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Hydrogen Pipelines

LESSONS LEARNT FROM PRACTICAL WORK TO DATE

Design Projects – Our Experience

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Agenda:

1. Setting the scene; our starting points as pipeline engineers tackling hydrogen pipeline projects.
2. Assessing the standards available to us.
3. Primary differences between natural gas and hydrogen standards.
4. Key design decisions.
5. Elevated design considerations.
6. Transitioning to hydrogen from natural gas service.

A New Era for Design Engineers

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Lessons from existing projects – or 'Hydrogen Pipelines for Dummies'

- ✓ Pipeline projects involving some consideration towards hydrogen as the transported gas seem to be gaining traction.
- ✓ The proportion of pipeline projects that call for a hydrogen-ready design seems to be increasing.
- ✓ Hydrogen-ready designs may become run-of-the-mill; the new normal.
- ✓ Engineers who focus only on the design of hydrocarbon pipelines may find these opportunities are decreasing.
- ✓ The world is changing – let's get involved!
- ✓ But what does an experienced pipeline engineer need to know to adapt into this growing demand for hydrogen pipelines?

Let's start with what we know

- ✓We know natural gas. We know AS 2885.
- ✓We're familiar with environmental and external interference threats to our pipelines, and we have a good awareness of the measures that are available to control such risks.
- ✓We're familiar with the communities through which our pipelines pass, and how our pipelines interact with these communities.
- ✓The general principles of ensuring the safety of high-energy linear infrastructure, running cross-country and through population centres, are well known to us.

AS 2885 – Familiar and Sound

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✓Australian designers of hydrocarbon pipelines are blessed with a thorough, well-written, and eminently usable series of pipeline standards that may be one of the best such documents on the planet.

(A parochial and possibly biased view, but not an uncommon view in our industry)

✓AS 2885 has been an asset to the Australian industry, we are fortunate to have this tool at our disposal in our oil and gas pipeline design projects.

✓How about this new hydrogen world?

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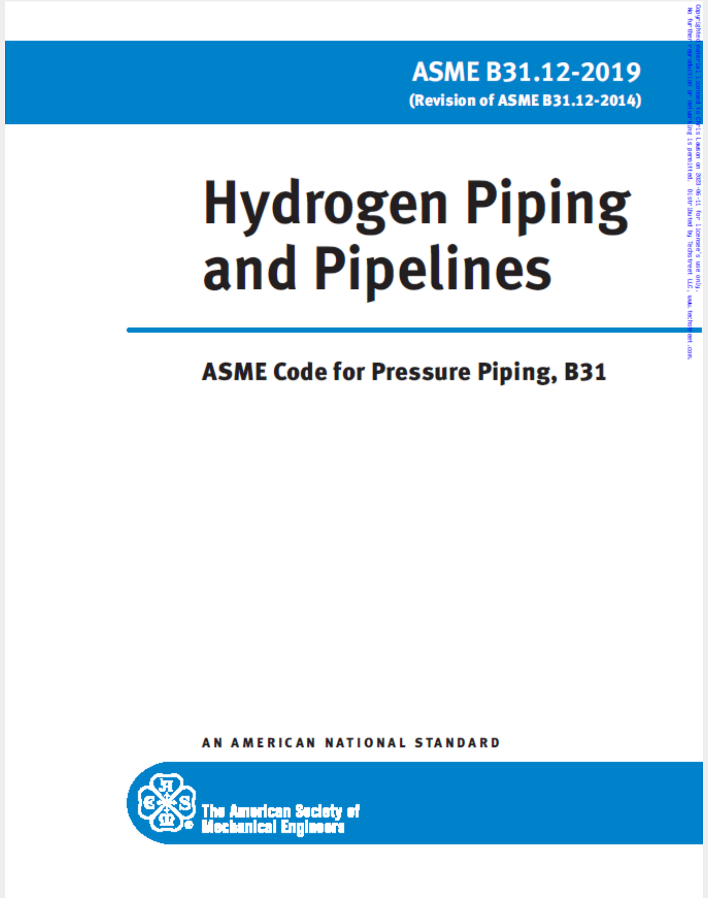
Up to now, B31.12

- ✓In the new hydrogen world, the list of mature and relevant standards has been relatively limited.
- ✓We have B31.12; AIGA / EIGA Guidelines; IGEM TD1, some others.
- ✓B31.12 seems to be the prominent standard - a commonly accepted choice as the best prescriptive/enforceable standard.
- ✓B31.12 was first issued around 2008 and revised multiple times since. The current edition is 2019, development is ongoing.

Now we have a code of practice as well!



AS 2885 – B31.12: Differences

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- ✓AS/NZS 2885.1 – wall thickness based on pressure containment needs, penetration resistance, constructability needs, allowances.
- ✓B31.12 wall thickness:
  - ✓Option A - prescriptive design. Use of conservative design factors and recommended materials, with simplified design and testing processes → heavier wall thickness.
  - ✓Option B - performance-based design. Greater engineering effort and testing requirements, leading to use of higher design factors → lighter wall thickness.
- ✓Other differences, including reduction in allowable hardness – eg weld hardness < 235 HV10.

Our design habits

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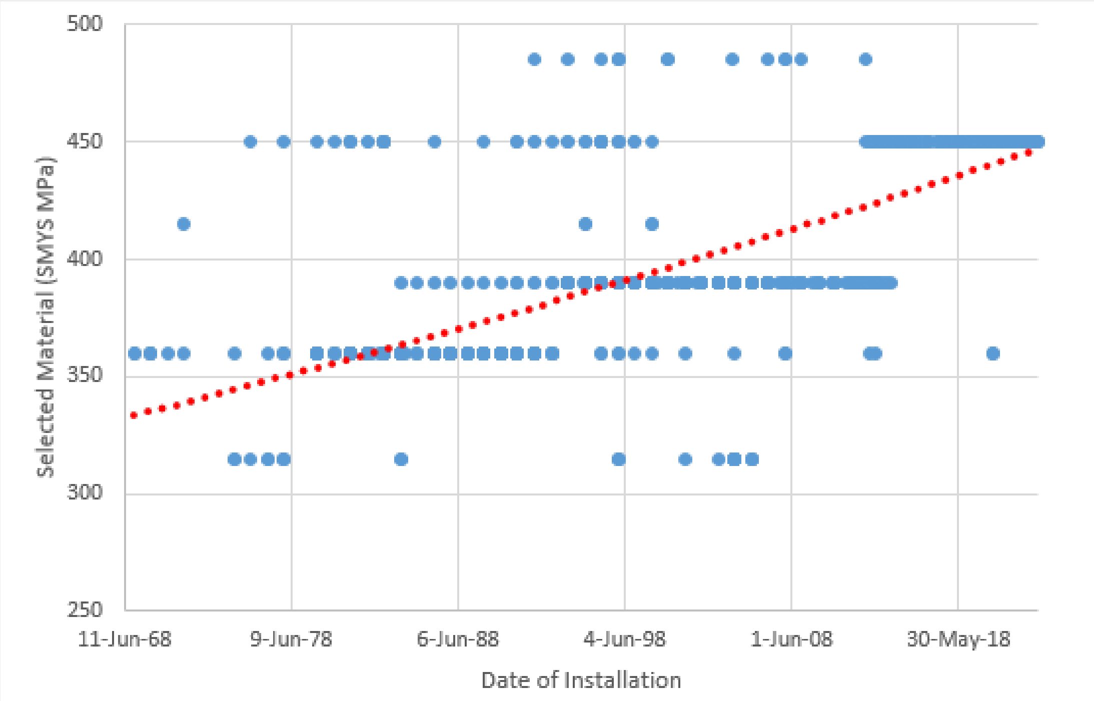
- ✓In Australia, pipelines tend to be lengthy and of small diameters.
- ✓Minimising steel costs has been important in maintaining project viability.
- ✓We've become accustomed to higher and higher steel grades - pipelines have trended towards perhaps a 'standard' design: X65 or X70, high toughness, thin wall, FBE-coated.
- ✓This is an evolution of earlier practices (late 1960s, 1970s), where X42 and X52 were the common grades.
- ✓Over time, new steels were developed, and tighter quality control in manufacturing, improved weldability, and other factors have lead us to accept and expect high-grade steels.
- ✓Now, we reset for hydrogen.



Option A Design

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- ✓ First choice might be to adopt an Option A design.
- ✓ We hard-reset towards lower grade steels and the use of conservative design factors, and find we end up with line pipe of significant wall thickness.
- ✓ Steel costs likely rise, and perhaps you'll need to compromise on the line pipe manufacturing technique (for example: wall thickness may be beyond ERW range).
- ✓ Heavy wall pipe may also bring disadvantages:
  - ✓ Incremental increase in transport and construction effort.
  - ✓ Heat input may need to be limited to keep weld hardness down and so avoid PWHT.
  - ✓ How about the Operators? Effective in-line inspection may present its own challenges.

The lesson? Option A conservatism may be the pragmatic approach.

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A softer reset – Option B design

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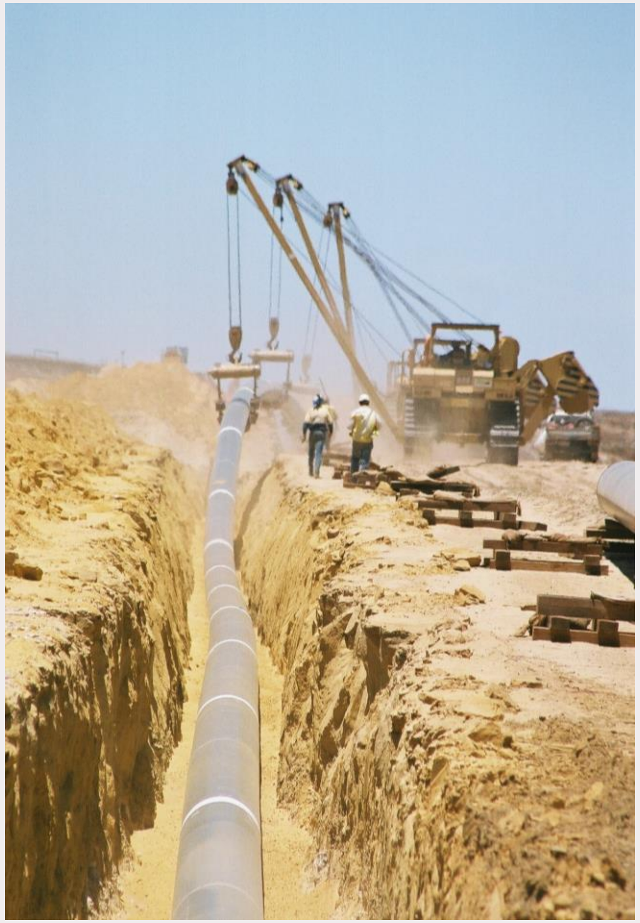
- ✓ We might instead be tempted to lean towards Option B designs.
- ✓ We can use familiar high-strength steels (to a point), but need to consider that:
  - ✓ While mills are developing appropriate materials, this is still a developing field and options may not be as plentiful as for traditional line pipe.
  - ✓ Mills might present material as 'pre-certified' but be aware of the conditions around this.
  - ✓ Plan early for immersive testing.
- ✓ The required testing may be extensive, and can be expensive at (anecdotally) $10k per test.
- ✓ Test facilities aren't as plentiful as for other testing, but there is a test facility in Australia and a number of others overseas. Ensure schedule impact is known.
- ✓ Note that the number of laboratories with the immersive testing capacity is growing. Test equipment is commercially available, eg Zwick/Roell, Kobelco and others, and efforts to reduce cost of testing are ongoing.
- ✓ **The lesson? Option B is tempting from a steel cost perspective, but don't underestimate engineering, testing and schedule implications**



Cost differences

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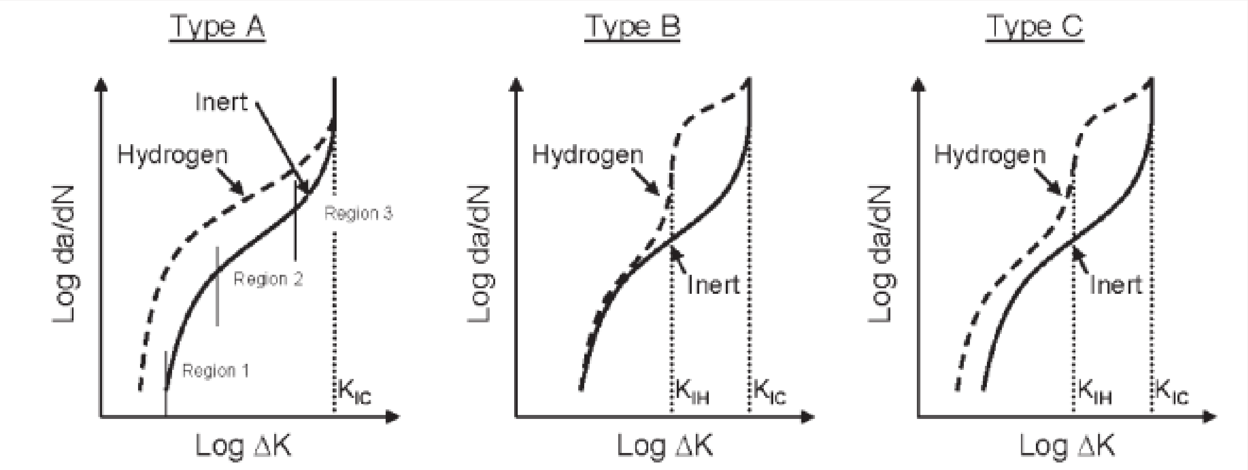
- ✓In very round numbers, for a 50 km DN300 pipeline with MAOP of 10.2 MPa:
  - ✓AS 2885: X65 with 0.72 design factor yields 5.10 mm wt; **2,000 tonnes**
  - ✓B31.12 Option A: X52 with 0.5 design factor yields 9.2 mm wt; **3,560 tonnes**
  - ✓B31.12 Option B: X60 with 0.6 design factor yields 6.6 mm wt; **2,600 tonnes**
- ✓Cost, based roughly on $3,450/tonne for coated Option B pipe, down to $3,100/tonne for coated AS 2885 pipe:
  - ✓AS 2885: around $6.2M for coated line pipe
  - ✓B31.12 Option A: around $11.5M for coated line pipe
  - ✓B31.12 Option B: around $9M for coated line pipe
- ✓Line pipe procurement package may be in the order of 10-15% of construction cost

Fatigue

✓Fatigue resistances decreases in hydrogen service.

✓As we know, hydrogen embrittlement plays a key part.

✓Reduction in tolerable cycles may be by a factor of 10 – the effect is significant.



Example of fatigue crack growth behaviour
[N Nanninga and Colleagues, 'A Review of Fatigue Crack Growth for Pipelines Steels Exposed to Hydrogen' Fig 1]

Fatigue

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- ✓ AS 2885.1: Life is relatively easy. We screen based on 35 MPa for 700,000 cycles down to 165 MPa at around 7,000 cycles.
- ✓Empirical data seems abundant; we can be confident in our engineering screening assessments relating to fatigue. We have clear and well-trodden paths to follow. Steel seems a resilient material under natural gas.
- ✓Under hydrogen? Fatigue is a completely different matter.
- ✓Be prepared to carry out analytical assessments if any stress cycling is likely or desired.
- ✓The good news for engineers: development in this field is ongoing; a number of people carrying out valuable work.
- ✓Keep abreast of latest body of knowledge* but be prepared to design with conservatism.
- ✓Regardless, wall thickness may need to increase to account for lower fatigue resistance in hydrogen service relative to natural gas.

Fatigue – what areas to consider?

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- ✓What other areas of fatigue?
- ✓Wherever dynamic loading and stress amplitude ranges need to be considered, then be aware of the conservatism required (factor of 10 applied to stress cycles).
- ✓For example, stress and loading calculations for hydrogen pipelines under road or rail crossings are relatively straight forward and align with the requirements for hydrocarbon pipelines.
- ✓How about frequency considerations at highway crossings? There is an obvious fatigue factor to consider here.
- ✓From a design perspective, should we revert to cased crossings for hydrogen pipelines until fatigue effects are fully determined?

Keeping gas within the pipeline

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- ✓Keeping 100% of all molecules within the pipeline 100% of the time has long been the admirable goal of pipeline engineers.
- ✓Particularly in Australia, we've been very good at this!
- ✓Hydrogen considerations:
  - ✓Hydrogen introduces the consideration of permeability.
  - ✓Permeability is not expected to be a practical concern, though you may be required to justify why that is the case – stakeholders are new to this field too.
  - ✓Hydrogen may be difficult to seal against at non-welded joints, and perhaps in isolation at MLVs.
- ✓In any case, our designs require knowledge of the consequence of not keeping the gas in the pipeline*
  - ✓*especially where we intentionally vent. With hydrogen, perhaps even venting a ball valve body cavity may become a riskier operation.

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Consequence assessment

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- ✓Determining radiation contours and energy release rates may not be as intuitive as it has become for natural gas.
- ✓For natural gas, familiar calculation methods are available - including in AS/NZS 2885.6 - and we have enough experience that sense-checking calculation results comes naturally.
- ✓Hydrogen is different: easier to ignite, less dense, and escapes at higher velocities.
- ✓Analytical calculation methods are available. Phast now has the Miller model for hydrogen jet fire analysis.
- ✓Comparisons seem to show a reduction in radius to 4.7 kW/m² contour for hydrogen relative to natural gas blends*.
- ✓Analytical modelling would be required recommended to confirm for your case, but designing for the natural gas case may be conservative for hydrogen.

Readiness for transition

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- ✓ Changing the transported gas from natural gas to hydrogen represents a significant change in operation.
- ✓ The mandatory AS 2885 requirements would be applicable:
  - ✓ Documents to update or generate include Pipeline Management System, Isolation Plan, PIMP, FFP Assessment.
    - ✓ FFP requires a full understanding of contemporaneous condition of the pipeline. Examination for cracking, gouges, and other anomalies will be critical and will inform PIMP.
    - ✓ Assessment may be required to consider accumulated fatigue.
  - ✓ Validate readiness via Change in Operation SMS workshop.
- ✓ For hydrogen-ready pipelines, the time and cost associated with preparing for the transition to hydrogen should be well considered and understood.
- ✓ Note also pipeline cleanliness to be appropriate for ongoing integrity management in a hydrogen regime.
- ✓ Other pipeline equipment (weld-end MLVs etc) may need to be considered.

Be sure to prepare for transition

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- ✓ Prepare for the transition from the start of design.
  - ✓ The design needs to consider the implications of, and the requirements for, safe transition; and
  - ✓ Transition requirements should be well documented for the benefit of the Licensee and Operator.

- ✓ Key learnings:
  - ✓ The Licensee and the Operator of the pipeline should be aware of requirements throughout the initial natural gas phase of the pipeline's life.
  - ✓ Pipeline operation, maintenance and particularly integrity management should be undertaken with the future transition to hydrogen.

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What has our experience been?

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- ✓Transporting hydrogen by steel pipeline isn't as scary a concept as it may have been to a pipeline engineer in 2010.
- ✓As an industry, we are very capable of designing and building safe, practical, and cost-effective* hydrogen pipelines.
- ✓We have new design considerations to keep in mind – be aware of the challenges associated with hydrogen.
  - ✓Revert back a few decades to lower grades and heavier wall configurations as the norm.
  - ✓All fatigue risks to be considered.
  - ✓Tighter construction constraints.
  - ✓Prepare for transition from the start.
- ✓One key lesson – don't rely only on standards, keep abreast of the latest papers and studies

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Thank you.