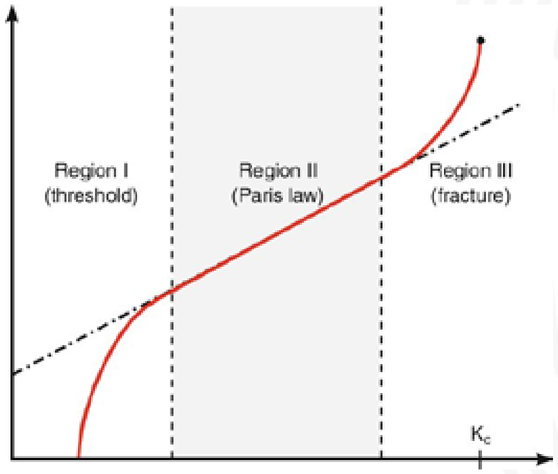
Characteristics:

- increase hardness
- inherently brittle material
- susceptible to the microcracks formation

Threats and vulnerability



Cracks and fracture/ fatigue crack growth



1. **Stress concentration**
2. **Brittleness**
3. **Microstructural changes**
4. **Residual stresses**

Hydrogen Assisted Cracking (HAC)

Hydrogen embrittlement (HE) is a process of degradation material due to diffusion of hydrogen atoms causing general reduction in ductility and toughness.

HAC mechanisms known as time-dependent damage since HE effect takes time to manifest in the form of crack

HE potentially inflicting HAC phenomena faster than in a hydrogen-blended natural gas environment compared with a dry natural gas environment.

Note: This applicable for $R > 0.5$ and relatively stable at lower stress ratio.

CS pipe in hydrogen environment are susceptible to HAC if hardness level exceeds 248 HV, according to API 1176. While subcritical cracking expected to happen above 228 HV.

Subcritical crack reach critical size rapidly in a hydrogen environment due to reducing ductility and fracture toughness.

Probability of HE increases with increasing pipe grade and the high strength low alloy (HSLA) steels are found to be most susceptible to HE

Quest Integrity

Environmental Assisted Cracking (EAC)

EAC is a general term encompassing various forms of cracking caused or accelerated by the synergistic interaction between three main factors

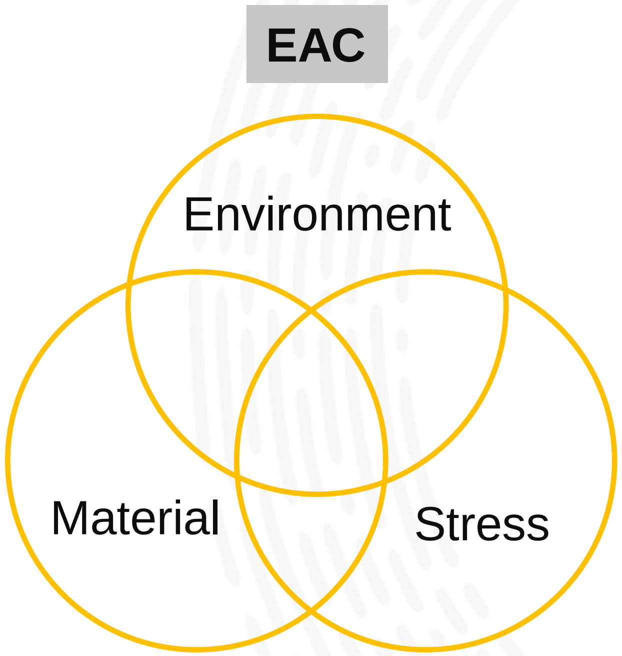
EAC is another time-dependent damage that can cause SCC and corrosion-fatigue cracking

The presence of hard spots in external surface contribute to the on-set of SCC initiation and propagation. It can be influenced by cathodic protection (CP) overpotential

Other SCC factors are coating type, soil type, geohazards, distance to compressor station, and other possible axial loading.

SCC initiates on the steel surface where corrosion happen, and the cracks observed are usually microscopic. Combined effect can lead to the formation and propagation of cracks.

The associated crack growth with further corrosion and interaction with hard spots is quite complex.



Effect of hydrogen on crack susceptibility

Key input for integrity assessment

Fracture toughness

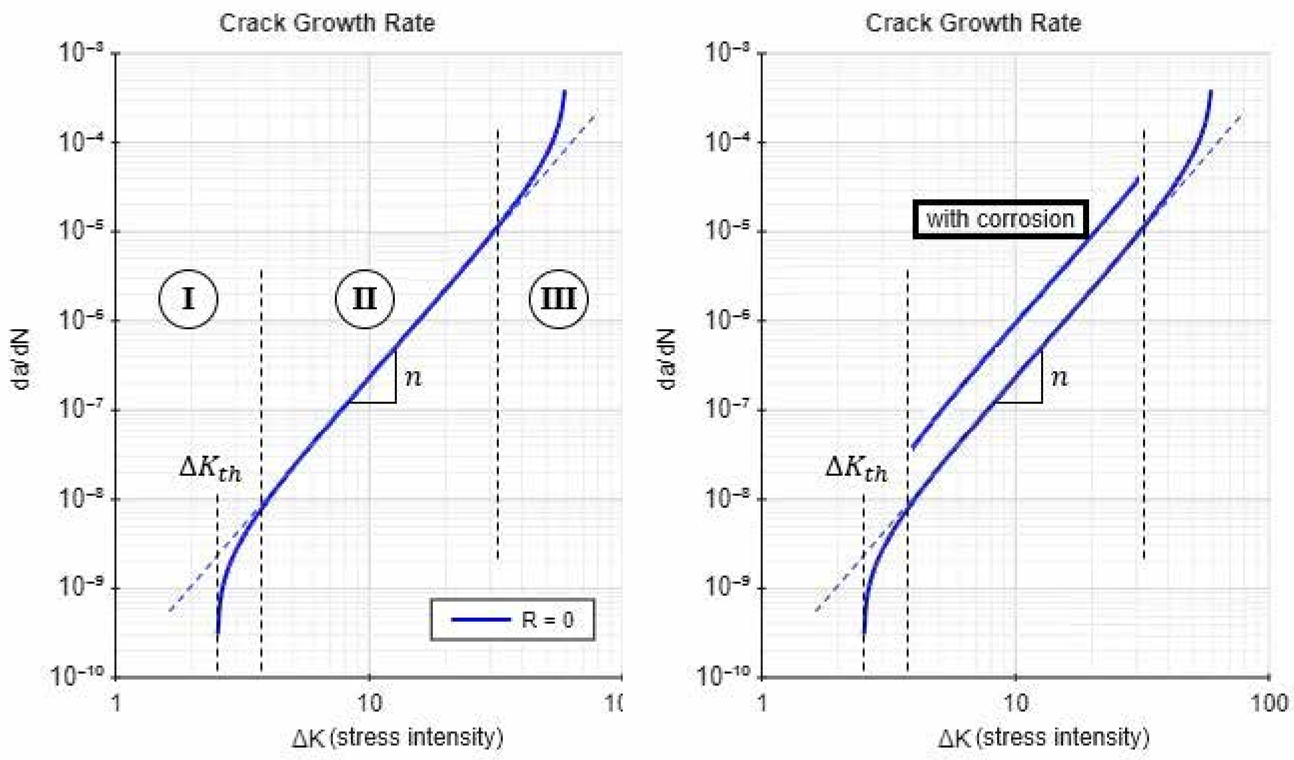
General trends show a consistent decrease in fracture toughness as the tensile strength increases

decrease in fracture toughness significantly impact the failure pressure and safety factors of pipelines

Fatigue crack growth rate (FCGR)

With cyclic loading, hydrogen-blended gas known to increase the FCGR however, the impact is not significant on typical low-strength pipeline steel grades

The presence of hydrogen from corrosion processes such as CP overpotential will generally accelerate the crack growth in the stage II (steady-state fatigue)



Identification of the threat of hard spots

Potential area for hard spots in steel pipes

TMCP is modern manufacturing process allows raw materials obtains high strength and excellent toughness by controlling the microstructure of steel.

Combining controlled cooling and rolling process thus minimizing the threat of hard spots at the pipe body.

Chance hard spots forming in steel pipe depends on types of manufacturing methods and welding process.

Hard spots in longitudinally welded pipe often form in the HAZ.

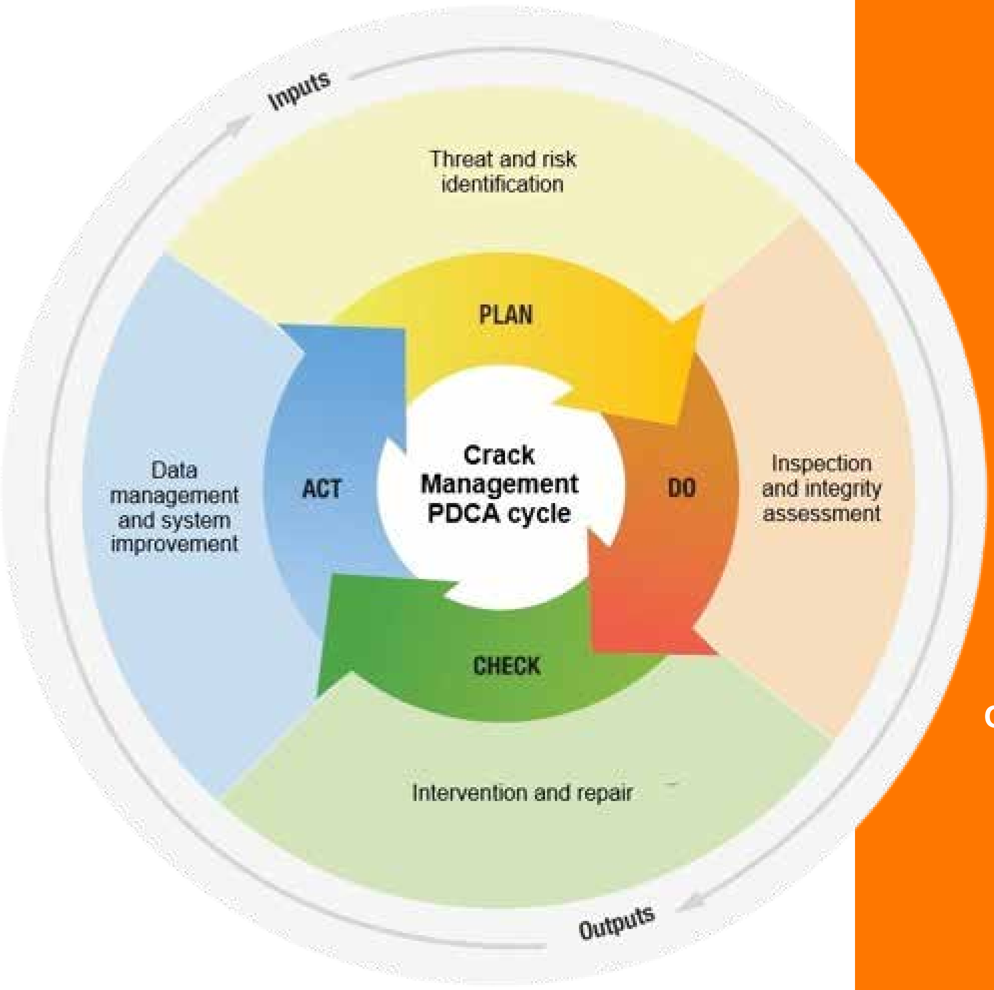
Pipe type	Method	Origin	Remarks	Hard spots formation
Seamless	Mandrel & extrusion	Billet	No weld	Less likely forming in the pipe body
Welded	Submerged arc weld (SMAW)	Plate	Weld direction straight	More at HAZ due high heat input from weld altering microstructure
Welded	Electric resistance weld (high-frequency current, HF-ERW)	Strip	Weld direction straight	At weld seam but generally lower since lower heat input and controlled process
Welded	Submerged arc weld (SAW)	Strip	Weld direction spiral or helical	At weld seam and HAZ but it distributes stress more evenly

Detection and characterization

In-line inspection technology for hydrogen-blended pipelines

Combination of the following technologies (API 1162, NACE SP0102, and POF 502).

Technology	Detection system	Capabilities	Suitability
LF-MFL	Low electromagnets saturation	Detecting surface, near-surface defects, and materials variation	Hard spots, corrosion, pitting, and erosion
HF-MFL	High-current electromagnets	- Circumferential MFL: detecting long, axial defects - Axial MFL: detecting short, circumferential defects	- Circumferential MFL: gouge, axial cracks, metal loss - Axial MFL: pitting, general metal loss, circumferential cracks
UT (contact-based sensor)	High-frequency sound waves from the contact-based UT transducers hence requires coupling	Identify defects within the pipe wall and mechanical deformation.	- Not suitable for gas medium environment - Hard spots and cracks
EMAT	Utilizing electromagnetic acoustic transducers emitting waves thus no coupling medium involved	Detecting longitudinal axial cracks located at the internal and external side of the pipeline	- Determine coating deterioration - Validating single cracks and colonies
Eddy current	Using principle of electromagnetic induction	Detect surface and near-surface defects in conductive materials	- Cracks, corrosion, or wall thinning - Surface breaking defects into internal of pipe or cladded pipe



PLAN

DO

CHECK

ACT

Crack Management

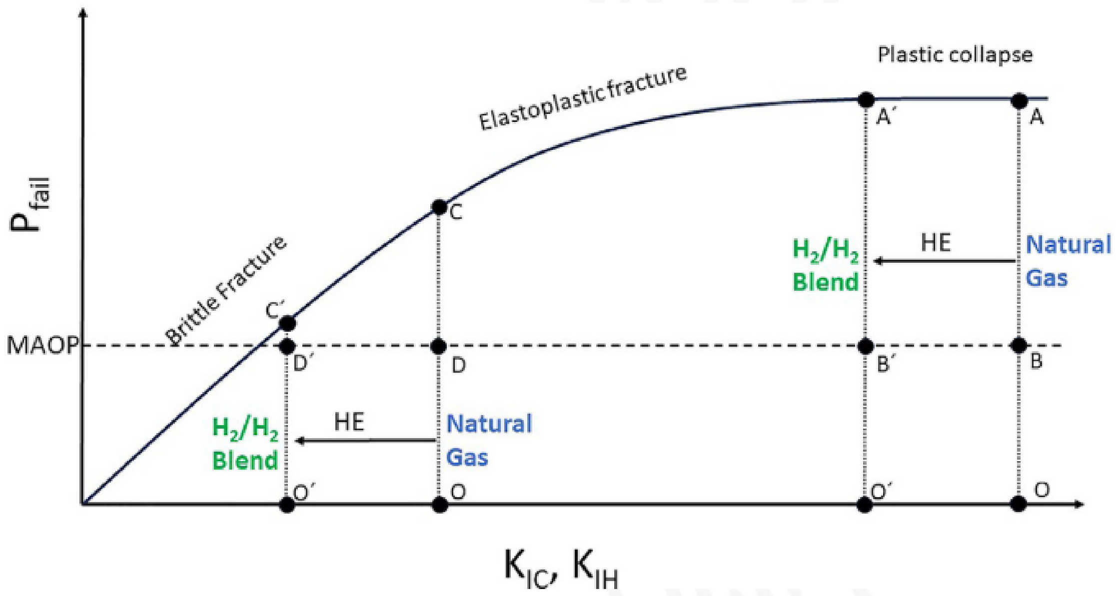
For hydrogen-blended pipelines

- HAC and EAC/SCC threat should be considered, including instances where hard spots is present.
- Emphasizes the importance of robust procedures, continuous process, stakeholder engagement, and leadership commitment.
- PDCA cycle approach is a comparable framework to that provided in AS 2885.3 and AS/NZS 2885.6
    - **Plan – threat and risk identification**
    - **Do – inspection and integrity assessment**
    - **Check – intervention and repair**
    - **Act – data management and improvement**

Integrity Assessment

Engineering critical assessment for crack-like defects

- Once credible threats are identified, inspection and monitoring of HAC, SCC and/or hard spots would likely involve a combination of the following:
  - In-line inspection (ILI) for metal loss and defects, including detection of hard spots and cracks/crack-like defects.
  - Review of external coating condition and CP system potential survey.
  - Utilize the Geographical Information System (GIS) and remote sensing to detect and identify landslides and other potential geohazards.
- Engineering critical assessment (ECA) e.g. fitness-for-purpose/ fitness-for-service assessment and/or supporting laboratory analysis as needed.
  - Crack growth rate to determine the time for ILI-reported crack-like anomalies to grow to critical size.
  - Conducting fitness-for-service (FFS) and engineering critical assessment (ECA) using methods and approach as described in API 579/FFS-1 Part 9 or BS 7910.



Failure pressure will be lower for pipelines exposed to hydrogen and resulted in an increased threat of brittle fracture, but with no significant threat with respect to plastic collapse.

Check and Act

Follow up actions and continuous improvement

- Depending on the severity of damage detected or confirmed and after engineering critical assessment, remedial actions and intervention may be needed.
  - Dig verifications and direct assessments to further investigate any key findings from the ILI.
  - Specific guidance with respect to direct assessment for SCC is available in codes and standards such as ASME STP-PT-011
- The extent of repair options that could be considered range from removal of the damage to a prescribed depth to permanent mechanical sleeves and cut-out replacements.
- Guidance around repair is available also in AS 2885 Part 3 and API 1176.

PCDA approach is iterative and intended to assist with continuous improvement and learnings.

As a result, data management of the information generated, from initial assessment to identify the credible threats to the results obtained during inspection and ECAs,

This is key as part of the "Check" and "Act" stages to ensure safe and reliable operation.

Summary and Conclusions

- Transporting hydrogen-blended natural gas will change the properties of the line pipe steel.
- The presence of hydrogen in the fluid will reduce the fracture toughness and can increase the fatigue crack growth rate.
- Hard spots formed during fabrication can become sites for crack initiation.
- The main integrity threats for hydrogen-blended pipelines that could initiate from hard spots include HAC, SCC and corrosion fatigue cracking. These are time-based threats.
- The combination of changes in the material properties and potentially increased susceptibility to cracking initiation from hard spots will result in some specific refinements to the current integrity and crack management approaches for hydrogen-blended pipelines
- Understanding the threat and risk prior to introducing the hydrogen-blended gas will allow operators to develop appropriate integrity and crack management plans.

Thank you

End of presentation