CGA Energy Nexus & Annual Technical Conference 2025

Technical Approaches and Outcomes of an Integrity & Risk Assessment for Blending Hydrogen into an Existing Network

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Fuelling the Future

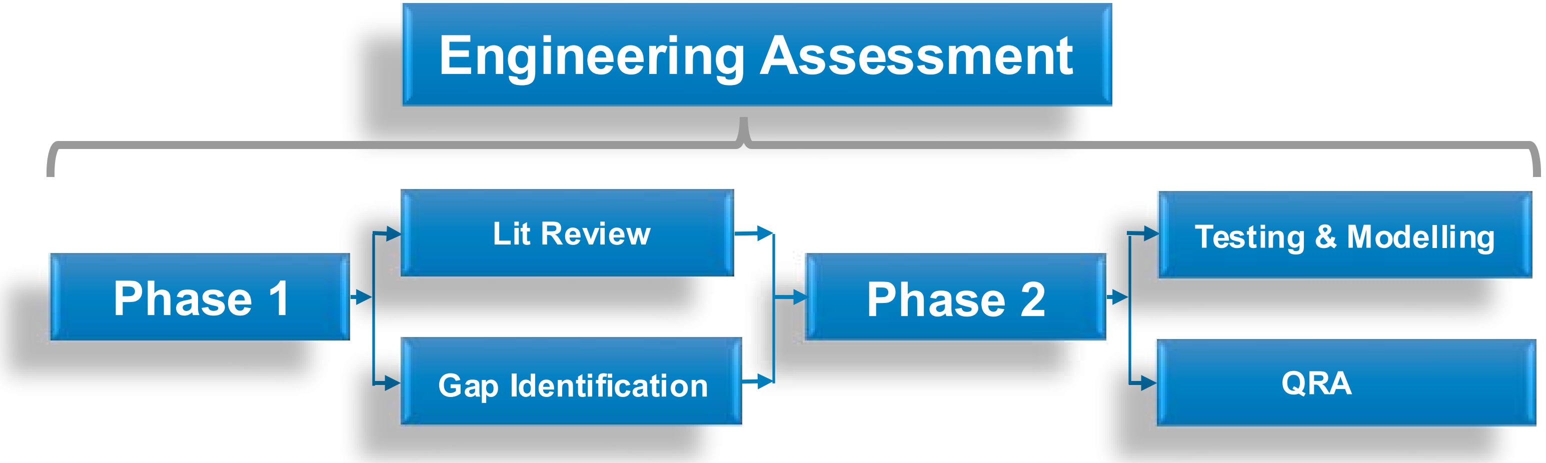
Outline

- EGQ H_2 Blending Project
- Recap from CGA Nexus 2024
- Steel Pipe Testing Project
    - Test Result
    - Critical Finding
- Cast Iron H_2 Compatibility
- Quantitative Risk Assessment - QRA
- QRA Results
    - Societal Risk
    - Individual Risk
- Next Steps

Enbridge Gaz Québec H_2 Blending Project

Gas Distribution Network

- **Total Customer:** ~44,000
- **Main Lines:** >1000 km
- **Service Lines:** >700 km
- **Assets:** Steel & PE pipeline, fittings & components
- **Stress at MOP:** >0 – 28% SMYS
- **Installation Years:** 1956 - 2021



Recap from CGA 2024

Phase 1 Findings: Asset Compatibility

Carbon Steel Pipe	PE Pipe & Soft Goods	Cast Iron Fittings
Reduced Ductility	Inert to H2	More brittle than carbon steel
Reduced Fracture Toughness	Higher Permeation	Fracture mechanical assessment
Increase *FCGR	-	-

**FCGR- Fatigue Crack Growth Rate*

Factors vs EGQ Network

Significant Factors	Enbridge Gaz Québec System
Hydrogen Fugacity	low pressure
Stress Level	Under 30% SMYS
Steel Grade	Lower grade steel
Plastic Density	MDPE pipe

Phase 2 Initiatives

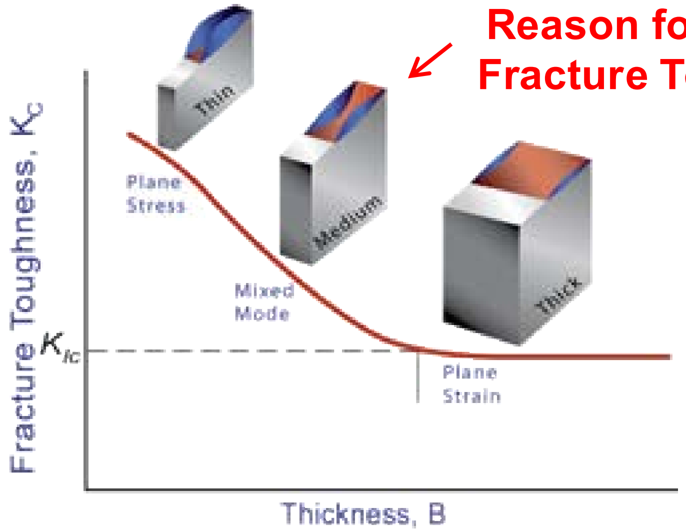
Carbon Steel
- NSERC Pipe Testing
- C-FER Testing Project

Cast Iron
- Lab Scale Testing
- Analytical Model
- Full Scale Testing

Application
- Asset Compatibility
- QRA

NSERC Testing Recap: Addressed H_2 effects on mechanical & metallurgical properties. Inconclusive data for fracture toughness → **initiated more FT testing**

Carbon Steel Pipe Testing Project



Reason for Inconclusive Fracture Toughness Data

Objective

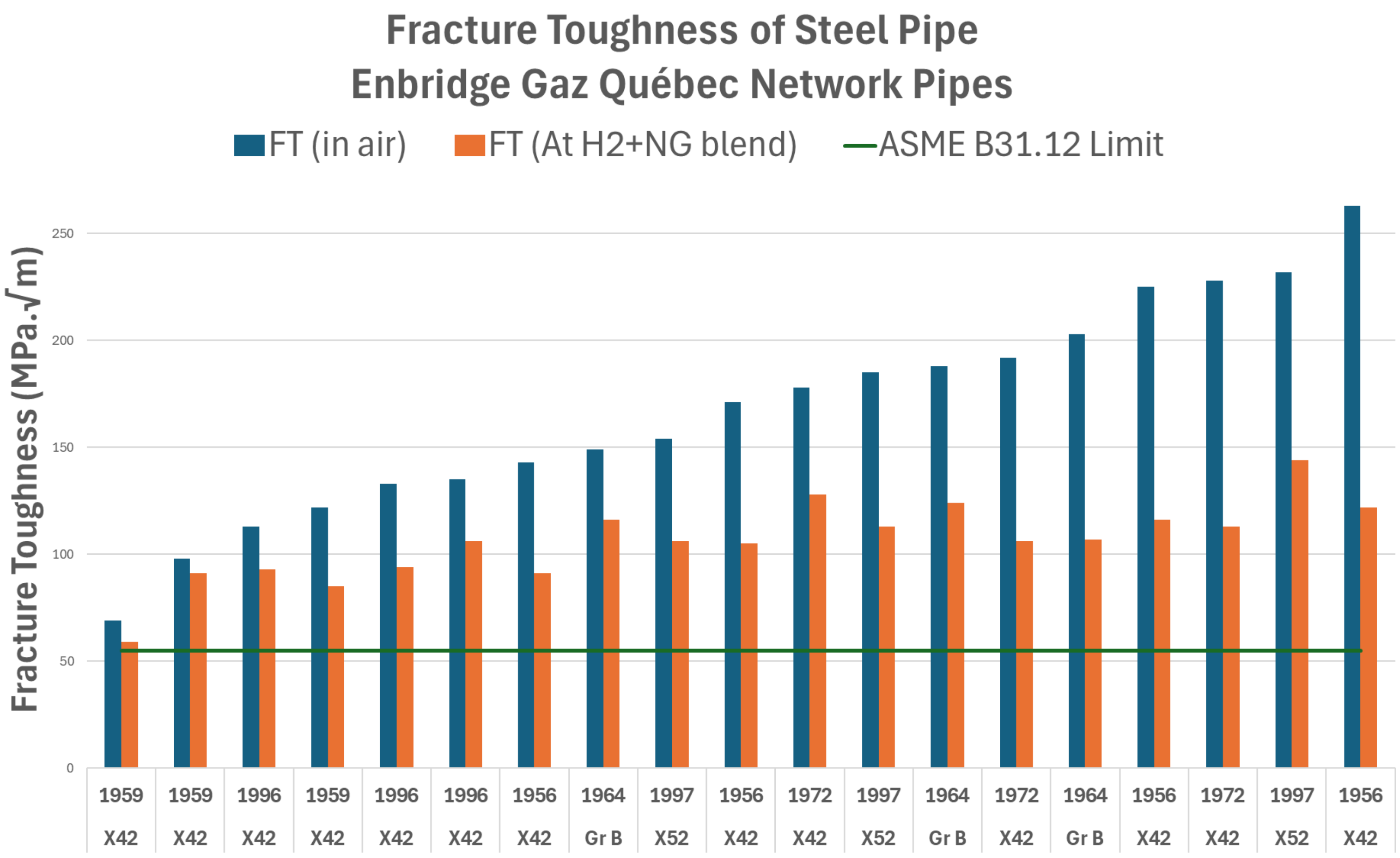
- Geometry independent Fracture Toughness (FT)
- Effect of H_2 on Charpy V-Notch (CVN) properties
- Compare CVN and FT

Test Plan

- **Pipe Grade:** Grade B - X42 (Grade 290)
- **Installation Year Range:** 1956-1997
- **Nominal Pipe Size:** NPS 6 – 12
- **Test Gas:** 30% H_2 + 70% CH_4
- **Test Pressure:** 500 Psi (FT test performed at variable pressure up to 1250 psi)
- **Test Type:** Hardness, CVN and Fracture Toughness
- **Test Locations:** Pipe body, Seam Weld & Girth Weld

Obtain data to develop the QRA model

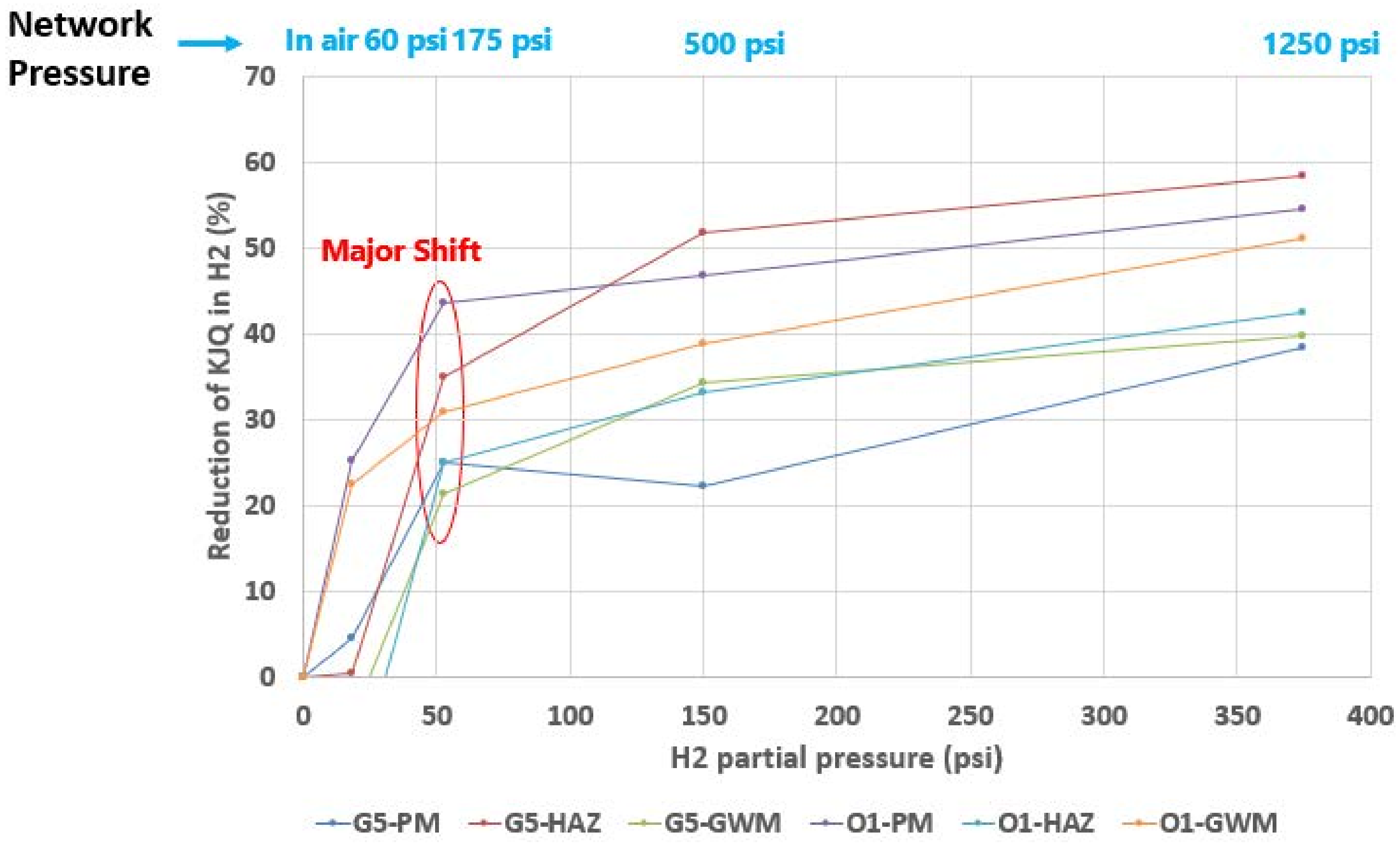
Fracture Toughness Test Results



Results

- Girth weld shows the highest baseline FT and highest %reduction
- Seam weld shows the lowest baseline FT and lowest %reduction
- All value meets ASME B31.12 minimum specified limit

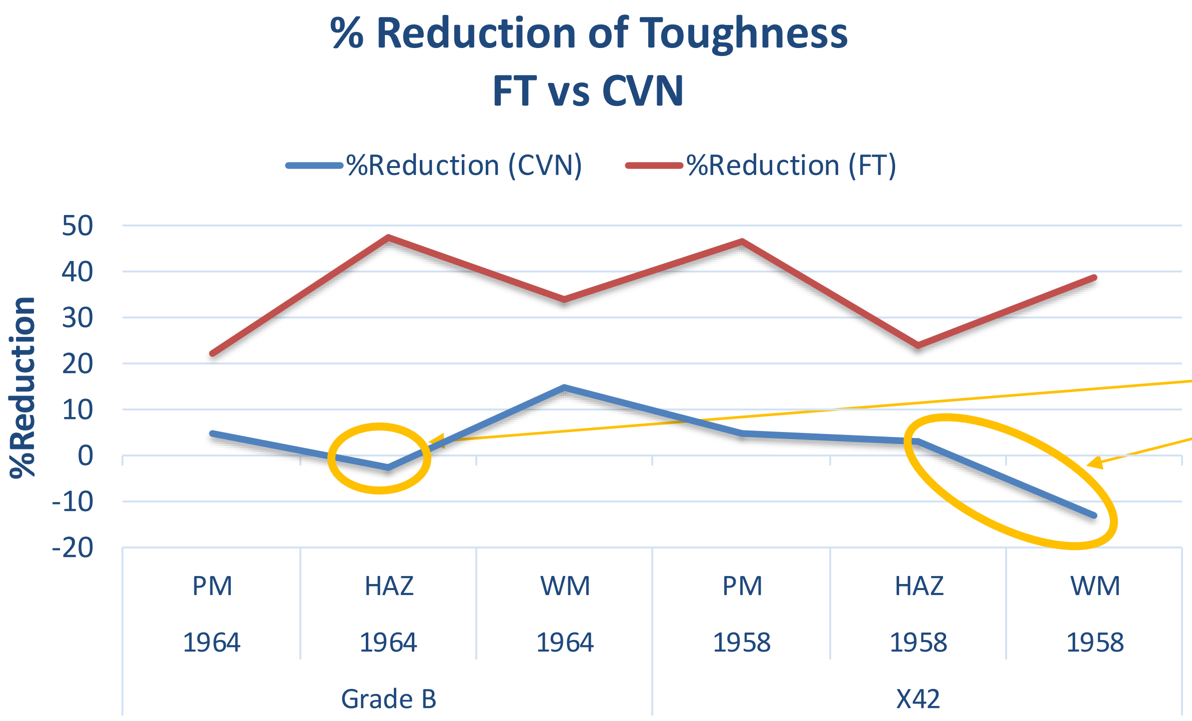
Critical Finding #1 - Effect of Operating Pressure



Results

- Higher pressure lead towards higher FT reduction
- No significant change up to 60 psi test pressure
- Major drop is observed at 175 psi total pressure (52.5 psi H2 Partial Pressure)

Critical Finding #2 – CVN vs FT?



Key Observation

- FT clearly exhibit more prominent embrittlement effect
- CVN shows negligible effect. Some cases Improved CVN energy is observed

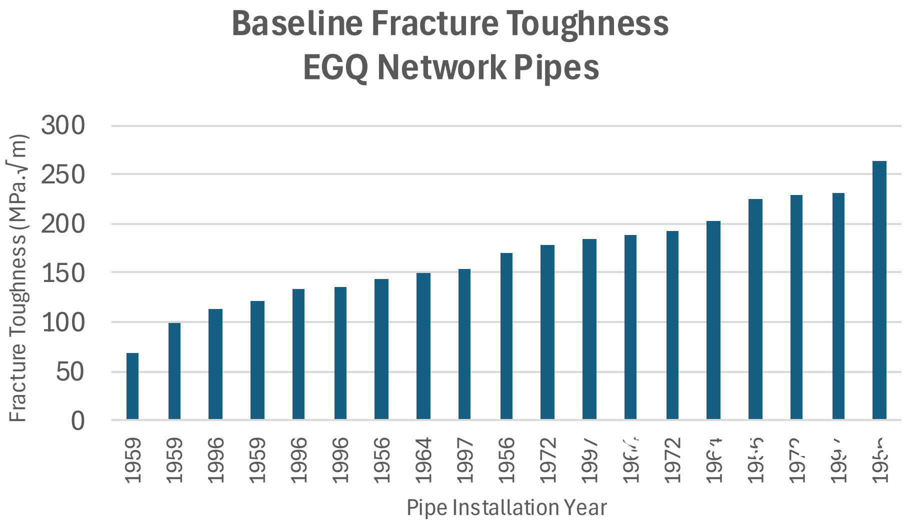
Probable Cause

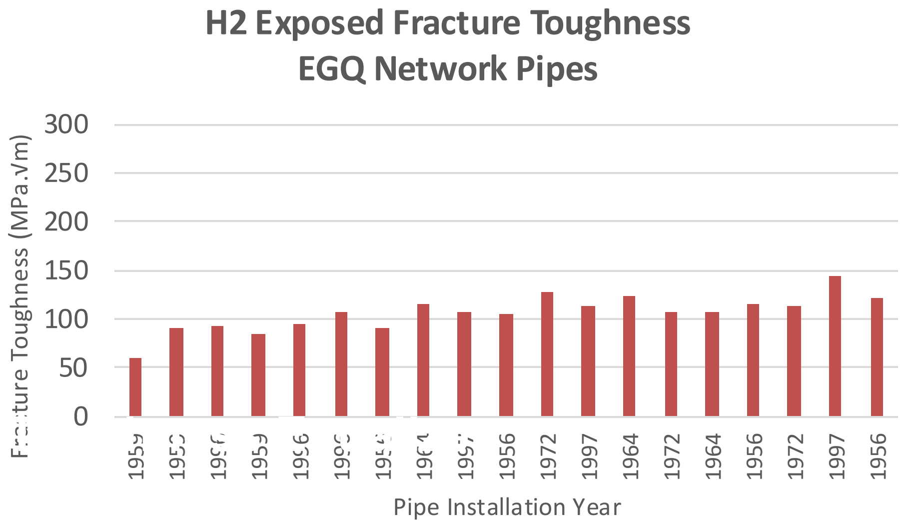
- ➢ Ex-situ testing setup
- ➢ Faster loading rate

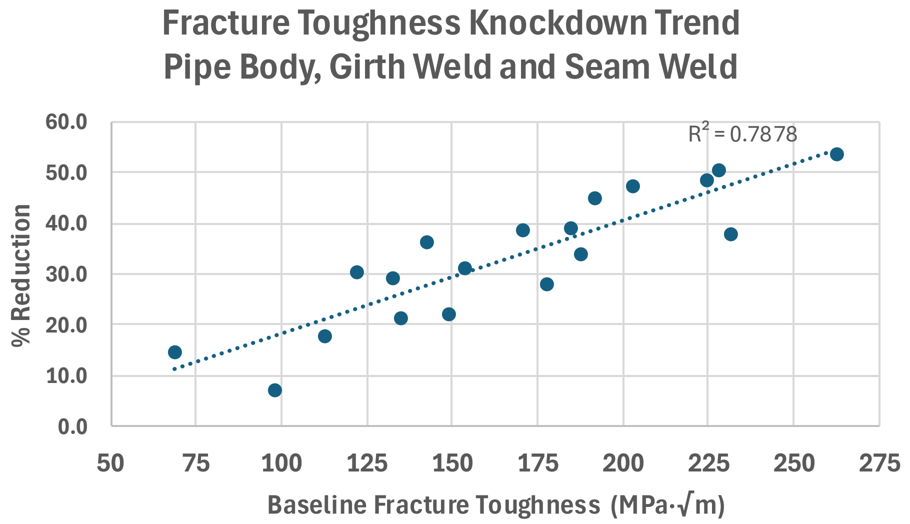
Value to Operators:

- ❖ **CVN is important for other design consideration, however no significant effect of H_2 was found by CVN testing**
- ❖ **For H_2 compatibility validation, Fracture Toughness shall be considered**

Critical Finding #3 – H_2 is a Toughness Equalizer







- **Higher baseline FT → higher reduction**
- **Microalloying, finer grain size probable cause**

Test Data Indicates H_2 is a Toughness Equalizer

Review of Cast Iron Applicability for H_2 Blending

	Valve (Ductile Iron)
	Threaded Fittings (BMI)
	Valve (Ductile Iron)
	Threaded Fittings (Cast Iron)
	Plug Valve (Grey Iron)

Relevant Pipeline Standards

- **ASME B31.12**: Cast iron is not recommended
  - PRCI's CER document permits use provided demonstrated suitability
- **AIGA 087**: Cast iron is not recommended
- **IGC 121**: Allows use under low-stress conditions
- **CSA Z662:** Direct to perform Engineering Assessment

Research Insights

- **NREL Report**: Suggests low-pressure systems might be compatible with cast iron
- **EA Findings**: Further assessment needed for BMI compatibility at operating pressure over 175 psi

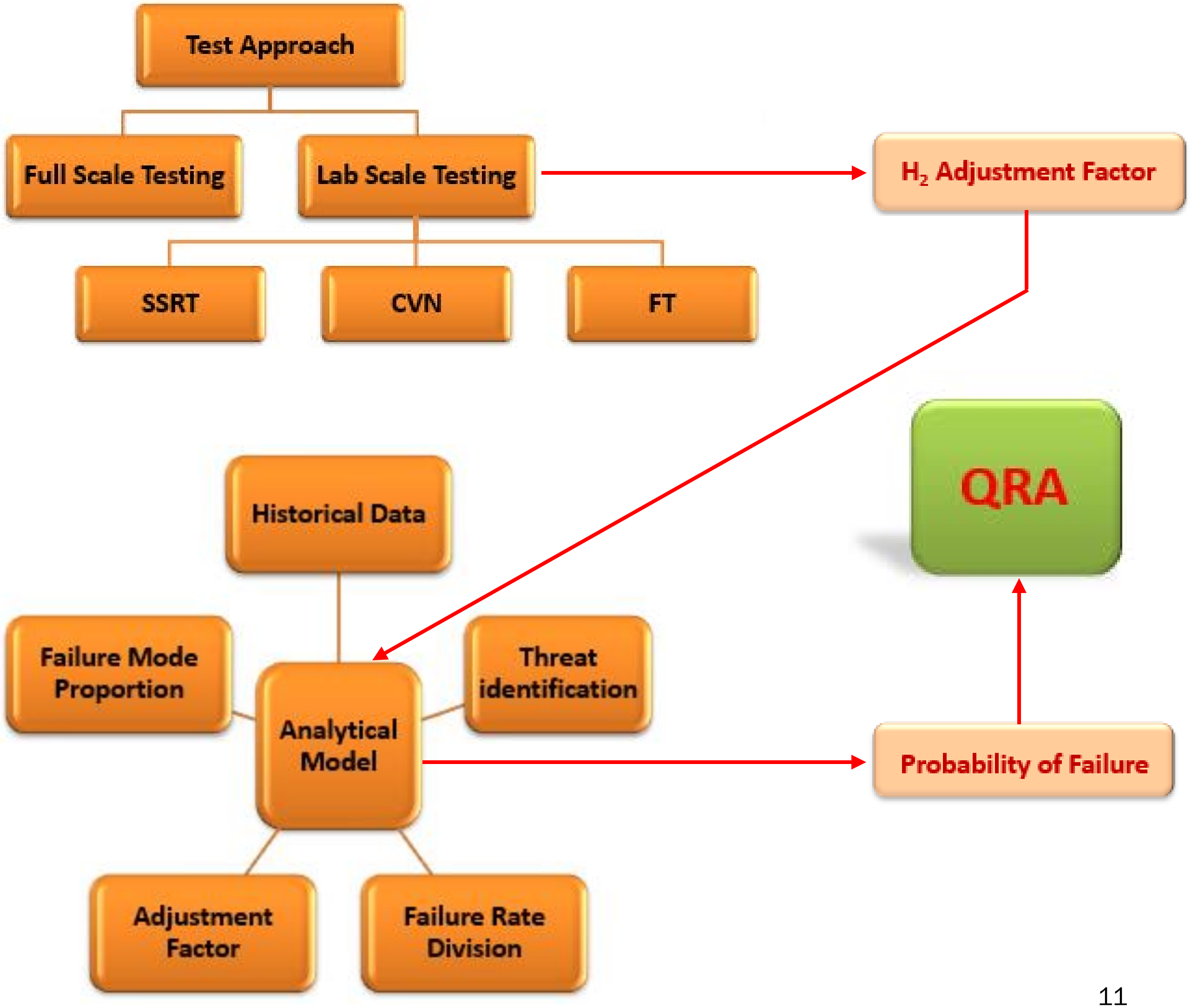
Assessing Cast Iron Components for H_2 Blending

Purpose

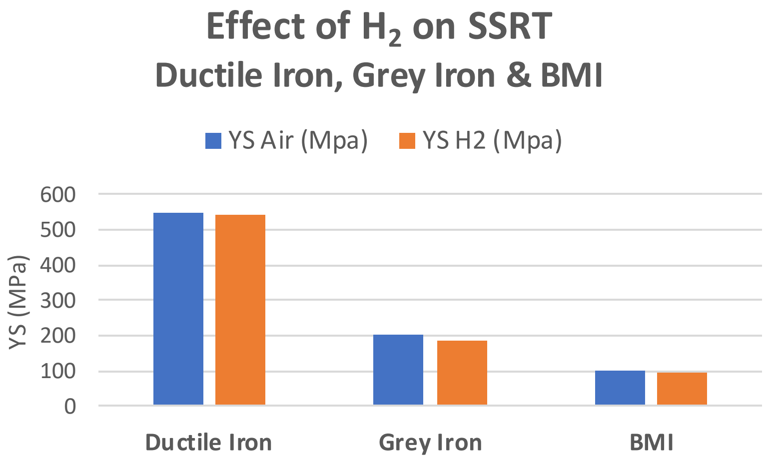
- Quantify H_2 impact on cast iron components that exist throughout the network.

Test Methodologies

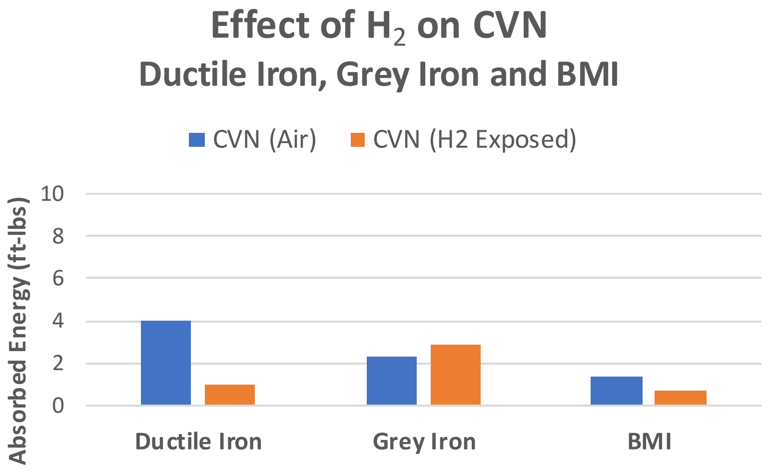
- **Cast Iron Samples:** Black Malleable Iron (BMI), Grey Cast Iron (GCI), & Ductility Cast Iron (DCI)
- **Test Conditions:** 30% H_2 at 500 psi, or 100% H_2 at 150 psi
- **Test Types:** Slow Strain Rate Test, Charpy V-Notch, and Fracture Toughness
- **Full-Scale Testing:** evaluating valve durability under simulated long-term service conditions until failure



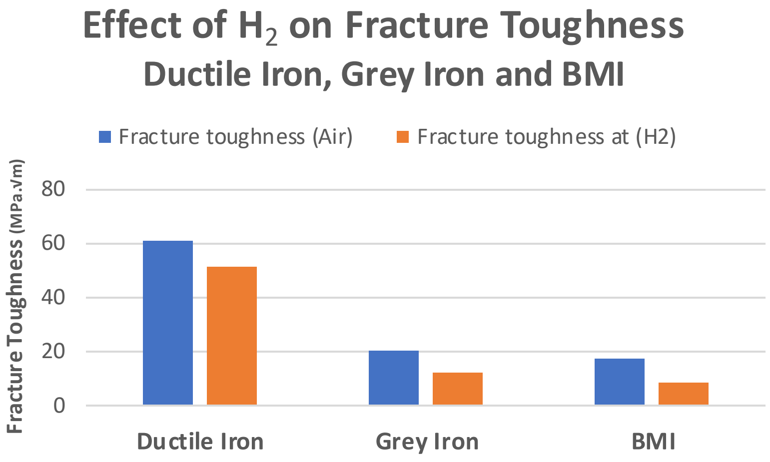
Cast Iron: Lab Scale Test Results



- No significant change in Strength
- All material showed reduced %elongation
  - BMI → 42% reduction
  - GCI → 28% reduction
  - DCI → 19% reduction



- No significant impact from H_2 was observed
- GCI exhibit enhanced energy after H_2 exposure
- Potential reasons:
  - Ex-situ test apparatus
  - Faster Loading rate



- All material showed reduced Fracture Toughness
  - BMI → 51% reduction
  - GCI → 40% reduction
  - DCI → 16% reduction

Cast Iron POF Data Plugged into the QRA Model to Assess the Overall Risk

Quantitative Risk Assessment - QRA

QRA is a systematic, data-driven methodology used to identify, analyze, and quantify risks associated with hazardous events to support risk management decision making.

Risk = likelihood x consequence

Key components:

- System Description
- Hazard Identification
- Frequency analysis
- Consequence analysis
- Risk estimation

Natural Gas → Natural Gas + Hydrogen (H_2) (5%, 15%, and 30%).

Quantify the incremental risk when introducing H_2 into the network.

Quantitative Risk Assessment - QRA

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- System Description
- Hazard Identification
- Frequency Analysis
- Consequence Analysis
- Risk Estimation

- **QRA System Scope**
  - Mains and services operating at different pressure (10 psi to 465 psi).
  - Steel and plastic.
- **Four Scenarios**
  - Natural Gas and 5%, 15%, and 30% H_2.
- **Failure threats (align with ASME B31.8S Managing System Integrity of Gas Pipelines, and existing company Risk Models)**
  - Corrosion (including internal, external and selecting seam weld corrosion)
  - Stress Corrosion Cracking
  - Manufacturing Defects
  - Construction/Fabrication Defects
  - Equipment Failure
  - Third-Party Damage
  - Incorrect Operations
  - Geohazards & Weather
  - Other

Quantitative Risk Assessment - QRA

ENBRIDGE

- System Description
- Hazard Identification
- **Frequency Analysis**
- Consequence Analysis
- Risk Estimation

Baseline (100% Natural Gas)

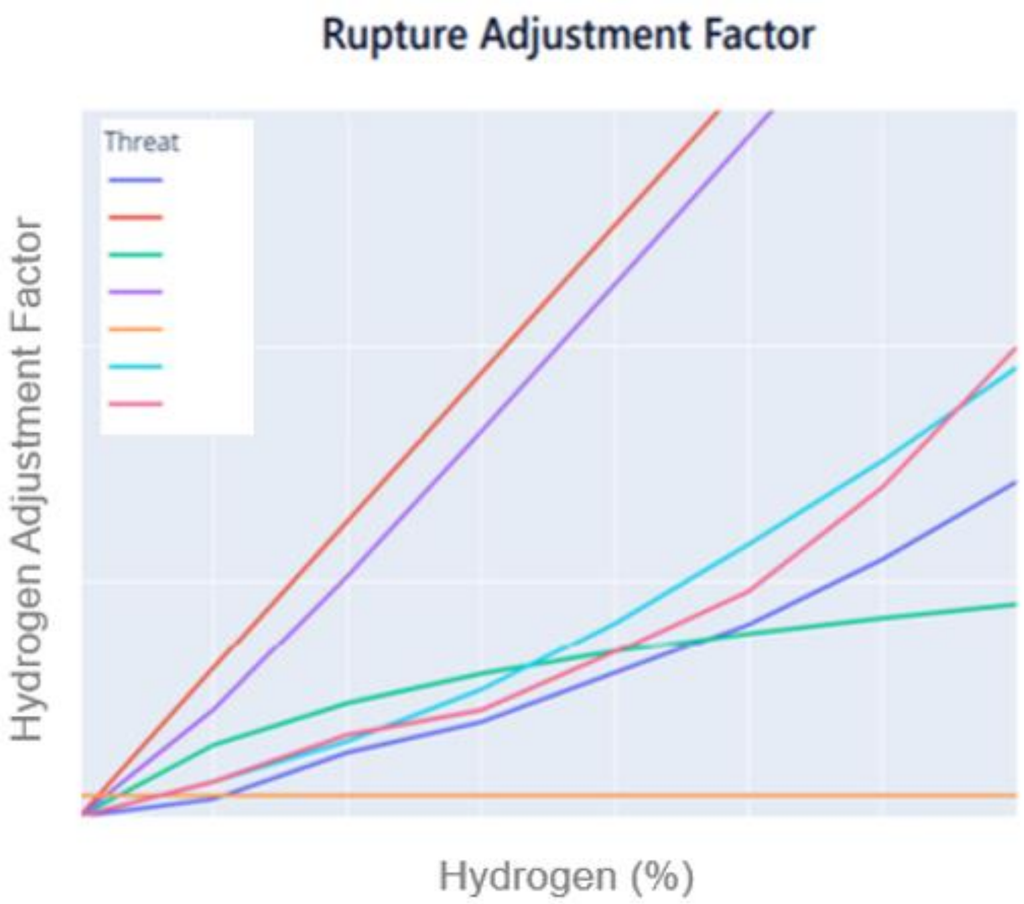
- Threat models derived from failure rates using industry incident and leak data for different failure modes: small leak, large leak and rupture.
- Reclassify/adjust the failure rates by threat, as applicable.

Hydrogen Modifications

- Threat specific adjustment factors were applied to baseline failure rates.
- Adjustment factors were derived from structural reliability and statistical reliability models accounting for reduction in fracture toughness.

Quantitative Risk Assessment - QRA

- System Description
- Hazard Identification
- **Frequency Analysis**
- Consequence Analysis
- Risk Estimation



Quantitative Risk Assessment - QRA

System Description

Hazard Identification

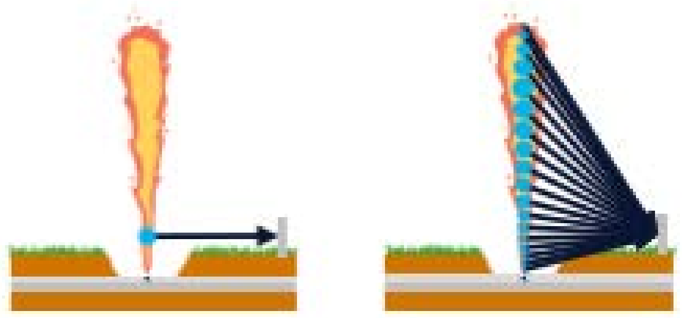
Frequency Analysis

Consequence Analysis

Risk Estimation

Baseline (100% Natural Gas)

- Jet Fire
  - Point Source Model.
  - Weighted Multi-Point Model.
- Migration-Explosion



Models account for level of development in an area, probability of ignition, and frequency of fatalities.

Hydrogen Modification

- Jet Fire
  - Increased probability of ignition.
- Migration-Explosion
  - Increased probability of migration-ignition.

Quantitative Risk Assessment - QRA

System Description

Hazard Identification

Frequency Analysis

Consequence Analysis

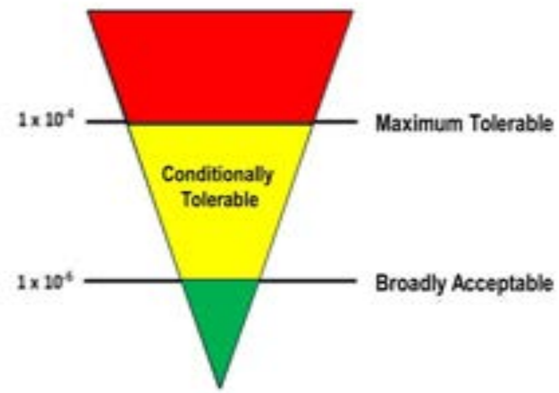
Risk Estimation

Risk estimation

- Based on CSA Z662:23 Annex B risk for Individual and Societal Risk.

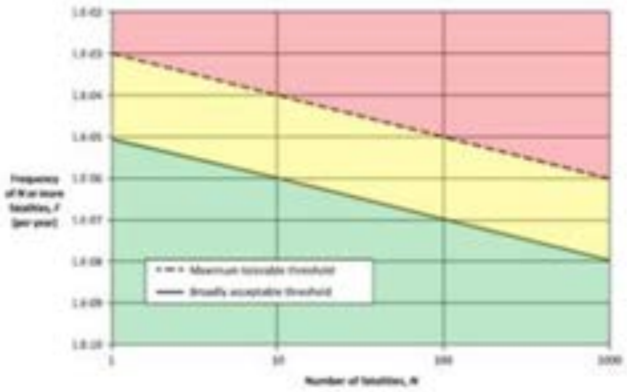
Individual risk

- Indoor
- Outdoor



Societal risk

- FN curve assessment.
- Two checks on societal risk:
  - Linear assets at a given length for higher pressure mains; and
  - All assets at a given perimeter circle



Quantitative Risk Assessment - Results

- For each scenario, individual risk and societal risk was assessed.
- The results in each scenario were compared against the quantitative individual and societal life safety risk criteria published in CSA Z662:23 Annex B:
  - Broadly Acceptable,
  - As Low As Reasonably Practicable (ALARP) referred as Conditionally Tolerable, and
  - Intolerable.

Scenario	Individual	Societal
Natural Gas	All assets are in the broadly acceptable region.	No assets into the Intolerable region.
30% H_2	No assets into the Intolerable region.	No assets into the Intolerable region.

For all scenarios, none of the assets falls into the Intolerable region

Quantitative Risk Assessment – Societal Results

Linear approach (mains operating at relatively higher operating pressure)

- +31,000 FN curves.
- For all scenarios, no assets fall in the Intolerable region.
  - For Natural Gas: majority of FN curves are in the broadly acceptable region.
  - For 30% H_2: around 50% in the of the FN curves reach the conditionally tolerable level.

Perimeter approach (all assets)

- +350,000 FN curves.
- For all scenarios, no assets fall in the Intolerable region.
  - For Natural Gas: majority of FN curves are in the broadly acceptable region.
  - For 30% H_2: additional assets reach the conditionally tolerable level, driven by modelling a higher hydrogen blend percentage.

Quantitative Risk Assessment

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Summary:

- A Quantitative Risk Assessment (QRA) was conducted to evaluate the incremental risk associated with blending hydrogen into the natural gas network.
- Four scenarios were assessed: 100% natural gas, and blends with 5%, 15%, and 30% H_2.
- Each threat was analyzed to include the impact of hydrogen (modification factor)
- Consequence models were also updated to consider the impact of hydrogen.
- Both individual and societal risks were estimated and compared against criteria in CSA Z662:23 Annex B.
- In all hydrogen blending scenarios, no assets were classified within the Intolerable risk zone.

Next Steps:

- Evaluate risk contributors and quantify the influence of hydrogen on overall risk results.
- Assess potential risk mitigation options (or combinations thereof) to support a cost-benefit analysis and determine ALARP (As Low As Reasonably Practicable), where applicable.
- Complete a risk assessment for aboveground assets.

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Integral Team
Integral Engineering

C-FER Team
C-FER Technologies

Multi-disciplinary team to identify and evaluate the multiple areas impacted by hydrogen.

Thank You

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