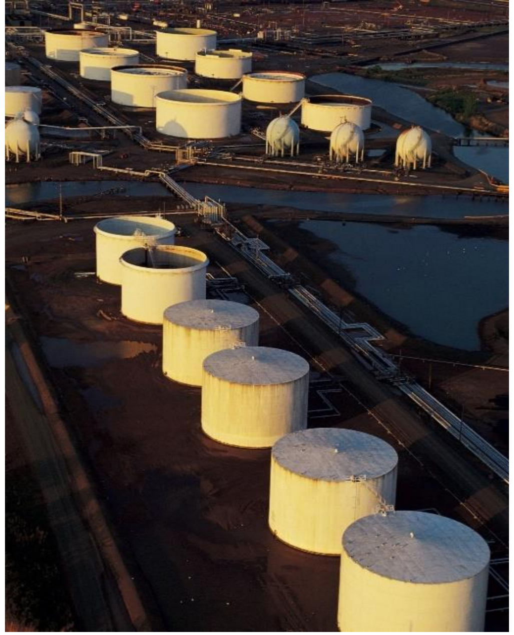




INJECT HYDROGEN INTO THE GAS NETWORKS

HOW RENEWABLE ENERGIES CHANGE THE GAS WORLD

PRODUCT MANAGEMENT
VERSION 02

Honeywell

AGENDA

- Context - Decarbonization of the energy system
- The Idea - Use of the established gas network for the efficient storage of renewable energies
- Impact on gas supply - Influence on supply networks, measurement technology and downstream processes
- Activities at Honeywell-Elster
- Appendix - Projects, List of references

CONTEXT

DECARBONIZATION OF THE ENERGY SYSTEM

CONTEXT

Decarbonization of the energy system to reach the climate protection goals

Essential tasks to achieve the goal:

- Switching electricity generation to almost exclusively renewable energies (RES)
- Transport sector emits no longer greenhouse emissions. It’s switched to the use of electricity and/or hydrogen
- Industry is largely decarbonized and largely electrified (including process heat)
- Transition in the household as well as in the trade and services sector has been implemented.

This requires:

- Massive expansion of renewable power generation (in particular wind power both on-shore and off-shore), which is then also used in the industrial and transport sectors
- Strong expansion of power transmission capacity to transport the power where it is needed
- Expand storage technologies to ensure security of supply even in periods of low wind and solar power

CONTEXT

Where does the gas network come into the game?

- Electrification - directly or indirectly via hydrogen, other synthetic gas or synthetic fuels - can only be achieved in industry and transport if adequate amounts of renewable electricity are available. This will also require sufficient transport and storage capacity.

- One option for this is the coupling between the electricity and gas sectors via the **power-to-gas technology**: The transport and storage of electrical energy takes place in the form of hydrogen or synthetic natural gas (SNG) in the natural gas network.

THE IDEA

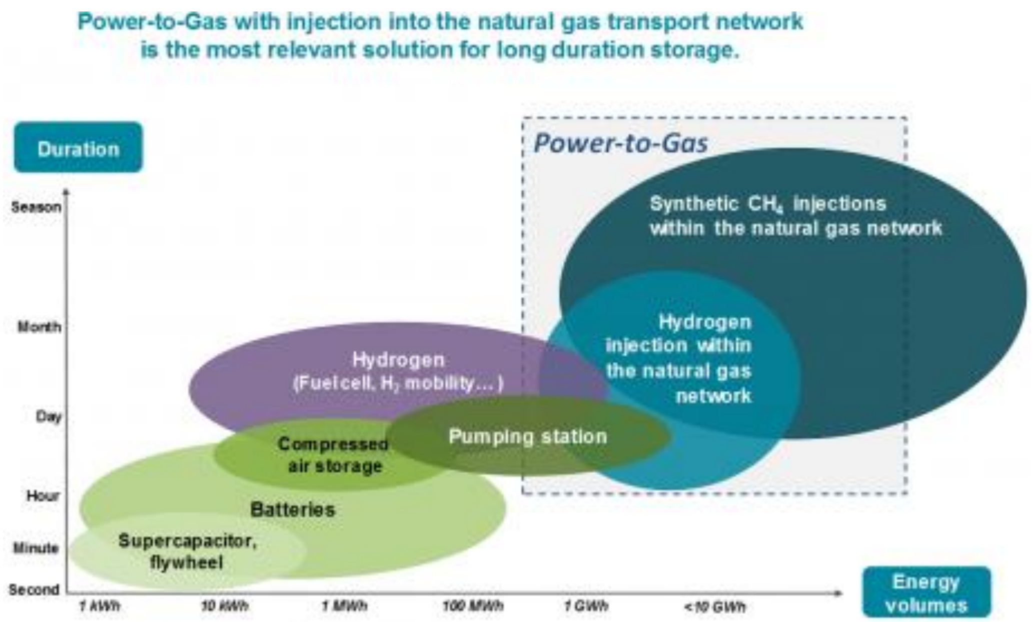
USE OF THE ESTABLISHED GAS NETWORK FOR THE EFFICIENT STORAGE OF RENEWABLE ENERGIES

THE CHALLENGE

- Renewable power generation is highly fluctuating and not consumption-oriented.
- The supply of electricity from wind and sun temporarily exceeds the demand, with the result that not only conventional power plants are shut down, but also wind turbines and solar plants have to be taken off the grid.
- The problem is that electricity can not be stored for a long time and on a large scale.
- So far tried and tested concepts, such as pumped storage power plants, underground compressed air storage, the idea of electric cars as mobile network storage or the development of giant lithium-ion batteries, can only realize a small part of the storage capacities required in the future.

A CONTRIBUTION TO THE SOLUTION

- Power-to-gas as a link between electricity and gas grids for the use of wind and solar power in the mobility, heat, industrial and power generation sectors.
- Gas pipeline networks represent a huge and comprehensive storage medium.
- For example the nearly 500,000 kilometers of the German network currently transports with almost 1,000 billion kilowatt hours of energy each year in the form of natural gas and biogas about twice the amount of energy in the German electricity grid.
- In addition, billions of kilowatt hours can be stored in underground gas storage facilities (Germany: almost 25 percent of gas sales and the capacity is to rise to 300 billion kilowatt hours by 2020).



Discharge time and storage capacity of various electricity storage systems in France
Source: Homepage 'Gas in focus' [1]

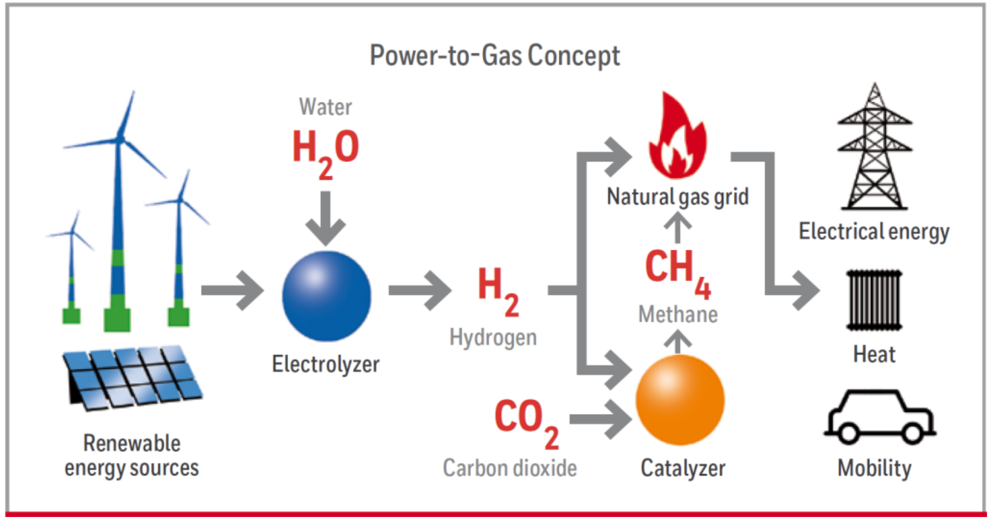
THE PROCESS: ELECTROLYSIS & METHANATION

First transformation step: Electrolysis

- Efficiency: at least 80 percent
- Only by-product: pure oxygen
- Feed into the natural gas grid in limited quantities, mainly because hydrogen has a much lower energy density than methane.

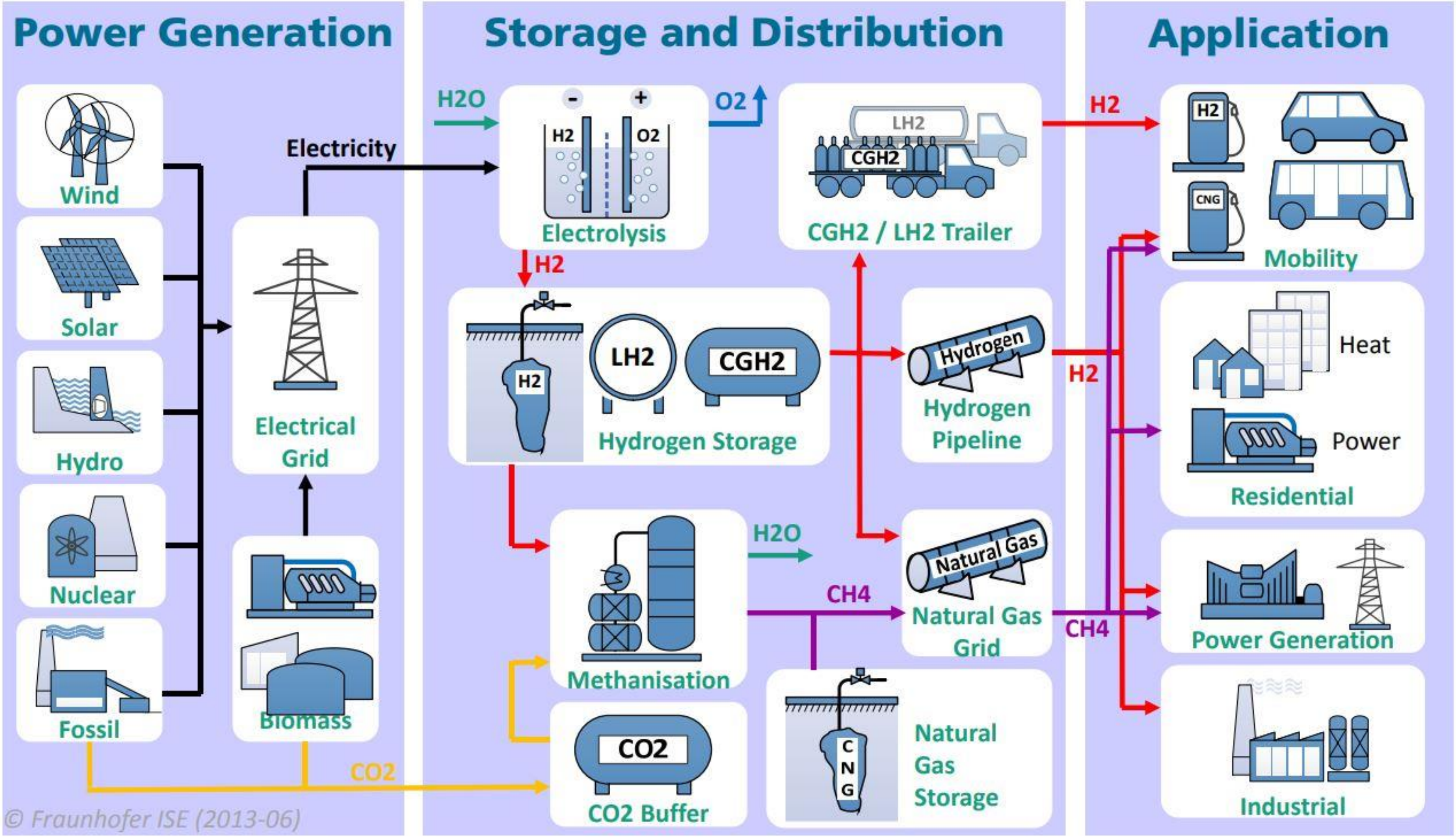
Possible second transformation step: Methanation

- Overall efficiency: approx. 60 percent.
- Use of carbon dioxide e.g. from the industry
- By-product: Water (CO2 + 4 H2 → CH4 + 2 H2O)
- Produced methane is fully compatible with natural gas and can thus be used without any restriction.
- Methanation only makes sense if the injection of hydrogen reaches its limits.



Power-to-Gas Concept
Source: Elster Profiles magazine 01/2019 [2]

THE PROCESS: FROM PRODUCTION TO USAGE



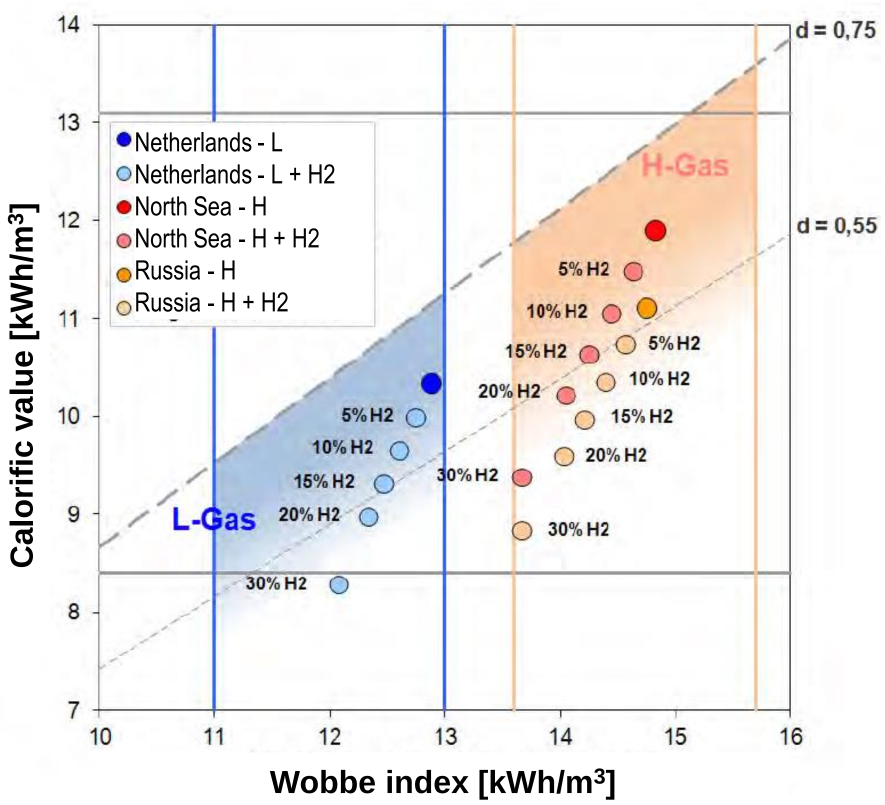
Source: Fraunhofer ISE [3]

IMPACT ON GAS SUPPLY

INFLUENCE ON SUPPLY NETWORKS, MEASUREMENT TECHNOLOGY AND DOWNSTREAM PROCESSES

PROPERTIES OF HYDROGEN

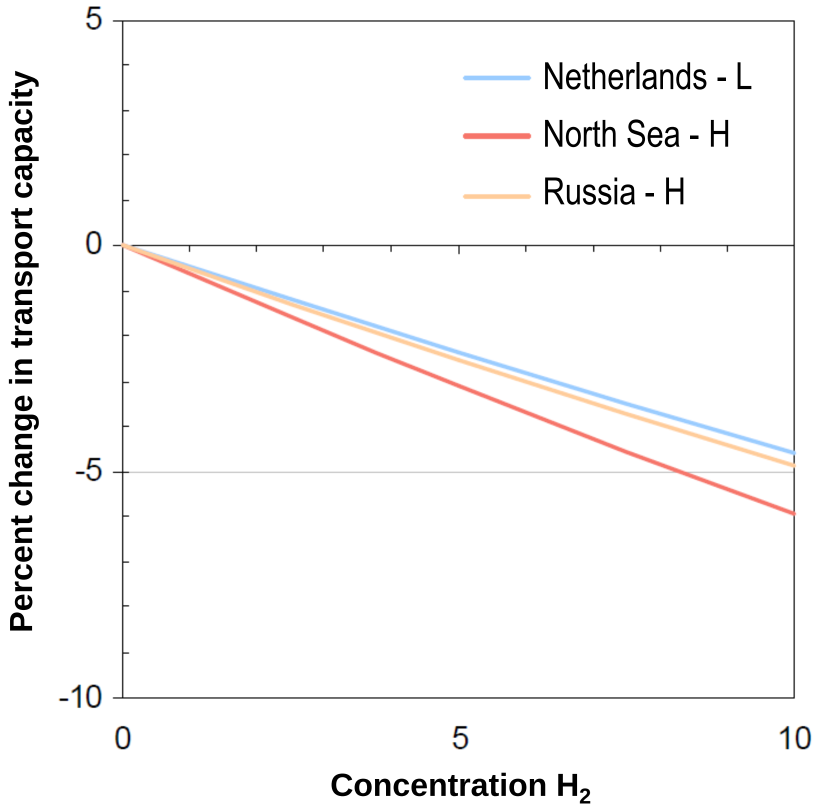
- Volume-related calorific value: approx. 1/3 of natural gas
- Density: about 1/7 of methane, about 1/10 of air
- Thermal conductivity: high, similar to helium
- Diffuses very quickly through porous materials or through the smallest leaks.
- Mixtures of hydrogen with air or especially with pure oxygen are very explosive (oxyhydrogen)



Change in gas quality Characteristics (Wobbe index, calorific value, relative density) as a function of the H2 concentration for three different natural gases
Source: DVGW [4]

INFLUENCE ON THE SUPPLY NETWORKS TRANSPORT CAPACITY

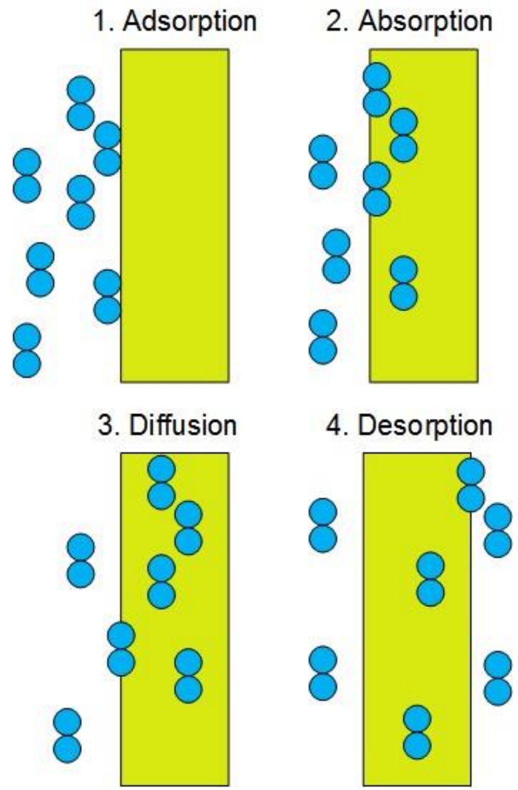
- Due to the low amount of energy per volume, hydrogen reduces the transportable capacity of a pipeline.
- The reduction of the transport capacity at 10% hydrogen is about 5% - 6% (depending on the natural gas type).
- This can be compensated partly by an increase in the volume rate (higher pressure gradient). However, higher compressor capacities (approx. 25%) are required for this, which have a negative effect on the energy losses.



Percent change in transport capacity as a function of the H2 concentration for three different natural gases
Source: DVGW [4]

INFLUENCE ON THE SUPPLY NETWORKS PERMEATION

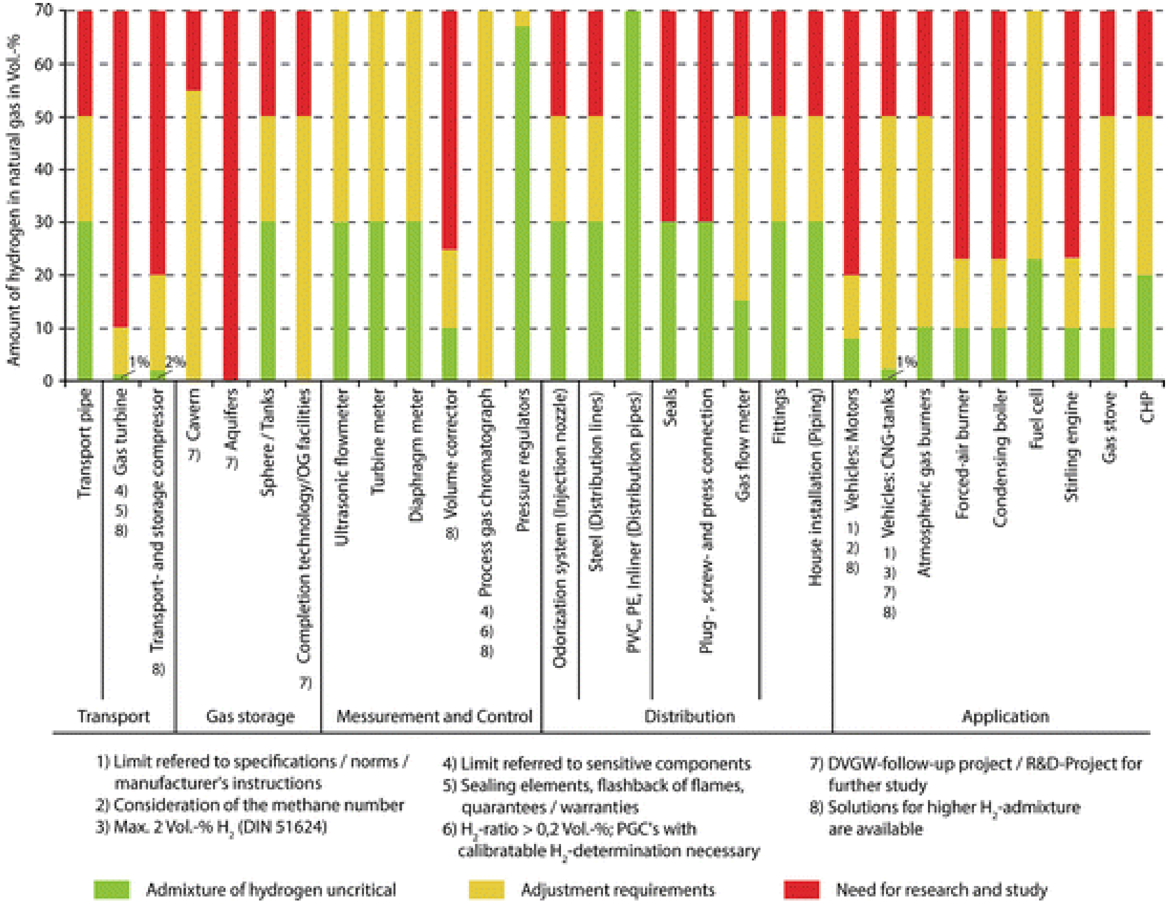
- The permeation of hydrogen through steel and plastic piping, connection technology, seals and membranes can lead to embrittlement and resulting material damage.
- The physical impairment takes place via the entry of atomic hydrogen; Within lattice imperfections and zones of highest elastic and plastic stresses hydrogen is preferably taken up.
- These zones can be starting points for possible cracking or crack propagation.
- Therefore, the use of optimized materials is required.



Simplified representation of the 4 individual processes of permeation
Source: DBI GUT [5]

INFLUENCE ON MEASUREMENT TECHNOLOGY OVERVIEW

- It is generally assumed that the existing infrastructure is largely suitable for about 10% by volume of hydrogen in natural gas.
- There is a need for research in e.g. natural gas storages, gas turbines, natural gas tanks.

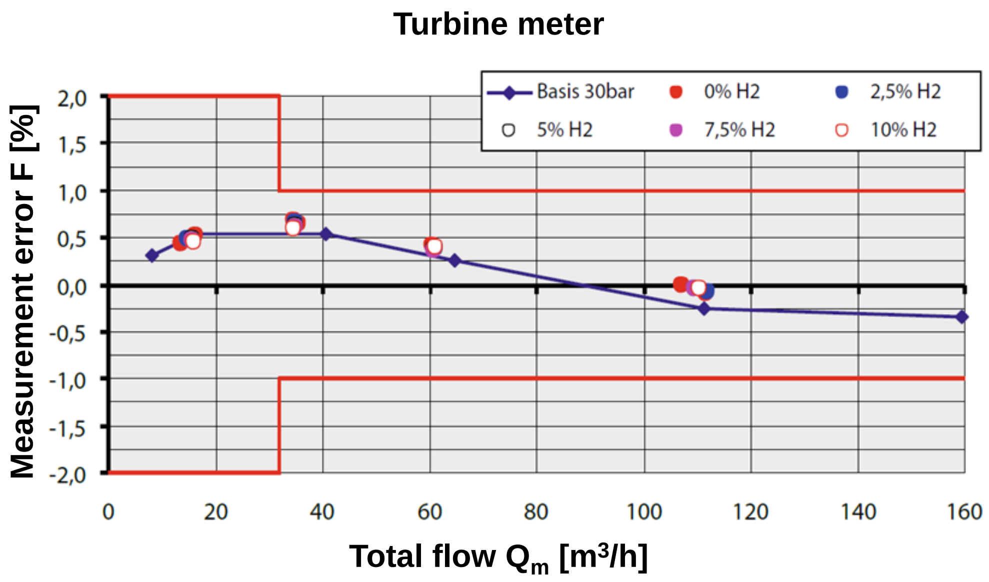


Overview: H2 tolerance of selected elements in the natural gas grid

Source: Springer [6]

INFLUENCE ON MEASUREMENT TECHNOLOGY TURBINE & ROTARY METERS

- Are considered to be generally suitable even at high H2 concentrations
- Investigations are to be carried out with regard to measuring accuracy with fluctuating gas properties as well as long-term stability, permeation and dynamic behavior at higher pressures.
- The lower drive torque for turbine meters resp. the lower force on the pistons for rotary meters at the same flow rate will increase the value of Qmin.
- The value for Qmax is determined by the speed limit and does not change. This leads to a limitation of the measuring range.



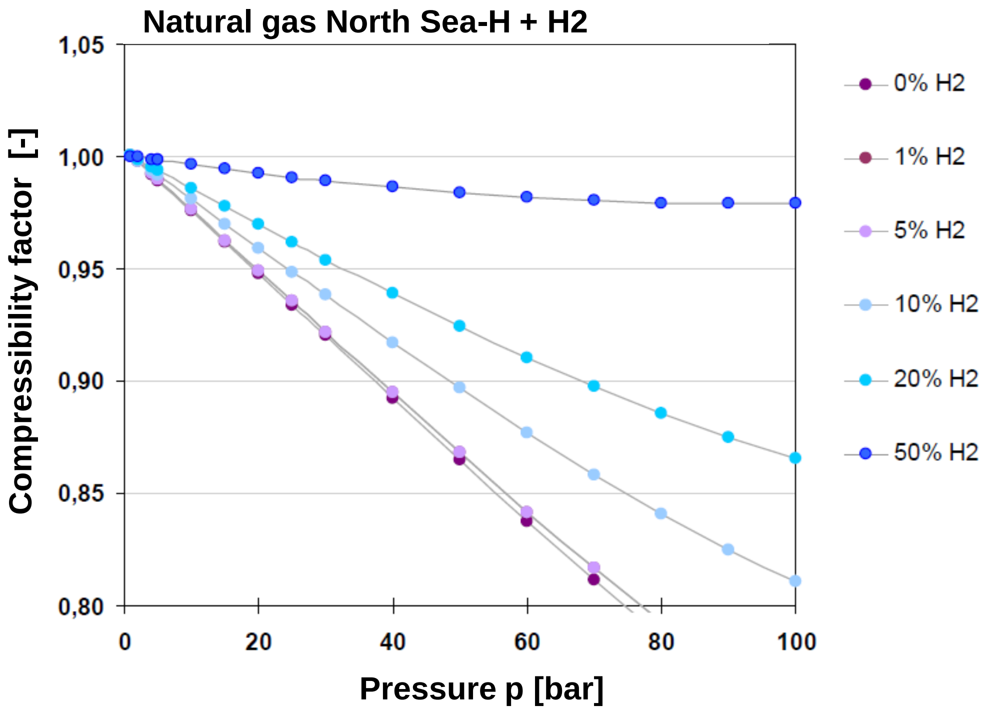
Measurement error depending on the H2 content
Source: gwf magazine 2013 - Influence of hydrogen on the high pressure error curve of natural gas meters

INFLUENCE ON MEASUREMENT TECHNOLOGY ULTRASONIC METER

- Ultrasonic gas meters are suitable for measuring 10 vol.% H2 within the calibration error limit.
- Theoretically also suitable for 100 vol.%.
- Adjustment of ultrasonic meters to the density of the gas mixture is to be made
- Lower density of H2 leads to higher sound velocities with an influence on the ultrasound signal; adjustments to the parameterization may be necessary.

INFLUENCE ON MEASUREMENT TECHNOLOGY COMPRESSIBILITY FACTORS

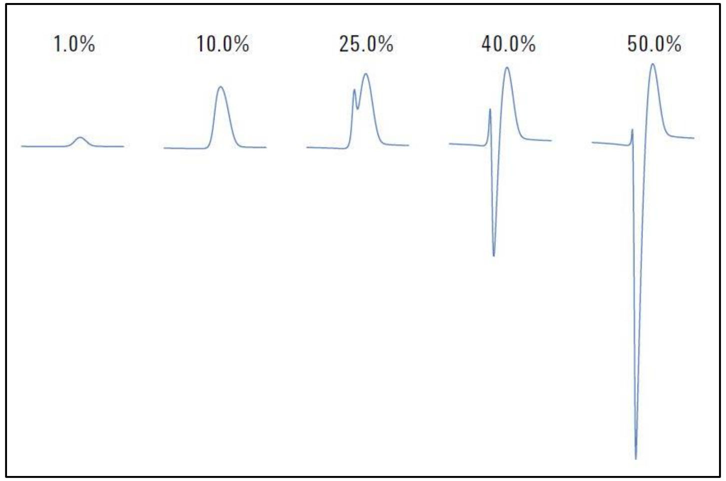
- AGA8:
  - Applicable with a measurement uncertainty of 0.1% up to a maximum of 10 mol%.
  - Can also be used for higher amounts of H2, but with significantly higher measurement uncertainties.
- SGERG-88: Applicable up to 10 mol%.
- GERG2004: Suitable for up to 40 mol%



Compressibility factors (GERG2004) for natural gas North Sea H with admixtures of hydrogen depending on the pressure (t = 10° C)
Source: DVGW Research report [7]

INFLUENCE ON MEASUREMENT TECHNOLOGY PROCESS GAS CHROMATOGRAPH (PGC)

- Due to the similar thermal conductivity values of helium and hydrogen, hydrogen can be detected relatively poorly when using helium as the carrier gas by a TCD.
- When argon is used as carrier gas instead of helium, the sensitivity for the other gas components is significantly reduced by a factor of 5 to 10.
- In addition, above a certain hydrogen concentrations in the carrier gas component mixture and the associated change in the thermal conductivity, a non-linear reaction and an inversion of the peak maximum occurs.
- If the hydrogen concentration continues to increase, this results in a zero crossing and a negative reaction to the detector

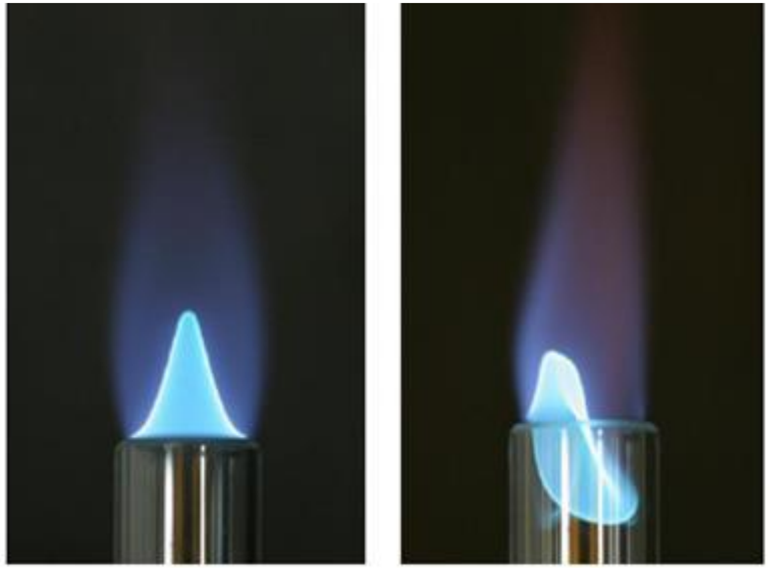


Peak shape of increasing hydrogen concentrations with helium carrier gas
Source: Agilent [8]

INFLUENCE ON DOWNSTREAM PROCESSES

Gas turbines

- H_2 concentration typically limited to 1-5 Vol.-%, so as not to damage burners.
- Increase of the flame propagation speed with the danger of flashback and thermal overload of combustion chamber components.
- Instability of the flame with the danger of flame loss.



ACTIVITIES AT HONEYWELL-ELSTER

INVESTIGATIONS ON THE TOPICS SAFETY & PERFORMANCE

1. Safety:
   - Gas resistance of materials e.g. housings, seals, pressure sensors
   - Security functionality e.g. of pressure regulators
   - PED approvals
   - Approvals for hazardous areas: e.g. explosion group (H_2: ATEX IIc)
2. Performance:
   - Functional accuracy (measurement technology, pressure control, energy calculation, etc.)
   - Long-term stability
   - Influence on Qmin and Qmax
   - Metrology approvals, e.g. MID
   - Name plate
   - Calibration
3. Production / Testing:
   - Test benches with H_2, e.g. for leakage test

MECHANICAL GAS METERS SUITABILITY FOR 10% HYDROGEN

			Approvals	Comment
Safety	Explosion protection		ATEX	o.k.
	Strength	Material	PED Module B	o.k.
		Production	PED Module D	o.k.
Characteristic	Measurement accuracy	Low pressure	MID	o.k.
		High pressure	MID	o.k.
Production	Leak test			o.k.
Installation	Leak test			o.k.
Long-term behavior	Material	Tightness		o.k.
		Characteristics		o.k.

MECHANICAL GAS METERS SUITABILITY FOR 100% HYDROGEN

			Approvals	Comment
Safety	Explosion protection		ATEX	check
	Strength	Material	PED Module B	o.k.
		Production	PED Module D	o.k.
Characteristic	Measurement accuracy	Low pressure	MID	Measuring range
		High pressure	MID	o.k.
Production	Leak test	Helium or Air?		check
Installation	Leak test	Gas?		check
Long-term behavior	Material	Tightness		
		Characteristics		

GAS QUALITY MEASUREMENT STATUS

EnCal 3000:

- H2 measurement finished and available (E-gas and Quad version)
- Metrological approvals: German PTB approval for up to 10% H2 available; Expansion to 20% in progress

EnCal 3000 proChain:

- Up to now only application is C6+
- First new application to develop should be H2

GasLab Q2:

- More than 0.1% hydrogen affects the analysis model and causes significant inaccuracies
- Feasibility study on different scenarios are in progress

COMPRESSIBILITY FACTORS IN EVCD, FLOW COMPUTER STATUS

- Together with OGE and PTB investigations are done to the usability of the AGA8 for natural gas with more than 10 mol% H2.
- OGE did calculations for the compressibility factor according to AGA8 and GERG2004 with higher H2 concentrations for typical gas vectors: As expected, the largest deviations are at high pressure, but the relative deviations are also within limits for more than 10 mol% H2.

- With 100% hydrogen, AFB ‘Table Z’ can be used in enCore devices to calculate the Compressibility factor.
- MID approval for FC1 available.

H2					
610A870A	-25	0	25	50	75
1	1,0006	1,0006	1,0006	1,0006	1,0005
10	1,0065	1,0062	1,0059	1,0056	1,0053
30	1,0195	1,0186	1,0177	1,0168	1,0159
50	1,0329	1,0313	1,0297	1,0281	1,0266
75	1,05	1,0474	1,0448	1,0423	1,0401
100	1,0675	1,0637	1,0601	1,0567	1,0536

APPENDIX

PROJECTS, LIST OF REFERENCES, ADDITIONAL INFORMATION

PROJECT ‘ELEMENT ONE’ (GASUNIE, TENNET AND THYSSENGAS)

https://www.tennet.eu/news/detail/gasunie-tennet-and-thyssengas-reveal-detailed-green-sector-coupling-plans-using-power-to-gas-tec/

Background:

- Storage technology for renewable electricity / green sector coupling with power-to-gas.

Content:

- Electricity and gas network operators plan to build a 100 MW power-to-gas plant in Lower Saxony.
- The facility is designed to link energy, transport and industry sectors.
- Stabilize power grids and limit the regulation of wind energy.

Details:

- Construction of the largest German power-to-gas plant (100 MW) to convert offshore wind power from the North Sea into hydrogen.
- Objective: To develop new storage potential for electricity from renewable sources.
- Sector coupling: Transport via existing gas pipelines for heat, hydrogen filling stations for mobility, storage in caverns for industry.
- Less expansion in the electricity grid.

PROJECT 'METHANATION PLANT IN FALKENHAGEN' (GERMANY)

https://www.dvgw.de/medien/dvgw/en/news/gempi-eroeffnung-methanisierungsanlage-falkenhagen-en.pdf

Background:

- International research project STORE & GO
- Demonstration of the technical feasibility of the power-to-gas process from electrolysis through methanation to the feeding of "green" gas into the natural gas grid.

Content:

- Converting regeneratively produced hydrogen with CO2 from a bioethanol plant to methane (synthetic natural gas).
- The heat generated during the process is used by neighboring industrial plant.

Details:

- The plant produces up to 1,400 cubic meters of synthetic methane (SNG) per day, which corresponds to approximately 14,500 kWh of energy.
- Product can be used in a variety of ways, for example as a fuel, for generating heat and electricity in power plants or in the home, and as a raw material for the chemical industry. Simultaneously opens up new possibilities for the transport and storage of energy from renewable sources through the unrestricted use of existing natural gas infrastructure.

PROJECT ‘H21 LEEDS CITY GATE’

http://www.northerngasnetworks.co.uk/2016/07/watch-our-h21-leeds-city-gate-film/

Background:

- Decarbonization of the Gas grid to reduce CO2 emissions.

Content:

- Ambitious plans to convert significant parts of the UK gas grid to be 100% hydrogen were launched by a project team led by Northern Gas Networks at an event in Westminster on 11 July 2016.
- Converting the UK gas grid to hydrogen will be a major step towards meeting the UK’s carbon reduction targets. Currently, over 30% of all UK carbon emissions come from domestic heating and cooking. A UK-wide conversion to hydrogen gas will reduce heat emissions by a minimum of 73% as well as supporting decarbonization of transport and localized electrical generation.

Details:

- Gas used for heating (6TWh/year) and cooking (Hydrogen burners and cookers required).
- Replace low and medium pressure distribution Iron pipes by Polyethylene.
- Hydrogen stored in salt caverns; separate H2 transmission pipeline.
- 3 years planned for conversion during summer months.

LIST OF REFERENCES

[1] Homepage ‘Gas in focus’
https://www.gasinfocus.com/en/focus/the-power-to-gas-technology-a-bridge-between-electricity-and-natural-gas-networks/

[2] Elster Profiles magazine 01/2019 – Power-to-Gas Concept
https://www.elster-instromet.com/assets/downloads/Profiles-Journale/Profiles_2019_1.pdf

[3] Fraunhofer ISE – Homepage „Power-to-Gas“
https://www.ise.fraunhofer.de/en/business-areas/hydrogen-technologies-and-electrical-energy-storage/electrolysis-and-power-to-gas/power-to-gas.html

[4] DVGW homepage - Information to Power-to-Gas
https://www.dvgw.de/english-pages/topics/dvgws-research-and-development-topics/renewable-gases/

[5] DBI GUT
https://www.dbi-gut.de/gas-grids-and-gas-facilities.html

[6] Sterner M. (2014) Power-to-Gas. In: Chen WY., Suzuki T., Lackner M. (eds) Handbook of Climate Change Mitigation and Adaptation. Springer, New York, NY

[7] DVGW Research report "Influence of hydrogen on energy measurement and billing”
https://www.dvgw.de/medien/dvgw/forschung/berichte/g3_02_12.pdf

[8] Agilent
https://www.agilent.com/cs/library/applications/5991-3199EN.pdf

ADDITIONAL INFORMATION

GRTgas video to Power-to-Gas
https://youtu.be/j6ktfz2R9fo

THANK YOU

Honeywell