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Technical Association of the European Gas Industry

MARCOGAZ TECH FORUM ON HYDROGEN SAFETY

27th October 2022

WELCOME

House Rules

- This Webinar is being **recorded**.
- All participants should **mute** themselves during the Tech Forum.
- We will have the **Q&A session** after all four presentations, and we will be pleased to accommodate your questions during this session.
- To ask a question, you may drop them into the chat, we kindly ask you to write **your name and your company** before your question.
- **Welcome**, we hope that you will find our webinar insightful.

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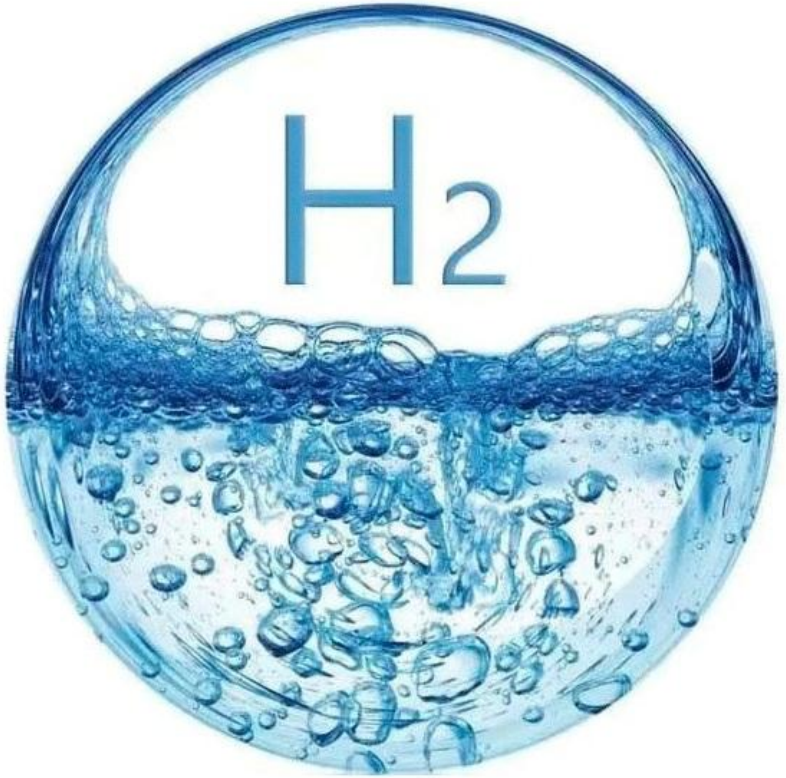
Introduction

MAREK WŁODARCZYK, Health and Safety and Fire Protection Specialist at Polska Spółka Gazownictwa

Hydrogen Tech Forum Marcogaz

MAREK WŁODARCZYK, Health and Safety and Fire Protection Specialist at Polska Spółka Gazownictwa



27 October 2022

Hydrogen – fuel of the future

Chances and dangers

How to meet hydrogen safety challenges

The special safety challenges of hydrogen

Chances and dangers

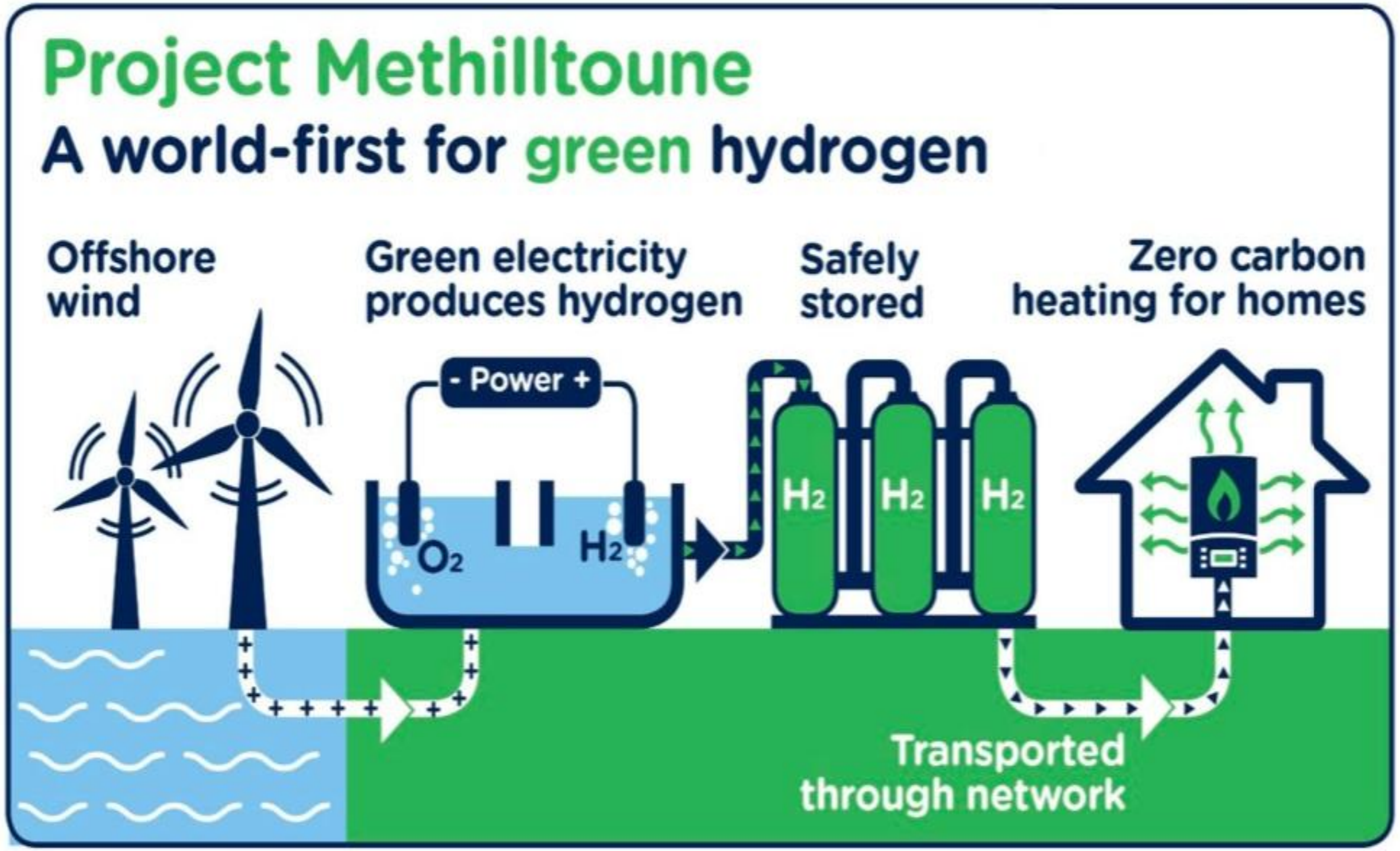
Assessing the risks – planning for safety

Hydrogen is the lightest gaseous chemical element, making up more than two-thirds of the total cosmic mass. It is estimated to be over 30% of the total mass of the Sun. It is the third most a common element on Earth. Currently, it is reported that 96% of the world's hydrogen production comes from fossil fuels, mainly as a result of the so-called steam reforming of natural gas. It is currently the cheapest production technology hydrogen

In a global shift towards carbon-neutral renewable energy sources, demand for more sustainably sourced hydrogen is increasing. Wind and solar farms have the option to produce this “green” hydrogen, but this presents new major safety hazards on their sites, due to the flammability and explosive properties of H2. Especially at the start of production, hydrogen is highly pressurised and highly flammable. The flame itself is virtually invisible, which means production of hydrogen require excellent safeguards against hydrogen explosions.

How to meet hydrogen safety challenges

Hydrogen it self is not toxic, but it poses special risks to safety on plants and for the infrastructure which produce, distribute or use it.



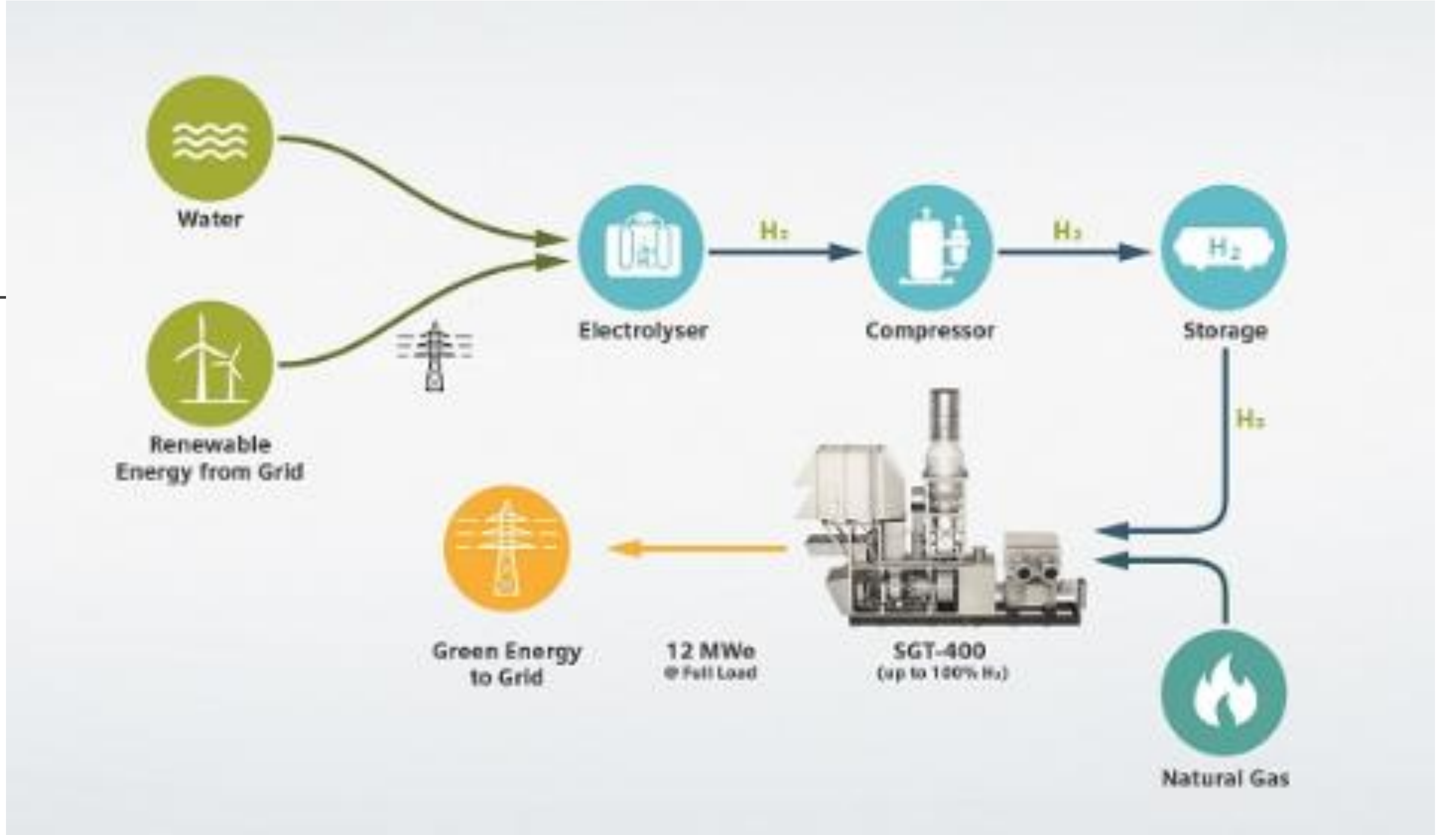
To handle them needs expert knowledge in all phases of the process.

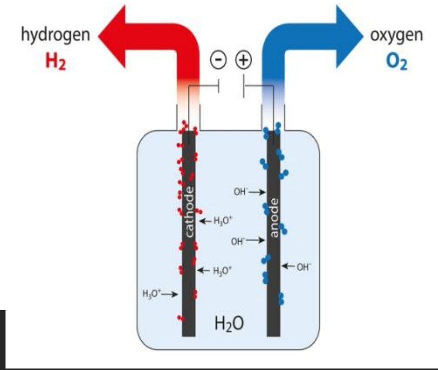
From transportation to heating, hydrogen is set to play a major role in the energy mix as countries move to decarbonise their economies. But with organisations in both the public and private sectors taking their first steps into the emerging hydrogen economy safety awareness could be due an update – both to reduce risk exposure through good preparation and safeguards, and to build confidence in the new technology as an energy source for the future.

How to meet hydrogen safety challenges

Applications and safety considerations:

- Hydrogen production
- Storage and distribution
- Safety consumption





The special safety challenges of hydrogen

Hydrogen is increasingly used by organization's to replace other fuels. Many of these new hydrogen users, although otherwise safety-aware in their systems and procedures, may be unfamiliar with the special challenges, safeguards and infrastructure required with hydrogen. Some may have knowledge of working with LPG as a fuel, for instance, but this has only limited applicability for working with hydrogen.

For this we have to create procedures on fundamental risk and safety issues to safe practice in system maintenance, the retips are in great demand practical aspects of working with hydrogen.

EXPLOSION

Unlike actual explosives, pure hydrogen cannot explode. The risk comes when it hits the air. For hydrogen to cause an explosion, oxygen needs to be present, and its volumetric concentration needs to be between 4 % and 77 % by volume in air, the Lower and Upper Explosion Levels (LEL and UEL). But if hydrogen is allowed to escape, even a static spark from clothing would be enough to set off an explosion.

INVISIBLE FLAME

Hydrogen burns with a very pale flame that is invisible in daylight. Because it emits little of the infrared radiation that humans perceive as heat, it cannot be sensed as heat (and is also less likely to ignite objects in the vicinity). A hydrogen flame does however emit substantial ultraviolet radiation. Special UV detectors are therefore required to alert to the presence of hydrogen flames.

LEAKS

Owing to its small molecules and low viscosity, hydrogen can leak from pipelines and other structures more easily than denser gases. In fact, when it leaks from a pipe at sufficiently high pressure, hydrogen can even self-ignite. As well as pipelines engineered to hydrogen-ready specifications, regular inspection is imperative to detect leak points at joints and along pipelines. Fixed leak detectors add another layer of safety.

PERMEATION

Hydrogen can easily permeate materials and in some cases embrittle them. For this reason, stainless steel and composite materials are typically used for storage tanks.

CO ALARMS

Carbon monoxide (CO) sensors are cross-sensitive to hydrogen. If used near possible hydrogen exposure, CO sensors should be compensated for hydrogen so that cross-sensitivity and false alarms are reduced to a minimum.

GAS POCKETS

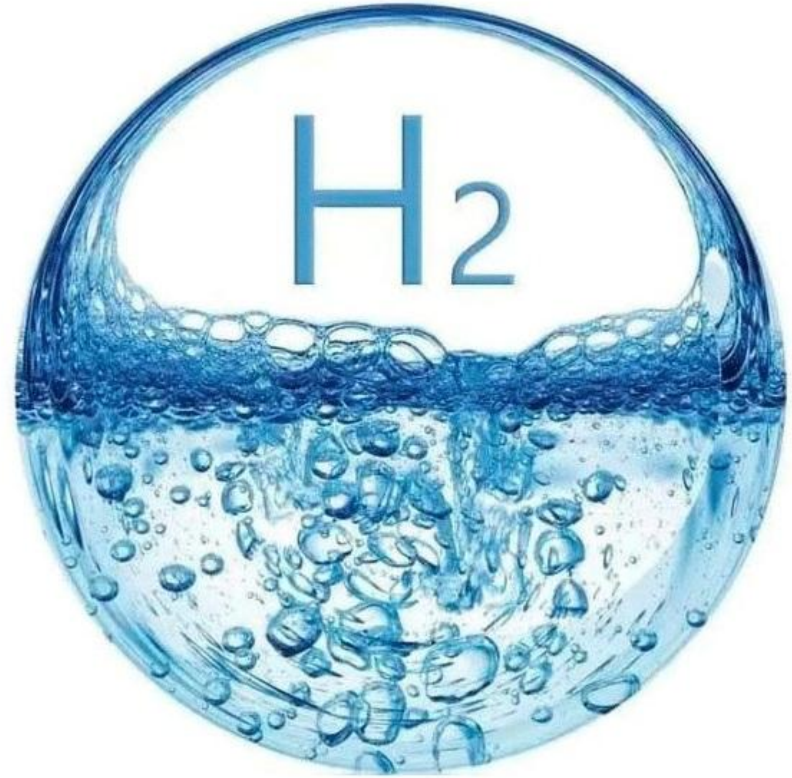
Like ammonia and methane, hydrogen is less dense than air and forms gas pockets below indoor ceilings when leaking. The presence of hydrogen will not be perceived at ground level, even when dangerous amounts are accumulating beneath the ceiling. When hydrogen and methane are mixed, hydrogen can form gas pockets above methane. Hydrogen detectors are therefore typically placed at the top, with methane detectors below that level.

ODOURLESS AND COLOURLESS

Hydrogen has no smell and no colour, so is undetectable for humans. With methane, this issue is mitigated by adding odorants, and research is in progress to determine whether this will also be possible with hydrogen. Gas and leak detectors are essential.

Thank you for your attention

MARCOGAZ TECH FORUM



ATEX: Hydrogen compared to Natural gas

PAUL HOGEWONING, Chair of the Working Group Health & Labour Safety

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Technical Association of the European Gas Industry

MARCOGAZ Tech Forum – Webinar on Hydrogen Safety

ATEX: Hydrogen compared to Natural gas

Paul Hogewoning, Chair of the WG HLS

Webinar on Hydrogen Safety – 27 October 2022

Introduction

- *Paul Hogewoning*
  - Senior HSE Advisor at Gasunie – Netherlands
  - > 40 years professional experience in Health, Safety & Environment (HSE):
    - Government
    - Consulting engineering
    - Chemical Industries
    - Gas industry
  - Chair of MARCOGAZ Working Group - Health and Labour Safety

Introduction

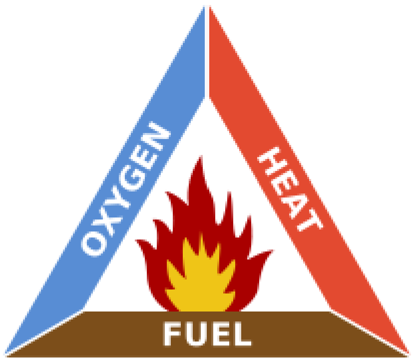
- *Today*
  - Explosion safety
  - ATEX
  - Properties of Hydrogen and natural Gas
  - Wrap up

Explosion Safety

- *Explosion:*
  - An explosion is a **sudden increase** in the **volume** of a quantity of matter and the **release** of **energy** in a **violent manner**.
  - It usually is accompanied by the generation of high temperatures and the release of gases.
  - An explosion causes **shock waves** in the medium in which it occurs.
  - Explosions are categorized as **deflagrations** if the shock waves are **subsonic** and as **detonations** if they are **supersonic**.

Explosion Safety

- *Fire, three elements a fire needs to ignite*:
  - Heat
  - Fuel
  - Oxidizing agent (usually oxygen in air)



- *Explosion limits*
  - Lower Explosion Limit (LEL), The lowest concentration (percentage) of a gas or a vapor in air capable of producing a flash of fire in the presence of an ignition source (arc, flame, heat).
  - Upper Explosion Limit (UEL), Highest concentration (percentage) of a gas or a vapor in air capable of producing a flash of fire in the presence of an ignition source (arc, flame, heat).

Explosion Safety

- *Minimum Ignition Energy (MIE)*
  - MIE is defined as the minimum electrical energy stored in a capacitor, which, when discharged, is sufficient to ignite the most ignitable mixture of fuel and air under specified test conditions.
- *Physical explosion*
  - instantaneous release of pressure
- *Chemical explosion*
  - Rapid and violent oxidation reaction often initiated by an electric spark or flame in the presence of oxygen
  - $CH_4 + 2\ O_2 \rightarrow CO_2 + 2\ H_20$ + Heath
  - $2\ H_2 + O_2 \rightarrow 2\ H_2O$ + Heath

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ATEX

- *ATEX is an abbreviation for "ATmosphere EXplosible"*
- *Directive 1999/92/EC*
  - of the European Parliament and of the Council of 16 December 1999 on minimum requirements for improving the **safety** and **health protection** of **workers** potentially at risk from **explosive atmospheres**
  - So-called **ATEX-153** (formerly ATEX-137) Directive
  - Explosion Protection Document
  - Identification and assessment of the explosion risks
  - Hazard zonings on the basis of standard EN IEC 60079-10-1 – Explosive atmospheres – Part 10-1: Classification of areas
  - Categories of equipment must be used in the zones

ATEX

Directive 1999/92/EC

- Zones

Zone	Definition	Categories of equipment
Zone 0	Area in which an explosive gas atmosphere is present continuously, or for long periods, or frequently.	1
Zone 1	Area in which an explosive gas atmosphere is likely to occur occasionally in normal operation.	1 or 2
Zone 2	Area in which an explosive gas atmosphere is not likely to occur in normal operation, but, if it does occur, will exist for a short period only.	1, 2 or 3

ATEX

- *Directive 2014/34/EC*
  - of the European Parliament and of the Council of 26 February 2014 on **equipment** and **protective systems** intended for use in **potentially explosive atmospheres**
  - So called **ATEX-114** Directive
  - Minimum safety requirements for explosion-proof equipment
  - Two types of Equipment groups:
    - - Equipment group I concerns all underground (mining) installations
    - - Equipment group II concerns all other above-ground installations

ATEX

- *Directive 2014/34/EC*
  - Gasgroups II
  - ISO/IEC 80079-20-1 chapter 5.2.4: methane with up to 25 % H2 is still IIA.
  - Equipment gas group IIB+H2 is available/suitable

Gasgroup	MIE (uJ)	Example
IIA	>200	Methane, Propane, Kerosene
IIB	20-60	Ethylene
IIC	0-20	Hydrogen, Acetylene

ATEX

- *Directive 2014/34/EC*
  - Temperature classes

Temperature class	Maximum permissible surface temperature
T1	450 °C
T2	300 °C
T3	200 °C
T4	135 °C
T5	100 °C
T6	85 °C

Properties of Hydrogen and Natural gas

Properties related to ATEX

Property	CH_4	H_2
Gas group (ATEX)	IIA	IIC
Temperature class	T1	T1
Minimum Ignition Energy (mJ)	0,28	0,017
Ignition temperature (°C)	537 (CH_4) – 670 (L-Gas)	560
LEL-UEL (vol %)	4,4 - 17	4 - 77
Molecular weight (g/mol)	16	2
Relative density	0,55	0,07

Wrap up

- *Equipment gas group IIB+H2 is available/suitable.*
- *Methane with up to 25 % H2 is still Gasgroup IIA.*
- *Differences between safety properties of H2 and CH4 result in:*
  - Upper Explosion Limits hydrogen much higher than methane
  - Relative density of hydrogen is very low:
    - Hydrogen rises about 6 times faster than methane
    - Hydrogen dilutes faster in air than methane
    - Accumulation of H2 at a ceiling (confined spaces)
  - Ignition energy hydrogen much lower than methane (stoichiometric mixture)
  - Ignition energy of 10% hydrogen comparable with methane (outdoor installations)

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Thank you!

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Measurement: Hydrogen compared to Natural Gas

HENK TOP, Senior Specialist Gas Analysis & Testing at DNV New Energy

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WHEN TRUST MATTERS

Measurement: Hydrogen compared to Natural Gas

Marcogaz Tech Forum – Hydrogen Safety 27 October 2022

Henk Top - Senior Specialist Gas Testing & Analysis

23 October 2022

DNV Laboratories Groningen, The Netherlands

Location Energieweg:

- Analytical lab
- Engine test lab
- Combustion lab
- Flow and Multi-Phase lab’s

Moving to new location December 2022 at Zernike Campus Groningen

Our expertise - Analytical lab

GAS QUALITY MEASUREMENT AND COMPLIANCE

DNV laboratories and on-site global measurement

GAS QUALITY DIVERSIFICATION

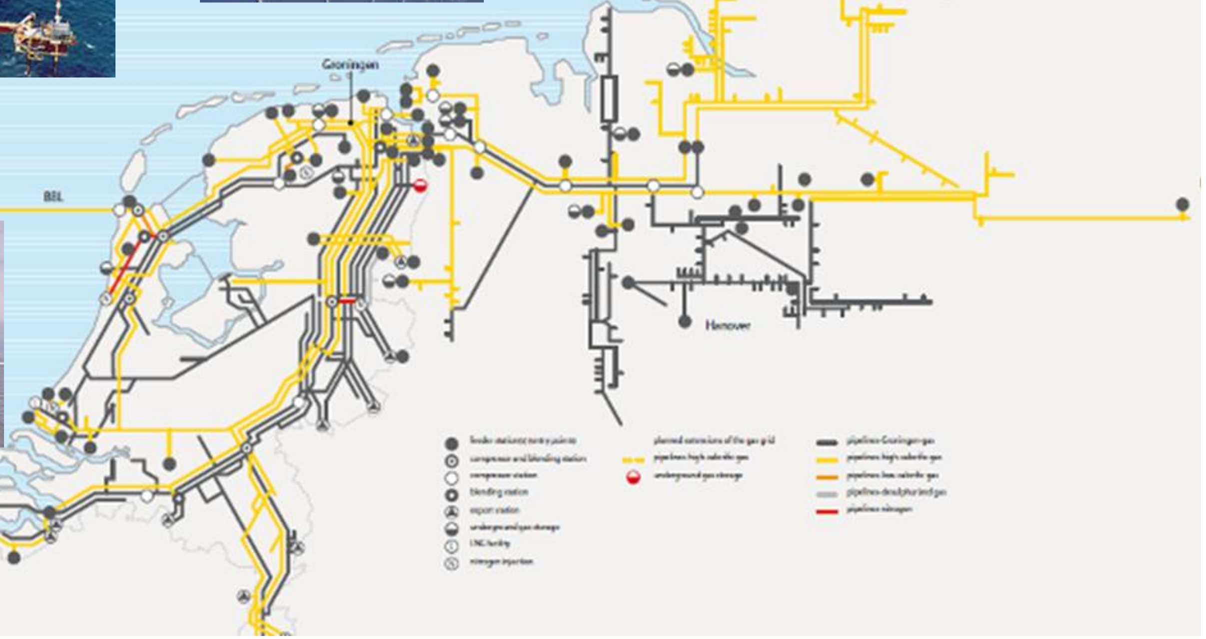
Gas quality diversification is a growing challenge for the gas industry. This is a result of depleting natural gas reserves and the increased production of renewables, hydrogen, shale gases and LNG. While the industry is diversifying, it's important to ensure safe, affordable and reliable transport, distribution and combustion of gas. In addition, custody transfer and the billing for energy content needs to meet governing standards. The understanding of gas composition and performance, in addition to compliance to standards, secures a safe, reliable and beneficial gas industry.

FUEL ANALYSIS SERVICES BY DNV

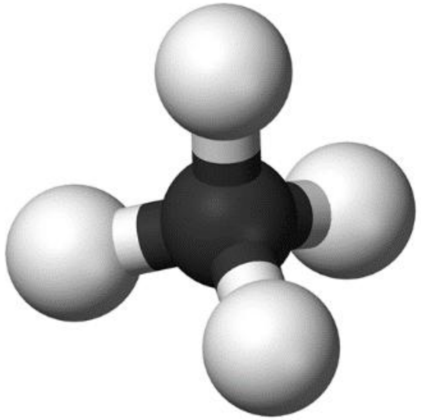
DNV offers a wide range of FUEL ANALYSIS SERVICES of gaseous energy carriers, like natural gas, synthetic gases, biomethane, hydrogen and emission gases. With the ISO 17025 accreditation for our operational environment, our methodology for analyses is traceable to the highest national and international standards.

The scope of our ISO 17025 accreditation can be found on www.rva.nl under registration number **K103**.

Natural gas (ISO 6974 and ISO 6976)



Component	Mole fraction range %
Hydrogen	0,001 to 0,5
Helium	0,001 to 0,5
Oxygen	0,001 to 5
Nitrogen	0,001 to 60
Carbon dioxide	0,001 to 35
Methane	40 to 100
Ethane	0,02 to 15
Propane	0,001 to 25
Butanes	0,000 1 to 5
Pentanes	0,000 1 to 1
Hexanes and heavier	0,000 1 to 0,5



Energy (MJ) = Volume (m^3_n) x Calorific Value (MJ/m^3_n)

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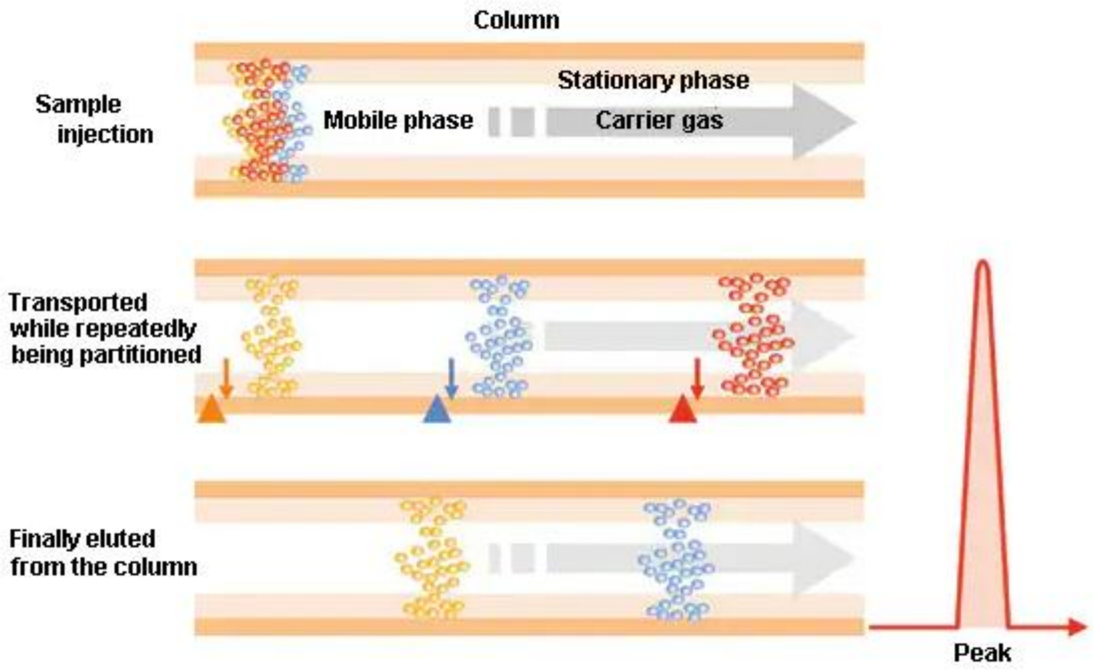
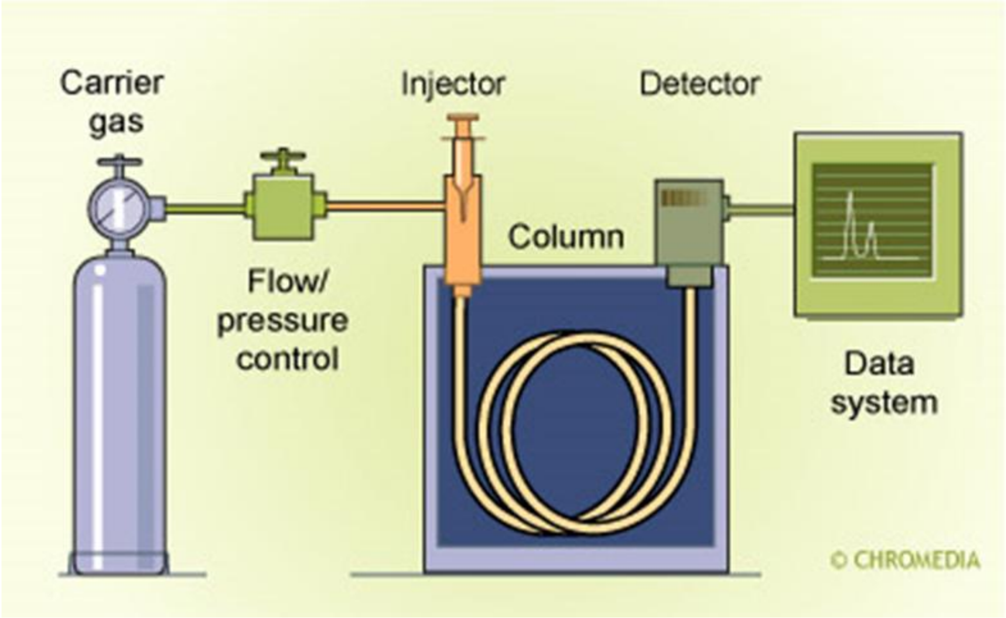
Principle of Gas Chromatography (GC)



Source: Shimadzu



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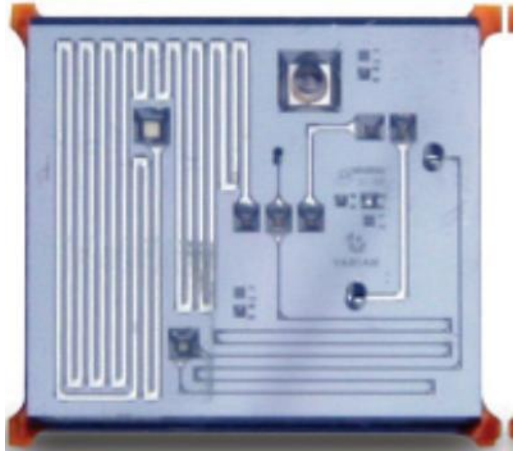
Parallel Gas Chromatography

A single (micro) GC can be configured with up to four GC modules for fast parallel analysis. Every module is a complete, miniaturized GC with electronic gas control, injector, narrow-bore column and detector, for fast, high efficiency separations. Each is independently controlled, including injection volume, column oven temperature, and carrier gas.

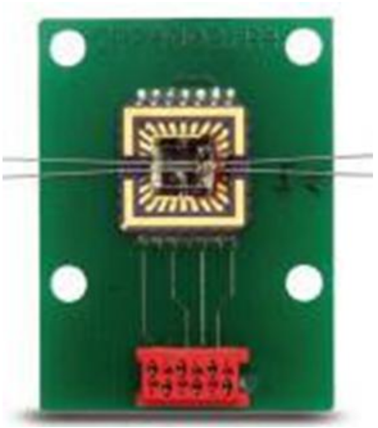
Agilent 490 dual channel



Sample injector

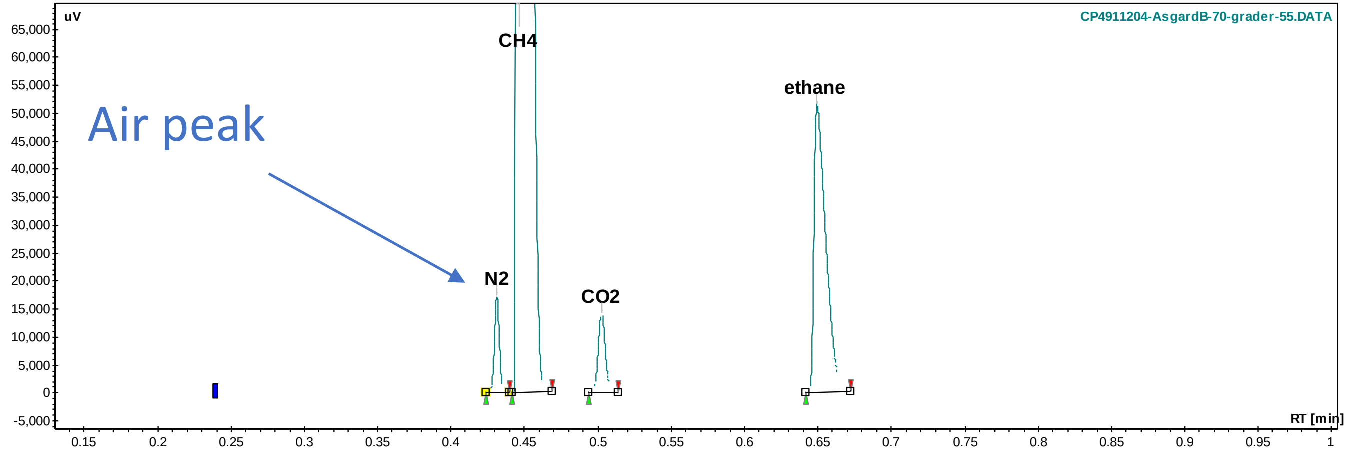
Capillary column

(separation of molecules)



Detector (TCD)

Natural gas analysis (helium carrier gas)

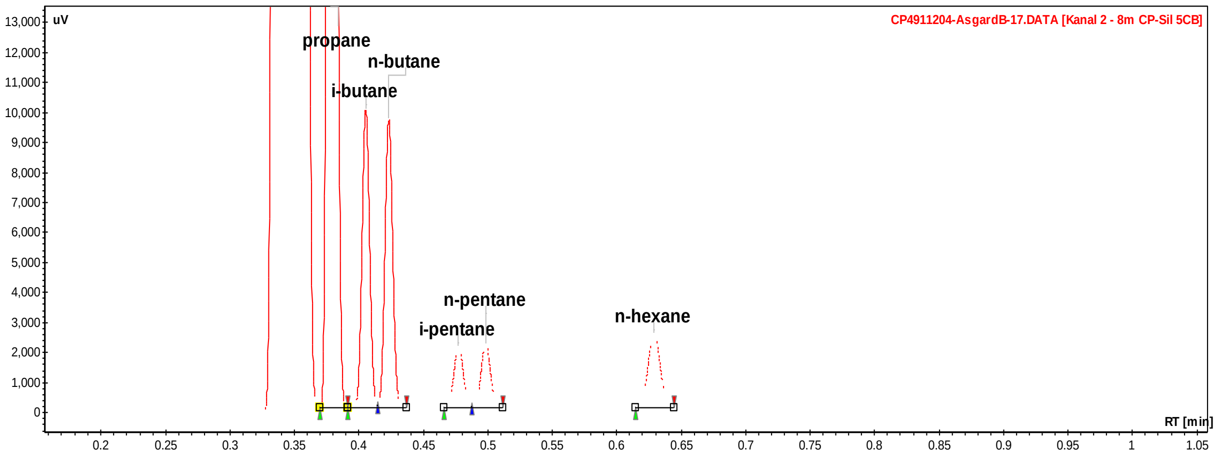


Air peak consist of the following permanent gasses:

- Helium
- Hydrogen
- Oxygen/Argon
- Nitrogen
- Carbon monoxide

Poraplot column: N_2, CH_4, CO_2, C_2H_6

DB-1 column: $C_3 – C_{6+}$ hydrocarbons



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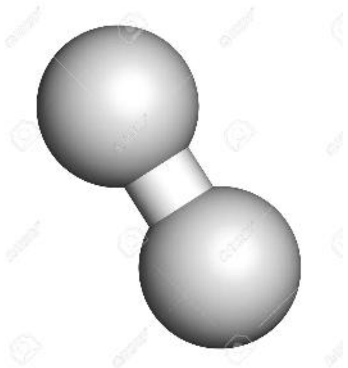
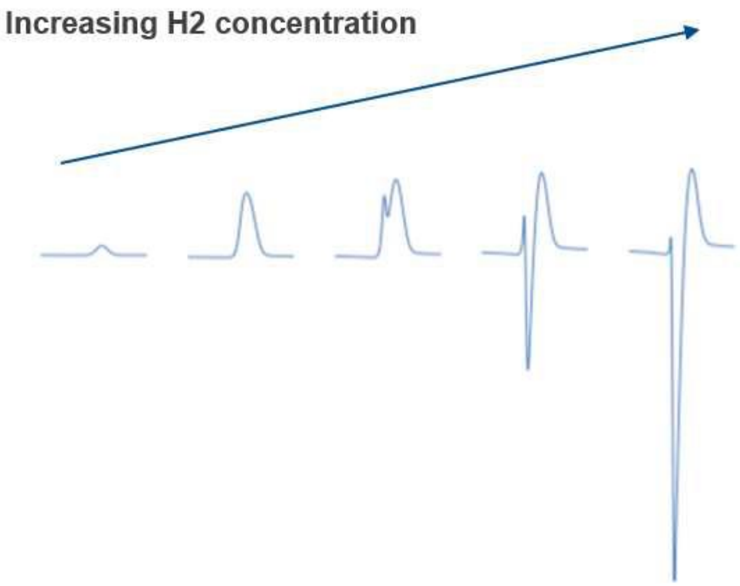
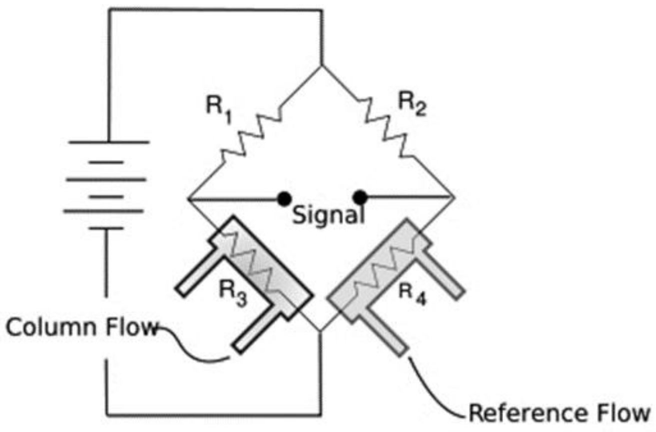
Problems with natural gas/hydrogen mixtures

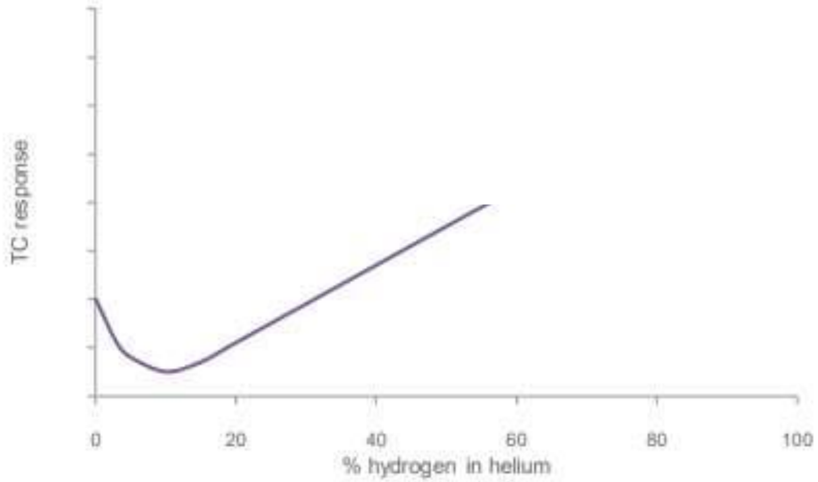
Carrier gas	Relative thermal conductivities	Carrier gas	Relative thermal conductivities
Hydrogen	47.1	Ethane	5.8
Helium	37.6	Propane	4.8
Methane	8.9	Argon	4.6
Oxygen	6.8	Carbon dioxide	4.4
Nitrogen	6.6	Butane	4.3
Carbon monoxide	6.4		





Thermal Conductivity Detector (TCD) principle:



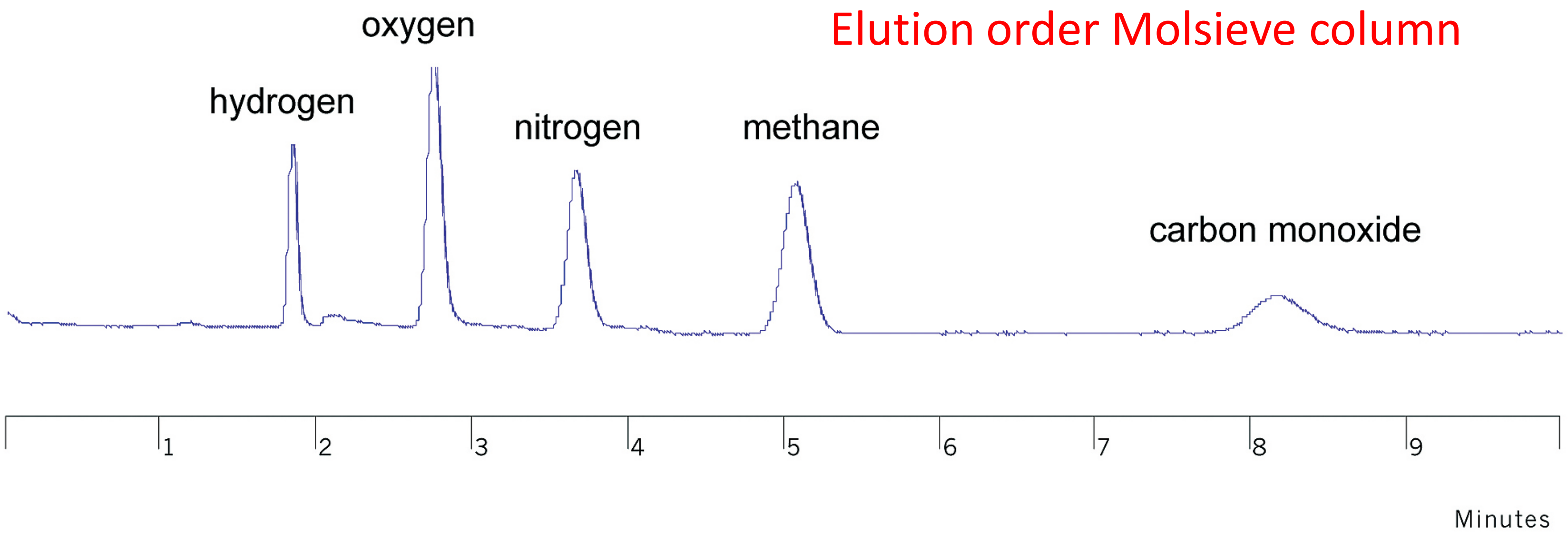


Source: Emerson

Hydrogen measurement with GC

Adding an extra module or channel and carrier gas to a GC will solve the problems for the analysis of hydrogen in natural gas mixtures when using argon as carrier. A typical analytical column is a Molsieve stationary phase. In addition it is also possible to measure Helium, Oxygen and Carbon monoxide. A disadvantage is the lower sensitivity for nitrogen.

Elution order Molsieve column



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Results improved GC for hydrogen measurement

Criteria Physical parameters

Physical parameter (T1 = 25° C; T2=0° C; 101,325 kPa)	Maximum error (%)
Calorific value	0,15
Wobbe	0,20
Relative density	0,15
Density	0,15

GC configuration

Module 1: He, H_2, O_2, N_2 and CO (carrier Ar)
Module 2: C_3 – C_6+ (carrier He or H_2)
Module 3: C_1,C_2 and CO_2 (carrier He or H_2)

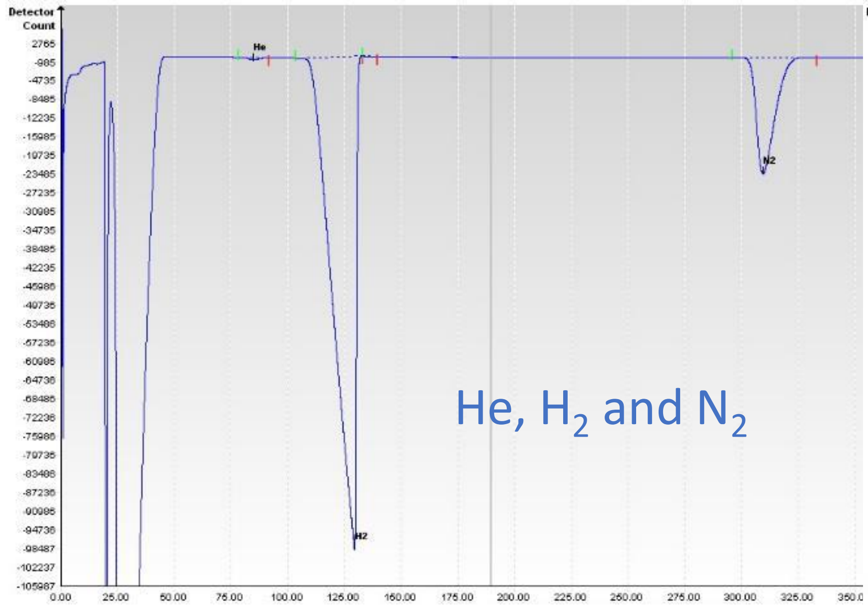
NG 1 Polynomial calibration		normalized estimated conc.	certificate	difference	pass/fail
Hs	[MJ/m3]	35.094	35.090	0.01	Pass
Hi	[MJ/m3]	31.671	31.667	0.01	Pass
Wobbe	[MJ/m3]	43.696	43.702	-0.01	Pass
rel density	[-]	0.645	0.645	0.05	Pass
density	[kg/m3]	0.834	0.834	0.05	Pass

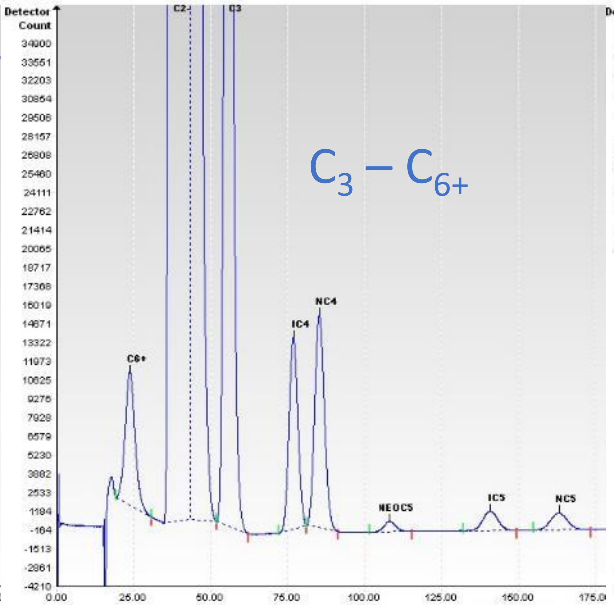
NG 2 Polynomial calibration		normalized estimated conc.	certificate	difference	pass/fail
Hs	[MJ/m3]	35.663	35.655	0.02	Pass
Hi	[MJ/m3]	32.189	32.182	0.02	Pass
Wobbe	[MJ/m3]	44.223	44.213	0.02	Pass
rel density	[-]	0.650	0.650	0.00	Pass
density	[kg/m3]	0.841	0.841	0.00	Pass

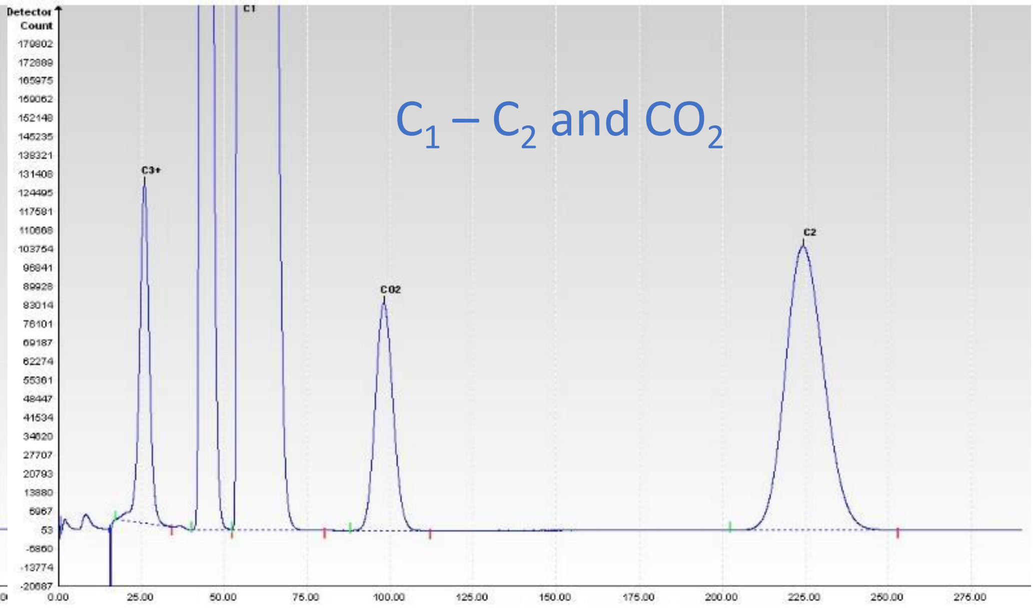
NG 3 Polynomial calibration		normalized estimated conc.	certificate	difference	pass/fail
Hs	[MJ/m3]	37.842	37.825	0.04	Pass
Hi	[MJ/m3]	34.166	34.152	0.04	Pass
Wobbe	[MJ/m3]	47.321	47.299	0.05	Pass
rel density	[-]	0.640	0.640	0.00	Pass
density	[kg/m3]	0.827	0.827	0.00	Pass

NG 4 Polynomial calibration		normalized estimated conc.	certificate	difference	pass/fail
Hs	[MJ/m3]	41.754	41.742	0.03	Pass
Hi	[MJ/m3]	37.712	37.701	0.03	Pass
Wobbe	[MJ/m3]	53.521	53.513	0.01	Pass
rel density	[-]	0.609	0.608	0.03	Pass
density	[kg/m3]	0.787	0.787	0.03	Pass

Results 5% hydrogen in natural gas

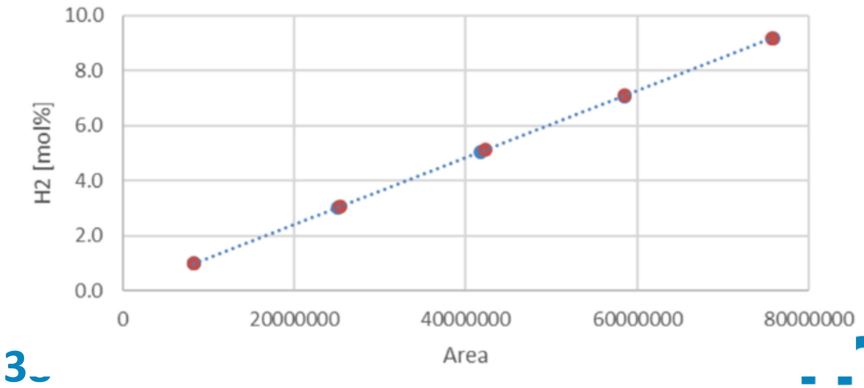






Cycle time approximately 5 minutes

Linear response for hydrogen 0 – 10%



Hydrogen Quality Measurements Fuel Stations

EN-17124:2018

Constituent	Characteristics	Method DNV
Hydrogen fuel index (minimum mole fraction)	99.97 %	100 % minus individual comtaminants
Total non-hydrogen gases	300 µmol/mol	Summation individual comtaminants
Maximum concentration of individual contaminants		
Water (H_2O)	5 µmol/mol	On-line (TDL)
Total hydrocarbons (THC) excluding methane	2 µmol/mol	GC-FID
Methane (CH_4)	100 µmol/mol	GC-FID
Oxygen (O_2)	5 µmol/mol	GC-TCD
Helium (He)	300 µmol/mol	GC-TCD
Nitrogen (N2)	300 µmol/mol	GC-TCD
Argon (Ar)	300 µmol/mol	GC-TCD
Carbon dioxide (CO2)	2 µmol/mol	GC-TCD
Carbon monoxide (CO)	0.2 µmol/mol	GC-PDHID
Total sulfur compounds (H_2S basis)	0.004 µmol/mol	GC-MS (SIM mode)
Formaldehyde (HCHO)	0.2 µmol/mol	Wash flask and UV-VIS
Formic acid (HCOOH)	0.2 µmol/mol	Under development (MS screening)
Ammonia (NH_3)	0.1 µmol/mol	Wash flask and UV-VIS
Halogenated compounds (halogenate ion basis)	0.05 µmol/mol	Wash flask and UV-VIS (chloride and fluoride)
Halogenated hydrocarbons	0.05 µmol/mol	GC-MS (screening)
Maximum particulates concentration	1 mg/kg	Filter gravimetric

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Thanks for your attention

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Impact of Hydrogen on Existing Materials in Gas Networks

ALFONS KROM, Material Integrity Specialist at N.V. Nederlandse Gasunie

gasunie
crossing borders in energy

27 October 2022

Impact of Hydrogen on Existing Steels in Gas Networks

Marcogaz Tech Forum 27 October 2022

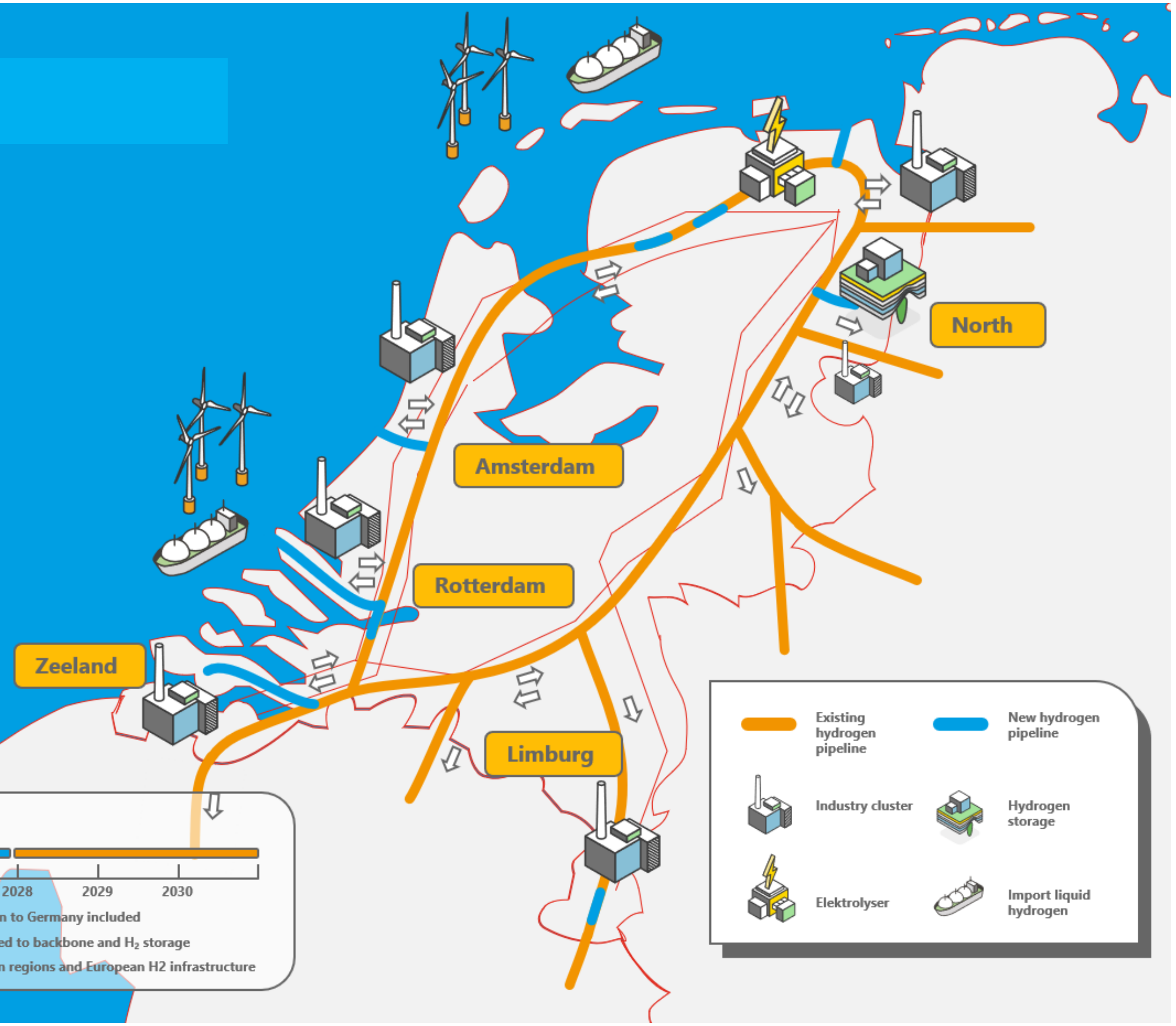
Alfons Krom

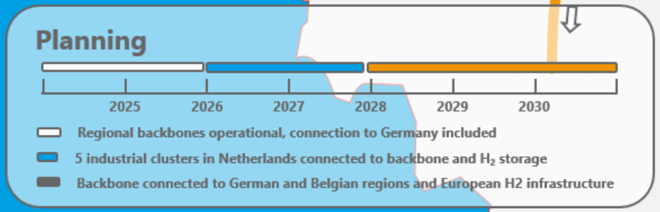
Contents

- The hydrogen gas network in NL
- What is hydrogen and hydrogen gas?
- Hydrogen embrittlement
- Hydrogen effect on mechanical properties of steel
- Translation to hydrogen gas network:
  pipeline, underground storage, reciprocating compressor

Waterstofnetwerk Nederland

- Development of national infrastructure for transport and storage of hydrogen
- Network will realize foundation for the green hydrogen market in North-West Europe.
- Status: Expression of Interest Q2 2021
- Planning: development of regional pipelines in industrial regions from 2023, including a connection to Belgium from Zeeland
- Connection of clusters to national backbone in the period 2026 - 2028 and connection to German and Belgian border points in 2030





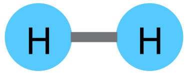
Parts of ‘Waterstofnetwerk Nederland’
simplified it consists of ….

Part	Sub-parts	Pressure range
Pipelines (new & old)	welded steel pipes & valves	30 bar initial 66 bar after 2035
Under ground storages	salt cavern & threaded steel pipes drying installations reciprocating compressor	160 -200 bar 30 – 200 bar
Reciprocating compressors *after 2035*	steel castings, steel pipes, pulsation dampener	30 – 66 bar

What is hydrogen?

- Hydrogen is the name of the chemical element consisting of one **atom** with symbool H.

- On earth, pure hydrogen is a **molecule** consisting of two hydrogen **atoms**



- However, most hydrogen atoms are bonded in other substances like water H_2O, methane CH_4.

- Hydrogen **ions** (H^+) are formed in corrosion reactions, e.g. sour gas corrosion.

In this presentation hydrogen is the **gaseous molecule** hydrogen but for hydrogen embrittlement hydrogen **atoms** are necessary.

Hydrogen gas composition in the “Waterstofnetwerk NL”

Hydrogen	≥ 98 mol %
Nitrogen, Argon, Helium	≤ 2 mol%
Hydrocarbons (C_xH_y)	≤ 1,5 mol%
Total Sulfur	≤ 3 mol ppm
Oxygen	≤ 10 mol ppm
Water dew point	–8 °C at 70 bar
Temperature	5 – 30 °C

Blending of hydrogen in natural gas in the Netherlands is not foreseen, however small amounts, < 2% can be possible.

Hydrogen embrittlement

The interaction between hydrogen atoms and a metal can have a negative effect on its mechanical behaviour or integrity. This effect has several "appearances":

- hydride formation (chemical reaction)
- cold cracking due to welding
- hydrogen induced cracking
- hydrogen attack
- decrease in ductility and toughness
- enhanced fatigue crack growth (HFCG)
- ….

The general term for these negative effects is called: **hydrogen embrittlement**.

Mainly for carbon steel but also for other metals

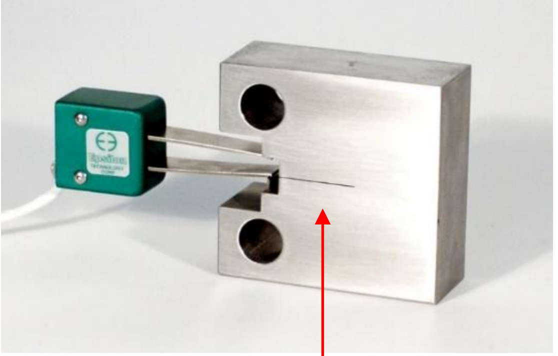
Effect of hydrogen atoms in mechanical test of steels

Mechanical test	Load	Specimen	Effect
Tensile	Semi static	Smooth	Decrease fracture strain *depending on strain rate* but not the yield strength
Impact	Dynamic	Notch	None
Fatigue	Cyclic	Smooth	Decrease of lifetime but probably not endurance limit
Toughness	Semi Static	Crack	Decrease fracture toughness *depending on strain rate*
Fatigue crack growth	Cyclic	Crack	Increase of growth rate > 10x

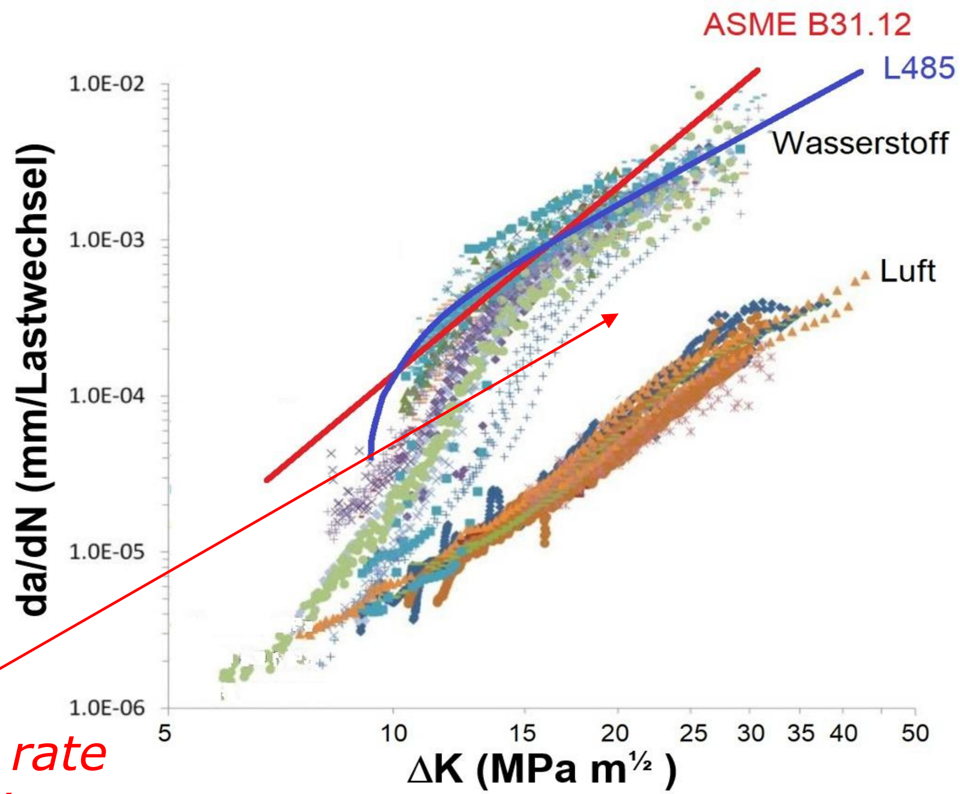
→ There is only an effect of hydrogen in combination with new slowly developing or cyclic intense plasticity and a crack-like defect.

Fatigue crack growth rate in hydrogen and air

compact tension specimen



crack



increase in growth rate more than 10X

$\Delta K = \Delta\sigma\sqrt{\pi a}$

crack driving force

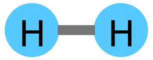
fatigue crack growth rate rather independent of:
+ steel grade
+ microstructure
+ vintage or modern steel
+ base or weld
+ hydrogen pressure

Full scale fatigue experiment of a line pipe with 70 bar H_2

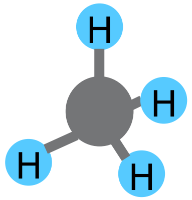
- pipe sections with multiple girth welds from Danish gas net
- 20 years in operation
- API 5L X70, diameter 20”, wall thickness 7 mm
- maximum pressure 70 bar
- pressure variation 30 bar, stress 109 MPa, frequency 0,0017 Hz
- 30.000 cycles, equivalent to 80 years of operations
- no leak or cracks found

→ Hydrogen in steel pipelines no problem as long as there are no large welding defects present.

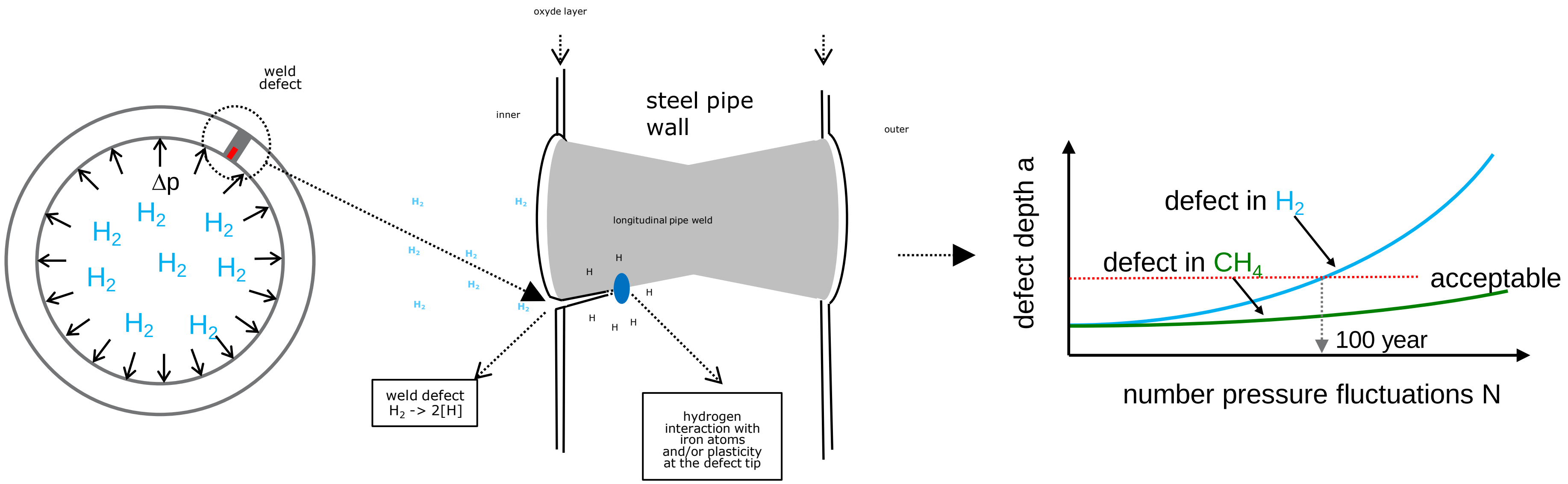
H. Iskov, Field test of hydrogen in national grid, report Dansk Gasteknisk Center, 2010



“Translation” of the hydrogen-enhanced fatigue crack growth (HFCG) in the hydrogen gas network



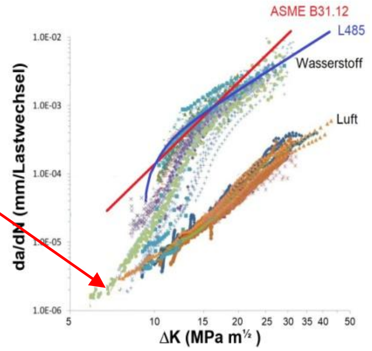
Pipes (& valves)



Estimation of defect growth over 100 year, one cycle per day

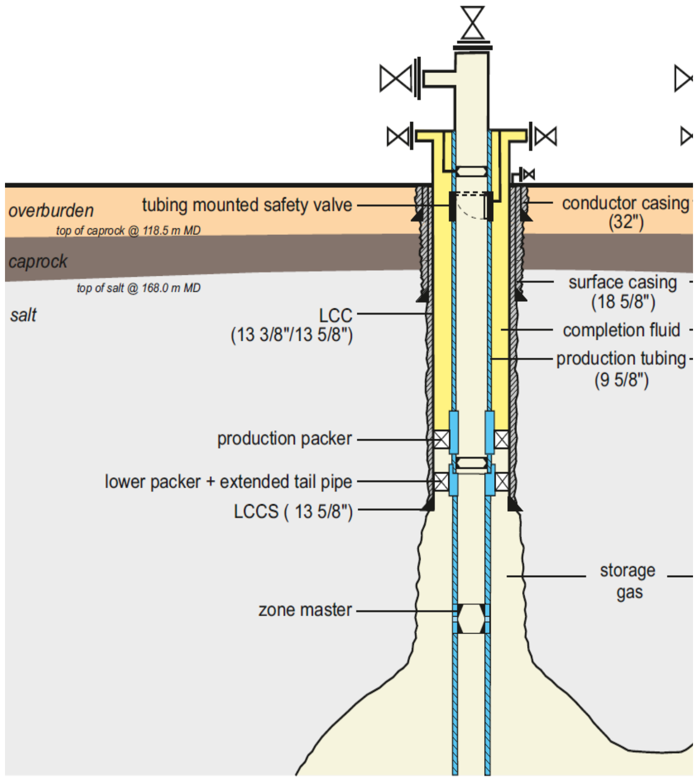
pressure cycle [bar]	defect orientation in weld	driving force variation ΔK [MPa√m]	crack growth rate [mm/cycle]	defect growth 100 year [mm]
5	longitudinal	3,0	$1{,}9 \cdot 10^{-7}$	0,007
	girth	0,8	$2{,}3 \cdot 10^{-9}$	0,0001
10	longitudinal	6,1	$5{,}6 \cdot 10^{-6}$	0,25
	girth	1,6	$2{,}2 \cdot 10^{-8}$	0,01

Defect growth is so small over a period of 100 year, 100% H_2 does not impose an integrity risk.
Monitoring of pressure variations

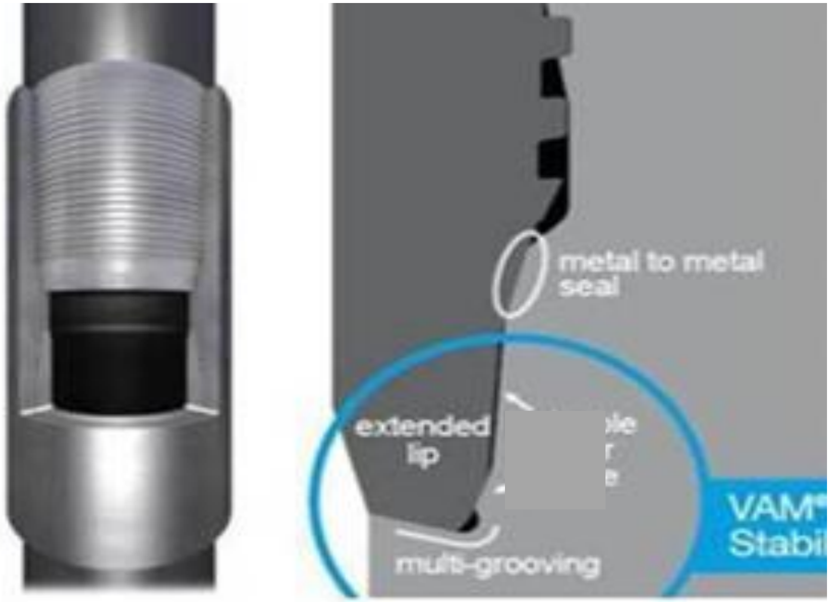


Underground storage: production tube (vertical pipeline)

salt cavern with production tube



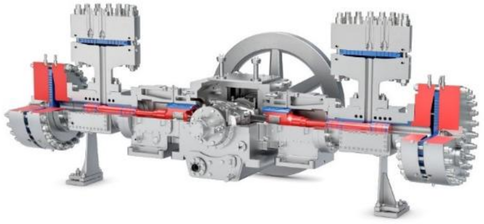
well **A1B** with
extended tail pipe and zone master



threaded connection of
two seamless pipes

Compressor OEM's viewpoint

- Reciprocating compressors: large historic experience
  - Pure H_2
  - Large pressure range, in excess of 200 bar
  - Temperatures in excess of 140 °C
  - Compressor components designed for ∞ lifetime; low cyclic stress levels
- Diaphragm compressors: considerable historic experience
  - Pure H_2
  - Large pressure range, in excess of 700 bar
  - Temperatures in excess of 200 °C
- **No embrittlement problems experienced** in these cases, even on materials that could be liable to embrittlement



Prevention against hydrogen-enhanced fatigue crack growth

- welds without crack-like defects (non-destructive testing)

- add small amount of oxygen (≈0,1%) in the hydrogen gas
- apply aluminium coating

- decrease stress cycle (increase of wall thickness)
- decrease number of cycles

Conclusion

- Hydrogen embrittlement: container term for various degradation mechanisms
- For transport network relevant degradation mechanism is:

  hydrogen-enhanced fatigue crack growth (HFCG)
- For existing applications with hydrogen, the industry (compressors) has the effects of HFCG under control.
- For the Waterstofnetwerk NL, HFCG is under control

Extra slides

Help in choice of material

- Technical Reference for Hydrogen Compatibility of Materials, Sandia National Laboratories, report SAND2012-7321, september 2012 (https://www.sandia.gov/matlstechref/)

- Basic considerations for the safety of hydrogen systems, ISO/TR 15916 (https://www.nen.nl/npr-iso-tr-15916-2015-en-214768)

- C. San Marchi, J. Ronevich, Dispelling myths about gaseous hydrogen environmental rracture and fatigue, Sandia Laboratories, 2018 (https://www.osti.gov/biblio/1502684)

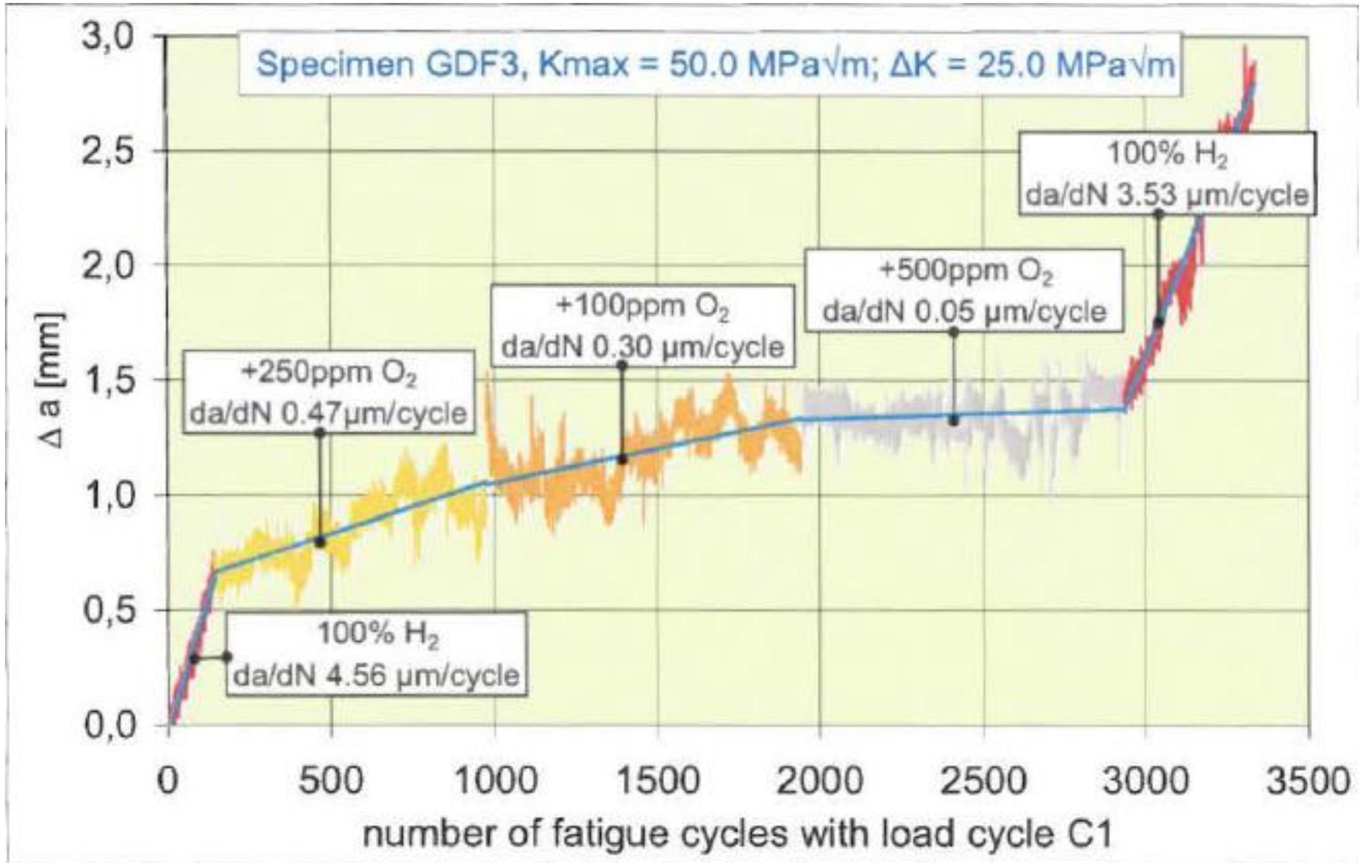
Nothing new

"*The major technical problem with transmission of hydrogen gas at high pressure is the possibility of slow fatigue crack growth from existing cracks or crack-like defects in the pipe body or weld*."

E. Anderson et al. Geneva Research Centre in "Analysis of the potential transmission of hydrogen by pipeline in Switzerland"

Proceedings of the 2nd World Hydrogen Energy Conference, Zurich, Switzerland, 21-24 August **1978**

Fatigue crack growth in hydrogen with oxygen (a little bit)



frequency 0,00164 s^{-1}, 66 bar H_2, steel L360 / X52

Q&A SESSION

JOSÉ MIGUEL TUDELA, Sustainability & Climate Action Director at ENAGAS and Chair of Sustainability Standing Committee at MARCOGAZ

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You can now drop your questions in the chat!

Please, make sure you write your name and company before your question, thank you!

Closing remarks

MANUEL COXE, Secretary General of MARCOGAZ

marcogaz

Technical Association of the European Gas Industry

THANK YOU!