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APPROACHES AND METHODS TO DEMONSTRATE REPURPOSING OF THE UK'S LOCAL TRANSMISSION SYSTEM (LTS) PIPELINES FOR TRANSPORTATION OF HYDROGEN

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#SGN Ltd, Energy Futures

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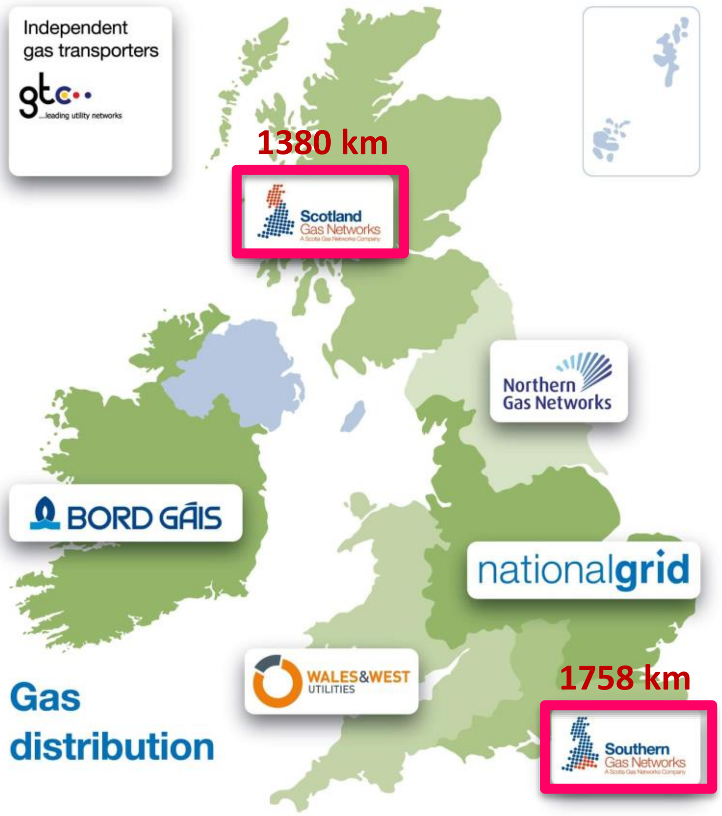
Contents

Introduction

- Decarbonisation of heat targets: Hydrogen as an energy vector
- Existing hydrogen pipelines worldwide, mainly purpose designed:
  - 3,500 km in USA
  - 1,600 km in Europe
- Repurposing pipelines for transporting hydrogen
  - Smaller lengths of repurposed hydrogen pipelines exist above ground: different threat profile to buried pipes
  - Recently re-purposed 12 km pipeline in Netherlands
- UK natural gas asset base potential
  - Extensive pipeline system
  - Various legacy assets installed over 50+ years
  - Large variety of pipe manufacture routes, grades and vintages

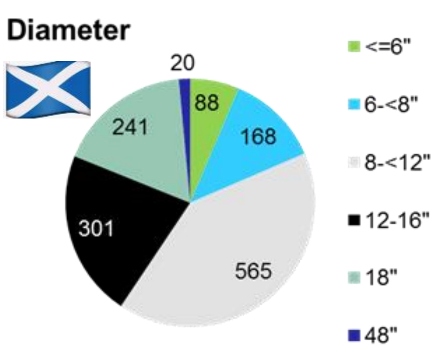
Overview of the UK gas network

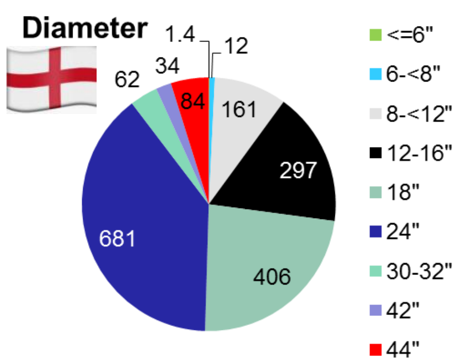
- Multiple companies operate across the UK.
- UK gas network includes:
  - National and Local Transmission network (7 to 60+ bar)
  - Distribution network (< 7 bar)
  - Domestic network (< 1 bar)
- Current paper focusses on 3,100 km of existing LTS pipeline system operated by SGN
- Aim: To assess the scientific and regulatory feasibility of repurposing the LTS for transport of hydrogen and carry out a demonstration feasibility study on an existing pipeline



Pipe type considerations in context of hydrogen repurposing

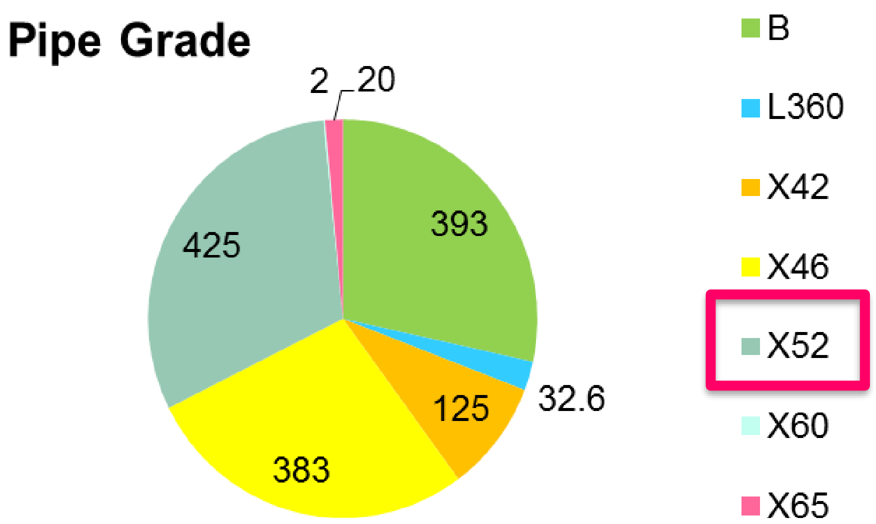
Pipe Manufacturing Route	Acronym	Typical pipe diameter range	Considerations for hydrogen integrity
Seamless	-	< 559mm (22”)	No welds or heat-affected zone (HAZ)
Eletro-Resistance welded and High frequency induction welded	ERW/ HFI	< 610 mm (24”)	Weld bond-line but same composition as parent pipe
Longitudinally submerged-arc welded	LSAW	> 406 mm (16”)	High-heat input factory weld; weld metal; HAZ; One orientation
Hellically submerged-arc welded	HSAW	< 1219 mm (48”)	High-heat input factory weld; weld metal; HAZ; Varying orientation
Girth welding of pipe lengths	-	All diameters	Low heat-input weld; refinement of HAZ; possibility of fabrication flaws

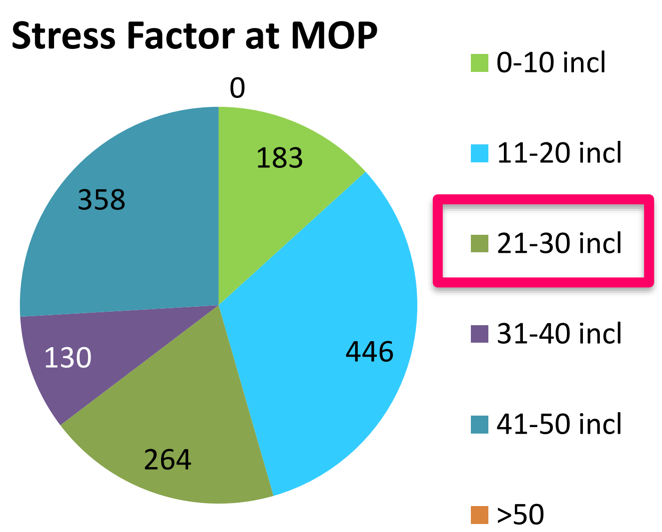




Example of Network Characteristics: Pipeline grades and stresses for Scottish sector

Length:	1380 km
Grade:	98% X52 and lower (YS 360 MPa)
Stress Factor at Maximum Operating Pressure (MOP):	65% F ≤ 30: Lower stress demands





Codes in-scope for hydrogen pipeline repurposing: Risk Assessment

- Pipeline Safety Regulations (PSR)
  - Risk-based goal setting approach to regulation
  - Major Accident Hazards (MAH) for Flammable fluids at >= 7bar
- PD8010: Pipeline Systems Parts 1 and 3: Steel pipelines on land: Code of practice and risk assessment
  - Design, construction, operation and maintenance
  - Hazard potential of the substance to be conveyed
  - Minimum Distance to Occupied Buildings (MDOB)
- IGEM TD/1 & TD/2: Steel pipelines and associated installations for high pressure gas transmission, Assessing the risks from HP natural gas pipelines
  - Design, construction, inspection, testing, operation and maintenance
  - Integrity management
  - Building Proximity Distance (BPD)

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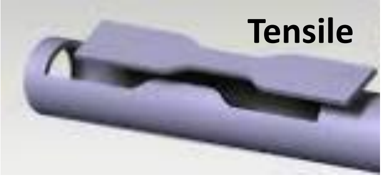
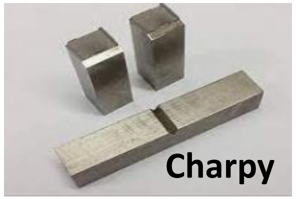
Codes in-scope for hydrogen pipeline repurposing : Integrity Assessment

- ASME B31.12; Hydrogen Piping and Pipelines
  - Emphasis on new-build pipelines
  - Blends 10-100% H_2; Pressures to 210 bar
  - Steel suitability up to X52 strength grade implied
- PD ISO TR 15916: Basic considerations for the safety of hydrogen systems
  - Safety considerations for gaseous and liquid H_2
  - Appendix on materials suitability classification of materials
  - Embrittlement susceptibility: Carbon steels ‘in need of evaluation’
- BS 7910: Guide to methods for assessing the acceptability of flaws in metallic structures
  - Fracture mechanics approach for defining critical flaw sizes
  - Fatigue life calculation methods
  - Used in pipeline industry, not hydrogen-specific

Pipeline operation: Threats and required properties

Threat example	Generic property required	Specific Properties
Elastic loading from gas pressure and external factors	Strength	Yield stress (YS); Ultimate tensile stress (UTS)
Ground movement Strains; Localised extreme loading	Ductility	Elongation; YS/UTS ratio
Third party damage	Toughness	Charpy impact energy; CTOD/K_{IC} fracture toughness
Fracture tolerance from pre-existing fabrication flaws (‘workmanship criteria’)	Toughness	Charpy impact energy; CTOD/K_{IC} fracture toughness
Fast running fractures	Impact toughness	Drop weight tear test (DWTT) energy and high % shear fracture; Charpy energy
Fatigue resistance	Fatigue crack growth law	Fatigue threshold ΔK; Fatigue crack growth rate





Literature Review: Effect of hydrogen on strength and ductility of pipeline steels

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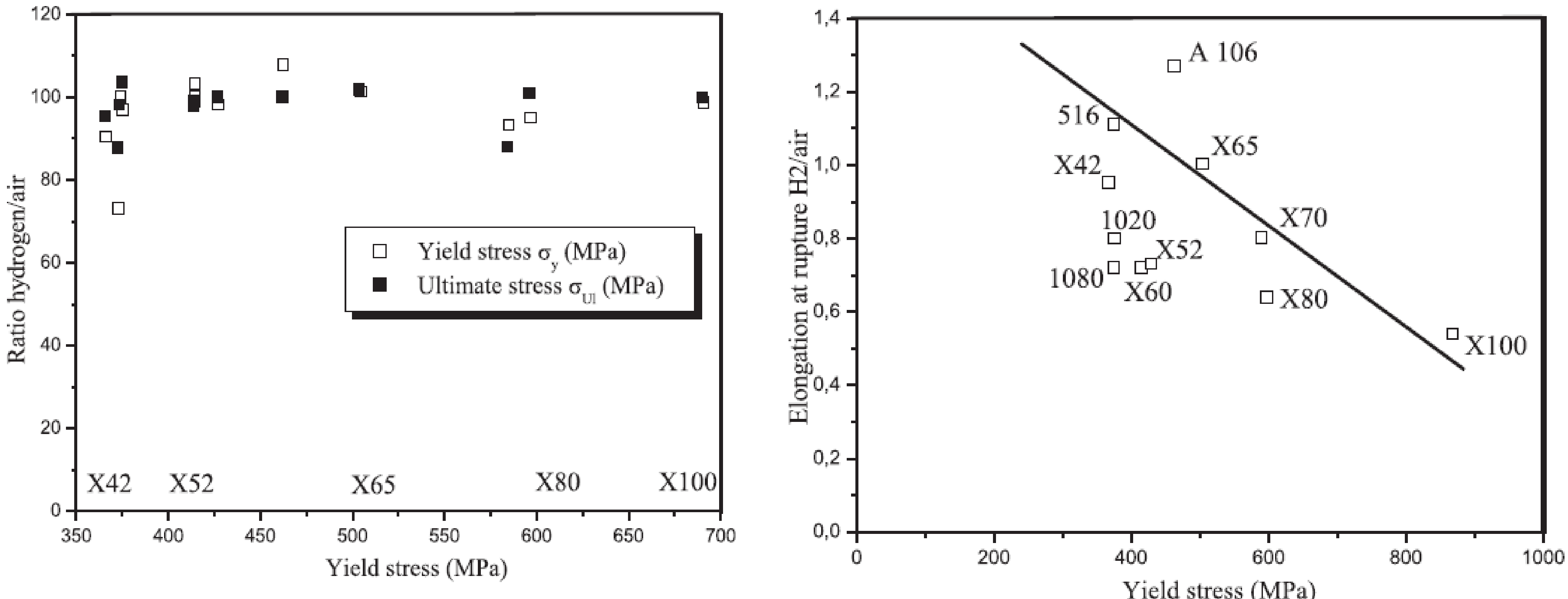

(H Boukorrt et al, 'Hydrogen embrittlement effect on the structural integrity of API X52 steel pipeline', Intl J. Hydrogen Energy, 2018)

Literature review: Fracture toughness of API pipeline grade steels in hydrogen service

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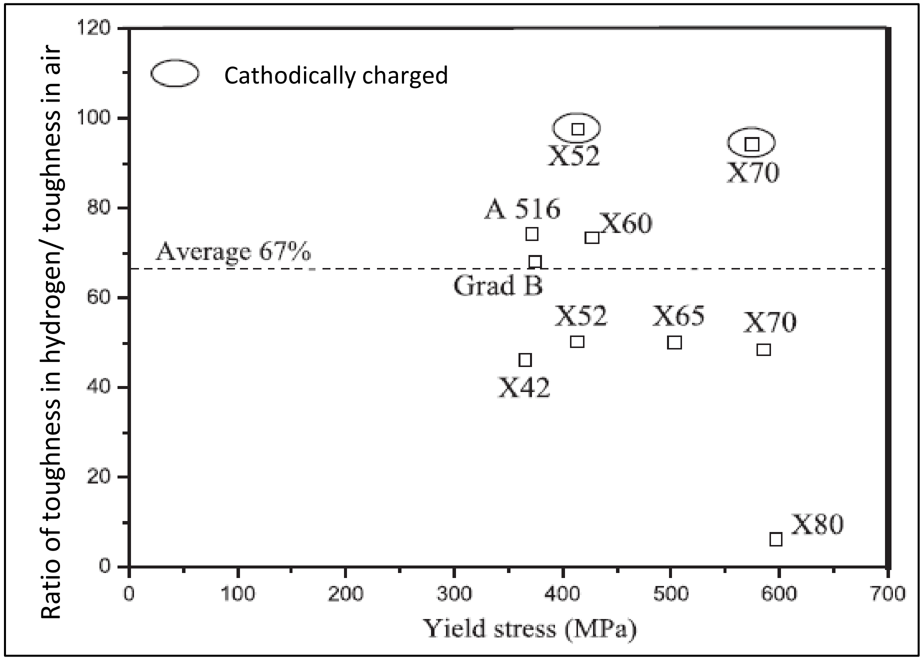

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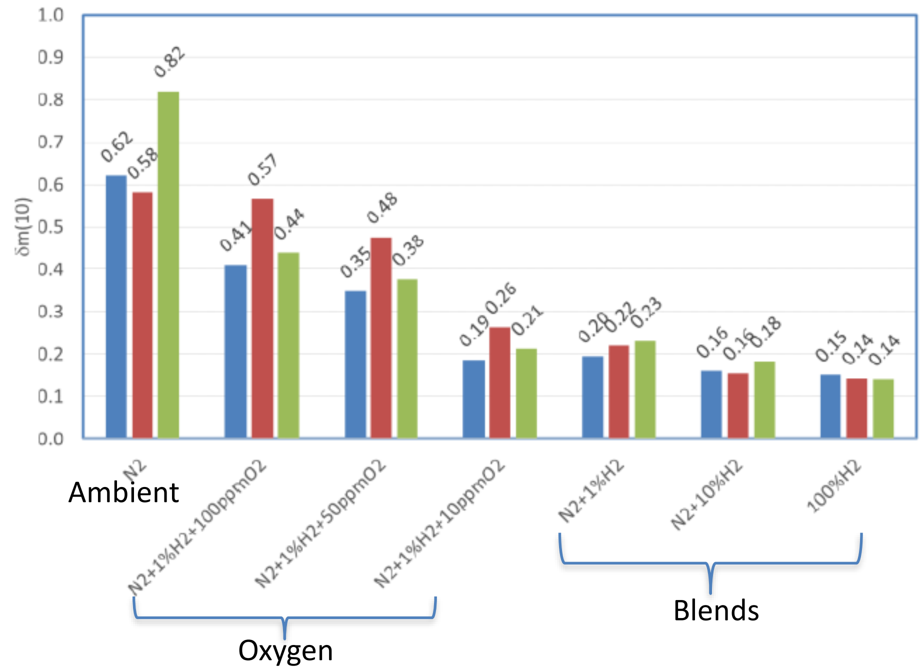
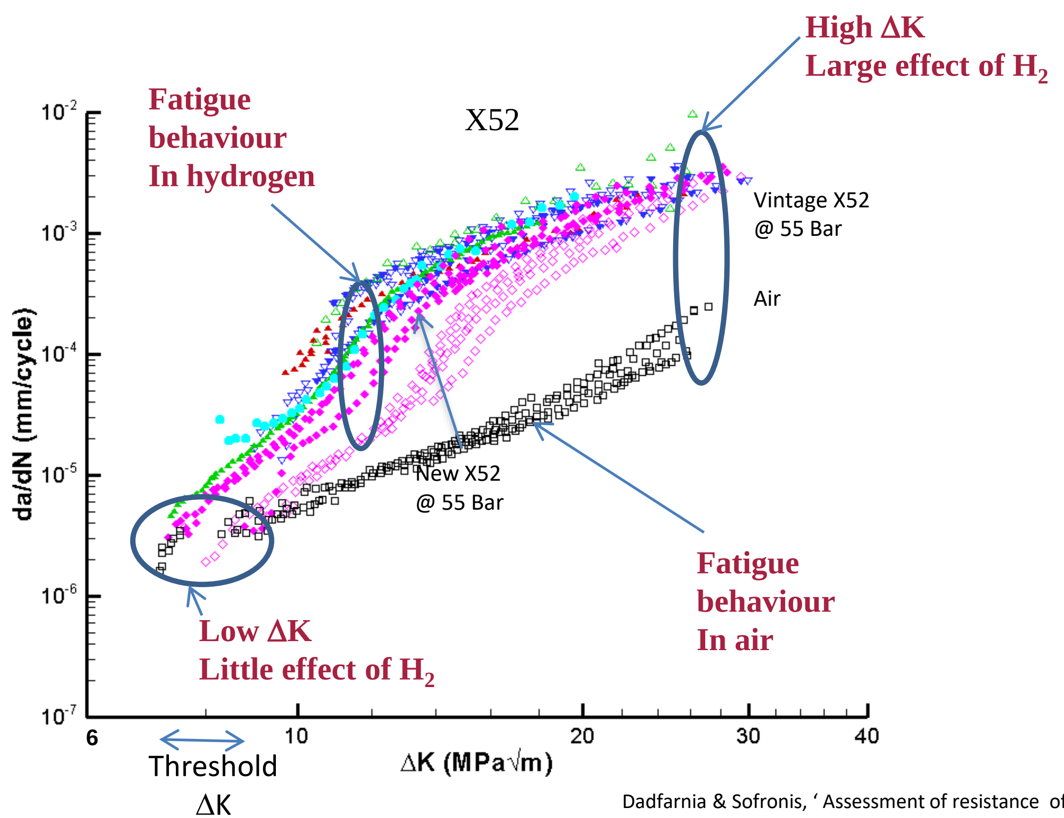


L. Briottet and H. Ez-Zaki, "Influence of hydrogen and oxygen impurity content in natural gas/ hydrogen blend on the toughness of an API X70 steel," in *ASME Pressure Vessels and Piping Conference*, Prague, 2018.

Steel Grade	Mean ratio of toughness in hydrogen/ toughness in air	Range of ratio of toughness in hydrogen/ toughness in air	Number of data sets
X42	0.48	0.22-0.90	17
X52	0.68	0.49-0.90	11
X60	0.62	0.35-0.96	7
X65	0.38	0.13-1.25	10
All Grades	**0.54**	**0.13-1.25**	**45**

Literature Review: Fatigue Crack growth rates of API pipeline grade steels in hydrogen service

- Variables: Steel grade; Steel vintage; R-ratio; Loading frequency
- Regions of fatigue: Threshold and steady growth regions
- At ΔK in range 10-20 MPam0.5, mean increase in FCGR in H2 from literature is x25
- Development of standardised fatigue crack growth constants for use within codes



Dadfarnia & Sofronis, ' Assessment of resistance of linepipe steels to hydrogen Embrittlement', university of Illinois, 2016

Effects of hydrogen on pipeline steels: Summary from literature

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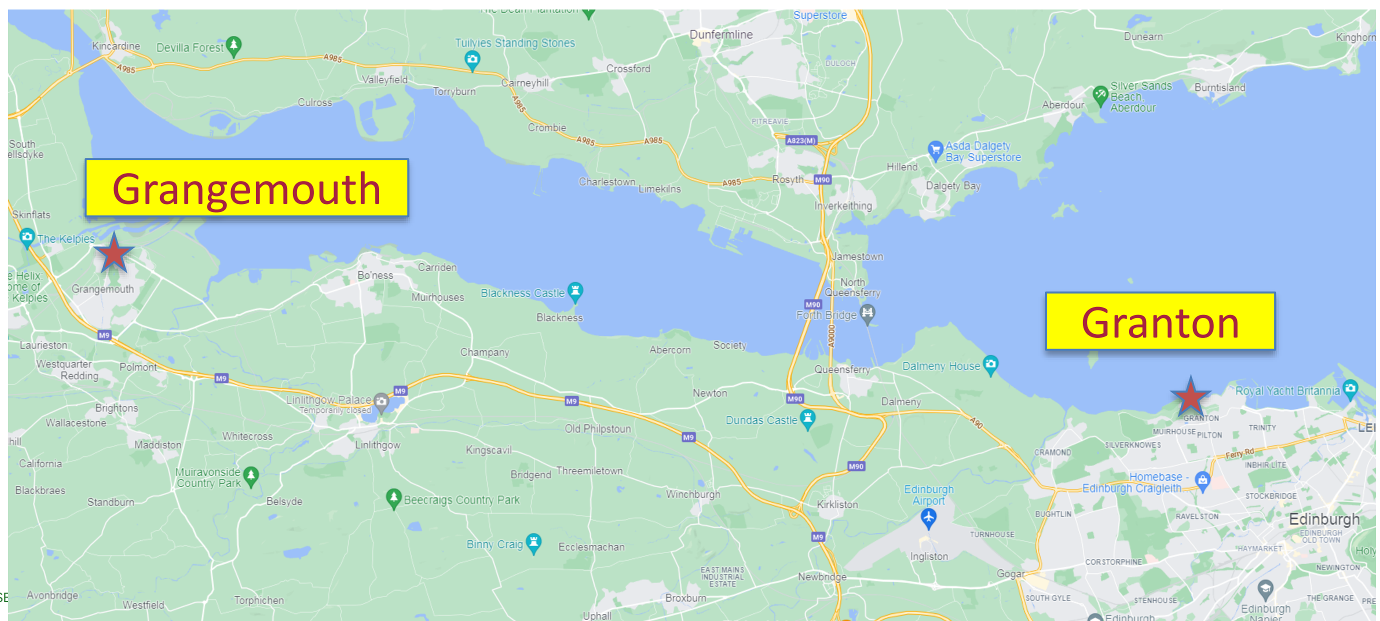
Limited or no effect	Some effect	Significant effect	Test unlikely to differentiate between H_2 and inert atmosphere/Ltd data.

Generic property	Parameters	Effect of Hydrogen
Strength	Yield (0.2% or 0.5% proof stress)	Limited effect
	Ultimate tensile strength (UTS)	Limited effect
	YS/UTS ratio (Y/T)	Limited effect
	Young's Modulus (E)	No effect
	Poisson's ratio (ν)	No effect
Ductility	Elongation (Total)	Significant reduction
	Elongation (Uniform)	Limited effect
Charpy impact	Charpy impact energy	Limited data and effect/ high strain rate
	Specific transition temperature (T27J, T40J)	Limited data and effect/ high strain rate
Crack propagation resistance	Drop weight tear test (DWTT) e.g. temperature for 85% shear fracture appearance	No data found on DWTT, but possibly limited effect due to high strain rate
Fracture toughness	K/J/CTOD initiation fracture toughness	Some reduction
	J/CTOD ductile tearing resistance	Significant reduction
Fatigue	Fatigue threshold stress intensity factor range (ΔKth)	Slight reduction in some cases, limited effect in many cases
	Fatigue Crack growth rate	Significant increase; many variables

Repurposing a natural gas pipeline for hydrogen

- 29 km Granton to Grangemouth steel pipeline (Edinburgh), decommissioned 1998, Originally transporting natural gas from BP Forties
- X52 steel pipeline of 457 mm diameter: 6.4 mm thick spiral welded and 9.5 mm thick seamless pipe
- Depth of cover = 1 m
- Assessment for change of operation to hydrogen at various pressures

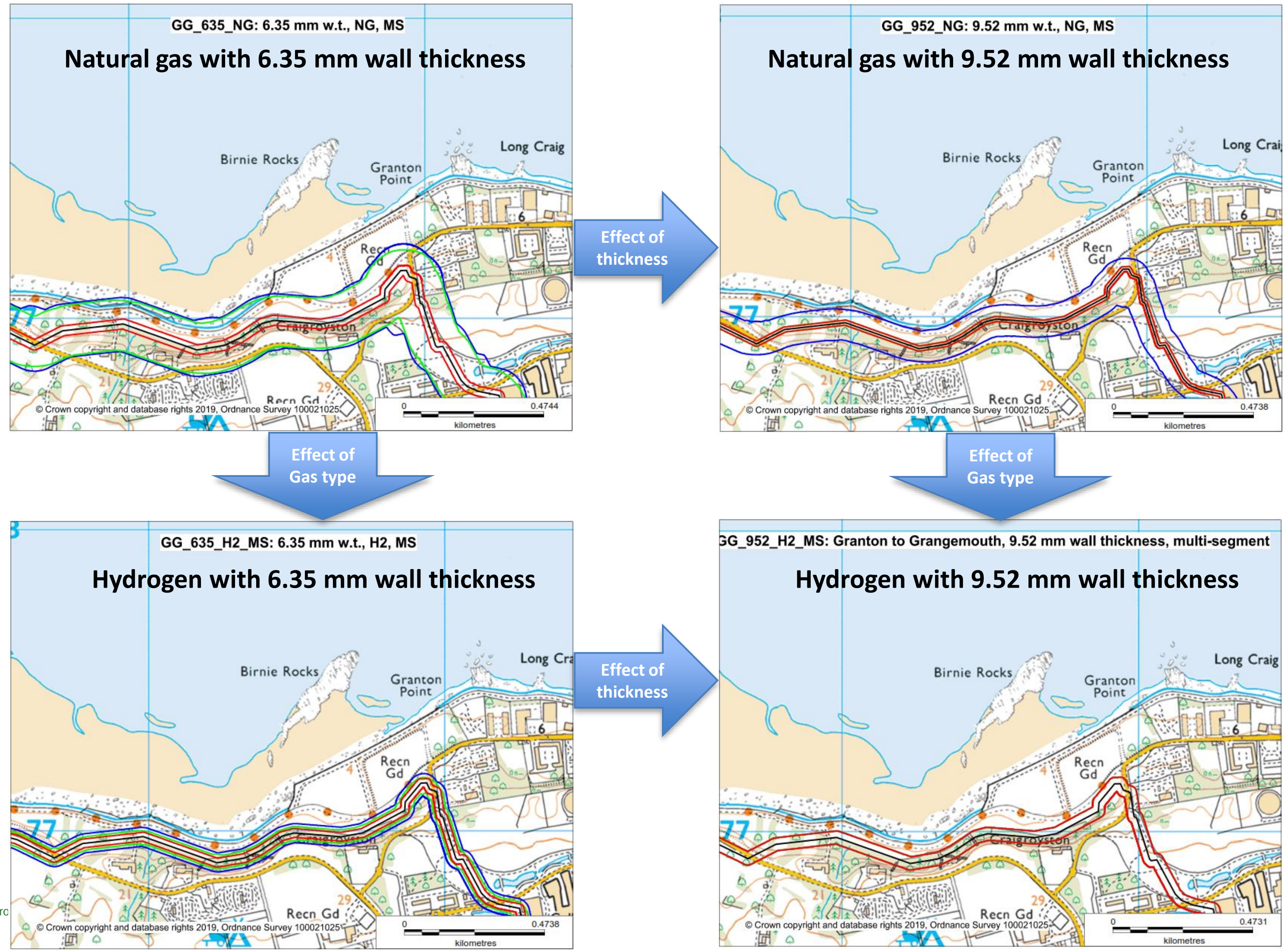


Risk Assessment Approach

- Identification of populations along pipeline to within specific distances
- Calculation of Minimum distances to occupied buildings (MDOBs)*
- PD 8010 pt 1 used for assessing population density along existing pipeline to assess suitability for repurposing
- Evaluation of LUP (Land-Use Planning) Zones:
  - Inner Zone (IZ)= 10 chances per million per year (cpm**)
  - Middle zone (MZ)= 1 cpm
  - Outer zone (OZ)= 0.3 cpm
- MISHAP*** pipeline risk assessment model was used
- Some simplifications/assumptions were necessary, sensitivity studies carried out to check on the effect of this uncertainty
- Applicable distance is that to the 'risk level' or to the 'MDOB/BPD', whichever is greater

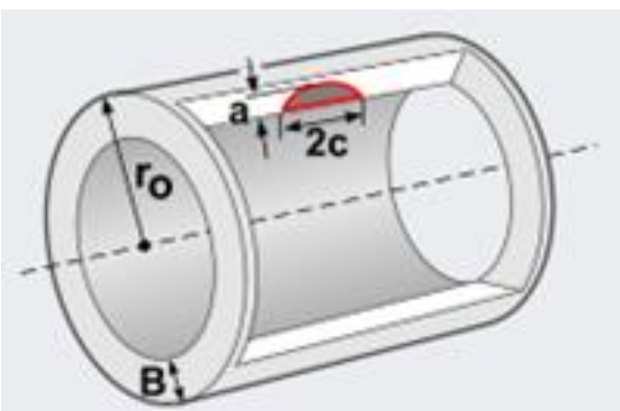
*For natural gas the term 'Building Proximity Distance '(BPD) is often used
** Cpm refers to the chance per million per year of an individual receiving a dangerous dose (equivalent to 1% lethality) or worse from a flammable, toxic or asphyxiate gas release
***Chaplin Z (2015). *Rewriting MISHAP: The development of MISHAP12.* HSE Research Report RR1040, HSE Books. http://www.hse.gov.uk/research/rrhtm/rr1040.htm,

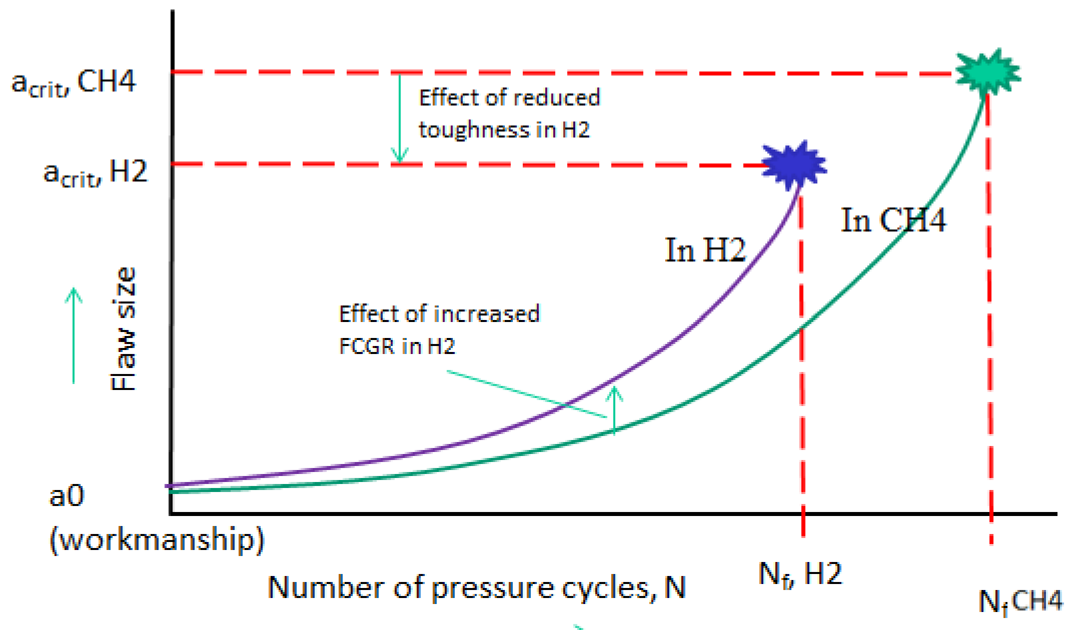
Snapshots of selected area of pipeline showing effect of gas type and wall thickness on LUP zones for 24 bar



Fitness-for-service approach for repurposing existing steel pipelines for hydrogen service

- Knowledge of material and workmanship criteria (‘as installed condition’)
- Knowledge of current condition (wall thickness, pre-existing flaws etc)
- Future pressures (static due to gas pressure, cyclic pressure due to line-packing)
- Knowledge of effect of H_2 on toughness and fatigue properties from literature
- BS7910* used for assessment of potential effects on integrity when repurposing





* BS7910 software ‘Crackwise’ from TWI Ltd used to automate the calculations

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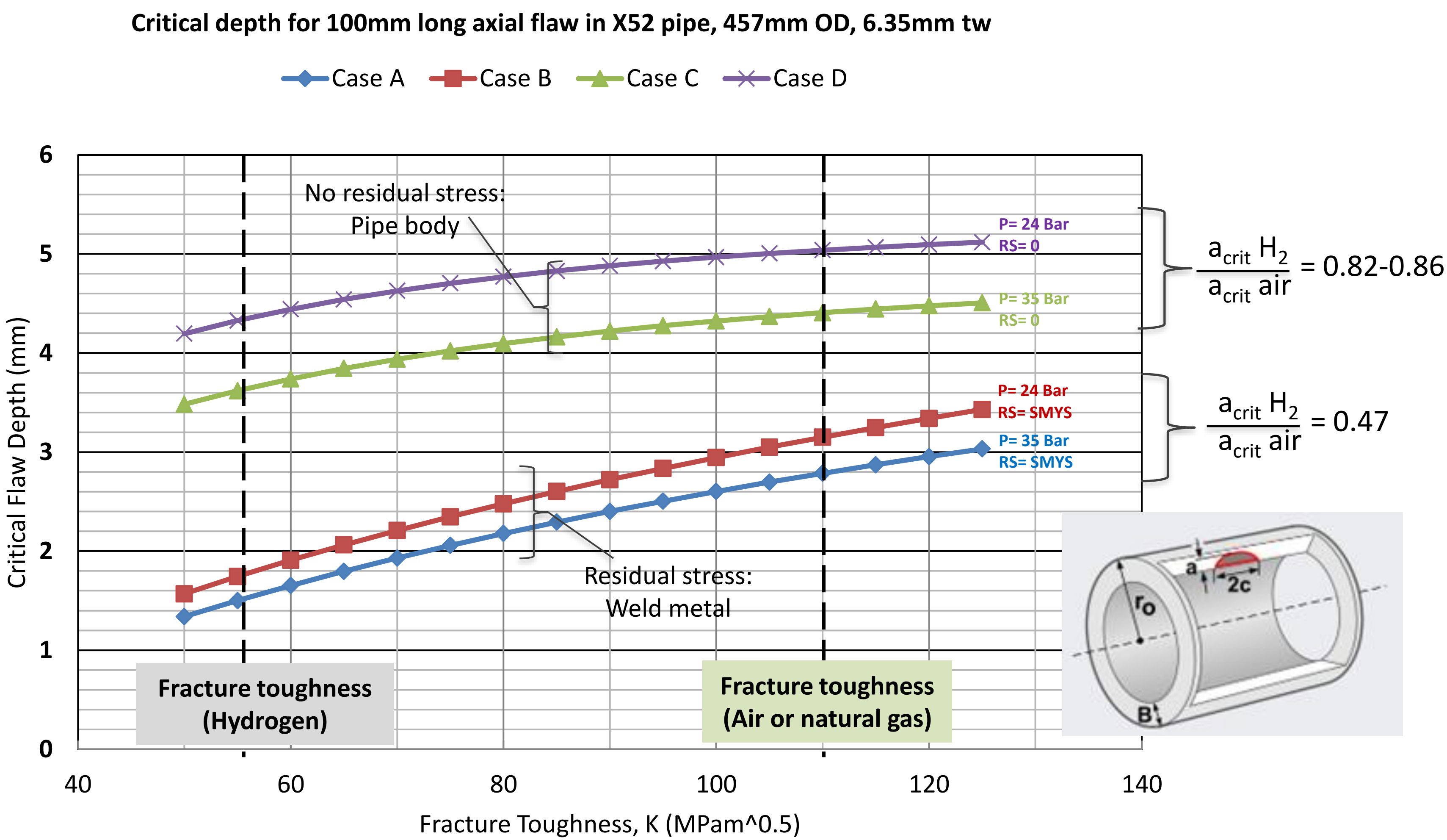
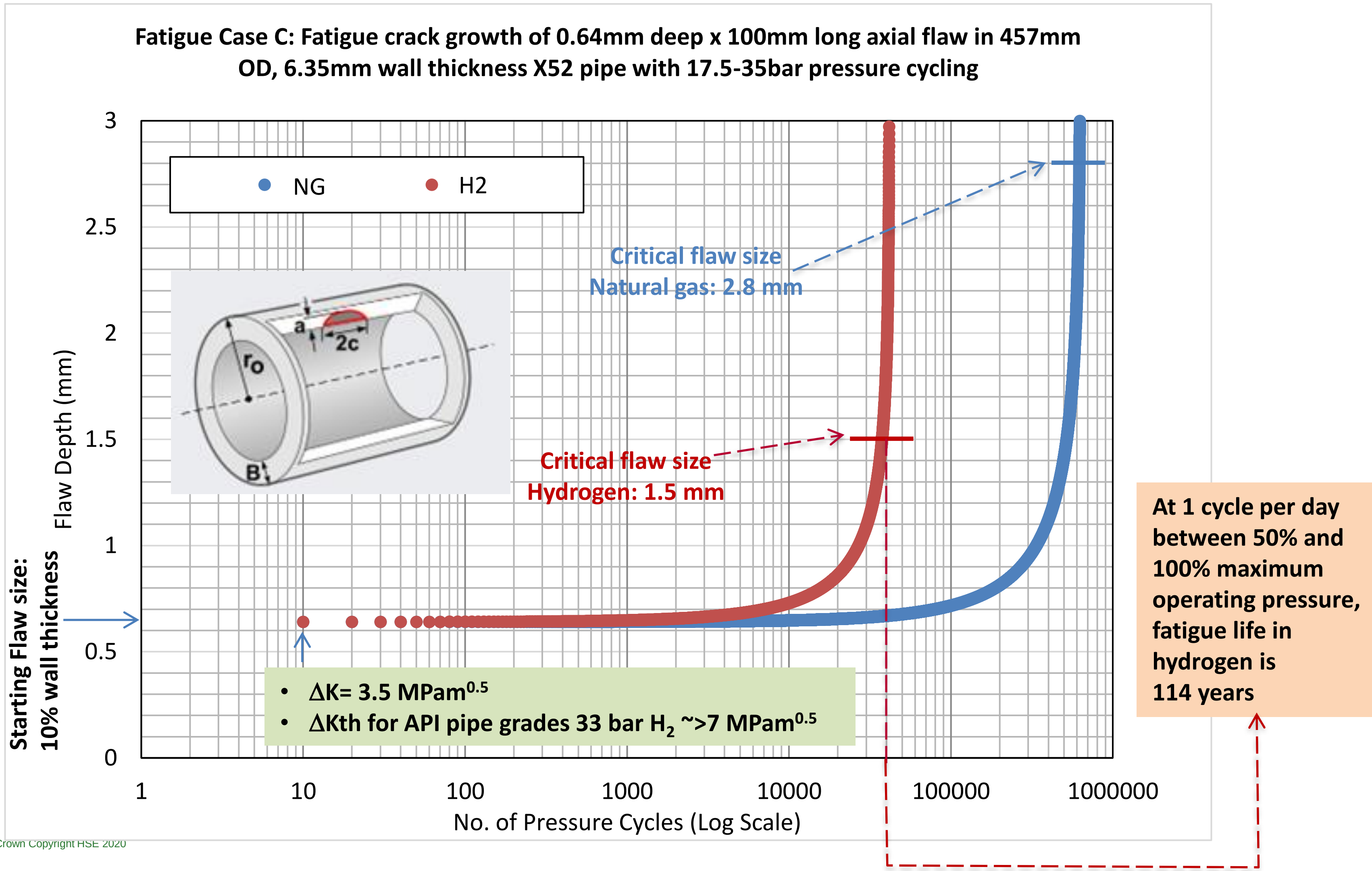
Critical flaw size analyses: 100mm axial flaw at 24 and 35 bar with and without residual stress



Analysis: Fatigue life assessment after repurposing



Conclusions and Forward View

- **Hydrogen Effects on Pipeline Materials**
  - Strength (0.2%PS, UTS, E) little affected by hydrogen
  - Effect on ductility, toughness and fatigue crack growth rate in pipeline steels: (Relative factors of ~0.7, 0.5 and x25 respectively)
- **Codes Applicable to Repurposing**
  - Pipeline Safety Regulations: Risk based goal setting for MAH pipelines
  - BS PD 8010: Hazard potentials, risk and Minimum Distance to Occupied Buildings
  - IGEM TD/1 & TD/2: Pipeline Integrity Management and guidance on assessing risk
  - BS 7910: Integrity assessment of pipelines and sensitivity analyses
- **Observations from Case Study**
  - Significant inputs required: Design, past operation, condition, risk assessment parameters
  - Determination of pipeline risk zones as function of gas type, pressure, wall thickness
  - BS7910 method for change in critical flaw size and predicted fatigue life: Inspection
  - Further work: Failure rates in hydrogen and sensitivity study, fatigue thresholds
- **Ongoing Programmes**
  - *Hytechnical/LTS Futures*: Addressing gaps for the LTS; H_2 supplements for IGEM standards
  - *Futuregrid*: Building a trial demo grid including legacy pipe and assets from the NTS

THANKS FOR LISTENING

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LUP zones for Natural Gas and Hydrogen at 24 barg

Zone	Distance (m) to zone assuming 6.35 mm wall thickness		Distance (m) to zone assuming 9.52 mm wall thickness	
	Natural gas	Hydrogen	Natural gas	Hydrogen
Inner	15	20	7	20
Middle	85	21	7	20
Outer	90	31	50	20

- The calculated distance is the distance required to reach the risk level (shown in purple) or the distance to the MDOB/ BPD (shown in blue), whichever is greater
- When the zones are based on risk, they are smaller for hydrogen than for natural gas
- When the zones are based on MDOB/BD they are larger for hydrogen than natural gas

Information requirements and gaps for risk assessments of pipelines to be repurposed

General area	Information needed	Availability of information	Gaps/further knowledge required
Information about the pipeline	Pipeline pressure; wall thickness; diameter; grade of steel	From operator	
	Depth of cover	From operator	
	Route (i.e. coordinates)	From operator	
Requirements under PD8010 (BSI, 2016; BSI, 2013)	Population data	Available via the NPD* provided the pipeline route is known	
	Ignition probabilities	References given in PD8010 Part 3. Also, HSE values.	Need to determine applicability to hydrogen and hydrogen blends.
Regulatory approvals	HSE Gas & Pipelines would inspect and assess information provided to them to ensure the pipeline is being/will be operated safely and that the pipeline is fit for purpose. HSE CEMHD5 calculates LUP zones that the local planning authority uses to help inform future planning decisions.		
Additional modelling information	Failure rates	Generic rates available in PD8010 Part 3, possible to use natural gas values	Need to determine suitability of generic rates for hydrogen and check applicability of natural gas failure rates.

*Population information can be obtained from the National Population Database (NPD, Gorce et al., 2018)

Inputs for BS7910 Assessment of Granton-to-Grangemouth Pipeline

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Type of inputs	Description	Values for natural gas	Values for hydrogen
Static Loading	Maximum operating pressure (MOP)	24/35 bar	same
	Maximum hoop stress	86/126 MPa	same
Cyclic loading	Cyclic pressure range	0.5 to 1.0 MOP	same
	Cyclic hoop stress range	43/63 MPa	same
	Cycles per day	1 (Line packing)	same
Strength and toughness	X52 steel yield stress	360 MPa	same
	Fracture toughness	110 $MPam^{0.5}$ (Min. from material spec.)	50%
Fatigue properties	Fatigue crack growth rate	BS7910 recommendations for ambient environment	X 10
	Threshold ΔK	BS7910 lower bound recommendation: 2$MPam^{0.5}$	same
Defect	Initial flaw depth	10% wall thickness: weld workmanship	same