HIGGS Closing Conference

21st November 2023 – Brussels EU Hydrogen Week

This project has received funding from the Fuel Cells and Hydrogen 2 Joint Undertaking (now Clean Hydrogen Partnership) under Grant Agreement No. 875091 'HIGGS'. This Joint Undertaking receives support from the European Union's Horizon 2020 Research and Innovation program, Hydrogen Europe and Hydrogen Europe Research.

HIGGS – Project Brochure

- Print version published on 21st of November
- **Can be accessed digitally:** https://higgsproject.eu/higgs-project-brochure/
- **Includes 3 main Topics:**
  - Material and component testing under H_2 atmosphere
  - Techno-economic modelling of repurposing of European gas grids
  - Potentials, barriers and enablers of H_2 injection in Europe
- Includes main **outcomes** and links to **reports**, **publications** and **deliverables**

No.	Topic	Who	Duration
	Welcoming-Breakfast (8:30-9:00)		
TOP1	Introduction to the project Joint Undertaking programm overview and projects on gas grids	Dr. Javier Sánchez Laínez (Aragon Hydrogen Foundation) Dionisis Tsimis (Project Officer Clean hydrogen Partnership)	9:00 - 9:25
TOP2	**<u>Keynote:</u> H_2 suitability of steels (SyWest H_2)** **Behavior of the gas grid to hydrogen admixing. Results of the experimental campaign** Discussion and questions	Tillmann Wiegold (Open Grid Europe) Dr. Virginia Madina (Tecnalia) Dr. Javier Sánchez Laínez (Aragon Hydrogen Foundation) ERIG / Audience	9:25 - 10:25
	Break (10:25-10:55; Coffee)		
TOP3	**<u>Keynote:</u> Growing Hydrogen in the EU** **Technoeconomic validation and modelling, enablers and interoperability considerations** Discussion and questions	René Schutte (Gasunie) Salvatore Oricchio (Eastern Switzerland University of Applied Sciences) ERIG / Audience	10:55 - 11:55
TOP4	**<u>Keynote:</u> Perspectives on Hydrogen in the EU** **Pathway towards integrating H_2 in EU gas networks** Discussion and questions	Alberto Cerezo Alarcón (Redexis) Dr. Michael Walter (DVGW German Technical and Scientific Association for Gas and Water) ERIG / Audience	11:55 - 12:55
TOP5	Closing	Dr. Javier Sánchez Laínez (FHA)	12:55-13:00

Hydrogen in Gas Grids

Introduction to the project

Closing event — 21st November 2023

Dr. Javier Sánchez Laínez
Coordinator of the hydrogen conditioning and transport – I+D

Aragon Hydrogen Foundation (FHa), SPAIN

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Project information

- **Name**: Hydrogen In Gas GridS: a systematic validation approach at various admixture levels into high-pressure grids
- **Acronym**: HIGGS
- **Call**:H2020 HORIZON FCH 02-5-2019: Systematic validation of the ability to inject hydrogen at various admixture level into high-pressure gas networks in operational conditions.
- **Starting date**: 01/01/2020
- **End date**: 31/12/2023
- **Type of action**: HORIZON-JU-RIA HORIZON JU Research and Innovation Actions
- **Total funding**: € 2,107,672.50 €
- **EU contribution**: 100 %

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Our Team

- Aragon Hydrogen Foundation (SPAIN)
- German Technical and Scientific Association for Gas and Water (GERMANY)
- Eastern Switzerland University of Applied Sciences (SWITZERLAND)
- Natural Gas Transmission System Operator (TSO) (SPAIN)
- tecnalia – MEMBER OF BASQUE RESEARCH & TECHNOLOGY ALLIANCE
- European Research Institute for Gas and Energy Innovation (Europe)

Goal

HIGGS project aims to pave the way to **decarbonisation of the gas grid** and its usage, by **covering the gaps of knowledge of the impact** that high levels **of hydrogen** could have **on the gas infrastructure**, its components and its management.

Project overview

HIGGS
Hydrogen in Gas Grids

WP1: Management and coordination

WP2 - Legal, regulatory and technical aspects: identification and follow-up

- Present regulations, standardizations and certifications (RSC) in EU regarding hydrogen concentrations in the gas system
- State-of-art of the current grid infrastructure

WP3 - Design, preparation and commissioning of testing facilities

- Admixture system to achieve hydrogen blends at high pressure
- Testing facility to study the impact of hydrogen on materials, components and equipment of the grid

WP5 - Techno-economic modelling and validation, enablers and interoperability

- Numerical model to describe technical operation and business impacts on high-pressure grids.
- Different hydrogen levels w/ or w/o membranes

WP4 - Systematic and experimental validation

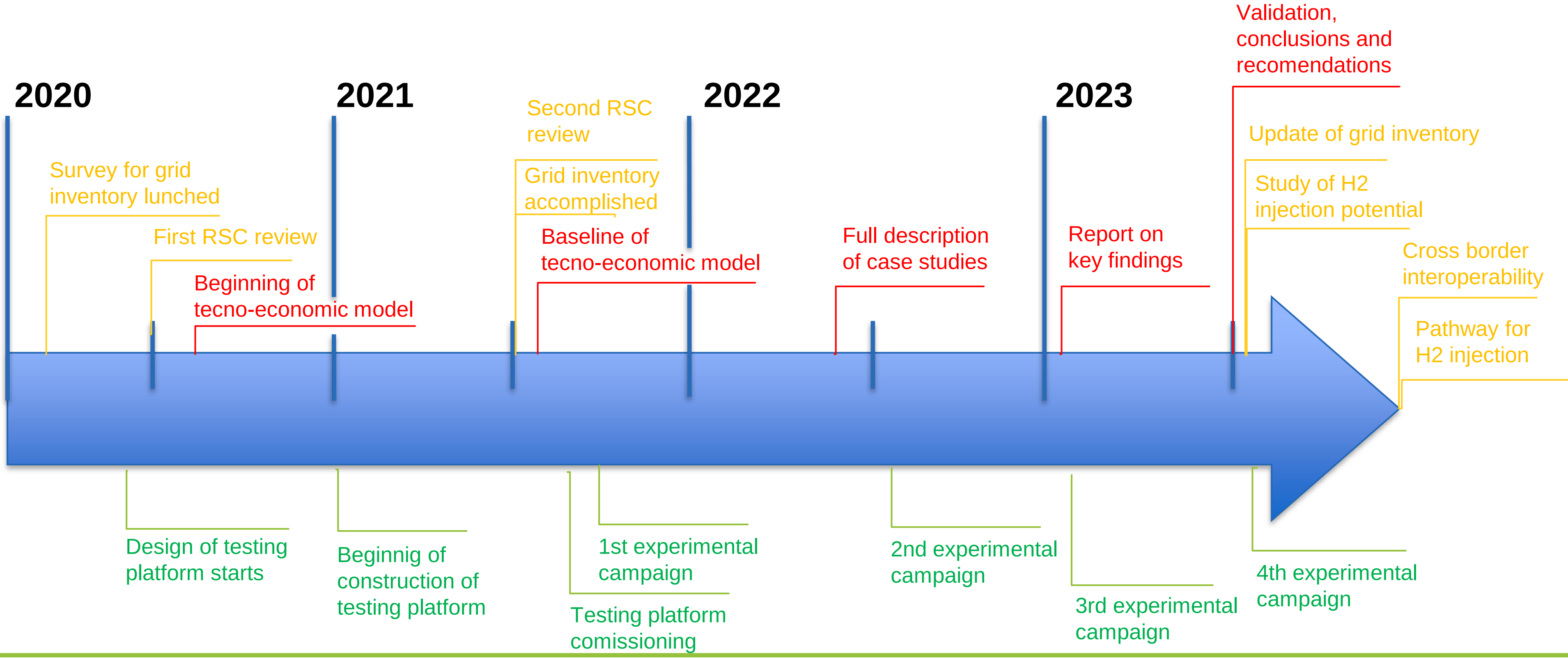
- Operation of the testing facility
- Hydrogen embrittlement lab test
- H_2/CH_4 separation with membrane prototype

WP6 - Description of pathway towards integrating H2 in EU gas networks

- Potential of hydrogen injection as enabler towards EU policies on decarbonisation.
- Study cross-border and interoperability in the gas grids.
- Updating the RCSs for further acceptance of hydrogen in the gas grid.

WP7: Communication, dissemination, exploitation

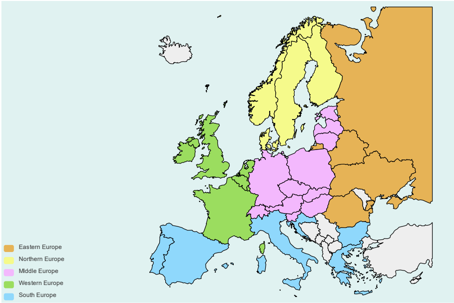
Timeline

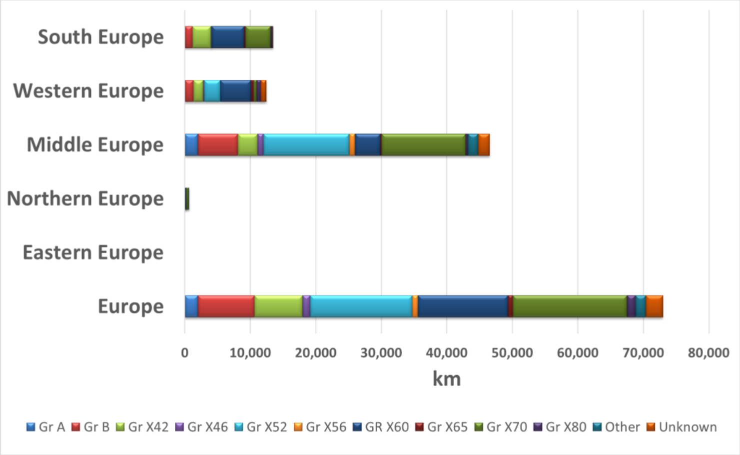


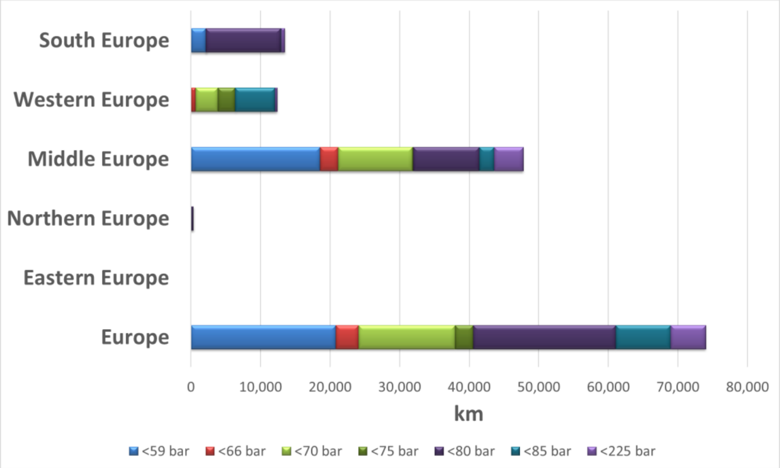
2020
2021
2022
2023
Survey for grid inventory lunched
First RSC review
Beginning of tecno-economic model
Design of testing platform starts
Beginnig of construction of testing platform
Second RSC review
Grid inventory accomplished
Baseline of tecno-economic model
Testing platform comissioning
1st experimental campaign
Full description of case studies
2nd experimental campaign
Report on key findings
3rd experimental campaign
Validation, conclusions and recomendations
Update of grid inventory
Study of H2 injection potential
Cross border interoperability
Pathway for H2 injection
4th experimental campaign

WP2 - Legal, regulatory and technical aspects: identification and follow-up

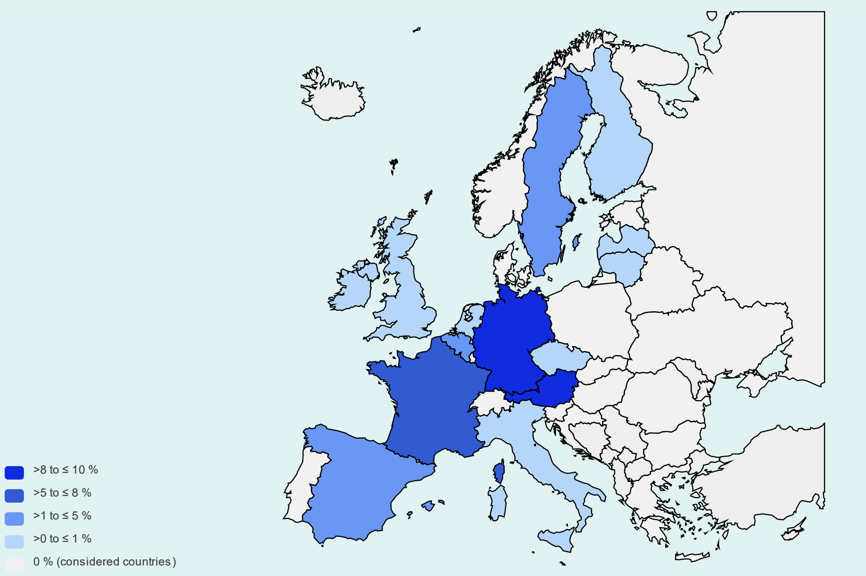
Cluster	South Europe	Western Europe	Middle Europe	Northern Europe	Eastern Europe	TOTAL
km public	65,640.57	52,648.60	74,270.66	10,758.00	51,430.00	254,747.83
km surveys	13,361.00	12,446.10	46,545.88	628.46	-	72,981.44
% covered	20%	24%	63%	6%	0%	29%







National framework of European countries



Allowed concentration of hydrogen in transmission grids

European technical framework

- Standards for gas transmission grids
- Relevant CEN and CENELEC Technical Committees and Sector Fora
- EC-CEN Pre-normative studies and request
- Testing methods for hydrogen tolerance

European standards for gas transmission grids

Standard reference	Title	Current version	Responsible TC
Gas quality standards			
EN 16723-1	Natural gas and biomethane for use in transport and biomethane for injection in the natural gas network - Part 1: Specifications for biomethane for injection in the natural gas network	2016	CEN/TC 408
EN 16726*	Gas infrastructure - Quality of gas - Group H	2015/ 2018	CEN/TC 234
prEN xxxx WI 00234096*	Gas infrastructure – Quality of gas – Hydrogen used in converted/rededicated gas systems	project stage	CEN/TC 234
EN ISO 6145*, parts 1, 4 to 11	Gas analysis - Preparation of calibration gas mixtures using dynamic volumetric methods	2008-2019	CEN/TC 238 – ISO/TC 158
EN ISO 6974* parts 1 to 5	Natural gas – Determination of composition and associated uncertainty by gas chromatography	2001-2014	CEN/TC 238 – ISO/TC 197

WP3 - Design, preparation and commissioning of testing facilities

HIGGS Hydrogen in Gas Grids

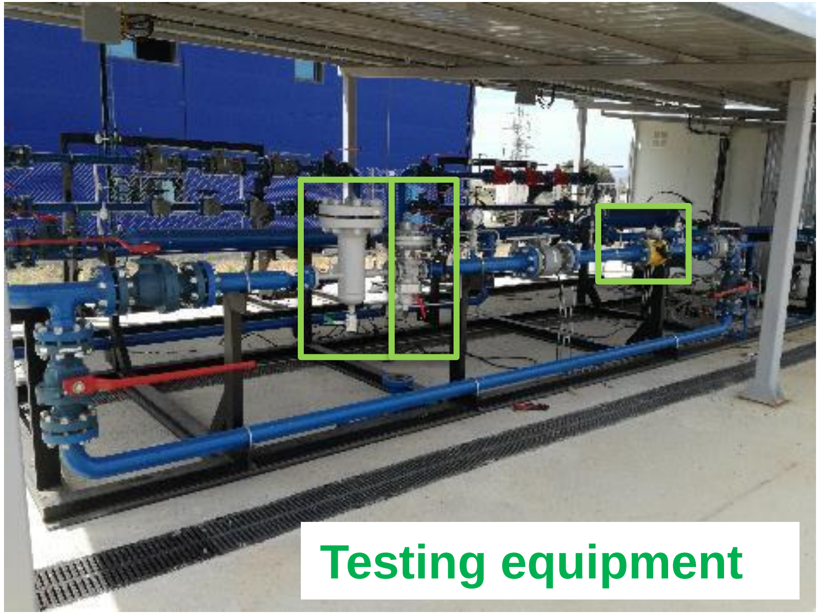
Testing platform
Exposure of testing materials

Purification prototype
H_2/CH_4 deblending at high pressure with membrane technology

Admixture system
Blending electrolytic hydrogen with “simplified” natural gas and injection at high pressure

WP3 - Design, preparation and commissioning of testing facilities

Tests on transport facilities



WP3 - Design, preparation and commissioning of testing facilities

Tests on pipelines

Welded pipes

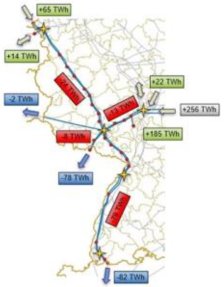
Constant strained specimens

- C-ring specimens
- 4-point bend specimens
- CT-WOL specimens

Hydrogen in Gas Grids

The TENP-MEGAL intersection

Pure natural gas “as-is”

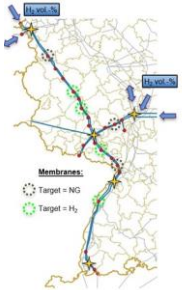


Premixed H2/NG blends at model inlets

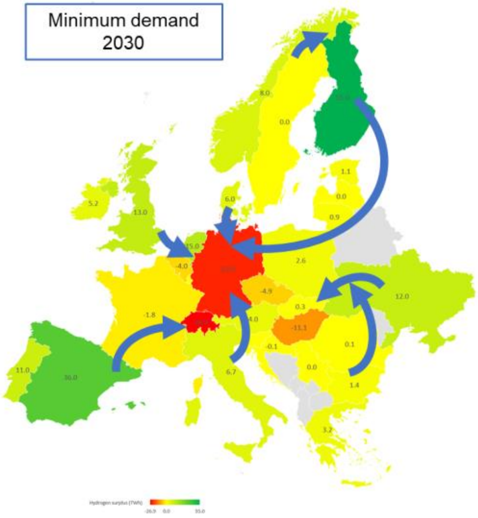
Locally injected hydrogen

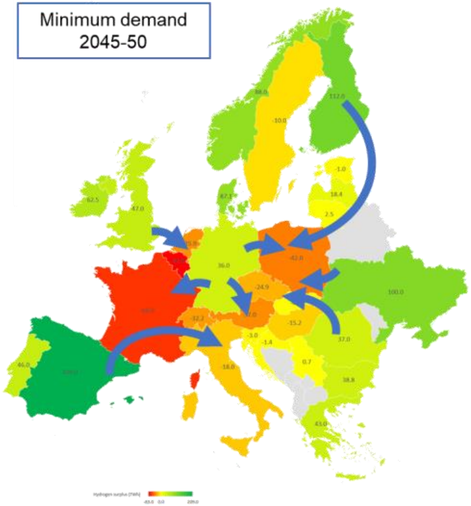
Membrane technology for hydrogen recovery

Technology diversification



WP6 - Description of pathway towards integrating H2 in EU gas networks





Coming soon…

- Design of injection station
- Interoperability, cross-border issues and gas market management and strategies
- Gas market and operation conditions for transmission grids
- Project findings with relevance for standardization of H2 in gas transmission grids

HIGGS

Hydrogen in Gas Grids

Thanks for your attention!

FOUNDATION FOR THE DEVELOPMENT OF NEW HYDROGEN TECHNOLOGIES IN ARAGON
DVGW
OST Ostschweizer Fachhochschule
Redexis
tecnalia Inspiring Business
ERIG

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Clean Hydrogen Partnership

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HIGGS Final Event
21/11/2023

European
Hydrogen
Week

D.Tsimis

Project Officer

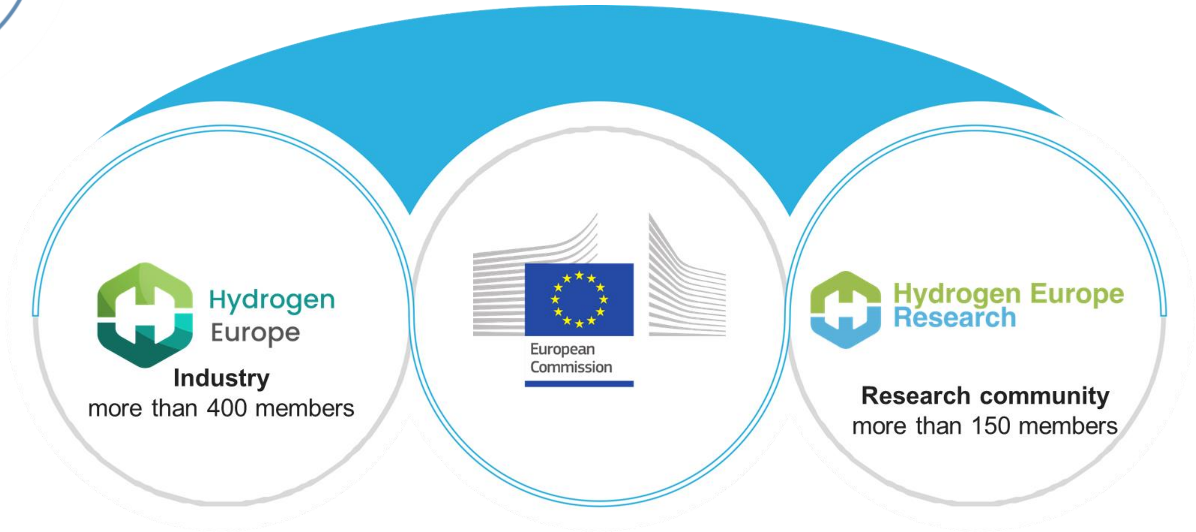
Clean Hydrogen Partnership

EUROPEAN PARTNERSHIP

Co-funded by the European Union

Clean Hydrogen Joint Undertaking

EU Institutional Public-Private Partnership (iPPP)

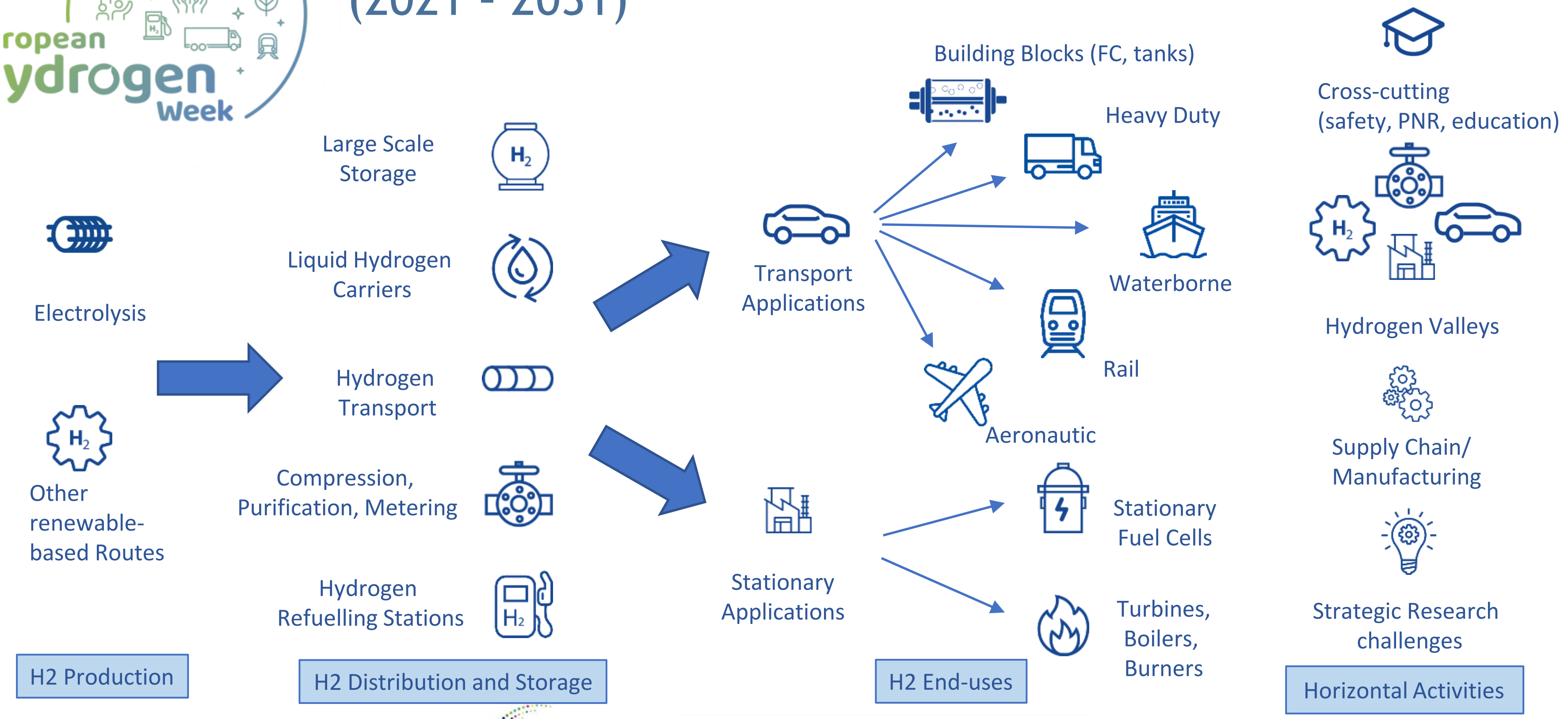


1 billion EURO from Horizon Europe* to implement R&I activities and facilitate the transition to a greener EU society through the development of hydrogen technologies

*** additional 200 million EURO** for Hydrogen valleys (under RePowerEU)

European Hydrogen Week

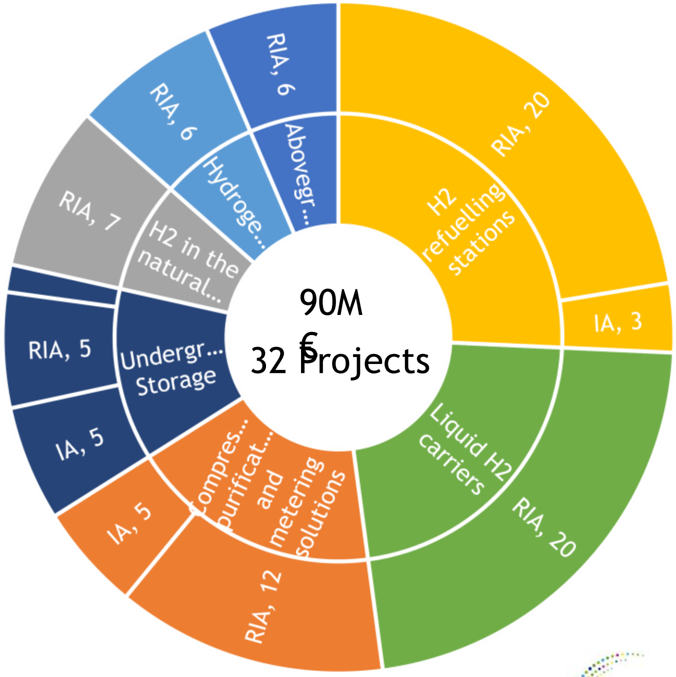
Strategic Research & Innovation Activities, SRIA (2021 – 2031)

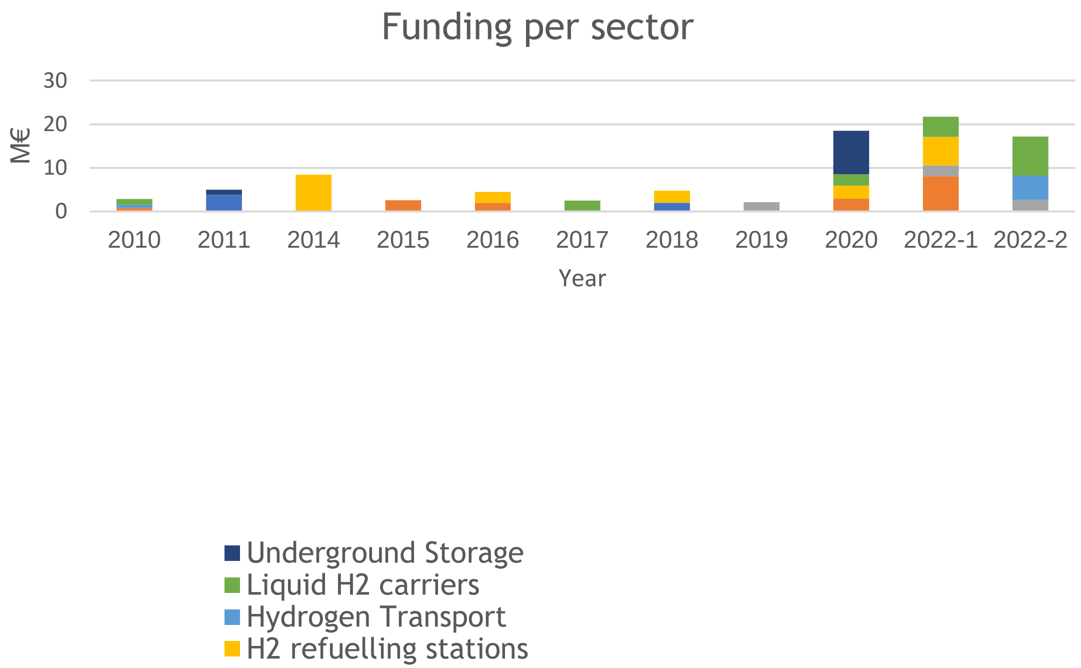


Clean Hydrogen Partnership
EUROPEAN PARTNERSHIP
Co-funded by the European Union

Hydrogen Storage and Distribution

Gaining traction within the program





Clean Hydrogen Partnership
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European Hydrogen

Hydrogen in the gas grid

Facilitating the formation of the backbone of a pan-European grid where the existing gas grid could be partially re-purposed

2019 HIGGS Hydrogen in Gas Grids

- 2 experimental campaigns run
- Effects of hydrogen on API 5L steels, valves etc
- High pressure testing platform
- Blends up to 20%H_2,30% and 100% H_2

2022 OPTHYCS

New sensor to be tested in:
- Pure and blended H_2
- Pipelines
- HRS
- Natural gas wells

2022

- Impact of 100% H_2 on non-steel metallic
- Focusing on low pressure distribution <16 bar
- Results will be fed to a publicly available database

2023

- Select steel specimens that cover >70% of the EU grid
- Impact of 100% H_2 on these components
- Harmonized testing protocols
- Results will be fed to a publicly available database

Clean Hydrogen Partnership EUROPEAN PARTNERSHIP Co-funded by the European Union

HIGGS – Project Brochure

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- **Includes 3 main Topics:**
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TOP5	Closing	Dr. Javier Sánchez Laínez (FHA)	12:55-13:00
*Break (13:00-14:00; Business Lunch together with the **Hydrogen Europe Research General Assembly**)*			

H_2 suitability of steels (SyWeSt H_2)

HIGGS Closing Conference
Tillmann Wiegold
21.11.2023

OGE

Why to create a DVGW-standard for fracture-mechanical assessment?

Design of Gas Pipelines acc. to DVGW G 463

- Barlow formula acc. to EN 1594 (S min. 1.6)
- Linepipes acc. to EN ISO 3183
- Toughness requirements acc. to EPRG recom.
- Additional for H2-Transport: Annex C

Conversion acc. to DVGW G 409

- ….
- ….
-


H2-dvgw.de
DVGW REGELWERK

Technical Rule – Standard
DVGW G 463 (A) October 2021

High Pressure Gas Steel Pipelines for a Design Pressure of more than 16 bar; Design and Construction

Gashochdruckleitungen aus Stahlrohren für einen Auslegungsdruck von mehr als 16 bar; Planung und Errichtung

H₂ Ready
GAS


DVGW REGELWERK

Technischer Hinweis – Merkblatt
DVGW G 409 (M) September 2020

Umstellung von Gashochdruckleitungen aus Stahlrohren für einen Auslegungsdruck von mehr als 16 bar für den Transport von Wasserstoff

Conversion of High Pressure Gas Steel Pipelines for a Design Pressure of more than 16 bar for Transportation of Hydrogen

GAS


H2-dvgw.de
DVGW REGELWERK

Technischer Hinweis – Merkblatt
DVGW G 464 (M) März 2023

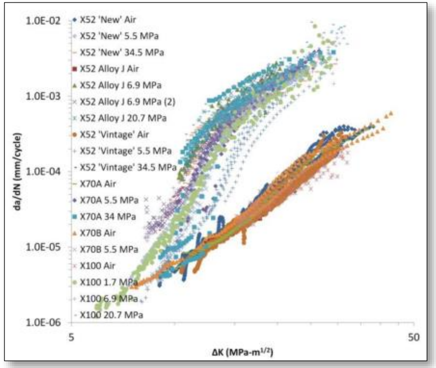
Bruchmechanisches Bewertungskonzept für Gasleitungen aus Stahl mit einem Auslegungsdruck von mehr als 16 bar für den Transport von Wasserstoff

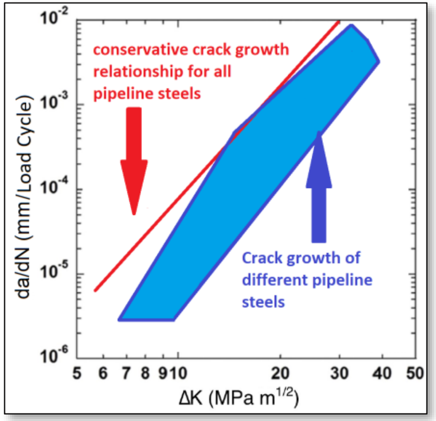
Fracture-Mechanical Assessment Concept for Steel Pipelines with a Design Pressure of more than 16 bar for the Transport of Hydrogen

H₂ Ready
GAS

Tasks of the DVGW-research project SyWeSt H_2

- Examination of commonly used steel materials for hydrogen suitability according to ASME B 31.12 (2019)
- Testing of pipeline steels - approx. 200 tests including characterization of the material (chem. analysis, mechanic-technological data, hardness testing of welds)
- Validation of the ASME crack growth relationship for steels typically used for implementation in the German DVGW regulations



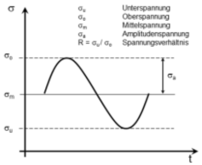


Source: Amaro et al.; EVELOPMENT OF AN ENGINEERING-BASED HYDROGEN-ASSISTED FATIGUE CRACK GROWTH DESIGN METHODOLOGY FOR CODE IMPLEMENTATION; Proceedings of the ASME 2014 Pressure Vessels & Piping Conference PVP2014, July 20-24, 2014, Anaheim, California, USA

SyWeSt H_2 - **test program**

Coverage of the samples

- 207 Tests:
  - **Crack growth (da/dN) acc. ASTM E 647-13a**
    (How fast is a crack?)
  - **K_{IC} / K_{JIC} acc. to ASTM E 1820**
    (When does a crack fail?)
- Different steel grades for pipes, valves, fittings
- Production time 1930 until today
- Base material, weld, heat affected zone
- Different test parameters for:
  - Hydrogen pressure
  - Mean stress
    R-Value ($R = \sigma_u/\sigma_o$)

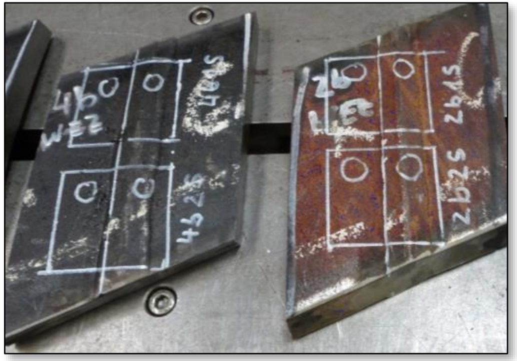


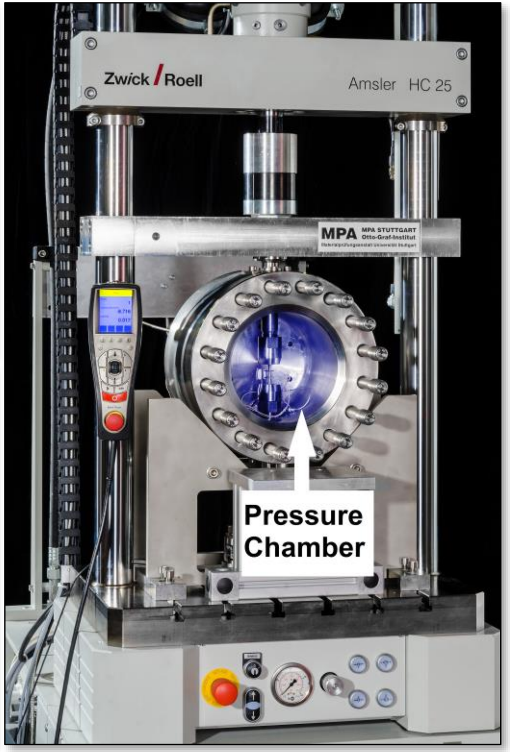
Material	Testing da/dN & K_{IC}	H_2 Test pressure [bar]	R-value
L290 NE	BM, SAWL	100	0.5
Grade A	BM, SAWL		
St35	BM		
15 k (St.35)	BM, SAWL, GW		
X42	BM, ERW, GW, HAZ		
RR St 43.7	BM		
P355 NH	BM		
L360 NE	BM		
StE 360.7	SAWL, BM		
L360 NB	SAWL BM		
14 HGS	BM, LW, GW		
TStE 355 N	BM		
WSTE 420	BM		
St53.7	GW, BM		
X56.7	BM, SAWL, GW		
St60.7	BM, GW		
P 460 NH	SAWL, BM		
X70	BM, SAWH, HAZ		
X70	BM, GW, HAZ		
L485	BM, SAWH, HAZ		
GRS550/X80	BM, SAWL		
L485 (HV high/low)	BM, GW, HAZ		
L415 (curve)	BM, SAWL		
P355 NL1 (Valve)	BM		
GJS 400 (Valve)	BM		
C22.3 (Valve)	BM		
GS C25 N (Valve)	BM		
P460 QL1 (Valve)	BM		
St35	BM	0 / 0.2 / 1 / 2 / 5 / 10 / 20 / 100	
L485	BM		
L360 NB	BM, WM	10 / 100	
StE 320.7	BM, GW		
StE 480.7 TM	BM, SAWL, GW		
L485	BM	100	0.1 / 0.5 / 0.7
L360	BM		

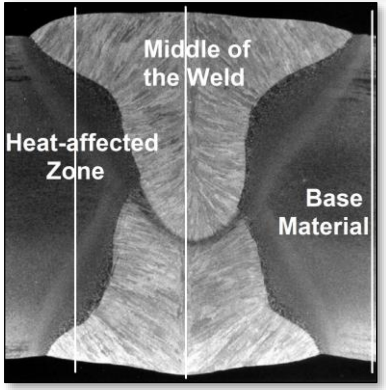
Legend

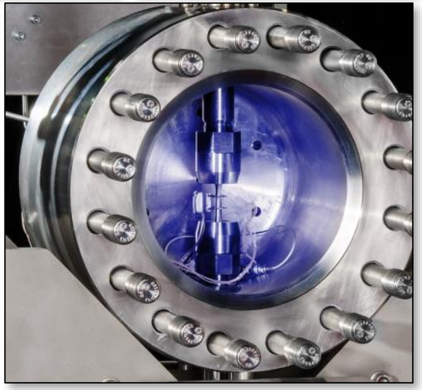
da/dN	Crack growth
K_{IC}	Fracture toughness
BM	Base material
HAZ	Heat-affected zone
SAWL	Submerged arc longitudinal weld
SAWH	Submerged arc spiral weld
ERW	Electric Resistance Weld
GW	Girth weld
LW	Longitudinal weld
WM	Weld material

Production of samples and testing at MPA Stuttgart



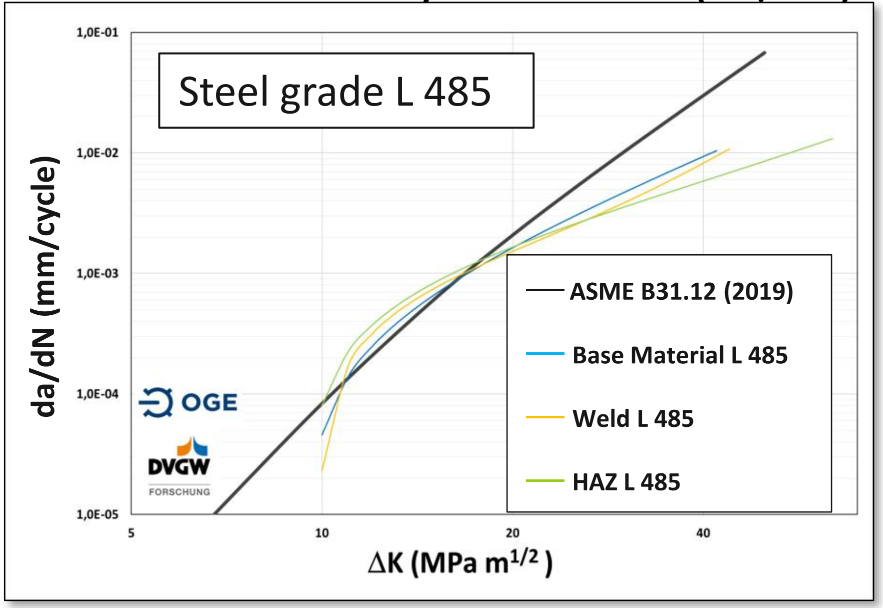


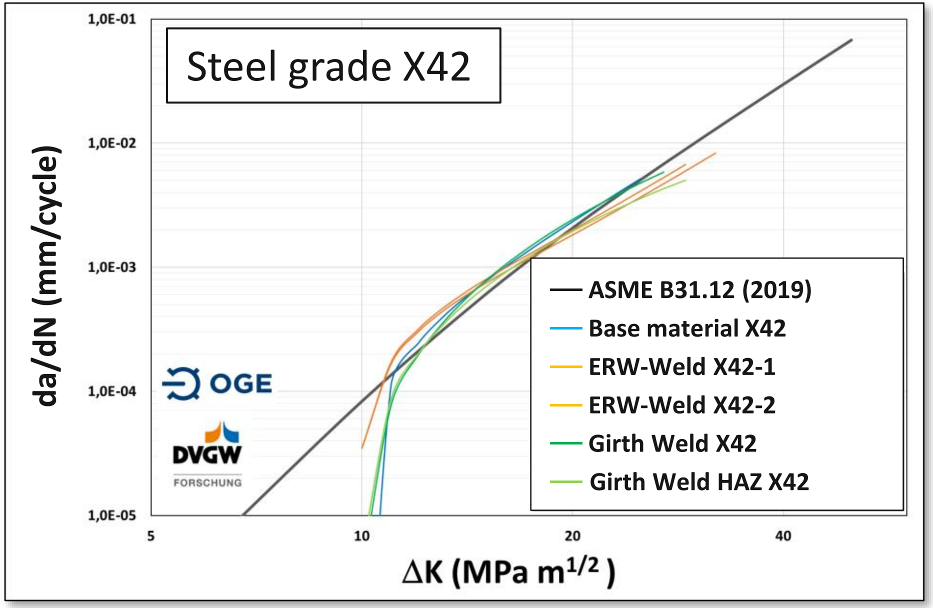




Source: MPA Stuttgart

Results of the dynamic tests (da/dN)





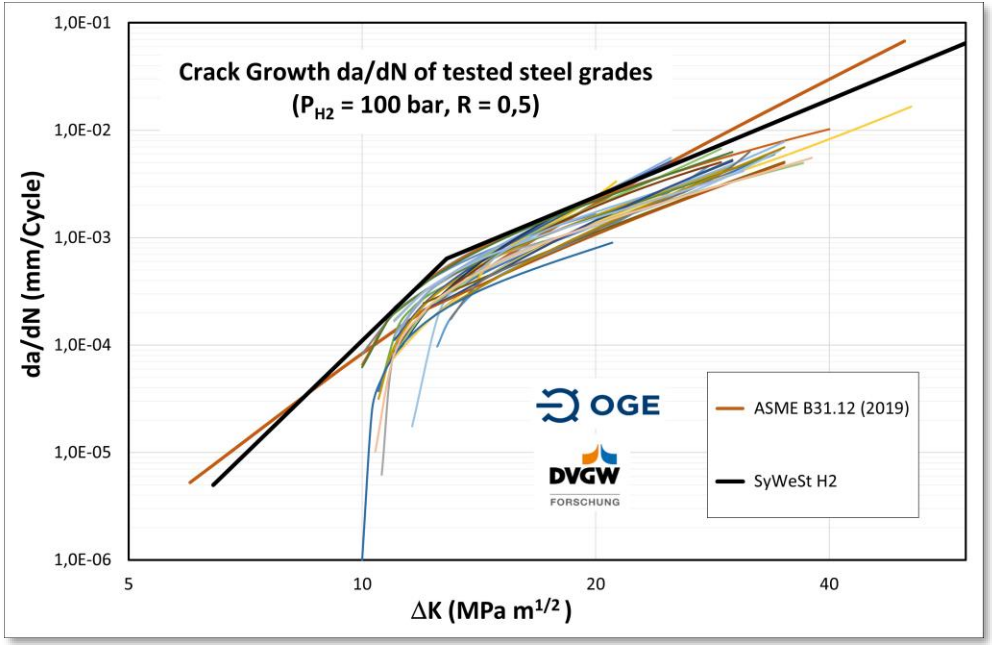
No relevant scatter of test results for

- different microstructures (base metal, weld seam, HAZ)
- different pipe materials

Results of the dynamic tests (da/dN)

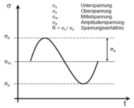
Result for all typical pipeline steels

- Crack growth confirmed acc. to ASME B 31.12
- Bilinear curve more conservative

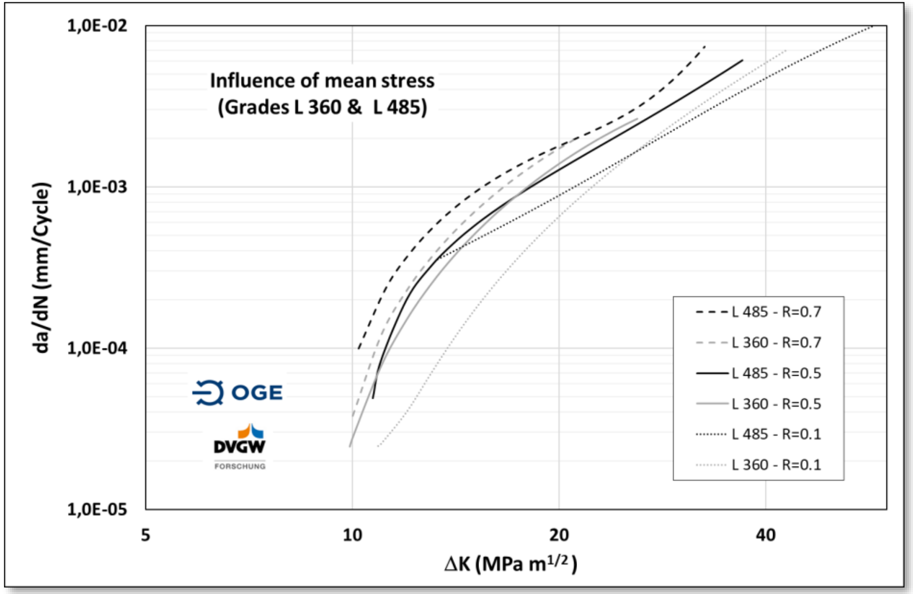


Influence of the mean stress (R-value) on da/dN

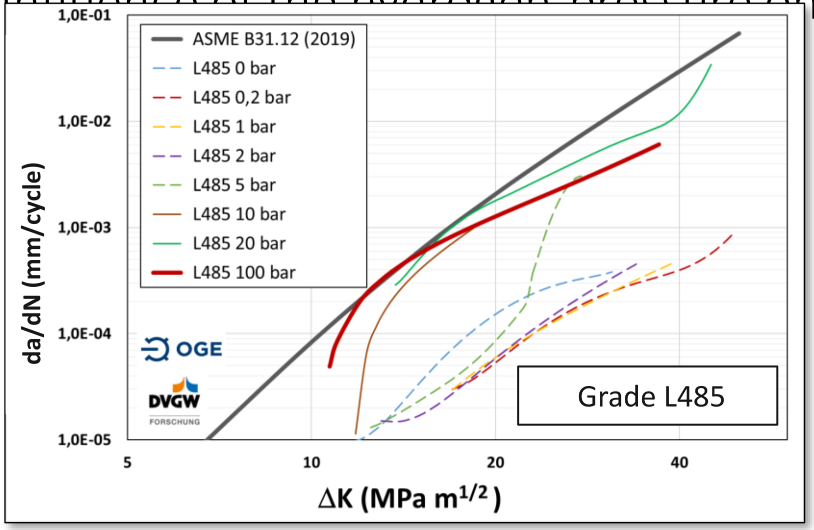
For small R-values

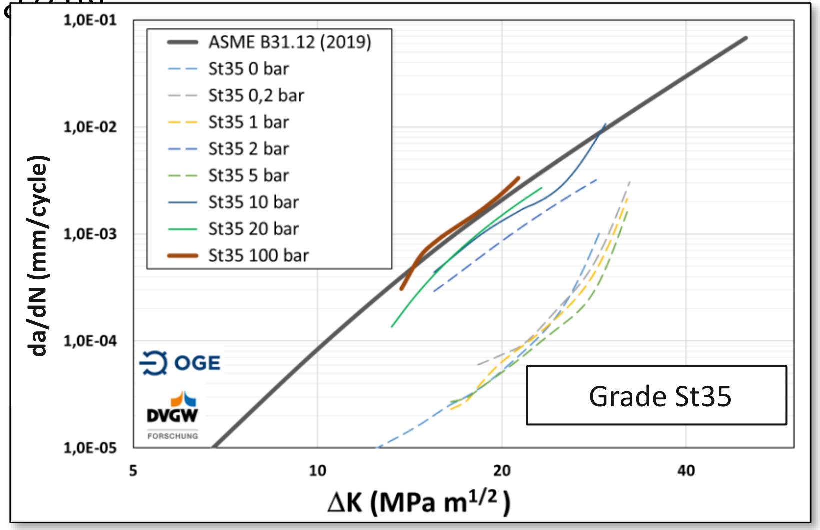


➔ the crack growth rate is small too



Influence of the hydrogen pressure on da/dN





- Below pressures p_{H2} = 1 to 2 bar no influence of H_2 on da/dN
- With increasing hydrogen pressure, increasing crack growth da/dN
- At higher loads ΔK, da/dN changes partly abruptly

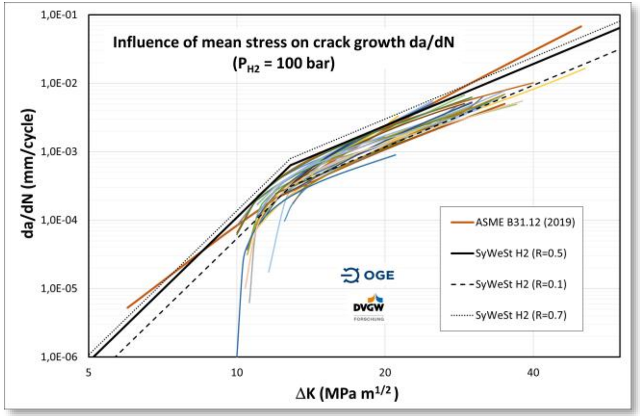
Derived **crack growth model** from the test results

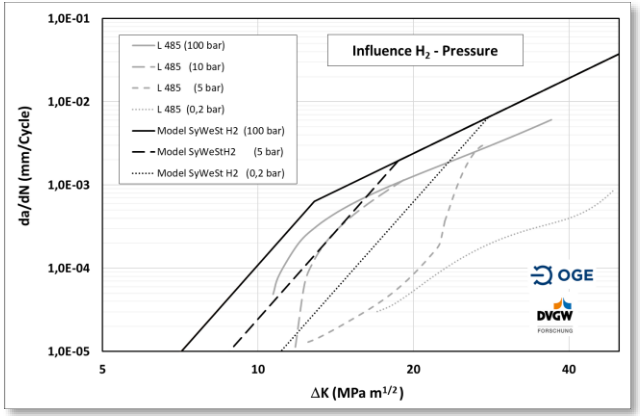
Assessment of steel pipelines possible

➔ Crack growth da/dN can be quantified well

➔ New bilinear model provided inclusive
- Influence of H_2-Pressure
- Influence of mean stress (R-value)

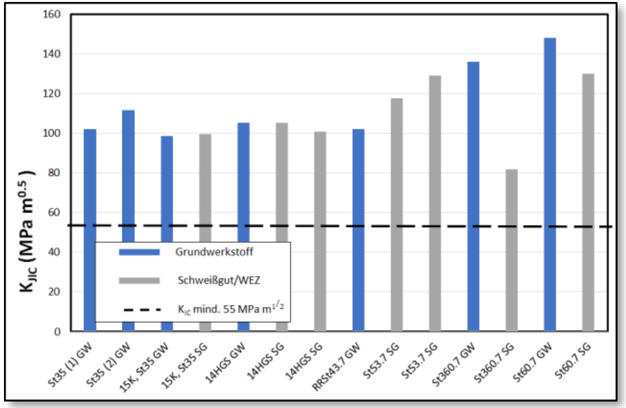
$\Delta K \leq \left[3.6667 \cdot 10^{-6}\sqrt{p_{H2}}\,\right]^{-0,25} MPa\sqrt{m}$	$\frac{da}{dN} = 4.4 \cdot 10^{-13} \cdot (1 + 3 \cdot R) \cdot \Delta K^{7} \cdot \sqrt{p_{H_2}}$
$\Delta K \geq \left[3.6667 \cdot 10^{-6}\sqrt{p_{H2}}\,\right]^{-0,25} MPa\sqrt{m}$	$\frac{da}{dN} = 1.2 \cdot 10^{-7} \cdot (1 + 3 \cdot R) \cdot \Delta K^{3}$



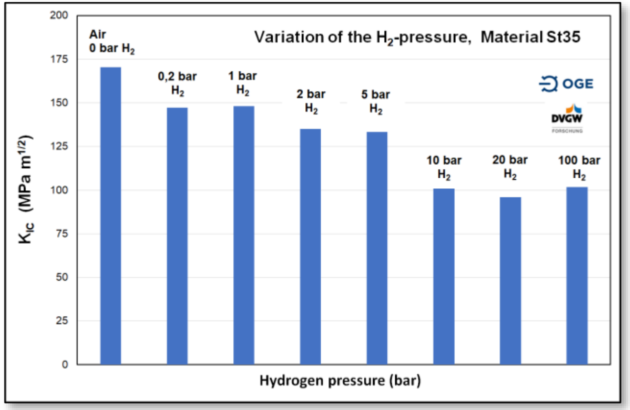


Results of the **static tests (K_{IC})**

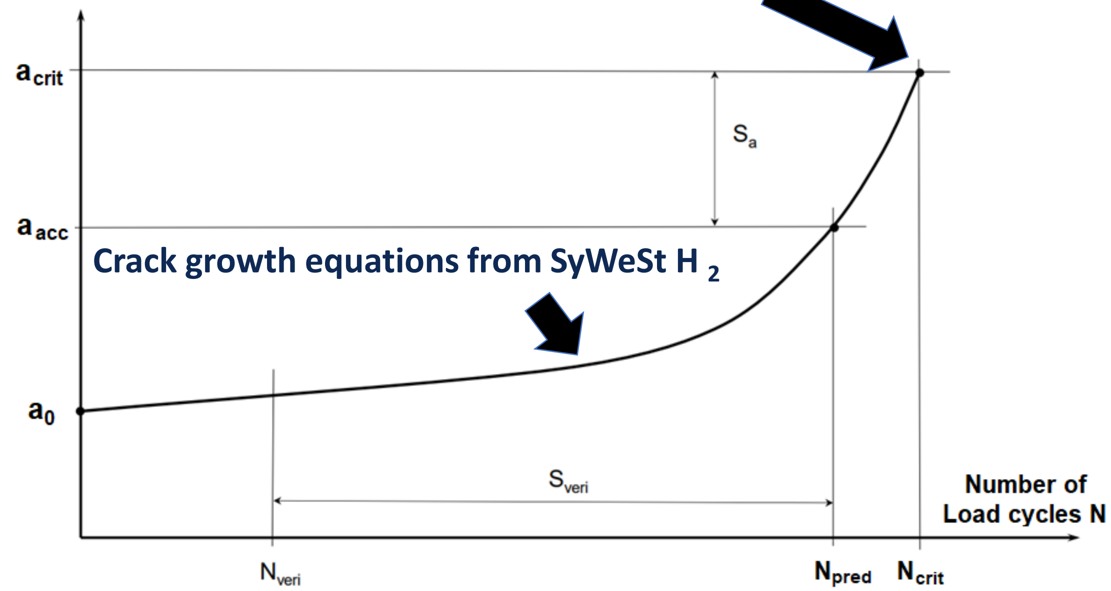
- **Result of all tests**: Fracture toughness (K_{IC}) **clearly above** the required minimum value (55 MPa $m^{0.5}$)



- Decreasing but sufficient fracture toughness (K_{IC}) with increasing hydrogen pressure



Application of the results acc. to DVGW G 464
(**Very conservative** calculation method)



Technical Rule – Standard
DVGW G 463 (A) October 2021
High Pressure Gas Steel Pipelines for a Design Pressure of more than 16 bar; Design and Construction

- Barlow formula acc. to EN 1594 (S min. 1.6)
- Linepipes acc. to EN ISO 3183
- Toughness requirements acc. to EPRG recom.

\+

Technischer Hinweis – Merkblatt
DVGW G 464 (M) März 2023
Fracture-Mechanical Assessment Concept for Steel Pipelines with a Design Pressure of more than 16 bar for the Transport of Hydrogen

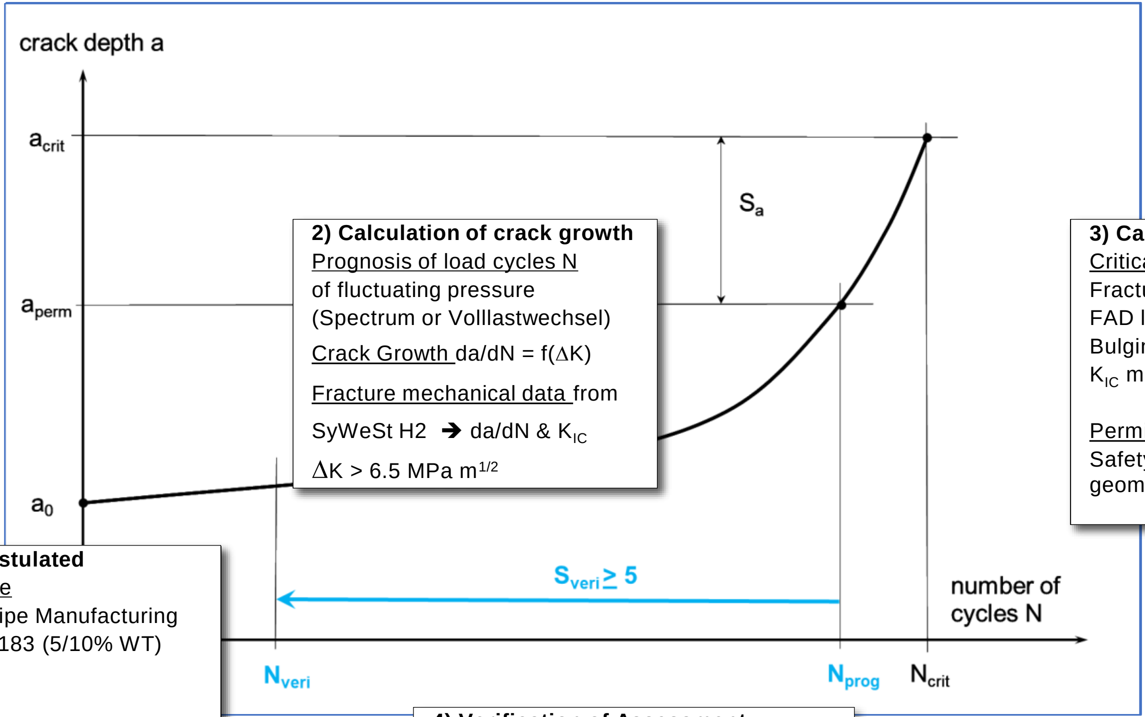
- a_{crit} = critical crack depth
- a_{acc} is the smaller value of wall thickness/2 or $a_{crit}/1.5$ (S_a=1.5)
- a_0 = initial crack depth
- N_{crit} = critical Number of Load cycles
- N_{pred} = predicted Number of load cycles (forecast)
- N_{veri} = Number of load cycles for verification (measurement or calculation)
- S_{veri}= N_{pred}/5 or at least after 10 years

Summary DVGW project SyWeSt H_2

- Characteristics of the tested steels under hydrogen are in accordance with ASME B31.12
- The material behavior under hydrogen could be described adequately up to pressures of 100 bar
- Results for all typically steel grades used in Ger/EU:
  all tested steel grades are suitable for the transport of hydrogen
- Results of the SyWeSt H2 project can be used in accordance with the DVGW G 464 “Fracture-Mechanical Assessment Concept“
- Fracture mechanics calculations confirms for typical operating conditions:
  Pipelines are suitable for transporting hydrogen

Back up

Method of Assessment acc. to DVGW G 464



1) Conservative Crack Postulated

Construction of new pipeline

depth a_0 = NDT acc. to Pipe Manufacturing DIN EN ISO 3183 (5/10% WT)

length $2c_0$ = 50 mm

Conversion of existing pipeline

depth a_0 = NDT acc. to standard at time of construction or found by ILI / NDT

length $2c_0$ = 50 mm

2) Calculation of crack growth

Prognosis of load cycles N of fluctuating pressure (Spectrum or Volllastwechsel)

Crack Growth da/dN = f(ΔK)

Fracture mechanical data from

SyWeSt H2 ➔ da/dN & K_{IC}

$\Delta K > 6.5$ MPa $m^{1/2}$

3) Calculation crack depth

Critical crack depth a_{crit}

Fracture Mechanic Standard (BS/API/...)

FAD level 2

Bulging factor

K_{IC} min. 55 MPa $m^{1/2}$

Permissible crack depth a_{perm} at N_{prog}

Safety factor S_a=1.5 for deviations of geometry & residual stress

4) Verification of Assessment

Recording operating pressure fluctuations (fluctuations > 2 bar)

Reassessment with real fluctuations at N_{Veri} with N_{prog} / S_{Veri} with $S_{veri} \geq 5$

HIGGS

Hydrogen in Gas Grids

Behaviour of the gas grid to hydrogen admixing. Results of the experimental campaign

HIGGS closing event — 21st November 2023

Dr. Javier Sánchez Laínez
Coordinator of the hydrogen conditioning and transport – I+D
Aragon Hydrogen Foundation (FHa), SPAIN
Dr. Virginia Madina
Researcher in Materials for Extreme Conditions / Hydrogen, Materials & Processes, TECNALIA, SPAIN

Clean Hydrogen Partnership

This project has received funding from the Fuel Cells and Hydrogen 2 Joint Undertaking (now Clean Hydrogen Partnership) under Grant Agreement No. 875091 'HIGGS'. This Joint Undertaking receives support from the European Union's Horizon 2020 Research and Innovation program, Hydrogen Europe and Hydrogen Europe Research.

State of art of the European transport grid (WP2)

Valve sectioning stations

Component
Ball Valve (flanged)
Butterfly Valve (flanged)
Plug valve (flanged)
Needle valve (screwed)
Ball valve (screwed)

Gas tightness + Embrittlement

Pressure regulation and/or metering stations

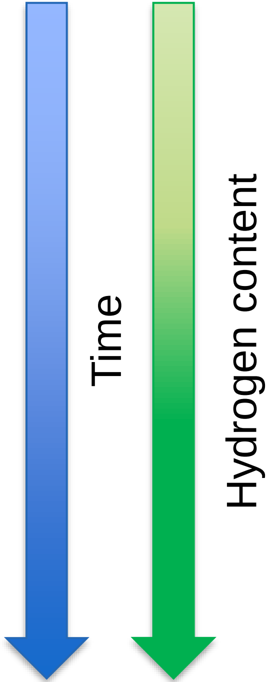
Equipment
Pressure regulator
Filter
Flow meter

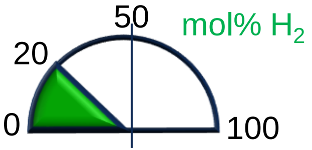
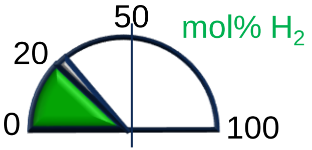
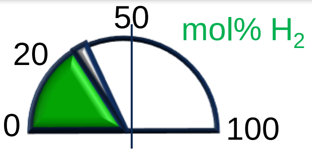
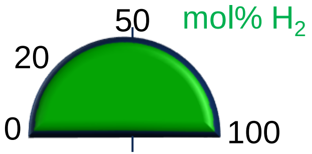
Pipelines

Carbon steels
API 5L X42
API 5L X52
API 5L X60
API 5L X70

Embrittlement (pressure regulation and/or metering stations; pipelines)

Overview of the experimental campaign



COMPOSITION		TEST
	20mol% H_2 80 mol% CH_4	• Gas tighness • Hydrogen sensitivity in steels • Inspection of equipment & valves • Gas separation
	20 mol% H_2 4 mol% CO_2 11 ppmv H_2S 76 mol% CH_4	• Gas tighness • Hydrogen sensitivity in steels • Inspection of equipment & valves
	30 mol% H_2 4 mol% CO_2 11 ppmv H_2S 66 mol% CH_4	• Gas tighness • Hydrogen sensitivity in steels • Inspection of equipment & valves
	100mol% H_2	• Gas tighness • Hydrogen sensitivity in steels • Inspection of equipment & valves • SSRT tests

MOP=80 barg

3-4 months exposure

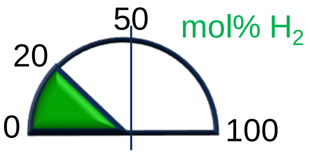
Gas tighness tests

Tests on transport facilities: Valves nodes

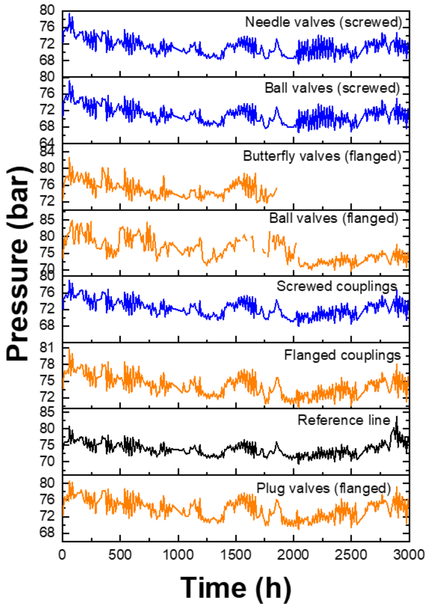
- Testing valves (x3) installed in several lines
- Reference lines with screwed and flanged couplings

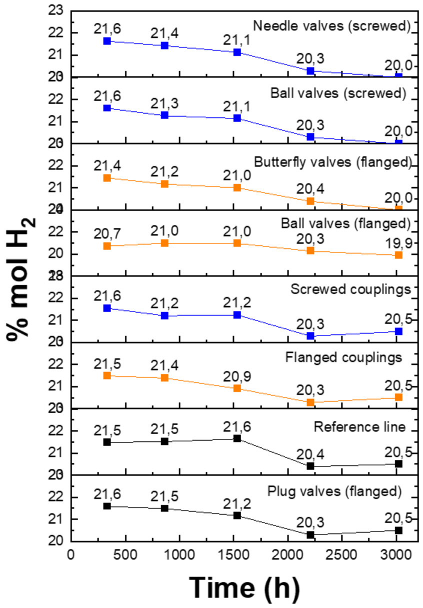
- Methodoly
  - Lines fed with gas at 80 bar and closed
  - Monitoring of pressure and temperature
  - Periodic analysis of gas quality
  - Venting and dissasembling

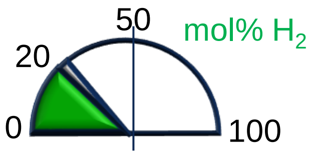
Gas tighness tests (II)



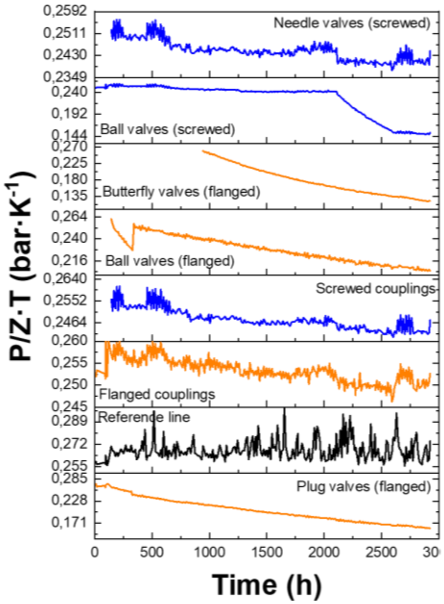
20mol% H_2
80 mol% CH_4

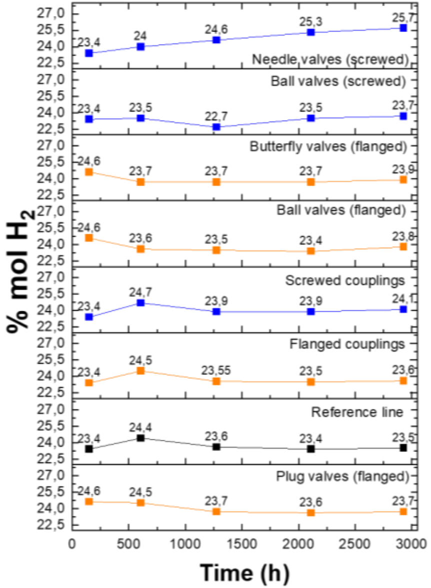




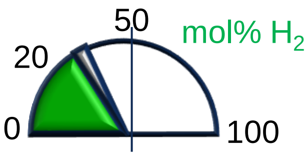


20 mol% H_2
4 mol% CO_2
11 ppmv H_2S
76 mol% CH_4

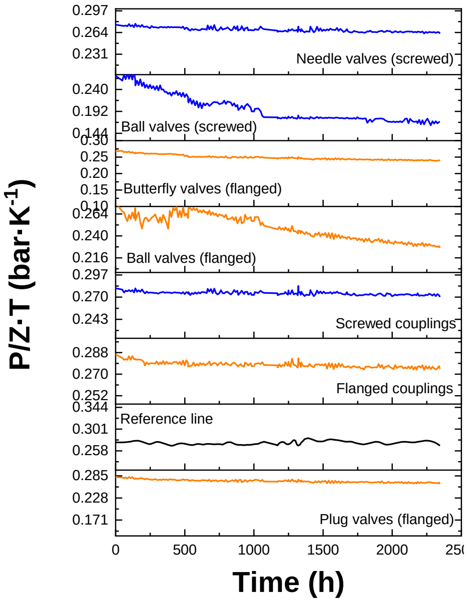


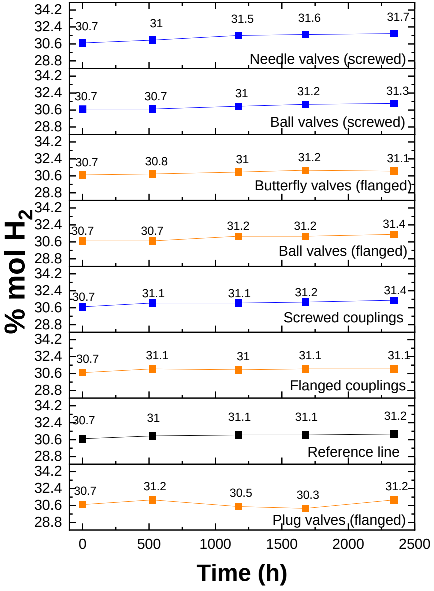


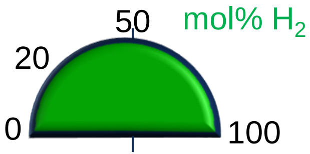
Gas tighness tests (III)



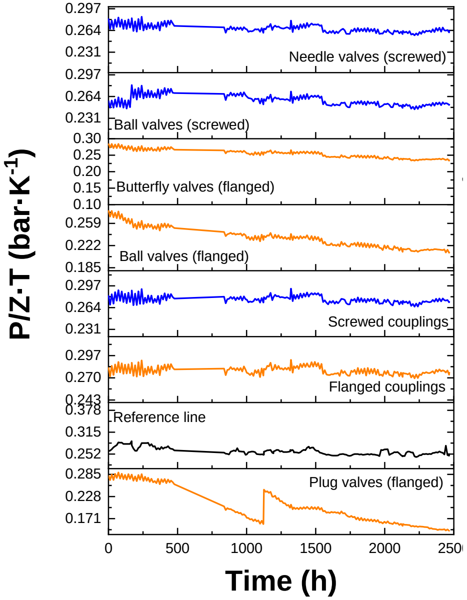
30 mol% H_2
4 mol% CO_2
11 ppmv H_2S
66 mol% CH_4



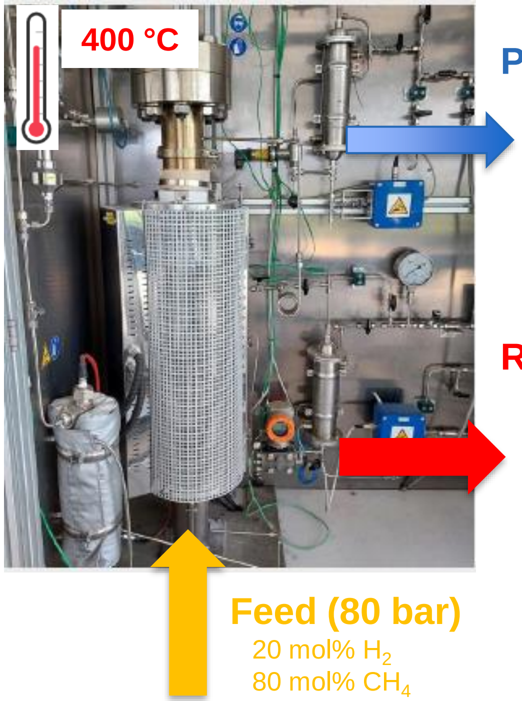




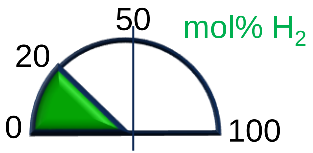
100mol% H_2



Gas separation tests

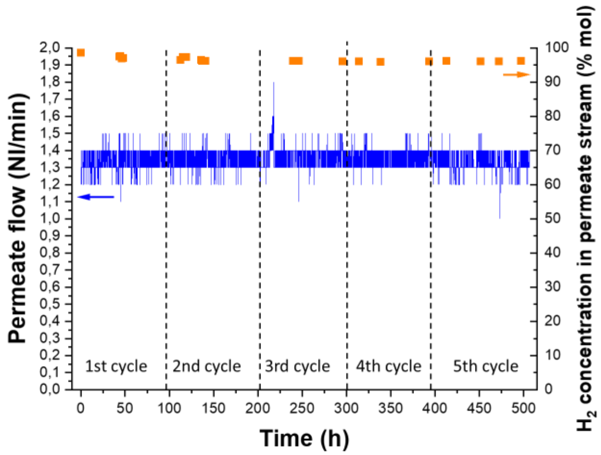


- End-users not able to accomodate high levels of hydrogen if gas is trasported as a blend ➔ gas separation for H_2 recovery
- Pd-based membranes
- Two tests performed:
  - Continuos operation ➔ long-term stability
  - Tuning operation conditions ➔ obtaining the highest H_2 purity



20 mol% H_2
80 mol% CH_4

Long term stability test



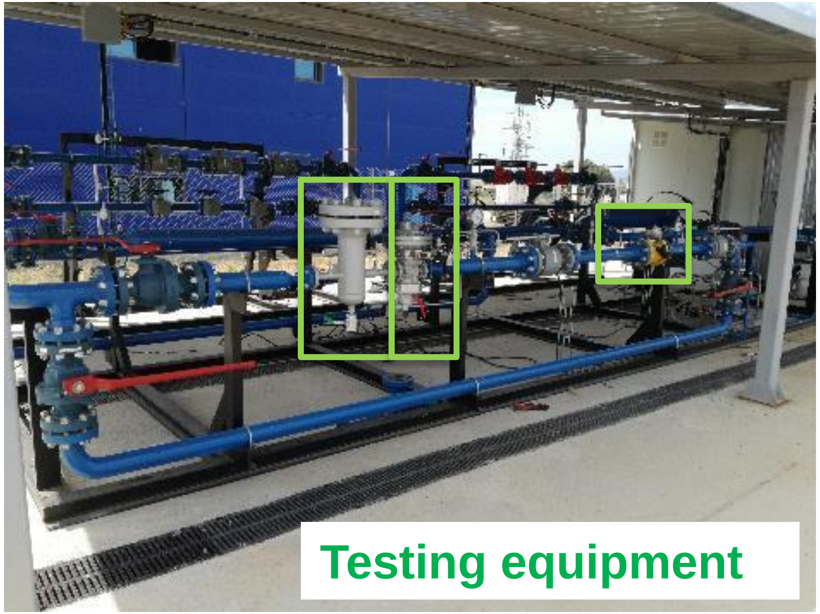
Tuning of operating conditions

Total feed flow (Nl/min)	Feed pressure (bar)	%H_2 permeate	%H_2 retentate	%H_2 recovery
8.30	10	99.9	14.9	30.1
8.30	20	99.8	10.3	54.1
8.30	40	99.6	7.8	66.0
8.30	60	99.5	6.6	71.9
8.30	80	99.5	5.3	77.9
Total feed flow (Nl/min)	**Feed pressure (bar)**	**%H_2 permeate**	**%H_2 retentate**	**%H_2 recovery**
1.12	10	99.8	12.2	44.6
2.24	20	99.8	7.6	66.9
3.12	40	99.6	4.8	79.9
4.63	60	99.5	3.4	85.9
6.15	80	99.5	2.7	90.0

Inspection of equipment and valves after H_2 exposure

Hydrogen in Gas Grids

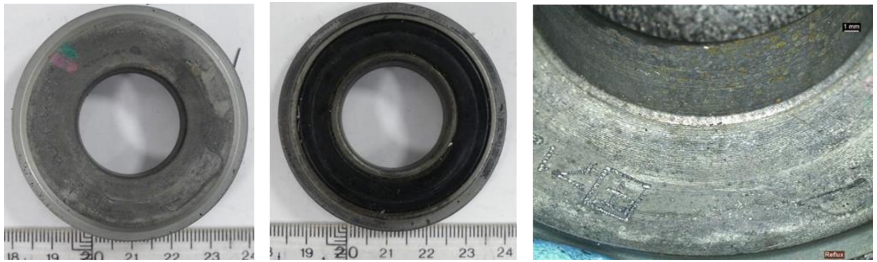
Tests on transport facilities: pressure regulation stations & valve nodes



- Impact of hydrogen on the main parts of equipment…
  - Pressure regulator
  - Gas meter
  - Filters
- …as well as valves
- Components dissassembled after gas exposure and characterised in the laboratory

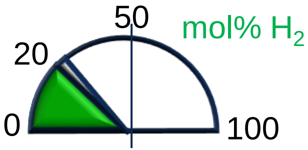
Inspection of equipment and valves after H_2 exposure

Hydrogen in Gas Grids

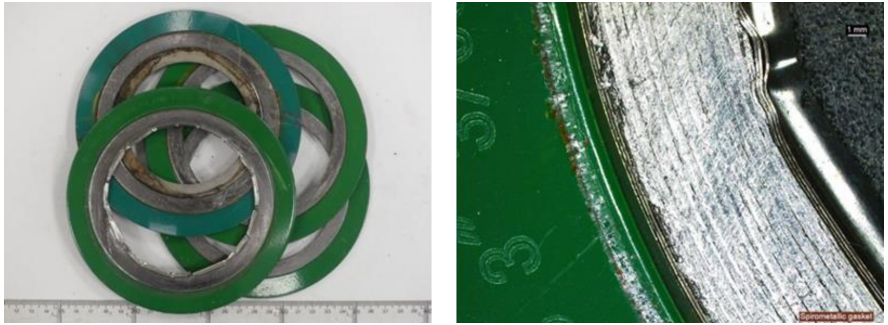


Components of pressure regulator

Components of flanged ball valve



20 mol% H_2
4 mol% CO_2
11 ppmv H_2S
76 mol% CH_4



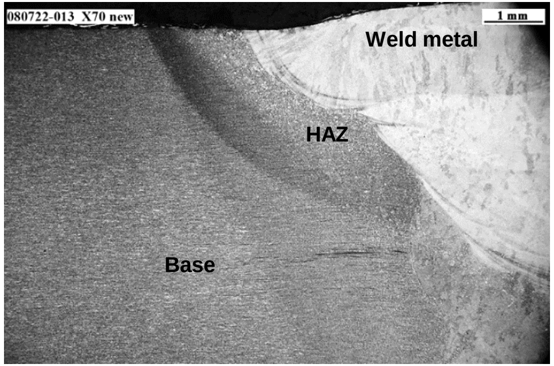
Spirometallic gaskets

Components of the flanged plug valve

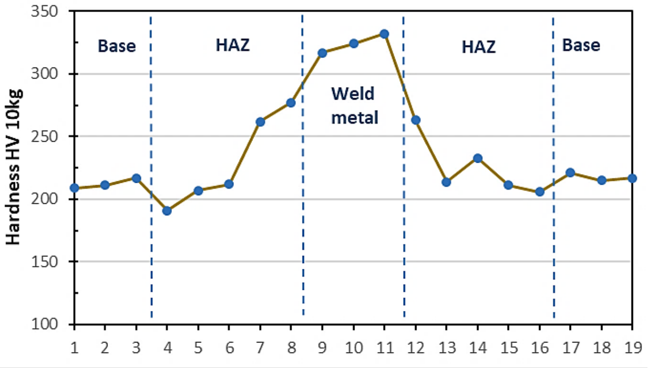
Properties of API5L steel pipes under study

API 5L steel grade	Outside diameter (mm)	Wall thickness (mm)	Yield strenght (MPa)		Ultimate tensile strenght (MPa)		Welding procedure /filler material	Microstructure (base steel)
			Tensile testing	API 5L (min.)	Tensile testing	API 5L (min.)		
X42	168.3	6.9	451	290	542	415	GTAW / ER70S-6	Ferrite + pearlite
X52	168.3	7.8	440	360	514	460	GTAW / ER70S-6	Ferrite + pearlite
X60	168.3	7.8	510	415	581	520	GTAW / ER90S-B3	Bainite
X70	406.4	8.2	549	485	675	570	GTAW / ER90S-B3	Ferrite + bainite

X70 API 5L steel pipe



X70 GTA weld joint



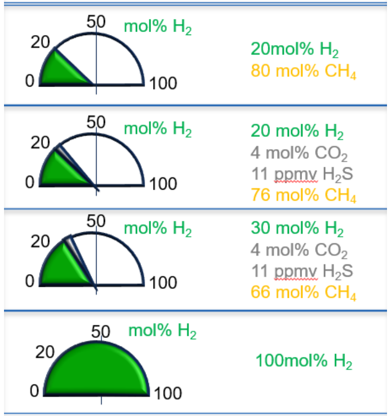
New steels

Detail of GTA welded joint cross section in X70 steel and micro-hardness evolution

Hydrogen embrittlement tests: Type of tests

Constant displacement tests at testing facility (FHA)

COMPOSITION (80 bar)



- C-ring specimens
- 4-point bend specimens (4pb)
- Compact tension (CT)-WOL specimens

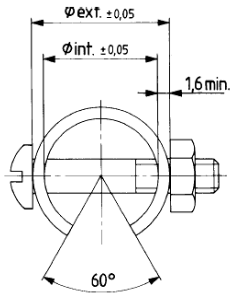
Dynamic loading tests in Tecnalia´s laboratories

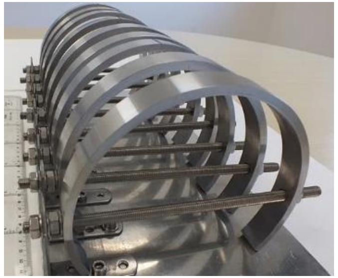
- Slow strain rate tests (SSRT) in 100% H_2 gas (80 bar)

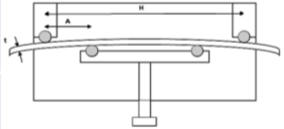
Constant displacement tests at testing facility

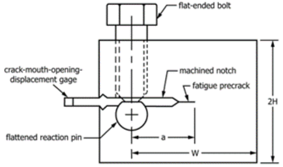
Type of specimen	Constant displacement specimens		
	C-ring	**4-pb**	**CT-WOL**
Condition	Smooth and notched base specimens	Base and welded specimens	Fatigue pre-cracked, base and welded specimens
Standards	ISO 7539-5, ASTM G38	ISO 7539-2, ASTM G39	ISO 7539-6, ASTM E1681
Stress level	100% Yield Strenght (YS)	100% YS	Stress intensity factor K_{IAPP} = 41-55 $MPam^{1/2}$
Test duration	2300-3000 hours		
Post testing evaluation	➢ Evidence of cracking in C-ring and 4-pb specimens ➢ Crack growth in CT-WOL specimens ➢ Metallographic and fractographic examination		

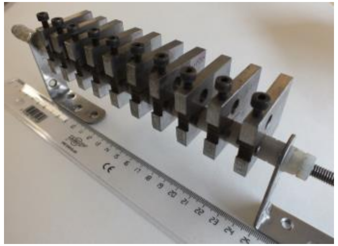
Once the deformation has been applied to the specimen, the "loaded" specimens are inserted into the pig trap and exposed to the hydrogen environment.



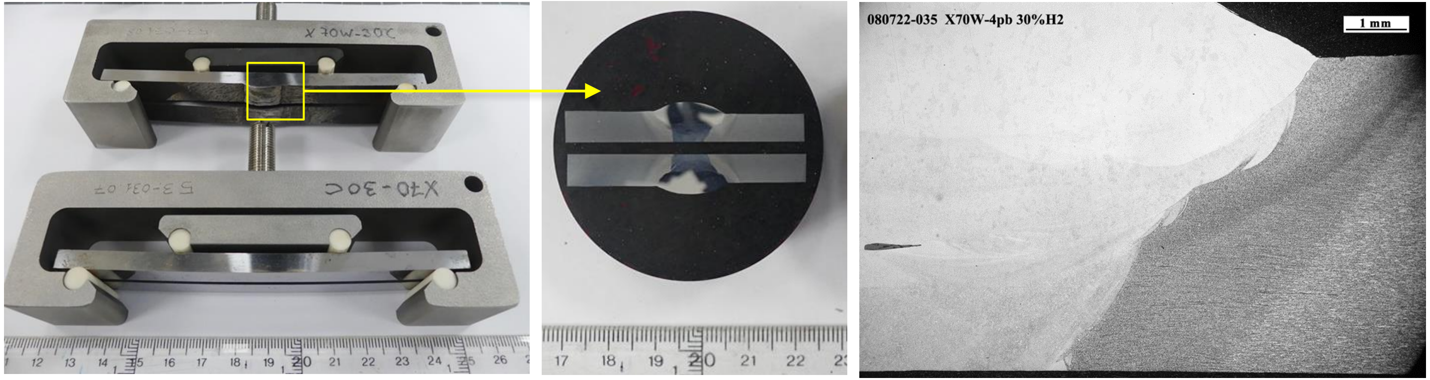




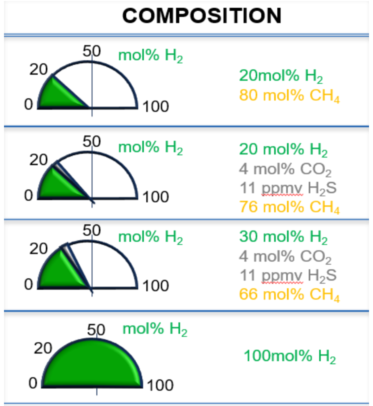




Constant displacement tests: RESULTS: 4pb specimens



X70 base and welded 4pb specimens tested at 30 mol% H_2

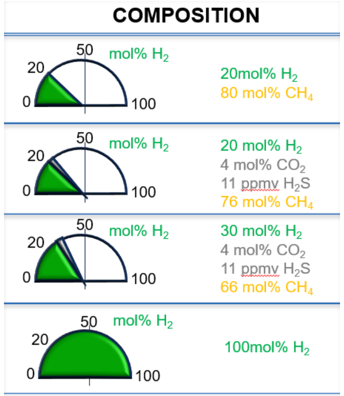


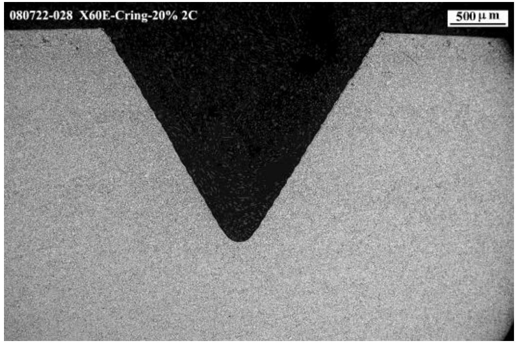
4pb specimens				
mol% H_2 (80 bar)	Test duration (h)	Steel grade	Applied stress	Results
20 / 30 / 100	2300-3000	X52 base	100% YS	No cracks
		X52 welded		
		X70 base		
		X70 welded		

No susceptibility to hydrogen embrittlement is observed for 4pb specimens

Constant displacement tests: RESULTS: C-ring specimens

Rack with tested C-ring specimens



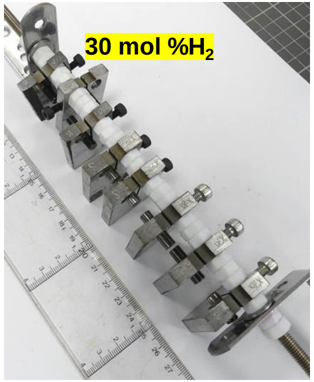


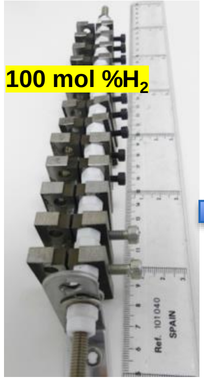
Optical micrograph of cross section of notched C-ring X60 specimen tested in 20 mol%H_2

C-ring specimens					
mol% H_2 (80 bar)	**Test duration (h)**	**Steel grade**	**Condition**	**Applied stress**	**Results**
20 / 30 / 100	2300-3000	X42 base	Smooth / notched	100% YS	No cracks
		X52 base			
		X60 base			

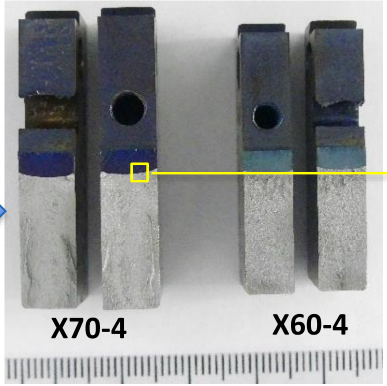
No susceptibility to hydrogen embrittlement is observed for C-ring specimens

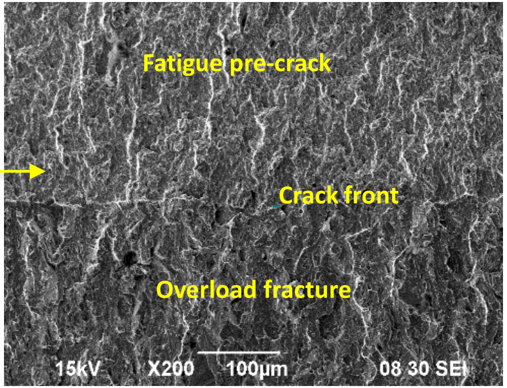
Constant displacement tests: RESULTS: CT-WOL specimens

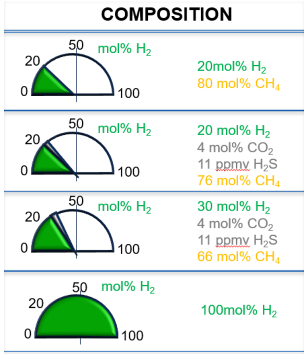




Racks with tested CT-WOL specimens







CT-WOL specimens					
mol% H_2 (80 bar)	Test duration (h)	Steel grade	Notch position/ crack plane orientation	Applied stress intensity factor K_{IAPP} ($MPam^{1/2}$)	Crack propagation after hydrogen exposure
20 / 30/ 100	2300-3000	X52	Base / TL	45	<0,25mm
		X60	Base / TL	45	
		X70	Base / TL	55	
		X70	Weld / TL	41	

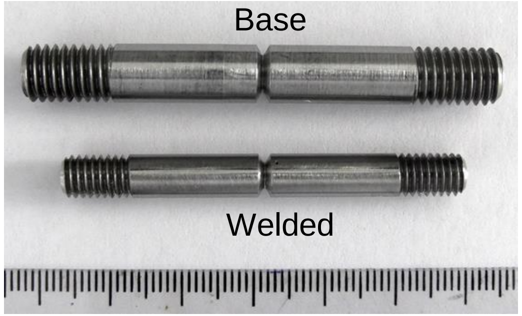
No susceptibility to hydrogen embrittlement is observed in CT-WOL specimens

Dynamic loading tests: Slow Strain Rate Tests (SSRT)

SSRT tensile, fracture and fatigue machine for testing in H_2 gas in Tecnalia H2Lab

Methodology

- The tensile specimen is subjected to a constantly increasing elongation, while exposed to the hydrogen environment.
- Mechanical values in H_2 are compared to those obtained in air.
- The **notched tensile strength (NTS) ratio** and the reduction of area (RA) ratios are evaluated for notched tensile specimens. These ratios are used as a material screening method.
- Standards: ASTM G142, ISO 7539-7

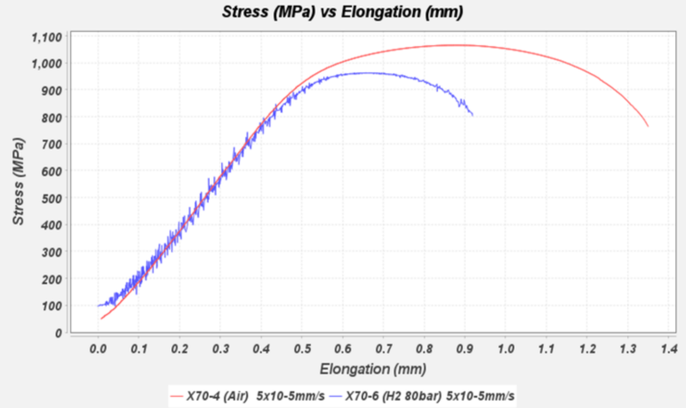


Geometry of the notched SSRT specimens used in Higgs

K_t= 4.5 (for base materials)

SSRT: Results (I)

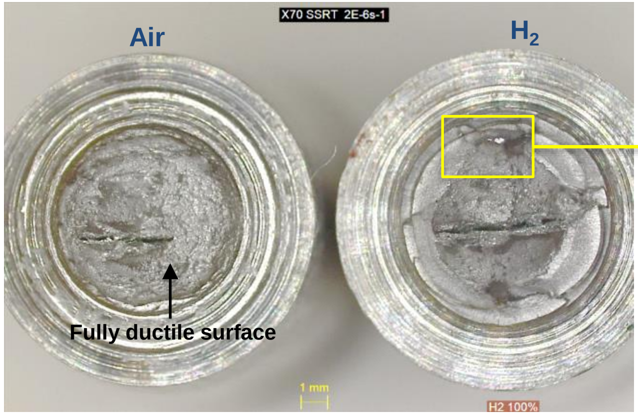
SSRT specimens							
Steel grade	**Test environment**	**Displacement rate (mm/s)**	**RA (%)**	**RRA**	**NTS (MPa)**	**RNTS**	**YS (MPa)**
X52	Air	$5x10^{-5}$	28.6		758		710
	80 bar H_2	$5x10^{-5}$	11.5	**0.40**	731	**0.96**	724
X60	Air	$5x10^{-5}$	29.0		979		924
	80 bar H_2	$5x10^{-5}$	9.71	**0.33**	903	**0.92**	903
X70	Air	$5x10^{-5}$	22.3		1069		972
	80 bar H_2	$5x10^{-5}$	9.37	**0.42**	965	**0.90**	958



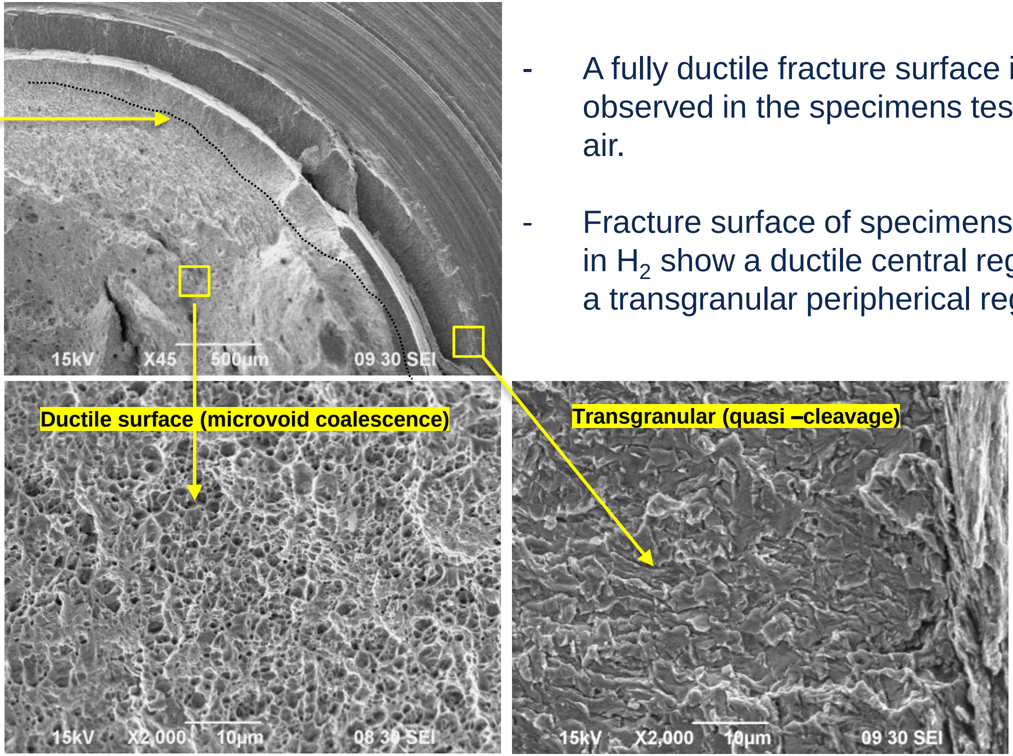
H_2 purity: 99.9999% H_2

- A quite significant RA loss is measured in all the notched steel specimens when tested in H_2 gas at 80 bar.
- The NTS is barely reduced due to hydrogen. In general, and in a qualitatively way, NTS ratios comprised between 0.90 and 0.96 are associated with a small category / low index of embrittlement.
- Small differences are observed when comparing X52, X60 and X70 steel specimens. The higher loss of ductility is observed for the bainite X60 steel. The lower NTS ratio (higher embrittlement effect) is observed in the steel with higher hardness (X70)

SSRT: Results (II)



Fracture surface of notched SSRT x70 specimens tested in air and in H_2 (80 bar)



SEM fracture surface of notched SSRT x70 specimen tested in H2 (80 bar)

- A fully ductile fracture surface is observed in the specimens tested in air.

- Fracture surface of specimens tested in H_2 show a ductile central region and a transgranular peripherical region.

Hydrogen embrittlement tests in HIGGS: Conclusions

HIGGS Hydrogen in Gas Grids

- ✓ **No cracking / no crack growth is detected for any of the** constant displacement specimens type C-ring, 4pb and CT-WOL, when exposed to the different mixtures of CH_4+ H_2 (20-30% mol) and 100% H_2, at 80 bar pressure, and test duration up to 3000 hours.

- ✓ A quite significant loss in the **RA** values is observed for the notch steel specimens when SSR tested at 100% H_2 at 80 bar pressure. However, the **NTS ratios** obtained in these tests show **embrittlement values categorized as low.**

The results obtained are indicative of low susceptibility to hydrogen embrittlement for API 5L steels grades X42, X52, X60 and X70, in the tests conditions established in HIGGS.

HIGGS

Hydrogen in Gas Grids

Thank you for your attention!

Dr. Javier Sánchez Laínez

Dr. Virginia Madina

This project has received funding from the Fuel Cells and Hydrogen 2 Joint Undertaking (now Clean Hydrogen Partnership) under Grant Agreement No. 875091 'HIGGS'. This Joint Undertaking receives support from the European Union's Horizon 2020 Research and Innovation program, Hydrogen Europe and Hydrogen Europe Research.

No.	Topic	Who	Duration
	Welcoming-Breakfast (8:30-9:00)		
TOP1	Introduction to the project Joint Undertaking programm overview and projects on gas grids	Dr. Javier Sánchez Laínez (Aragon Hydrogen Foundation) Dionisis Tsimis (Project Officer Clean hydrogen Partnership)	9:00 - 9:25
TOP2	**Keynote: H_2 suitability of steels (SyWest H_2)** **Behavior of the gas grid to hydrogen admixing. Results of the experimental campaign** Discussion and questions	Tillmann Wiegold (Open Grid Europe) Dr. Virginia Madina (Tecnalia) Dr. Javier Sánchez Laínez (Aragon Hydrogen Foundation) ERIG / Audience	9:25 - 10:25
	Break (10:25-10:55; Coffee)		
TOP3	**Keynote: Growing Hydrogen in the EU** **Technoeconomic validation and modelling, enablers and interoperability considerations** Discussion and questions	René Schutte (Gasunie) Salvatore Oricchio (Eastern Switzerland University of Applied Sciences) ERIG / Audience	10:55 - 11:55
TOP4	**Keynote: Perspectives on Hydrogen in the EU** **Pathway towards integrating H_2 in EU gas networks** Discussion and questions	Alberto Cerezo Alarcón (Redexis) Dr. Michael Walter (DVGW German Technical and Scientific Association for Gas and Water) ERIG / Audience	11:55 - 12:55
TOP5	Closing	Dr. Javier Sánchez Laínez (FHA)	12:55-13:00

gasunie
crossing borders in energy

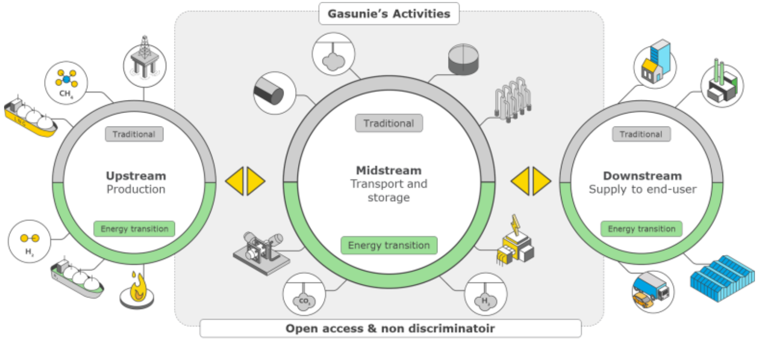
Growing Hydrogen

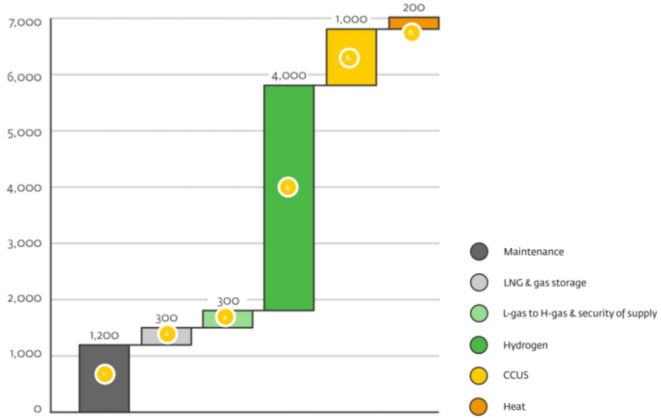
René Schutte
Director HyNorth

November 21, 2023

Gasunie: a European energy infrastructure company

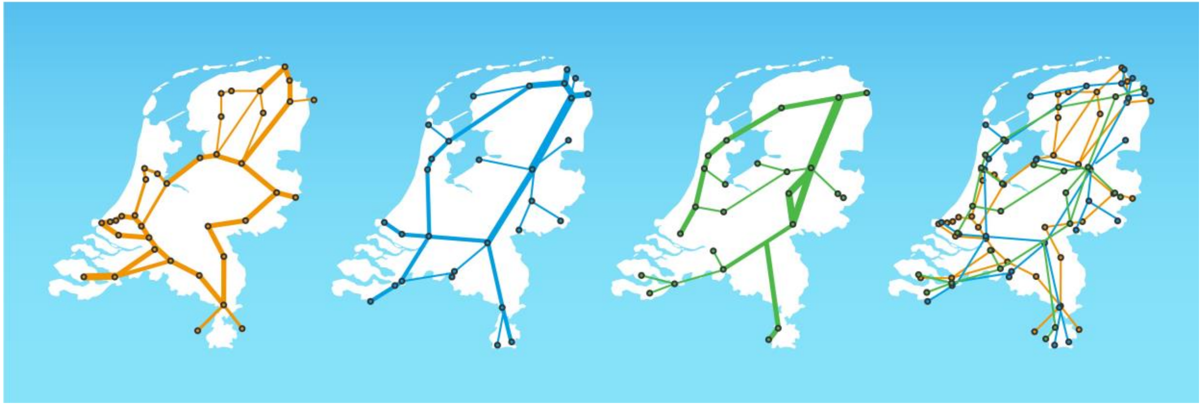
Open access – (renewable) gas, CCS and Heat





System integration is key

Electricity Grid + Hydrogen Grid + Methane Grid = Combined Grid



Capacity 20 GW | **Capacity 350 GW**

Owner: TenneT
High-voltage electricity grid

Investment plans:
Reinforcing existing grid
New offshore wind connections

Owner: Gasunie
High-cal gas grid

Investment plans:
Hydrogen grid by 2030, connecting
industrial clusters and storage

Owner: Gasunie
Low-cal gas grid

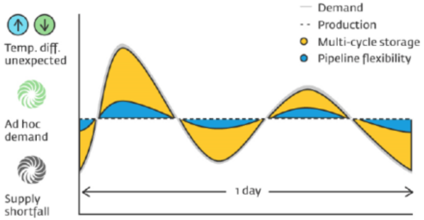
Investment plans:
Facilitate 2 bln m^3
green gas feed-in

*Dutch grids taken as an example.

In a Combined Grid:

- Power plants use green hydrogen or (bio) gas to produce electricity
- Electrolysis plants use green electricity to produce green hydrogen

Why hydrogen is needed



Source: Infrastructure Outlook 2050

The HyWay 27 project explored if and under which conditions, parts of the Dutch natural gas network can be repurposed for transmission of hydrogen

Key research questions

1

Is a transmission network for hydrogen **needed**, and **if so, when**?

2

Is it possible to use the existing natural gas for hydrogen transmission, and **if so**, **would that be desirable**?

3

What **government intervention** will be required to create a transmission network for hydrogen?

Findings

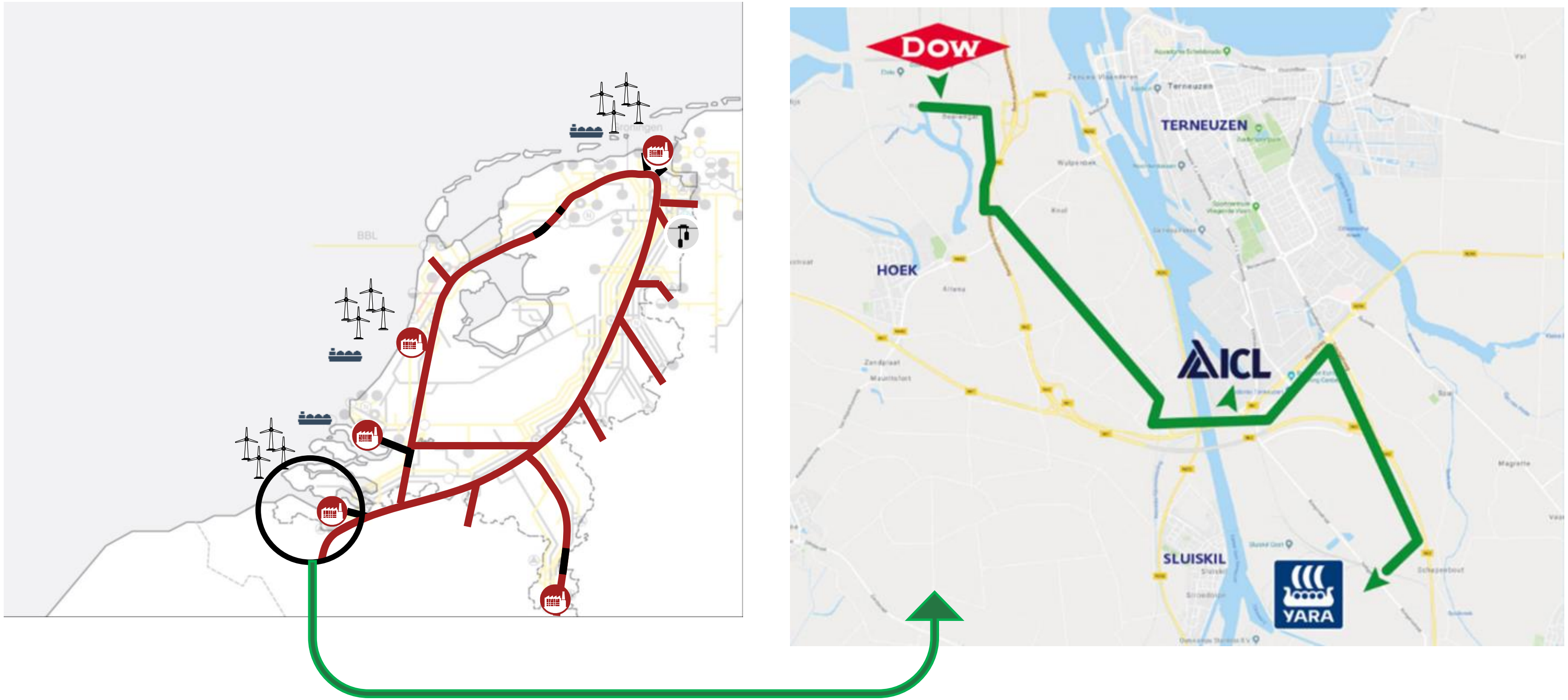
In a climate-neutral economy, pipelines for hydrogen are necessary to connect producers and users of hydrogen cost effectively. **Towards 2030** a transport network is needed to meet ambition of 3-4GW electrolysis

Existing natural gas infrastructure offers enough capacity for future hydrogen volumes and **can technically be modified**/repurposed. The **cost** per km investment is **4 times lower than new-build**

Government intervention should be aimed at financially supporting both **transport and production/usage** of hydrogen **in parallel**. Advice is to **initiate next steps** in repurposing existing natural gas grid

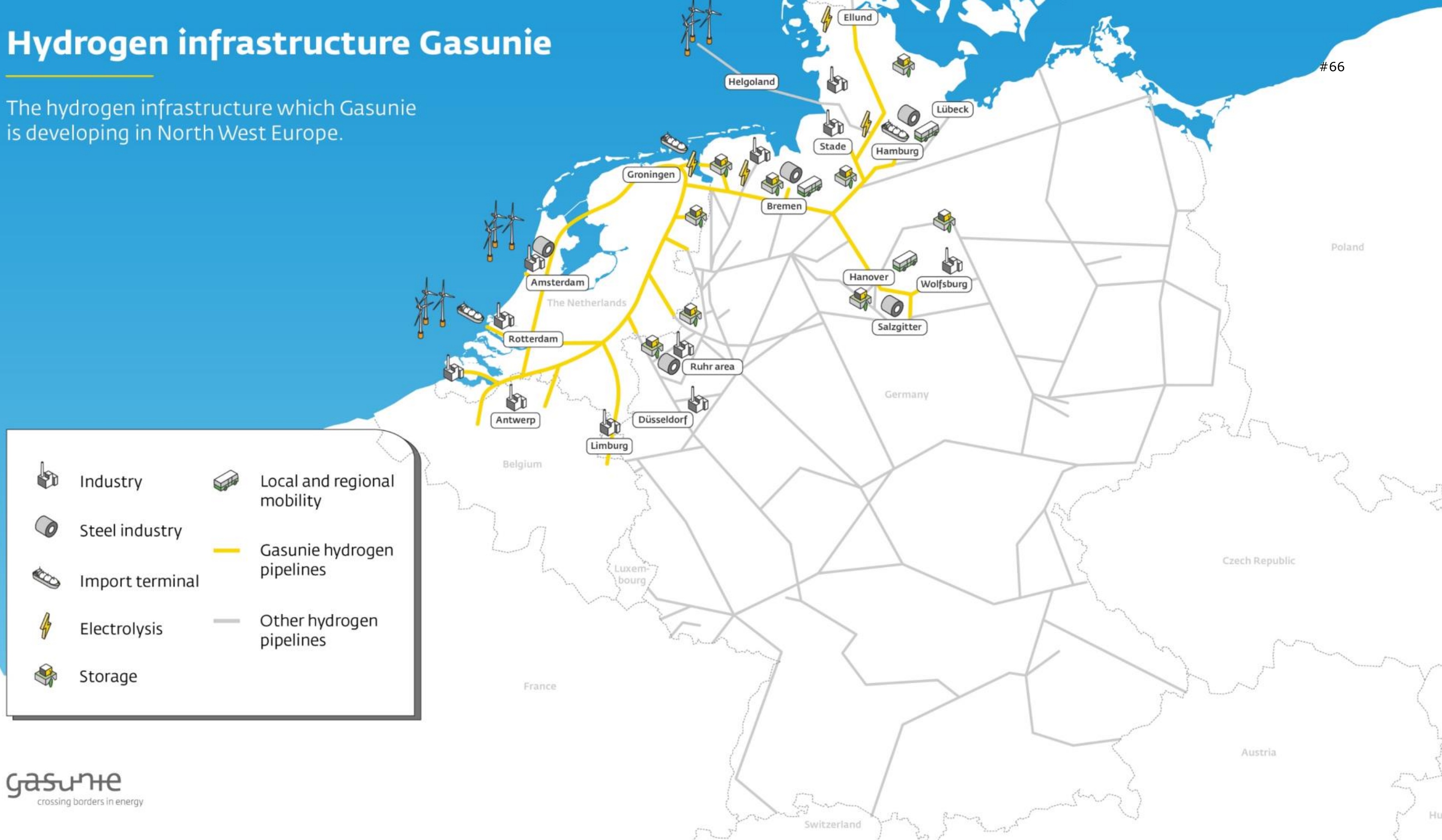
Source: HyWay 27 Strategy& - PwC

Repurposing gas infrastructure; cost efficient and safe



Hydrogen infrastructure Gasunie

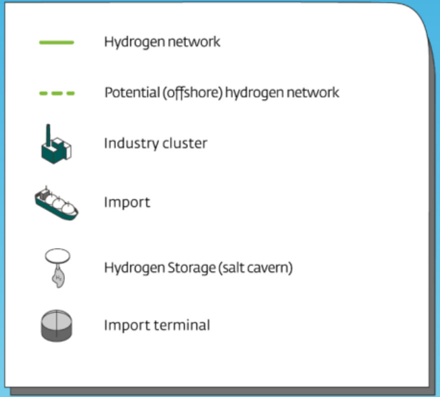
The hydrogen infrastructure which Gasunie is developing in North West Europe.



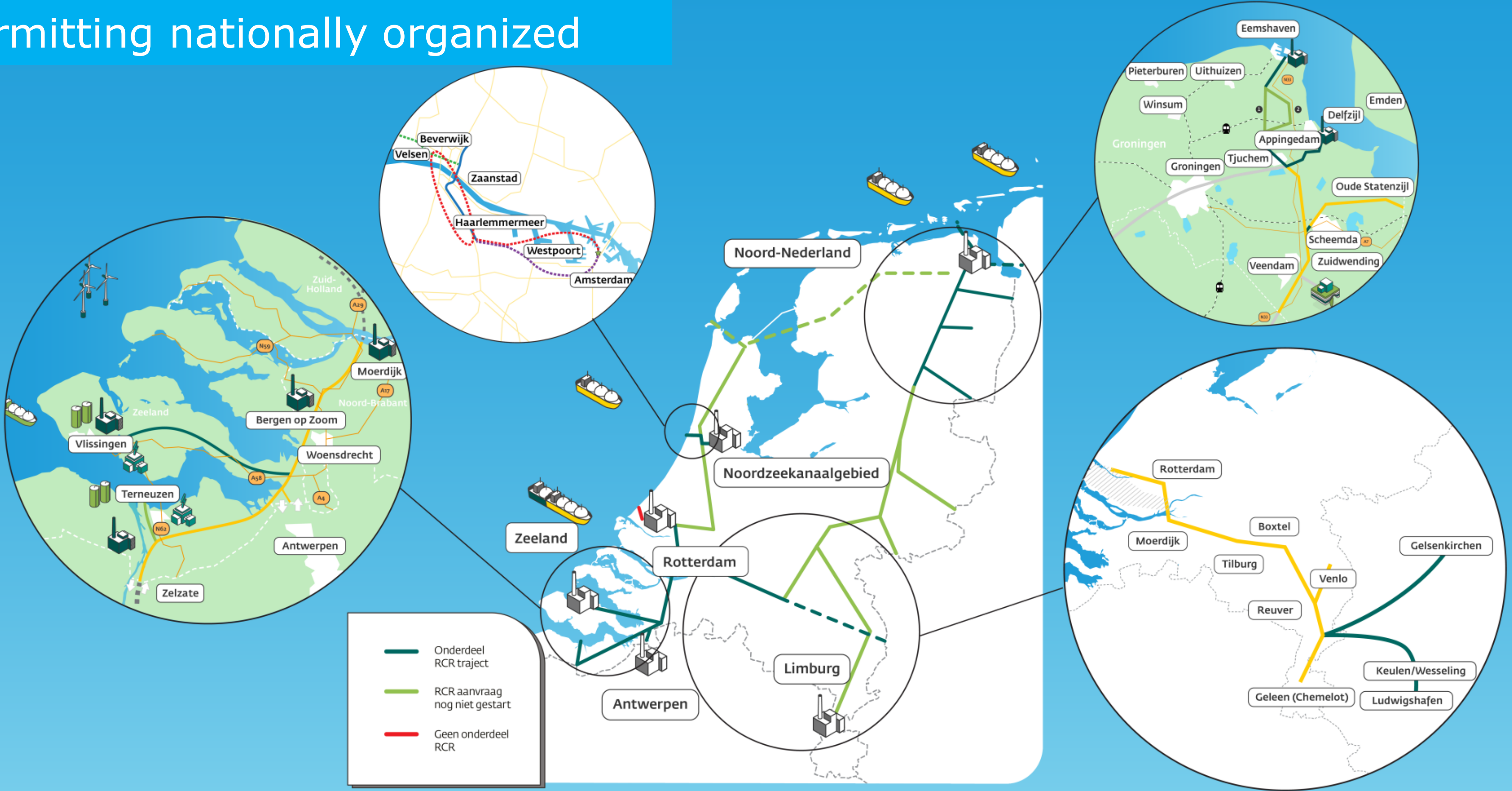
Phase 3: 2030 and beyond

Intended network - Netherlands

- 1200 km, 85% repurposing
- Pressure range 50 -> 30 bar(g)
- Capacity 10 – 15 GW, costs ± 1.500 M€
- Cost of repurposing ± 25% of newbuild
- No transport compression required
- Large scale pipelines (average 42”)
- Quality > 98,0% H2
- Connecting all 5 Dutch industrial clusters and neighboring cross border industrial clusters in Germany and Belgium
- Connecting to storage
- 50% capex funding Dutch state



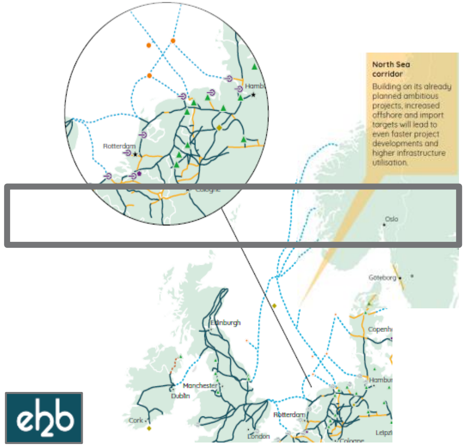
Permitting nationally organized



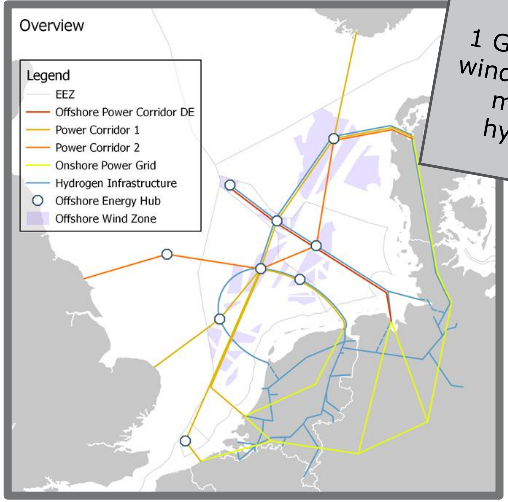
North Sea H_2 Offshore Network Plans: Cross-border and Energy System integrated

The Netherlands, Germany and Denmark are geographically well positioned to play a role in future hydrogen transit flows

EHB identifies 5 import corridors



European Hydrogen Backbone as platform for H_2 infrastructure planning



1 GW offshore wind is app 0,1 megaton hydrogen

Integrated Network Planning: Electricity and Hydrogen

HYNETWORK SERVICES

Physical properties of hydrogen and natural gas

The main physical properties of natural gas and hydrogen
Source: Bilfinger Tebodin (2019), IFV (2020), Gasunie (2019), NEN (2015)

Property	Methane (natural gas)	Hydrogen
Colourless	Yes	Yes
Odourless	Yes	Yes
Flammable	Yes	Yes
Explosive	Yes	Yes
Corrosive	No	No
Molecule size [pm]	200	75
Relative density (air = 1)	0.55	0.07
Flammability limits (lower and upper limit [%])	4.4 - 17	4.0-77
Minimum ignition energy [MJ][1]	0.26	0.02
Calorific value [MJ/m^3]	32	11
Flame colour	Blue	Colourless
Greenhouse gas (infrared absorption)	Yes	No
Hydrogen embrittlement	No	Possible
Required purity	N/A	≥ 98%

For hydrogen transport to be as safe as possible, changes will have to be made to the existing grid and procedures

Summary of measures needed to ensure safe hydrogen transmission *Source: Gasunie, Bilfinger Tebodin, AVIV, DNV GL*[1]

Focus point		Measure	Type
1. Leakage	1A	Replacing and/or reconditioning valves on account of possible leakage	Adjustments to existing network
	1B	Replacing other leak-prone parts (except for valves)	Adjustments to existing network
2. Contaminations	2A	Cleaning existing pipelines	Adjustments to existing network
3. Lower combustion energy	3A	Configuring or replacing metering equipment to bring it into line with flow speed and gas composition	Adjustments to existing network
	3B	Adding compressors (in the long term) on account of the incompatibility of existing compressors	Adjustments to existing network
4. Defect growth	4A	Mapping maximum operating pressures, changing operational procedures, and creating pipeline files	Adjustments to procedures
	4B	Developing and changing procedures for inline inspections	Adjustments to procedures
5. Ignition risk	5A	Training technicians to handle hydrogen	Adjustments to procedures
	5B	Changing pipeline modification procedures	Adjustments to procedures
	5C	Procuring safe electronic metering equipment for management and maintenance	Adjustments to procedures

= Adjustments to existing network *= Adjustments to procedures*

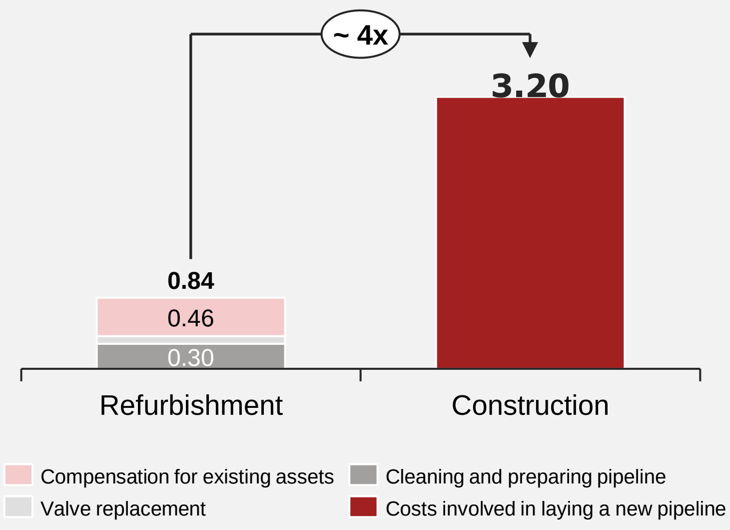
1. This table was put together based on information obtained from the various HyWay 27 stakeholders and desk research into previous studies (including DNV GL, 2017; DNV GL, 2020b; Gasunie, 2019; Bilfinger Tebodin, 2019; AVIV, 2019). PwC Strategy& did not conduct a technical analysis itself.

1. **Hydrogen may be more prone to leakage due to its smaller molecular size**
2. **Some hydrogen applications are more sensitive to contamination**
3. **Hydrogen has a lower calorific**
4. **In hydrogen transport, large and frequent pressure fluctuations may accelerate defect growth**
5. **Hydrogen ignites more easily and burns in oxygen with a nearly invisible flame**

HYNETWORK SERVICES

Pipelines can be repurposed with relatively little modification costs – per-km investment is four times lower than new-build

Comparison of per-km investment required for reuse and new-build *(millions of € per km, based on 36-inch pipeline)*



- Investments for refurbishing of existing grid is expected to be **~4 times lower than new built** of similar capacity
- Cost off refurbishment consists of:
  - ~55% is compensation for taking over existing assets from GTS, at regulated asset value (GAV)
  - ~45% is actual modification costs, i.e. cleaning and preparation of the pipelines, also depending on the desired purity of hydrogen
- In order to connect all industrial demand centers, main export routes and gas storage fields in 2030, Gasunie estimates **total capex** to be **~€1,5 billion**

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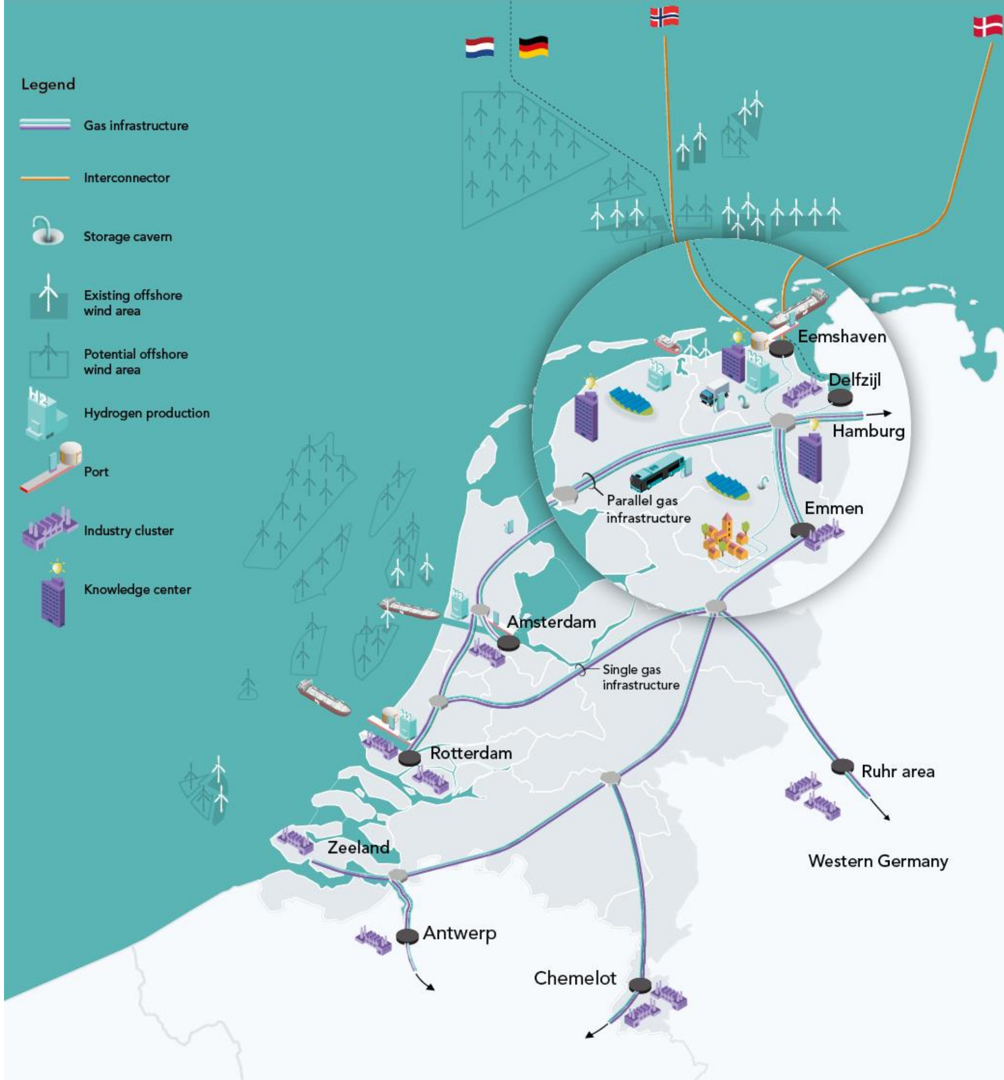
Investment Plan Hydrogen Northern-Netherlands 2020

- Unique access to essential means
- Systemic approach
- Project pipeline with >50 planned projects



gasunie crossing borders in energy
GRONINGEN SEAPORTS
provincie Drenthe
provincie groningen
New Energy Coalition

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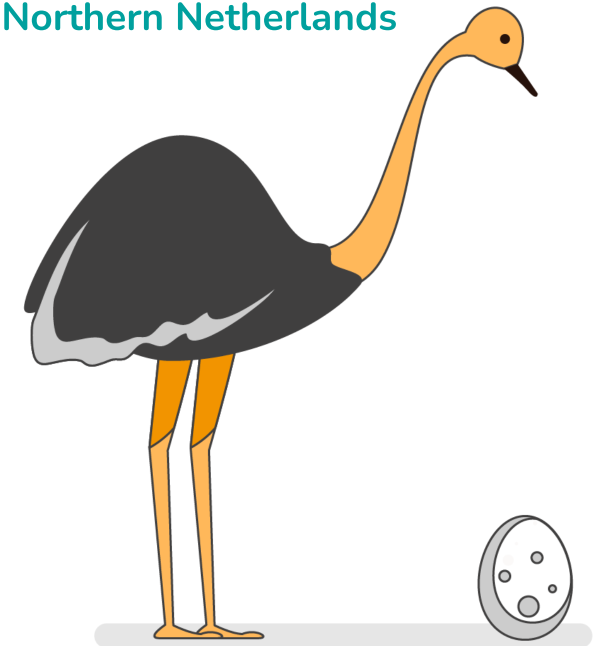
Mission HyNorth:
The Hydrogen Valley is a functioning eco system in Northern Netherlands



Build a new eco system and develop hydrogen market

- Renewable energy
- Production (supply)
- Transport
- Storage
- End users (demand)

& Manufacturing Industry
& Human Capital (knowledge and jobs)

Synchronise investment decisions all links in the chain

HyNorth connects the partners in the chain

- Integration & Coordination
- Identify gaps
- Facilitate available funding
- Identify barriers

2030 Milestones:

6 GW	100 PJ	400 PJ	>EUR 9 bn	5,000 FTEs
Dedicated offshore wind	Hydrogen production	Addressable hydrogen market	Investments	Job creation

The value chain: Hub and Spoke

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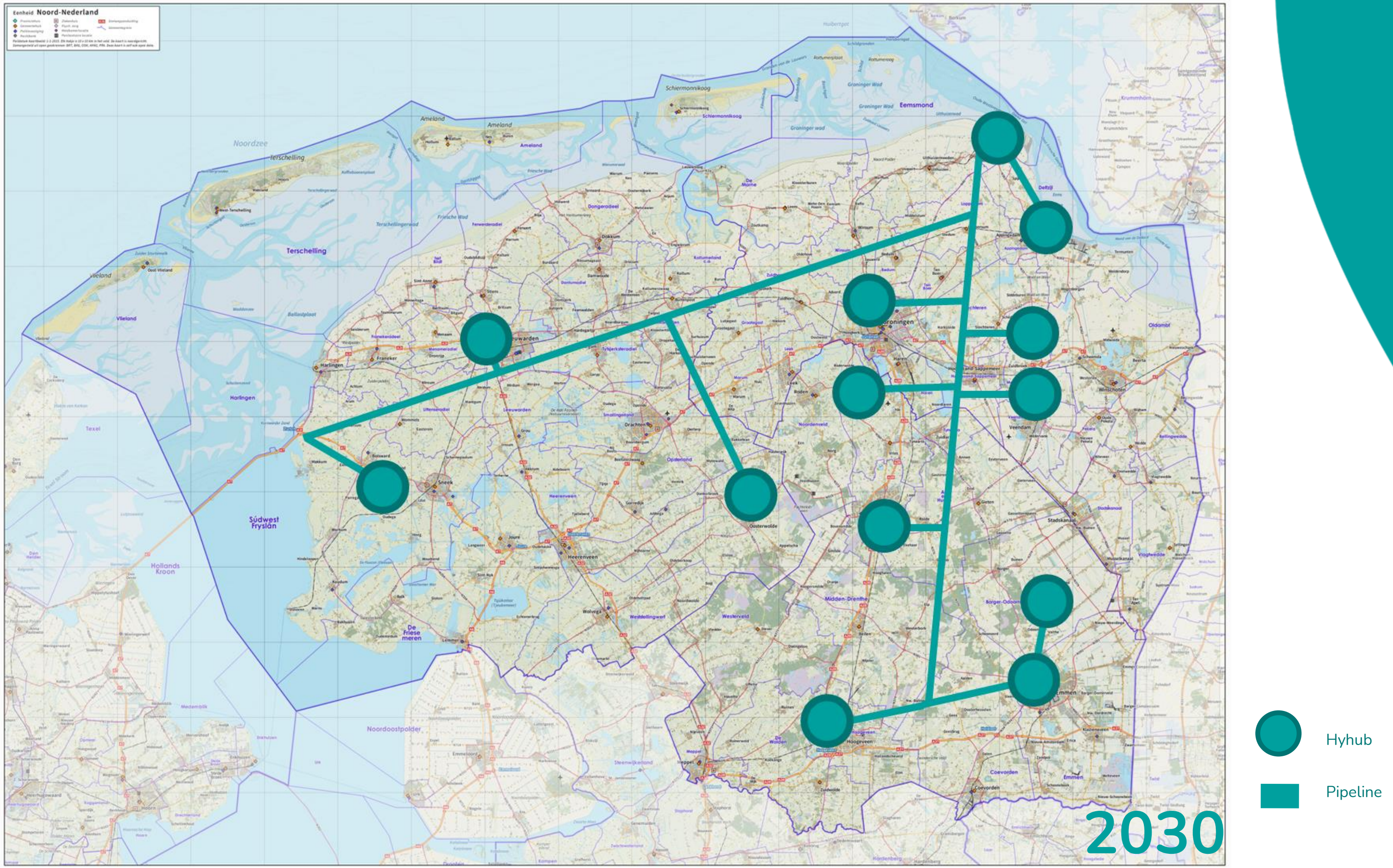
What is the critical mass to get the Northern Hydrogen Valley moving?



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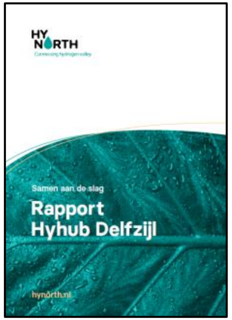

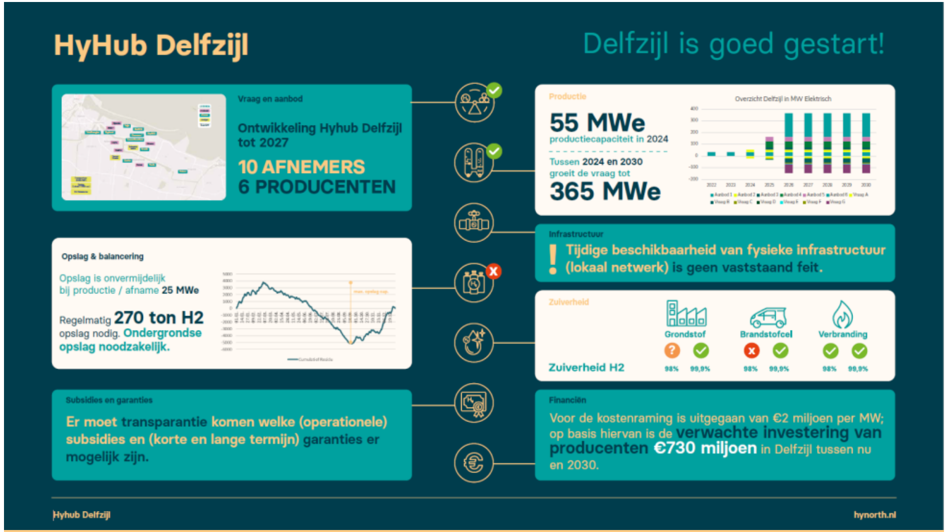

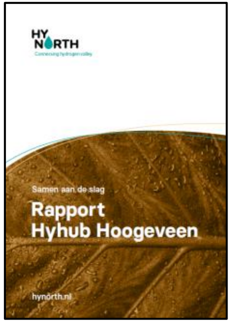

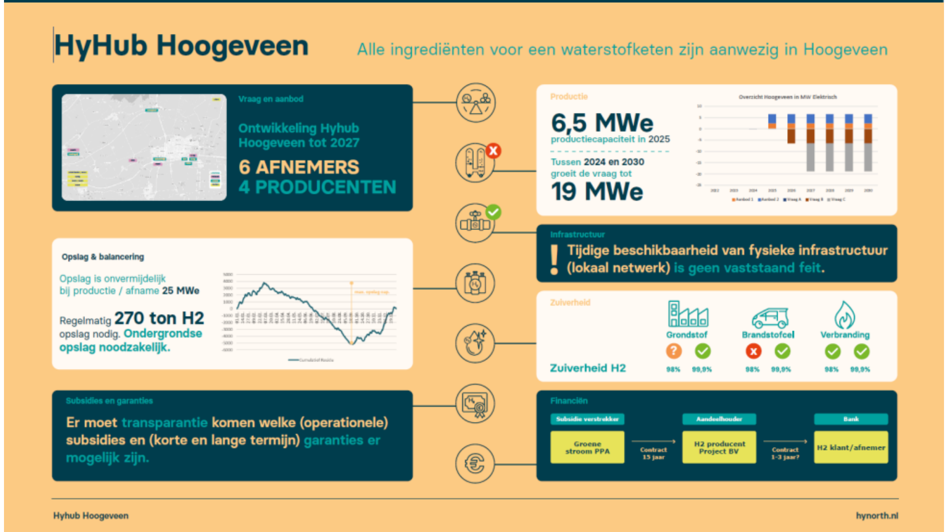

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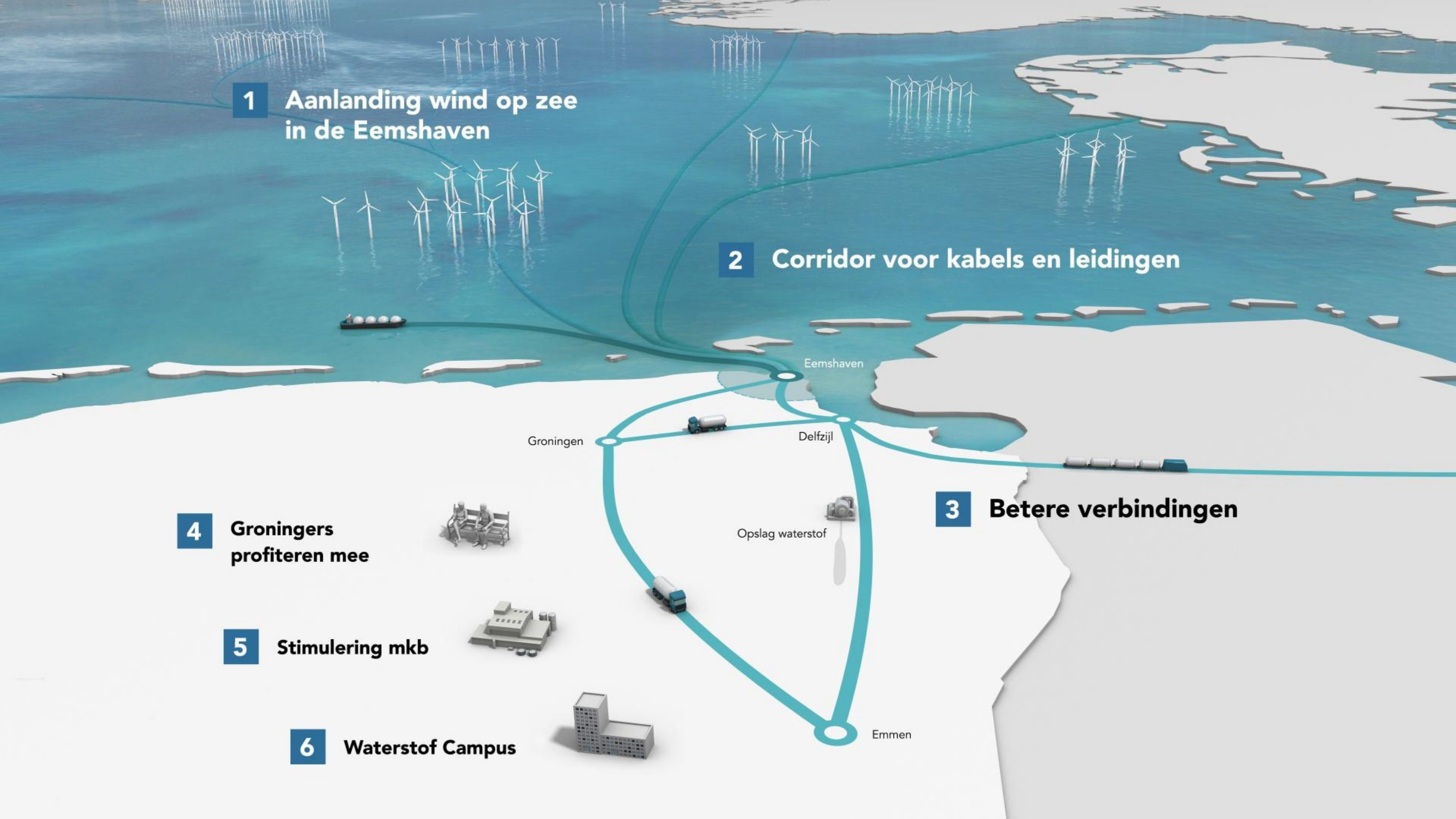
Challenges ahead: coordination required

- Supply & demand uncertain (FID possible?)
- Balancing & storage crucial, but not always recognised
- Hydrogen purity is crucial
- Timely stakeholder engagement essential
- Local chain coordination necessary?
- Access to (offshore) green electricity necessary
- Access to (confidential) information is difficult
- Green H_2 certification unclear (REDII)
- Subsidies, Financing & Price are question marks
- Training/Knowledge/ Change management insufficient priority
- Permits for surface storage
- No clear (tried & tested) regulation
- Role for distribution (public or private)?
- Support of governmental organisations, how to improve?



1 Aanlanding wind op zee in de Eemshaven
2 Corridor voor kabels en leidingen
Eemshaven
Groningen
Delfzijl
3 Betere verbindingen
Opslag waterstof
4 Groningers profiteren mee
5 Stimulering mkb
6 Waterstof Campus
Emmen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Hydrogen in Gas Grids

WP5 - Techno-economic modelling and validation, enablers and interoperability

Salvatore Oricchio, 21.11.2023
WP5 leader, OST
salvatore.oricchio@ost.ch

This project has received funding from the Fuel Cells and Hydrogen 2 Joint Undertaking (now Clean Hydrogen Partnership) under Grant Agreement No. 875091 'HIGGS'. This Joint Undertaking receives support from the European Union's Horizon 2020 Research and Innovation program, Hydrogen Europe and Hydrogen Europe Research.

Agenda

OST – Eastern Switzerland's University of Applied Sciences

- Erste Ebene

3'800 Enrolled students

  - Zweite Ebene

6 Departments

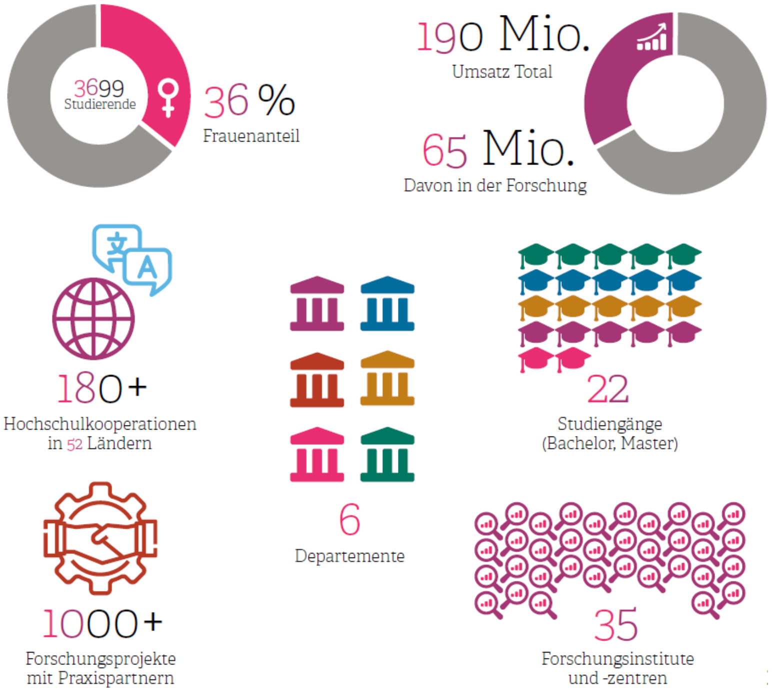
    - Dritte Ebene

1'500 Employees

      - Vierte Ebene

>1'000 Ongoing research projects

        - Fünfte Ebene
          - Sechste Ebene
            - Siebte Ebene



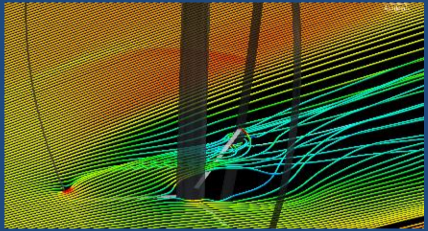
Our expertise @ IET

- We offer our clients and partners interdisciplinary and comprehensive research and services in the following technical fields:

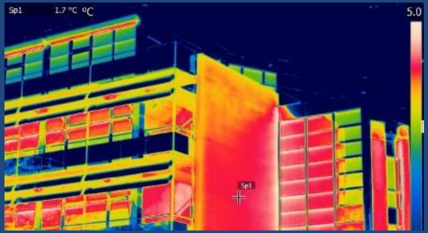
Erste Ebene
- Zweite Ebene
  - Dritte Ebene

Power-to-X / Power-to-Gas

Scientific Computing & Engineering



Building technology



Wind Energy

Electrical Energy Technoglogies

WP5: Goals and objectives overview

HIGGS Hydrogen in Gas Grids

Goal

To develop **operation strategies** and **business implications** of increased and variable contents of H_2 in the high-pressure transmission grid.

Show how **increased H_2 content** in the high pressure gas grid can contribute to the overall goals of **reduced carbon emissions** from the energy sector.

Specific Objectives:

1. **Define case studies** for operator of high pressure gas grids, gas buyers or gas producers injecting hydrogen.
2. **Define generic structures** of the high-pressure transmission grid relevant in the European context.
3. **Compile a numerical model** to describe technical operation and business impacts of high pressure grid.

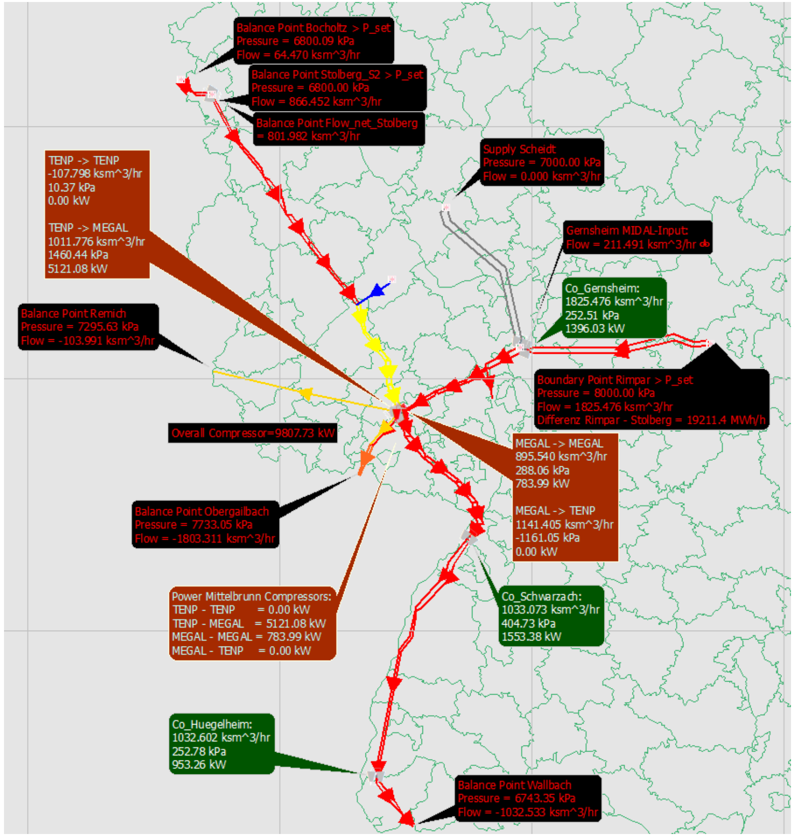
WP5 Deliverables

Deliv.	Deliverable name	Lead participant	Type	Diss. level
D5.1	Report on baseline for the techno-economic model, assumptions and scope	OST	Report	Public
D5.2	Complete description of the model, including case studies	OST	Report	Cons.
D5.3	Intermediate report: key findings on potential and enablers	OST	Report	Public
D5.4	Techno-economic validation: main conclusions and recommendations	OST	Report	Public

https://higgsproject.eu/downloads/

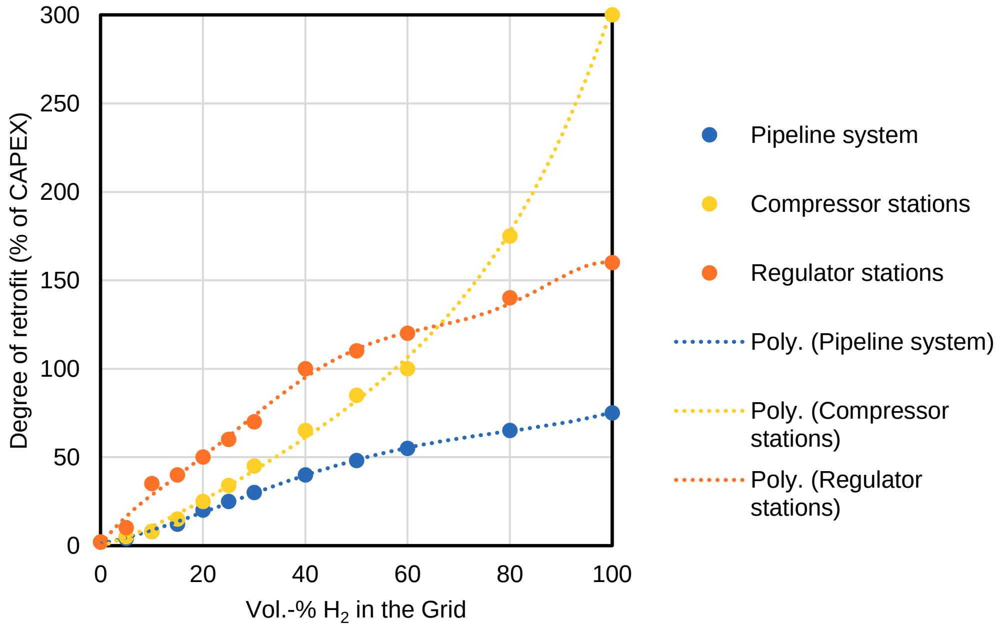
Techno-economic modelling

- Generic topology of TENP/MEGAL modelled with open-source software and imported in network calculation software.
- <u>Modelling scope:</u>
  - Pipelines:
    - Length: ~1560 km
    - Length related Ø-Diameter: ~960 mm
  - Compressors:
    - Units: 7
    - Ø-Capacity per unit: ~50 MW
  - Regulator stations:
    - Units: 20
    - Ø-Flow: ~72'000 m^3/h



Retrofit of the transmission grid

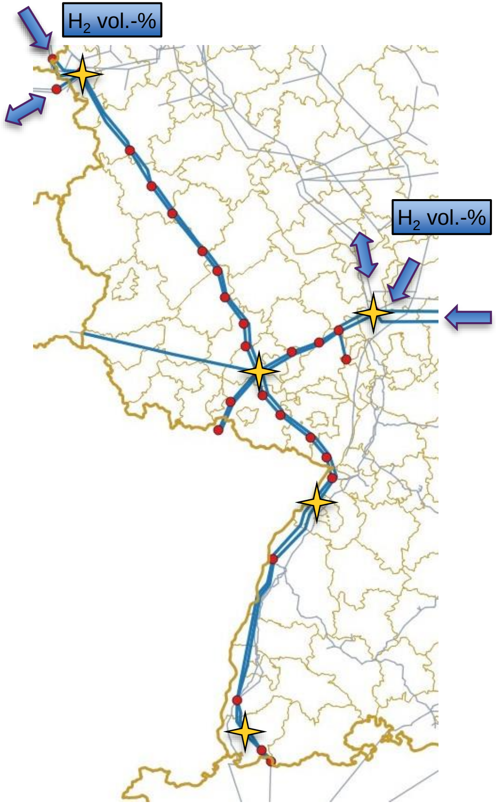
Degree of modification required with respect to hydrogen content:



Parameter	Unit	Value
Electricity price	€/MWh	90
Heat & Gas price	€/MWh	50
O&M cost:		
- Pipeline*	% of CAPEX	2
- Compressor**	% of CAPEX	6
- Regulator station	% of CAPEX	3.5
Interest rate	%	6
Amortisation period	Years	15**, 30*

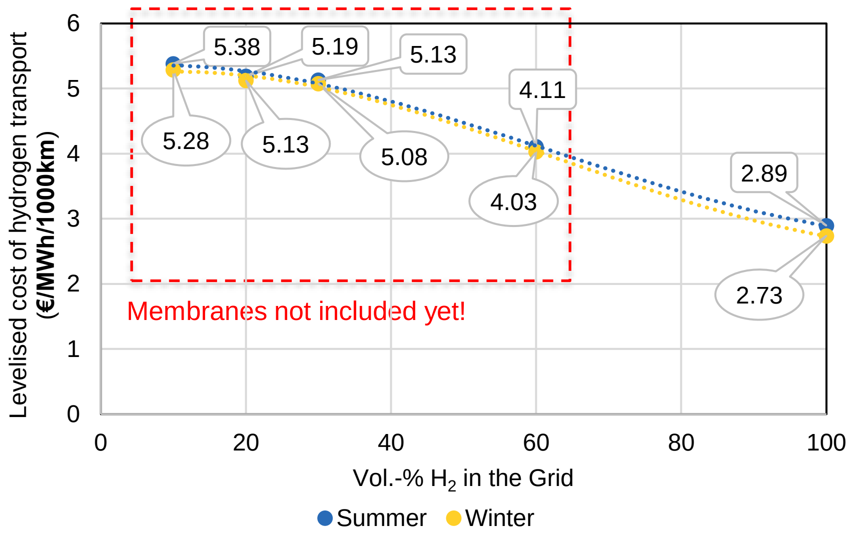
Case 2.1 – Premixed gases at model inlet nodes:

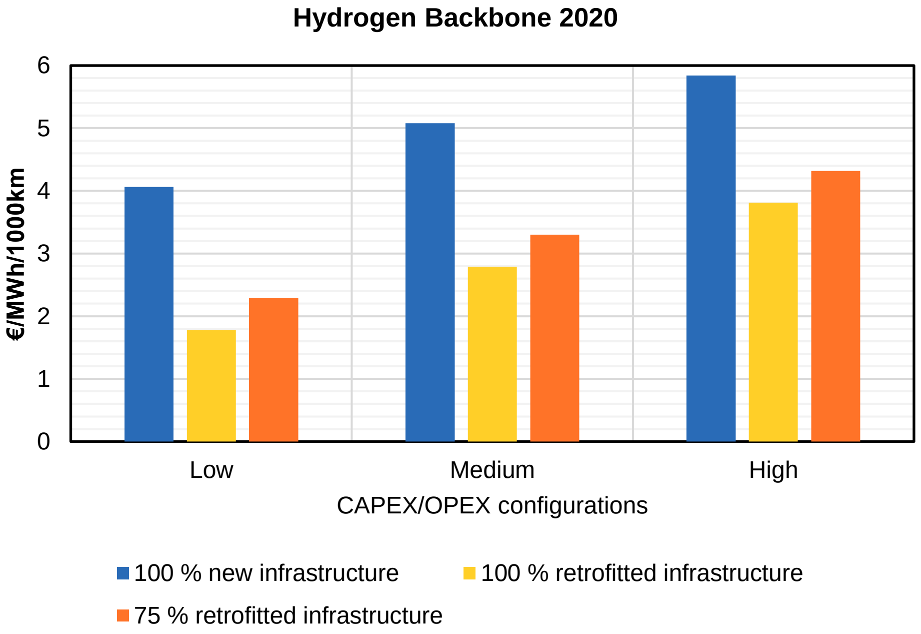
- Assumptions:
  - The network calculations are performed with different admixture levels at the inlet nodes of the model.
  - To be analyzed: **10, 20, 30, 60, 100 (H_2 vol.-%)**
- **Target parameters:**
  - Fixed OPEX:
    - Maintenance and operation cost for transport systems
  - Variable OPEX:
    - Compression work for gas transport
    - Energy expenses for preheating at regulator stations
  - CAPEX for system retrofit
  - Levelised cost for hydrogen transport (€/MWh/1000km)



Modelling not considering gas separation technologies

Case 2.1 – Premixed gases at model inlet nodes: Results





Modelling not considering gas separation technologies

Case 2.1 – Premixed gases at model inlet:

- Comparison with
  - Pipeline (compressed)
  - Truck (compressed, LOHC)
  - Ship (liquified)
- **Pipelines most cost effective**
  - Especially for long distance
- Low volumetric density speaks against large scale transport by truck
  - less critical for LH2 but energy requirement and infrastructure needed impact cost negativly

Comparison with other means of transport

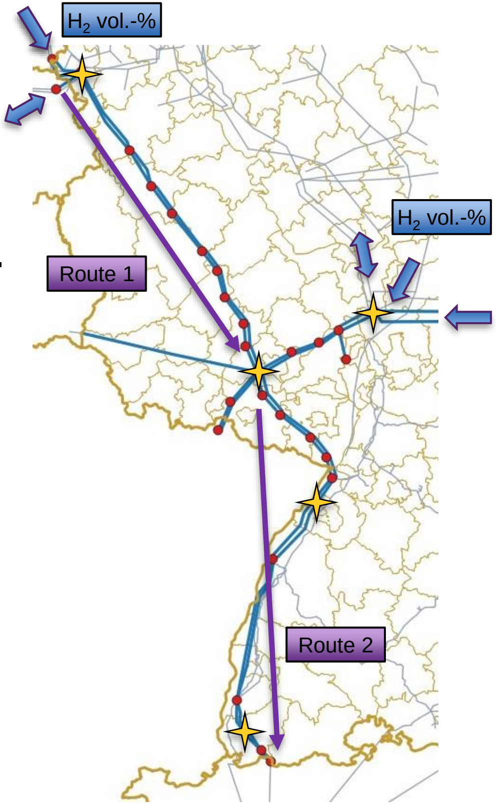
Form	Mean of transport	€/MWh/1000km	Source
CGH_2	Pipeline	2.7 – 5.8	WP5 HIGGS
CGH_2	Pipeline	2.3 – 4.3	[1]
CGH_2	Pipeline	2.5 – 14.5	[2]
CGH_2	Truck	17 – 43	[2]
LH_2	Ship	> 15	[2]
LH_2/LOHC	Truck	24 – 97	[2]

[1] Rik van Rossum, Jaro Jens, Gemma La Guardia, Anthony Wang, Luis Kühnen, Martijn Overgaag. 2022. *European Hydrogen Backbone*. *A European hydrogen infrastructure vision covering 28 countries*. EHB
[2] Bhavnagri, K. Hydrogen Economy Outlook. Key messages.

HIGGS Hydrogen in Gas Grids

Case 2.2 – Moderate use of hydrogen:

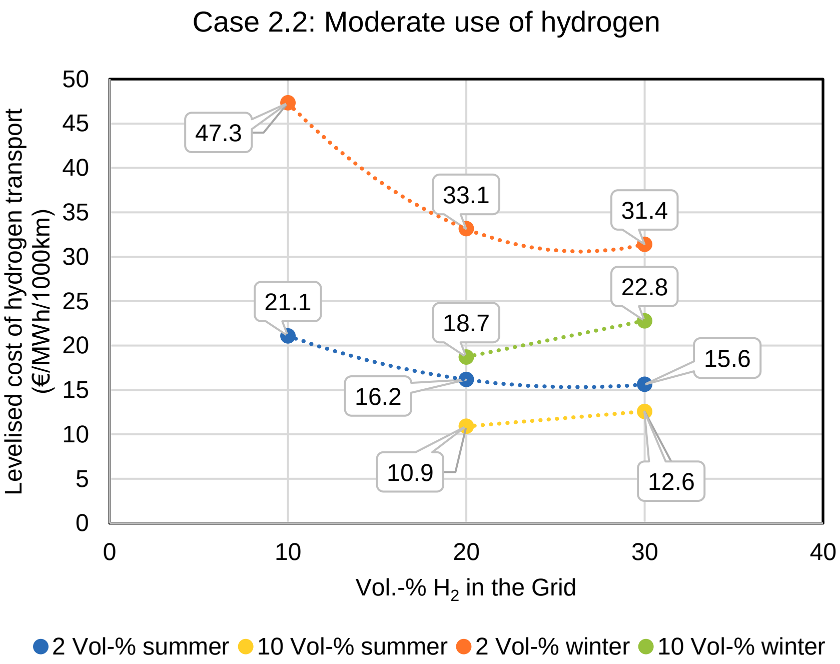
- Assumptions:
  - All exit nodes are equipped with membranes (units).
  - Non-target product from separation is reinjected into the grid.
  - To be analyzed: **10, 20, 30 (H_2 vol.-%)**
- **Target parameters:**
  - OPEX (fixed and variable)
  - CAPEX for system retrofitting and membranes
  - Levelised cost for hydrogen transport (€/MWh/1000km)
  - Comparison with hydrogen transport via…
    - Pipeline system for pure hydrogen (new)
    - Road by trucks and trailers (CH_2, LH_2)



Modelling considering gas separation technologies

Case 2.2 – Moderate use of hydrogen:

- Significantly higher transport costs when including separation
  - Approx. 5 €/MWh/1000km without separation
  - 2–9.5x higher transport costs with separation
- Major seasonal differences in transport costs
  - Higher amount of H2 in during winter in this analysis
  - Higher CAPEX/OPEX for separation & re-injection
- Reduction in transport costs when higher Vol-% of H2 is allowed in permeate
  - less energy demand for separation
  - Less membrane area needed



Modelling considering gas separation technologies

Case 2.2 – Moderate use of hydrogen:

- Due to seasonal diffrences cost-optimal transport medium not so clear as before
  - In summer cheaper by pipeline, but only when > 20 vol.-% H2 in the mix
- LH2:
  - By ship: lack of shipping routes
  - By truck: lack of demand that justifies extra expenditure for liquification
- Leaves only truck and LOHC
  - However, big overlap with in costs as can bee seen in the table

Comparison with other means of transport

Form	Mean of transport	€/MWh/1000km	Source
CGH_2	Pipeline	10.9 – 47.3	WP5 HIGGS
CGH_2	Truck	17 - 43	[2]
LH_2	Ship	> 15	[2]
LH_2/LOHC	Truck	24 - 97	[2]

[2] Bhavnagri, K. Hydrogen Economy Outlook. Key messages.

D5.3 Techno-economic modelling: Key finding

HIGGS Hydrogen in Gas Grids

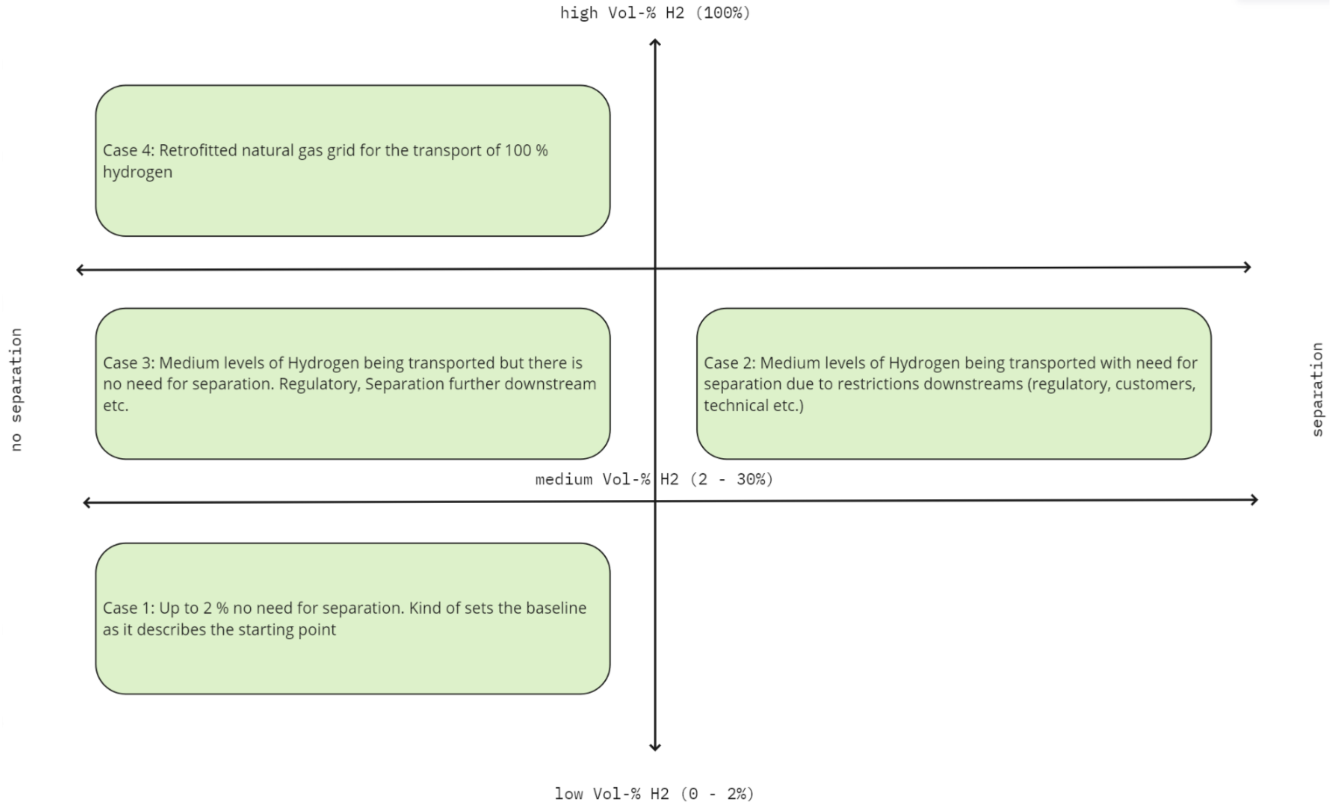
Retrofitting European gas grid

- Some conditions that should be fulfilled when considering a retrofit:
- Existence of (parallel) natural gas pipeline networks, at least parts of which could be converted to transport hydrogen.
- Ensuring gas supply to consumers during and after the conversion
  - free capacities for natural gas transport
  - alternative supply routes
- Acceptance of the hydrogen market in the regions serving this hydrogen corridor.
- synchronous development of supply and demand for green hydrogen

Cross border transport

- “Problem”: non-harmonised hydrogen concentrations in the mixture with gas EU-wide
  - Need for separation
  - Need for measuring equipment
  - Need for redundancy

- ➢ Negatively affecting costs and therefore competivness
- ➢ EU Gas Package sets treshold up 5 vol-% H2 at border interconnection points


high Vol-% H2 (100%)
Case 4: Retrofitted natural gas grid for the transport of 100 % hydrogen
no separation
Case 3: Medium levels of Hydrogen being transported but there is no need for separation. Regulatory, Separation further downstream etc.
Case 2: Medium levels of Hydrogen being transported with need for separation due to restrictions downstreams (regulatory, customers, technical etc.)
separation
medium Vol-% H2 (2 - 30%)
Case 1: Up to 2 % no need for separation. Kind of sets the baseline as it describes the starting point
low Vol-% H2 (0 - 2%)

D5.4: Main recommendations

HIGGS Hydrogen in Gas Grids

Technical point of view

- **Compatibility assessment**
  - Check if the gas grid infrastructure can safely handle hydrogen
  - Hydrogen has different material compatibility requirements compared to gas
  - Evaluate the integrity of pipelines, valves, compressors, and other equipment
- **General system retrofit**
  - Identify necessary retrofit or modifications based on an inventory of the affected grid section(s)
  - Upgrade and/or replace pipelines, install hydrogen-specific equipment, implement safety measures, adjust control- and monitoring systems
- **Blending ratio**
  - Determine the optimal blending ratio of hydrogen and gas depending on the local circumstances
  - Start with low percentages and gradually increase them to ensure compatibility, safety, and experience
  - Consider factors such as hydrogen supply availability, local regulations, and end-use requirements
- **Separation technology**
  - Use separation of gas and hydrogen selectively where applications further downstream cannot be adapted to the new mixture or can only be adapted slowly
  - Separation technology can enable cross-border transport of hydrogen by adhering to permissible concentrations
- **Hydrogen dedicated grid**
  - Repurpose parts of the existing gas grid for the use of 100% hydrogen in the long term
  - Retrofit individual pipelines where several pipelines run in parallel as a first step
  - Demand for hydrogen in the EU and UK will be around 2150 - 2750 TWh by 2050, which is 20 - 25 % of final energy consumption [EHB]
  - Domestic production potential of green (and blue) hydrogen far exceeds this demand
  - Transporting pure hydrogen in a dedicated grid is the most cost-effective option [D5.3]

D5.4: Main recommendations

HIGGS Hydrogen in Gas Grids

Economic point of view

- **Cost-benefit analysis**
  - Evaluate the economic viability of retrofitting depending on the local circumstances
  - Consider the costs of infrastructure upgrades, equipment modifications, safety enhancements, and ongoing maintenance
  - Compare the potential benefits such as reduced carbon emissions or compliance with renewable energy targets
  - Cost for transport of hydrogen vary significantly depending on the business case chosen
- **Hydrogen supply**
  - Assess the availability, cost, and reliability of hydrogen supply in the region
  - The goal is to offer green hydrogen in a cost-efficient way compared to other generation sources, with full cost accounting → A price for CO2 is needed
    - To compete with e.g. grey hydrogen, green hydrogen must be supplied at 2 €/kg with a CO2 price of at least 100 €/t [EHB]
- **Regulatory environment**
  - Push local and national regulations related to hydrogen blending
  - Incentives, grants, favorable policies or national strategies for hydrogen integration
- **Stakeholder engagement**
  - Engage with stakeholders, including gas grid operators, energy providers, industry partners, and local communities
  - Collaborative efforts and partnerships can help share the costs and risks associated with retrofitting
- **Long-term planning**
  - Consider the short- and mid-term viability and sustainability of hydrogen blending in the gas grid before eventually switch to a 100 % hydrogen grid
  - Evaluate future energy market trends, technological advancements, and potential scalability of hydrogen production to ensure the economic benefits can be sustained over time

D5.4: Conclusions

- **Discussed future gas grids offer specific opportunities and risks, but also many overlaps:**
  - Opportunities: Reduced carbon emissions, increased renewable energy integration, improved energy security and flexibility and new markets and customers
  - Risks: Technical and regulatory challenges, high upfront costs, uncertain demand and supply and public acceptance/awareness
- **Gaps that need to be closed:**
  - Legal barriers: need for new laws to regulate, simplify and promote hydrogen transport in Europe
  - Supply and demand: scaling up green hydrogen production and seasonal storage of renewable energy
- **Local conditions influence the direction of gas grid development: supply, demand, infrastructure, regulations**
  - Different solutions may emerge in the short to medium term depending on local conditions
  - Long term need for a holistic European solution that increases cooperation and resilience
- **WP5 final statement: Hydrogen in the gas grid can be economically competitive compared to other means of transport and is necessary to meet the emission targets**

HIGGS

Hydrogen in Gas Grids

THANKS FOR YOUR ATTENTION!

FOUNDATION FOR THE DEVELOPMENT OF NEW HYDROGEN TECHNOLOGIES IN ARAGON

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ERIG

Clean Hydrogen Partnership

This project has received funding from the Fuel Cells and Hydrogen 2 Joint Undertaking (now Clean Hydrogen Partnership) under Grant Agreement No. 875091 'HIGGS'. This Joint Undertaking receives support from the European Union's Horizon 2020 Research and Innovation program, Hydrogen Europe and Hydrogen Europe Research.

No.	Topic	Who	Duration
	Welcoming-Breakfast (8:30-9:00)		
TOP1	Introduction to the project Joint Undertaking programm overview and projects on gas grids	Dr. Javier Sánchez Laínez (Aragon Hydrogen Foundation) Dionisis Tsimis (Project Officer Clean hydrogen Partnership)	9:00 - 9:25
TOP2	**<u>Keynote:</u> H_2 suitability of steels (SyWest H_2)** **Behavior of the gas grid to hydrogen admixing. Results of the experimental campaign** Discussion and questions	Tillmann Wiegold (Open Grid Europe) Dr. Virginia Madina (Tecnalia) Dr. Javier Sánchez Laínez (Aragon Hydrogen Foundation) ERIG / Audience	9:25 - 10:25
	Break (10:25-10:55; Coffee)		
TOP3	**<u>Keynote:</u> Growing Hydrogen in the EU** **Technoeconomic validation and modelling, enablers and interoperability considerations** Discussion and questions	René Schutte (Gasunie) Salvatore Oricchio (Eastern Switzerland University of Applied Sciences) ERIG / Audience	10:55 - 11:55
TOP4	**<u>Keynote:</u> Perspectives on Hydrogen in the EU** **Pathway towards integrating H_2 in EU gas networks** Discussion and questions	Alberto Cerezo Alarcón (Redexis) Dr. Michael Walter (DVGW German Technical and Scientific Association for Gas and Water) ERIG / Audience	11:55 - 12:55
TOP5	Closing	Dr. Javier Sánchez Laínez (FHA)	12:55-13:00

Perspectives on Hydrogen in the EU
Pathway towards integrating H_2 in EU gas networks

Redexis: Insights as TSO

Alberto Cerezo, Redexis

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Hydrogen in Gas Grids

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1 About Redexis…

Redexis is an **energy infrastructure company** that is dedicated to promoting the **energy transition, economic development, and growth**. The company focuses on generating value in the communities where it operates through a sustainable and environmentally responsible business model.

- **Natural gas Transmission.**
- **Natural gas Distribution.**
- **Distribution and sale of piped LPG.**
- **Assets to improve energy efficiency.**
- **VNG and green hydrogen refueling infrastructure.**
- **Injection of renewable gases, such as biomethane and green hydrogen.**
- **Production of renewable gases, such as biomethane and green hydrogen.**
- **Photovoltaic solar energy production.**

Redexis is committed to **the growth of gas infrastructures and energy efficiency**, and dedicated to the **development of renewable gas projects**, such as biomethane or renewable hydrogen, which it aims both to produce and to inject into its distribution and transmission grids, thus contributing to the energy transition and decarbonization, as well as meeting the objectives of the circular economy.

NATURAL GAS NETWORK OPERATOR

- **Redexis is the second largest NG TSO in Spain.**

Its grids have more than 1,645 kilometers and enables the transmission of natural gas to industrial centers and connection points of existing distribution grids in compliance with the prevailing laws and regulations.

- **Redexis is the third largest NG DSO in Spain.**

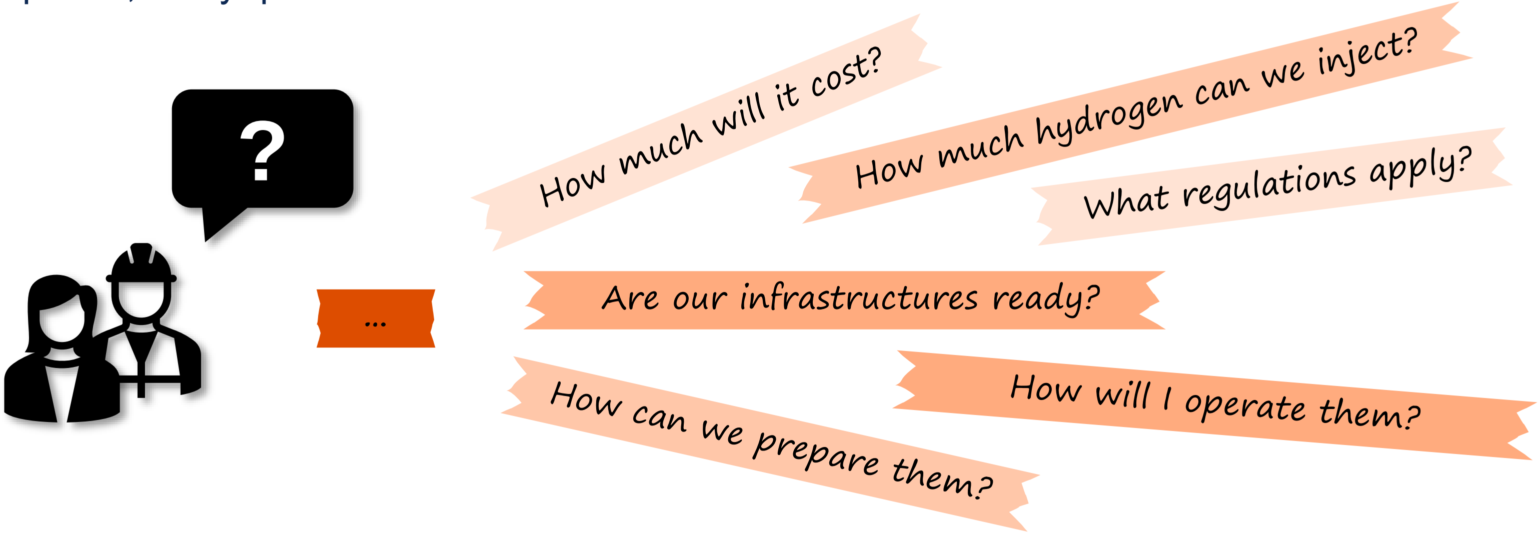
It builds, operates and maintains modern distribution grids that extend over 10,413 kilometers, supplying natural gas to 769,955 connection points across the 12 autonomous communities where it operates.

As for energy passing through its infrastructures, Redexis' total activity during 2022 amounted to 28,893 GWh.

2 HIGGS for us…

Redexis actively promotes the development of renewable hydrogen and its injection into our gas networks.

In this development, many questions arise…



Thus, we are very conditioned by the presence of important **barriers**, among them the **absence of a clear legal, regulatory and normative framework**, and the **lack of knowledge** of the possible **effects** that hydrogen injection can have on our infrastructures, the acceptable **injection levels**,…

HIGGS Hydrogen in Gas Grids

How HIGGS addresses these challenges...

- **Regulatory and normative gaps:** HIGGS Project carries out an analysis of the SoA of European legislation and regulations, identifying existing knowledge gaps and proposing actions to cover them.
- **Technical and technological gaps**: HIGGS Project identifies the materials and elements present in European natural gas transportation networks and analyzes their behavior when facing mixtures of NG and H_2, and when facing 100% H_2, providing useful information to validate these components for a future use of hydrogen in networks.
- **Limitations to the use of NG and H_2 mixtures** in gas networks and final consumers: HIGGS Project develops and tests different membrane technologies for the separation of NG and H_2 mixtures.

The HIGGS Project directly **addresses these challenges**, **providing** on the one hand well-founded **proposals** that should serve as a **basis for developing new specific regulations** on the injection of hydrogen into natural gas networks and, on the other hand, results of practical tests and **specific knowledge** on the behavior of materials and common equipment in transmission networks in the presence of hydrogen.

These contributions are very useful to us to **assess the validity of our infrastructures** in the face of imminent decarbonization scenarios, but above all they serve to **generate trust** at all levels, not only in **gas infrastructure operators**, but also in the **Administration**, **H_2 producers**, **end users** and **society** in general.

a. Regulatory and normative gaps

Current situation and legal and regulatory needs:

- There is a quite diverse picture on the status of national legal and technical framework in regards of hydrogen implementation in Europe.
- European Commission, Council and Parliament are working intensely on the preparation of legislation regarding hydrogen and hydrogen admixtures in NG transmission grid.
- It is necessary to introduce simplifying measures in the processing of renewable hydrogen projects, analogous to those already introduced in the electricity sector, such as:
  - Considering these projects of "public interest" (reducing the administrative deadlines procedures by half).
  - Establishing a procedure for determining exceptional environmental impact that minimizes environmental processing times.
- It is necessary that the connections of hydrogen production plants with the natural gas grid for blending can be considered not only direct lines (private infrastructures) but also distribution or transportation facilities of the gas system, so producers have the choice (and not the obligation) to promote these connection pipelines.

There is already a regulatory framework, but it is temporary, pending the approval of the Gas Package, in any case it requires further development on issues such as the establishment of priorities in the access of H_2 producers for network injection, etc..

3 Redexis' points of view…

HIGGS Hydrogen in Gas Grids

a. Regulatory and normative gaps

GREEN HYSLAND. The Redexis experience

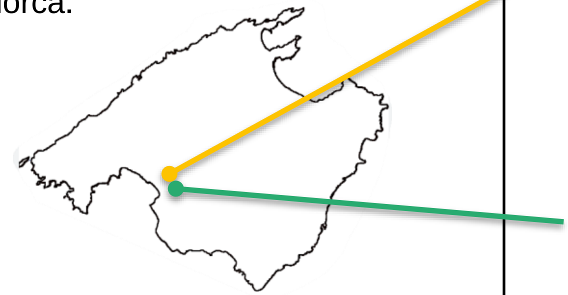
GREEN HYSLAND. First H_2 pipeline and H_2 injection system in the Spanish natural gas transmission grid.

GREEN HYSLAND

Clean Hydrogen Partnership

This project has received funding from the Fuel Cells and Hydrogen 2 Joint Undertaking (now Clean Hydrogen Partnership) under Grant Agreement No 101007201. This Joint Undertaking receives support from the European Union's Horizon 2020 Research and Innovation programme, Hydrogen Europe and Hydrogen Europe Research.

2 facilities necessary for the injection of H_2 into the NG transmission grid of Mallorca.



GREEN HYSLAND Project is developed in parallel to the HIGGS Project.

H2 blending in NG grid (National Administration) — Jan'22 to Dic'22

- Action on a NG transmission facility.
- Gas Sector Regulations applies.
- There are **no specific** national or local **regulations** regarding **blending.**

Processed according to **Gas Sector Regulations.**

Hydrogen pipeline (Balearic Administration) — Oct'21 to Aug'23

- **Local legislation** applies.
- There is a local Legal Framework for Energy Facilities.
- There are **no specific** national or local **regulations** regarding **H_2 pipe**.

Processed according to **Regional Regulations.**

In the processing of these facilities, we suffered from the absence of specific regulations, which meant delays in the final authorizations, construction,…

3 Redexis' points of view…

b. Technical and technological gaps

How to build and operate an H_2 injection facility?

Current situation and standards and codes needs:

- Lack of expertise. Technical knowledge about the injection of H_2 into NG networks and the adaptation of these networks and the experience of engineering or consulting companies are limited or not very accessible.
- There are no European specific standards regarding…
  - The construction of H_2 pipelines or the injection into the natural gas network.
  - The adaptation of NG infrastructure for use with mixtures of NG and H_2, or only H_2.
  - The operation of NG infrastructures when they are used with mixtures of NG and H_2, or only H_2.
- There are some international references and codes (ISO, ASME, etc.), but they are not included in European regulations, nor are they mandatory.
- Technical fundamentals are required by Operators (TSO & DSO) to analyze the technical and economical feasibility of infrastructure adaptation and to define injection projects. Also, on the Administration side, to have criteria for the processing and approval of projects. Also, for H_2 producers, ...

It is necessary to have clear technical criteria that provide safety and trust throughout the chain (producers, operators, administration, consumers, etc.).

b. Technical and technological gaps

GREEN HYSLAND. The Redexis experience

GREEN HYSLAND. First H_2 pipeline and H_2 injection system in the Spanish natural gas transmission grid.

The H_2 pipeline and NG valves node modification projects were prepared by Redexis with the collaboration of usual engineering companies in the gas sector, according to technical criteria for gas installations and based on specific international hydrogen codes.

The selection of pipe and valve materials was carried out according to these codes, and taking into consideration the study of pipe steels carried out at HIGGS.

The blending system was contracted to technological suppliers with (limited) experience in the development of this type of facilities and according to their own technical design criteria.

H_2 Pipeline and H_2 injection point currently under construction

- API 5L Gr. B pipe, Ø 4"
- Length 3.151 meters
- Operating flow rate 575 Tons/year 800 m^3(n)/h (prepared for higher flows).
- Maximum operating pressure 85 bar.

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c. Present and future

Role of gas infrastructure in the energy transition

The **Natural Gas Grid** will play a **key role** in the transition towards renewable energies and in the European energy future, considering different point of views:

1. aligned with European sustainability policies, considrering the use of existing and fully operational infrastructure…

- Built in part based on remuneration terms and therefore paid by everyone.
- Infrastructures that are largely compatible with hydrogen in blending with NG and even or 100% hydrogen. And for low mixing percentages (≤10%) they do not require significant adaptations in the network.
- Infrastructures that reach the end customer and therefore allow direct access to hydrogen.

2. The injection of H_2 into the network can be proposed in several ways…

- Blending of GN ($BioCH_4$) and H_2 (% up to 20%) / Deblending before supply to end users with limitations on the admission of H_2.
- Dedicated use of NG infrastructure with 100% H_2.
- Methanation ($CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$) and injection.

3 Redexis' points of view…

c. Present and future

Role of gas infrastructure in energy transition

Therefore…

The **potential of hydrogen** in Spain and Europe **is huge** if we consider the existing networks that now circulate natural gas but are infrastructures prepared to transport hydrogen.

Europe has shown its great commitment to **sustainability** and in this sense…

- ✓ The necessary means must be enabled to facilitate the different TSOs and DSOs to offer their networks for this new energy vector.
- ✓ The solution of injecting hydrogen into natural gas networks is sustained from an economic point of view, as it is a very reasonable investment solution compared to dedicated hydrogen networks that may be necessary on other occasions.
- ✓ The solution is also sustained from a point of view of social and environmental impact, since it will guarantee less impact on natural resources and better access to this source of energy for all potential users.

This approach is therefore fully aligned with the commitments of the 2030 Agenda and will offer a great opportunity to contribute to the challenge of the energy transition to current natural gas operators.

HIGGS Hydrogen in Gas Grids

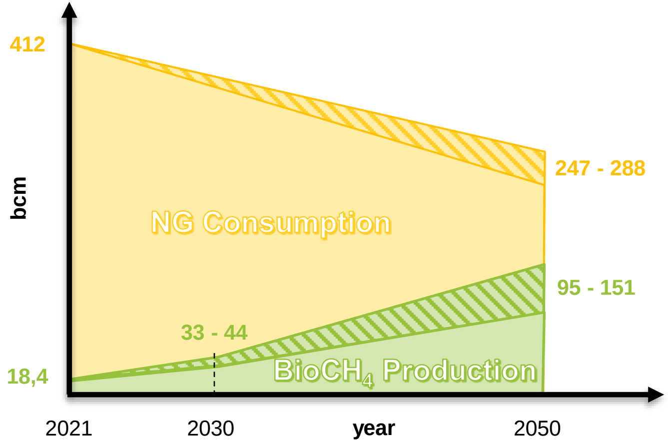
c. Present and future

Blending, a long-term solution?

So, is clear than in the current context of energy transition, hydrogen is one of the key solutions, but having infrastructures 100% dedicated to hydrogen will not happen from one day to the next, and this would also require significant investments not only in transmission and distribution infrastructures, but also in supply and end-users' infrastructures…

Biomethane must also play an essential role in the decarbonisation of the network.

Then, blending can be a short-term solution to start decarbonizing the gas sector and all sector dependent on it (industry, energy, transport, etc.) but, in the long term?



Considering the estimates of the evolution of NG consumption and Biomethane production in Europe*…

- $BioCH_4$ will cover 50 – 65 % NG demand in 2050.
- The remaining 35 - 50% must be covered by other renewable gases, such as H_2.

It will be key to inject hydrogen into the grid with biomethane to fully decarbonise the gas sector, so blending must be considered a long-term solution

(*) NG consumption and biomethane production data from the European Commission, European Biogas Association and The Gas for Climate consortium.

HIGGS

Hydrogen in Gas Grids

Thanks for your attention!!

Alberto Cerezo, Redexis

alberto.cerezo@redexis.es

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1^{st} results of WP 6 – Description of pathway towards integration of H_2 into EU gas networks

Project Closing Event November 21, 2023

Dr. Michael Walter, DVGW e.V.

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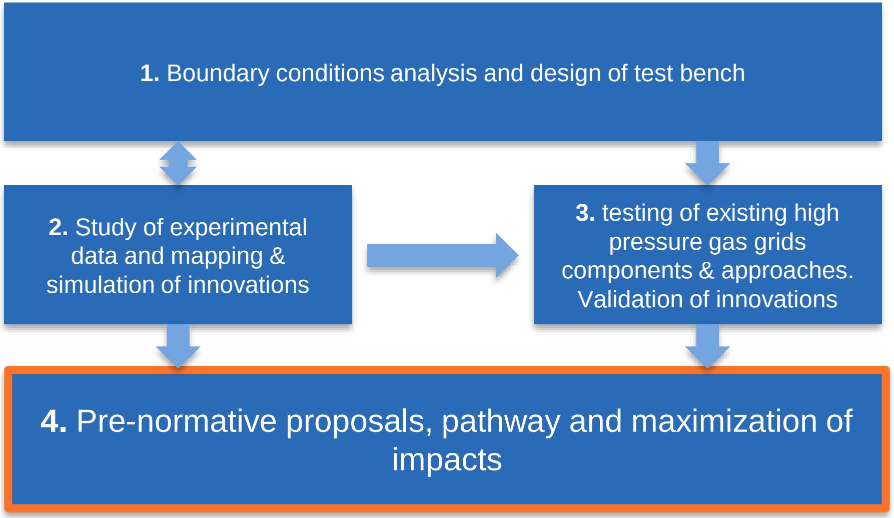
Navigator

1. Work Package 6 and HIGGS Work Scope
2. Potential for H2 injection: alignment with EU policies
3. EU policies and hydrogen admixtures in transmission grids
4. Conclusion

Work Package 6 and HIGGS Work Scope

HIGGS Hydrogen in Gas Grids

- **6.1 Potential for H2 injection: alignment with EU policies**
- **6.2 Interoperability, cross-border issues and gas market management and strategies**
- **6.3 Preparing a pathway and set proposals towards a higher acceptance of H2 in EU gas grid network**
  - Optimal design for H2 injection and mixing systems
  - Gas market and operation considerations
  - Regulations, codes, standards



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DVGW

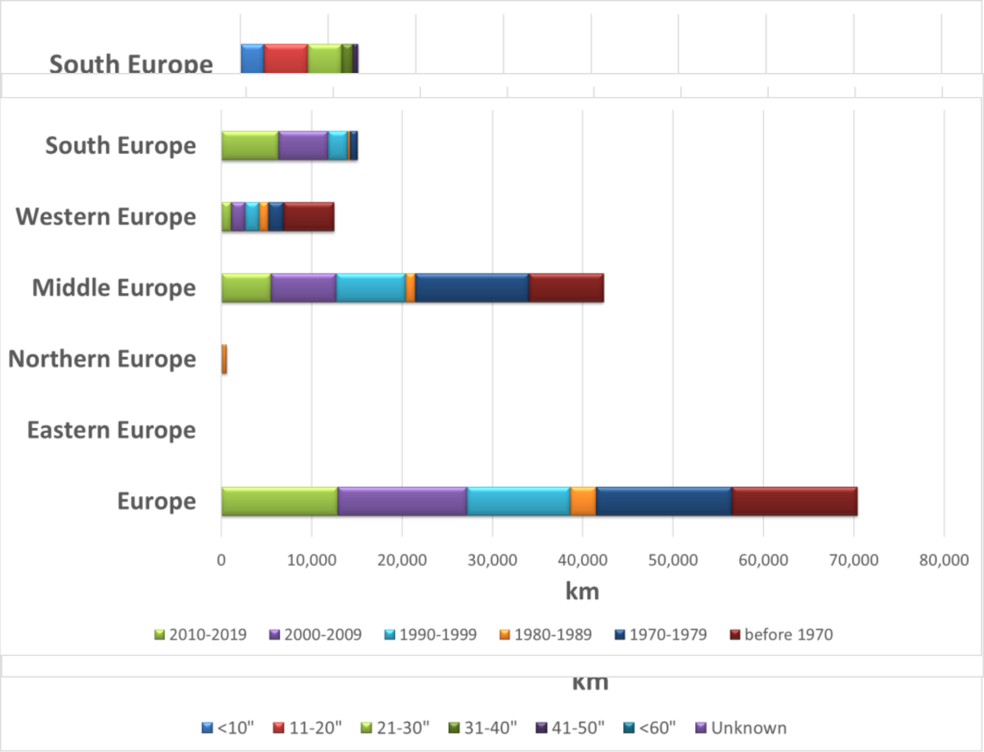
Redexis

Potential for H2 injection: alignment with EU policies

- Inventory of the EU gas grid by survey

- Analysis of EU countries legally allowed H_2 concentration in gas grid

- Alignment with EU policies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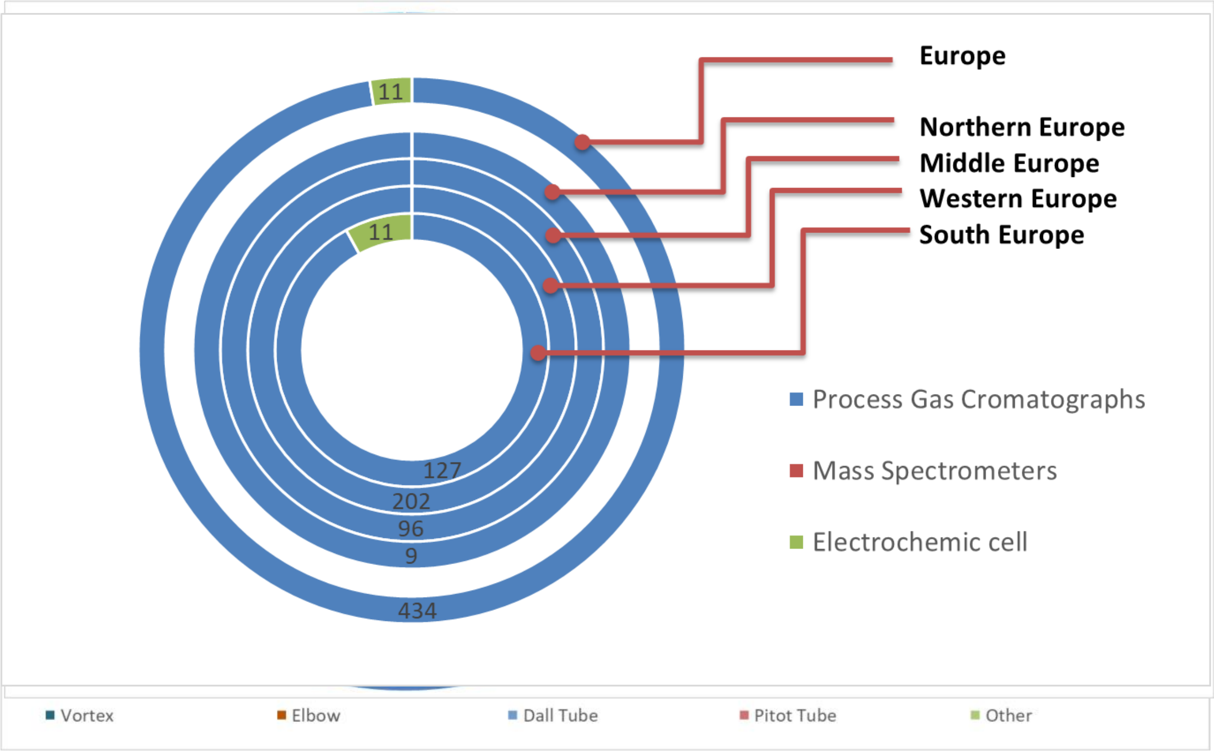
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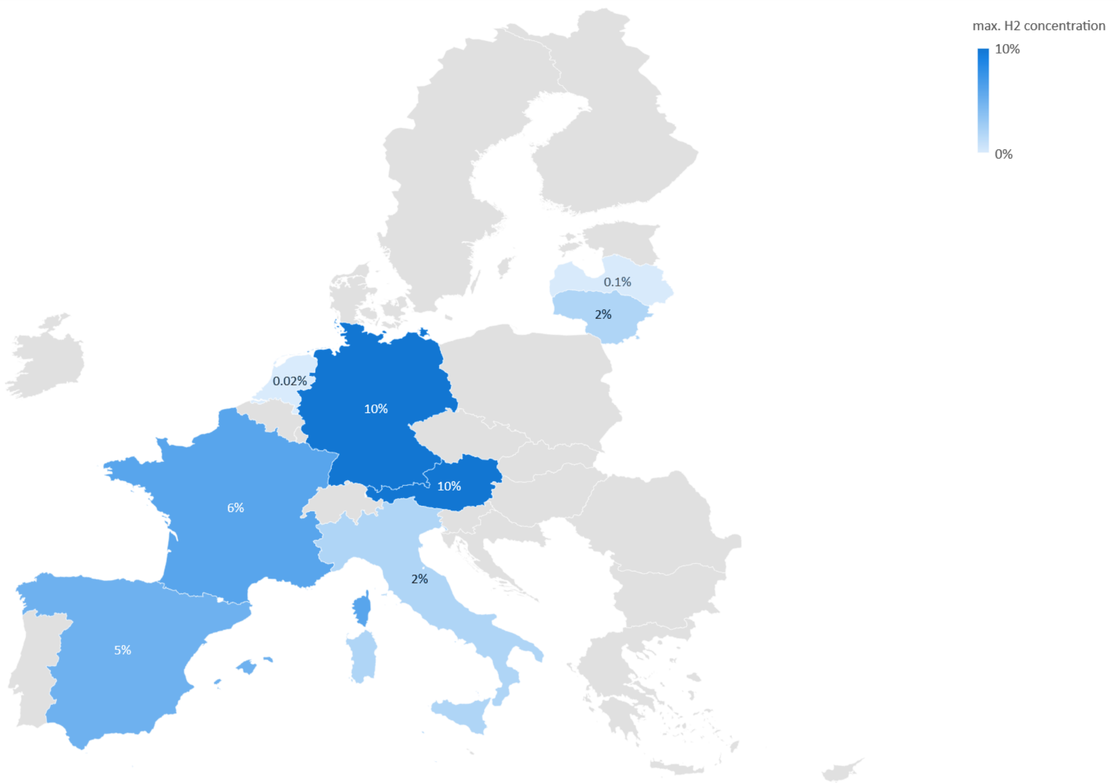
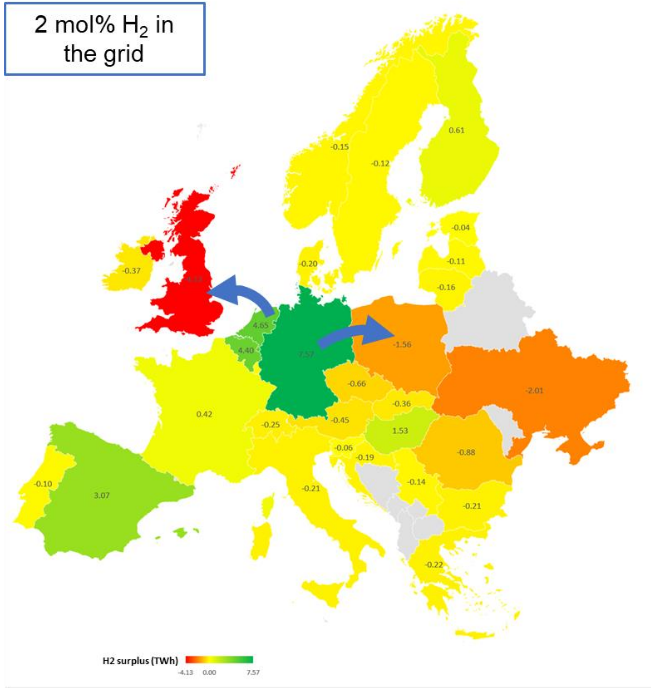
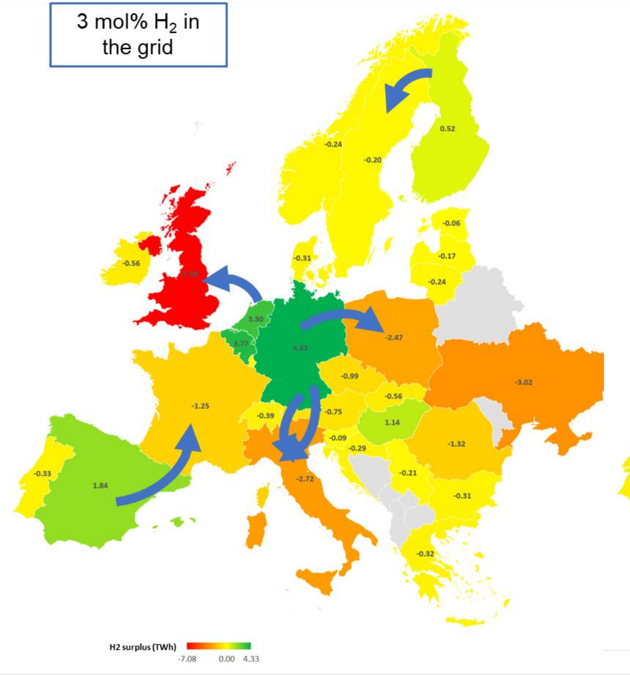
11
127
202
96
9
434
Process Gas Cromatographs
Mass Spectrometers
Electrochemic cell
Vortex
Elbow
Dall Tube
Pitot Tube
Other

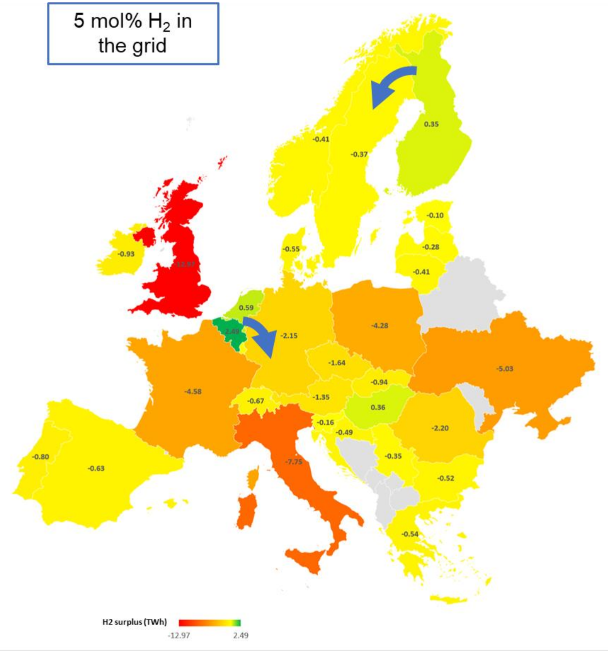
Hydrogen concentration legally admissible in national grids



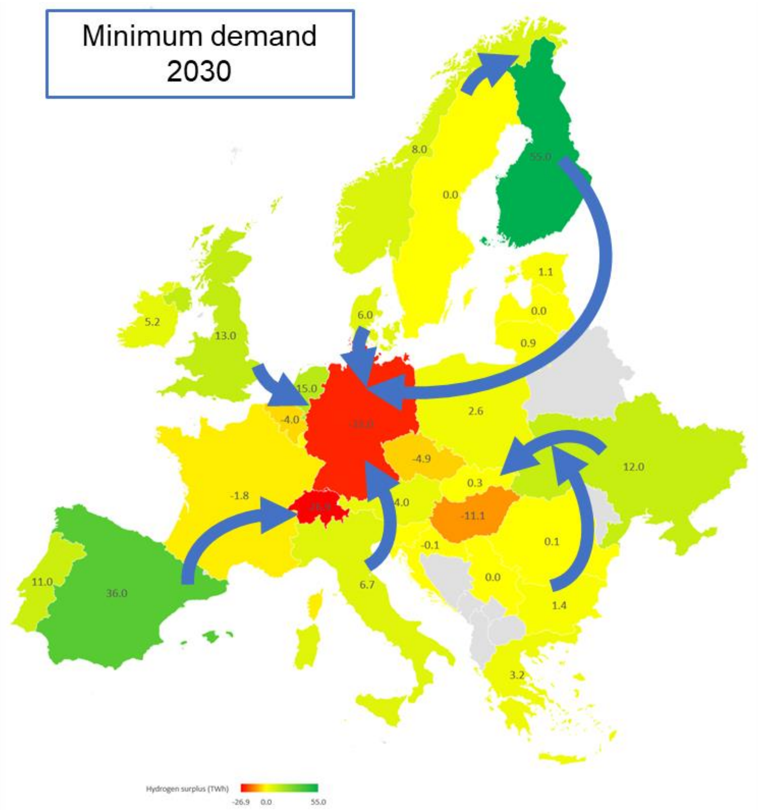
Hydrogen surplus if injected to dedicated concentration levels

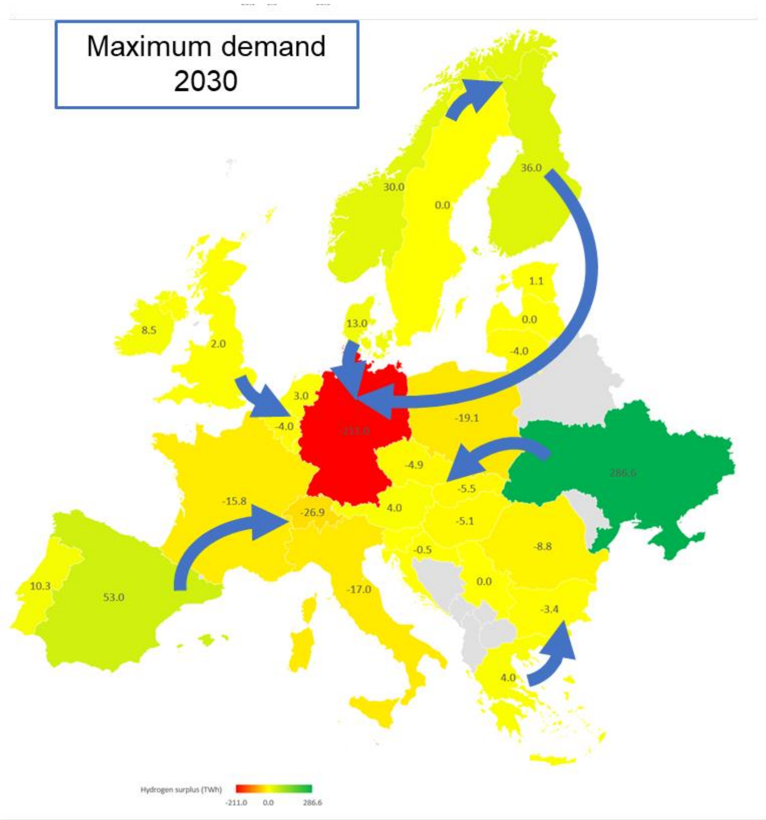




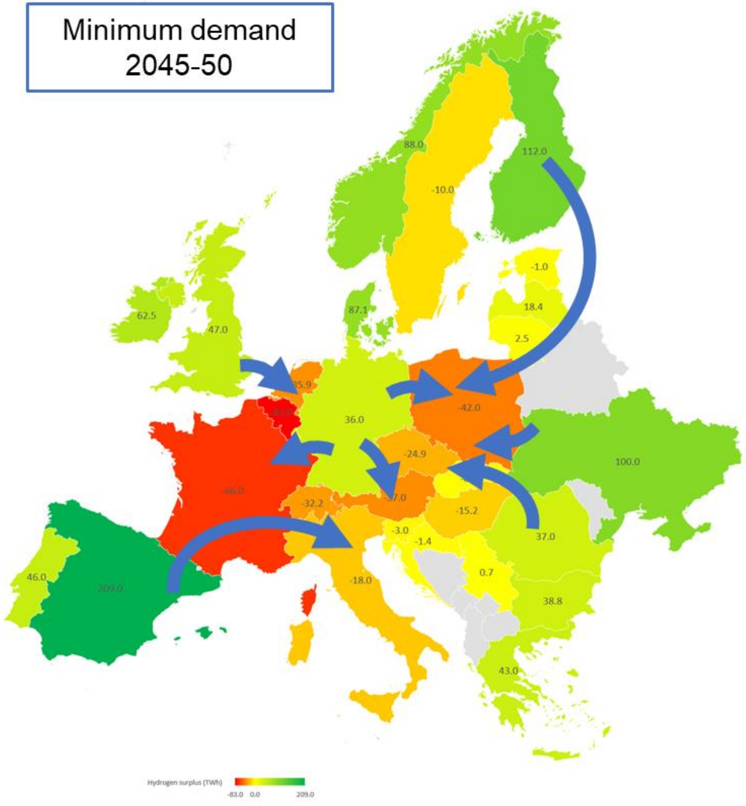


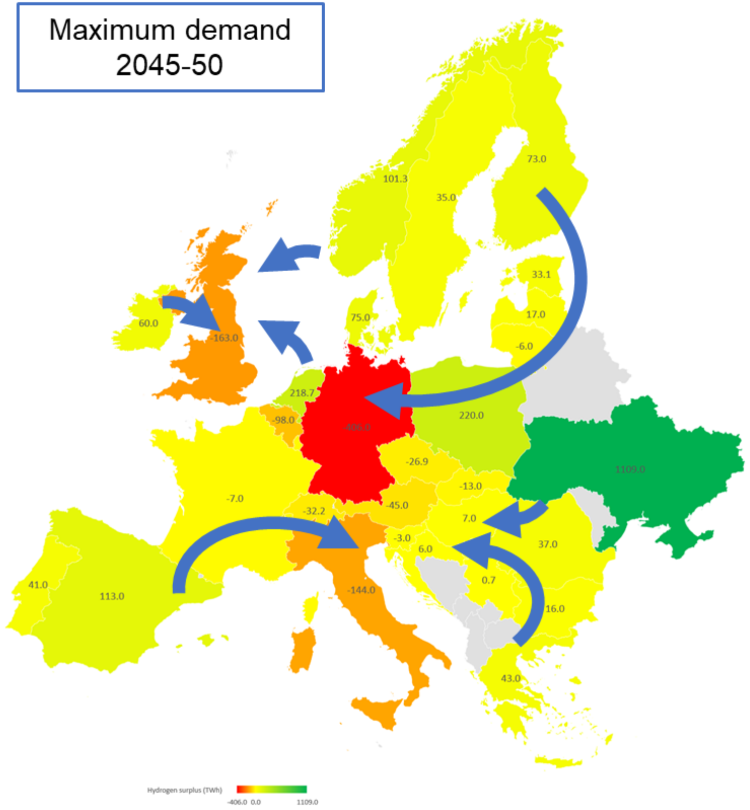
Future Scenarios – Midterm 2030





Future Scenarios – Longterm 2045 - 2050





EU policies and hydrogen admixtures in transmission grids

EU policies with direct impact

1. TEN-E regulation - Regulation on Guidelines for Trans-European Energy Infrastructure - guidelines
   - development and interoperability of trans-European energy infrastructure including hydrogen
   - ensuring interconnections, energy security, market and system integration and competition
2. EU Gas Directive - DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on common rules for the internal markets in renewable and natural gases and in hydrogen

   → max. 5% H_2 concentration at cross-border interconnection points

Conclusion

- EU transmission grid is suitable
- Huge potential for injecting hydrogen
- EU hydrogen picture
  - Some countries suppliers
  - Some countries demander

  → considered hydrogen production is water electrolysis hydrogen
  → need to cover other renewable hydrogen sources
- Admixing H_2 most likely not happening due to EU Gas Directive
  - Not in cross-border transmission grids
  - Different story in single EU countries → determined by national legislation
  - Admixing most likely in distribution grids

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HIGGS

Hydrogen in Gas Grids

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