Hydrogen Blending in Enbridge Gas Networks: Exploring Viability of Legacy Pipelines for Sustainable Energy Transition

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Energy Nexus | Annual Technical Conference
Fuelling the Future

Outline

- Case for H_2 Blending
- Enbridge Initiative
- Gazifère Gas Distribution Network
- Technical & Regulatory Gaps
- Engineering Assessment
- R&D Initiatives
- EA Phase 1 Findings
  - Effect of H_2 on Pipeline Network
  - Key Factors Affecting Gas Distribution Network
  - PE Pipe Compatibility
  - Challenges with Fittings
- Steel Pipe Testing Data
  - Pipe Information
  - Material Characterization
  - Mechanical Properties
  - Steel Microstructure
  - Fracture Surface
- Technical Challenges
- Next Steps

The Case for Hydrogen Blending

Reduction in Carbon Intensity

- Reduction in GHG emissions

Renewable Energy Storage

- H_2 puts surplus electricity to work when it's needed most

Regulations

- GHG reductions targets set by governments
- In Quebec, 2% Renewable gas by 2024, 5% by 2025, 10% by 2030

(Renewable = Green H2 & RNG)

Additional info at : https://www.enbridgegas.com/sustainability/renewable-hydrogen.

Enbridge's Early Investment in Hydrogen

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2018 — Power-to-Gas Pilot Project

- N. America's first utility-scale Power-to-Gas facility (2.5+ MW)
- Provided demonstration of grid balancing capabilities and energy storage
- 280,000+ kg of H2 produced since inception

2021 — Markham, Ontario Blending Pilot Project

- N. America's first H_2 / NG blending facility
- Blend up to 2% H2 for ~4,000 customers
- 97-120 tCO2e annual emissions avoidance potential

2023 2024 — H2 Fuel Cell Vehicle

(H2/NG) CHP

- Hyundai Nexo hydrogen fuel-cell vehicle fleet, 4 of only 20 in Canada
- Developing supporting infrastructure (fuelling station)
- N. America's first dual-fuel H2/NG Combined Heat and Power (CHP) system

2026 — Gatineau, Quebec Proposed Blending Project

- Proposed system-wide blending up to 45,000 customers
- Approx. 55 MW of renewable hydrogen through project partners
- 20 km dedicated H_2 pipeline and injection station

2025 2026 — Active on Two Hydrogen Blending Studies

- Technical Evaluation: Determine tolerable hydrogen blending limits for existing infrastructure
- Hydrogen Roadmap: Techno-economic analysis and plans for redeployment of assets
- Hydrogen Standards: Changes to Operating and Integrity Management Practices

2028 — Project YaREN: Blue ammonia at Ingleside

- Enbridge & Yara have a LOI to develop and construct a low-carbon blue ammonia project
- Enbridge and Oxy Low Carbon Ventures to jointly develop a CCS hub in Corpus Christi, Texas
- Enbridge's Texas Eastern Transmission Pipeline is expected to provide the feed gas

Mid-Atlantic Hydrogen Hub (MACH-2)

- 1 of 7 hydrogen hubs selected by Dept of Energy for funding
- Project development partner connecting producers to customers across DE, PA, NJ and beyond

Proving out technology and scaling up capability in a disciplined manner

Gazifère Gas Distribution Network

- ❑ **Location** – Gatineau, Quebec
- ❑ **Total Customer** – 45,000 (Approximately)
- ❑ **Network Assets** – Steel & PE pipelines, Fittings, Soft goods, Meters, End Use equipment etc.
- ❑ **Main Lines** – Over 1000 km
  - Steel: Approximately 25-30% (Grade 172 to 359)
  - PE: rest (PE 2406, 2708 - MDPE)
- ❑ **Service Lines** – Over 700 km
  - Steel: Approximately 3-6% (Grade 172 to 359)
  - PE: rest (PE 2406, 2708 - MDPE)
- ❑ **Fittings** – Steel, Brass, Stainless steel, Copper, Cast Iron & BMI (Black Malleable Iron)
- ❑ **Sealing Materials** – Teflon, Epoxy, Buna-N, & Viton

Legacy Pressure Class	Maximum Operating Pressure	Operating Pressure Range	Stress at MOP (%SMYS)	Year of Installation
LP	3.5 kPa (0.5 psi)	1.5-3.5 kPa (0.2-0.5 psi)	~0	1963-2021
IP	440 kPa (64 psi)	70-380 kPa (10-55 psi)	0.7-7.2	1958-2021
HP	1207 kPa (175 psi)	485-1207 kPa (70-175 psi)	1.9-19.8	1956-2021
XHP	3206 kPa (465 psi)	700-3206 kPa (100-465 psi)	7.2-28.2	1992-2012

Technical & Regulatory gaps

CSA Z662 gaps - Existing assets were not designed for H_2 service

- H2 Taskforce working on code updates to support repurposing of existing pipelines to H_2/H_2-blended gas service
- Integrity & risk management program
- Specific guidelines to develop or repurpose existing network to hydrogen/blended gas service
- Distribution focused guideline for repurposing existing low-stress pipeline systems

Lack of relevant material properties database

- Fitness for service assumptions become conservative
- For probabilistic models (ALARP* and similar model)
- Risk models

Universal testing criteria

- Similar testing parameters and environmental condition

- **DVGW** – German Gas and Water Industry Association tested 28 different types of steels
- All test surpassed the minimum fracture toughness requirement specified in the ASME B31.12
- Crack growth rate meets the ASME B31.12 critical crack growth rate requirement
- The project concluded there are no differences in terms of the basic suitability for transporting hydrogen compared to natural gas.

**As Low as Reasonably Practicable*

Source: DVGW Project SyWest H_2: "Investigation of Steel Materials for Gas Pipelines & Plants for Assessment of their Suitability with Hydrogen"

Asset Deployment Engineering Assessment

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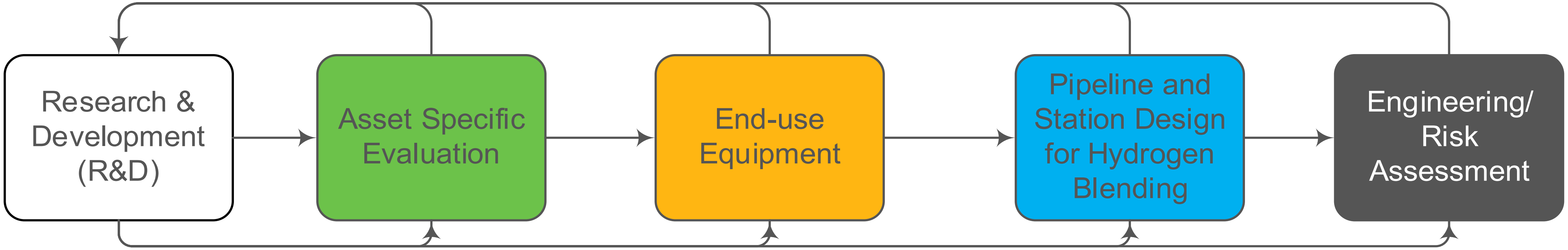

Phase 1 'Desktop' Study	Practical starting point based on the acceptable ranges of H_2 content (% by vol.) in existing literature	Identify all installed assets and their materials of construction and evaluate their H_2 compatibility	Confirm material suitability through a field survey. Complete fuel interchangeability analysis. Modelling of indoor releases.	Define design requirements for the pure hydrogen/ blended gas pipeline, and blending station	Recommend maximum % by vol. H_2 and provide list of action items to be completed for the safe and reliable distribution of blended gas

"Site-specific / System-specific" Engineering Assessment

Phase 2 Validation & Testing	PRCI, NRC, C-FER, Rosen, Integral	Gas measurement, Material testing (Steel, Cast Iron, elastomers, PE)	Appliance testing (burners, ICE, turbines)	Leak detectors Updated H2 Ready Documents	IMP Risk Assessment

Research & Development (Pipeline Network)

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Industry Studies with Enbridge Participation

NSERC Pipe testing (Dal U., NRC, EGI-Complete)	Research program to evaluate the compatibility of hydrogen with natural gas piping using materials supplied by Enbridge. **Three EGI pipe are included**
NRC Vintage Pipe Testing (OERD)	Vintage pipe testing program to evaluate baseline fracture properties and potential knockdown at distribution operating pressure
C-FER Technologies (both studies expect to complete by 2024)	**Cast Iron** assets hydrogen compatibility assessment **(BMI, Grey CI and Ductile Iron)** **Steel pipe** testing pre and post hydrogen blended gas exposure at distribution operating pressure **(Total 8 vintage pipe)**
HyBlend Project *(final report is expected in 2026, interim test data is expected by early 2025)*	DOE funded study, working with national Labs and North American Industry leaders Plastic and steel pipe testing **(Gazifère and EGI pipe included)**
PRCI- Emerging Fuels Institute (EFI) (interim data expected by late 2024 or early 2025)	Research on technical issues around the safe transportation and storage of hydrogen and renewable natural gas. (2022-2025) Full-scale testing on steel pipe Elastomeric sealing material assessment

DALHOUSIE UNIVERSITY

NRC · CNRC

C-FER Technologies
A SUBSIDIARY OF ALBERTA INNOVATES

HyBlend
U.S. DEPARTMENT OF ENERGY

PRCI Pipeline Research Council International
LEADING PIPELINE RESEARCH

Engineering Assessment Phase 1 Findings (Pipelines)

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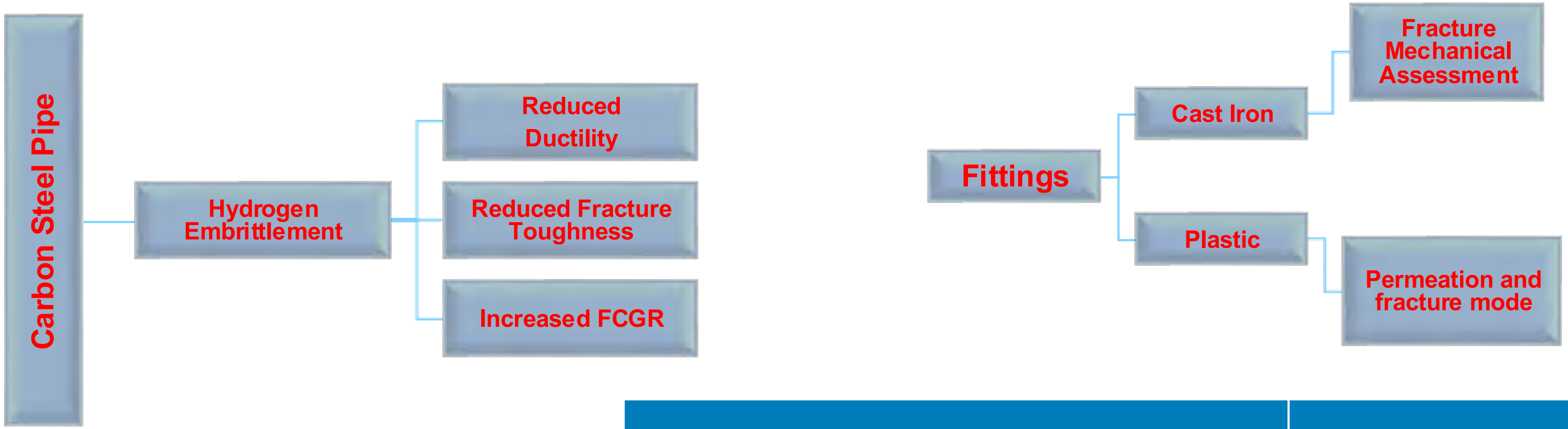

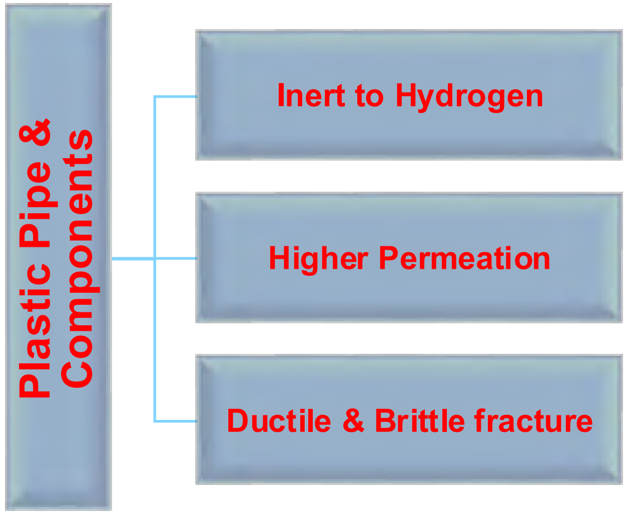

Significant Factors	Gazifère System
Hydrogen Fugacity: depends on the operating pressure	Operates at low pressure
Stress Level: higher stress favors more H2 damage	Runs under 30% SMYS
Steel Grade: higher grade steel is more susceptible	Lower grade steel
Plastic Density: high density pipe is more vulnerable	Only includes medium density PE pipe

H_2 Blending in the Distribution Network (<30% SMYS)

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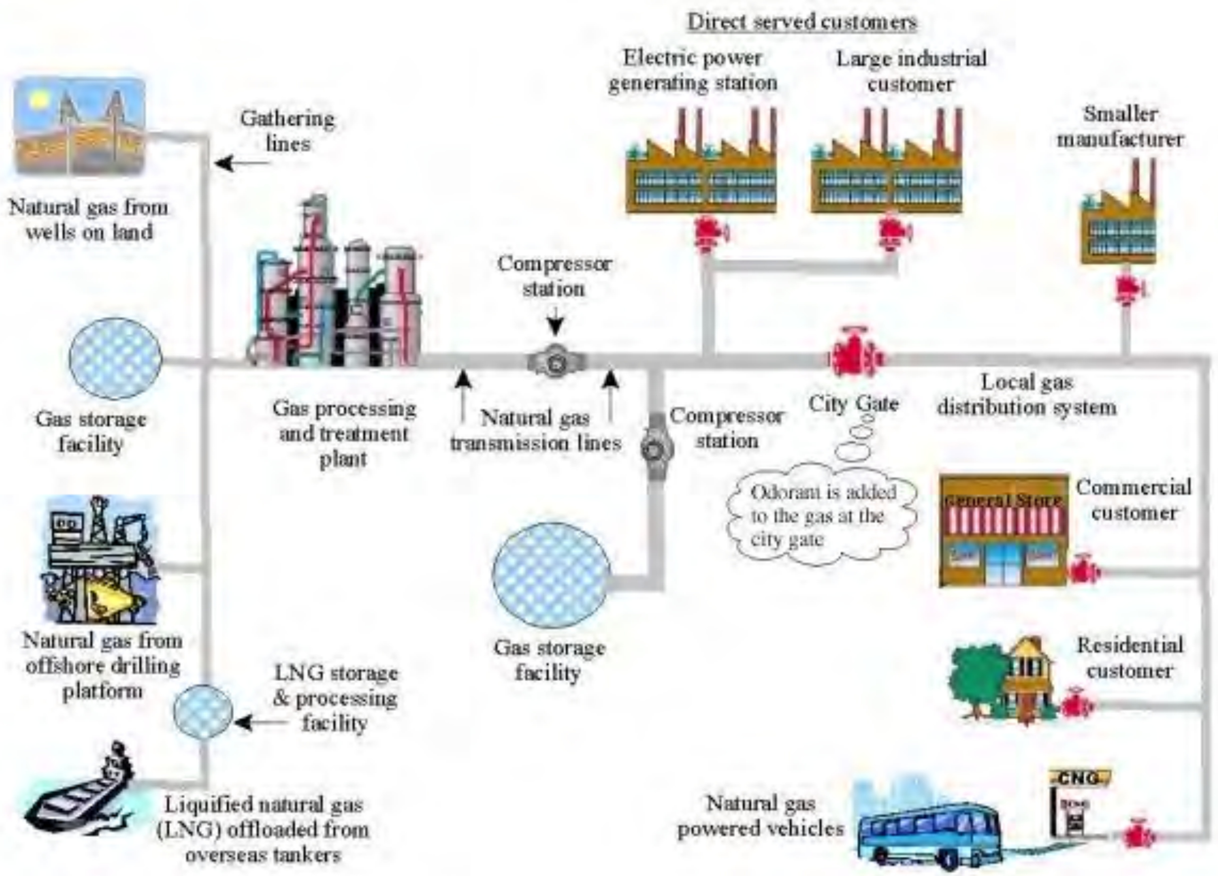


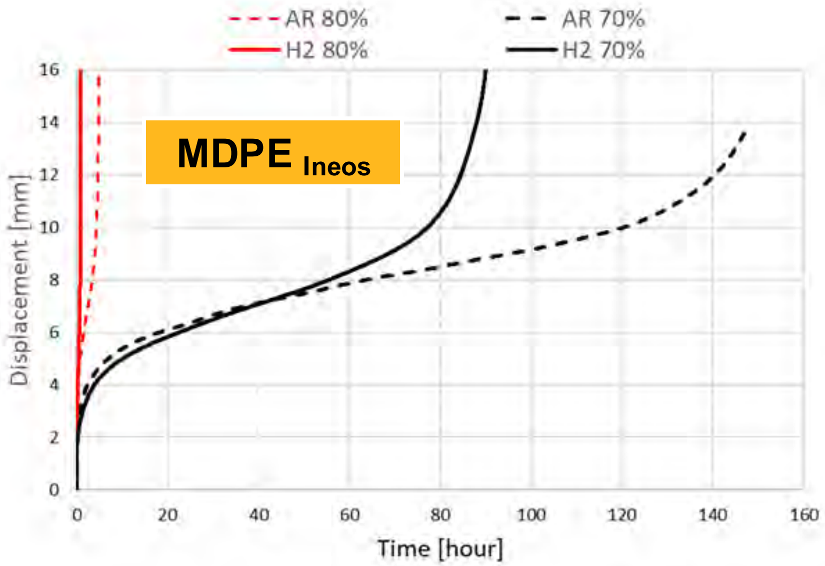
Pros	Cons
Low Operating Pressure	No ILI/pigging data
Negligible Pressure Variation	Thin-Walled Pipe, Absence of relevant property database
Low Strength Steel Grade	Gaps in relevant Codes & Standards
Majority of the network consist of MDPE pipes	New technology, lack of enough past history

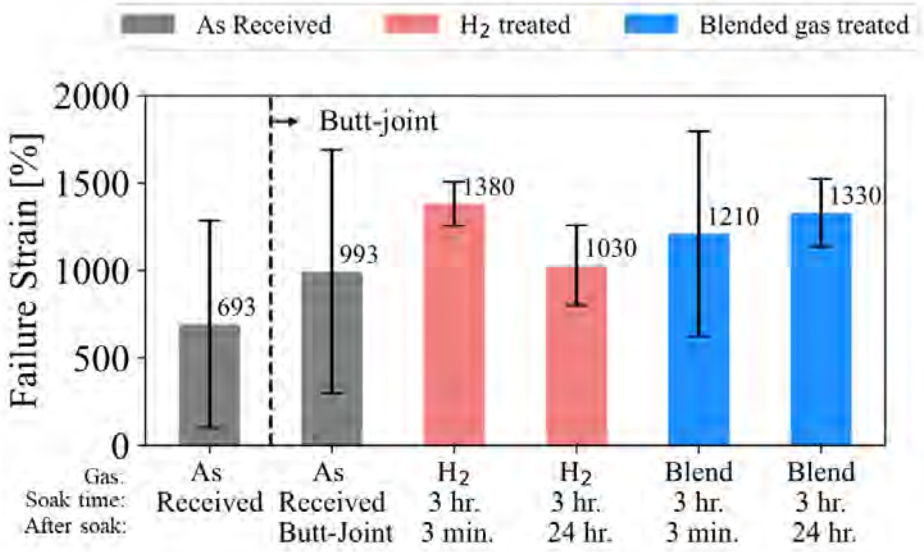
Solution in brief

- Develop a probabilistic risk model
- Test existing pipes at H_2 exposure
    - Asset compatibility
    - Raw data for risk model
- Plugin data in the risk model
- Find out the network compatibility

PE Pipe Compatibility – Recent Findings

- Behavior of PE resin displays irregularities, potentially due to varying manufacturing processes.
- $MDPE_{modern}$ pipes demonstrate enhanced failure strain and minimal fracture energy degradation
- Fusion joints showed improved properties at hydrogen exposure.
- The permeation gas loss is not significant. The maximum gas loss is less than 0.04% 250 psi at RT.
- HDPE pipes are more susceptible to fracture at hydrogen environment. However, Gazifère network doesn't have any HDPE pipe.
- Based on the PNNL-SANDIA report from the HyBlend study, it is challenging to conclusively determine the lifespan impact. However, the study doesn't warrant any immediate failure threat, phase 2 report will show more data.





Challenges with Fittings (Sealing Materials)

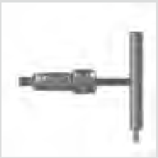
Material Name	Acronym	Suitability of use with Hydrogen Gas			
		EIGA Hydrogen Transportation Pipeline Doc 121/04/E	ISO 11114-2	ISO TR15916	*Research paper
Fluoroelastomer (Viton)	FKM	Good	Acceptable		
Nitrile Butadiene Rubber (Buna N)	NBR	Good	Acceptable	Suitable	
Polytetrafluoroethylene (Teflon)	PTFE	Good (up to 250C)	Acceptable	Suitable	
Polyepoxide (Epoxy)	EP	-	-		Suitable
Styrene-Butadiene	SBR	Good	-		
Butyl Rubber	IIR	Good	Acceptable		
Silicone Rubber	VMQ	Fair	Acceptable (permeation needs to be evaluated)		
Ethylene Propylene Diene Monomer Rubber	EPDM	-	Acceptable		
Polyvinyl Chloride	PVC	Good (up to 60C)	Acceptable		
Fluorosilicone Rubber	FVMQ	-	Acceptable (permeation needs to be evaluated)		
Polyethylene	PE	Good (up to 60C)	Acceptable		
Natural Rubber	-	Fair	-		
Polyether Ether Ketone	PEEK	-	Acceptable		
Polychloroprene	CR	Good	Acceptable	Suitable	
Polyaryetherketone	PAEK	-			

- Common elastomer materials in North American pipelines, such as O-rings and seals, are likely compatible with hydrogen gas.
- Most sealing materials are acceptable for hydrogen exposure per EIGA and ISO standards.
- Further studies required to evaluate fitness-for-service evaluation for higher pressure service.
- HyBlend and PRCI projects are evaluating the long-term hydrogen effect on sealing materials.

*Source: Epoxy Resin for Sealing the Underground Hydrogen Storage Reservoirs

Challenges with Fittings (Cast Iron Components)

Challenges	Solution
• Cast iron components are not permitted in ASME B31.12 and AIGA 087 • The existing network was not initially designed to transport hydrogen • Not much literature available • Lower fracture toughness and are more susceptible to potential embrittlement effects • GDS network includes valves, flanges, fittings, and similar components • Significant potential replacement cost	• NREL stated cast iron fittings are compatible at low pressure system • Cast iron H2 compatibility assessment: o Material Testing o Analytical Model • Evaluate the H2 effect on the mechanical and metallurgical properties • Include the analytical model data in the overall risk model

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

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Pipe Testing Data

Testing Project at NRC

Selected Pipe for Testing

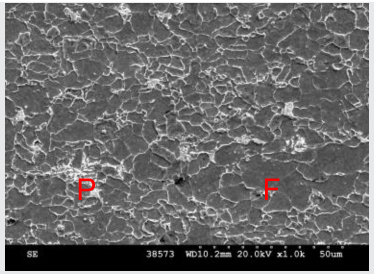
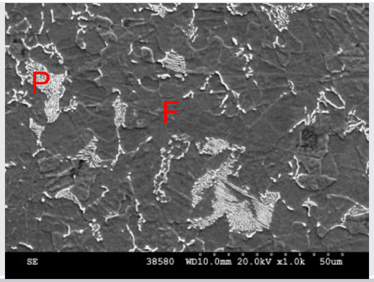
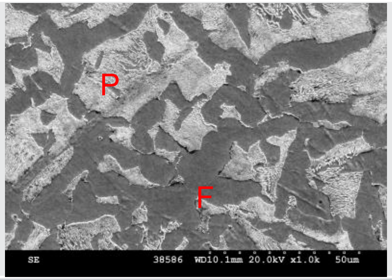
Pipe Source	Diameter (inches)	Wall Thickness (inches)	Grade	Installation Year	Label
GTM	26	0.281	359	1954	Vintage
Gazifère	12	0.250	290	1975	Legacy
GDS	24	0.500	448	2016	Modern

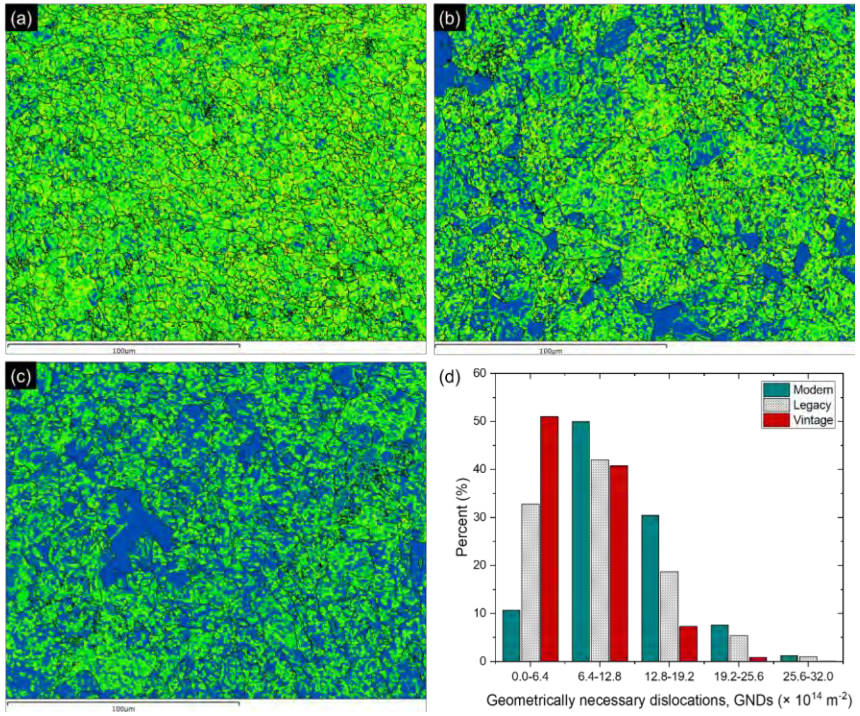
Materials	Nominal Composition (wt%)											
	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	V	B	Fe
New Pipe (2016)	0.052	1.44	0.010	0.003	0.212	0.168	0.123	0.040	0.135	0.029	0.0003	Bal
Gazifère (1975)	0.186	0.79	0.005	0.015	0.002	0.024	0.023	0.030	0.003	0.002	0.0001	Bal
GTM (1954)	0.280	1.07	0.010	0.023	0.034	0.207	0.081	0.032	0.009	0.002	0.0001	Bal

Materials	Nominal Composition	
	Nb	Ti
New Pipe (2016)	0.053	0.0095
Gazifère (1975)	0.013	0.0008
GTM (1954)	0.002	0.0009

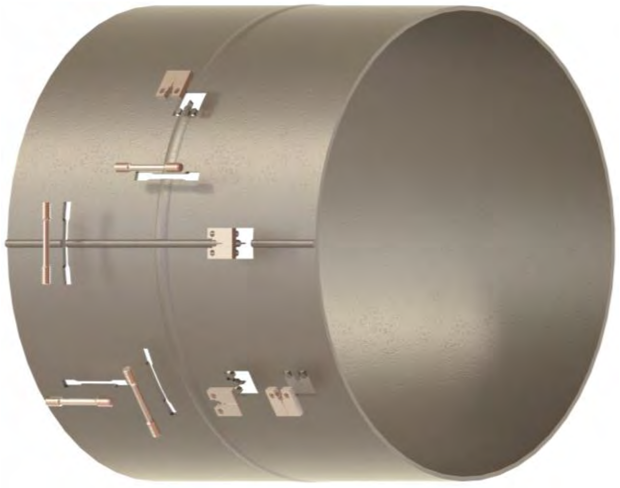
- Vintage pipe – higher %C, more pearlite in microstructure
- Modern pipe – higher %alloying element and significantly less impurity
- Nb based design vs conventional ferrite/pearlite microstructure

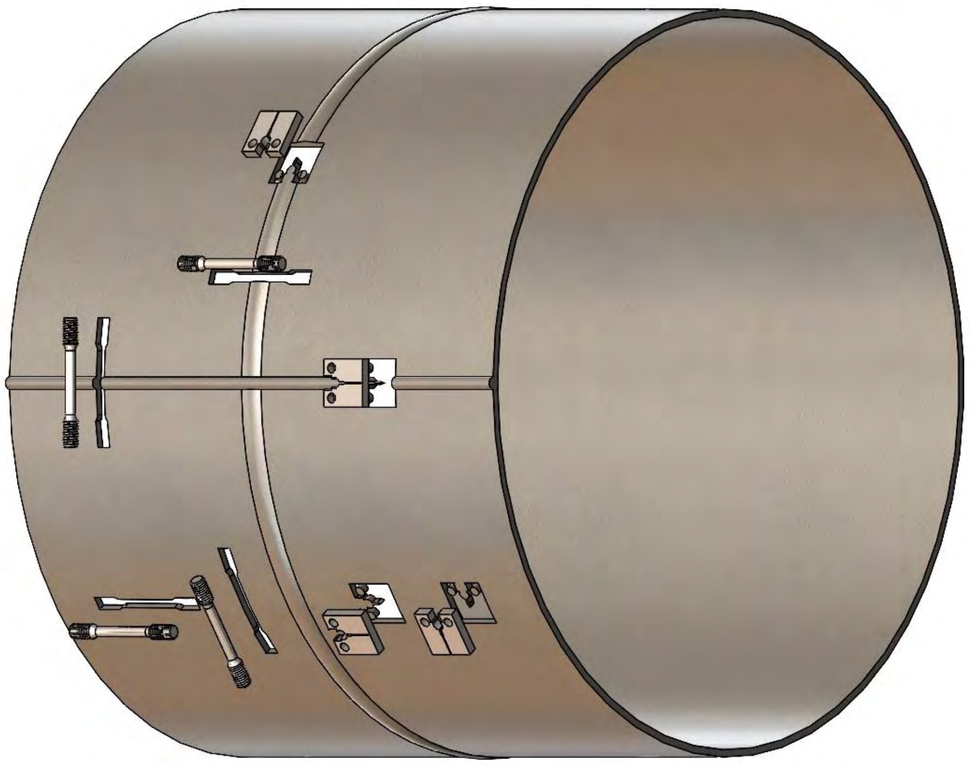
Materials Characterization (cont.)

Characterization	Materials		
	Modern	Legacy	Vintage
SEM Micrograph			
Microstructure	Pearlite + Ferrite	Pearlite + Ferrite	Pearlite + Ferrite
Hardness (HV_{1kgf})	224.8 ± 2.0	148.3 ± 2.8	202.4 ± 4.1
% Pearlite	4.1	22.2	35.0
Average grain size (μm)	15.4 ± 4.0	59.5 ± 6.5	88.0 ± 15.4

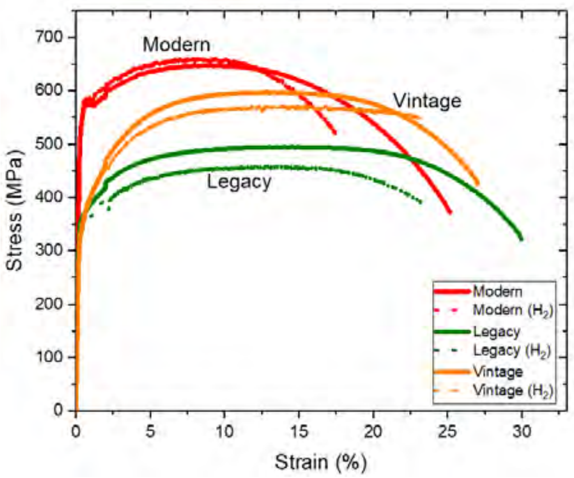


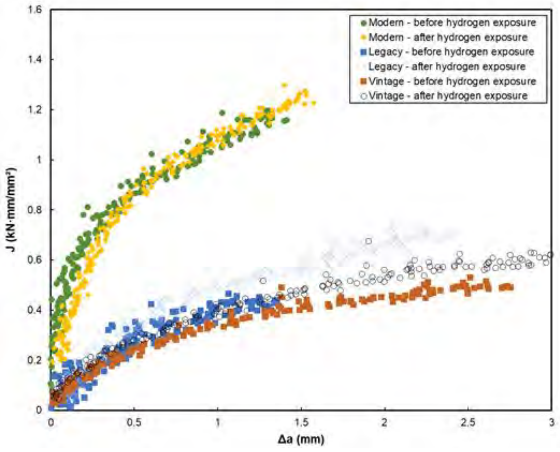
Sample Mapping on Pipe

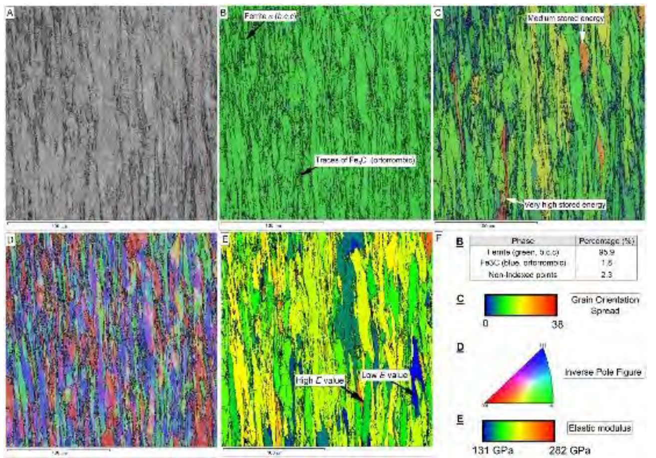




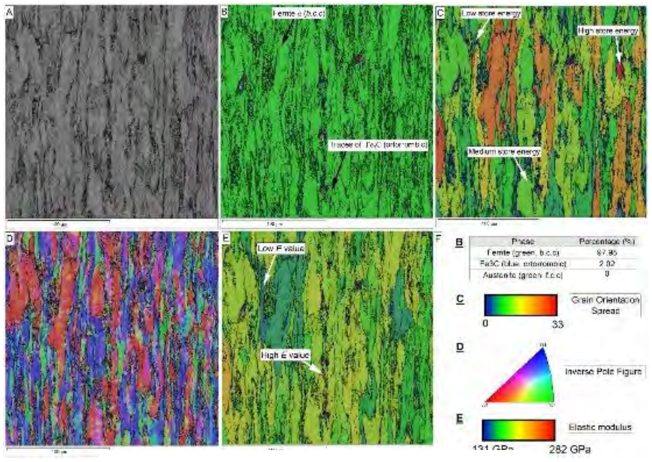
Effect of Hydrogen in Pipeline Steel



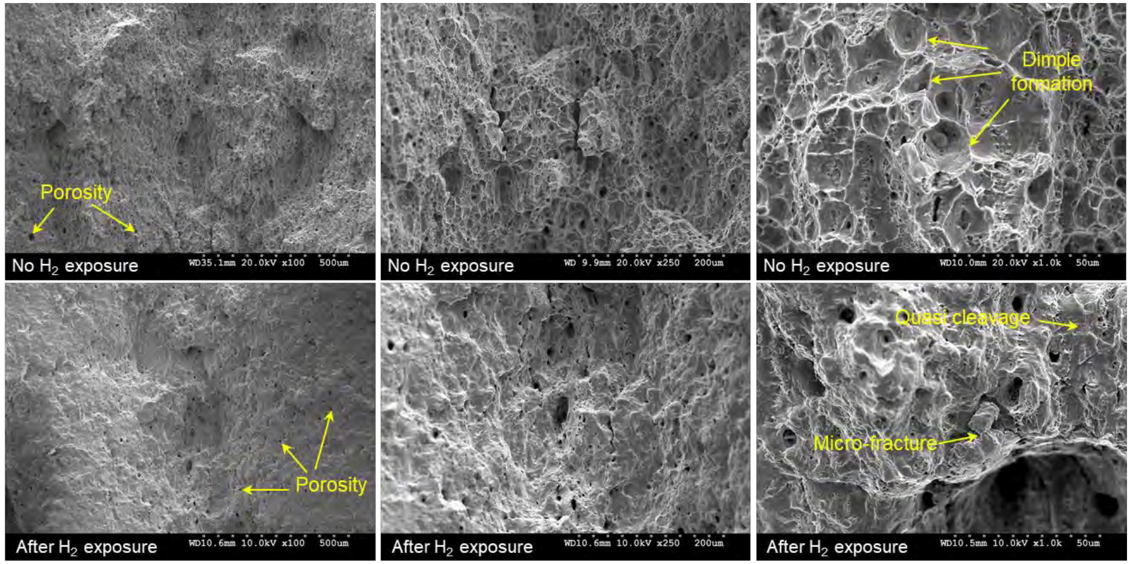


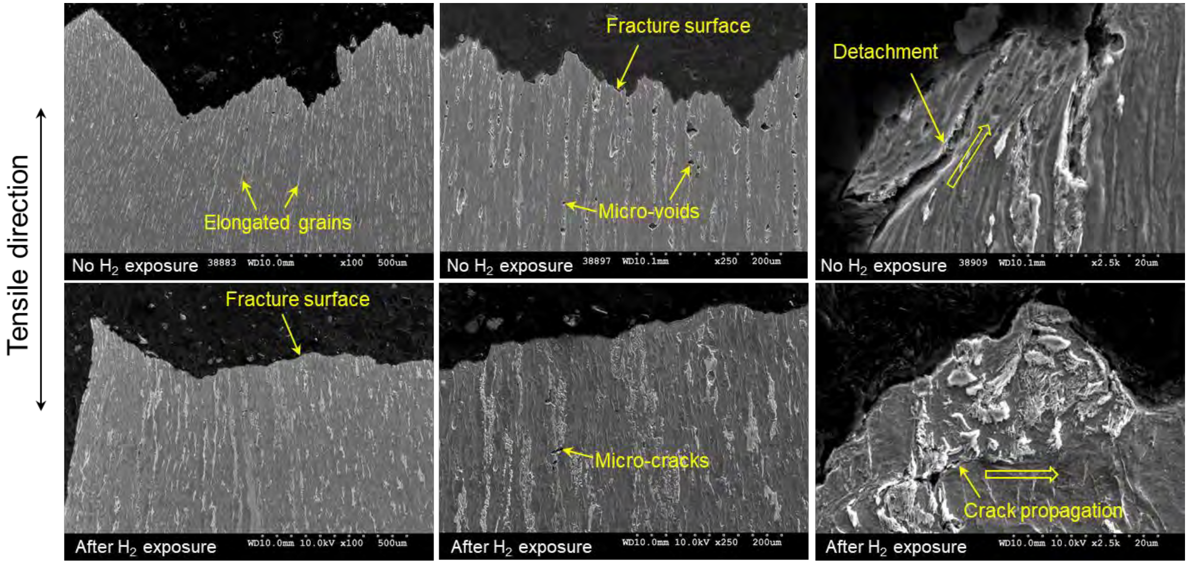


Before hydrogen exposure

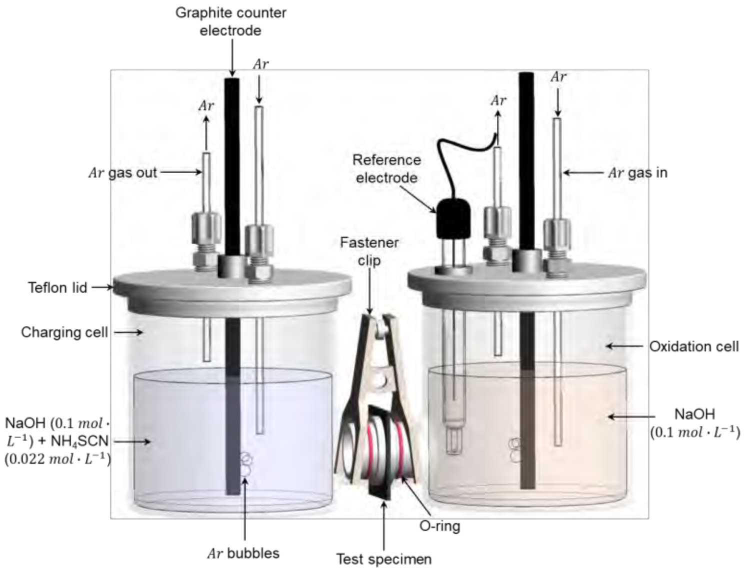


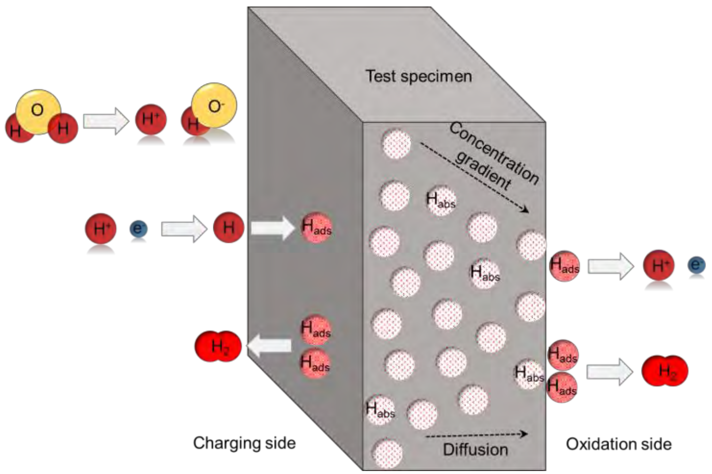
After hydrogen exposure

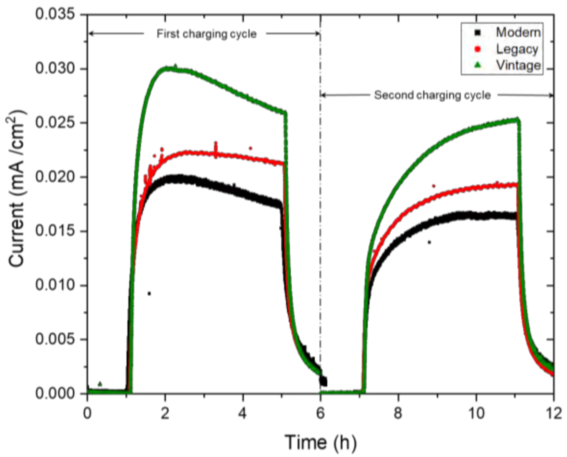


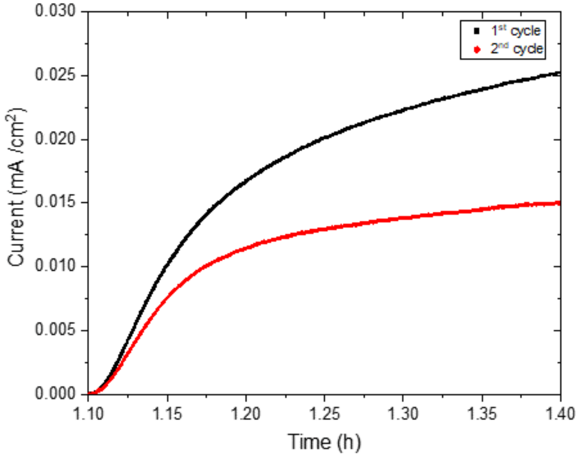


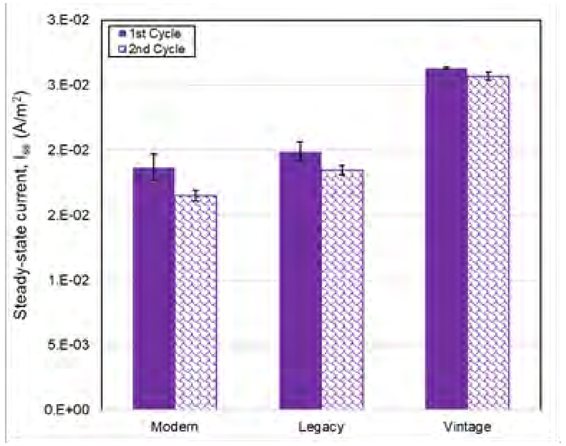
Effect of Steel Microstructure

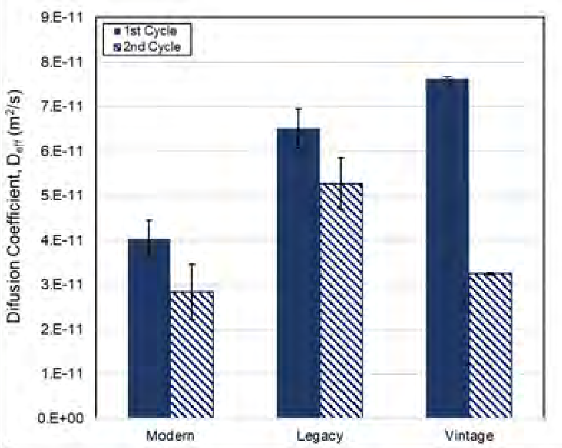


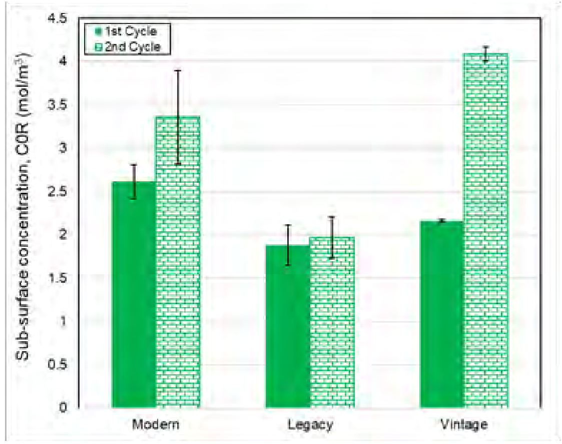


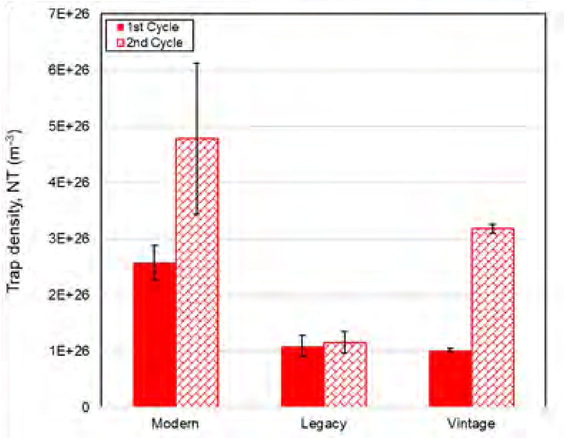












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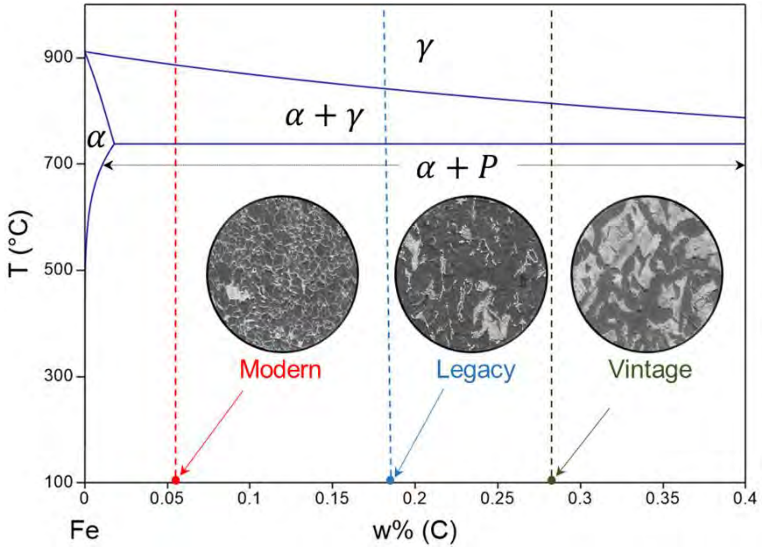
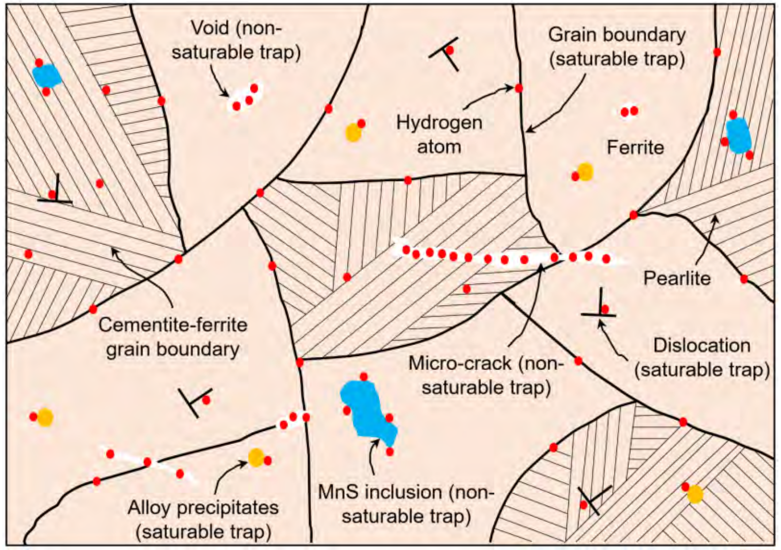
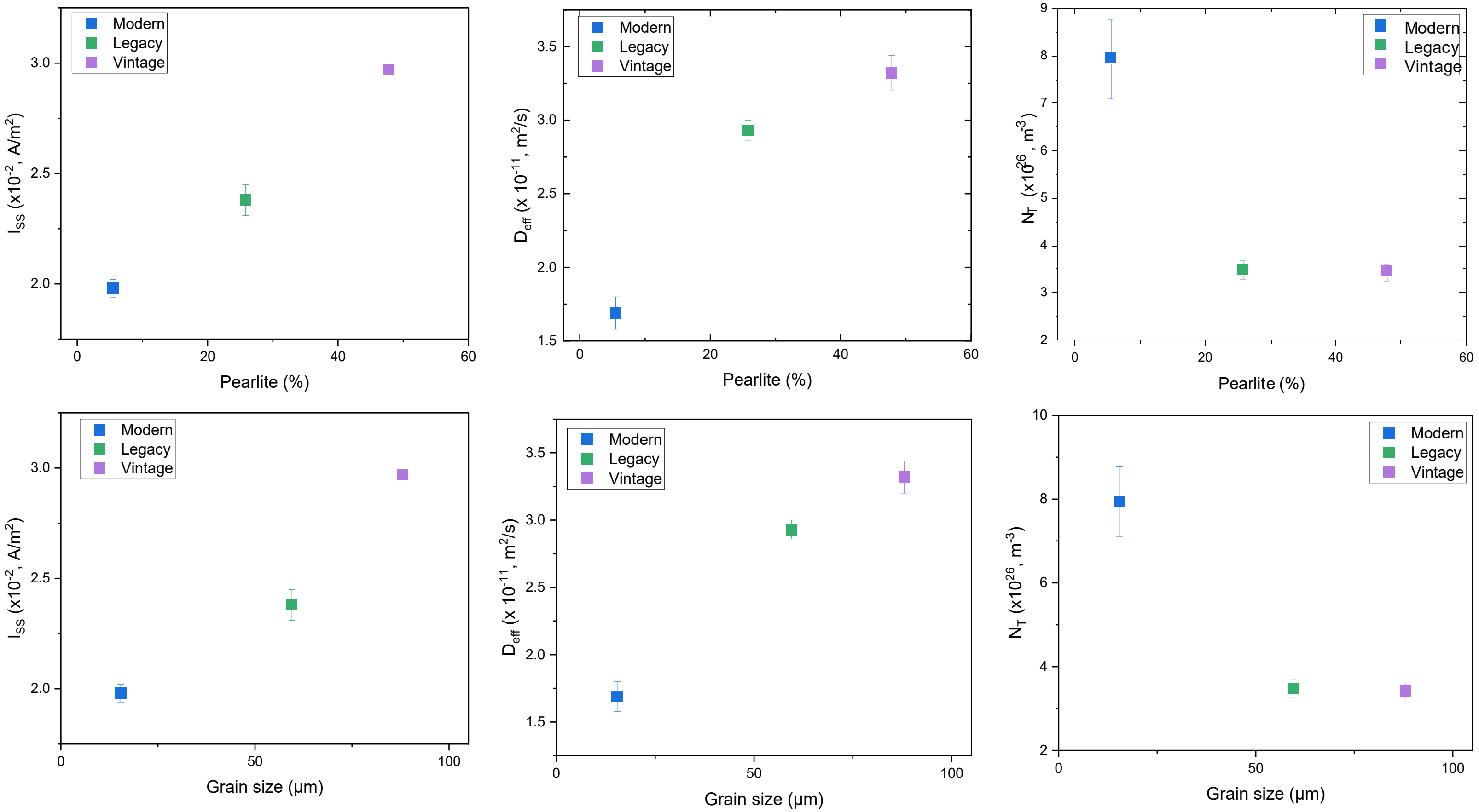
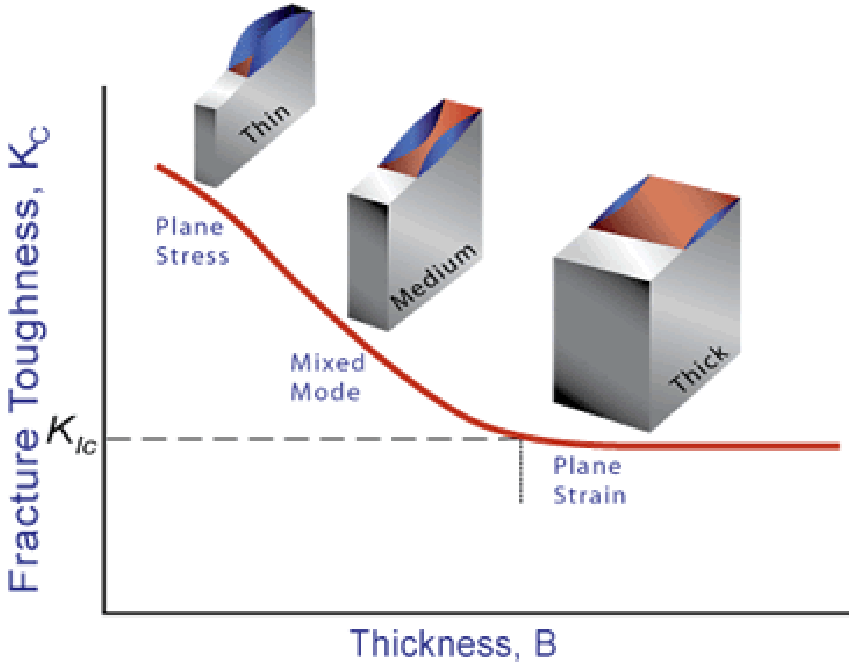
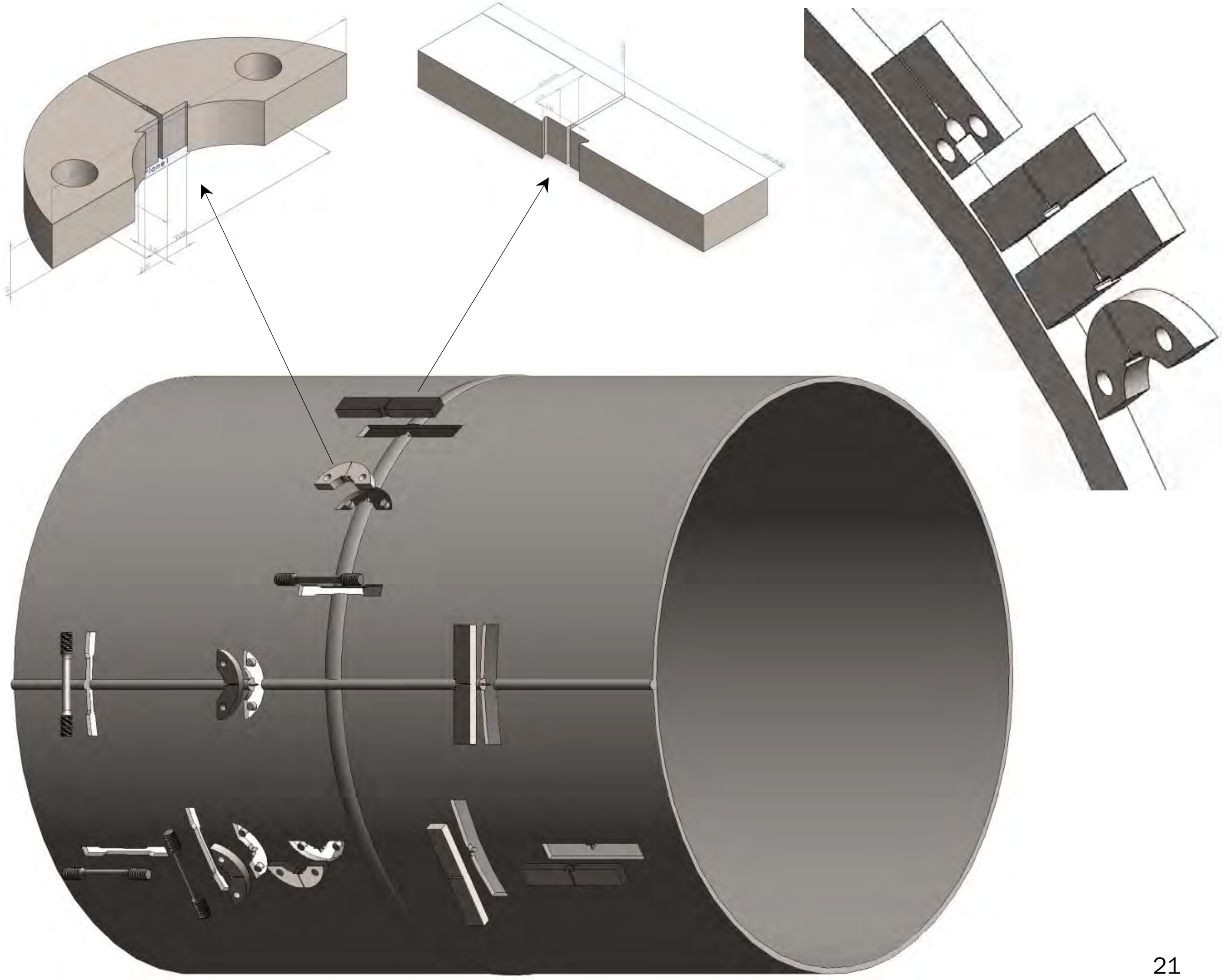






Technical Challenges with Thin-walled Pipes





- **Fracture toughness is often geometry dependent**
  - Critical stress intensity (K_C) decreases with increasing thickness until it plateaus at the plane strain fracture toughness (K_{IC}) which is a materials property
  - Smaller coupons can still be used for comparative purposes

Next Step (NRC)

- Establish universal fracture toughness testing criteria based on pipe size and geometry. ***- Ongoing***
- Set up a full-scale pipeline testing facility (0-100% H_2). ***- Ongoing***
- Develop a comprehensive material property database for hydrogen service.
- Create a unified platform for Canadian utilities and energy companies for collaboration and implementation of hydrogen service. ***- Ongoing***
- Launch a Canadian hydrogen value chain website. ***- Ongoing***

Next Step (Enbridge)

- Complete ongoing pipe and fittings testing project ***- Ongoing***
  - **Pipe Testing Project A:** Test 8 vintage pipes under H_2 exposure from the Gazifère and EGI networks.
  - **Pipe Testing Project B:** Test 3 vintage pipes from the EGI network.
  - **Fittings Evaluation:** Test cast iron fittings (BMI, ductile iron, grey iron) and develop an analytical model to determine the probability of failure.
- Develop a comprehensive risk model for the pipeline network, including fittings ***- Ongoing***
- Evaluate pipe test data and input relevant parameters into the risk model.
- Assess risk analysis and make decisions based on risk factors.
- Address any bottlenecks before blending hydrogen with natural gas.
- Revise operational and maintenance documents as needed for pure and blended hydrogen lines ***- Ongoing***
- Develop an integrity and risk management program for the blended gas network ***- Ongoing***

Thank You

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