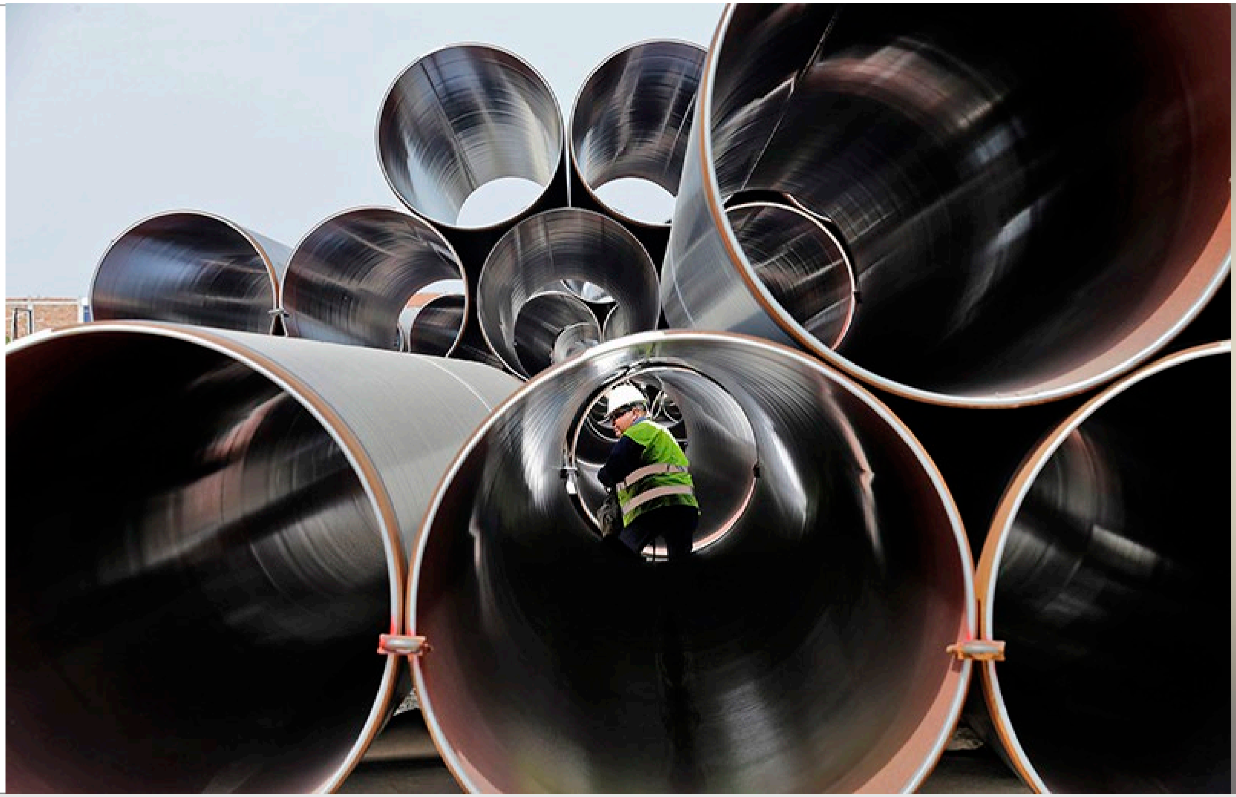

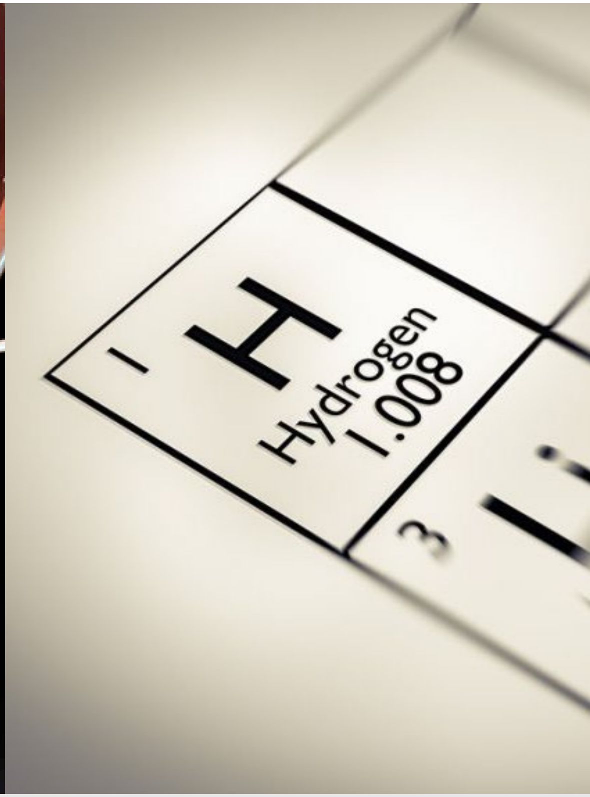

Hydrogen Pipeline Code of Practice

Overview

Josh Wickham | APGA Brisbane Convention September 2022

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FFCRC Project RP3.2-10:

Hydrogen Pipeline Code of Practice: Design, Construction and Operation

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Background

- **Why hydrogen pipelines?**
  - H2 potential for large energy export commodity
  - Pathway to decarbonisation of domestic energy
- **Growth of projects & assessments**
  - Pilot projects now in operation (low pressure)
  - Increasing scale / higher pressure blending
  - Localised pipeline conversion projects
  - Potential long distance H2 export pipelines
- **Economic comparison**
  - H2 pipelines cheaper/more reliable than powerlines infrastructure for moving energy over distance
  - Potential for additional energy storage

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Quiz Time!!

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1. Who's worked on a hydrogen pipeline related project or study?
2. Who expects they will need to in the next 5 years?
3. Next 10?
4. Never?
5. Who has assets they expect will need to convert for future H2 service?

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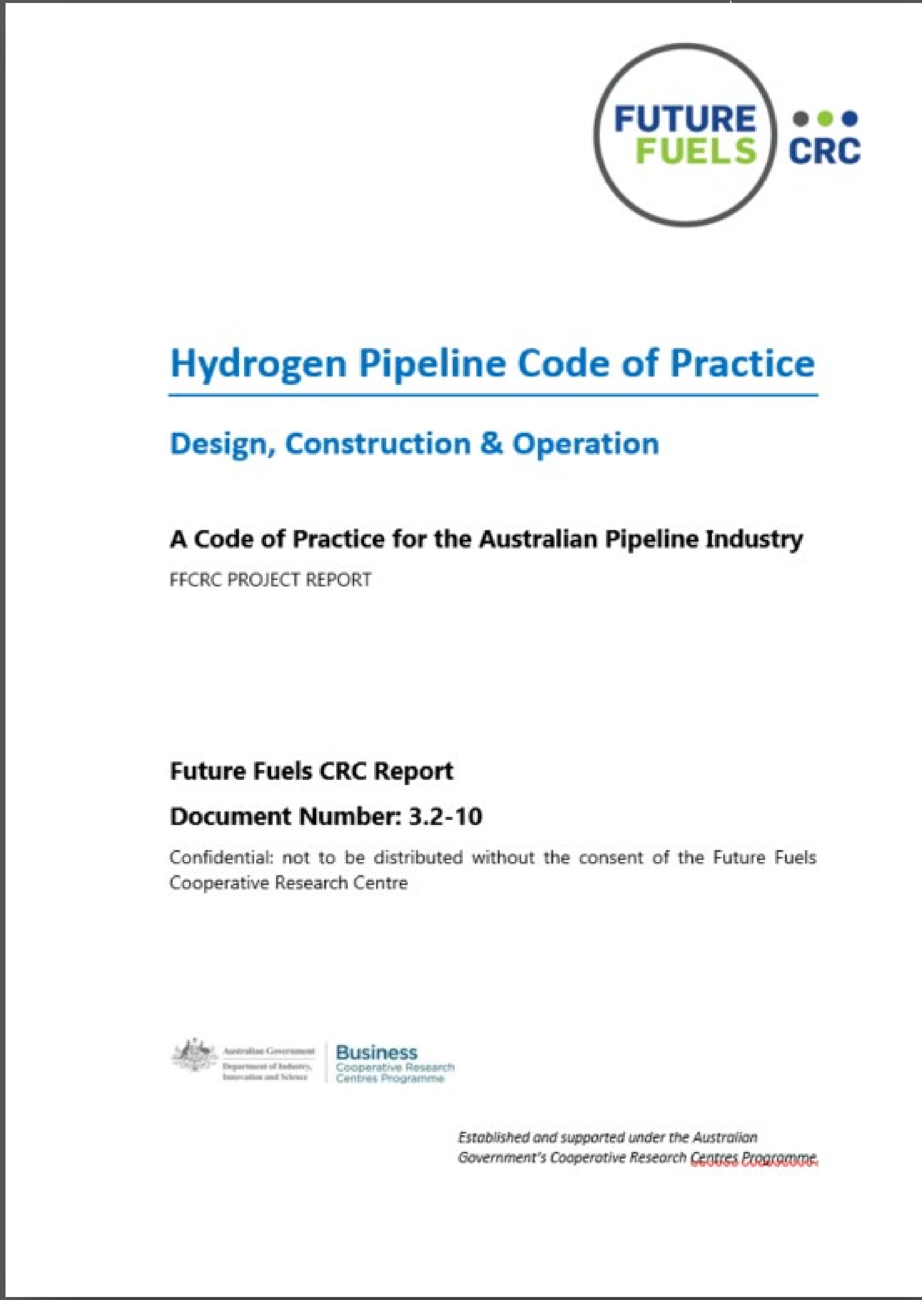
Scope

- Must be done safely, reliably and efficiently
- Enable integration of guidance and rules into our existing framework for pipelines (AS2885 series)
- Hydrogen introduces difference that need special consideration

The Hydrogen Pipeline Code of Practice:
Design, Construction and Operation

"Guidance and recommended practice for the design, construction and operation of transmission pipeline systems for transporting hydrogen or blends of hydrogen and hydrocarbon fluids"


FUTURE FUELS CRC

Hydrogen Pipeline Code of Practice

Design, Construction & Operation

A Code of Practice for the Australian Pipeline Industry

FFCRC PROJECT REPORT

Future Fuels CRC Report

Document Number: 3.2-10

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Business Cooperative Research Centres Programme

Established and supported under the Australian Government's Cooperative Research Centres Programme

Agenda

- **CoP Content Overview**
- **Interaction with AS2885 Series**
- **Risk Based vs. Prescription**
- **Chapter Focus & Summary**
  - C4. Hydrogen as a Fluid
  - C5. System Compatibility for H2 Service
  - C6. Carbon Steel Linepipe for H2 Service
  - C7. Hydrogen Pipeline Design (Carbon Steel)
  - C8. Welding
  - C9. Conversion of Existing Pipelines
  - C10, Operations & Maintenance
  - C11. Composite Pipeline Design
  - C12. Safety
- **Challenges & Lessons Learned**
- **Future Revisions & Wider Publication**
- **Acknowledgements**

Hydrogen Pipeline CoP – Content Overview

C1. Introduction (Scope & Pupose)
C2. Background
C2. Australian & International Standards
C4. Hydrogen as a Fluid
C5. System Compatibility for H2 Service
C6. Carbon Steel Linepipe for H2 Service
C7. Hydrogen Pipeline Design
C8. Welding
C9. Conversion of Existing Pipelines
C10: Operations & Maintenance
C11. Composite Pipelines
C12. Safety

- **Appendix C**: Linepipe Specification & Supplementary Testing Guidance
- **Appendix D**: Future Proofing New Pipelines
- **Appendix E**: ILI Technology for Hydrogen Service
- **Appendix F**: Pipeline Conversion Checklist
- **Appendix G**: Pipeline Sizing Guidance

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Interaction with AS2885 Series

- CoP will remain a live ‘companion’ document
- Future Part of AS2885, or a Technical Spec under Australian Standards?
- Structure complementary to Parts of AS2885 series

Australian/New Zealand Standard™

Pipelines—Gas and liquid petroleum

Part 1: Design and construction

Australian Standard®

Pipelines—Gas and liquid petroleum

Part 3: Operation and maintenance

Australian/New Zealand Standard™

Pipelines — Gas and liquid petroleum

Part 2: Welding

Australian/New Zealand Standard™

Pipelines—Gas and liquid petroleum

Part 6: Pipeline safety management

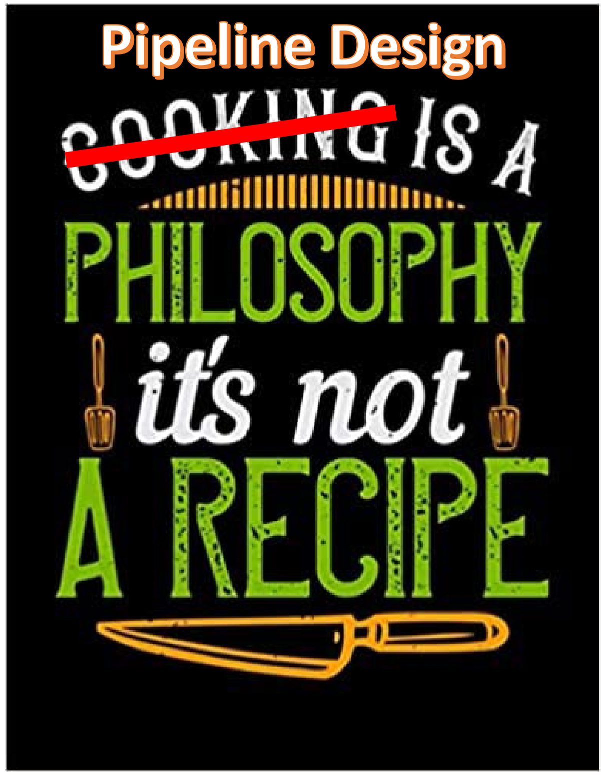
CoP Section	AS2885 Related Part
C5. System Compatibility for H2 Service	AS2885 Part 1 – *Section 3 Pipeline Materials*
C6. Carbon Steel Linepipe for H2 Service	AS2885 Part 1 – *Section 3 Pipeline Materials*
C7. Hydrogen Pipeline Design	AS2885 Part 1 – *Section 5 Pipeline Design*
C8. Welding	AS2885 Part 2 Welding
C9. Conversion of Existing Pipelines	AS2885 Part 3 – *Section 10 Change of operating conditions*
C10. Operations & Maintenance	AS2885 Part 3 Operations & Maint.
C11. Composite Pipelines	AS2885 Part 1 - *Appendix S Fibreglass Pipe Manufacture*
C12. Safety	AS2885 Part 6 – Safety Management

Risk Based vs. Prescription

- Prescriptive recommendations provided – where knowledge/experience supports rules

- In areas where knowledge gaps exist:
  - Detailed commentary, and back ground information provided
  - Information on how these damage mechanisms contribute to a failure mode
  - Guidance on how failure modes can be addressed
  - Guidance on knowledge gaps and where individual assessment needed

A key outcome is the CoP, informs and educates the user, to support informed judgement – **it is not a recipe book!**



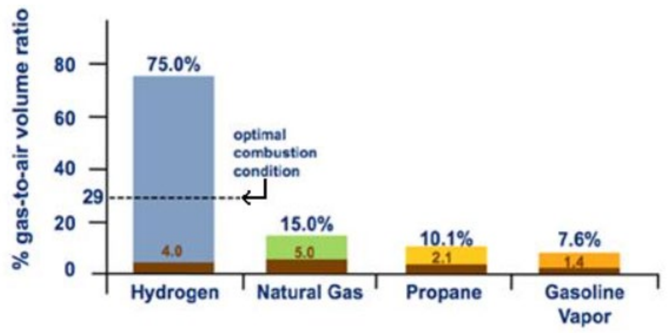
Chapter 1-3: Introduction, Background, Standards

- **Chapters 1-2** –
  - Scope, background, scene setting,
  - References research activities and knowledge gaps that remain to be closed.
- **Chapter 3**
  - Related standards, including relevant international codes (directly referenced in the CoP or relevant for information),
  - Interaction with AS2885 Parts

Chapter 4: Hydrogen as a Fluid

- Physical properties and characteristic of pure hydrogen and blends of hydrogen within natural gas.
- Highlights differences to natural gas.
- Guidance on how differences impact;
  - Process modelling, hydraulic simulation and line sizing,
  - Safety in design considerations,
  - Release events, dispersion, radiation contours, overpressure contours
  - Ignition energy & probability
  - Hazardous area classification

Parameter	100 % CH_4	10 % H_2 / 90 % CH_4	100 % H_2
Molecular Weight (g/mol)[i]	16.042	14.639	2.016
Standard Density (kg/Sm^3)[i]	0.6785	0.6191	0.0853
Specific Gravity Relative to Air[i]	0.554	0.505	0.070
Joule Thomson Coefficient	Positive	Positive	Negative
Higher Heating Value (MJ/Sm^3)[i]	37.71	35.15	12.10
Wobbe Index	50.67	49.44	45.87
Auto Ignition Temperature (°C)[ii]	600	560 to 600	560
Hazardous Area Temperature Class[ii]	T1	T1	T1
Lower Flammability Limit (vol%)[ii]	4.4	4.4	4.0
Upper Flammability Limit (vol%)[ii]	17.0	18.4	77.0
MESG (mm)[ii][iii]	1.12	0.87	0.29
MIC ratio [ii][iii]	1.00	n/a	0.25
Hazardous Area Equipment Group[ii]	IIA	IIB	IIC



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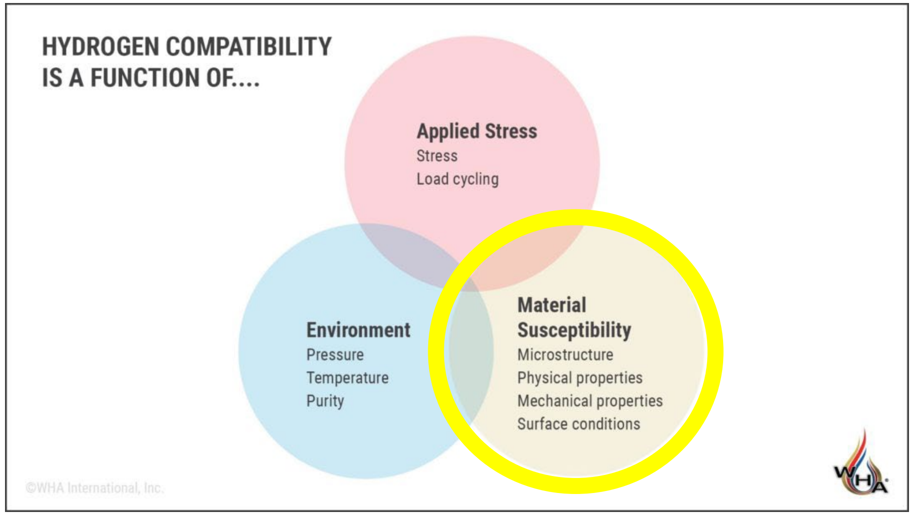
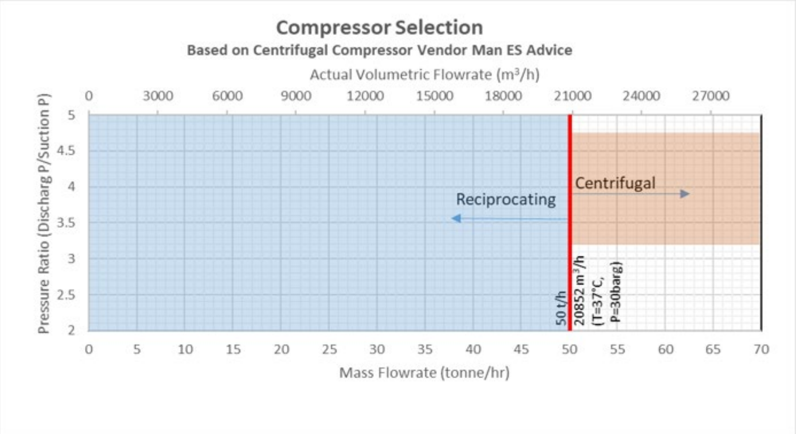
Chapter 5: System Compatibility for H2 Service

- Outlines impact of H2 on pipeline system piping materials, components and equipment – and their applicability for H2 service.
- Provides overview of damage mechanisms
- **Material reference tables**
  - Metallic materials
  - Elastomers, thermoplastics
  - Other materials (e.g. graphite / asbestos)
  - Minor equipment & accessories (vavles, filters, vessels, isolation joints, flow meters, pressure regulators, pressure relief systems)
- Major equipment: Compression





Chapter 5: System Compatibility for H2 Service

Y	suitable for use; minimal deterioration in hydrogen (chemically resistant)
P	does not deteriorate, but is considered permeable to hydrogen
C	may be suitable, subject to supplementary consideration or further assessment required by the Designer
U	unknown (no information available at time of writing)
N	not suitable for use
N/A	Not applicable, as material is not used at that pressure

Category	Description	Examples of Specifications	Notes/remarks	P ≤ 1,050 kPag	1,050 < P < 20,600 kPag	References
	Cr-Mo steels	ASTM A29 4140 ASTM A335	Chrome-Moly steels are highly susceptible to embrittlement: hydrogen reduces tensile properties, lowers fracture toughness, and accelerates fatigue crack growth. Control over yield strength, hydrogen gas pressure and temperature may allow safe use of Cr-Mo steels in hydrogen environments.	C[1]	C[1] Refer Chapter 6	[1], [2], [20], [21]
	Cr-Mo-V steels		Increased suitability in hydrogen than Cr-Mo steels; Vanadium is known to have a positive effect on resistance to hydrogen embrittlement. These steels may be used provided the material meets the requirements of API 941.	C[1]	C[1]	[20], [21]
	Ni-Cr-Mo low-alloy steels with Ni<5.5 wt%, Cr 2.0 wt% and Mo<0.75 wt%	AISI 4340, ASTM A372, ASTM A517, ASTM A29	Low and intermediate Nickel alloy steels are not permitted. Ni-Cr-Mo steels are quenched and tempered. They are susceptible to hydrogen embrittlement. Use in a hydrogen environment requires control of loading rate, yield strength, stele composition, hydrogen gas pressure and temperature.	C	N	[1], [2]
	High-alloy steels	9Ni-4Co	High-strength martensitic steels are not appropriate for use in hydrogen	N	N	[1]

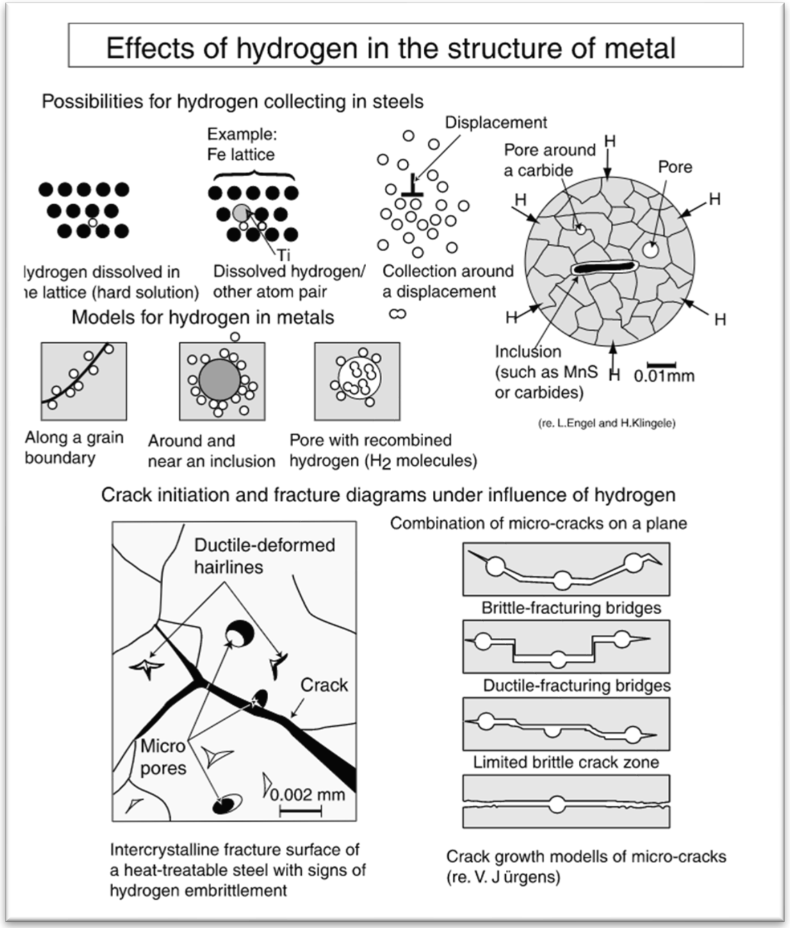
Chapter 5: System Compatibility for H2 Service

Y	suitable for use; minimal deterioration in hydrogen (chemically resistant)
P	does not deteriorate, but is considered permeable to hydrogen
C	may be suitable, subject to supplementary consideration or further assessment required by the Designer
U	unknown (no information available at time of writing)
N	not suitable for use
N/A	Not applicable, as material is not used at that pressure

Component Type	**Manufacturing Standard**	**Discussion**	**Compatibility (0 < P < 20,600 kPa)**	**CoP Section Reference**
Valves	API 6D and ASME B 16.34	Avoid gate valves where possible unless sealing can be assured. Pay attention to sealing and packing types.	Y	5.5.2
Pressure relief systems		Avoid burst disks.	Y	5.5.3
Pressure regulators		Investigate hydrogen performance of regulating diaphragm.	C	5.5.4
Flow Meters		Coriolis, thermal mass and ultrasonic meters are suitable for hydrogen service.	Y	5.5.5
		Turbine and rotary meters may be suitable.	C	
		Diaphragm meters are not expected to be suitable.	N	
Composition Meters		Hydrogen-specific analysers are required.	C	5.5.6
Filters and strainers		Metallic components are suitable.	Y	5.5.7

Chapter 6: Carbon Steel Linepipe for H2 Service

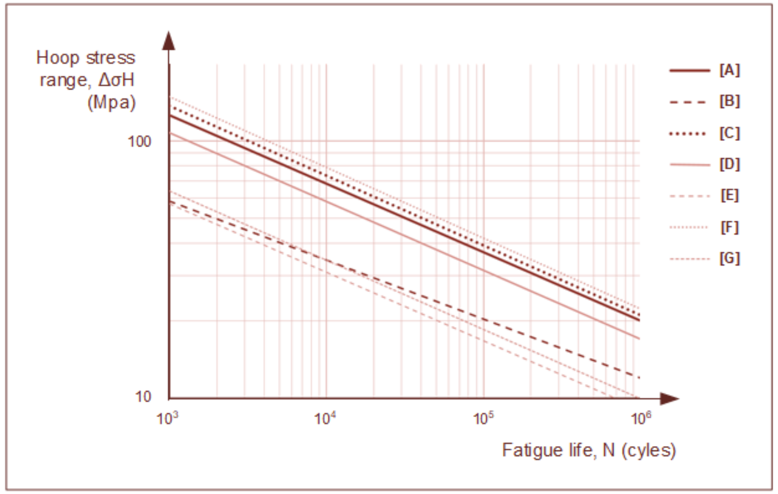
- Defines impact of hydrogen on the properties of carbon steel line-pipe materials
- Best practice to specify a material for optimal performance in hydrogen.
- Provides overview of hydrogen embrittlement, and impact to;
  - Ductility
  - Fracture initiation toughness
  - Fatigue life / fatigue crack growth rate
  - Fracture propagation resistance
- Detailed discussion on both fracture and fatigue
- **Ongoing research essential to furthering knowledge in this area**



Chapter 7: Hydrogen Pipeline Design

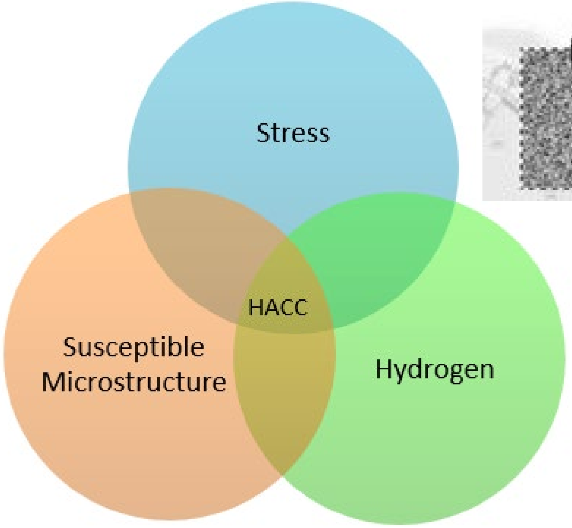
- Principles and rules for designing a carbon steel pipeline carrying hydrogen, and associated facilities, consistent with the scope AS 2885.1.
- Design criteria in AS2885 impacted by the effects of hydrogen
  - Fracture resistance and critical defect length.
  - Fatigue resistance and cyclic stress amplitude.
  - Propagating fracture arrest.
  - Design for hydrotest, to ensure non-critical defects in operation
- Control of fatigue critical! Requires assessment to justify design life & ILI practices.
- Guidance on vent design, AIV/FIV, field strength testing

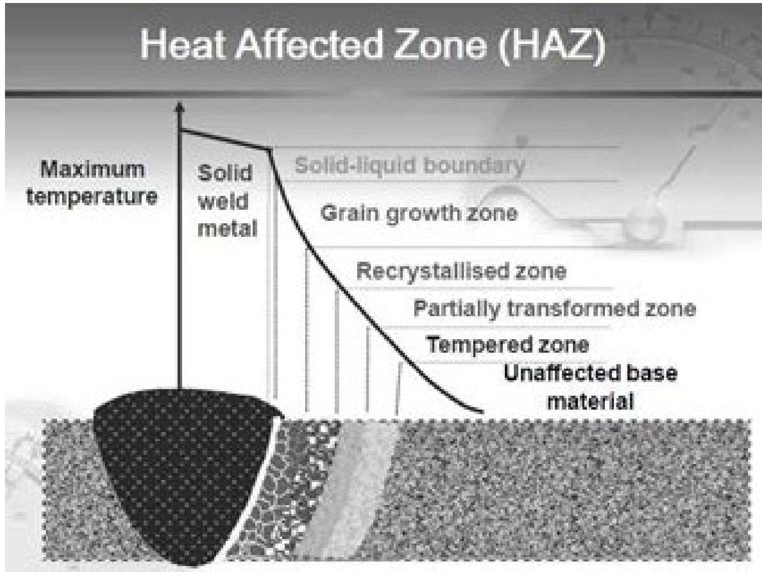
Diameter range	Max design factor, F_D	Min toughness	a	b	
DN100 to DN600	0.5	$C_v \geq 27$ J	3.761	7.825	[A]
	0.5	$C_v \geq 10$ J	4.361	5.080	[B]
	0.72	$K_{IC} \geq 55$ MPa(m)$^{0.5}$	3.683	7.414	[C]
DN650 to DN1050	0.5	$C_v \geq 54$ J	3.746	4.061	[D]
	0.5	$C_v \geq 10$ J	3.764	0.407	[E]
	0.72	$K_{IC} \geq 70$ MPa(m)$^{0.5}$	3.641	7.985	[F]
	0.72	$K_{IC} \geq 55$ MPa(m)$^{0.5}$	3.721	0.526	[G]

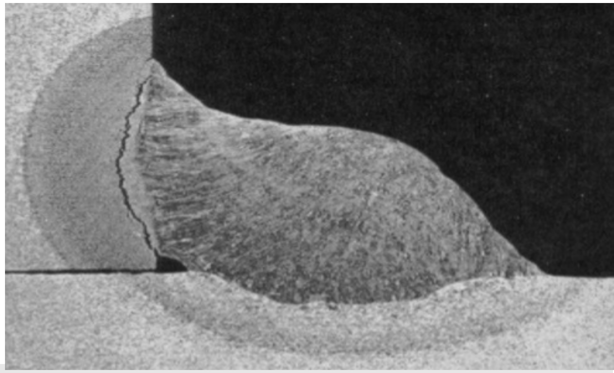


Chapter 8: Welding

- Outlines impacts of hydrogen on the properties of girth welds on carbon steel pipelines and suggests appropriate measures to mitigate these impacts.
- H2 interaction with defects
  - Minimizing likelihood of weld region being an initiating site for fatigue crack growth in H2 service
  - Preventing cracks in weld metal & HAZ
  - Avoiding sharp defects
  - Promote more suitable microstructure
- Defect criteria – currently proposed to retain AS2885 Part 2 requirements
- Increase in minimum toughness from 27J to 40J
- Hardness remains an area of ongoing research

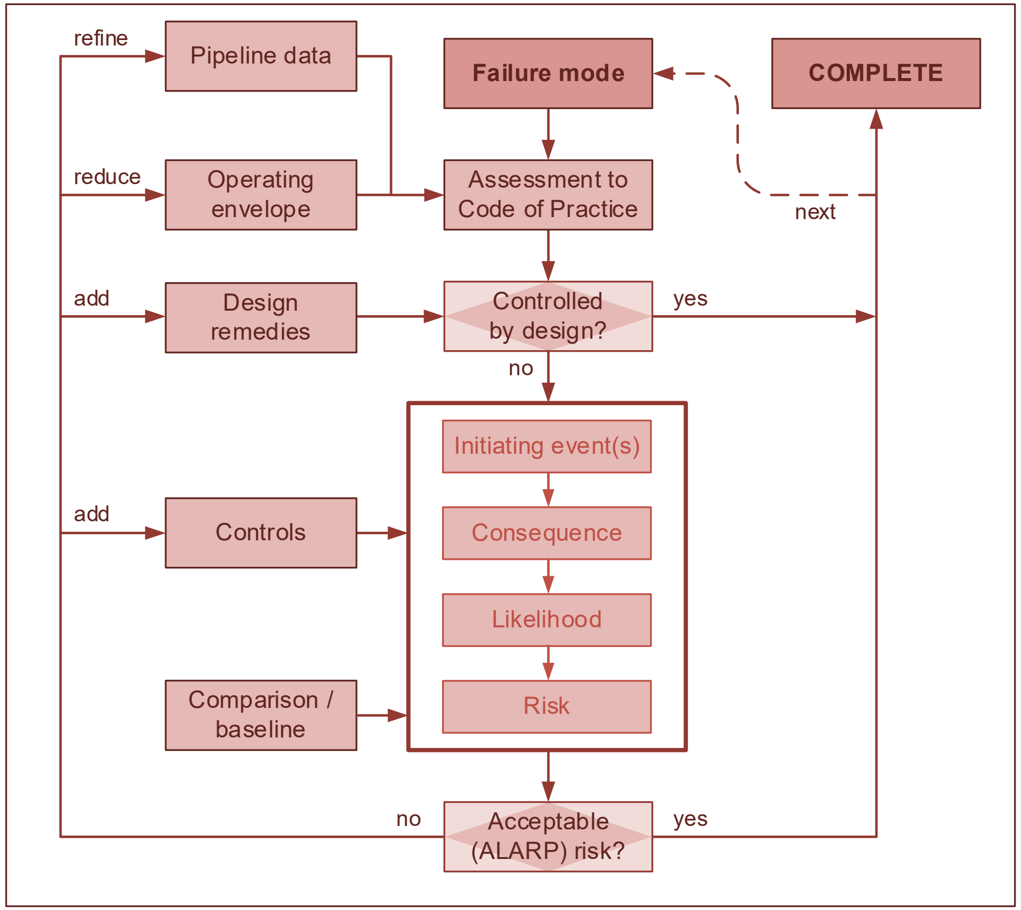




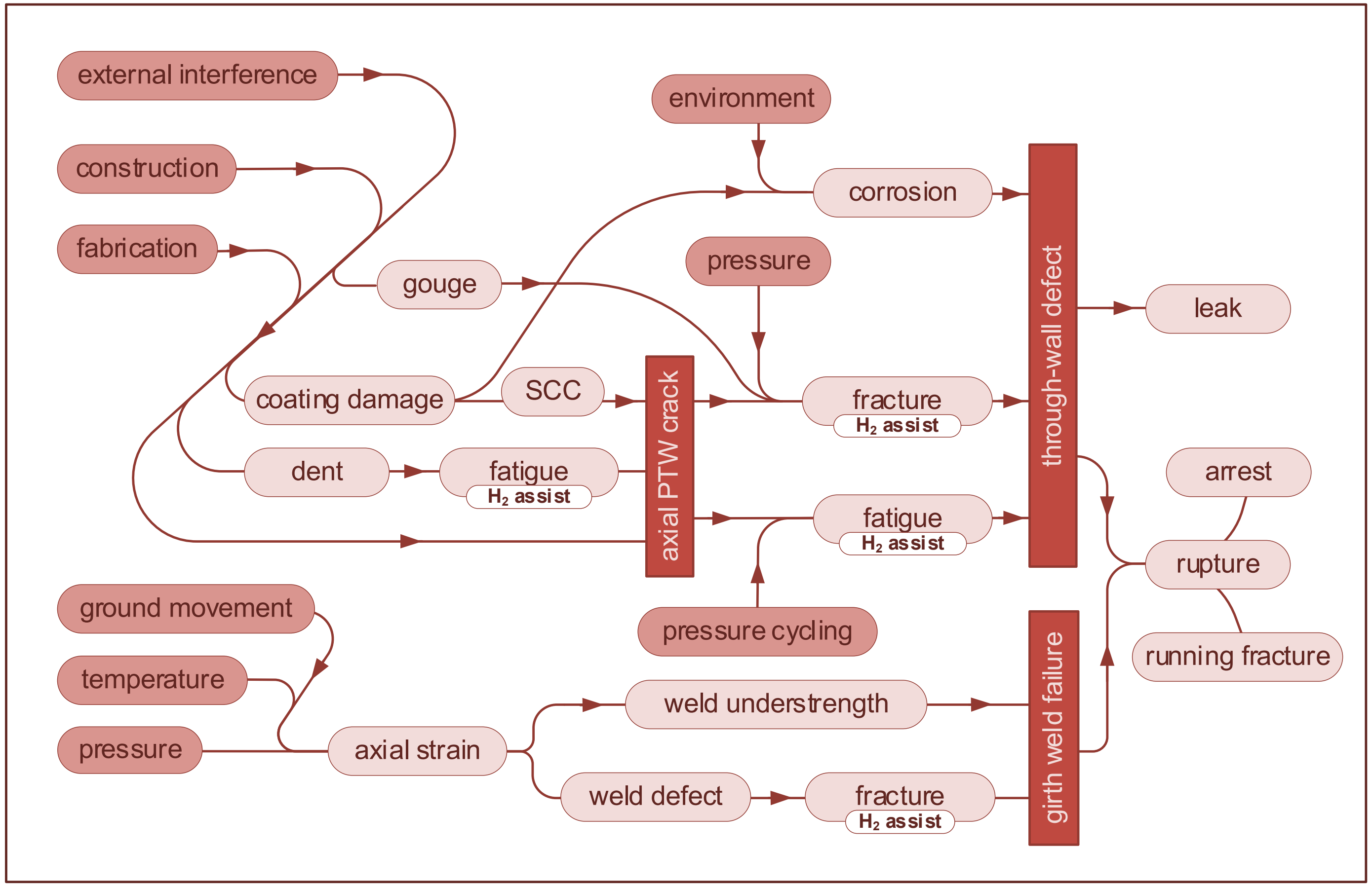


Chapter 9: Conversion of Existing Pipelines

- Outlines a requalification process – focused on both the linepipe, as well as equipment and components and implications for station design
- Provides assistance in how to gather & assess;
  - Current / historical data
  - Design / construction records
  - Maintenance records
  - Operations and integrity management records
  - Acknowledges there will be incomplee
- Complete assessment againce CoP (gap analysis)
  - Condition assessment to prioritise issues sensitive to H2 embrittlement & accelerated fatigue
  - Guidance on failure modes included
- Apply risks analysis and controls

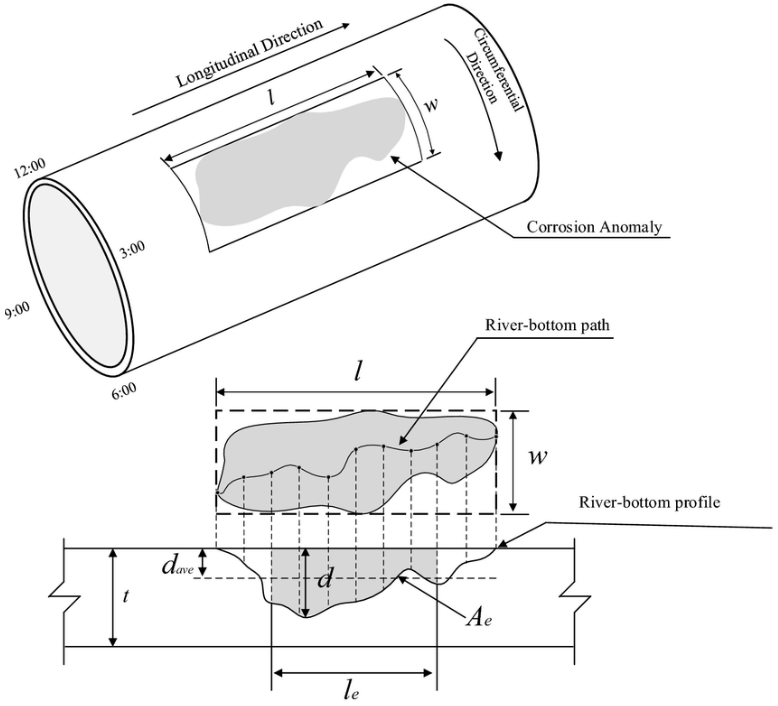


Chapter 9: Conversion of Existing Pipelines



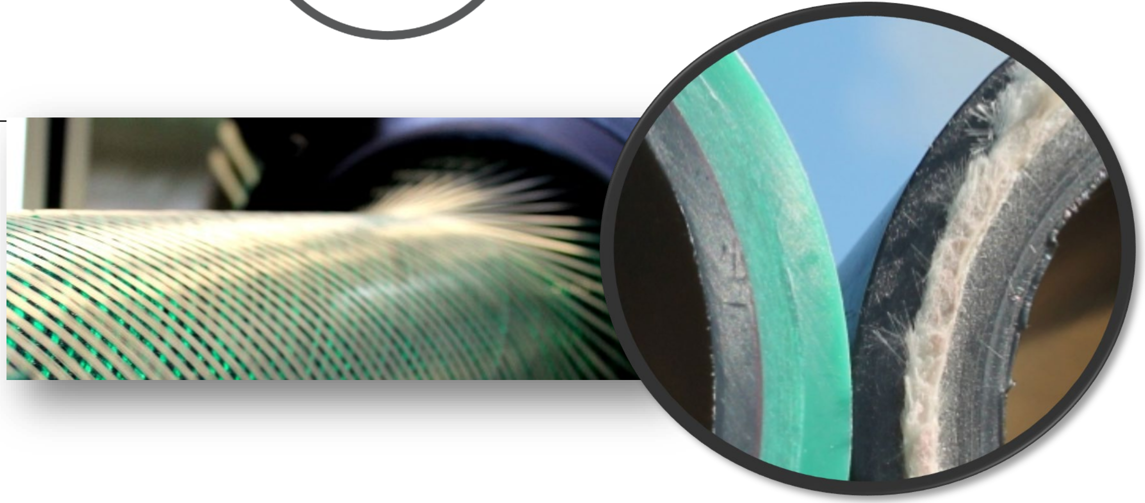
Chapter 10: Operations & Maintenance

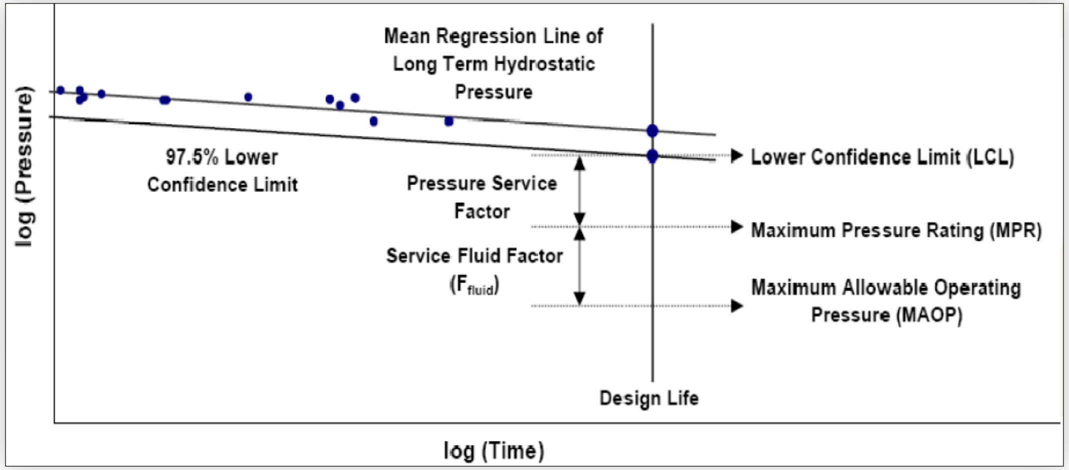
- By difference or complementary to AS2885 Part 3
- Guidance for areas such as;
  - structural integrity,
  - anomaly assessment & repair,
  - monitoring operating conditions,
  - purging and venting,
  - pressure cycle monitoring (fatigue management)



Chapter 11: Composite Pipelines

- Applicable to high pressure spoolable composite pipelines (multilayer fibre reinforced plastics)
- Design principles, fluid service conditions and qualification requirements that are impacted by hydrogen.
- Some H2 specific designs, limited qualification testing or in-service experience
- Ensure the vendor has assessed the failure modes and mitigated via a design and qualification process





Chapter 12: Safety

- Provides guidance on the safety-related provisions of AS2885 focussed on hydrogen-specific issues that affect:
  - Pipeline safety management
  - Process safety applied to facilities
  - Emergency management
- Identifies;
  - Which properties of hydrogen specifically relate to safety assessments, and
  - why they require specific consideration for hydrogen service

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Challenges & Lessons Learned

- Provides guidance on the safety-related provisions of Natural Gas pipelines have decades of best practice, driving a 0.8 design factor
- Existing industrial hydrogen pipes do not require fluctuating storage requirements that are valuable in transmission pipelines
- Must balance flexibility to apply the latest developing knowledge with ensuring safe design and operation
- Global effort needing intellectual property from many jurisdictions

Dissemination, Future Revisions & Wider Publication

Code of Practice Document (FFCRC):

- DRAFT report to be available to FFCRC membership soon
- Final report before end of year to FFCRC membership

Two Page Summary (FFCRC):

- Summary of the project deliverable will be produced for the FFCRC website, which will also function as a promotional material.

Seminar (Q1 2023):

- Half day or full day seminar will be produced based on the Code of Practice (Target Q1 2023)

Future Revisions

- Future revisions will be required as research data, empirical and industry experience progresses. Expect further updates over next 12-24 months.

Wider Publication

Two pathways being considered:

1. APGA branded document
2. Technical Specification under Australian Standards (recommended to be managed under ME-038 committee)

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thankyou.

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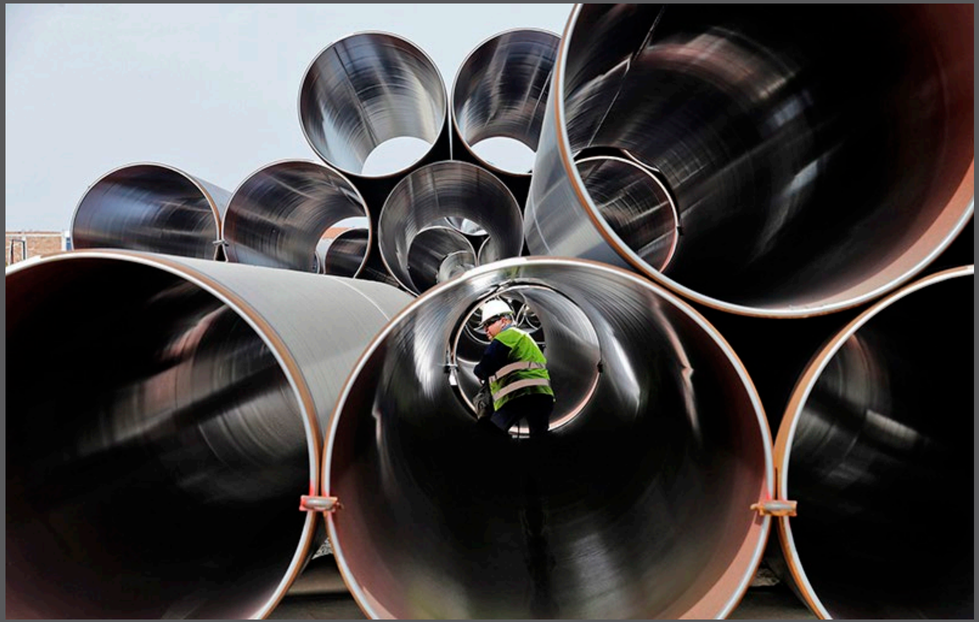

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