# HyUSPRe

## **Hy**drogen **U**nderground **S**torage in **P**orous **Re**servoirs

## E-Newsletter #5


### In this issue:

# Welcome by the Coordinators

This is the last newsletter of the HyUSPRe project. After 33 months of intense work the consortium concluded the project with a final conference at TNO-The Geological Survey of the Netherlands in Utrecht. 50 colleagues were present physically and many more online, to follow overview talks about results achieved in the various HyUSPRe work packages. The key note was given by Remco Groenenberg, lead scientist of HyUSPRe, about the *Roadmap for succesful deployment of underground hydrogen storage in porous reservoirs in Europe*. This roadmap sketches necessary steps to make geological hydrogen storage a considerable cornerstone of the energy transition. As most deliverables, the roadmap document is downloadable from the project's website. Other presentations shed light on the many results achieved within the geochemical, geomechanical and microbiological experimental program. Those were vividly discussed and show that the hydrogen storage community still needs to learn a lot on the effects of storing hydrogen in porous rocks.


*At the HyUPSRe final conference in Utrecht, 19 June 2024.*

Focus of this newsletter lies on the introduction of a number of research reports that have been published since the last newsletter. These include results about the geochemical, geomechanical and microbiological laboratory experiments but also about European-scale hydrogen system scenarios and levelized cost of hydrogen and hydrogen storage.

All HyUSPRe research reports are available on the project's website or via the 'Results' button of the HyUSPRe CORDIS site. It's also worth to visit the website of Hystories, the sister project of HyUSPRe finished in June 2023, and compare results of HyUSPRe with those obtained in Hystories.

It was a pleasure for Remco and me to serve the HyUSPRe consortium as coordinator and lead scientist, respectively.

Enjoy reading!

Holger Cremer, TNO, consortium manager
Remco Groenenberg, TNO, lead scientist

# About HyUSPRe

## **Hy**drogen **U**nderground **S**torage in **P**orous **Re**servoirs

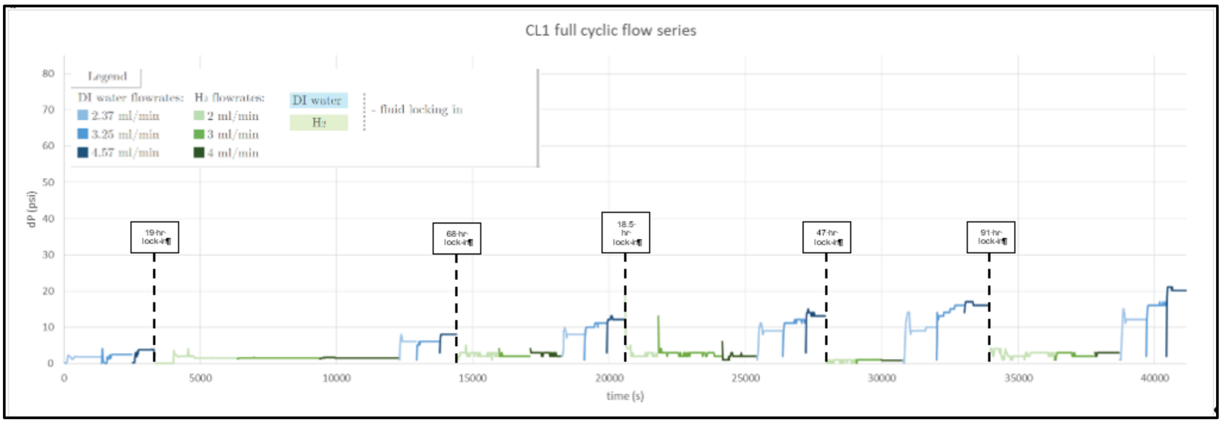
The HyUSPRe project researches the feasibility and potential of implementing large-scale underground geological storage for renewable hydrogen in Europe. This includes the identification of suitable porous reservoirs for hydrogen storage, and technical and economic assessments of the feasibility of implementing large-scale storage in these reservoirs to support the European energy transition to net zero emissions by 2050. The project will address specific technical issues and risks regarding storage in porous reservoirs and conduct an economic analysis to facilitate the decision-making process regarding the development of a portfolio of potential field pilots. A techno-economic assessment, accompanied by environmental, social, and regulatory perspectives on implementation will allow for the development of a roadmap for widespread hydrogen storage by 2050, indicating the role of large-scale hydrogen storage in achieving a zero-emissions energy system in the EU by 2050.

This project has two specific objectives. Objective 1 concerns the assessment of the technical feasibility, associated risks, and the potential of large-scale underground hydrogen storage in porous reservoirs for Europe. HyUSPRe will establish the important geochemical, microbiological, flow, and transport processes in porous reservoirs in the presence of hydrogen via a combination of laboratory-scale experiments and integrated modelling; and establish more accurate cost estimates to identify the potential business case for hydrogen storage in porous reservoirs. Suitable storage sites will be identified, and their hydrogen storage potential will be assessed. Objective 2 concerns the development of a roadmap for the deployment of geological hydrogen storage up to 2050. The proximity of storage sites to large renewable energy infrastructure and the amount of renewable energy that can be buffered versus time varying demands will be evaluated. This will form a basis for developing future scenario roadmaps and preparing for demonstrations.

# Research reports in the spotlight

## Impact of chemical reactions on reservoir pore space and mechanical integrity over time

Recent studies have explored the influence of hydrogen on geological formations, specifically on minerals like clay, quartz, calcite, and others found in reservoir and cap rocks. This task involved conducting reactive flow experiments under reservoir conditions to assess the potential impact of hydrogen-brine-rock reactions on pore space reduction. This initiative aimed at addressing uncertainties surrounding hydrogen storage in porous reservoirs, particularly its effects on reservoir hydraulic properties such as porosity and permeability and potential implications on mechanical integrity. The methodology included a series of hydrogen flow rig experiments using conventional reservoir rock and caprock samples. These experiments, conducted over a range of temperatures and pressures, sought to evaluate permeability and fluid chemistry changes through petrophysical analysis and X-ray micro-CT scans. The focus was on understanding the impact of cyclic hydrogen flow on storage properties, geochemical equilibrium, and fluid-rock geochemical properties. The key findings of the work suggest a minimal likelihood of significant reactions affecting permeability on the employed timescales. Observations of permeability changes were primarily attributed to residual trapping of free gas, underscoring the need for further testing.




*Example for cyclic flow series experiments: Differential pressures and flow rates for the full cyclic flow experiment on Clashach Sandstone.*

A notable variation between cores suggests that future research should concentrate on the residual trapping of hydrogen gas. Fluid chemistries indicated limited hydrogen-induced reactions, highlighting the challenges in resolving specific geochemical effects within the experimental setup. The experiments underscored the need for extended timescale testing and consideration of hydrogen availability in dissolved states. The issue of brine-rock disequilibrium was identified, recommending a more meticulous approach to pre-equilibration of brines with host-rock for accurate experimental results. The experiments revealed significant influences of dissolved hydrogen on Eh values, suggesting its potential as an indicator for hydrogen-induced reactions. Read the full report here.

## Impact of hydrogen-brine-rock reactions on caprock integrity

This study assessed the consequences of interactions between hydrogen, brine, and rock on the caprock seals for porous rocks storage reservoirs. The conducted experiments aimed to determine whether these interactions could lead to notable alterations in caprock properties and potentially impact the secure containment of hydrogen within geological storage formations.

The research methodology included four sets of experiments, combining batch and flow-through techniques to assess caprock reactivity: (i) static batch experiments involved exposing powdered caprock samples to brine under hydrogen pressure for several weeks, followed by chemical analysis of the fluid to detect any significant reactions; (ii) stirred batch reactor experiments involved a more dynamic setup where fluid samples were regularly collected for analysis, alongside post-reaction solid analysis via SEM, to identify dissolution or precipitation features; (iii) flow-through experiments on fractured caprocks were undertaken in a Hassler cell and a caprock analogue, these experiments alternated between deionised water and hydrogen flows to observe chemical reactions and changes in the permeability of a fractured caprock; and (iv) enhanced flow-through experiments, employing more sensitive monitoring equipment, to provide a clearer picture of fracture permeability changes using actual reservoir caprock and synthetic brine to simulate real conditions.

The findings from the static batch experiments did not conclusively demonstrate significant reactions within the brine-caprock-hydrogen system, though some evidence suggested limited reactivity. The flow-through experiments indicated minimal reaction between the brine and rock over short timescales. However, variations in elemental concentrations during hydrogen cycles suggested possible enhanced mineral dissolution. Despite this, there was no significant impact on the measured permeabilities, indicating that any dissolution had minimal effect on bulk rock properties.

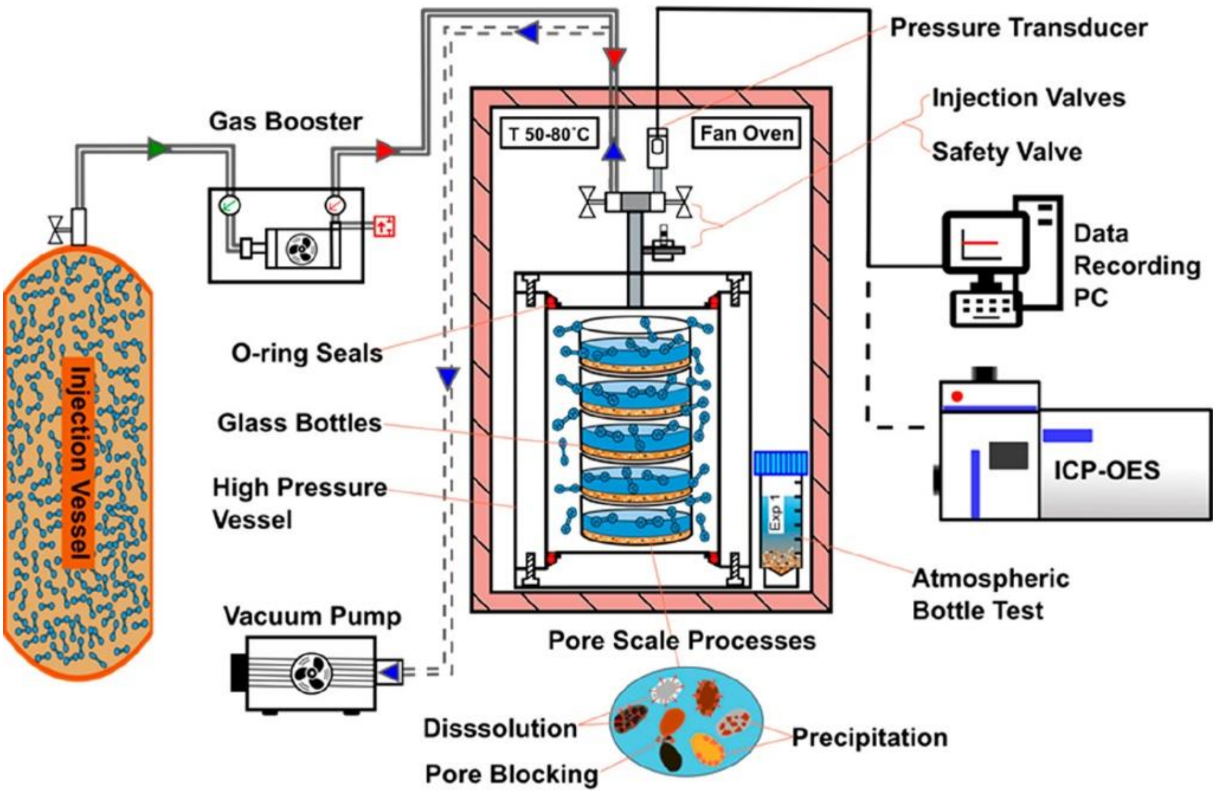



*Illustration of the static batch experimental setup.*

Overall, the work undertaken concluded that hydrogen-brine-rock reactions over short periods are unlikely to significantly affect caprock integrity, with minimal dissolution of primary minerals observed. However, over longer timescales such reactions could have more significant effects as the system drives towards the new hydrogen-water-rock equilibrium. Given the described findings, the study recommends further investigation to better understand the nature and rate of reactions that could occur at the reservoir scale. The full study can be downloaded from the HyUSPRe website.

## Kinetics of microbial growth and activity, and competition dynamics between different microbial metabolisms

Underground storage of hydrogen ($H_2$) in depleted porous reservoirs, salt caverns and aquifers presents is a viable option, but also harbors challenges due to potential microbial metabolic activities. Microorganisms, particularly those involved in methanogenesis, sulfate reduction and acetogenesis, can impact hydrogen storage in various ways, including the consumption of the stored $H_2$, the production of contaminating gases like sulfide ($H_2S$) and methane ($CH_4$), the induction of microbial-influenced corrosion and pipe clogging by the accumulation of biomass and bio-based solids. Environmental parameters play a crucial role in limiting or completely inhibiting microbial growth and metabolic activity. Understanding the impact of environmental conditions enables predicting these microbial-influenced risks. One promising approach is to estimate the microbial kinetics, which is linked to a complex interplay between environmental conditions and microbial activity, by modeling to assess risks in the field.

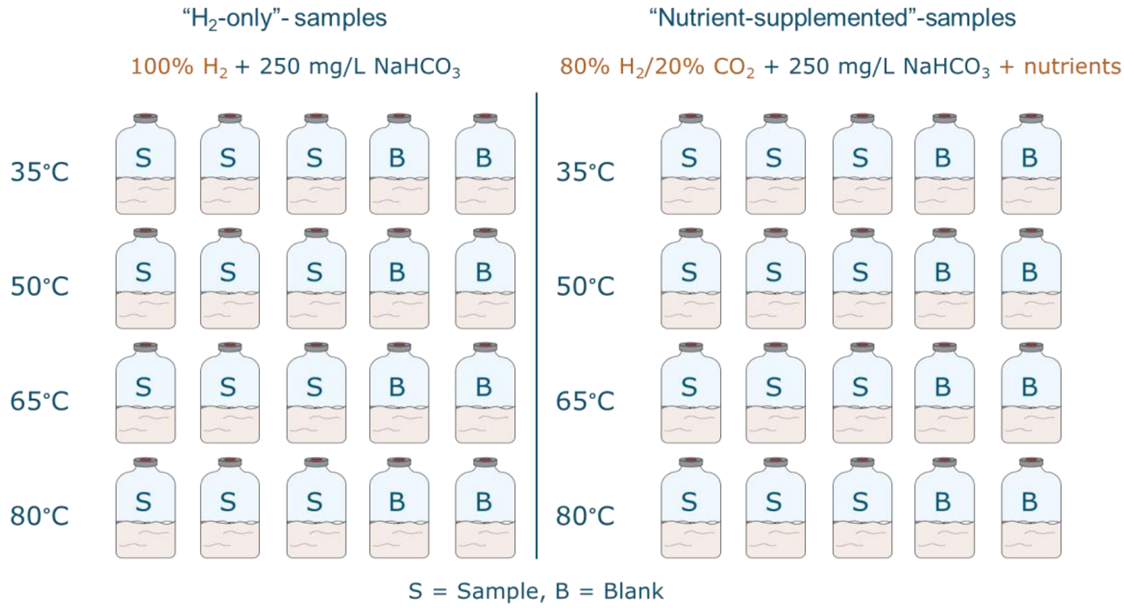
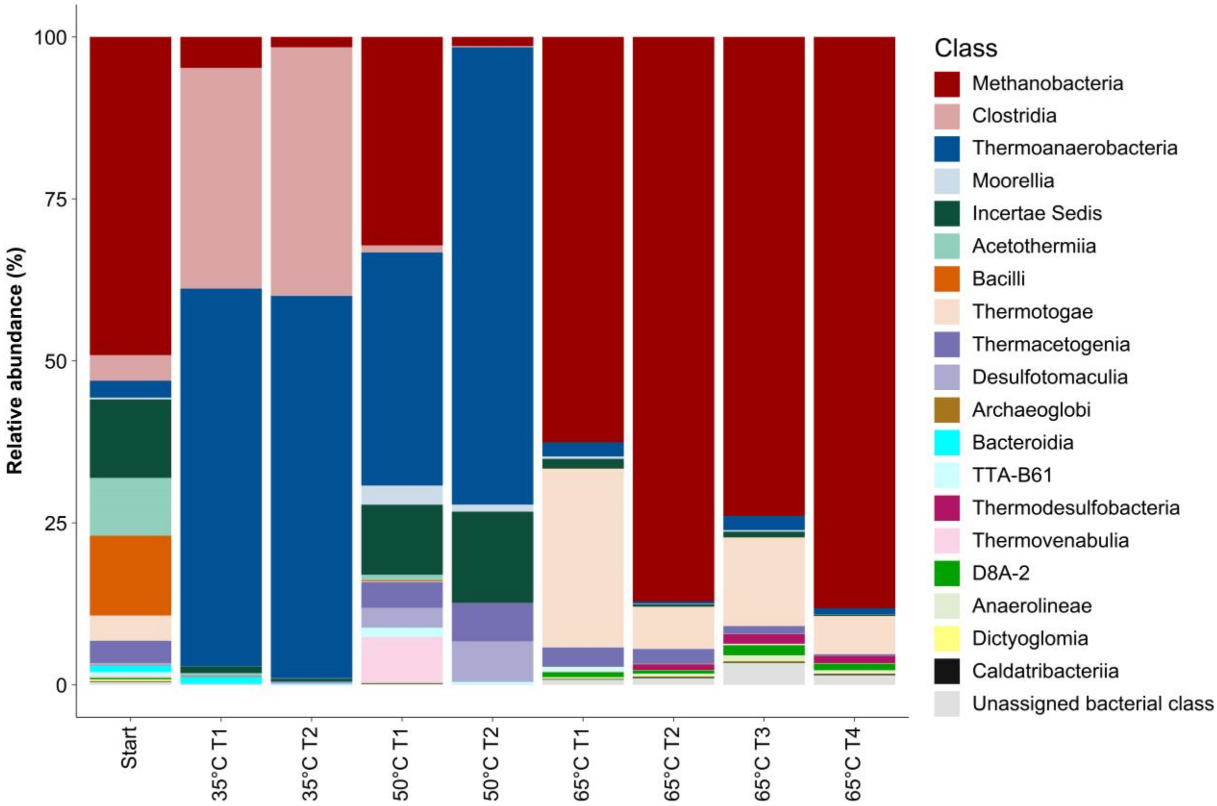



*Illustration of the experimental setup.*

This work studied the effect of temperature (range 35-80°C) and nutrient addition on incubation experiments with reservoir brine samples from a potential hydrogen storage site. Microbial $H_2$ consumption and formation of $CH_4$ and acetate varied with the temperature (less activity at 80°C) and were boosted by the addition of minerals and vitamins during the incubation experiments. Furthermore, the accumulation of $CH_4$ and acetate resulted in pH fluctuations, influencing metabolic activities. These observations confirm that analyzing microbiological and geochemical characteristics of potential storage sites and monitoring them continuously is essential.

Data on microbial growth, $H_2$ consumption and product formation were implemented in numerical simulations to provide insights into microbial growth dynamics by determining the maximum growth rate (1/s), the yield factor (1/mol), and the half velocity constant of $H_2$ and $CO_2$ (mol/mol). This helped to parameterize a model for predicting microbial kinetics in subsurface environments. These simulations offered valuable insights into the impact of microbial activity on $H_2$ storage operations. Hence, modeling microbial growth and reactions based on laboratory studies can offer a comprehensive evaluation of risks associated with subsurface hydrogen storage.

The team also looked at the community composition during the incubation experiments using reservoir brine samples from a potential hydrogen storage site. Microbial consumption of $H_2$ was associated to the formation of $CH_4$ and acetate. No sulfidogenic activity was detected for the reservoir brine samples studied. The extent of $H_2$ conversion varied with temperature and was enhanced by the addition of minerals and vitamins during the incubation experiments. Analysis of microbial community composition suggested that $CH_4$ was produced by hydrogenotrophic methanogens, while acetate was likely produced through homoacetogenesis and fermentative pathways. These findings show the importance of analyzing the microbiological and geochemical characteristics of potential hydrogen storage sites and continuously monitoring them.



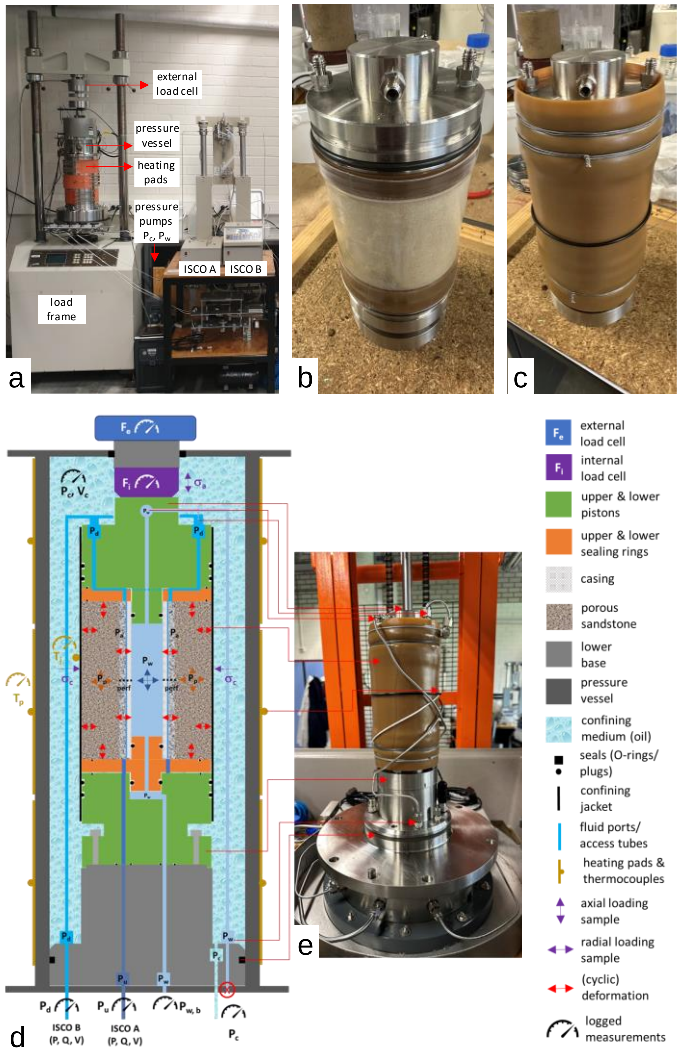

*Relative abundance of the microbial community at class level of "$H_2$/$CO_2$-nutrient supplemented" incubations at the start and at the end each incubation cycle at 35, 50 and 65°C.*

Short summary reports for both studies are available on the HyUSPRe website: kinetics report and competition dynamics report.

## Experimental data for scaled-down well system on hydrogen reactions and its implications for durability and integrity of well systems

Underground hydrogen storage in porous subsurface reservoirs requires cyclic operations of injection and withdrawal of a hydrogen gas stream. During these operations, the well system will be subject to various processes, including:

- Changes of stress on the well system and expansion or contraction of casing, cement sheath and reservoir due to cyclic variation in pore pressure and temperature
- Changes in chemical environment due to long term exposure of hydrogen gas streams that may change the mechanical properties of well materials
- Degradation of well materials due to microbiological or chemical reactions in the reservoir that may lead to corrosive by-products such as hydrogen sulphide ($H_2S$). These processes may affect the durability and integrity of well systems, in particular on interfaces between steel casings, well cements, and reservoir rock.




*Scaled-down well system (SDW) used in triaxial experiments. (a) Triaxial apparatus and pressure pumps. (b, c) Sample SDW006_BH007 with pistons, sealing rings and O-rings, protective jackets (b) and sealing jackets (c). (d) Schematic diagram of setup showing most important components, conditions, and logged measurements. (e) Sample mounted on lower base of triaxial vessel. See legend for symbols and components.*

This study experimentally investigated the effects of hydrogen ($H_2$) exposure and well pressure cycling with a newly developed scaled-down well system. The system consists of a steel casing that is cemented in a hollow porous sandstone sample that can be placed in autoclaves for $H_2$ exposure and in a triaxial apparatus to perform pressure cycling at pressures, temperatures and stresses representative of porous sandstone reservoirs at depths up to 2.5 km. Casings were either fully perforated to hydraulically connect casing and sandstone, partially perforated to hydraulically connect casing to the interface between casing and intact cement sheath, or not perforated to prevent hydraulic connection between cemented sandstone and casing.

In the experiments, well-cemented, consolidated Rijswijk White and Bentheim sandstones were tested. Rijswijk White sandstone was exposed to $N_2$ or $H_2$ for ~143 days at ~19 MPa and 80°C in autoclaves. The scaled-down well samples were subjected to 34-454 well pressure cycles of 1, 10 or 100 hrs for 104-842 hrs at axial stresses of 16.6-57.4 MPa, confining stresses of 16.0-40.0 MPa and temperatures of 19-75°C. Effects of $H_2$ exposure and well pressure cycling was studied by analyzing sandstone pore pressure response and injected or produced fluid volumes, and based on a proxy for injectivity and productivity (IP index).

The experiments show that:

- effects of $H_2$ exposure and well pressure cycling on sandstone injectivity and productivity or integrity of the scaled-down well systems are small for stress conditions equivalent to reservoirs up to ~2.5 km depth

- prolonged well pressure cycling at reservoir conditions for scaled-down well systems exposed to $H_2$ shows a small decrease injectivity and productivity likely due to inelastic deformation (compaction) of the sandstone
- hydraulic connection between casing and sandstone is observed after prologened well pressure cycling for scaled-down well systems with partially perforated casings with intact cement sheath. The connection is likely caused by fracturing of the cement sheath

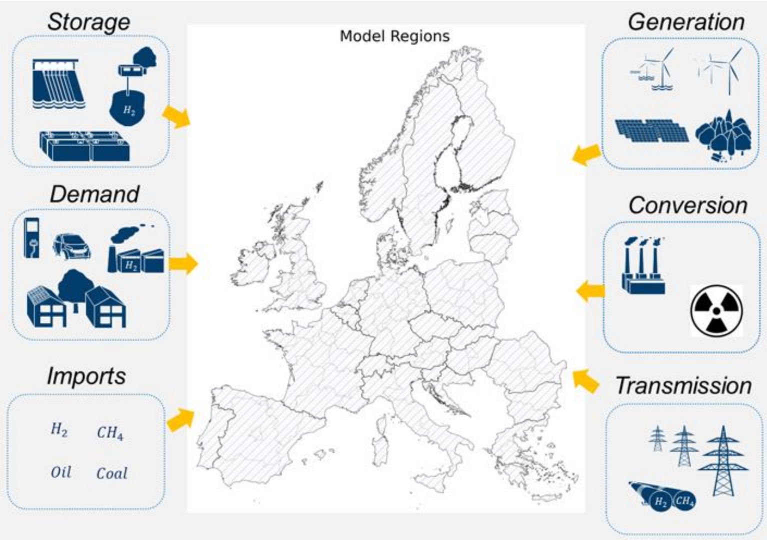
Implications for underground hydrogen storage and mitigation options for loss of durability and integrity of well systems include that:

- effects of cyclic $H_2$ injection and withdrawal on sandstone injectivity and productivity are limited for the type of sandstone and conditions tested in the experiments
- formation damage or hydraulic fracturing need to be taken into account when determining optimum injection and withdrawal conditions
- mitigation options for loss of durability and integrity are:
  i. detailed monitoring of well pressures to detect changes in reservoir injectivity and productivity
  ii. changing the location for injection and withdrawal of the $H_2$ gas stream in the reservoir by re-perforating wells or drilling new wells, an
  iii. perform proper assessment of the status of all (active and decommissioned) wells.

Read the full report via this link.

## EU scale hydrogen system scenarios

HyUSPRe has conducted an extensive study on the techno-economic assessment of EU-scale scenarios for hydrogen storage. Aim of the study was to investigate the role of hydrogen storage in porous reservoirs within a future European hydrogen system using a spatio-temporal energy system optimization model. The report describes in detail applied models, selected scenarios, the generated results but also the limitations of the model.
Preparatory activities were performed earlier, including the quantification of the spatially resolved potentials for green hydrogen production from renewables and demand in European countries, hydrogen import potentials, the evaluation of possible hydrogen transport infrastructure, and potential locations and capacities for underground hydrogen storage sites. The findings of these research activities were used as input for the energy system model presented in the referred report.




*Spatial scope and technology portfolio of the European energy system optimization model.*

All scenarios show that underground hydrogen storage is required for a successful and affordable transformation of the European energy system to greenhouse gas neutrality due to the increasing prominence of hydrogen in the energy transition. The share of pore storage as hydrogen storage increases to more than 60% of the required hydrogen storage capacity by 2050, and all countries with available pore storage potential develop it to some extent, leading to a more homogenous distribution of storage across Europe.

The study shows that hydrogen storage in both, caverns and porous reservoirs, can play a pivotal role in balancing the supply and demand dynamics of the evolving European energy system. As hydrogen continues to gain prominence in the energy transition, these findings underscore the importance of strategic planning for storage infrastructure and conducting further research on large-scale underground hydrogen storage. Continued investment in research and development is crucial to refine storage technologies and address safety concerns.

Download the full report via this link.

## Roadmap towards EU-wide underground storage of renewable hydrogen

Renewable hydrogen is one of the key elements for Europe to enable the transition to a fully decarbonised energy system in 2050. Hydrogen is a versatile molecular energy carrier that can be produced from renewable electricity sources such as wind or solar energy. Hydrogen will be crucial to decarbonize hard-to-abate sectors that rely on renewable hydrogen to be able to reach their sustainability goals. The European Union has set ambitious targets for domestic hydrogen production and import for 2030 to kick-start the development of a hydrogen economy. Moreover, in anticipation of a rapidly growing hydrogen demand in the period after 2030, the transport and storage of hydrogen becomes a critical aspect to match the intermittent production of hydrogen from renewables with varying demand in space and time. A unique advantage of hydrogen over electricity is that it can be safely stored in large quantities. Suitable sites in the subsurface include salt caverns and porous reservoirs (depleted gas fields, aquifers) where hydrogen can be stored for longer time periods ranging from days to seasons. Stored hydrogen can this way offer essential services to society in the form of balancing solutions for unavoidable intra-seasonal to inter-seasonal variations in energy supply and demand. Hydrogen storage will also contribute to strategic energy reserves. Salt cavern storage is considered a promising solution that is nearing commercial deployment. Storage of hydrogen in porous reservoirs offers an alternative solution that currently is being studied in various projects. While in many ways similar to storage of natural gas, the feasibility of underground hydrogen storage is not yet fully proven.

The HyUSPRe project was initiated to study the feasibility and techno-economic potential of implementing hydrogen storage in porous reservoirs in Europe to support the energy transition to net-zero emissions by 2050. HyUSPRe finds that cavern storage and storage in porous reservoirs are complimentary, providing essential system services at competitive costs compared to aboveground alternatives. Underground hydrogen storage (UHS) is expected to become a key enabler for the decarbonization of the European energy system, with an estimated potential of 920 TWh in depleted gas fields and salt caverns combined. This potential far exceeds the storage demand, which is currently projected to reach 270 TWh by 2050, with porous rock storage accounting for more than half of the capacity by that time.

To realize the projected potential of UHS and accelerate its deployment in porous reservoirs in Europe, the HyUSPRe consortium developed a roadmap with targeted measures and concrete actions for five themes: i) technology development; ii) environmental impact and spatial planning; iii) economics and market; iv) policy and regulation; and v) societal awareness and acceptance.

Initiatives to advance the technology readiness of UHS in salt caverns and reservoirs are gaining momentum in Europe, often with support of national governments and the European Union, reflecting commitment by governments and industry to establish a hydrogen economy. Ongoing pilot- and demonstration projects mostly leverage existing infrastructure, while also developing innovative solutions to optimize storage capacity, efficiency, and safety. In the next decade, the UHS project portfolio is expected to expand significantly to realize the required TWh-scale of storage capacities within Europe. By implementing the actions formulated in the roadmap the chance of successful and timely UHS deployment will be greatly improved.

Download the full roadmap from the HyUSPRe website.

# HyUSPRe scientific publications

In 2024 the HyUSPRe consortium published several scientifc publications that are listed here in alphabetical order together with the paper abstract.

**Hogeweg, S. et al. (2024) Empirical and numerical modelling of gas-gas diffusion for binary hydrogen-methane systems at underground gas storage conditions. Transport in Porous Media, 151: 213-232 (https://doi.org/10.1007/s11242-023-02039-8)**

The physical process in which a substance moves from a location with a higher concentration to a location with a lower concentration is known as molecular diffusion. It plays a crucial role during the mixing process between different gases in porous media. Due to the petrophysical properties of the porous medium, the diffusion process occurs slower than in bulk, and the overall process is also affected by thermodynamic conditions. The complexity of measuring gas–gas diffusion in porous media at increased pressure and temperature resulted in significant gaps in data availability for modelling this process. Therefore, correlations for ambient conditions and simplified diffusivity models have been used for modelling purposes. In this study, correlations in dependency of petrophysical and thermodynamic properties were developed based on more than 30 measurements of the molecular diffusion of the binary system hydrogen–methane in gas storage rock samples at typical subsurface conditions. It allows reproducing the laboratory observations by evaluating the bulk diffusion coefficient and the tortuosity factor with relative errors of less than 50 % with minor exceptions, leading to a strong improvement compared to existing correlations. The developed correlation was implemented in the open-source simulator DuMu$^x$ and the implementation was validated by reproducing the measurement results. The validated implementation in DuMu$^x$ allows to model scenarios such as Underground Hydrogen Storage (UHS) on a field-scale and, as a result, can be used to estimate the temporary loss of hydrogen into the cushion gas and the purity of withdrawn gas due to the gas–gas mixing process.

**Hogeweg, S. et al. (2024) Development and calibration of a bio-geo-reactive transport model for UHS. Frontiers in Energy Research, 12 (10.3389/fenrg.2024.1385273).**

The increased share of renewable energy sources will lead to large fluctuations in energy availability and increases energy storage's significance. Large-scale hydrogen storage in the subsurface may become a vital element of a future sustainable energy system because stored hydrogen becomes an energy carrier available on demand. Large hydrogen amounts can be stored in porous formations such as former gas fields or gas storages, while caverns can contribute with high deliverability. However, the storage of hydrogen induces unique processes in fluid-fluid and rock-fluid interactions (for example, bio- and geochemical reactions), which may affect the efficiency of the storage. In the present study, a mathematical model describing the two-phase multicomponent flow in porous media, including bio- and geochemical reactions, is developed to predict these hydrogen-related processes. The proposed model extends an existing model in the open source simulator DuMux describing the bio-reactive transport process considering methanation and sulfate-reduction by geochemical reactions. Significant attention is placed on the reduction from pyrite-to-pyrrhotite coming with the generation of harmful hydrogen sulfide. This reaction is calibrated by developing a kinetic model in DuMux that mimics the observations of reactor experiments from literature. The developed and calibrated model is afterwards used for simulation runs on field scale to assess the impact on Underground Hydrogen Storage (UHS) operations. The developed kinetic model describes the reduction from pyrite-to-pyrrhotite in agreement with the observations in the literature, whereby particular focus was placed on the hydrogen sulfide production rate. The consecutive implementation of the transport model in DuMux on field scale, including the bio- and geochemical reactions, shows the potential permanent hydrogen losses caused by reactions and temporary ones induced by gas-gas mixing with the initial and cushion gas.

**Thaysen, E.M. et al. (2023) Microbial risk assessment for underground hydrogen storage in porous rocks. Fuel, 352 (https://doi.org/10.1016/j.fuel.2023.128852).**

Geological hydrogen storage, e.g. in depleted gas fields (DGF), can overcome imbalances between supply and demand in the renewable energy sector and facilitate the transition to a low carbon emissions society. A range of subsurface microorganisms utilise hydrogen, which may have important implications for hydrogen recovery, clogging and corrosion. We gathered temperature and salinity data for 75 DGF on the UK continental shelf and mapped their suitability for hydrogen storage in terms of the risk of adverse microbial effects, based on a novel collection of microbial growth constraints. Data on wind and solar operational capacities as well as offshore gas and condensate pipeline infrastructure were overlaid on the microbial risk categorization to optimize geographical centers of green hydrogen production, transport infrastructure and underground storage. We recommend storing hydrogen in 9 DGF that are at no microbial risk due to temperatures > 122 °C, or in the 35 low-risk DGF with temperatures > 90 °C. We recommend against utilising high-risk DGF with temperatures < 55 °C (9 DGF). Alignment with centers for renewable energy production and out-of-use pipelines suitable for repurposing to transport hydrogen suggests that no-risk and low-risk DGF in the Southern North Sea are the most suitable candidates for hydrogen storage. Our results advise site selection choices in geological hydrogen storage in the UK. Our methodology is applicable to any underground porous rock system globally.

# HyUSPRe event attendance

## HyUSPRe final conference (Utrecht, 19 June 2024)

All oral and poster contributions are published in the meeting report that is available on the HyUSPRe project website.

## GET2023 – EAGE Global Energy Transition Conference & Exhibition (Paris, November 14-17, 2023)

**Ter Heege, J. et al. (2023) De-Risking Subsurface Operations of Large Scale Underground Hydrogen Storage Projects in Porous Reservoirs (https://www.earthdoc.org/content/papers/10.3997/2214-4609.202321098).**

Underground storage of hydrogen in porous reservoirs is a promising candidate to facilitate required energy storage in energy systems with large contributions from intermittent renewable sources such as wind and solar energy. However, the long term interaction between hydrogen and rock or well materials combined with cyclic pressure, temperature and stress changes during injection and withdrawal of hydrogen may affect the integrity and durability of critical elements in the storage system. The efficiency of storage operations will depend on the relative importance of risks associated with these processes and operations. In this study, the H2 gas stream, storage reservoir, caprock, faults, wells and surface are distinguished as critical elements. We outline a data-driven risk management framework that addresses overarching risks for these critical elements in underground porous reservoir storage systems. A combination of observations from field cases, laboratory experiments and model simulations are used. As an example, it is shown how laboratory experiments can be used to constrain the risks associated with well operations and near-well reservoir injection and withdrawal. The laboratory experiments allow critical conditions for onset of leakage and flow rates along casing-cement-rock interfaces to be determined under reservoir conditions.

## 62nd British Sedimentological Research Group Annual Meeting (Loughborough, December 18-20, 2023)

**Wilkonson, M. (2023) Geological Storage of Hydrogen: Towards Net Zero in Europe in the HyUSPRe project.**

## EGU2024 (Vienna, April 14-19, 2024)

**Ter Heege, J. et al. (2024) Durability and integrity of well and rock materials for large scale underground hydrogen storage projects in porous reservoir: insights from laboratory experiments (https://meetingorganizer.copernicus.org/EGU24/EGU24-19609.html).**

Large scale storage of hydrogen in porous reservoirs can buffer intermittent energy supply and demand in energy systems with large contributions of wind and solar energy. The efficiency of long term injection and withdrawal of hydrogen streams with large concentrations of hydrogen can be particularly affected by the long term interaction between hydrogen and rock or well materials in combination with cyclic pressure, temperature and stress changes during injection and withdrawal. Critical elements of hydrogen storage systems that may be affected are (1) the hydrogen gas stream, (2) the storage reservoir, (3) the caprock, (4) faults, (5) the well system, and (6) the surface environment. In particular, effects on the durability and integrity of well systems and on the mechanical and flow properties of porous sandstone reservoirs may impact the efficiency of storage operations. In this study, we show how results of laboratory experiments on rock and well materials at high pressure and temperature conditions can be used to assess effects of hydrogen exposure and cyclic pressure, temperature and stress changes on well systems and porous sandstone storage reservoirs. Key results of experiments on well cement (Portland type G), sandstone reservoirs, caprock and a scaled-down well system consisting of a casing, well cement and reservoir rock are reported. Samples were placed under relevant high pressure, temperature and stress conditions (100-200 bar, 50-100°C), both in an autoclave for reaction with H2 and N2 and in a triaxial cell for testing injection/withdrawal scenarios. The results show (1) no major effects of H2 exposure or cyclic loading on mechanical properties of well cement and reservoir sandstone under investigated conditions, (2) different behavior for sandstones exposed to N2 (stiffer) and H2 (less stiff) during cyclic loading, (3) some cumulative plastic deformation during cyclic loading of sandstone that may affect flow and mechanical properties, even in the elastic regime, (4) indications of increasing stiffness in caprock due to cyclic loading, (5) importance of casing-cement reservoir interfaces as potential leakage pathways for hydrogen along wells, and (6) large effects of sample variations that complicate disentangling effects of N2/H2 exposure and cyclic loading. These results suggest that effects of interaction between hydrogen and rock or well materials in combination with cyclic pressure, temperature and stress changes during injection and withdrawal are limited for the investigated materials and conditions. However, they also emphasize the need for further research to understand the long-term effects of H2 exposure and cyclic loading in different geological settings and under extended exposure durations.

# HyUSPRe Consortium & Funding

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## Disclaimer

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# More Information

Visit the HyUSPRe website to learn more about the project and for download of results reports.