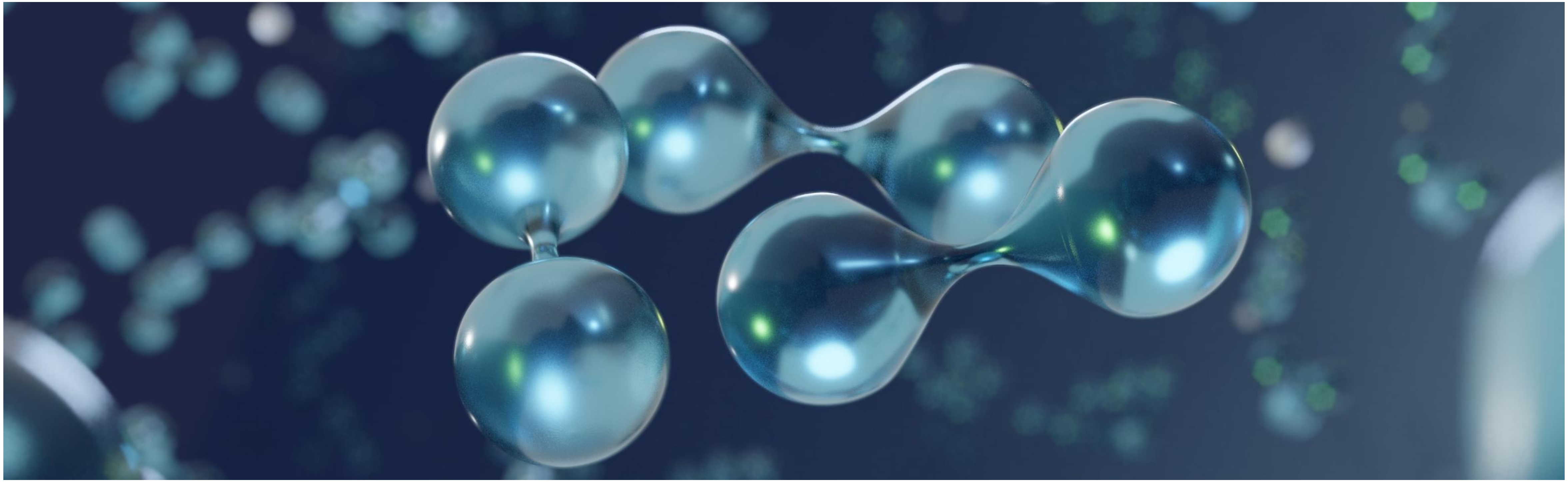

REPURPOSING OF PIPELINES IN THE ENERGY TRANSITION

TWI / Icorr Branch Meeting – 22/09/22, Neil Gallon, © ROSEN Group · 2022

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THE ROLE OF HYDROGEN IN THE ENERGY TRANSITION

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Lightest and most abundant
Hydrogen is the first element in the periodic table. It is the lightest, most abundant and one of the oldest chemical elements in the universe.

Never alone
On earth, hydrogen is found in more complex molecules, such as water or hydrocarbons. To be used in its pure form, it has to be extracted.

High energy density
Hydrogen has the highest energy content of any common fuel by weight.

Can be produced without a carbon footprint
through electrolysis or SMR + CCS

Can be transported over long distances,
allowing the distribution across regions.

Can be used as a buffer
to increase system resilience.

Produces clean power and heat
for transport and stationary applications.

Required as a clean feedstock
in industry when recycling captured CO_2.

GRADUAL CREATION OF A DEDICATED HYDROGEN INFRASTRUCTURE


11,600 km

Connecting industrial clusters to an emerging infrastructure in 2030

Dedicated European Hydrogen Backbone can develop with a total length of approximately 11,600 km, consisting mainly of retrofitted existing natural gas pipelines.

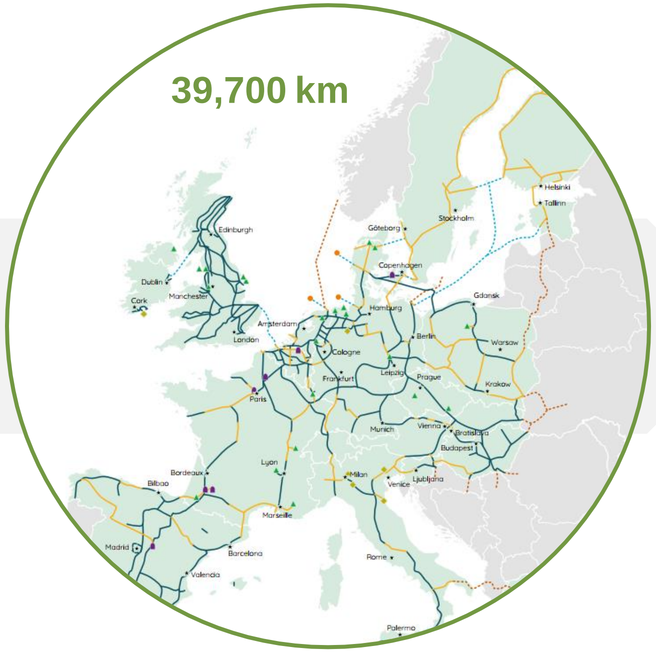
Regional backbones are expected to form in and around first-mover hydrogen valleys.


26,100 km

Growing network by 2035 covers more countries and enables import

The European Hydrogen Backbone will continue to grow, covering more regions and developing new interconnections across member states.

Dedicated hydrogen storage facilities such as salt caverns, depleted fields and aquifers become increasingly important to balance fluctuations in supply and demand.


39,700 km

Mature infrastructure stretching towards all directions by 2040

The proposed backbone can have a total length of 39,700 km, consisting of approximately 69% retrofitted existing infrastructure and 31% of new hydrogen pipelines.

Total estimate investment is expected to be between 43 and 81 billion euros

EFFECTS OF GASEOUS HYDROGEN

Hydrogen Source	Equilibrium Hydrogen Concentration (atomic ppm)*	Equivalent Hydrogen Pressure (bara)
81 bara gaseous hydrogen	0.25	81
0.01 bar H_2S	14	7100
Active cathodic protection	56	11000
3 ml H_2 / 100 g welding electrode	150	15000
1 bar H_2S	185	16000
Cathodic Charging	650	21000

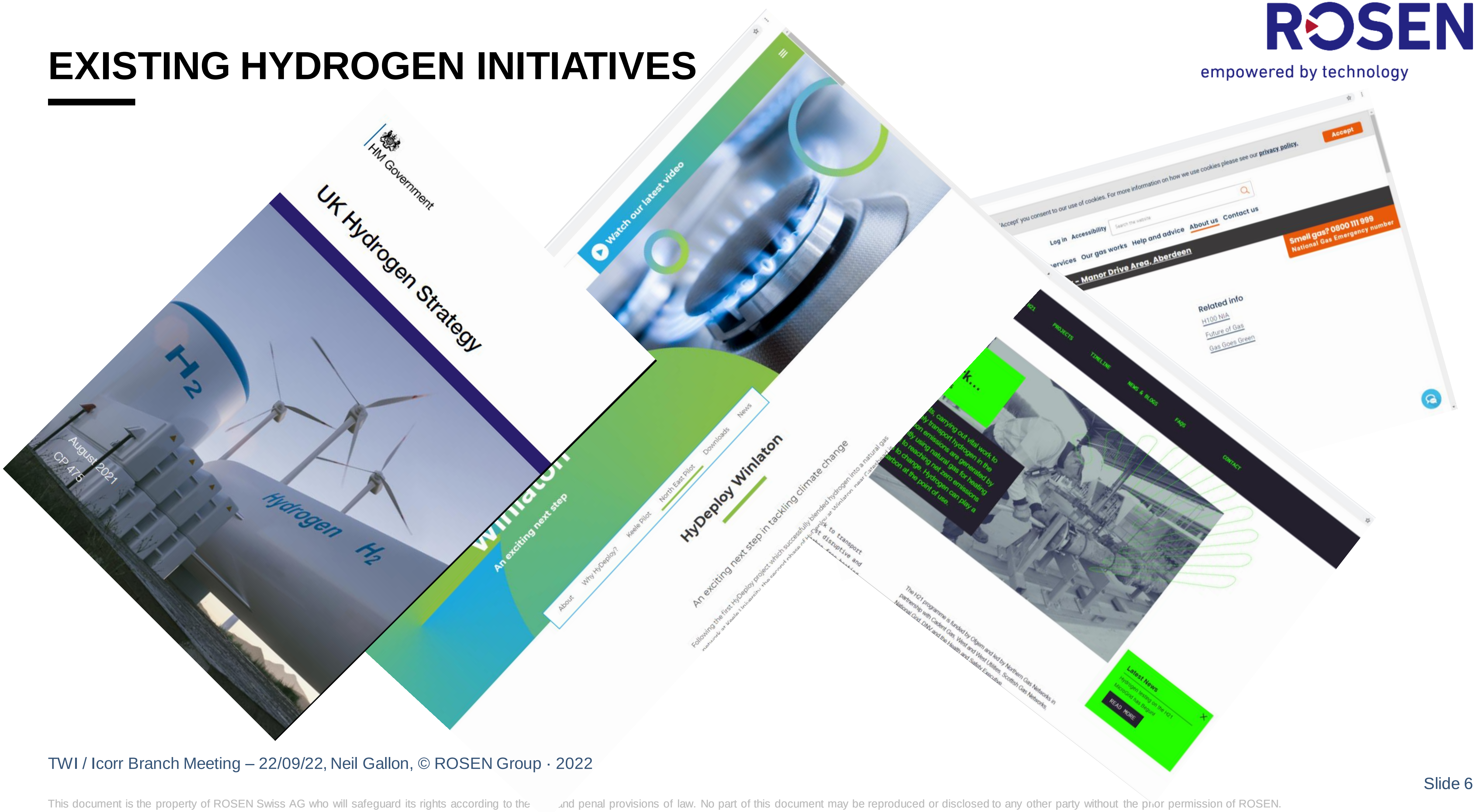
From BS PD CEN/TR 17797:2022

EXISTING HYDROGEN PIPELINES

Company	km	Miles
Air Liquide	1936	1203
Air Products	1140	708
Linde	244	152
Praxair	739	459
Others	483	300
World Total	**4542**	**2823**
U.S.	2608	1621
Europe	1598	993
Rest of World	337	209

https://h2tools.org/hyarc/hydrogen-data/hydrogen-pipelines

EXISTING HYDROGEN INITIATIVES



HM Government

UK Hydrogen Strategy

August 2021

CP 475

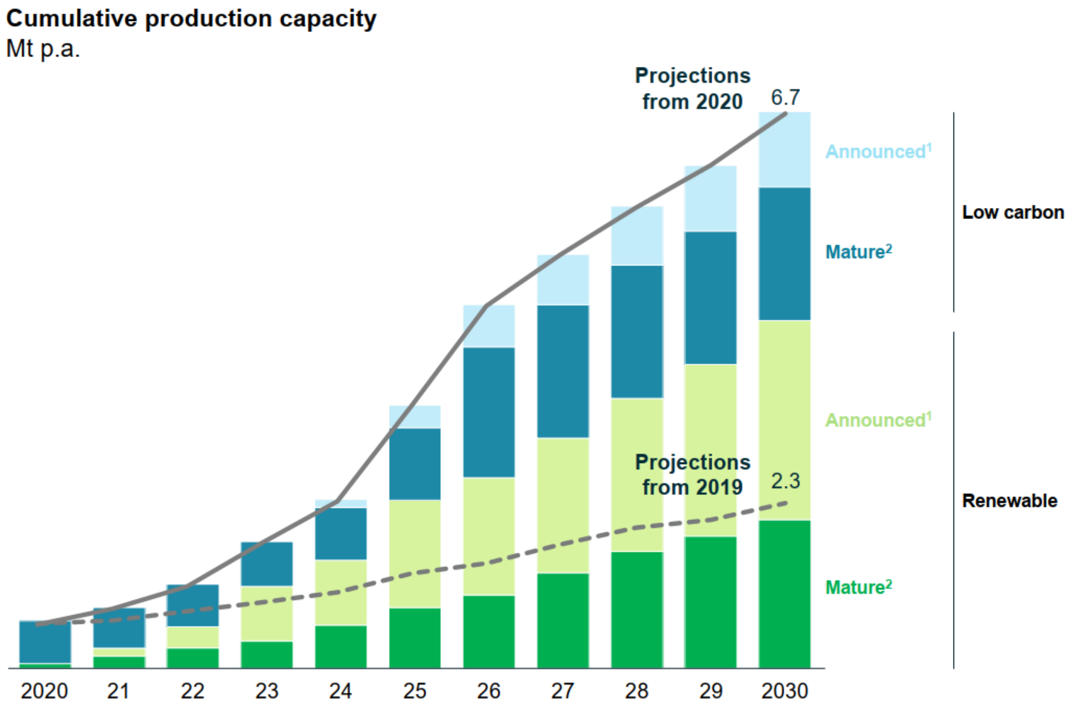
HyDeploy Winlaton

An exciting next step in tackling climate change

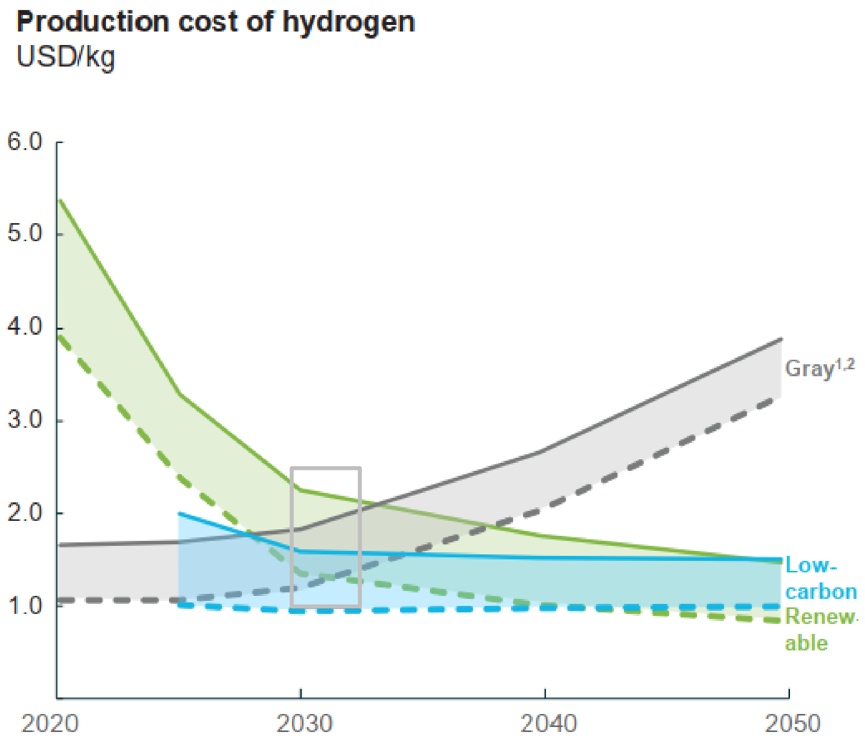
The H21 programme is funded by Ofgem and led by Northern Gas Networks in partnership with Cadent Gas, Wales and West Utilities, Scottish Gas Networks, National Grid, DNV and the Health and Safety Executive.

INVESTMENTS INTO HYDROGEN ARE GATHERING MOMENTUM

Announced clean hydrogen capacity through 2030



Role of 'Blue hydrogen' in transition

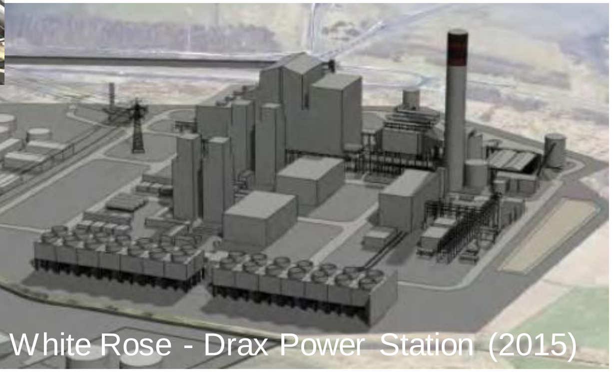


Source: Hydrogen Insights Report 2021, Hydrogen Council, McKinsey & Company, February 2021

CCUS – AN UNCERTAIN ERA?

2005 – 2015 - Series of EU CCS Projects cancelled


EON Kingsnorth (2010)


White Rose - Drax Power Station (2015)


Longannet (2011)

….2007 – 2015 … 2 UK funding competitions cancelled….

G8 2005 Gleneagles Communiqué

"…We will work to accelerate the development & commercialization of CCS technology…"

Rt Hon David Cameron, December 20 2007, China

"…All existing coal-fired power stations should be retro-fitted with CCS, and all future coal-fired power stations should be built with CCS…"

CCUS – A NEW DAWN?

“…Any pathway to mitigate climate change **requires the rapid reduction of CO_2 emissions and negative-emissions technologies** to cut atmospheric concentrations…”

“Without CCUS, the transition would become much more challenging”

McKinsey - 2020

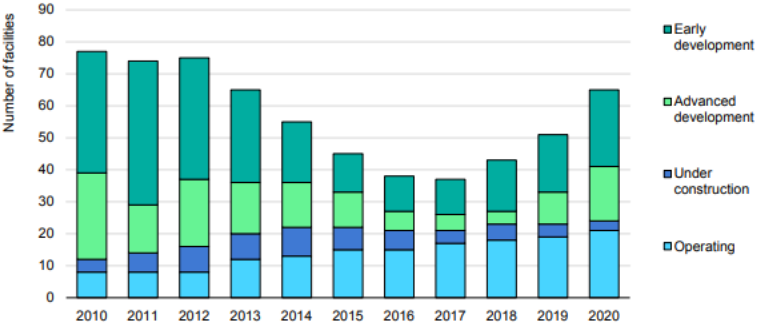
“Currently, some 40 Mt of CO_2 are captured and stored annually. ***This must increase at least 100-fold by 2050*** to meet the scenarios laid out by the IPCC…”

Global CCS institute

Enabling the production of low-carbon hydrogen at scale…

New momentum pushed by policies

COP24, December 2018



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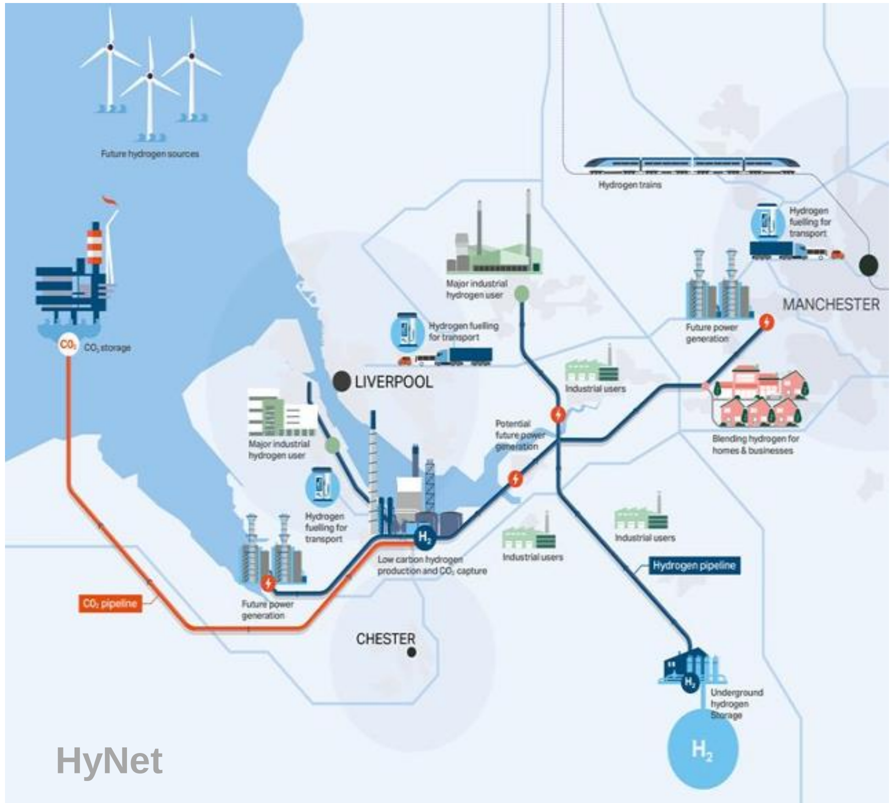
RETROFITTING EXISTING PIPELINES FOR CO_2

"Transportation infrastructure to be built in the coming 30-40 years to be ~ 100 times > than current"

Repurposing Existing Assets



CO_2 PIPELINES… EXPERIENCE?

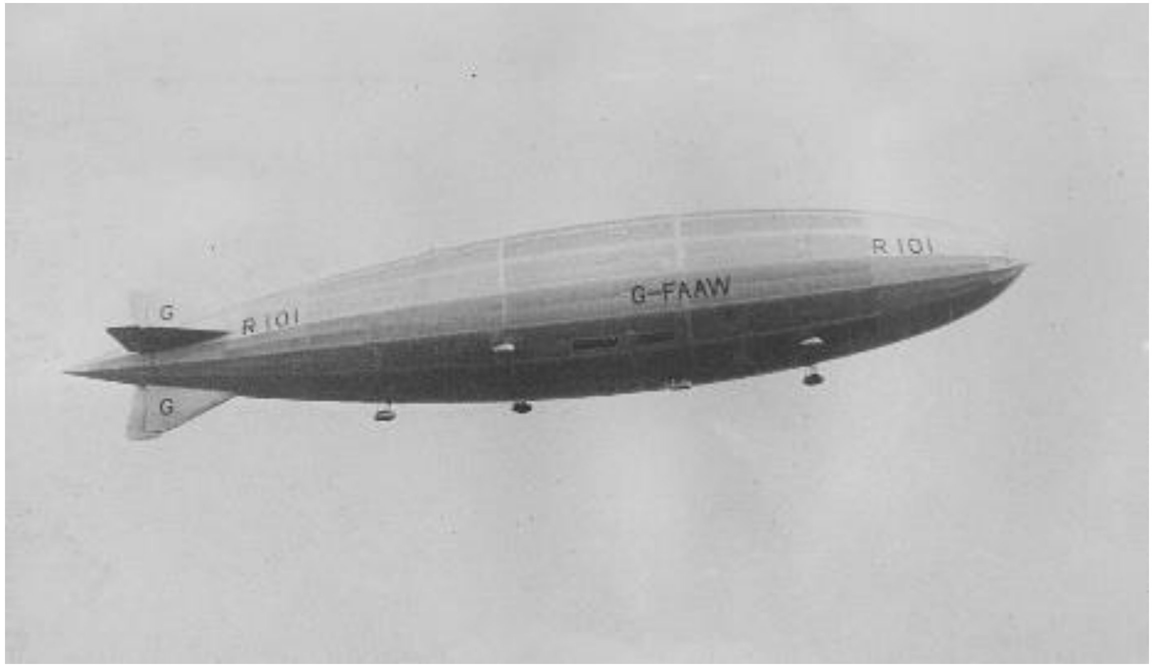
Existing CO_2 pipelines

2021

Projects

Project	km
U.S. (Sample)	
Cortez	808
Sheep mountain	656
Canyon Reef	354
Central basin	231.75
Bairoil	258
Salt creek	201
Canada	
Weyburn	330
ACTL	240
Quest	84
Saskpower Boundary Dam	66
EU	
SnØhvit (Norway)	153
OCAP (Netherlands)	97
Rest of world	
Gorgon (Australia)	8.4

HYDROGEN TRANSPORT



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The End

?

PIPELINES CAN FAIL

By Bryan - cropped from Close Up Pictures of Gas Line Explosion Damage, CC BY 2.0,
https://commons.wikimedia.org/w/index.php?curid=11465628

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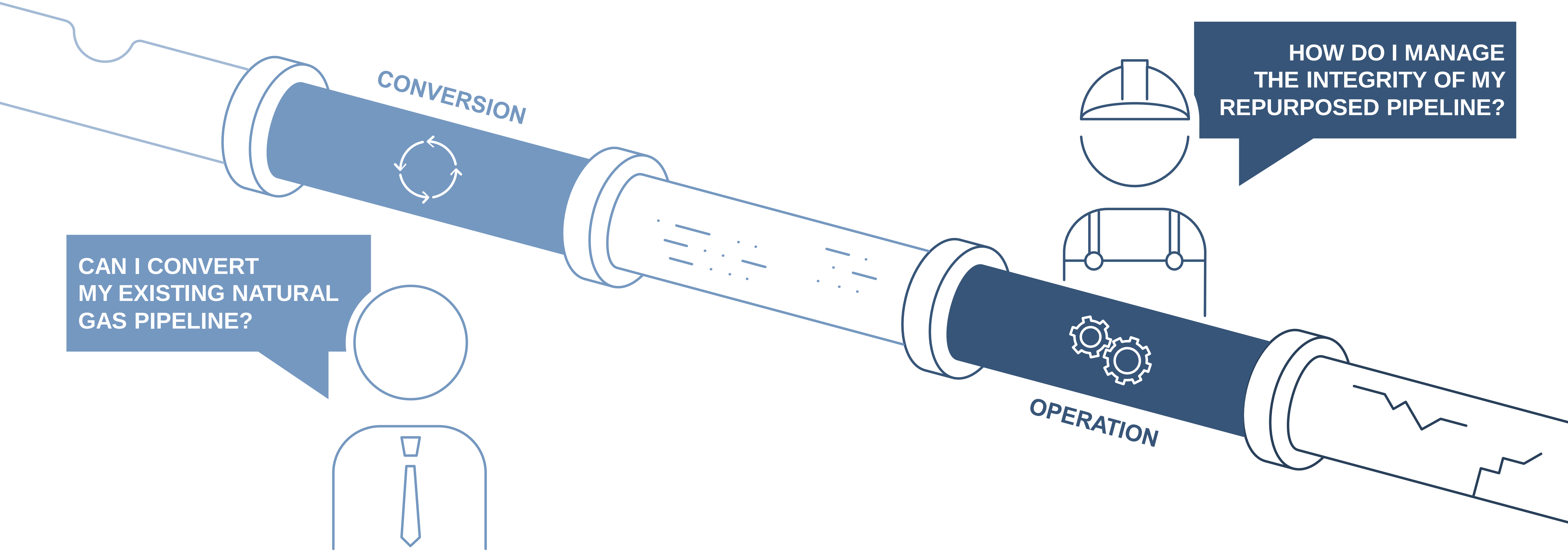
Hydrogen

PIPELINE OPERATORS ARE NOW FACING NEW CHALLENGES



CAN I CONVERT
MY EXISTING NATURAL
GAS PIPELINE?

HOW DO I MANAGE
THE INTEGRITY OF MY
REPURPOSED PIPELINE?

CODE GUIDANCE TO HYDROGEN PIPELINES

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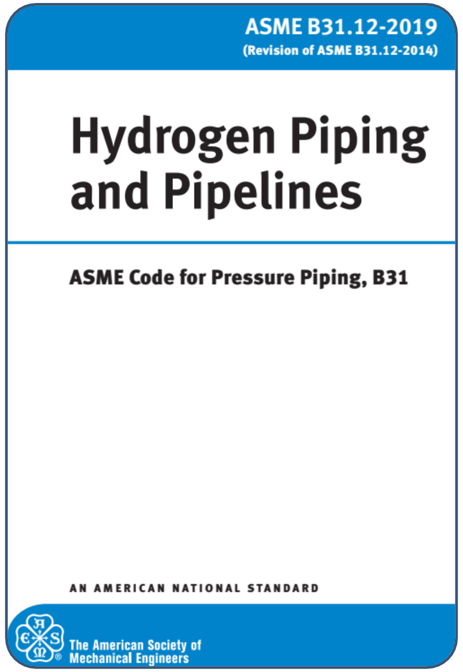
Weld and base metal coupons shall be subject to laboratory analysis to assess the presence of weld inclusions (such as slag), hardness, yield strength, and ultimate tensile strength.
A minimum of one sample per 1.6 km (1 mi) should be examined.”

If the original mill certificates are unavailable, the material description shall be determined by chemical and physical analysis of samples of the pipeline material. The sampling rate shall be **one examination per 1.6 km (1 mi) of pipeline**. The material performance factor H for a pipeline shall be the lowest value obtained from any of the samples.

For piping and pipelines made from materials that may fracture at a pressure lower than the hydrotest pressure when in service, all of the following are required:
(a) **The critical crack size shall be calculated considering the possibility of both fracture and plastic collapse,** using the API 579-1/ASME FFS-1 failure assessment diagram (FAD) approach (Level 2 or Level 3), or other proven fracture mechanics method.



ASME B31.12-2019
(Revision of ASME B31.12-2014)

Hydrogen Piping and Pipelines

ASME Code for Pressure Piping, B31

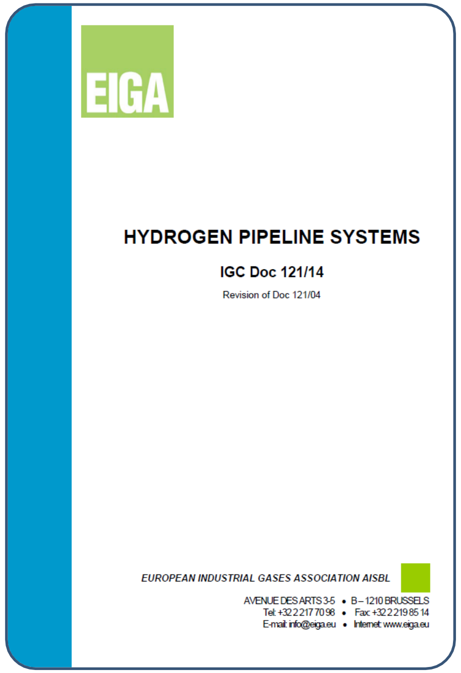
AN AMERICAN NATIONAL STANDARD

The American Society of Mechanical Engineers

Integrity Management of pipeline systems. The integrity management process for hydrogen pipelines shall follow ASME B31.8S except as shown below:
(1) Pipelines with design pressures <15200 kPa (2,200 psi) whose material of construction has a SMYS <358 Mpa (52 ksi) should be considered Location Class 3 pipelines unless they are operating in Location Class 4 areas. **Pipelines with design pressures > 15200 kPa (2,200 psi) whose material of construction has a SMYS <358 Mpa (52 ksi) should be considered Location Class 4 pipelines.** All pipelines whose material of construction has a SMYS > 358 Mpa (52 ksi) shall be considered Location Class 4 pipelines.
(2) Integrity management processes should take into account the embrittlement effects of dry hydrogen gas on carbon steel pipeline materials and welds used to join pipe sections.

Stress concentrations that may or may not involve a geometrical notch may also be created by a process involving thermal energy in which the pipe surface is heated sufficiently to change its mechanical or metallurgical properties. These imperfections are termed “metallurgical notches”. Examples include an arc burn produced by accidental contact with a welding electrode or a grinding burn produced by excessive fore on a grinding wheel. **Metallurgical notches may result in even more severe stress concentrations than a mechanical notch and shall be prevented or eliminated in all pipelines intended to operate at hoop stress levels of 20% or more of the SMYS.**

Internal pipeline inspection is suggested:
If cathodic protection records are missing, or if they indicate that protection has been inadequate if the previous service history of the pipeline is unknown, or **if it has carried fluids such as crude oil or wet natural gas which are known to increase the likelihood of internal corrosion.**
If original material data reports for the pipeline are missing, internal inspection is required to supplement data obtained from samples. Internal pipeline may be waived if an internal inspection has already been made within 5 years of the evaluation, assuming that satisfactory records are available. The internal pipeline inspection device shall be capable of locating internal and external corrosion, buckles and dents, and actual wall thickness.



EIGA

HYDROGEN PIPELINE SYSTEMS

IGC Doc 121/14

Revision of Doc 121/04

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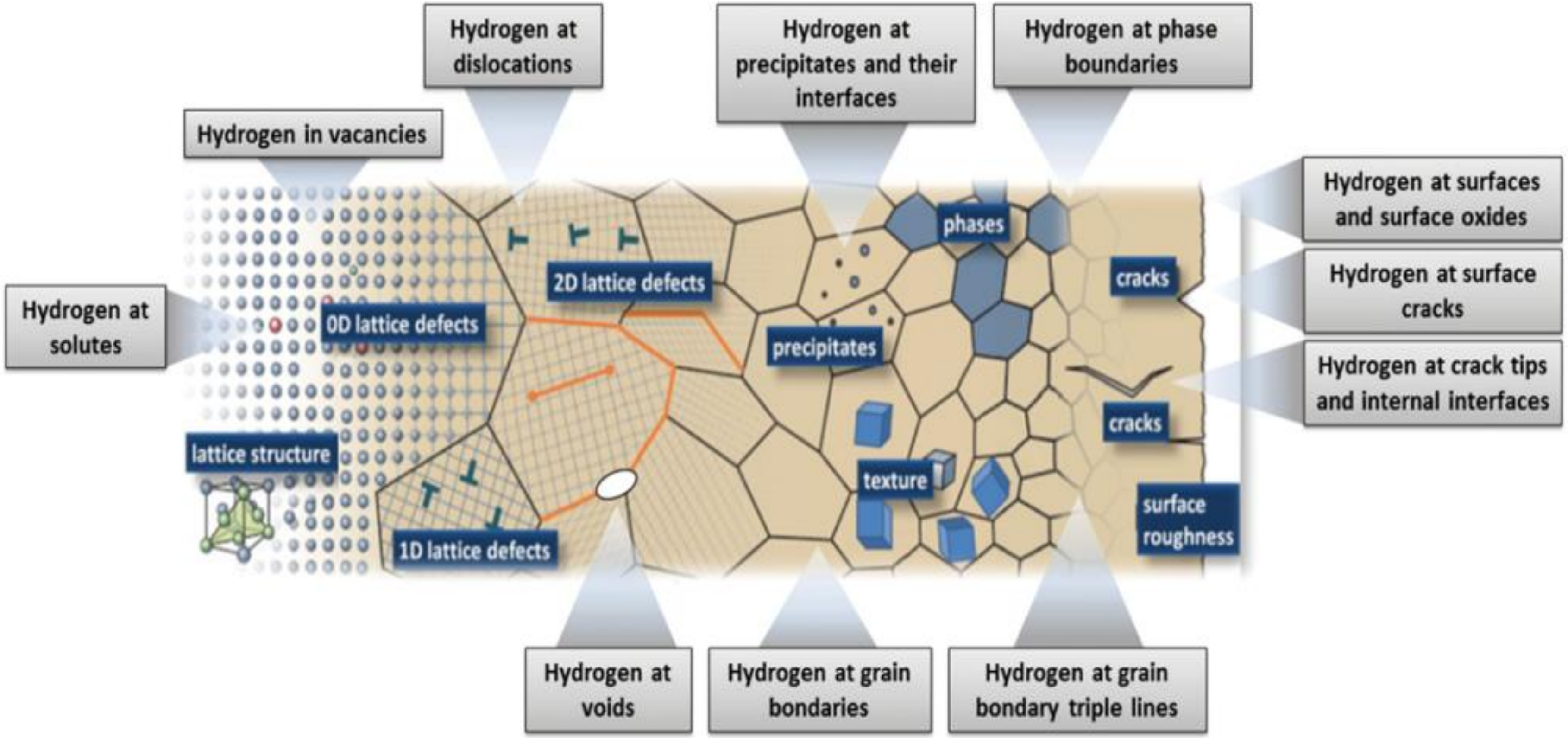
Various methods can be used to detect defects as caused by the many different types of threats to a pipelines. Some of the assessment methods include in-line inspection, pressure testing, and types of direct assessment. **The process of determining and assessing defects is defined in ASME B31.8S,** titled, “Managing System Integrity of Gas Pipelines”.

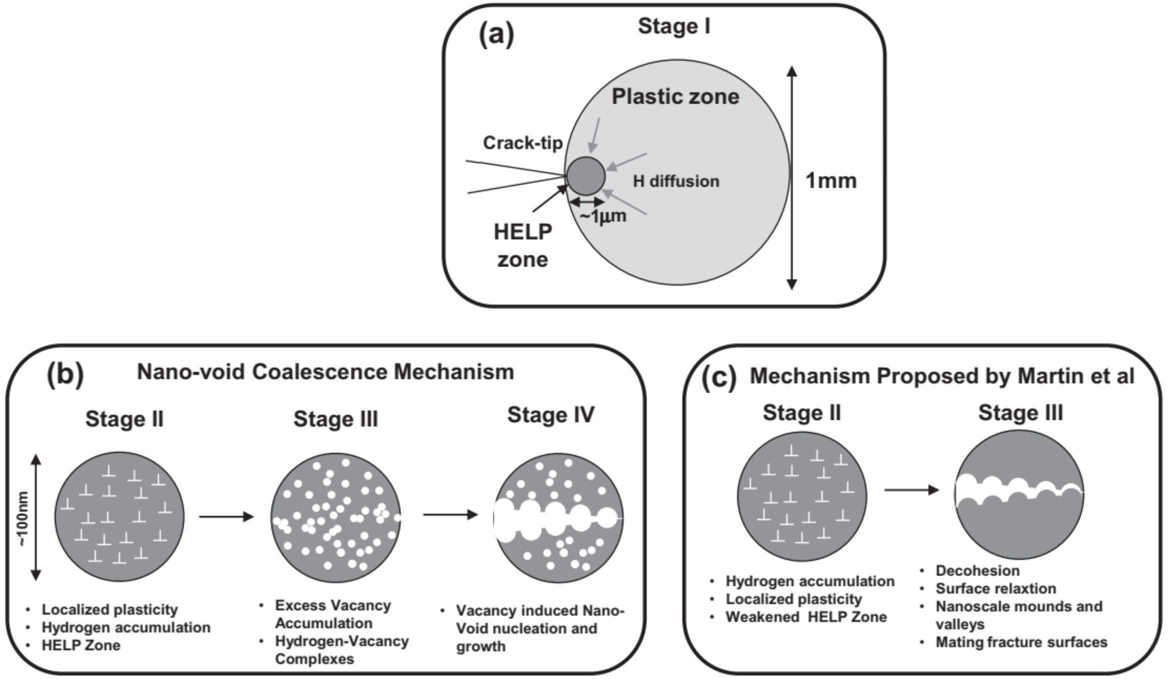
Therefore, PSL 2 material is advantageous for hydrogen piping. Further, it is recommended that only **lower strength API 5L grades (X52 or lower)** be used. API 5L PSL 2 grades meet the requirements discussed below.

EFFECTS OF HYDROGEN ON MECHANICAL PROPERTIES



Schematic Showing Possible Hydrogen Traps from Koyama et al., Recent Progress in Microstructural Hydrogen Mapping in Steels, Quantification, Kinetic Analysis and Multi-Scale Characterisation, Materials Science and Technology, 2017, Vol. 33, pp 1481-1496

MECHANISMS OF HYDROGEN EMBRITTLEMENT



Schematic NVC mechanism – from Neeraj et al., Hydrogen embrittlement of ferritic steels: Observations on deformation microstructure, nanoscale dimples and failure by microvoiding, Act. Mat. 60(2012, 5160-5171

HEDE – Hydrogen Enhanced Decohesion

AIDE – Adsorption Induced Dislocation Emission

IHAC – Internal Hydrogen Assisted Cracking

HEAC – Hydrogen Environment Assisted Cracking

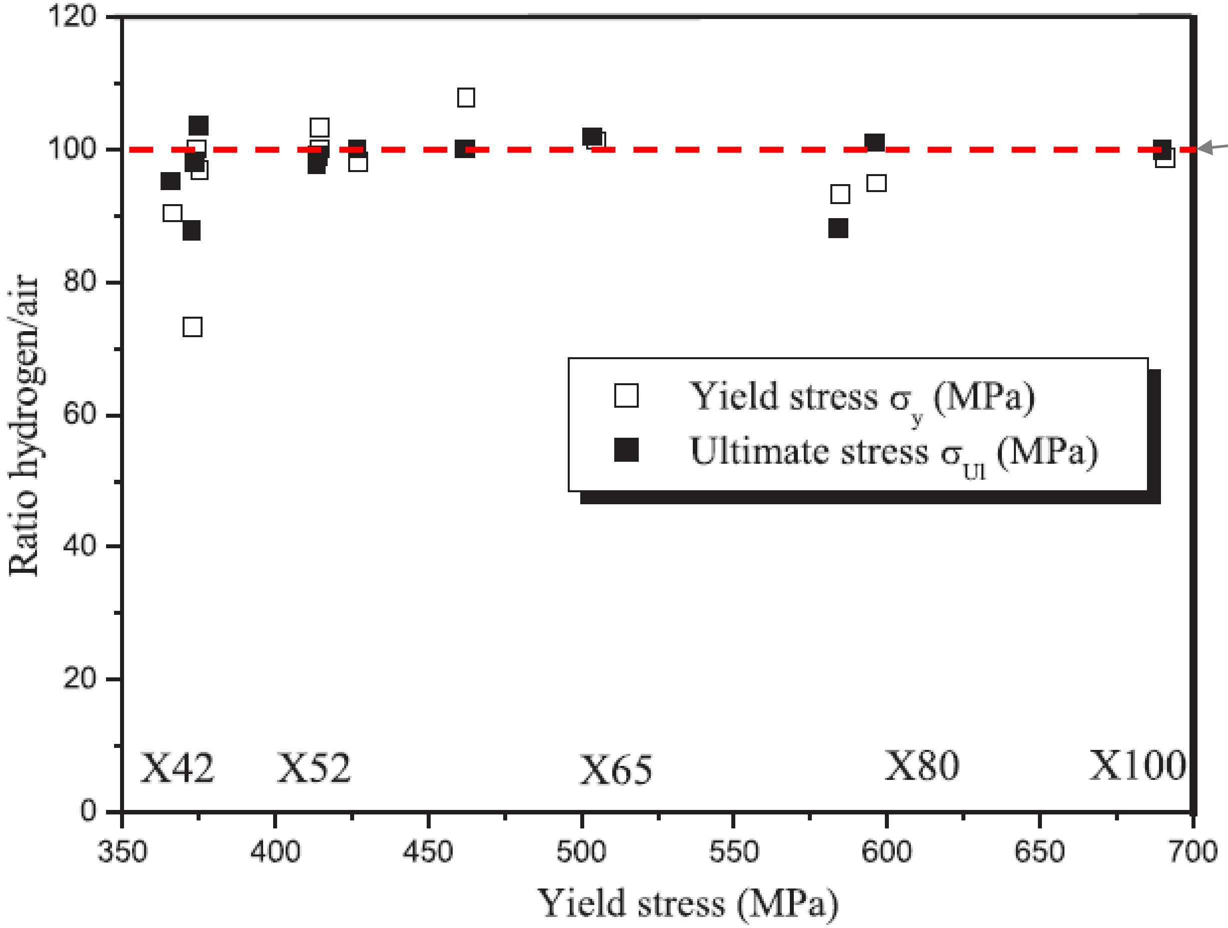
NVC – Nano Void Coalescence

HELP – Hydrogen Enhanced Local Plasticity

EFFECTS OF HYDROGEN ON MECHANICAL PROPERTIES

Property	Effect of Hydrogen
Strength	↔
Ductility	↓
Fracture Toughness	↓
Fatigue Crack Growth Rate	↑

EFFECTS OF HYDROGEN ON STRENGTH

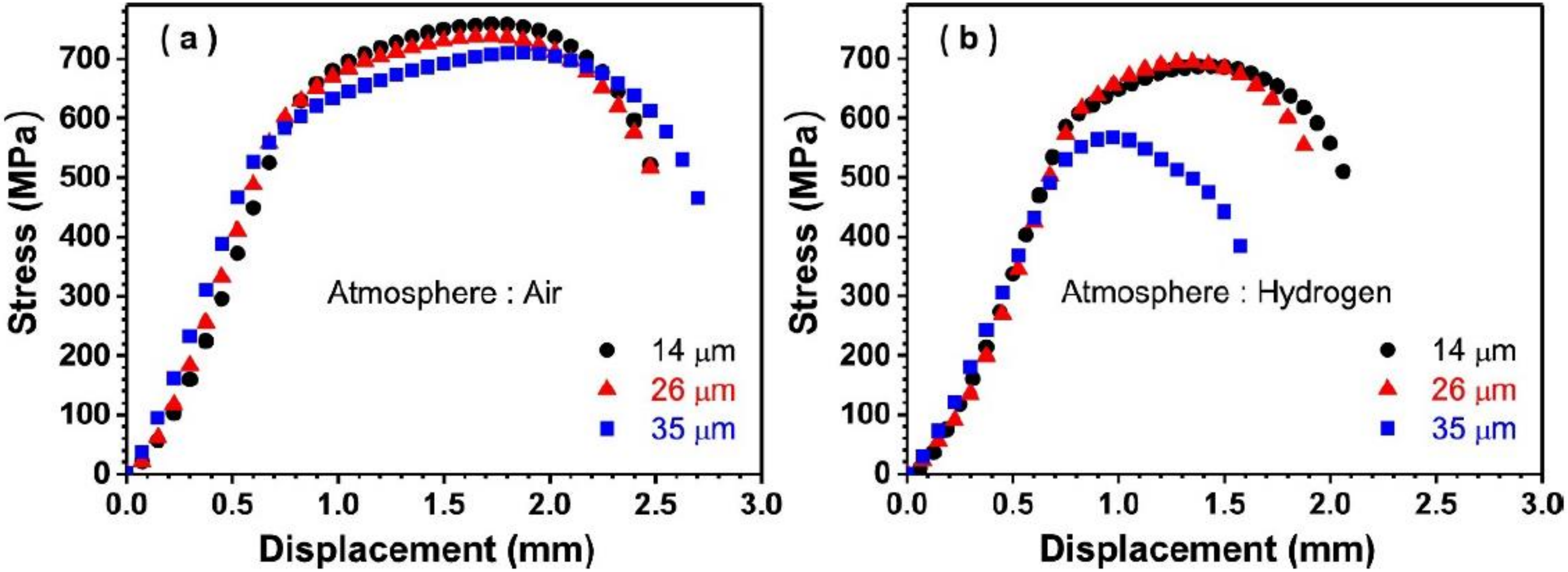


"The analysis of results of various pipeline steels indicates that there is practically no effect of the hydrogen embrittlement on the yield strength and ultimate tensile strength, whatever was the yield strength"

Really?

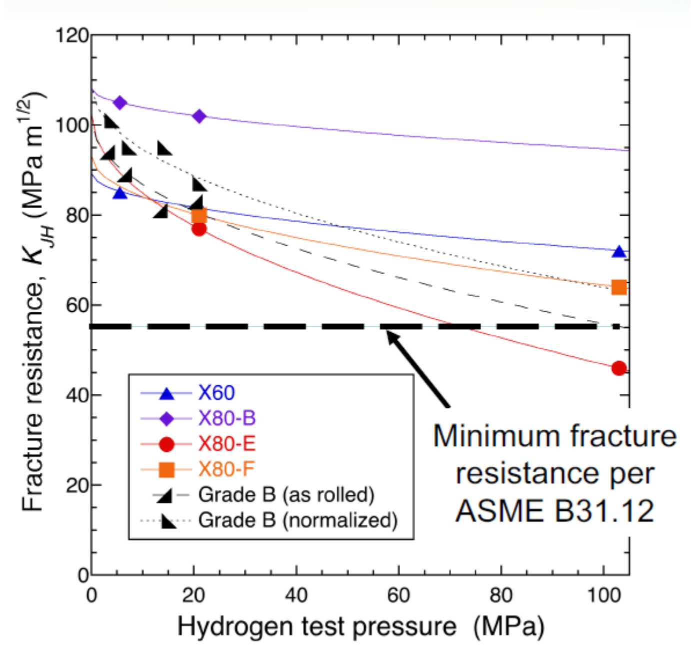
From Boukortt et al. – Hydrogen embrittlement effect on the structural integrity of API 5L X52 steel pipeline, International Journal of Hydrogen Energy 2018

EFFECTS OF HYDROGEN ON DUCTILITY

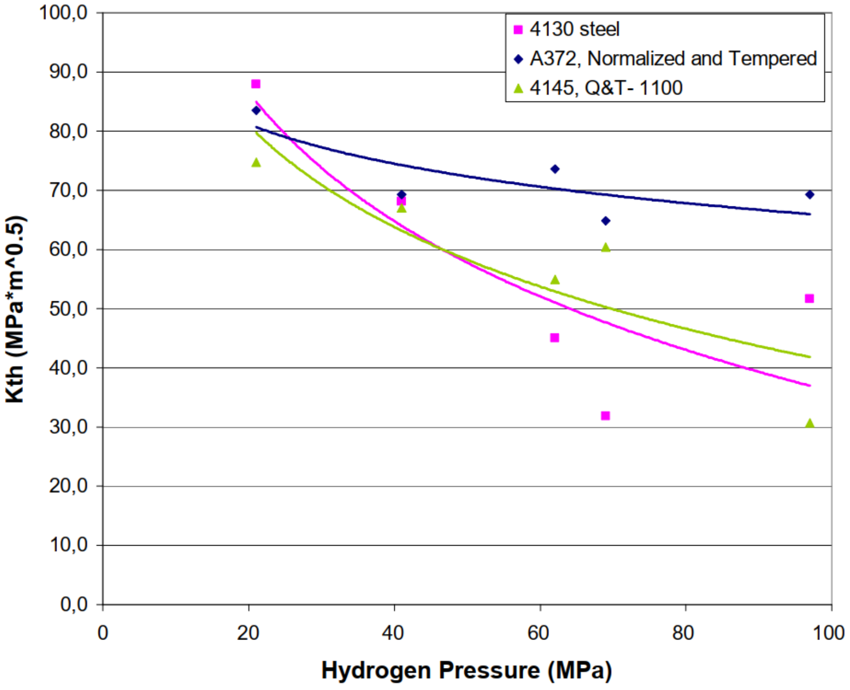


From Park et al., Effect of grain size on the hydrogen embrittlement of API 2W Grade 60 steels using in situ slow-strain-rate testing. Corrosion Science 2017. 128 pp 33-41

EFFECTS OF HYDROGEN ON FRACTURE TOUGHNESS

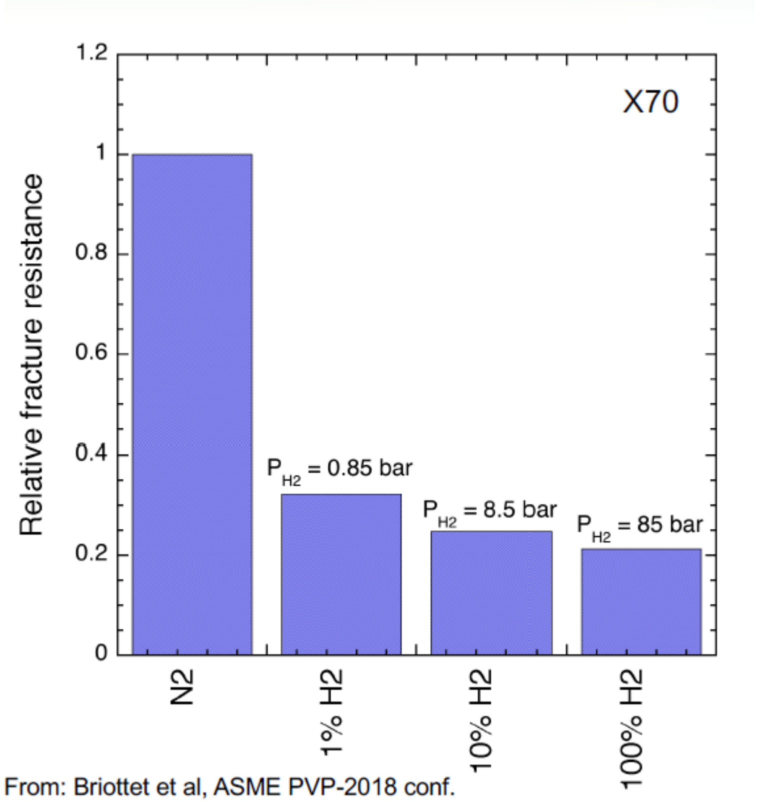


From: San Marchi et al. ASME PVP-1011 conf.



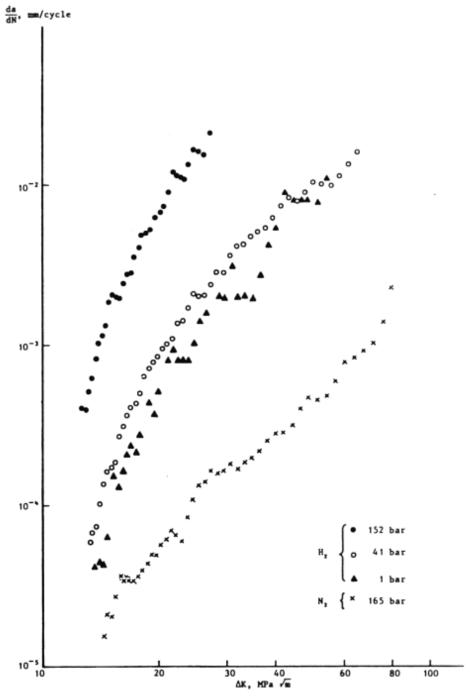
From: Barthelemy, Effects of Purity and Pressure on the Hydrogen Embrittlement of Steels and Other Metallic Materials,

http://conference.ing.unipi.it/ichs2009/images/stories/papers/149.pdf



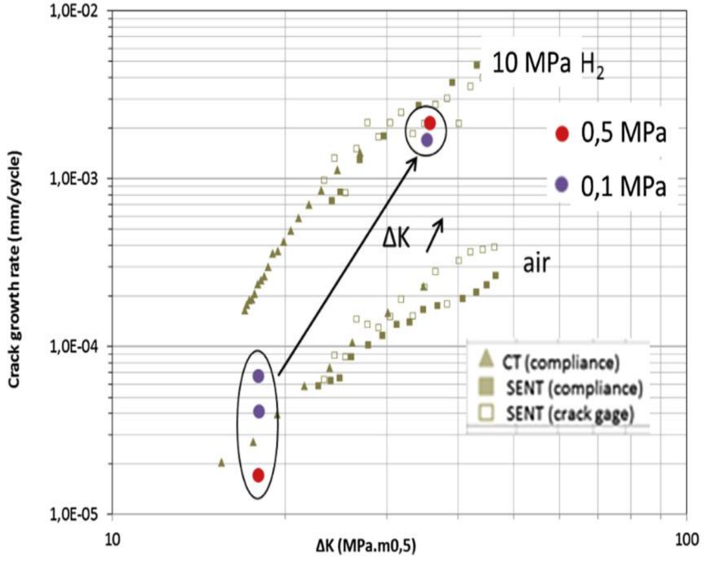
From: Briottet et al, ASME PVP-2018 conf.

EFFECTS OF HYDROGEN ON FATIGUE CRACK GROWTH

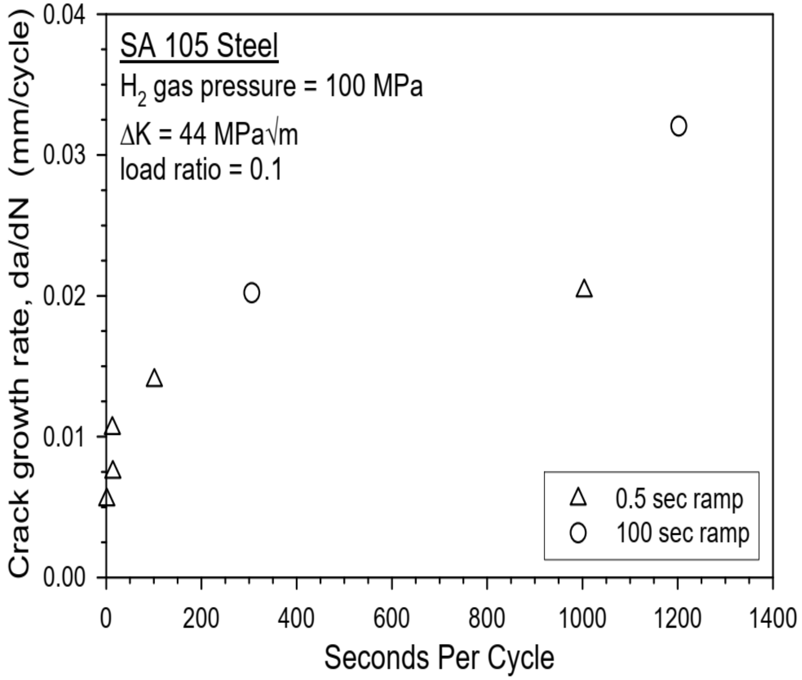


THE EFFECT OF HYDROGEN PRESSURE ON THE FATIGUE CRACK GROWTH RATE IN HIGH STRENGTH 1% CrMo STEEL - TESTS PERFORMED AT 1 Hz

From Barthelemy et al. Hydrogen Gas Embrittlement of Steels, Synthesis of a Subtask of the CEC Hydrogen Energy Programme (1975-1983), Luxembourg, Commision of the European Communities, 1985



From Briottet et al., Fatigue Crack Initiation and Growrth in a CrMo Steel Under Hydrogen Pressure, International Journal of Hydrogen Energy, 2015



From Somerday et al., Technical Reference on Hydrogen Compatibility of Materials, Sandia National Laboratories, 2012

EFFECTS OF HYDROGEN ON FITNESS FOR PURPOSE ASSESSMENTS

Reduced Fracture Toughness

- Charpy – assumed no effect due to strain rate but no data
- Fracture toughness (K, J or CTOD) falls – increases K_r on FAD

Reduced Yield and Tensile Strengths

- Increased L_r on FAD

Reduced Ductility

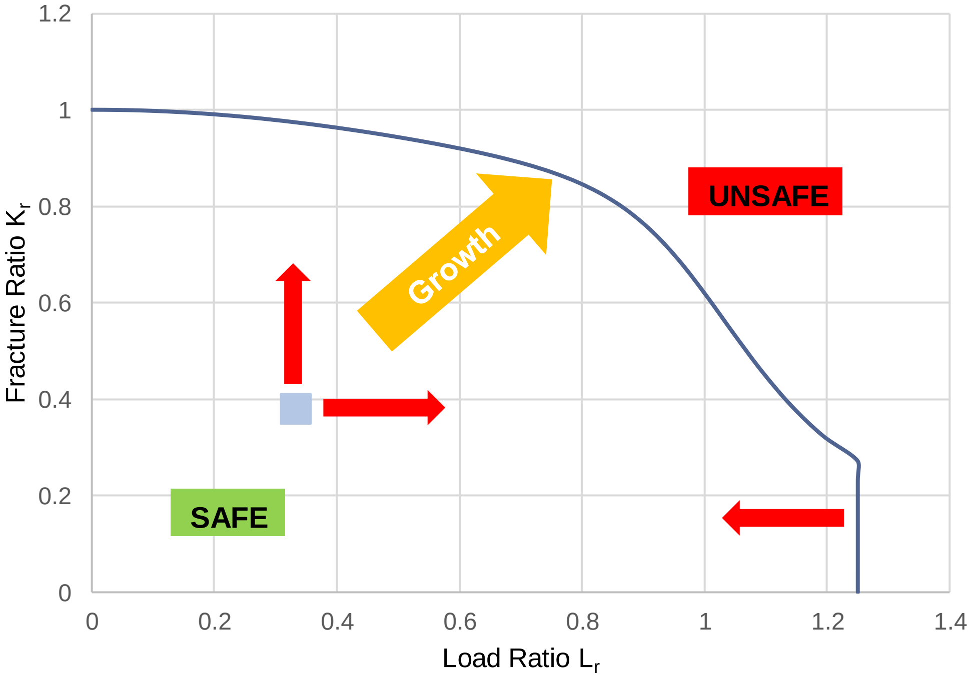
- Y/T reduced – moves $L_{r,max}$ cut-off on FAD to left

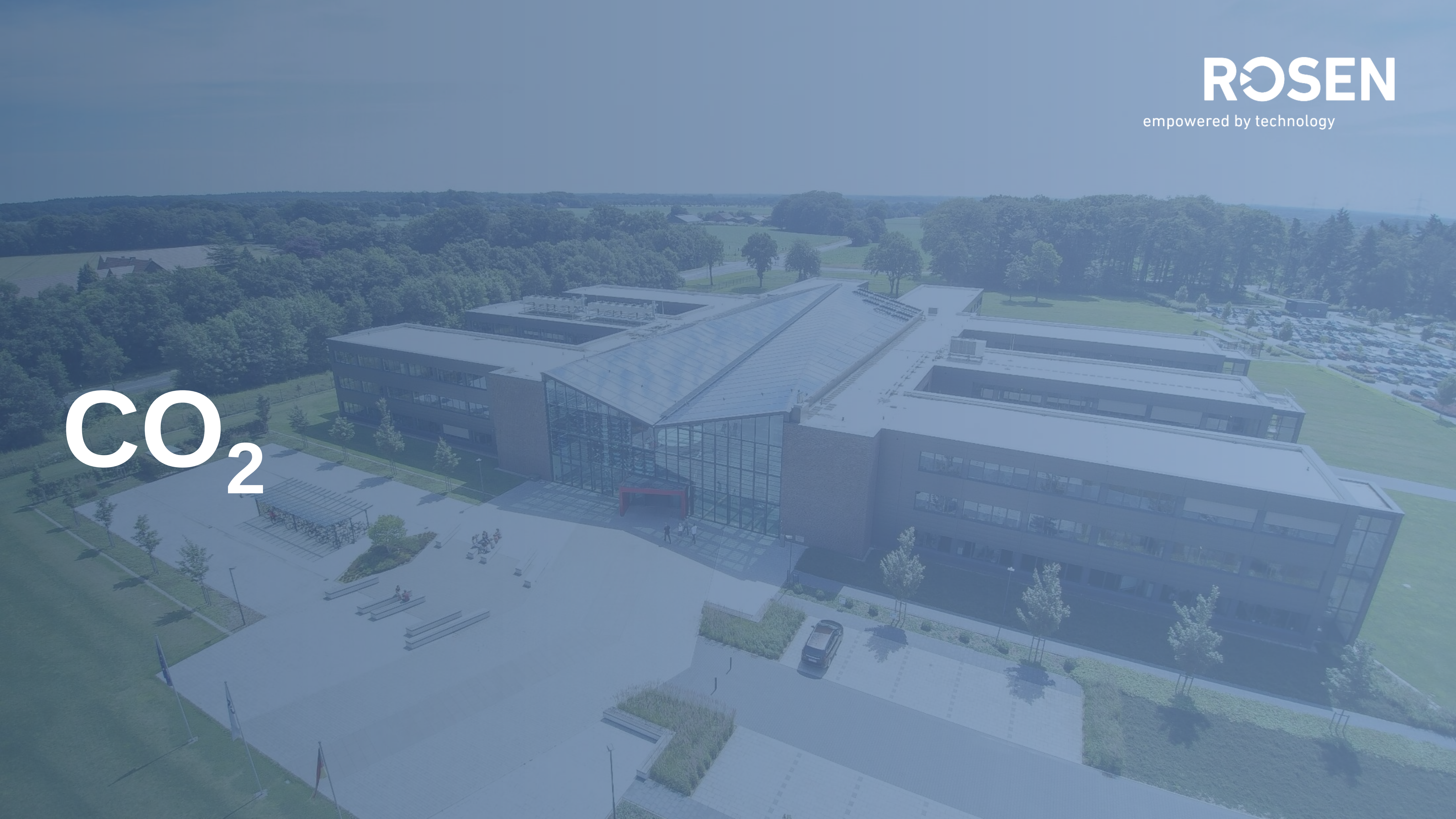
Increased Fatigue Crack Growth Rates

Existence of Threshold K_I for Time Dependent Crack Growth

Safety Factors

- Assessment methods have implicit or explicit safety factors but no experience with hydrogen





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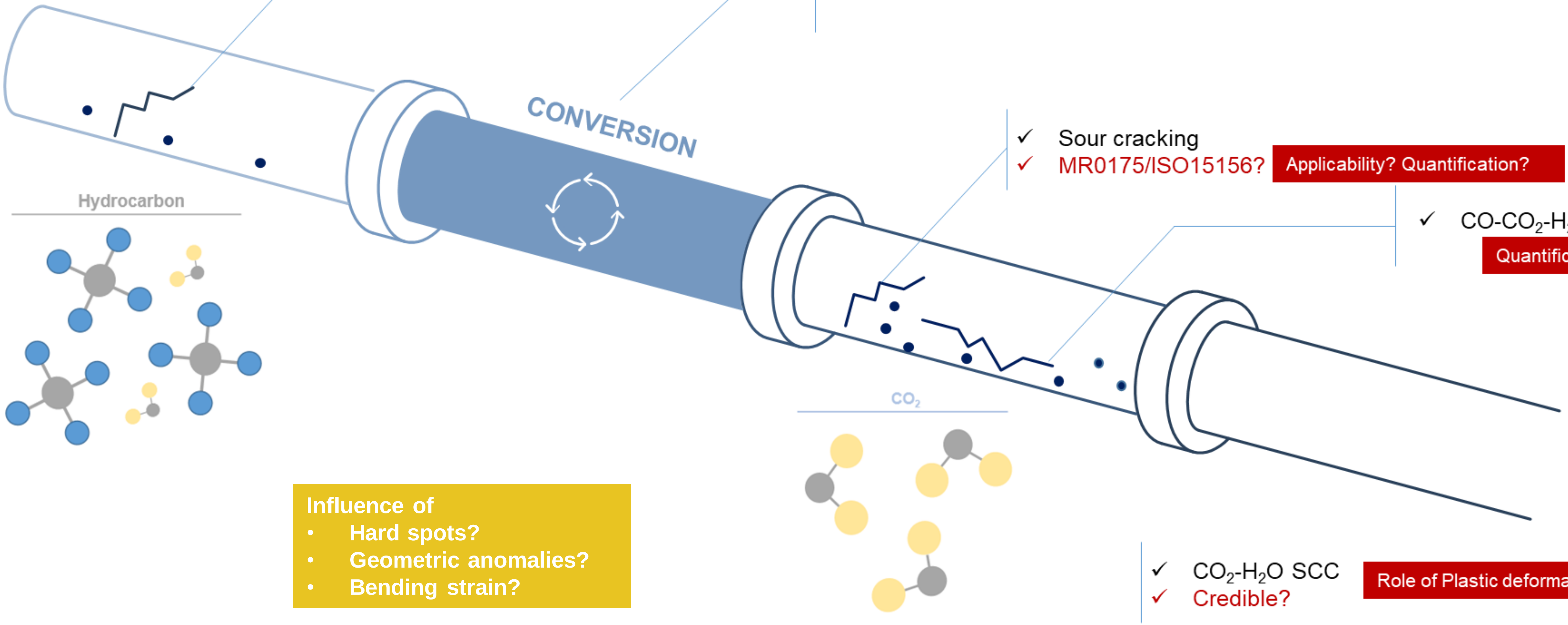
CO_2

RETROFITTING EXISTING PIPELINES FOR CO_2

Key Integrity Topics	Management
Internal corrosion	✓ **Water solubilities** vs. CO_2 composition ✓ Impurity types & levels
Internal Environmentally Assisted Cracking	✓ **As above** ✓ Presence of Hard spots / plastic deformation?
Fracture propagation Control *(Dense CO_2)*	✓ **Material Toughness** ✓ Crack Arrestors

SMR- RICH CO_2 … CONVERSION MANAGEMENT

Internal SCC



- ✓ Sour cracking
- ✓ MR0175/ISO15156

- ✓ CO_2 + imp. H_2S, CO
- ✓ Escalation of EAC?
- ✓ Water management(?)

Threat Quantification? (testing?)

Solubility limits vs. specs? (case by case)

- ✓ Sour cracking
- ✓ MR0175/ISO15156?

Applicability? Quantification?

- ✓ CO-CO_2-H_2O SCC?

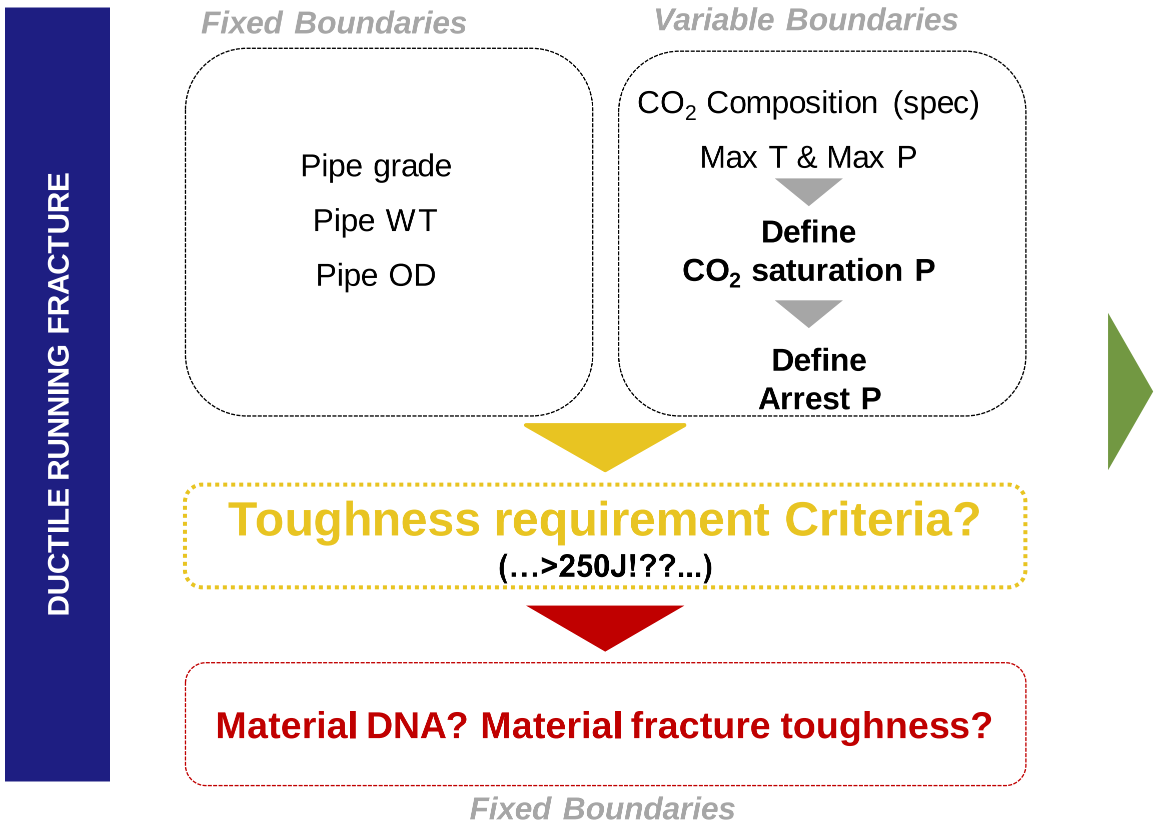
Quantification?

- ✓ CO_2-H_2O SCC
- ✓ Credible?

Role of Plastic deformation?

Influence of
- **Hard spots?**
- **Geometric anomalies?**
- **Bending strain?**

SMR- RICH CO_2 … CONVERSION MANAGEMENT



DUCTILE RUNNING FRACTURE

Fixed Boundaries

Pipe grade

Pipe WT

Pipe OD

Variable Boundaries

CO_2 Composition (spec)

Max T & Max P

Define
CO_2 saturation P

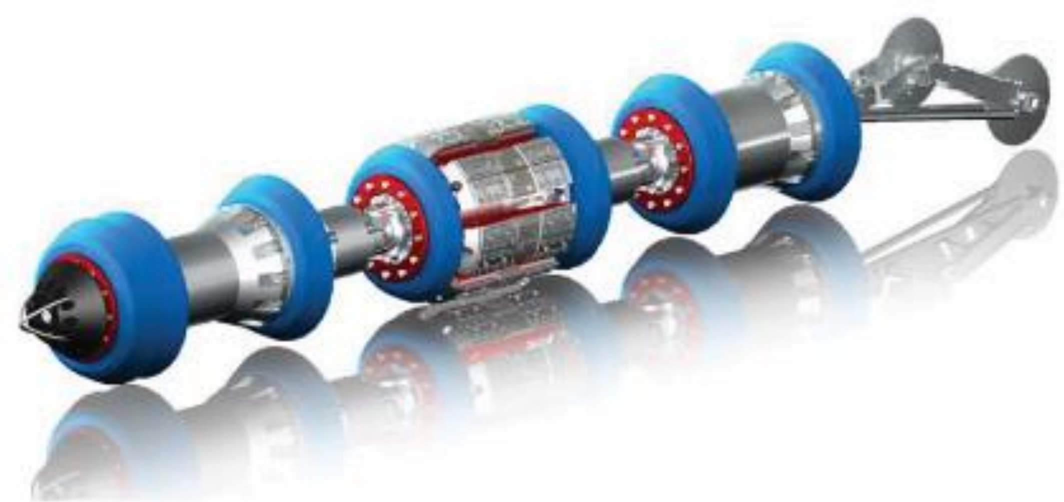
Define
Arrest P

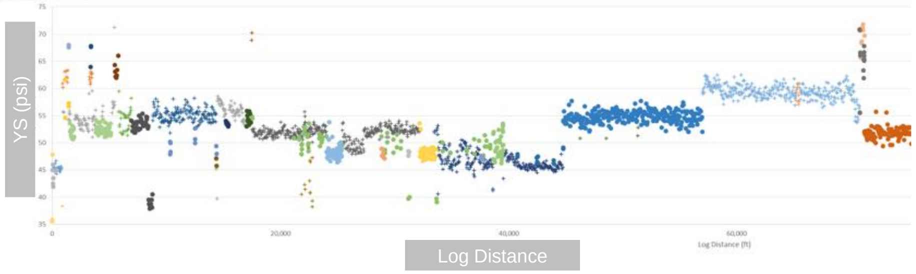
Toughness requirement Criteria?
(…>250J!??...)

Material DNA? Material fracture toughness?

Fixed Boundaries

Material sampling strategy & testing?





RoMat-PGS…"intelligent-targeted sampling"

REPURPOSING APPROACH – EXAMPLE PHASE APPROACH

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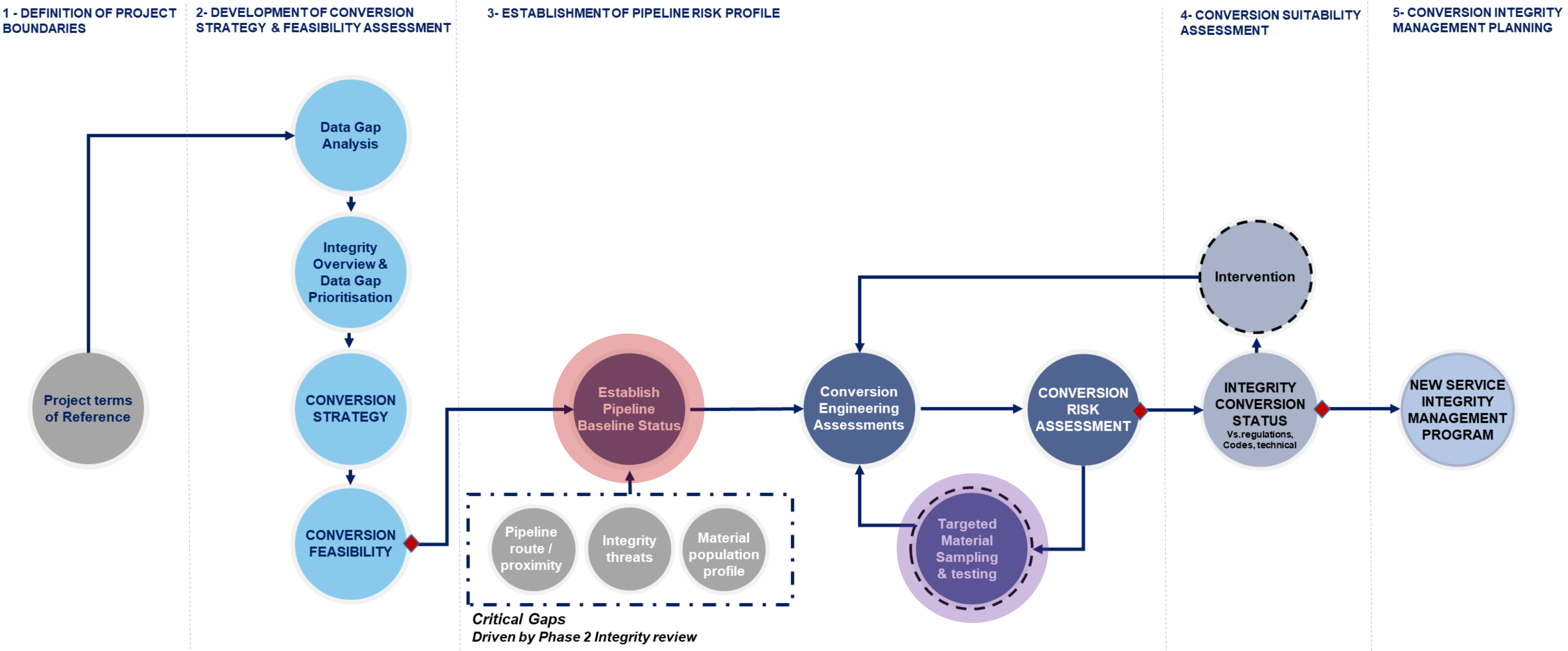

1 - DEFINITION OF PROJECT BOUNDARIES

2- DEVELOPMENT OF CONVERSION STRATEGY & FEASIBILITY ASSESSMENT

3- ESTABLISHMENT OF PIPELINE RISK PROFILE

4- CONVERSION SUITABILITY ASSESSMENT

5- CONVERSION INTEGRITY MANAGEMENT PLANNING

Project terms of Reference

Data Gap Analysis

Integrity Overview & Data Gap Prioritisation

CONVERSION STRATEGY

CONVERSION FEASIBILITY

Establish Pipeline Baseline Status

Pipeline route / proximity

Integrity threats

Material population profile

Critical Gaps
Driven by Phase 2 Integrity review

Conversion Engineering Assessments

CONVERSION RISK ASSESSMENT

Targeted Material Sampling & testing

Intervention

INTEGRITY CONVERSION STATUS
Vs.regulations, Codes, technical

NEW SERVICE INTEGRITY MANAGEMENT PROGRAM

HYDROGEN CHALLENGES

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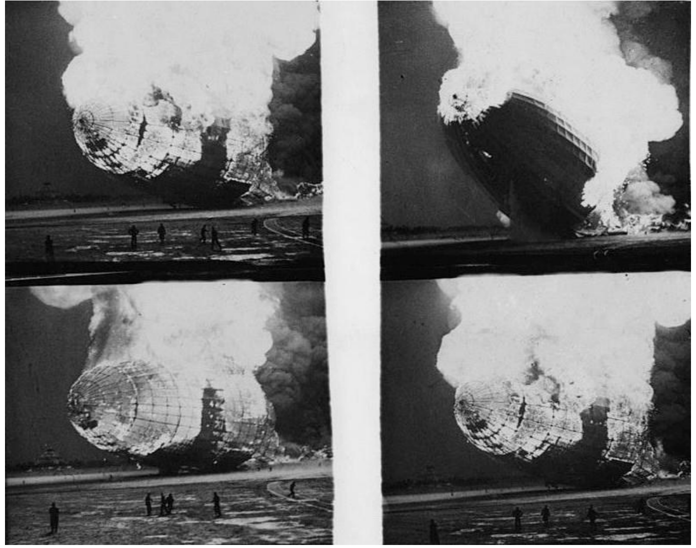

ANY QUESTIONS?

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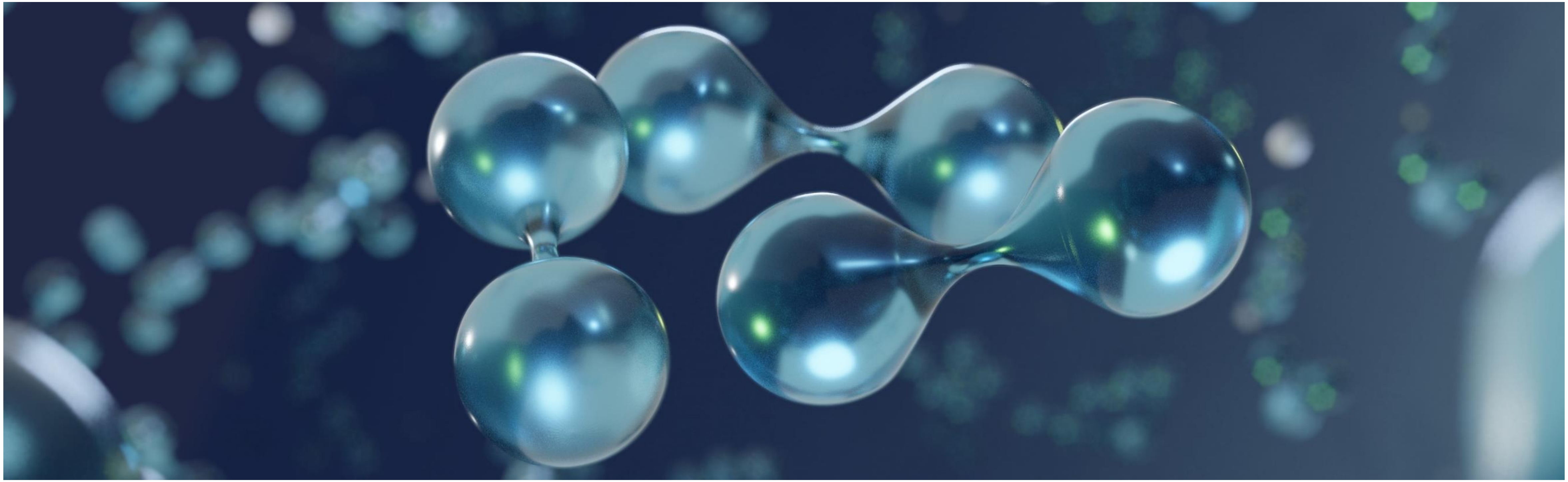
e: ngallon@rosen-group.com
e: dsandana@rosen-group.com



THANK YOU FOR JOINING THIS PRESENTATION.

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