Metrology for Advanced Hydrogen Storage Solutions

ENERGY GASES

MefHySto – Overview and Tangible Results

EMN Energy Gases "Measurement Solutions for Energy Gases" Workshop
Lisbon, Protugal, March 22nd, 2023

Michael Maiwald

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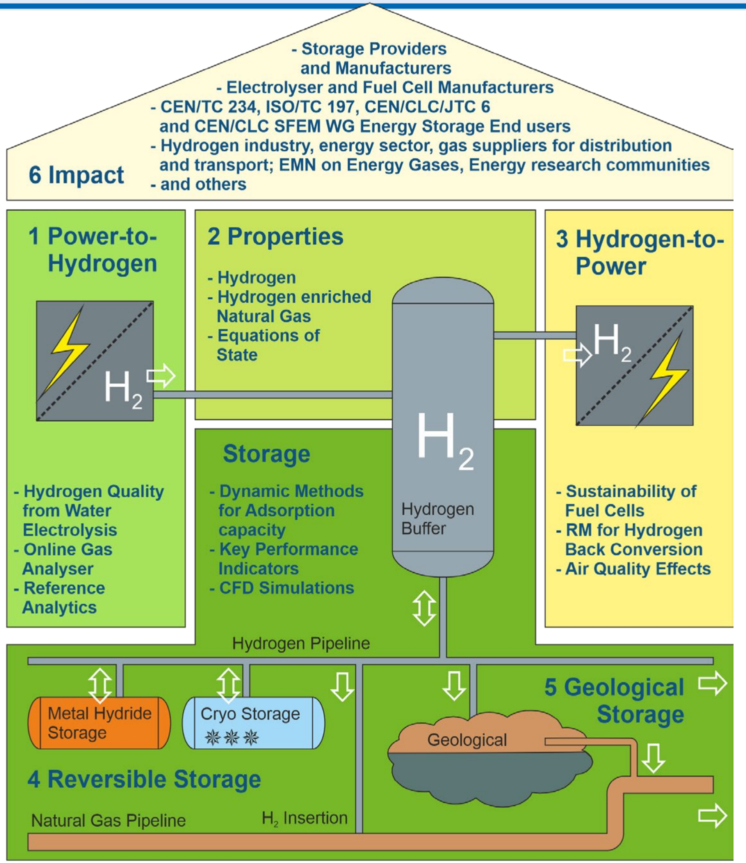
MefHySto – Introduction
Metrology for Advanced Hydrogen Storage Solutions

MefHySto
Metrology for Advanced Hydrogen Storage Solutions

- Duration 2020–2023
- EU Funding 2.3 M€
- Coordinator: BAM
- 14 Partners

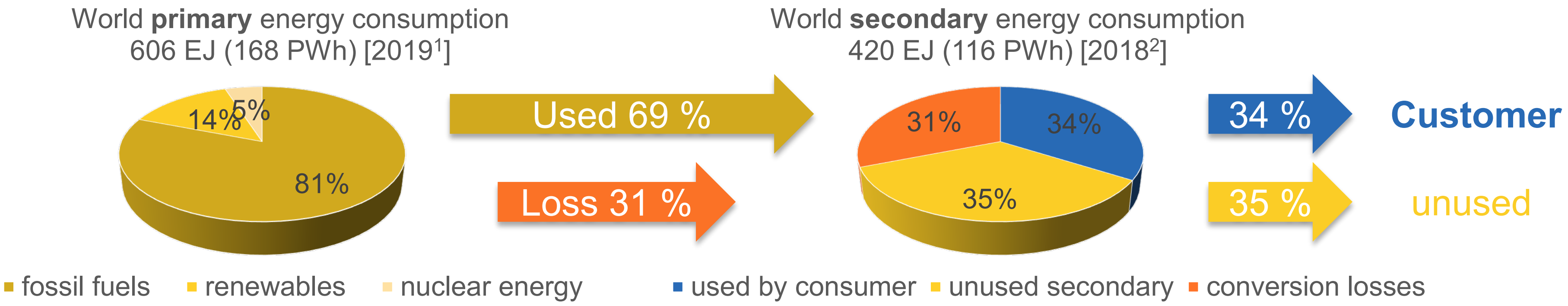
- Power-to-Hydrogen
- Thermophysical properties
- Hydrogen-to-power
- Reversible storage
- Geological storage

- Ambitious new EU energy target of using 32 % → 40 % of renewable energy by 2030
- Cannot be reached without advanced energy storage solutions, e.g., H_2 storage
- Measurement science is critical for realisation of this commitment
- Financial concerns of amount of hydrogen generated – stored – back-converted



BAM, CMI, cea, MAHYTEC, UNIVERSIDADE DA CORUÑA, ERIG European Research Institute for Gas and Energy Innovation, reganosa, DBI, NPL National Physical Laboratory, PTB Physikalisch-Technische Bundesanstalt Braunschweig und Berlin, Universidad de Valladolid, Max Planck Institute for Intelligent Systems, DVGW

Hydrogen as a Secondary Energy Carrier



- Conversion from thermal machines such as turbines and motors are limited by Carnot efficiency

- **Hydrogen as new secondary energy carrier**
- Can be produced from primary energy with much higher conversion efficiency
- Electrolysers, batteries, and FCs, which have theoretical efficiencies approaching 100 %

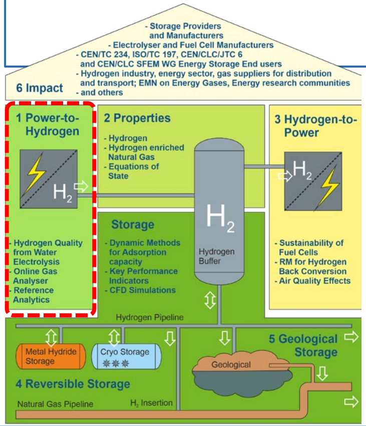
Sources
[1] IEA, Total primary energy supply by fuel, 1971 and 2019, IEA, Paris - https://www.iea.org/data-and-statistics/charts/total-primary-energy-supply-by-fuel-1971-and-2019
[2] IEA, World total final consumption by source, 1973-2018, IEA, Paris - https://www.iea.org/data-and-statistics/charts/world-total-final-consumption-by-source-1973-2018

WP1 Metrology for Hydrogen Quality from Power-to-Hydrogen

- Quality from Water Electrolysis
- Online Gas Analysis
- Reference Analytics

Tasks

- New metrology for realisation and measurement of H_2 key impurities with fast response
- Testing and validation of instruments for measuring H_2 key impurities
- Trials of rapid response analysis of H_2 key contaminants from electrolysis in-situ



Exchange and networking with

METROLOGY for HYDROGEN VEHICLES 2

WP lead NPL

partners liten, PTB, DBI, reganosa

- Water vapour and oxygen identified as key impurities.
- Water vapour step change facility with a 4-way switching valve developed with traceability to NPL Primary Standard Humidity Generator.

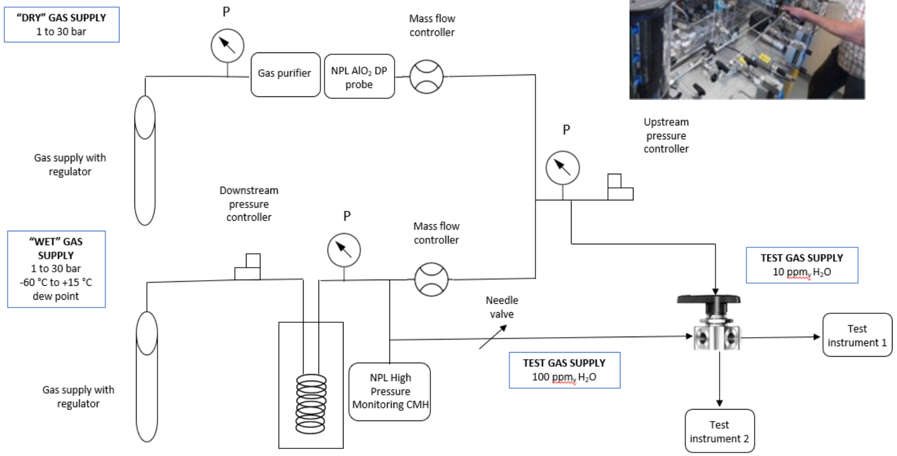


Figure 1: NPL facility for testing hygrometer response time to step changes in hydrogen water content

WP1 Metrology for Hydrogen Quality from Power-to-Hydrogen

- Hygrometers with seven different measurement principles tested including: SAW, metal oxide dew-point probe, fibre optic, chilled-mirror, electrolytic and spectrometry.
- Fitting function to response time data developed to estimate t_{90} values with uncertainties.

- Two laboratory electrolyser setups prepared at NPL and CEA with online impurity measurement at the cathode.
- Impact of operating conditions and transient profiles on the cell performances and on the quality of produced hydrogen to be studied with online sensors (including µGC and GC-methaniser-FID)

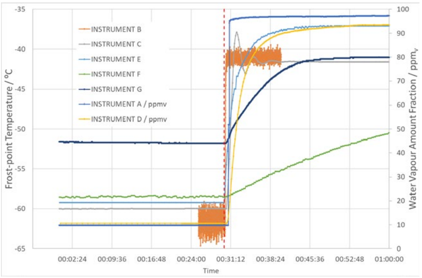


Figure 2: t_{90} response time analysis for seven hygrometer types.

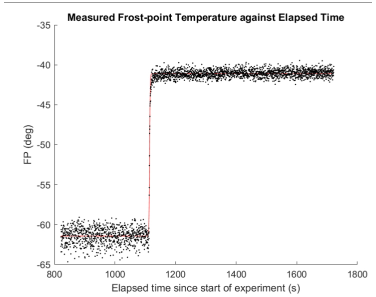


Figure 3: Rising series response time data fit

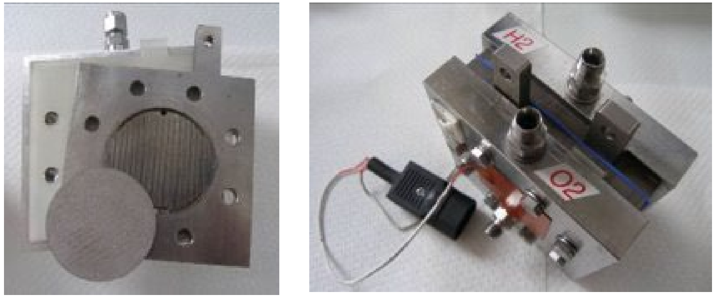
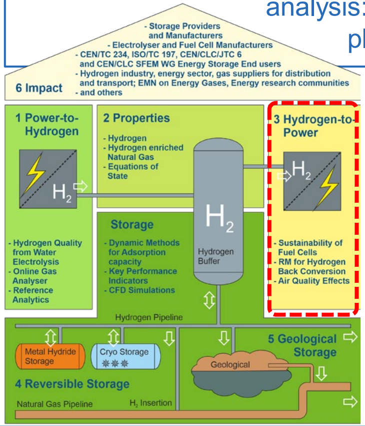


Figure 4: PEMWE testing at single cell level test bench specifications

- Impact of Impurities on Fuel Cells
- Reference Materials
- Air Quality Effects

Tasks

- Gas Reference Materials for fuel cell tests
- Impact of impurities on fuel cell performance; standards for H_2 quality
- Specify a process air quality sensor for monitoring fuel cell performance and durability
- Validation of metrological chain for gas analysis: complete H_2 platform level



Impact of Hydrogen and Air Impurities

- Literature review on previous/current work on hydrogen and air impurities to set specific compositions to be studied
- Synergy effects between NO_x and SO_x species has been highlighted in literature and will be further studied for air supply
- Development of analytical methods for VOC (Volatile Organo-halogenated Compounds) analysis in air and sorbents qualification is ongoing

Exchange and networking with

METROLOGY for HYDROGEN VEHICLES 2

WP lead: liten

partners: UNIVERSIDADE DA CORUÑA, reganosa, NPL National Physical Laboratory, BAM

Figure 1: Example of sorbents for VOCs sampling/enrichment

Figure 2: Fuel cell lab with analytics for FC stack and single cell (@CEA)

WP3: Metrology for Hydrogen Quality from Electrical Energy Storage by Hydrogen Back Conversion

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Testing Facilities and Test Results

- Fuel cell single cell and stack technologies were set up and are now available
- First reference tests under both reference “pure” H_2 and air were conducted
- Preparation of Gas Mixture for fuel cell tests following the H_2 ISO 14687-2 with all contaminants at their maximum respective levels
- Fuel cell tests (performance and durability) planned with this H_2 composition

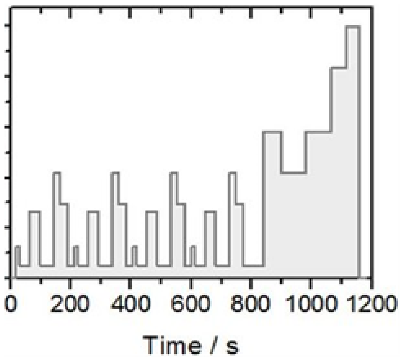

Figure 3: FC-DLC automotive load profile for ageing test

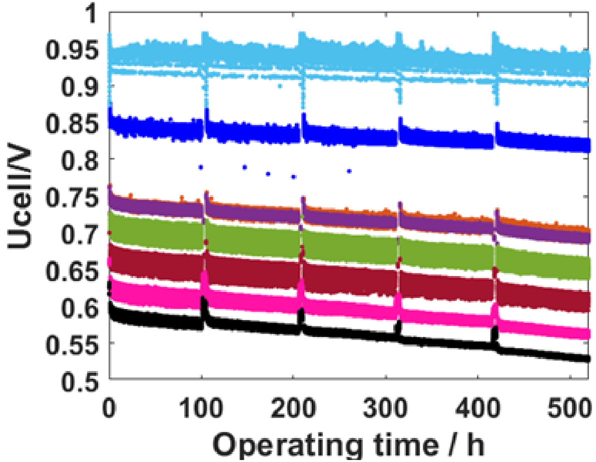

Figure 4: Cell voltage evolution during reference durability tests for 500 h using FC-DLC in 25 cm² single cell

WP2 Thermophysical Properties of Hydrogen

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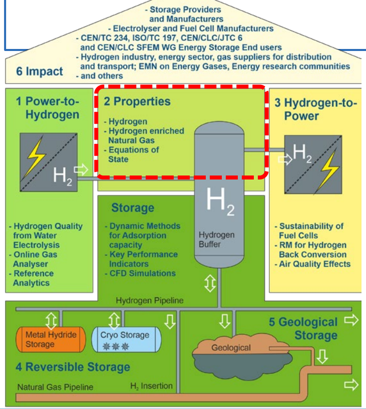
- Thermophysical Properties of H_2 and H_2 enriched natural gas
- Equations of State

Tasks

- Develop and test lab techniques to provide reference mixtures of humid H_2/ H_2-enriched natural gas
- Influence of H_2 content on the saturation curve of H_2-enriched natural gas mixtures
- Develop reference equations of state (EOS) for H_2-enriched natural gas mixtures and H_2 under geological storage conditions



WP lead

partners

Equations of State

- European Gas Research Group (GERG)-2008 equation of state (EoS) is the approved ISO standard (ISO 20765-2)
- For increased H_2 content of NG, the GERG-2008 EoS needs to be extended to application range for diversification
- As part of this, high-precision experimental pressure, mass density and temperature (p, ρ, T) data for gravimetrically prepared synthetic natural gas mixtures are needed.

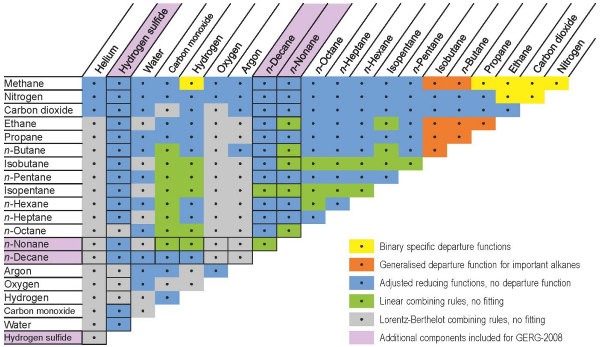


Figure 1: GERG-2008 Reference Equation of State Compound Matrix [1]

Reference

[1] O. Kunz; W. Wagner; J. Chem. Eng. Data 57, 3032—3091, 2012. DOI: 10.1021/je300655b © 2012 Am. Chem. Soc.

WP2 Deep Dive
Gravimetric Preparation of Gas Mixtures

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- Preparation of gas mixtures that qualify as reference materials (according to ISO 6142-1)
- Pre-treatment of cylinders > filling station direct filling, small cylinder, liquid injection > use of pre-mixtures > fine weighing
- Mixture validation by process-GC
- Bracketing method according to ISO 12963

Cylinders	
A1–A3:	Typical 11 component nat. gas (+0 %, +10 %, +20 % H_2)
A4–A6:	Further 11 component nat. gas (+0 %, +10 %, +20 % H_2)
B1–B2:	Typical natural gas (+ 20 %, + 50 % H_2)
C1–C3:	H_2 (25 %, 50 %, 75 %) + natural gas Comp1 (e.g. CO_2)
D1–D3:	H_2 (25 %, 50 %, 75 %) + natural gasComp2 (e.g. CO)

Table 1: Proposed gas mixtures within MefHySto

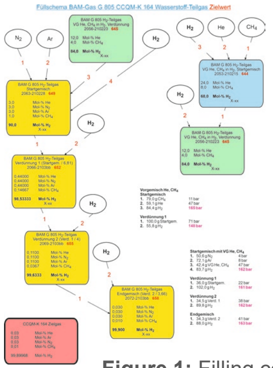


Figure 1: Filling concept

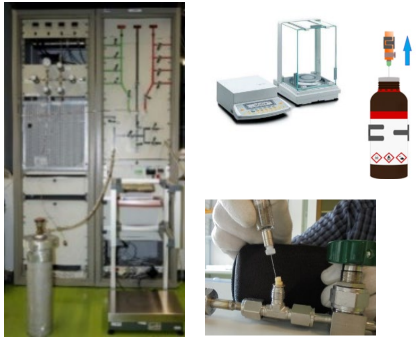


Figure 2: Experimental stand for filling gas cylinders, liquid injection

Figure 3: mechanical balance Voland HCE 25: 25 kg ± 15 mg

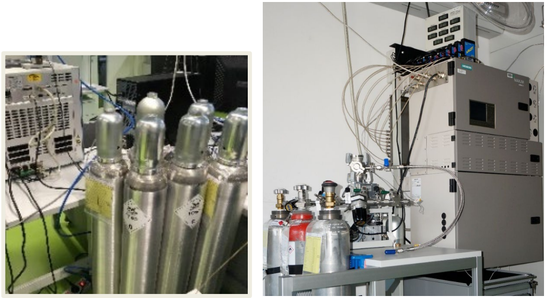


Figure 4: Multichannel process GC (12 TC detectors, one single isothermal method (t = const. = 60 °C), 40 min run)

- A new spherical microwave resonator has been built for high precision measurements of thermophysical properties of hydrogen
- A reference humidity generator and reference hygrometer were set up
- Density measurements over a large *p*,*T*-region using a single-sinker densimeter with magnetic suspension coupling

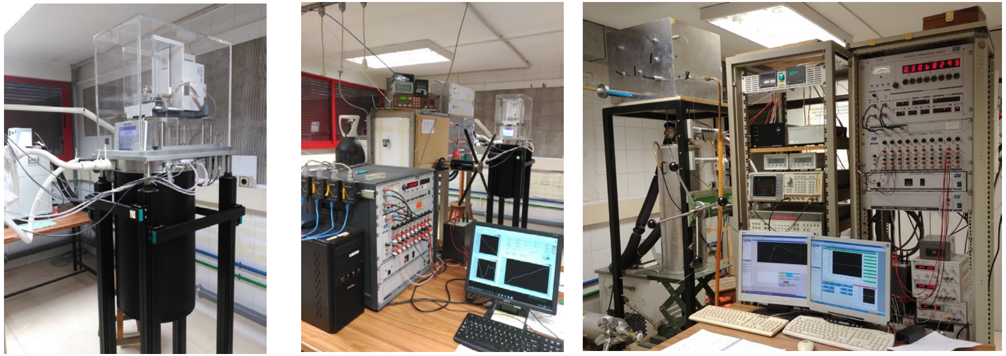
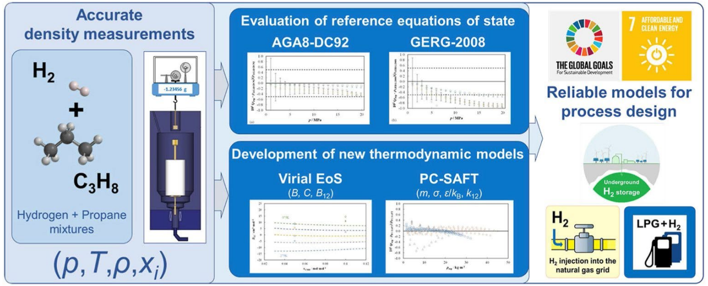


Figure 5: Magnetic suspension coupling allows the measurement of the apparent sinker mass without any contact between the balance and the sinker. This ensures high accuracy



Reference

[2] D. Lozano-Martín et al., International Journal of Hydrogen Energy 48(23) 8645–8667, 2023

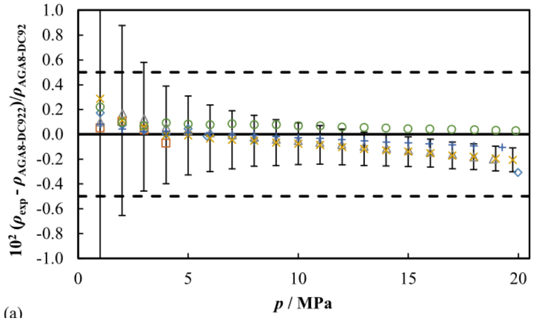


Figure 6: Relative deviations of experimental density of the binary (0.95 H2, 0.05 C3H8) from **AGA8-DC92 EoS** calculated values

WP 4: Metrology for Reversible Hydrogen Storage Technologies – (a) Metal Hydride Storage

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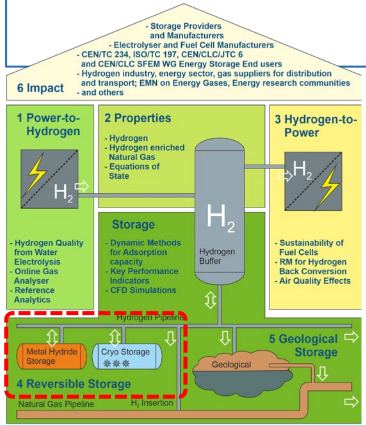
Metrology for Advanced Hydrogen Storage Solutions

- Dynamic Methods for Adsorption Capacity
- Storage Key Performance Indicators

Tasks

- Assess and harmonize key performance indicators for H_2 adsorption using dynamic methods
- Develop dynamic methods for H_2 ad/absorption capacity and influence of pollutants
- Develop reference materials and reference methods for H_2 ad/absorption capacity



WP lead MAHYTEC

partners MAX PLANCK INSTITUTE FOR INTELLIGENT SYSTEMS, BAM

Storage Key Performance Indicators

- The dynamic methods for H_2 adsorption need to be harmonised, e.g., using reference materials.
- Metal hydride AB5 alloy was purchased and verified
- Interlaboratory comparisons ongoing

Figure 1: Metal Hydride Storage Container @MAHYTEC

Effect of Impurities

- The selection of pollutants was based on ISO 14687-2-2019 (PEM fuel cell specs)
- Most important impurities for metal hydride hydrogen compression process are O_2 and water vapour from electrolysis, or traces of CO_2 and CO from carbonaceous feedstock

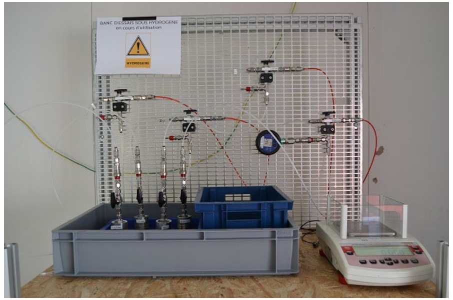


Figure 2: Experimental bench on the effect of some pollutant in hydrogen on

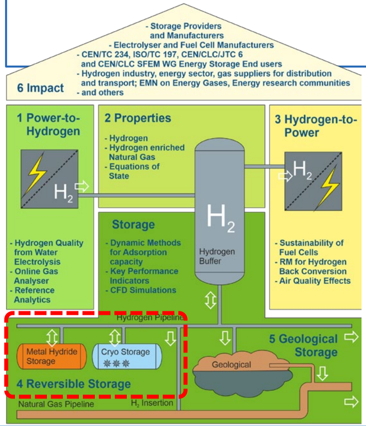
WP 4: Metrology for Reversible Hydrogen Storage Technologies – (b) Cryo Storage in Metal-Organic Frameworks

MefHySto
Metrology for Advanced Hydrogen Storage Solutions

- Dynamic Methods for Adsorption Capacity
- Storage Key Performance Indicators

Tasks

- Assess and harmonize key performance indicators for H_2 adsorption using dynamic methods
- Develop dynamic methods for H_2 ad/absorption capacity and influence of pollutants
- Develop reference materials and reference methods for H_2 ad/absorption capacity



WP lead MAHYTEC

partners MAX PLANCK INSTITUTE FOR INTELLIGENT SYSTEMS, BAM

Storage Key Performance Indicators

- Despite two decades of research, the dynamic methods for H_2 adsorption need to be harmonised, e.g., using reference materials
- Metal-organic framework (MOF) material ZIF-8 (Zn and 2-methylimidazole) was selected, purchased and verified [1]
- Interlaboratory comparisons almost completed

Figure 1: Cryo-adsorption labs @BAM and @MPI

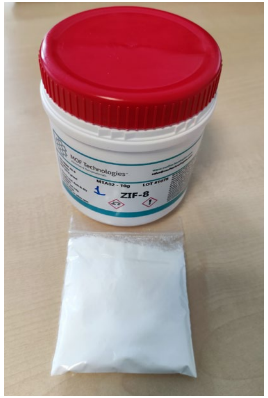


Figure 2: First gram scale batches of MOF Reference Material produced

[1] R. Balderas-Xicohtencatl, J. A. Villajos, et al., ZIF-8 Pellets as a Robust Material for Hydrogen Cryo-Adsorption Tanks, *ACS Applied Energy Materials* – DOI: 10.1021/acsaem.2c03719

WP 4 Deep Dive
Cryo Storage in MOFs – ZIF-8 Reference Material [1]

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- ZIF-8 was mechanochemically synthesized using a reactive extrusion process (Fig. 3) allowing the scale of the synthesis of the material to large quantities (Fig. 4)
- PXRD confirms that the powders and pellets are composed completely of ZIF-8 crystalline phase
- The pellets maintain the ZIF-8 phase with high crystallinity
- The pellets show higher uptake at p/p0 values ca. 0.01 compared to powder, indicating a slightly higher BET area (ca. 2%, see Table 1).

Sample	$A_{BET}/m^2\ g^{-1}$	$V_p{}^a/cm^3\ g^{-1}$	C
ZIF-8 Powder	1115	0.54	3634
ZIF-8 Pellets	1142	0.55	3550
Cycled ZIF-8 Pellets	1128	0.54	3553

^{a}Total pore volume at $p/p_0 = 0.9$.

Table 1: Textural Properties of the Powder and Pelletized ZIF-8

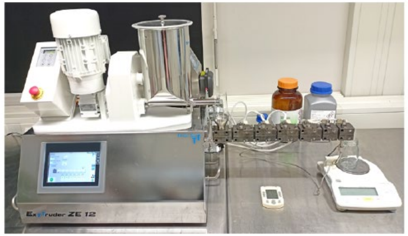
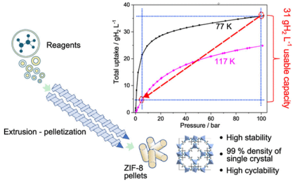


Figure 3: Lab Twin-Screw Extruder @BAM


Figure 4: Gram scale batches of pelletised MOF RM [1]



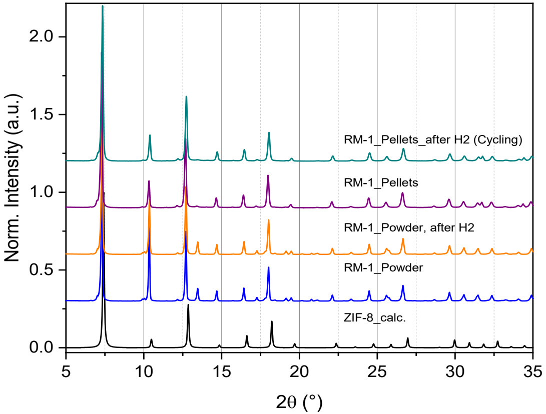


Figure 5: X-ray diffraction of the material RM-1 in powder, compared to the calculated X-ray diffraction pattern for the theoretical crystalline framework

[1] R. Balderas-Xicohtencatl, J. A. Villajos, et al., ZIF-8 Pellets as a Robust Material for Hydrogen Cryo-Adsorption Tanks, *ACS Applied Energy Materials* – DOI: 10.1021/acsaem.2c03719

WP 4 Deep Dive
Cryo Storage in MOFs – Reference Material and Comparisons

Metrology for Advanced Hydrogen Storage Solutions

ZIF-8 material characterisation for protocol

- The H_2 adsorption uptake at 77 K was measured with high accuracy considering the amount of analyzed sample, gas purity, activation conditions, and calibration procedures.
- The relative standard deviation (RSD) of 14 independent H_2 measurements is < 2 % at any pressure (up to 100 bar), indicating excellent reproducibility between the used analyzers.
- The operation stability of the material was demonstrated after 47 adsorption−desorption cycles

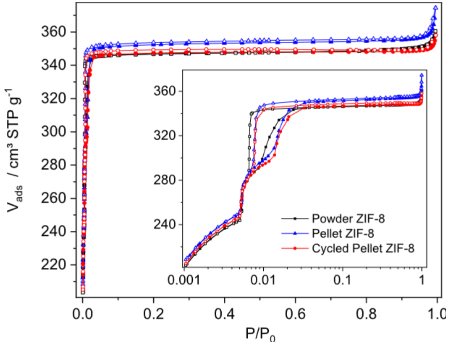


Figure 6: N2-adsorption/desorption isotherms at 77 K of powder and pelletized ZIF-8 samples

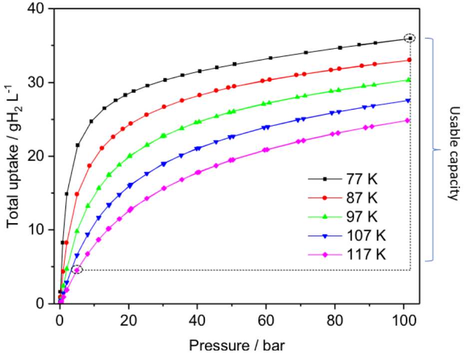


Figure 7: Usable capacity of pelletized material ZIF-8 calculated for a TSA cycle from 77 K – 100 bar and 117 K – 5 bar

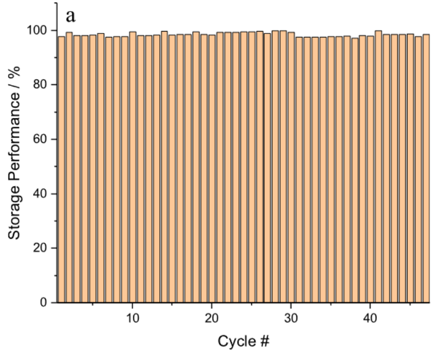


Figure 8: Cycling adsorption−desorption experiments of ZIF-8 pellets.

Figure 9: Protocol for interlab comparison

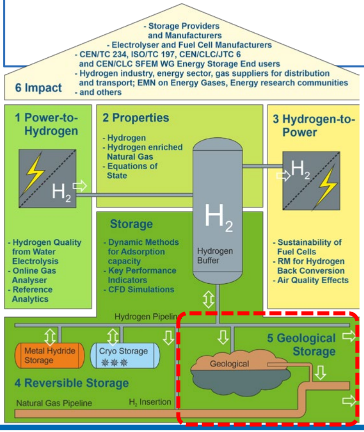
WP5 Large-Scale Storage of Gases in Geological Storage Facilities

MefHySto – Metrology for Advanced Hydrogen Storage Solutions

- Measurement Technology
- CFD Simulations
- Flow Metering

Tasks

- Determination of the requirements for the measurement technology
- Measurement of storage-relevant impurities (blanket, glycols) and traces of hydrocarbons in hydrogen
- Flow metering in gas mixtures (20/80; 50/50; 80/20)

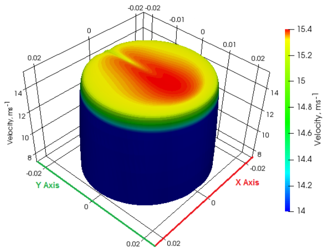


WP lead DBI

partners NPL National Physical Laboratory, liten cea tech, UNIVERSIDADE DA CORUÑA, reganosa, BAM

- Course of the changeover of UGS from natural gas to hydrogen varies depending on the type of the storage
- In caverns a changeover to high H_2-contents can be achieved quickly
- Pore storage tanks must be converted over long periods of time
- **Analytical requirements compiled** through expert statement by underground storage operators

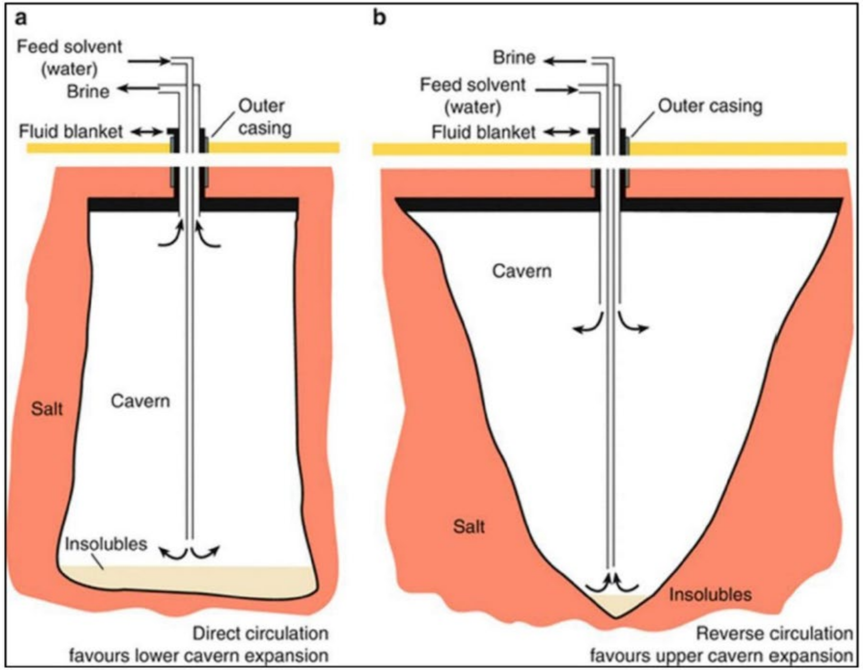
	Component / substance group	backround	type of UGS - relevance		relevance		frequency of use	Measurement in natural gas at UGS	type of measurement	measurement relevant for		limit*			
			cavern	Aquifer	injection	exit				NG/H_2 -mixtures	pure hydrogen	natural gas	Mixture	Hydrogen 1 (≥98 Mol.-%)	Hydrogen 2 (≥99,97 Mol.-%)
Technical requirements	O_2	corrosion	x	x	x			x	continuously	x	x	10 ppm	10 ppm		5 ppm
	Glykcol	hydrat inhibation	x	x		x		(x)	sampling						
	Methanol*	hydrat inhibation	x	x		x		(x)	sampling	x	(x)				2 ppm
	Bactericidal	Microbiological problems		x	x		rare		none						
	Anti-corrosive agents	corrosion	x	x	x		rare		none						
	acids	Microbiological problems around the borehole		x	x		rare		none						
	higher Hydrocarbon	blanket - Oil for the separation of gas and water phases	x			x	partially		none		x				2 ppm
	higher Hydrocarbon	compressor oil	x	x	x	(sometimes)			none		x				2 ppm
	oils, fats	Start of microbiological activity		x	x				none						
	Sulphur componds (Input)	Conversion of S components in the underground storage		x	x		some countries	(X)	sampling / continuously	x					
	Glycol	gas drying -Desiccant in absorption processes	x	x		x	standard process		none		x				2 ppm
Gas quality measurements	O_2	corrosion	x	x		x		x	continuously	x	x	10 ppm	10 ppm	10 ppm	5 ppm
	H_2	applications	x	x		x		x	continuously PGC	x	x	0 - 20 Mol.-%	1 - 98 Mol.-%	98 - 100 Mol.-% or rest	Measurement rest
	H_2O	Prevention of condensation components in UGS	x	x		x		x	continuously	x	x	50 mg/m³	50 mg/m³	50 mg/m³	5 ppm
	S total*		x	x		x			none		x	6 mg/m³	6 mg/m³	6 mg/m³	4 ppb
	H_2S + COS		x	x		x		x	continuously/ sampling	x	x	5 mg/m³	5 mg/m³	5 mg/m³	4 ppb
	Mercaptans		x	x		x		(x)	sampling	x	x	6 mg/m³	6 mg/m³	6 mg/m³	4 ppb
	HC Dewpoint	Prevention of condensation		x		x		(x)	continuously	x		< -2°C (0 - 70 bara)	< -2°C (0 - 70 bara)		
	Hydrocarbon (trace)		x	x		x			none		x				2 ppm
	Methane (trace)		x	x		x			none		x				100 ppm
	CO					x			none		(x)				0,2 ppm
	NH_3 / Amins	Amine for CO_2-Treatment		x		x			sampling	(x)		< 10 mg/m³	< 10 mg/m³	< 10 mg/m³	0,1 ppm
	Halogens*		x			x			none		(x) ?			≤ 0,05 ppm	≤ 0,05 ppm
	Dust,		x	x		x			none			technical free	technical free	technical free	1 mg/m³
	Silizium*			x		x			none		(x) ?	0,3 mg/m³			x
	N_2			x		x		x	continuously PGC	x	x	0 - 20 Mol.-%	0 - 20 Mol.-%	0 - 2 Mol.-%	0,03 Mol.-%
	CO_2								continuously PGC	x	x	2,5 - 4 Mol.-%	2,5 - 4 Mol.-%	?	2 ppm
	non H_2-Gases (He, Ar)								continuously PGC	(x)	x				≤ 300 ppm
Gas Quality Measurements for billing	gas composition	billing	x	x	x	x		x	continuously PGC	x	x				
	flow Measurement	billing	x	x	x	x		x	continuously	x	x				
	physical propoerties	billing	x	x	x	x		calculation	continuously PGC	x	(x) ?				



Flow metering
CFD Simulations (@CMI)

WP5 Deep Dive
Type of Underground Gas Storages (UGS) – Salt Caverns

- Caverns are artificial chambers created (drilled)
- within salt domes or bedded salt deposits
- in a thick cylindrical pit by controlled freshwater injection from the surface down to the deposits
- AKA Solution mining

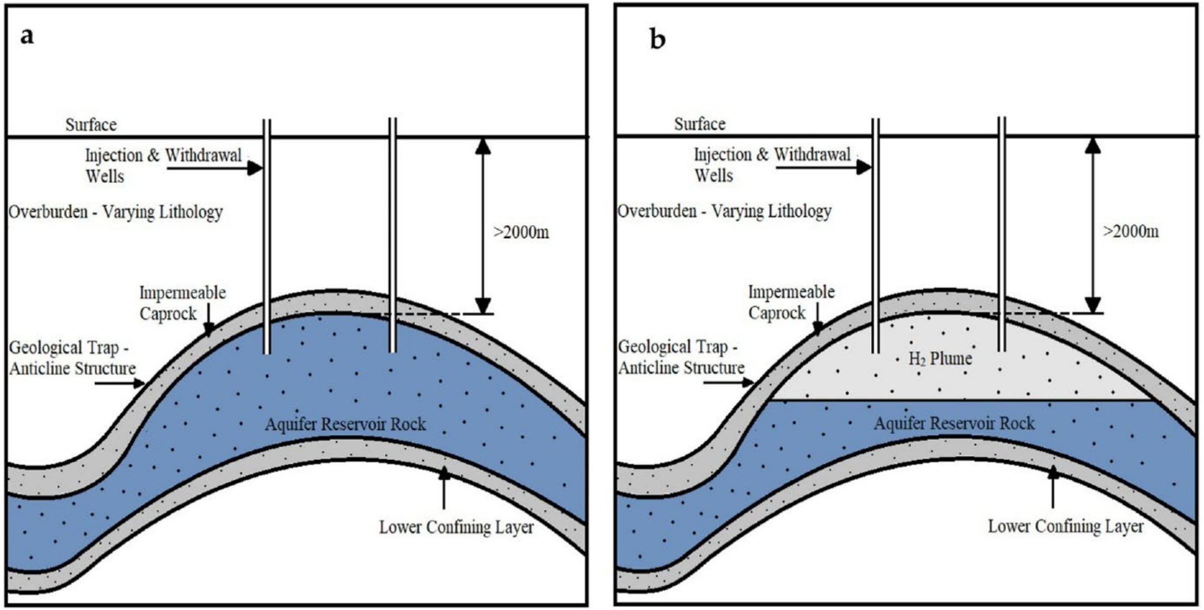


Salt cavern schematic showing different dissolution setups [1, 2]

Sources
[1] Muhammed, N. S., et al. A review on underground hydrogen storage: Insight into geological sites, influencing factors and future outlook, Energy Reports 8 (2022) 461–499 https://doi.org/10.1016/j.egyr.2021.12.002
[2] Wallace, R.L., Cai, Z., Zhang, H., Zhang, K., Guo, C., 2021. Utility-scale subsurface hydrogen storage: UK perspectives and technology. Int. J. Hydrogen Energy 46, 25137–25159. http://dx.doi.org/10.1016/j.ijhydene.2021.05.034.

Type of Underground Gas Storages (UGS) – Aquifers

- An aquifer is a subsurface layer of permeable and porous rock
- It is filled with fresh or saline water
- Often hundreds of feet deep
- In the absence of caverns and depleted hydrocarbon reservoirs, they are primarily utilized for UHS



Aquifer schematic (a) before H_2 injection, and (b) after H_2 injection [1, 2]

Sources
[1] Muhammed, N. S., et al. A review on underground hydrogen storage: Insight into geological sites, influencing factors and future outlook, Energy Reports 8 (2022) 461–499 https://doi.org/10.1016/j.egyr.2021.12.002
[2] Wallace, R.L., Cai, Z., Zhang, H., Zhang, K., Guo, C., 2021. Utility-scale subsurface hydrogen storage: UK perspectives and technology. Int. J. Hydrogen Energy 46, 25137–25159. http://dx.doi.org/10.1016/j.ijhydene.2021.05.034.

Type of UGS – Depleted Oil and Gas Reservoirs

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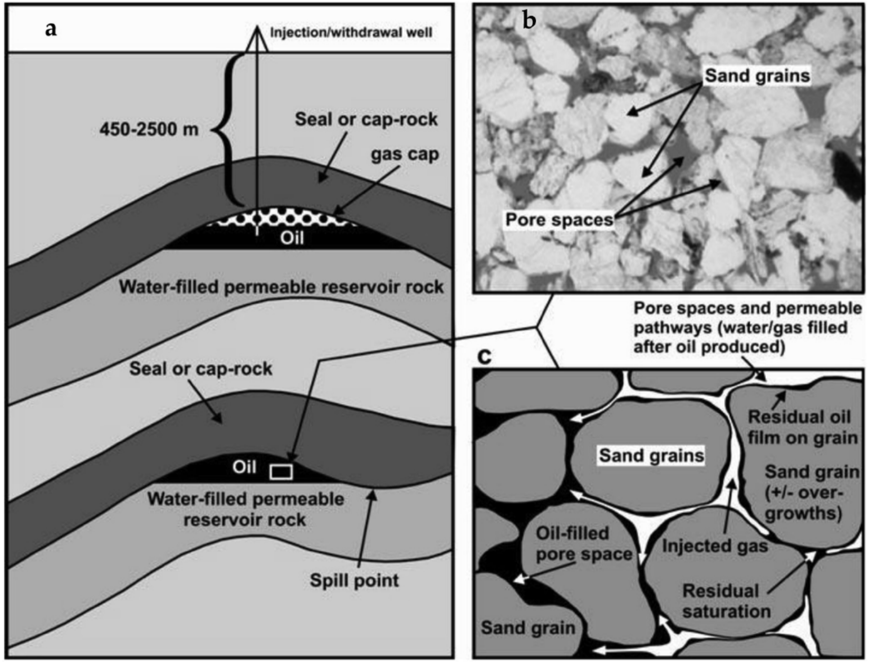
- Depleted reservoir is the conventional storage means for natural gas
- Porous and permeable hydrocarbon reservoir
- Located thousands of feet beneath the subsurface
- Can be considered as a portion of an aquifer (geological traps)



An overview of a depleted reservoir condition (a), microscopic image of reservoir pores (b, c) [1, 2]

Sources
[1] Muhammed, N. S., et al. A review on underground hydrogen storage: Insight into geological sites, influencing factors and future outlook, Energy Reports 8 (2022) 461–499 https://doi.org/10.1016/j.egyr.2021.12.002
[2] Wallace, R.L., Cai, Z., Zhang, H., Zhang, K., Guo, C., 2021. Utility-scale subsurface hydrogen storage: UK perspectives and technology. Int. J. Hydrogen Energy 46, 25137–25159. http://dx.doi.org/10.1016/j.ijhydene.2021.05.034.

WP5 Deep Dive
Worldwide Successful H_2 Storage Sites

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Metrology for Advanced Hydrogen Storage Solutions

- Globally, successful H_2 storage in underground geological formations is limited to the caverns and aquifers
- Sites become interesting in a favorable area near renewable energy generation plants

Salt caverns					
Field name (s)	**Country**	**Depth (m)**	**Volume (m^3)**	**Operating conditions**	**H_2 (%)**
Teesside	UK	400	3 × 70,000 each	45 bars	95
Clemens	USA	1,000	580,000	70–137 bars	95
Moss Bluff	USA	1,200	566,000	55–152 bars	95
Kiel	Germany	–	32,000	100 bars	60
Aquifers					
Field name (s)	**Country**	**Depth (m)**	**Volume (m^3)**	**Operating conditions**	**H_2 (%)**
Lobodice	Czech Republic	400–500	–	90 bars/34 °C	54
Beynes	France	430	3.3×10^8	–	50
Ketzin	Germany	200–250	–	–	62

Table: Worldwide successful H_2 storage sites [1, 3]

Sources
[1] Muhammed, N. S., et al. A review on underground hydrogen storage: Insight into geological sites, influencing factors and future outlook, Energy Reports 8 (2022) 461–499 https://doi.org/10.1016/j.egyr.2021.12.002
[3] Liebscher, A., Wackerl, J., Streibel, M., 2016. Geologic storage of hydrogen - fundamentals, processing, and projects. In: Hydrog. Sci. Eng. Mater. Process. Syst. Technol., Vol. 2. Wiley-VCH Verlag GmbH & Co. KGaA, Weinheim, Germany, pp. 629–658. http://dx.doi.org/10.1002/9783527674268.ch26..

WP5 Deep Dive
Capacities and H_2 Storage Requirements

- Storage capacity in UGS in Germany approx. 24 Bn. m³ of gas
- H_2 only 16,5 Bn. m³
  - approx. 7 Bn. m³ of pore storage facilities
  - approx. 9.5 Bn. m³ caverns
- Extrapolated capacity for H_2 with 3.54 kWh/m³
  - 57 TWh
  - approx. 34 TWh in caverns

- H_2 storage demands
  - BMWK (2021)   2050: 47–73 TWh
  - Guidehouse (2021)   2050: 110 TWh

Gas storage capacity in Germany from 2003 to 2019 (in billion cubic meters)

Source: https://erdgasspeicher.de/erdgasspeicher/gasspeicherkapazitaeten/

Cavern Storage – Conversion

- Conversion from natural gas to H_2 without any problems for new caverns
- All planned projects with pure H_2 in Germany are cavern projects
- Primarily caverns that have not previously been used for natural gas
- Brine is directly displaced by H_2
- Impurities
  - Water
  - Blankett (traces of hydrocarbons)
  - Sulphur compounds
- Can be achieved quickly
- Conversion of used caverns – Traces of gas could then be detectable in the hydrogen
- Microbiological processes are possible in brine, but not safe – metrological monitoring

Source	new cavern	converted cavern (from oil/gas)
H_2S (Microbiology)	X	X
CO_2 (Microbiology)	X	X
H_2O	X	X
Blankett (e.g. Diesel)	(X)	X
Rests of oil / gas	-	X

Pore Storages (Former Oil and Gas Fields, Aquifers) – Conversion

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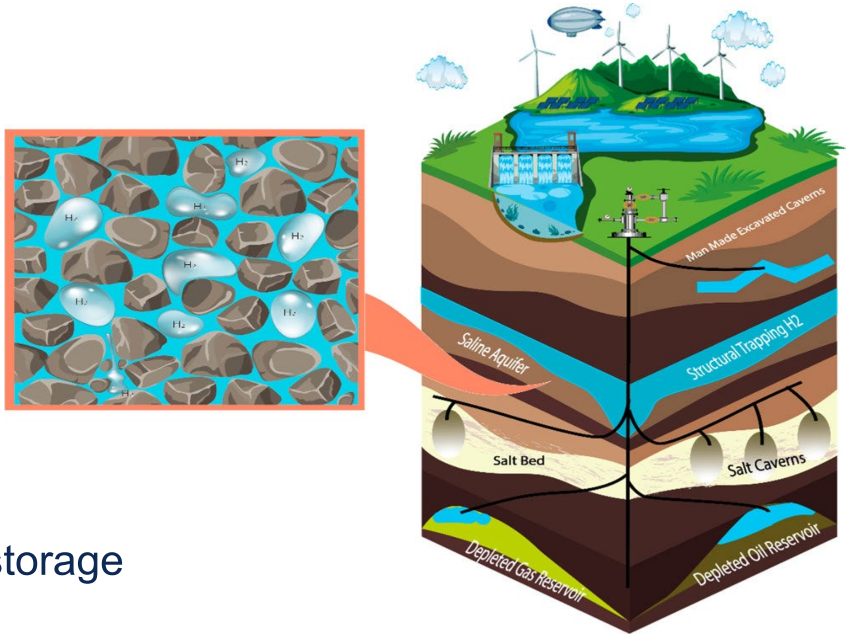
- Pore storage widely used in Germany and other European countries
- Problem: filled with natural gas
- New storage facilities conceivable, but not very likely
- Contaminants
  - Methane and other hydrocarbons (residual natural gas)
  - Water
  - Sulphur compounds (e.g., odorants in French storage facilities)
- Gradual changeover over long periods of time expected
- H_2 cavern possibly in 2026 (relevant order of magnitude)



Source:
Adnan Aftab et al., Toward a Fundamental Understanding of Geological Hydrogen Storage Ind. Eng. Chem. Res. 2022, 61, 9, 3233–3253, https://doi.org/10.1021/acs.iecr.1c04380

WP5 Deep Dive
Measurement Requiremets

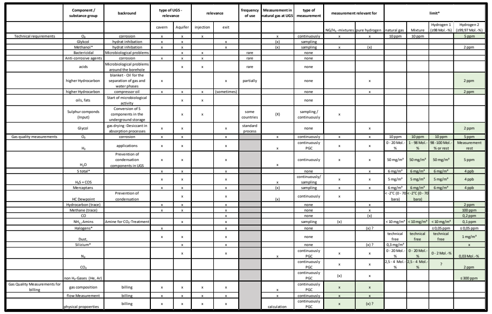
Metrology for Advanced Hydrogen Storage Solutions

Component / substance group	measurement relevant for		limit*			
	NG/H_2 - mixtures	pure hydrogen	natural gas	Mixture	Hydrogen 1	Hydrogen 2
					≥98 Mol.-%	≥99,97 Mol.-%
Methanol	(x)	(x)				
higher Hydrocarbon Blanket		x				2 ppm
higher Hydrocarbon Compressor		x				
Glycol		x				
O_2	x	x	10 ppm	10 ppm	10 ppm	5 ppm
H_2	x	x	0 - 20 Mol.-%	1 - 98 Mol.-%	2 - 20 Mol.-%	Measurement rest
H_2O	x	x	50 mg/m³	50 mg/m³	50 mg/m³	5 ppm
S total		x	6 mg/m³	6 mg/m³	6 mg/m³	4 ppb
H_2S + COS	x	x	5 mg/m³	5 mg/m³	5 mg/m³	4 ppb
Mercaptans	x	x	6 mg/m³	6 mg/m³	6 mg/m³	4 ppb
HC Dewpoint	x		< -2°C (0 - 70 bara)	< -2°C (0 - 70 bara)		
Hydrocarbon (trace)		x				2 ppm
Methane (trace)		x				100 ppm
CO		(x)				0,2 ppm
NH_3 / Amins	(x)		< 10 mg/m³	< 10 mg/m³	< 10 mg/m³	0,1 ppm
Halogens		(x) ?			≤ 0,05 ppm	≤ 0,05 ppm
Dust,			technical free	technical free	technical free	1 mg/m³

- Hydrogen Qualities currently discussed (*based on expert discussion)

More Information

- mefhysto.eu

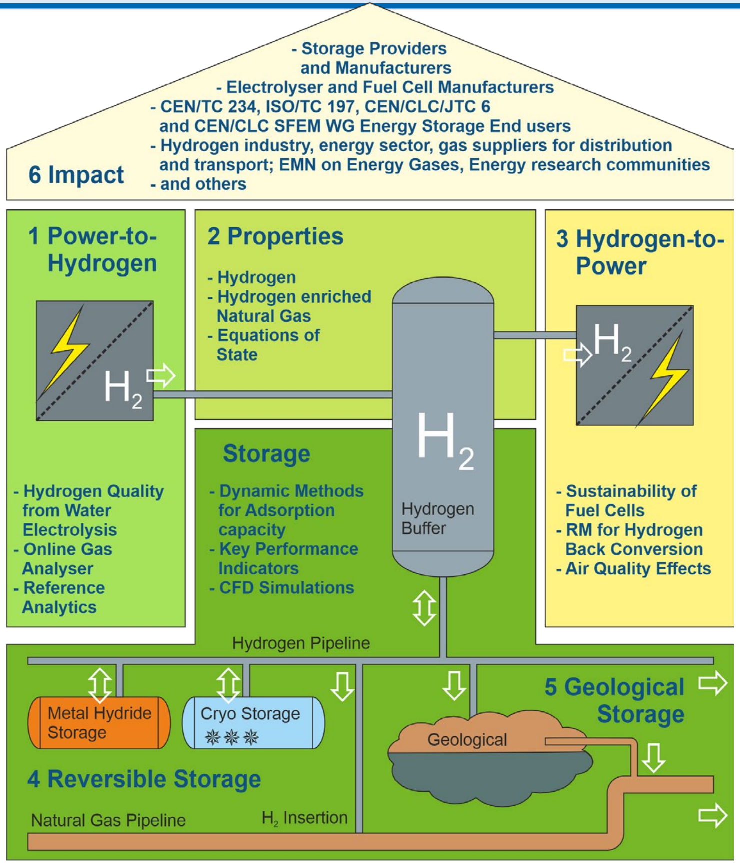


Summary

MefHySto
Metrology for Advanced Hydrogen Storage Solutions

- EU renewable energy target cannot be reached without advanced energy storage solutions
- Hydrogen as new secondary energy carrier
- Development of swift analytical methods
- Development of certified reference materials
- Thermophysical Properties of H_2 and H_2 enriched natural gas → extending Equations of State

- Save the Date: Final Conference and Workshops: **03.–05. July 2023, Berlin/Germany**
- MefHySto.eu



BAM, CMI, cea, MAHYTEC, UNIVERSIDADE DA CORUÑA, ERIG European Research Institute for Gas and Energy Innovation, reganosa, DBI, NPL National Physical Laboratory, PTB Physikalisch-Technische Bundesanstalt Braunschweig und Berlin, Ha Fundación para el Desarrollo de las Nuevas Tecnologías del Hidrógeno en Aragón, Universidad de Valladolid, Max Planck Institute for Intelligent Systems, DVGW

MefHySto

Metrology for Advanced Hydrogen Storage Solutions

ENERGY GASES

Thank you

Michael Maiwald, BAM and the Consortium

EMPIR 19ENG03

EMPIR EURAMET

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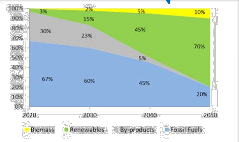
Further Discussion

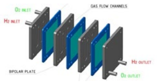
Metrology for Advanced Hydrogen Storage Solutions

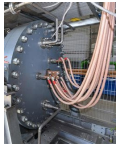
MefHySto – Introduction
Project Landscape Towards H_2 Readiness and a Rapid Market Launch

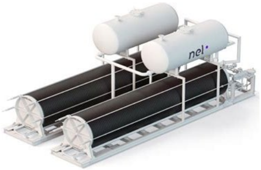
Energy Sector

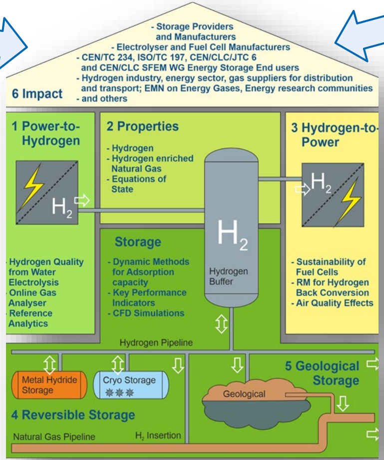


Electrolyser and Fuel Cell Manufacturers

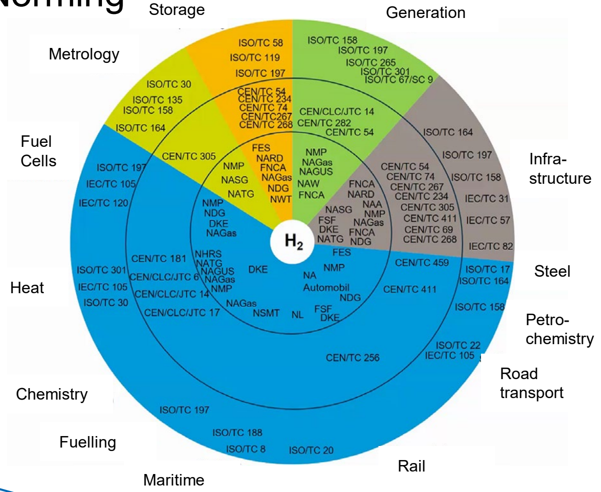








Norming



Instrument and Software Manufacturers

Project Landscape

Metrology

Hycora (FCH, 2014–2017)
Hydrogen (15NRM03, 2016–2019)
Hydraite (FCH, 2018–2020)
MetroHyVe (16ENG01, 2017–2020)

MetroHyVe2 (19ENG04, 2019–2023)
Decarb (20IND10, 2021–2024)
Met4H2 (21GRD05, 2022–2025)