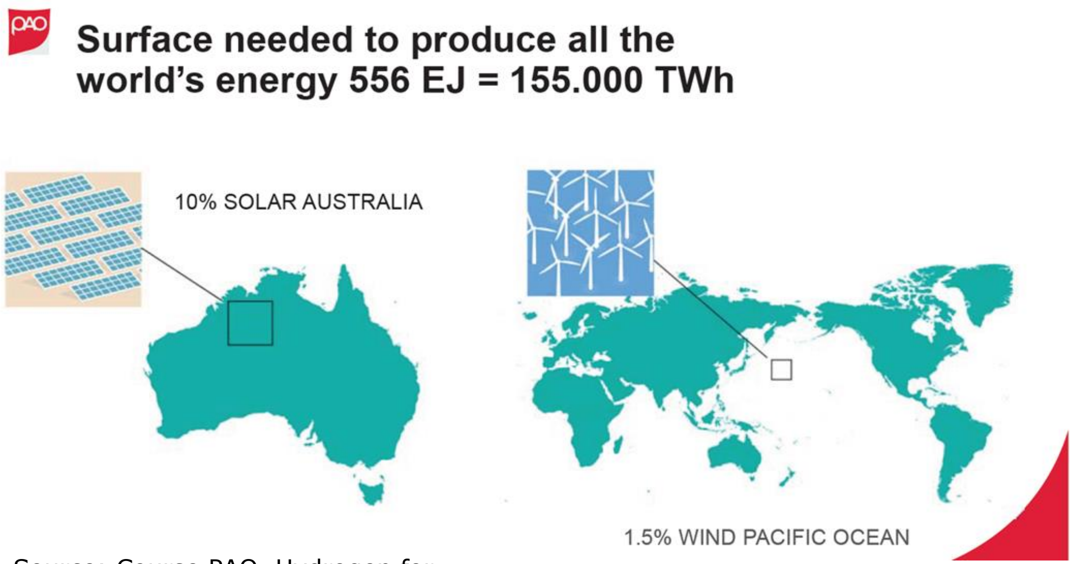
Gasunie: Crossing borders in energy

Hydrogen in Gas transmission lines

Contents

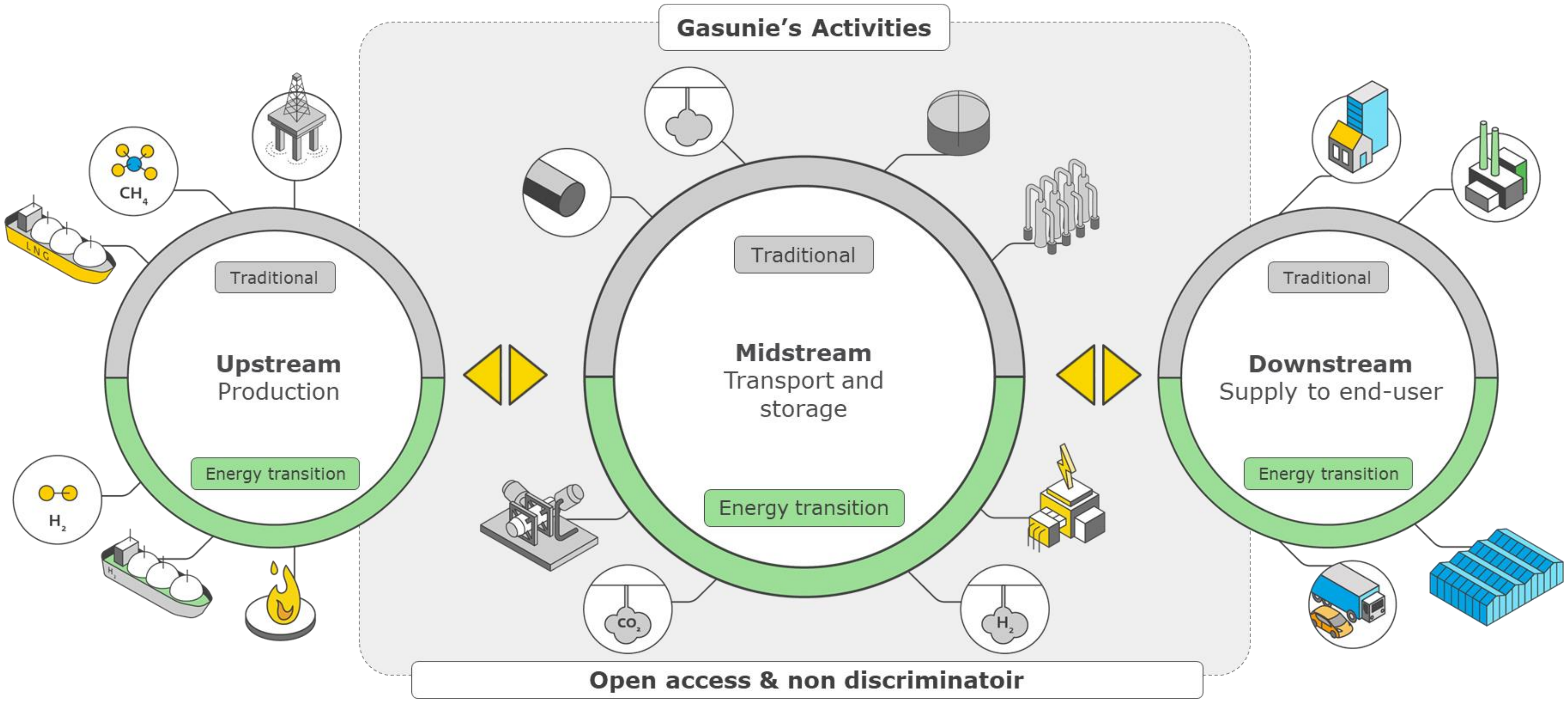
- N.V. Nederlandse Gasunie
- Hydrogen embrittlement
- Lifetime



Source: Course PAO, Hydrogen for professionals, prof A.J.M van Wijk TU Delft

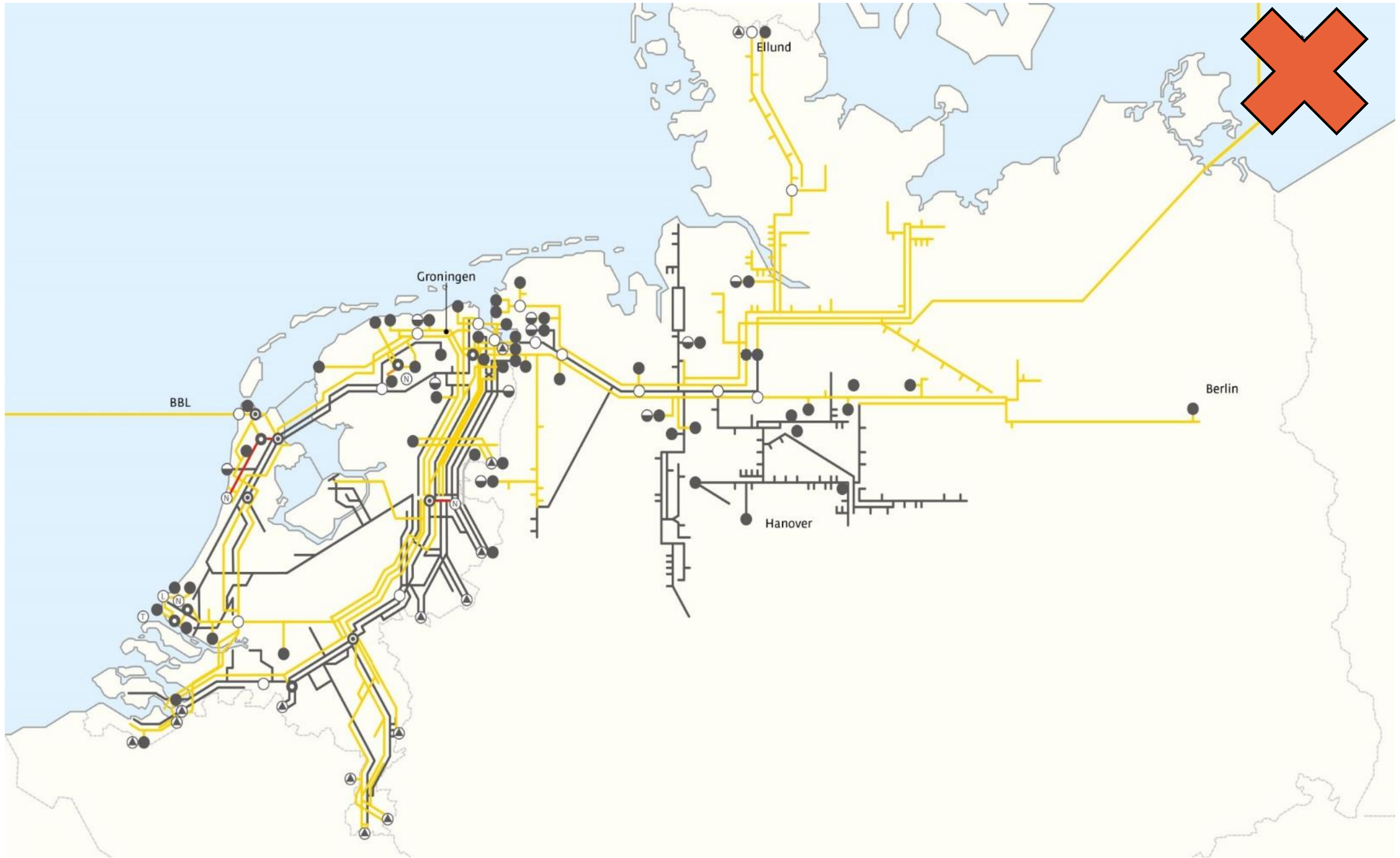
A connecting factor in the energy value chain

Providing open access and non-discriminatory infrastructure in The Netherlands and Germany



Gasunie: a European energy infrastructure company

15,500 km pipelines. Offices in The Netherlands, Belgium and Germany



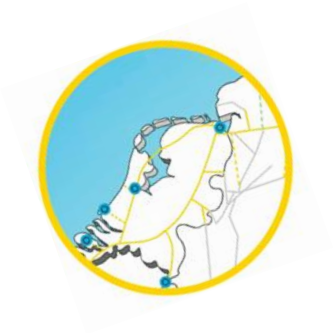
Gasunie hydrogen ambition

- Ambition
  To be the driver of the hydrogen market in the Netherlands and Germany. With the use of our deep technical and engineering know-how for gas infrastructure, market insights and partner relations.
- Goals
  Realizing the required hydrogen infrastructure early to connect supply and demand.
- Approach
  Our services will include: onshore and offshore pipeline transport, underground storage and import terminals. Our customers are: all suppliers and users of and traders in hydrogen, with an initial focus on early adopting large industrial players.
- The role of Gasunie
  Develop and manage the required hydrogen infrastructure fully owned or in partnerships. With focus on pipeline transport, underground storage and import terminals.

Gasunie has organized hydrogen development activities along four lines ('pillars')

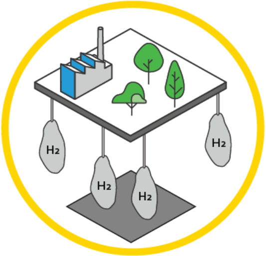
1

Transport



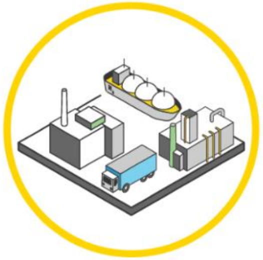
2

Storage



3

Import

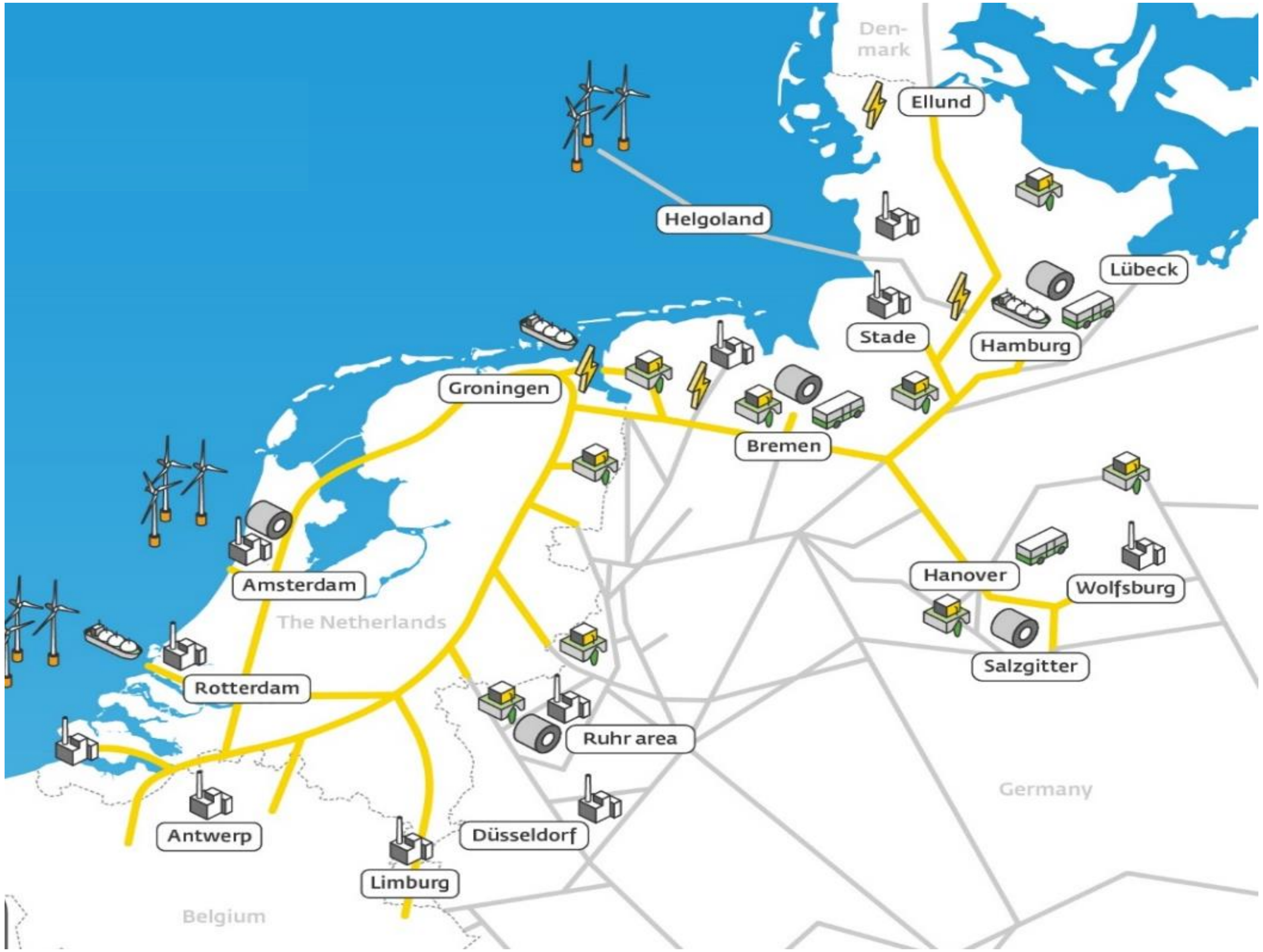


4

Offshore

Gasunie hydrogen backbone

- Connecting industrial clusters
- 70% re-purposed NG lines
- Re-purposing 1/3 cost compared to a new line

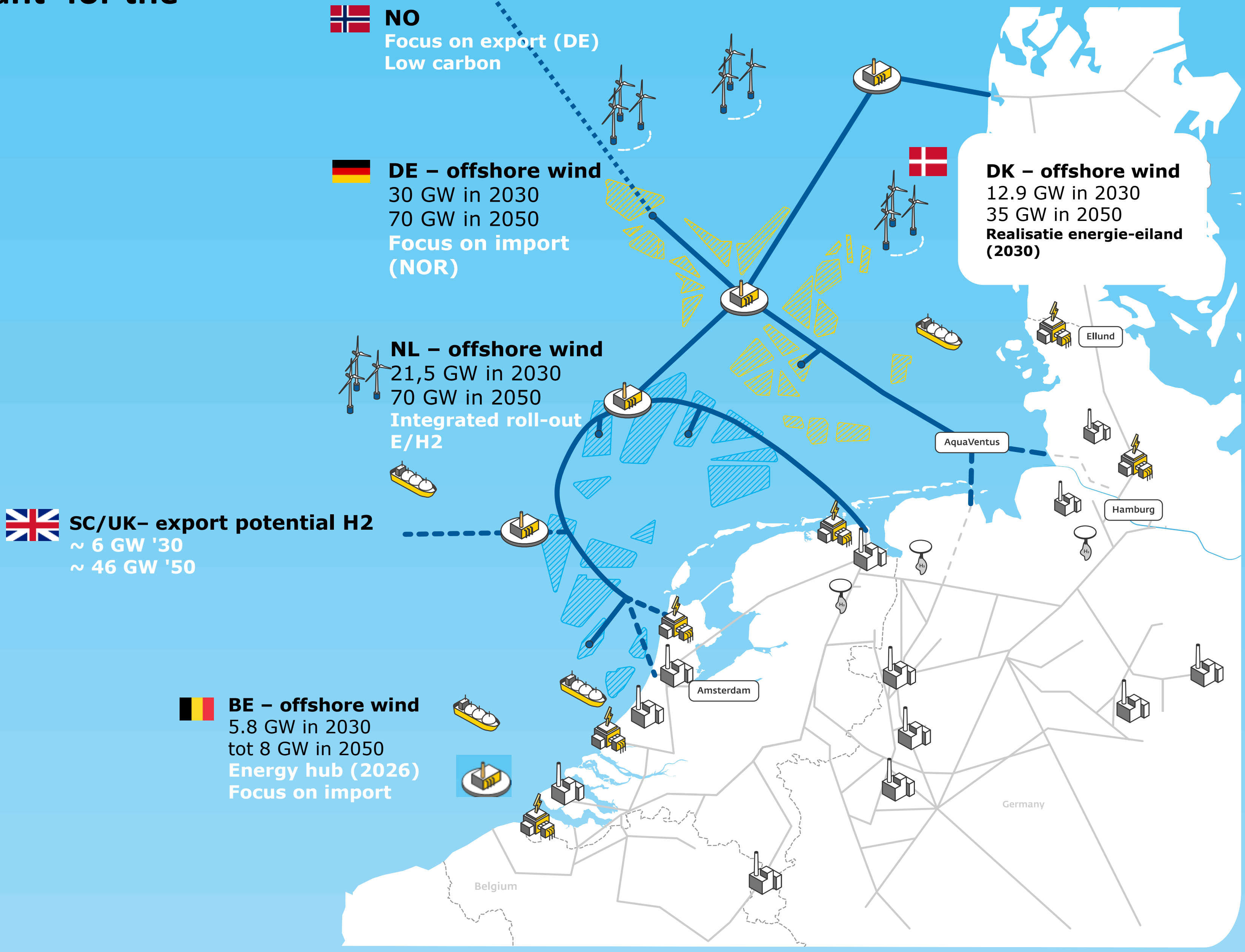


The North Sea as 'green powerplant' for the NW-European energy supply

Esbjerg Declaration

65GW offshore wind - 2030
20 GW on- & offshore electrolysis – 2030

- Joint North Sea approach governments and TSOs
- NL chairing NSEC 2023
- National policy-making in infrastructure plans and implementation
- Offshore infrastructure and services needed for effective deployment and integration E/H2 into energy system
- Interconnection of infrastructure needed for crossborder flow
- Analysis and exploration with TSOs started
- Position of Gasunie in German North Sea different from NL



Januari 2023

Hydrogen line: in service 01-2019

- Owned and operated by Gasunie Waterstof Service

- Steel pipeline:
  - existing line used (1996)
  11,7 km 16“- StE 415.7 TM
  - new (2017)
  0,7 km 12“- L415ME

- Operating pressure 32 bar (o)

Producer Dow Chemicals
Unused gas from Naphtha Cracker

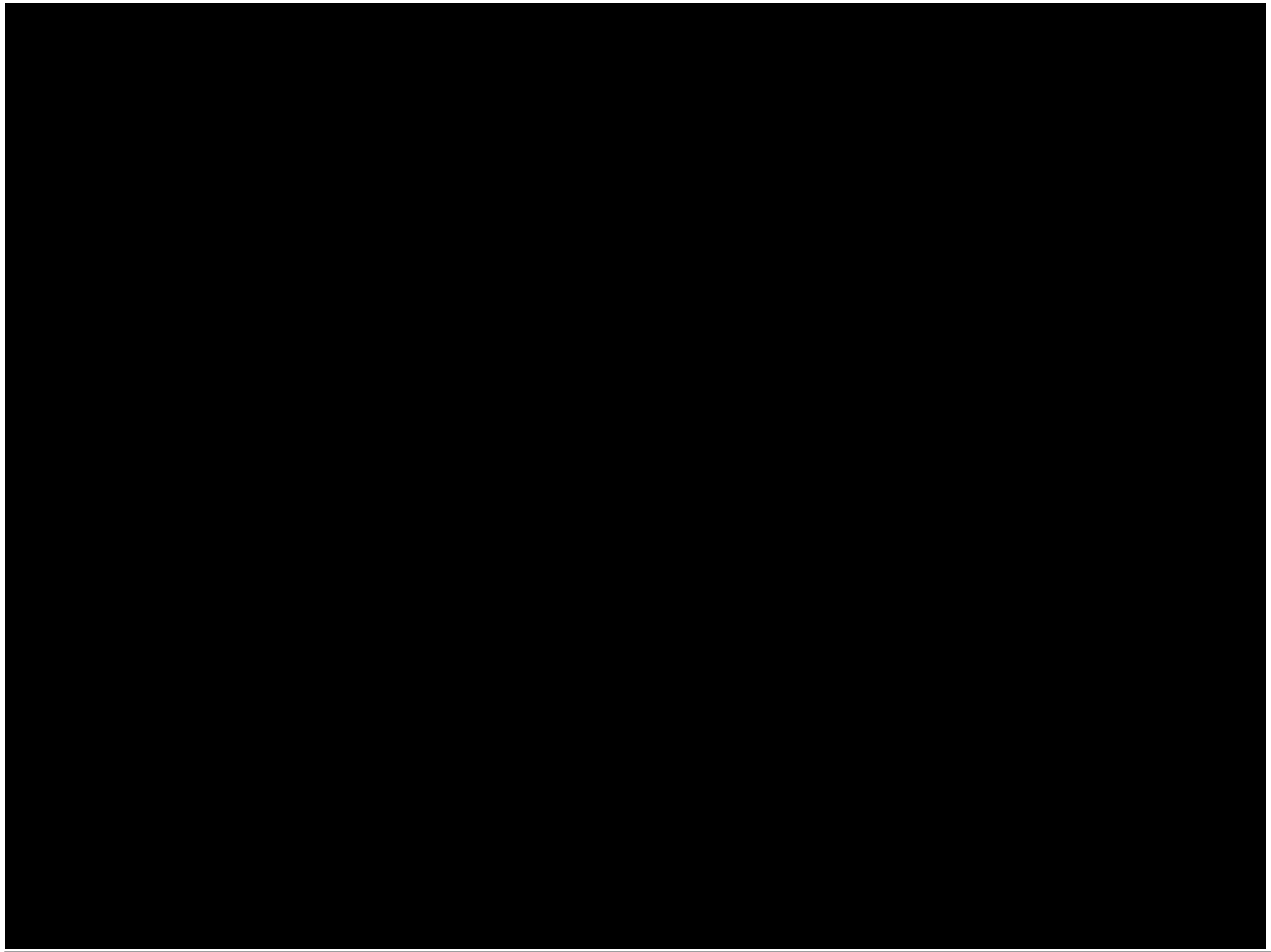
User: Yara, fertilizer producer

Hydrogen Embrittlement

The key issue is the influence of hydrogen ATOMS on the mechanical behaviour of steel.
The following 6 types are known for ferritic steels

1. Metalhydride
2. Hydrogen attack
3. Hydrogen induced cracking
4. Reduction in elongation
5. Reduction in toughness
6. Increased fatigue crack growth rate

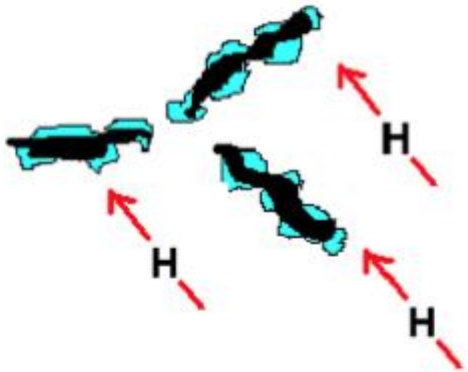
HE: Hydride forming



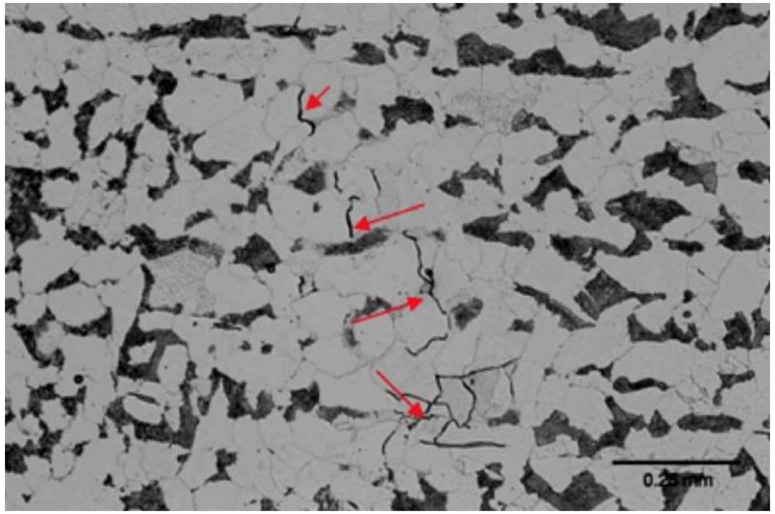
H_2 pipeline: no chemical reaction between hydrogen and iron

HE: Hydrogen attack

CH4 gas pockets (blue)

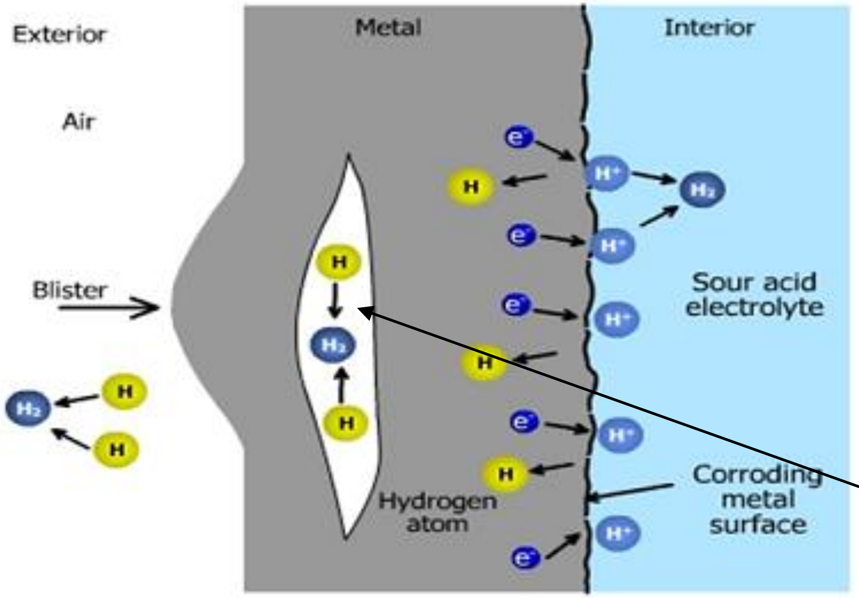


H is driven into the steel by heat & pressure, and reacts with the Fe3C to form CH4 gas



H_2 pipeline: no HA, hydrogen pressure and temperature is too low

HE: Hydrogen-induced cracking recombination of H-atoms in existing defects

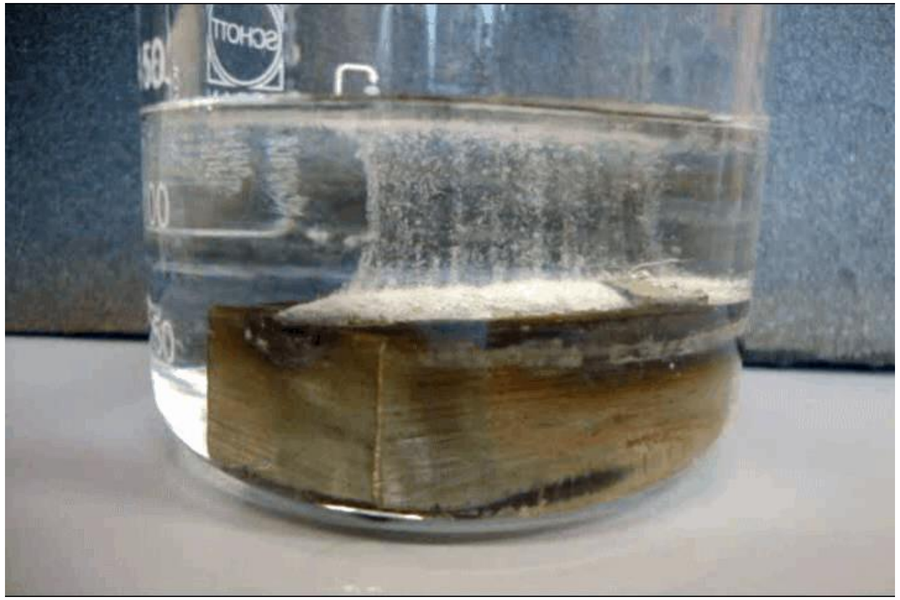


pipe wall

blister

H_2 pipelines: hydrogen pressure is too low

Hydrogen from the weld electrode may cause cold cracking



H_2 pipelines: no cold cracking because hydrogen concentration is too low

Hydrogen concentration in steel source of H:

Hardness limitations B31.12-EIGA 121/14??

Source of hydrogen	Concentration H atoms [atomic ppm]	Equivalent pressure [bar (a)]
3 ml H_2/100 g Welding electrode	150	15000
81 bar H_2	0,25	81
0,01 bar H_2S	14	7100
active CP	56	11000
1 bar H_2S	185	16000
Cathodic charged	650	21000

0,25 atomic ppm H = 1 hydrogen atom on 4 million iron atoms virtual conference „Mannesmann H2ready“ 2021-02-25

Hydrogen Uptake – sample exposure to H_2 gas

SALZGITTER MANNESMANN FORSCHUNG
A Member of the Salzgitter Group

Test parameter to promote hydrogen uptake

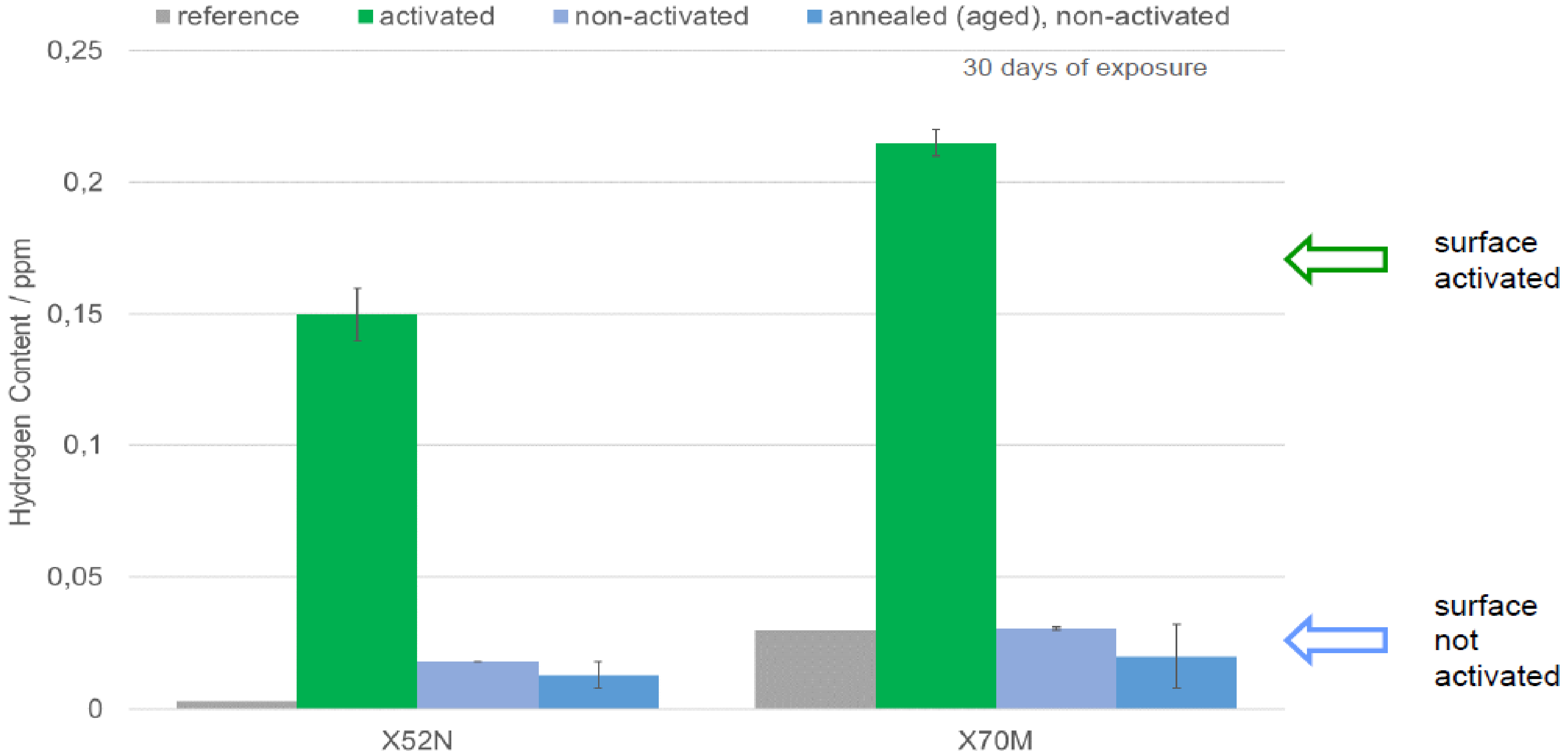
- Hydrogen gas pressure: 100 bar at room temperature
- Preparation of autoklave
  - 10 x evacuation and pressure increase to 10 bar H_2
- Sample surface
  - grinded short-term before test, storage of samples in ethanol until test starts
- Time of exposure
  - 30 days
- Measurement of hydrogen content by carrier gas hot extraction

Test parameters are decisive to obtain a hydrogen uptake

virtual conference „Mannesmann H2ready“ 2021-02-25

Hydrogen Uptake – sample exposure to H_2 gas

SALZGITTER MANNESMANN FORSCHUNG
A Member of the Salzgitter Group



Total hydrogen uptake as expected
in case of activated sample surface only

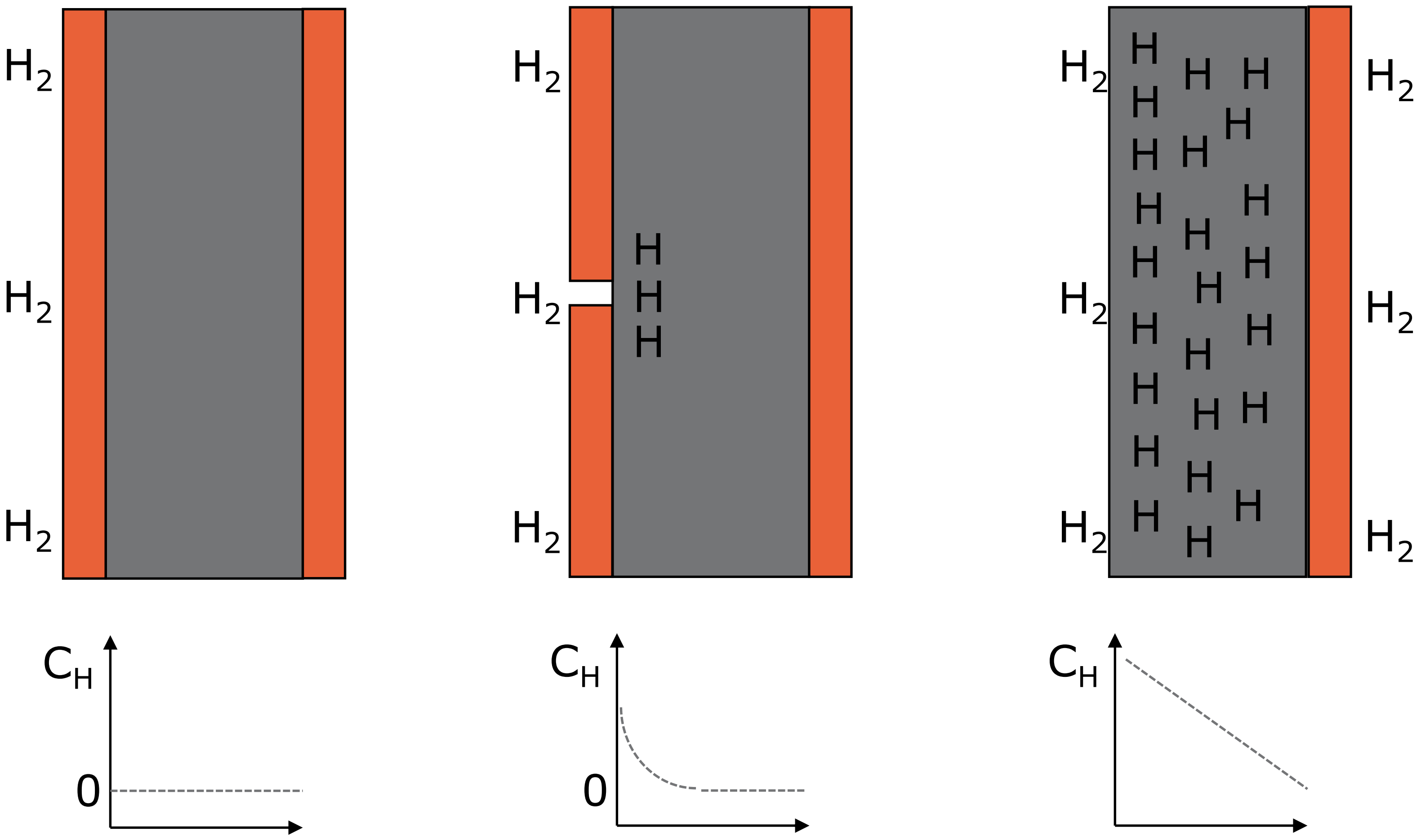
Hindenburg (now in a positive way)

In December 1998, during demolition work, two large hydrogen gas cylinders were found on the premises of a chemical company near Frankfurt, which had been there since the 1930s. From there the zeppelins at Frankfurt Airport were supplied with hydrogen. When gas was no longer needed after the Hindenburg accident in 1937, the two containers had apparently been completely forgotten. They were still full. In the case of metal containers, the problem of diffusion through the container wall is of no practical importance because the speed of this process is much too low. The structure surfaces can be passivated, which prevents the penetration of hydrogen.

https://www.energiedienst.de/fileadmin/energiedienst/Dokumente/Unternehmen/Aktuelle_Projekte/Wasserstoffanalge/Wasserstoff_Kompendium.pdf

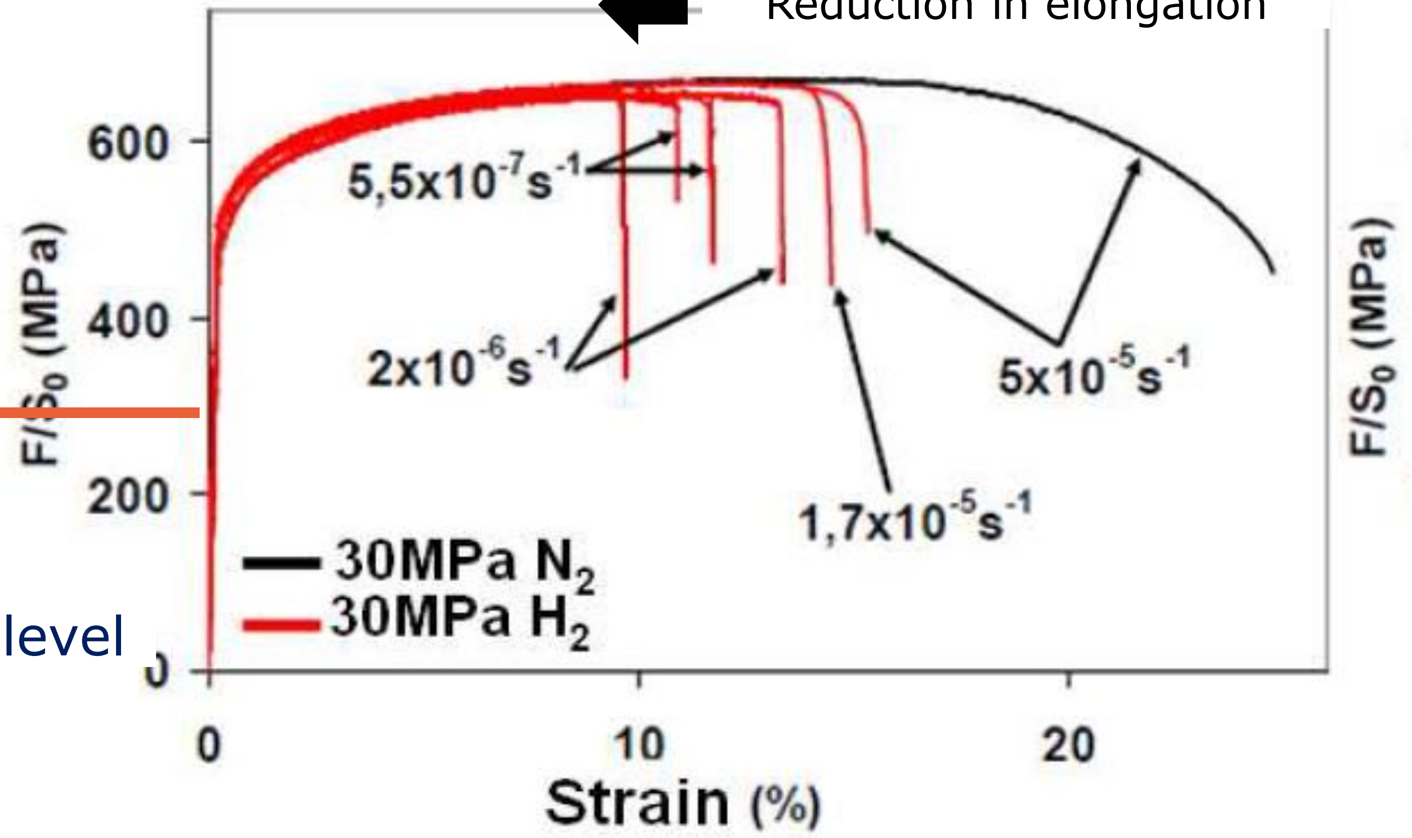
Par 1.4

Absorption of hydrogen atoms in a steel wall
effect of oxide layer



Reduction in Elongation

Reduction in elongation

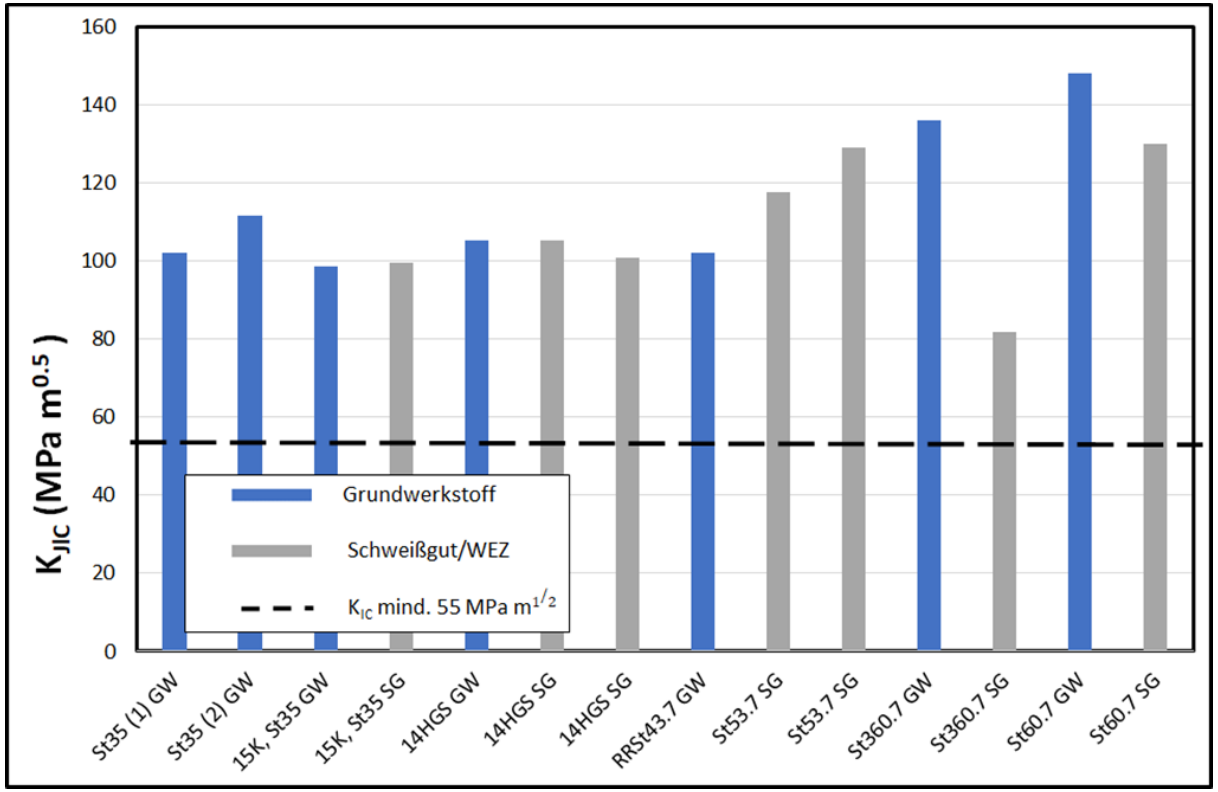


Pipeline Stress level

H_2-pipeline, not applicable in normal operation, stress to low

L. Briottet, I. Moro, P. Lemoine, Quantifying the hydrogen embrittlement of pipe steels for safety considerations, International Conference on Hydrogen Safety, 4th, San Francisco, 2011

Reduction in toughness

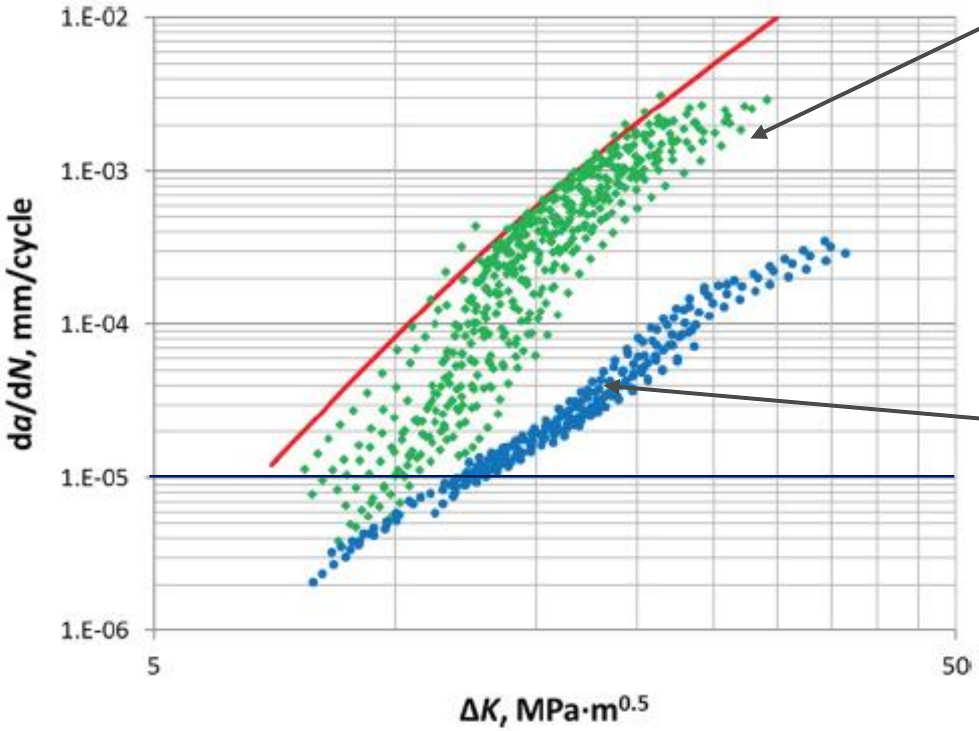


Toughness (K_{JC}) 1930-1975*

H_2-pipeline- no impact, no constant elongation under normal operation

* https://www.dvgw.de/medien/dvgw/forschung/berichte/g202006-sywesth2-steel-dvgw.pdf

Increased fatigue crack growth rate



Hydrogen

0,01 μm/Cycle

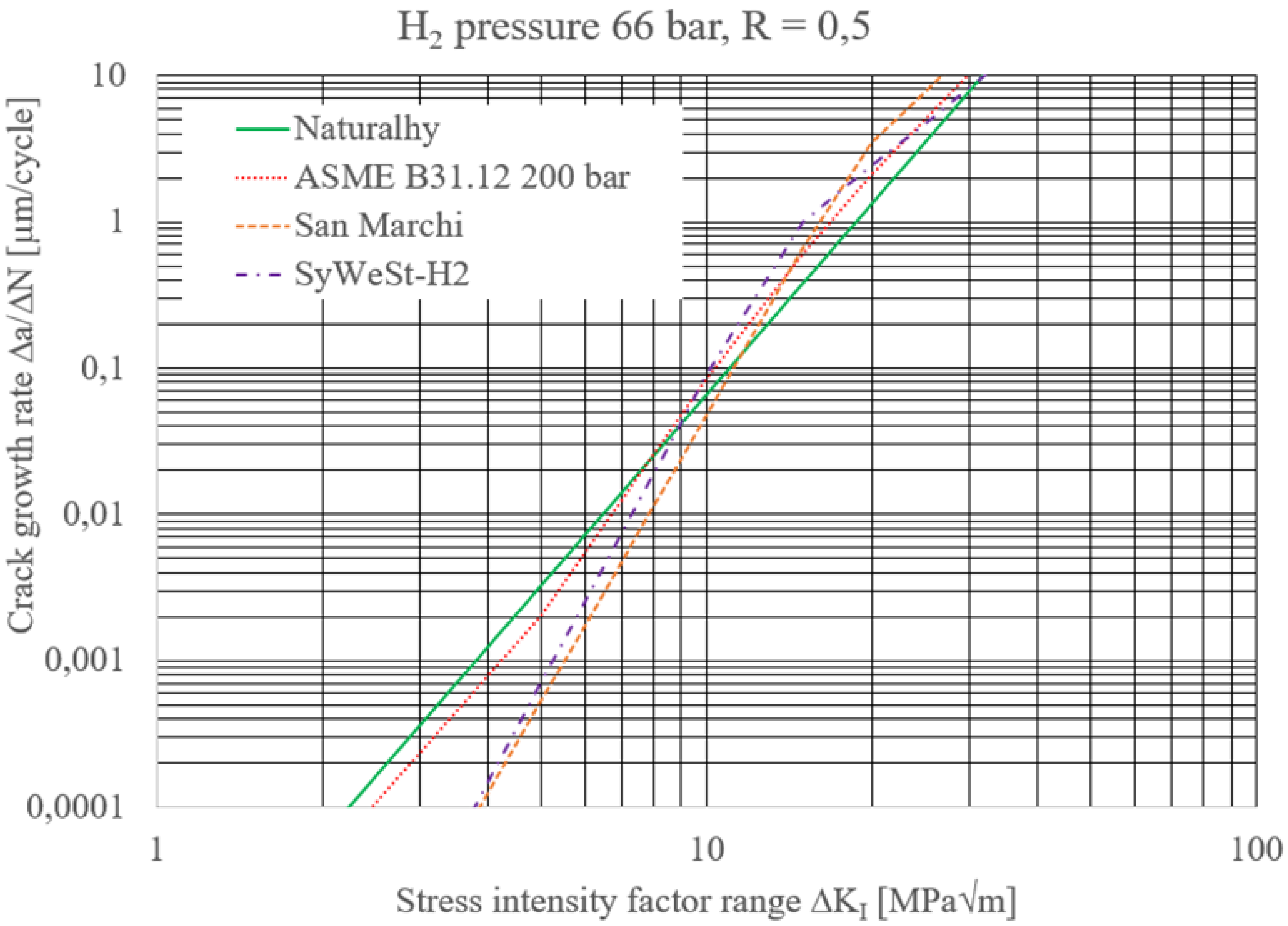
Ai
r

X52=L360, X70=L485
H_2 < 200 bar

A.J. Slifka, Fatigue measurement of pipeline steels for the application of transporting gaseous hydrogen, Journal of Pressure Vessel Technology, 2018

gasunie
crossing borders in energy

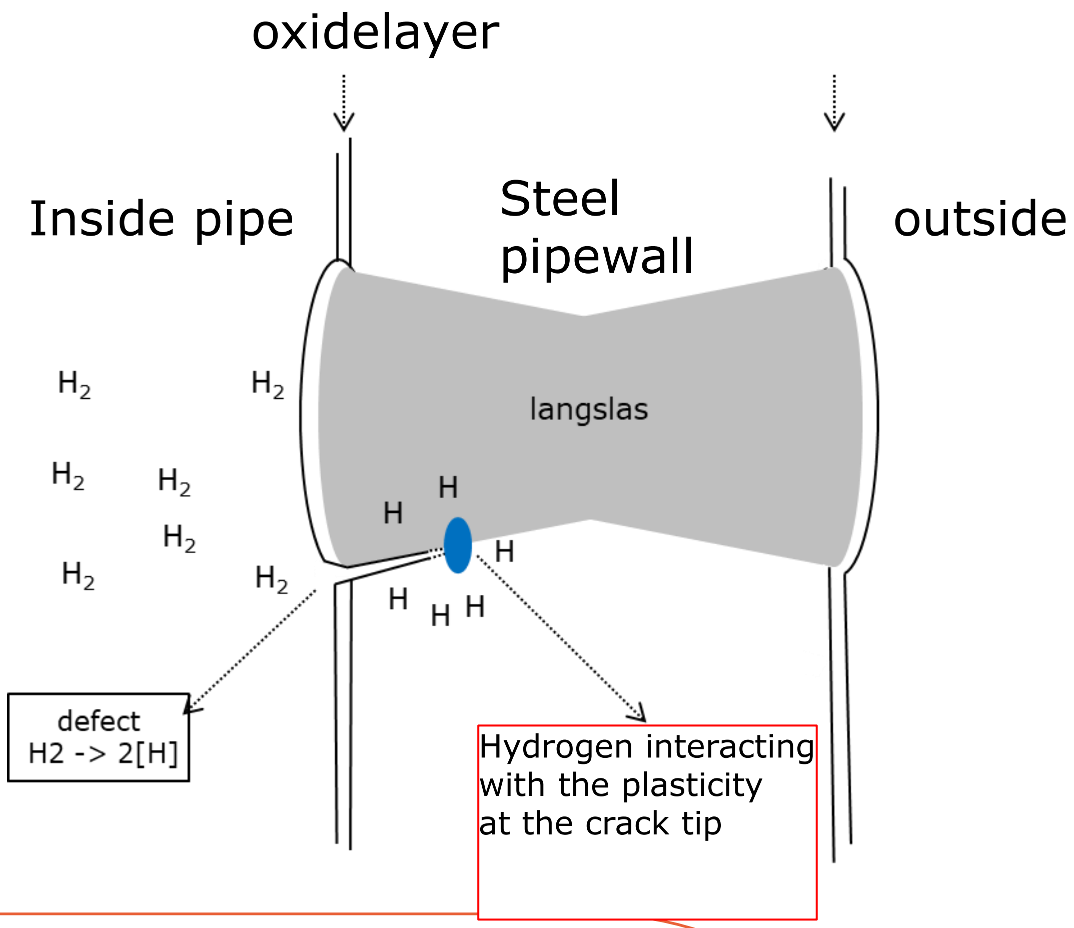
Developed H2 FCG laws*

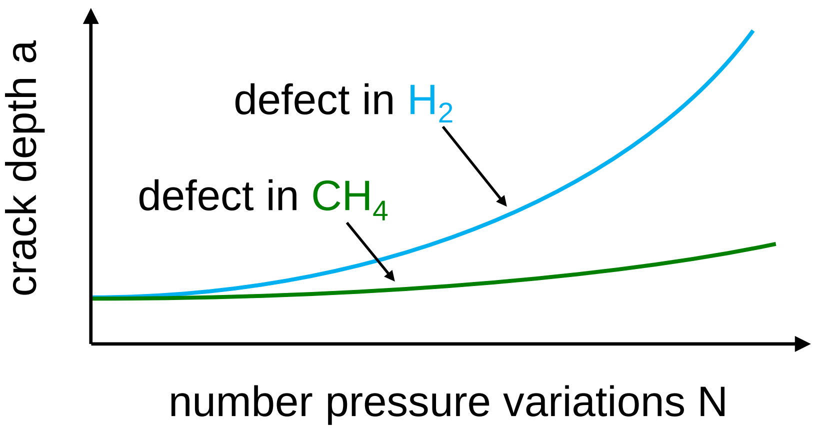


- Naturalhy Gasunie GRTgaz-2003-2006 research
- ASME B31.12
- San Marchi- ASME PVP 2022-84757
- DVGW publication Investigation of Steel Materials for Gas Pipelines and Plants for Assessment of their Suitability with Hydrogen.

* EF 2023-057 Huising et al

Scenario for hydrogen-enhanced fatigue crack growth





The approach for dealing with hydrogen-enhanced fatigue of existing natural gas pipelines

	description	example
1	Set initial defect size	weld defect typically: 3 mm high and 50 mm long
2	the stress intensity factor ΔK of the assumed defect (“crack force”)	see next slide
3	the fatigue load (stress range and number of cycles)	daily pressure variation of 10% of internal pressure
4	the required lifetime of the pipeline	100 year
5	the fatigue crack growth rate at ΔK of the assumed defect in H_2 gas	see next slide
6	the lifetime of the assumed defect	see next slide

Step 2 & 3 crack force ΔK and stress range Δσ assumed defect is 3 by 50 mm in longitudinal pipe weld or girth weld in a X70, 48”, 14,1 mm, 66 bar

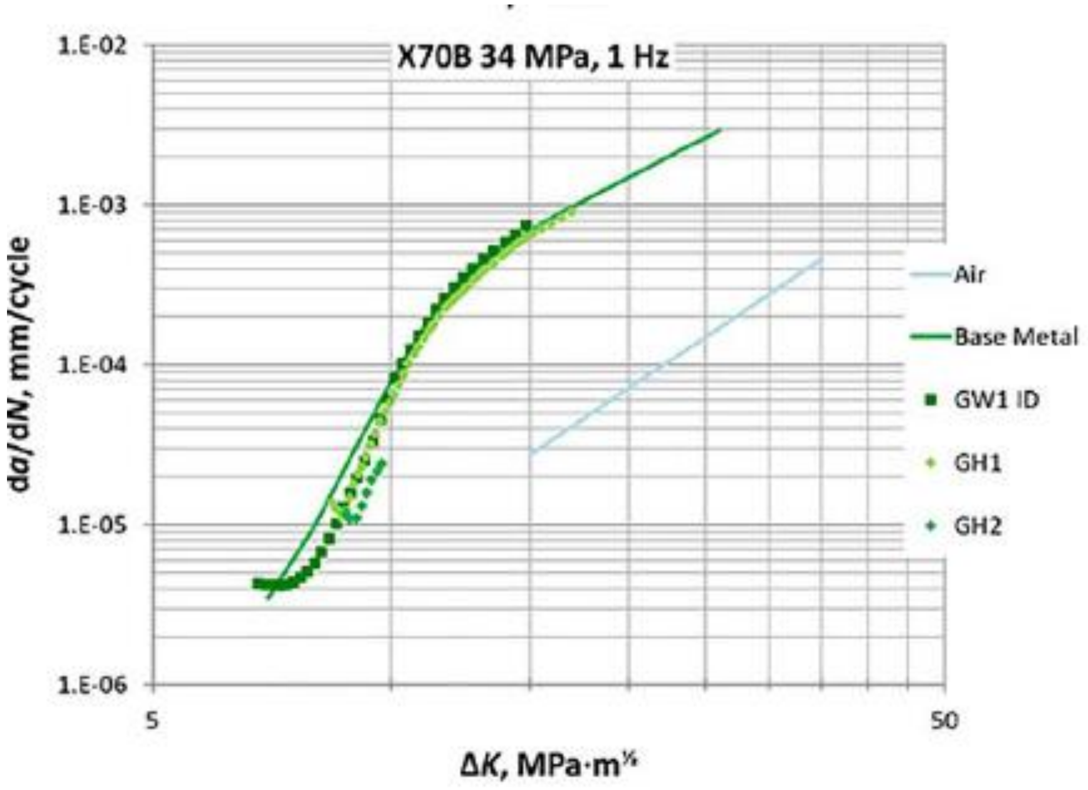
pressure cycle		crack orientation in weld	stress [MPa]	stress range Δσ [MPa]	crack force variation ΔK [MPa√m]
[%]	[bar]				
10	6,6	longitudinal	292	29	**3,4**
		girth	150	15	**1,7**

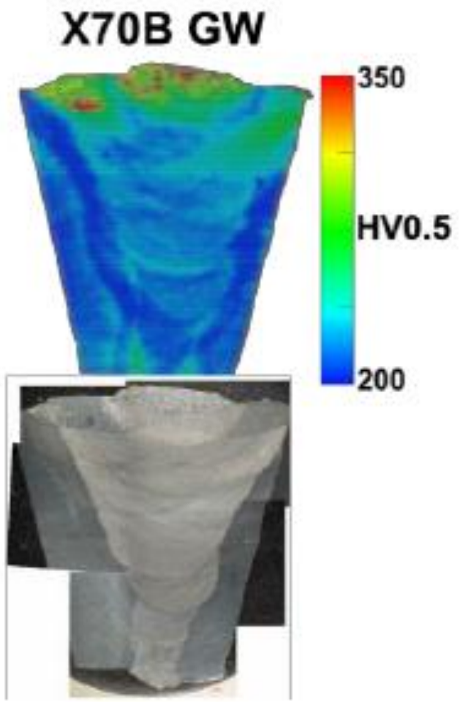
Step 5 & 6 ΔK of the assumed defect in H_2 gas and the crack growth over 100 year

pressure cycle [bar]	crack orientation in weld	crack force variation ΔK [MPa√m]	crack growth rate [mm/cycle]	crack growth 100 year [mm]
6,6	longitudinal	3,4	$< 10^{-5}$	0,012
6,6	girth	1,7	$< 10^{-5}$	0,002

Crack growth is so small over a period of 100 year, 100% H_2 at 66 bar with a daily 10% MAOP cycle does not impose a integrity risk.

Hardness of welds





Journal of Research of the National Institute of Standards and Technology, Volume 124, Article No. 124008 (2019) https://doi.org/10.6028/jres.124.008

Hardness induced Cracking

PAPER NUMBER
186

CORROSION/81

The International Corrosion Forum Sponsored By the National Association of Corrosion Engineers / April 6-10, 1981 / Sheraton Centre, Toronto, Ontario, Canada.

FACTORS AFFECTING THE SULFIDE STRESS CRACKING
RESISTANCE OF STEEL WELDMENTS

A.A. Omar, R.D. Kane and W.K. Boyd

Battelle Houston Operations, Houston, Texas

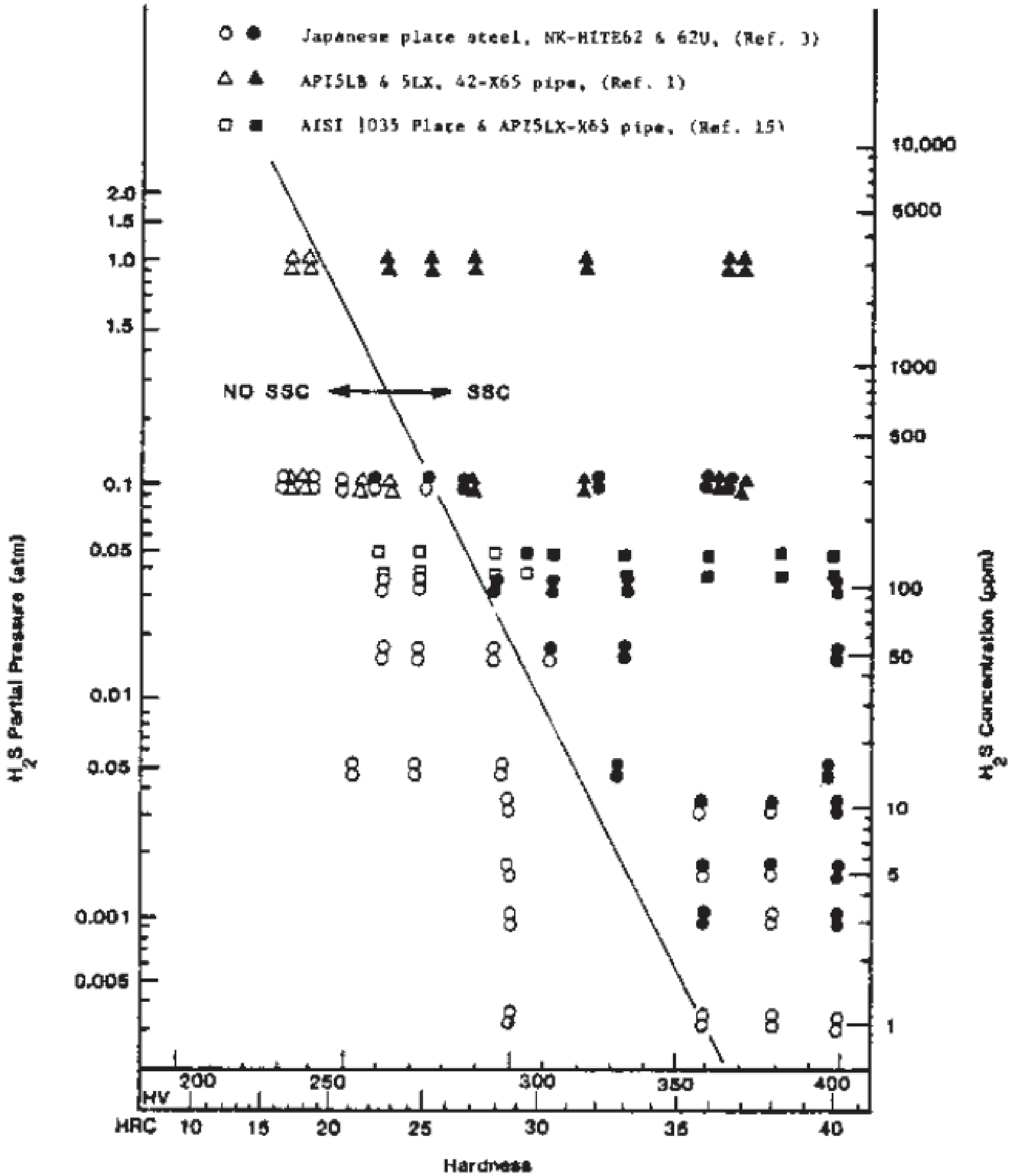


FIGURE 1. RELATION BETWEEN H_2S CONCENTRATION, PARTIAL PRESSURE, AND THE HARDNESS IN THE HAZ.

HyTap


ATEX-Gaslocatie
Verboden toegang voor onbevoegden!
Roken en open vuur verboden
Brandvertragende Antistatische kleding
Veiligheidsbril
Veiligheidshelm
Veiligheidsschoenen
Verboden te fotograferen
Gasdetectie- meter
Verboden te bellen
Gehoorbescherming
Let op !
waterstofleiding
onder druk
gasunie
HYTAP
crossing borders in energy

Conclusion (1/3)

Where hydrogen gas is being transported in pipelines at ambient temperatures and moderate pressures, the relevant hydrogen degradation mechanism is hydrogen-enhanced fatigue crack growth. When taking this degradation mechanism into account, 100% hydrogen gas up to the design pressure can be transported in existing natural gas pipelines without affecting the integrity of the pipeline during its lifetime.

….

Conclusion (2/3)

Though the integrity may not be affected by the hydrogen, it does not mean that hydrogen can actually be transported in the existing pipeline. Hydrogen is a smaller molecule than the methane molecule and the ignition energy is much lower.

Conclusion (3/3)

So before hydrogen can be transported in an existing pipeline the following has to be considered:

- cleanliness of the pipeline
- explosive safety of equipment (ATEX)
- is the leak tightness of existing valves (internal and external) sufficient?
- is the leak tightness of existing flanges sufficient?
- do the risk contours of the pipeline become larger because the risk assessment for hydrogen is different?
- can operational and maintenance activities be performed in a safe manner?


thanks for your attention
danki mèsi nkosi wado saha
zikomo sobodi vinaka mahalo talofa shukran
buznyg dėkoju grassie gràcies matondi
dziekuje stuutiyi misaotra
spas bayarlalaa
arigato obrigada tanmirt tenki
shakkran maururu cheers
gratzias dankewol soolong bedankt
welalin manjuthe meharbani
blagodaria dakujem köszönöm shukria miigwech chokrane shukriyaa grazie
multumesc supas dziakuju dankegon barkal blagodaram
rahmat omol kinisou marahaba yekeniele modupe
gracias danke sađol nandri ngiyabonga dekuji
matondo taiku obrigado
merci spasiba nuhun waybale
aitäh skee tashakor murakoze
paldies trugéré madlobt merkzi tanemirt dankie salamat
tack ahsante sulpáy kiitos aabar takk akiba
manana tänan waita menlau

questions?