Australian Gas Infrastructure Group

GPA

# 2021 APGA Annual Convention

## A new assessment framework for low hydrogen concentration natural gas blends in transmission pipelines, with a case study of the Dampier-Bunbury Pipeline


Dampier Bunbury Pipeline | Multinet Gas Networks | Australian Gas Networks

October 2021

# DBNGP – Case Study, acknowledgments

Department of
Jobs, Tourism, Science and Innovation
GOVERNMENT OF WESTERN AUSTRALIA

Jointly Funded by the WA Renewables Fund
'Preparing the DBNGP as critical support infrastructure for WA's emerging hydrogen industry'
Feasibility Study

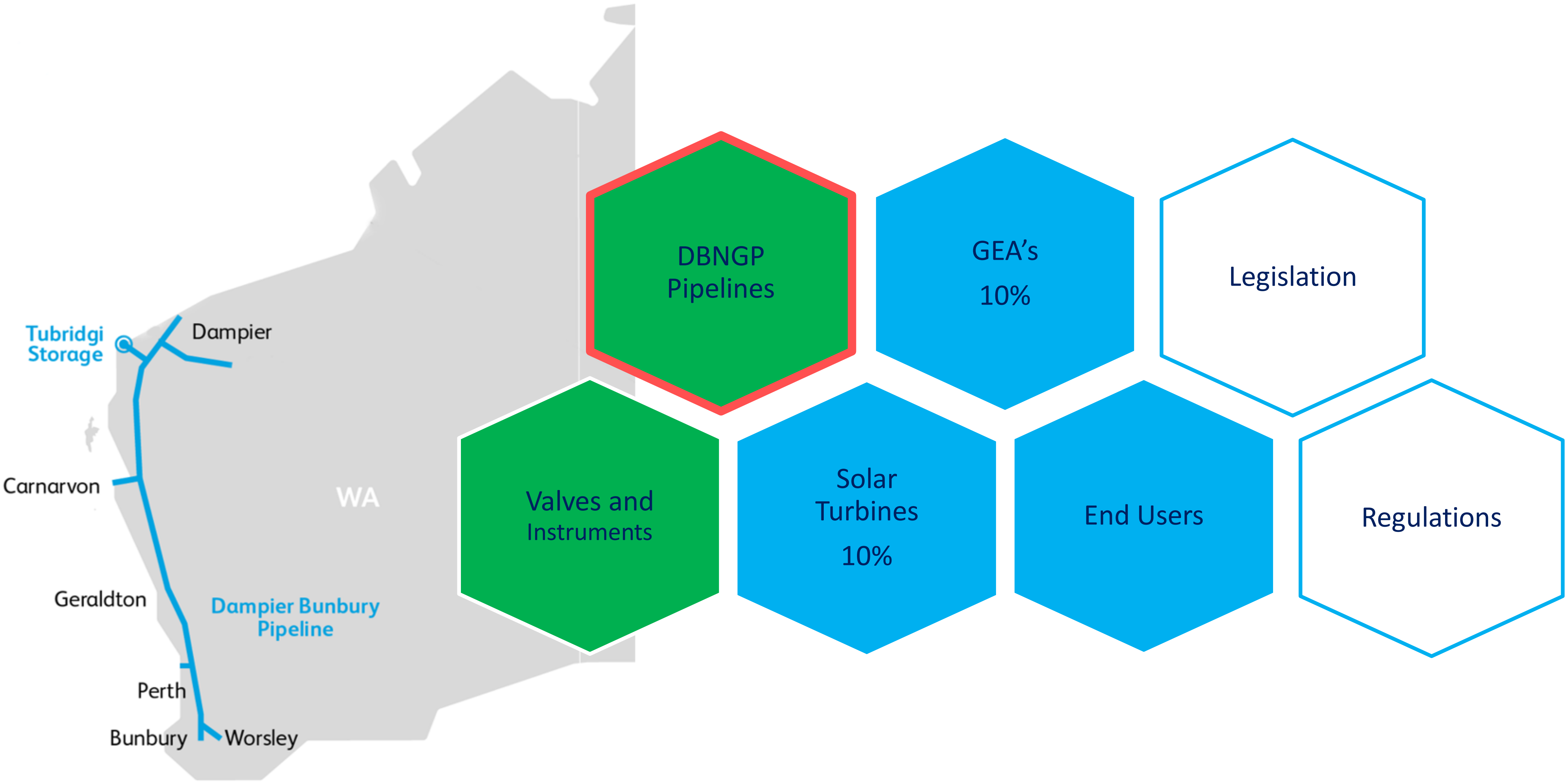
APGA

'A new assessment framework for low hydrogen concentration natural gas blends in transmission pipelines, with a case study of the Dampier-Bunbury Pipeline'

FUTURE FUELS CRC

Research Program 3 - Network Lifecycle Management

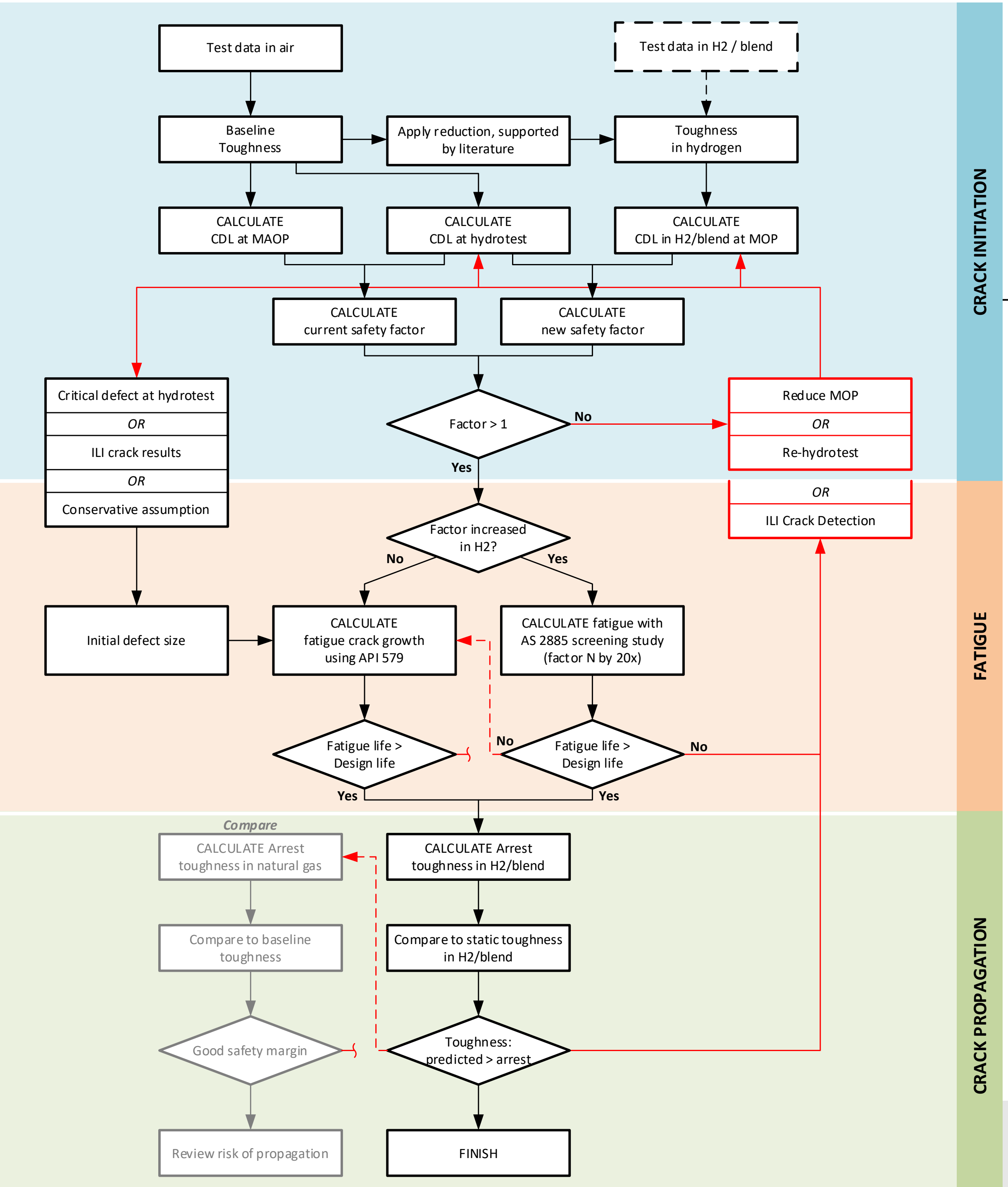
# STUDY | Scope


Tubridgi Storage
Dampier
Carnarvon
WA
Geraldton
Dampier Bunbury Pipeline
Perth
Bunbury
Worsley
DBNGP Pipelines
GEA's
10%
Legislation
Valves and Instruments
Solar Turbines
10%
End Users
Regulations

# DBNGP Assessment Project

- Pipeline data collection
- Literature review
- Creation of assessment framework
- Ranking of pipeline sections by toughness demand
- Calculations for relevant sections

## Assessment process

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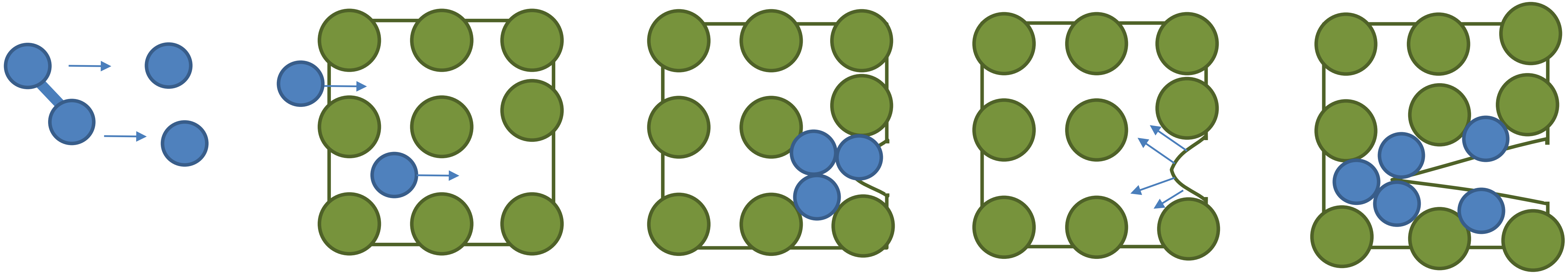
# Hydrogen embrittlement

1. Hydrogen molecules dissociate into atomic form
2. Hydrogen atoms permeate into the steel
3. Hydrogen atoms collect at defects
4. Greater pressure on crack tips
5. Steel is more likely to crack than deform



# Material fracture

Hydrogen affects the following three important material behaviours, which are all related to **fracture mechanics**:

### 1. Crack initiation

*The conditions for a defect to become a crack.*

In hydrogen, the *smallest crack* that will result in a pipe rupture (the '**critical defect length**' or CDL) will reduce.

### 2. Fatigue

*The growth of cracks as a result of pressure cycling*

The *rate* that a crack grows increases in hydrogen, so the pipeline has lower tolerance for pressure cycling.

### 3. Crack propagation

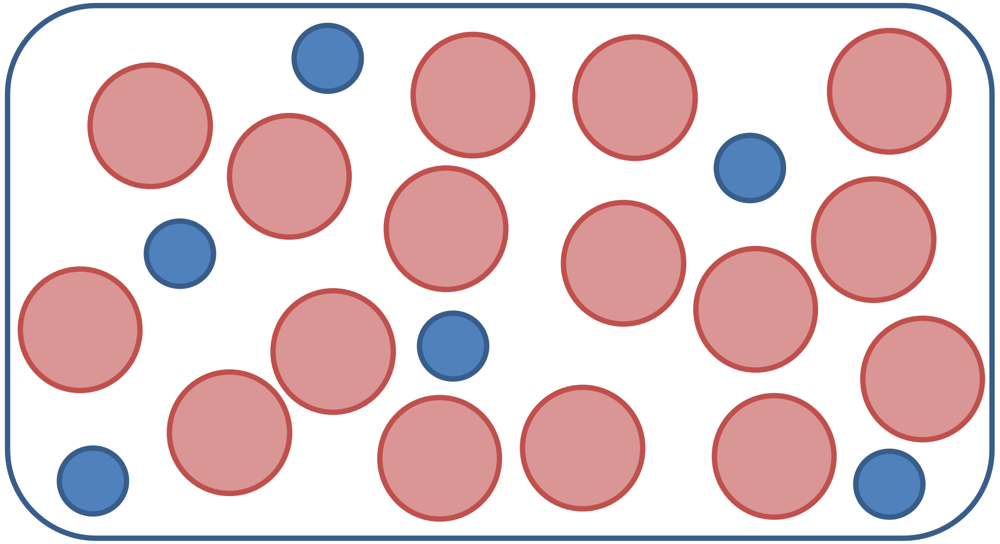
*The ability of a crack to keep growing, rather than arrest*

The crack growth rate may be accelerated due to hydrogen embrittlement.

# Partial pressure

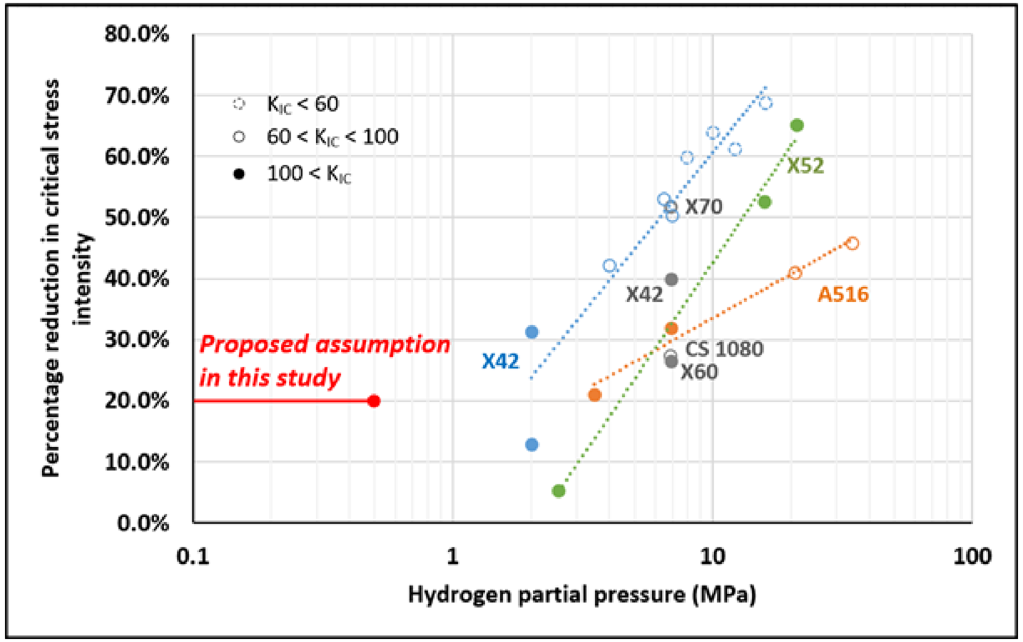
- Provided there are no other gas components to inhibit or accelerate the uptake of hydrogen:

*The effect of pure hydrogen at a certain pressure is equivalent to the effect of hydrogen in a mixture at the same partial pressure*



# Crack initiation

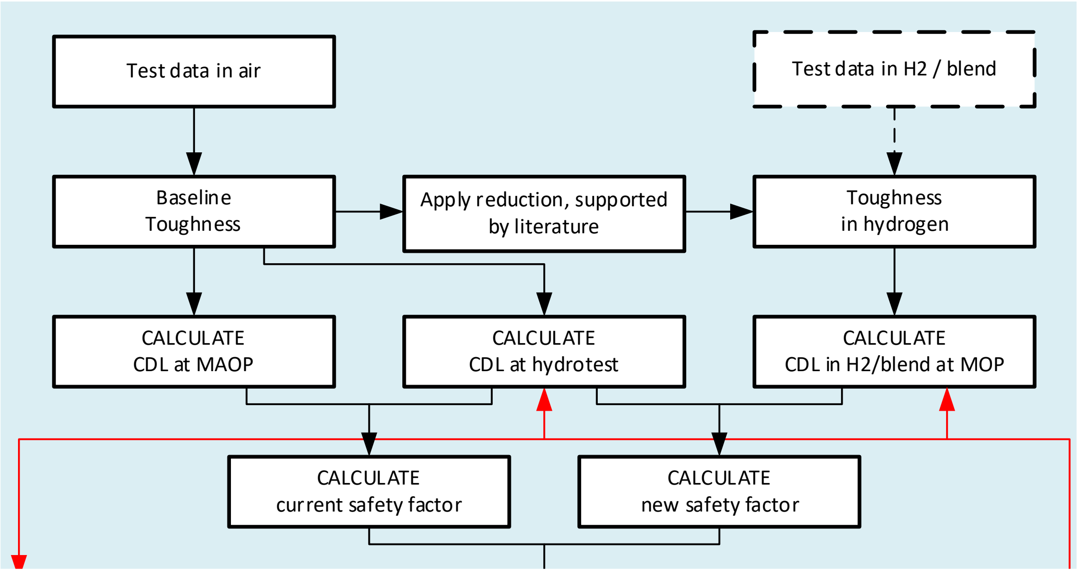
**What happens:** The toughness of the material is reduced due to hydrogen



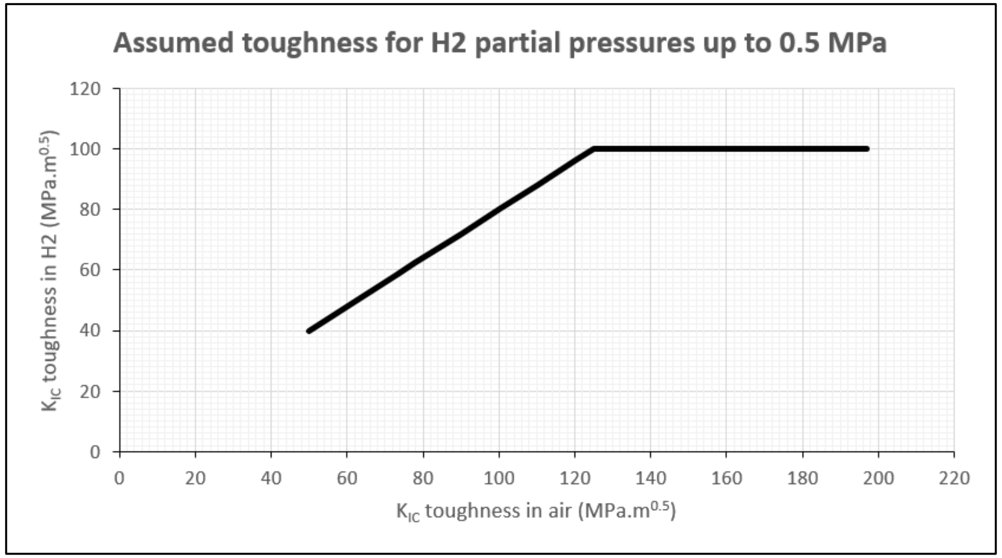

***BUT***
***The toughness does not reduce to zero***

This data taken from Sandia *Technical Reference for Hydrogen Compatibility of Materials.*
Other sources were also included in the literature review.

# Crack initiation




$$K_{IC}(H_2) = \min(0.8K_{IC}\,, 100)\quad \mathrm{MPa.m}^{1/2}$$




- If toughness in hydrogen is not known, use model
- Use material toughness to calculate CDL
- Calculate the safety factor

# Crack initiation

**Case Study:**

- CDL is reduced only slightly
- Safety factor remains >1 in lean hydrogen
- Fracture initiation conditions are acceptable.

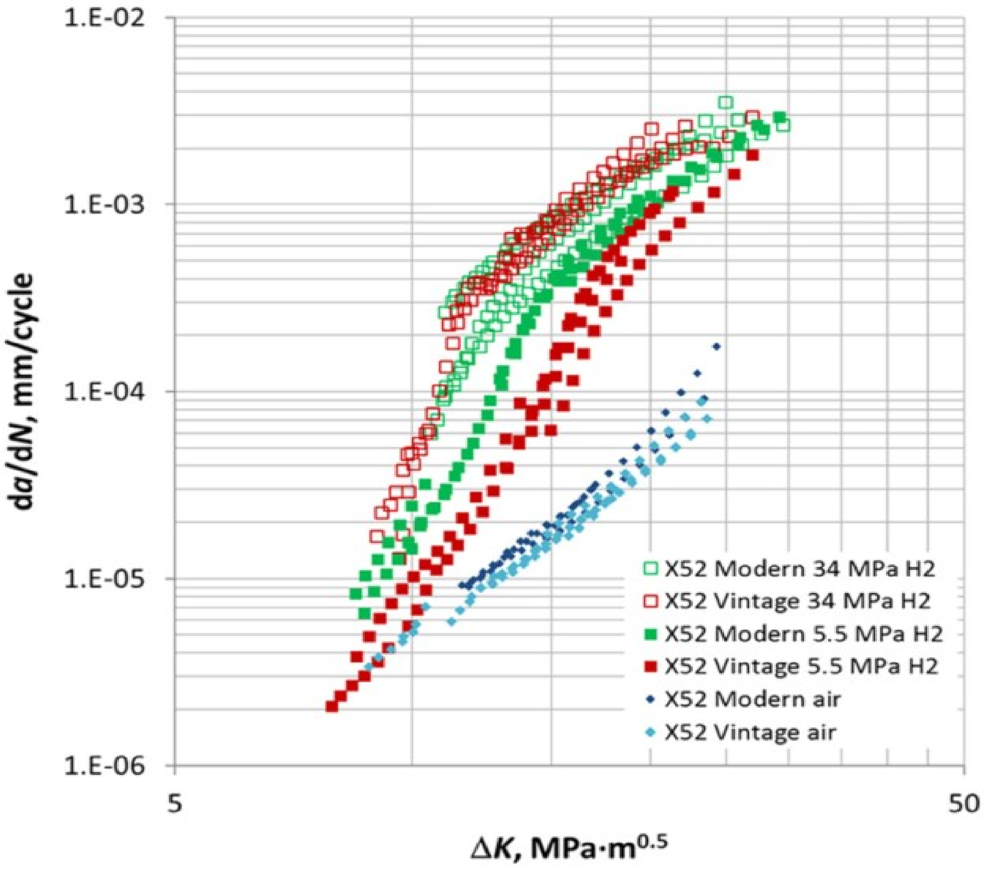
- Otherwise, reduce the maximum operating pressure (MOP) until risk *is* acceptable (relates to SMS).

| Variable | DBNGP Lateral 1 |
|---|---|
| ***Initial*** | |
| Charpy toughness | 184 J |
| Critical stress intensity | 192 $MPa.m^{0.5}$ |
| CDL – hydrotest | 136 mm |
| CDL – operating at MAOP | 181 mm |
| Safety factor | 1.33 |
| ***With lean hydrogen (estimated reduction in $K_I$)*** | |
| Charpy equivalent | 52 J |
| Critical stress intensity | 100 $MPa.m^{0.5}$ |
| CDL – operating w. **lean hydrogen at MAOP** | 178 mm |
| Reduced safety factor | 1.31 |
| CDL – operating w. **lean hydrogen at MOP 5MPa** | 319 mm |
| Revised safety factor | 2.34 |

# Fatigue

**What happens:**

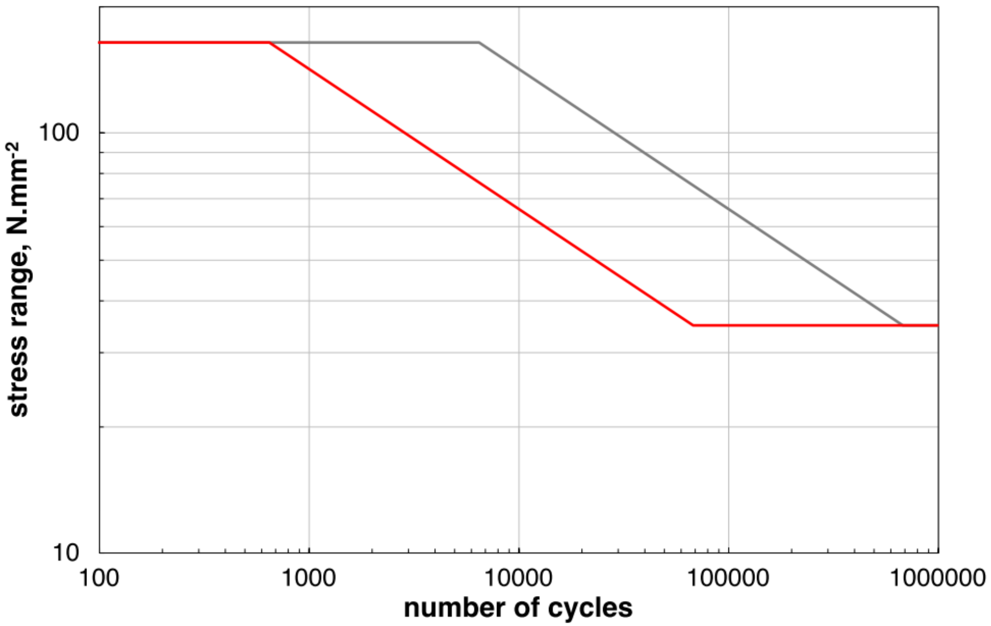
1. The fatigue growth rate of the material is reduced due to hydrogen.
2. The fatigue end-point may also be changed due to the previous item—a reduction in critical crack size at failure.



# Fatigue

**Analysis:** Case 1

- If the safety factor for fracture initiation (previous point) has *increased*…
- Use the **AS 2885.1 screening study** with a reduction factor of 20x.
- This is a simple, quick calculation and pipelines operating in fairly steady-state conditions will pass.




This same approach has also been proposed in draft supplement to IGEM/TD/1 Edition 6, though with a different factor (10x)

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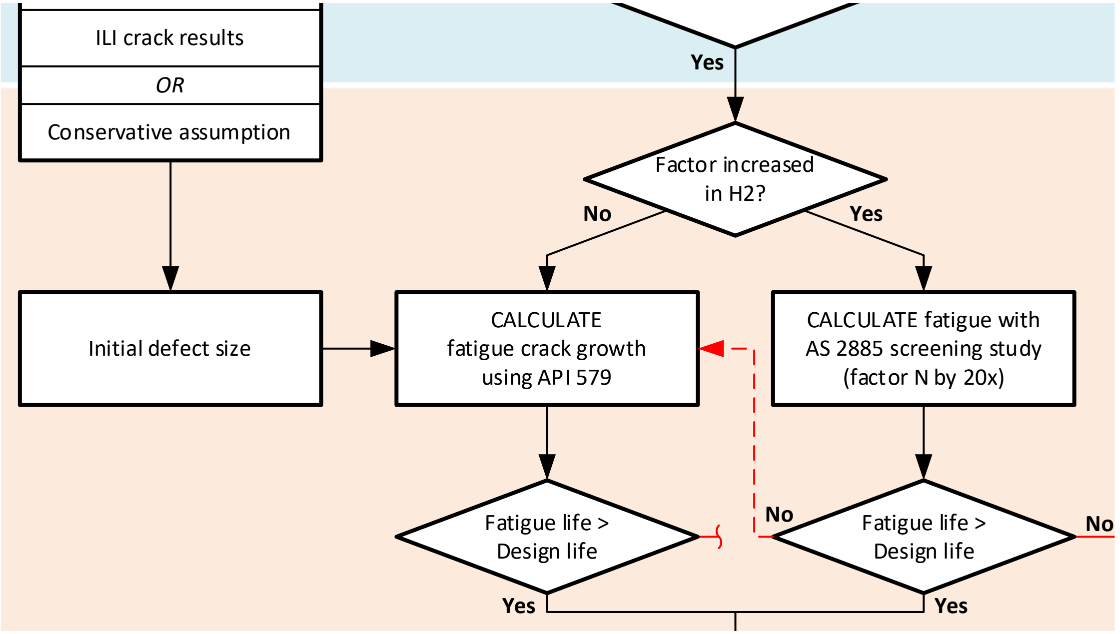
# Fatigue

## **Analysis:** Case 2

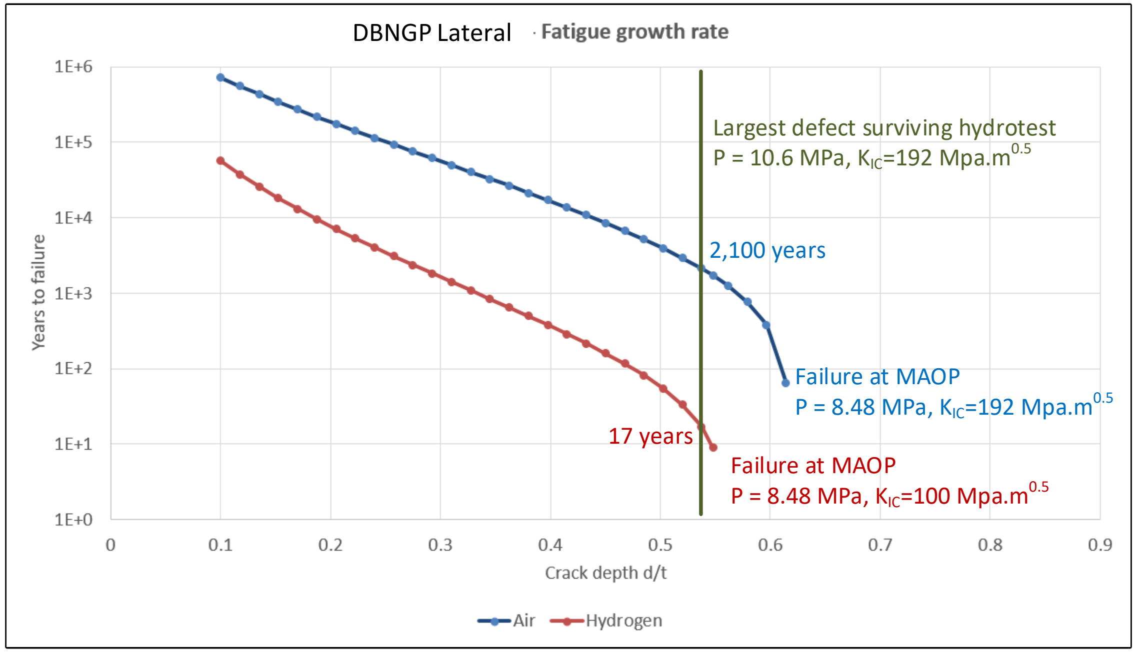
- Use fatigue growth models to simulate crack growth.
  - Sandia and Amaro models are endorsed by ASME
- Current models are based on 100% hydrogen
- Use inspection data, hydrotest conditions or other assumption to determine *initial* defect size for modelling.



# Fatigue

## Case Study:

- Minimise pressure cycling.
- Protect against large amplitude cycles, which contribute most damage.
- Reduce MOP when fracture endpoint is the critical factor.
- In-line crack inspection (ILI) or hydrotest can increase life when fracture start-point is the critical factor.

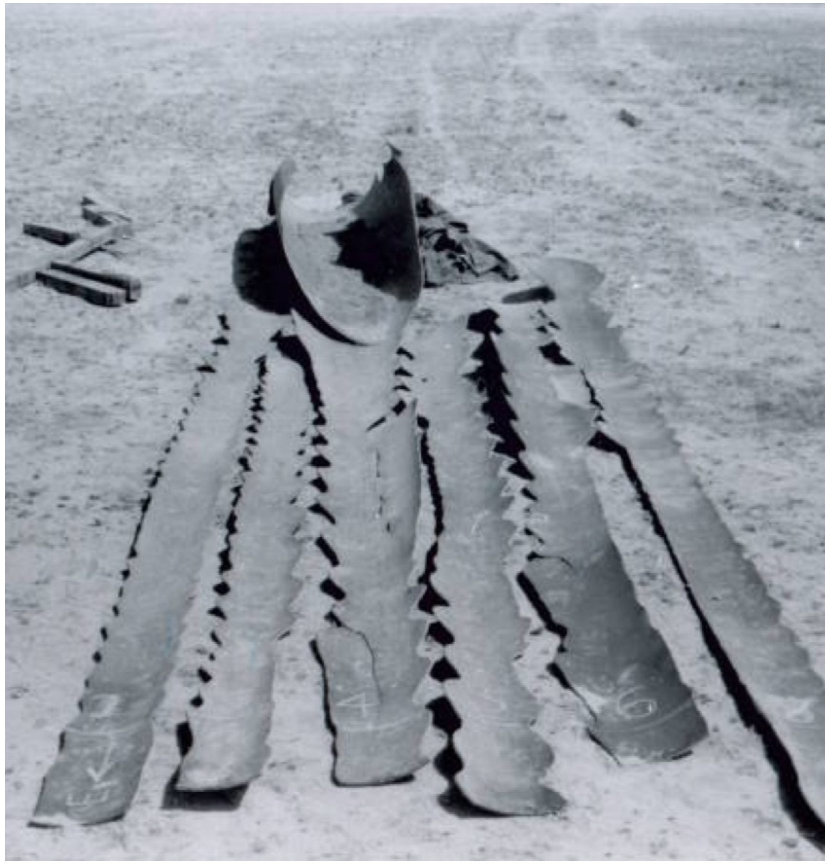



Case study fatigue crack growth calculation.

# Crack propagation

**What happens:**

- A crack propagates along the pipe until it "arrests".
- Arrest occurs when the pressure on the crack tip reduces due to gas decompression.
- If the crack grows faster than the decompression wave, it won't arrest.
- The decompression wave speed is related to toughness.



# Crack propagation

**Analysis:**

› No fracture velocity data is available.

› Dynamic fracture is *less* affected by hydrogen than static fracture.

› Use Battelle Two-Curve Method (EPDECOM.net) to conservatively calculate arrest toughness

› Compare with the reduced static toughness (i.e. the toughness that governs crack initiation)

› Some margin of safety will give good confidence of arrest conditions. Low design factor is also a strong protection (e.g. less than 30 %SMYS).

# Crack propagation

## Case Study:

- Arrest toughness < reduced static toughness
- If required, reduce MOP, or accept risk of propagation through SMS process.
- Treat deficiency in toughness like a retrospective pipeline fracture control assessment.

Case study arrest toughness calculation.

| Pressure | Arrest toughness at 15°C | | | |
|---|---|---|---|---|
| | 0% H2 | 1% H2 | 5% H2 | 100% H2 |
| **3.5 MPa.g** | 3.6 J | 3.6 J | 3.5 J | 1.2 J |
| **8.48 MPa.g** | 10.2 J | 10.2 J | 9.9 J | 4.2 J |

# Assessment protocol

Hydrogen affects the following three important material behaviours, which are all related to **fracture mechanics**:

**1. Crack initiation**

- Measure or approximate toughness change in hydrogen
- Calculate corresponding crack defect length
- Calculate whether the safety factor is still >1

**2. Fatigue**

- Use fatigue models to assess change in fatigue life
- Calculate whether fatigue life > design life

**3. Crack propagation**

- Calculate arrest toughness using EPDECOM
- Check arrest toughness < reduced toughness from Stage 1

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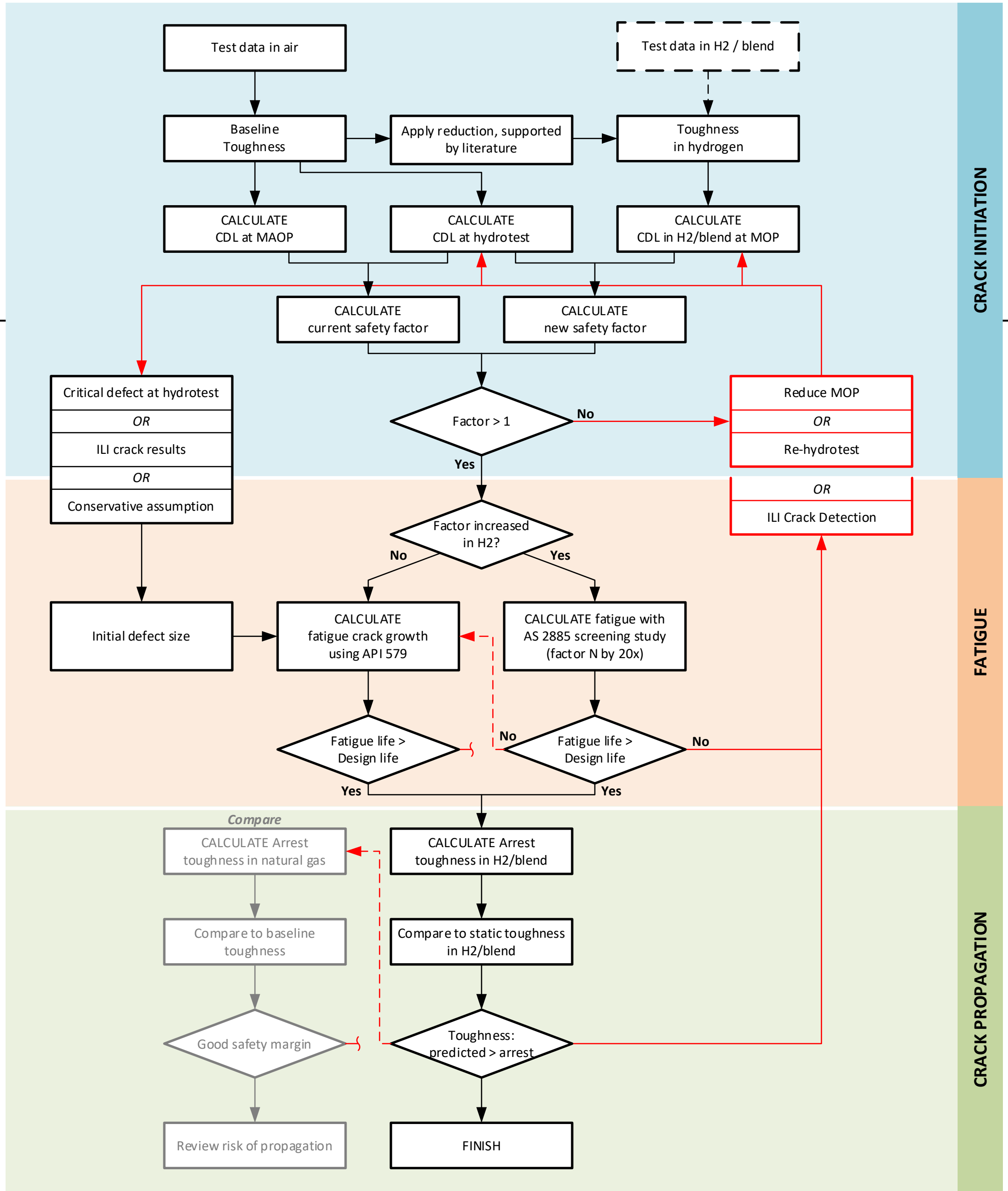
# Assessment process

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# Conclusions

**1.**

Injection of a lean concentration of hydrogen (<0.5MPa) into a transmission pipeline can be managed

**2.**

A framework has been established to assess an existing pipeline for hydrogen injection

**3.**

A case study of a section in the DBP network shows that it will retain an acceptable margin of safety in hydrogen with a controlled stress cycling regime

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