HYUSPRE PROJECT BRIEFING

HYDROGEN UNDERGROUND STORAGE IN POROUS RESERVOIRS

THE HYUSPRE CONSORTIUM

7 EXECUTIVE PARTNERS, 9 INDUSTRY PARTNERS, FUNDED BY THE FCH JU

INDUSTRY

- CENTRICA – United Kingdom
- EBN – Netherlands
- EQUINOR – Norway
- Hungarian Gas Storage - Hungary
- NAFTA – Slovakia
- NEPTUNE – Netherlands
- RAG – Austria
- Shell – Netherlands
- SNAM – Italy
- UNIPER – Germany

RESEARCH INSTITUTES

- TNO – NL (project coordinator)
- Energy Institute Linz – Austria
- Fondazione Bruno Kessler – Italy
- FZ Jülich – Germany

UNIVERSITIES

- University of Edinburgh – UK
- Clausthal University – Germany
- Wageningen University – Netherlands

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PROJECT AT A GLANCE
GENERAL INFORMATION ABOUT THE PROJECT

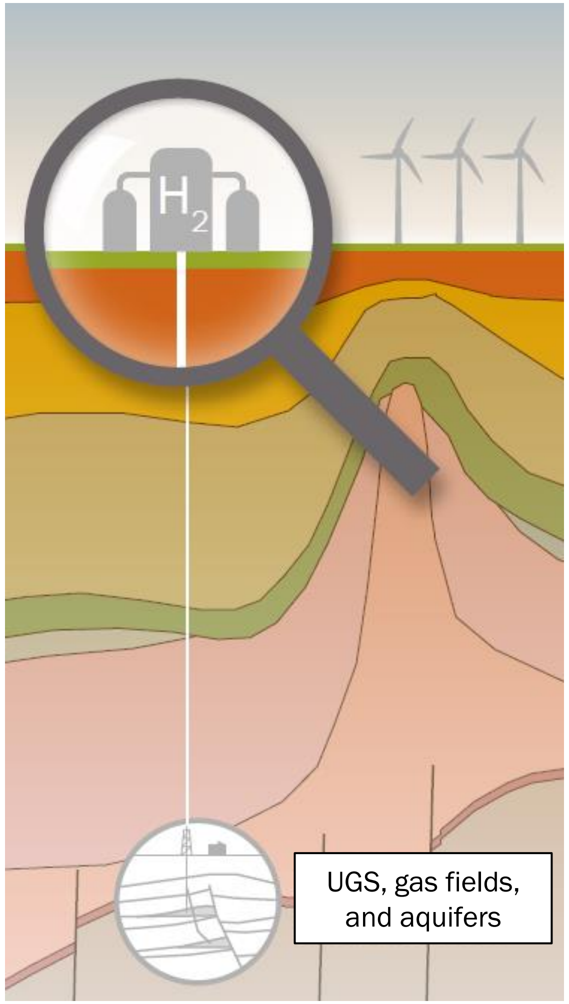
- **HyUSPRe** stands for “**Hydrogen Underground Storage in Porous Reservoirs**”
- **R&D project** granted by Fuel Cells and Hydrogen Joint Undertaking (FCH JU) under the Horizon 2020 call **Research and Innovation Action: FCH-02-5-2020**
- **Project budget** is **3.5 million EUR,** of which 2.5 million EUR subsidy from the FCH JU
- **Project duration** is **27 months (Oct. 2021 – Dec. 2023)**
- **Consortium** consists of **7 executive partners** and **9 industry partners**
- **Project coordinator** is **TNO,** the Netherlands Organisation for Applied Scientific Research
- **See** HyUsPRe site on **CORDIS website** for further **details**

RATIONALE
WHY THIS PROJECT?

- Future energy scenarios foresee a prominent and growing role for hydrogen as a clean and flexible energy carrier in multiple sectors of the energy system (e.g. electricity, industry, heating, transport). Intermittency and variability of energy production and consumption will require flexibility and balancing at hourly, daily and inter-seasonal timescales. It is very likely that a demand for large-scale hydrogen storage will emerge that exceeds the capacity of typical aboveground energy storage technologies.

- Natural gas is already safely stored in large quantities in subsurface porous reservoirs in many countries in Europe, including depleted hydrocarbon reservoirs and aquifers, to balance supply and demand on a daily basis and to secure supply during cold winters. No sites exist however where pure hydrogen is stored in reservoirs.

- The different properties and behavior of hydrogen pose a range of research challenges which need to be resolved before underground hydrogen storage (UHS) can be implemented safely and economically. Successful implementation in the future energy system depends on geological screening of suitable reservoirs, evaluation of viable and safe subsurface and operational conditions, assessment of environmental and societal impacts and analysis of viable business concepts. These insights form the basis for establishing a robust regulatory framework and best practices for responsible and societally accepted UHS development.



Groenenberg, R.M. et al., Large-Scale Energy Storage in Salt Caverns and Depleted Fields (LSES) – Project Findings (2020). TNO report 2020 R12006. Link

PROJECT OBJECTIVES

WHAT DO WE WANT TO ACHIEVE?

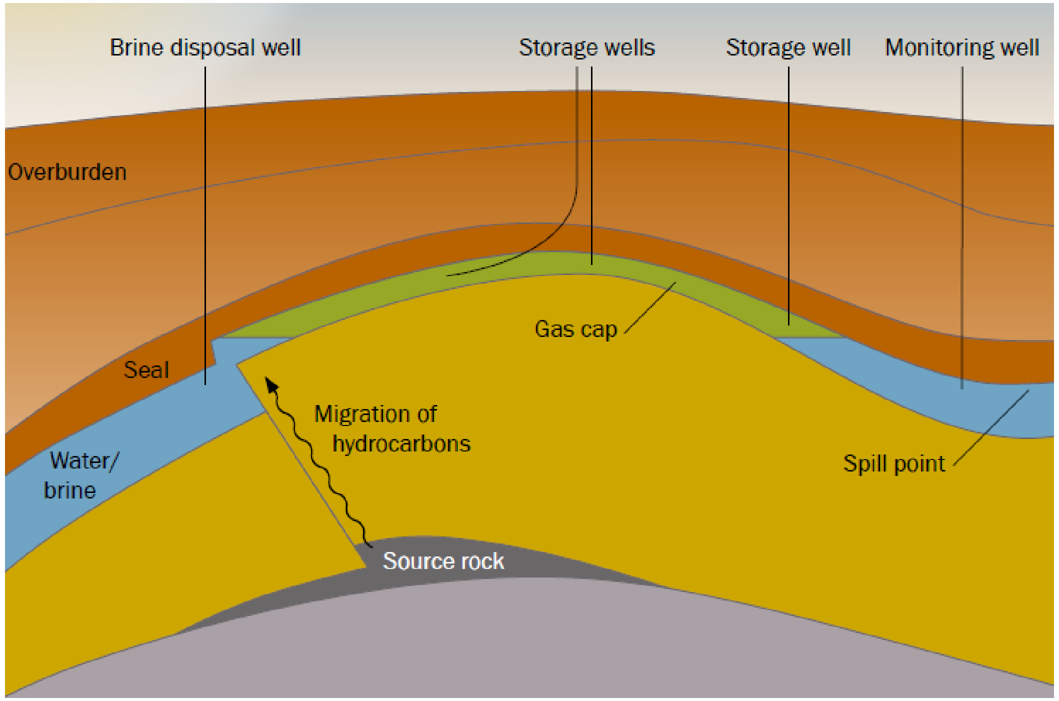
- HyUSPRe's main objectives include:

A. Studying the feasibility and potential of implementing renewable hydrogen storage in porous reservoirs in Europe by

- Examining the geochemical, geomechanical, microbiological, flow and transport processes in porous reservoirs to better understand the risks of contamination and/or loss of hydrogen, reservoir performance degradation and well integrity issues.
- Conducting cost estimates and identifying the business case for hydrogen storage in porous reservoirs.
- Identifying suitable storage compartments and quantifying their hydrogen storage potential.

B. Techno-economic assessment of how the underground storage of renewable hydrogen could facilitate achieving a zero-emissions energy system in Europe by 2050 by

- Mapping the proximity of potential underground hydrogen storage reservoirs to large renewable energy infrastructure.
- Evaluating the amount of renewable energy that can be buffered versus time-varying demands.
- Developing future scenario roadmaps for Europe-wide implementation.



HyUnder D3.1, "Overview on all Known Underground Storage Technologies for Hydrogen", 2013. Link

EXPECTED IMPACTS

TO ADVANCE UNDERGROUND STORAGE OF RENEWABLE HYDROGEN TOWARDS IMPLEMENTATION

- The major envisaged impact of HyUSPRe is to prepare the deployment of one or more hydrogen storage pilot projects in Europe. This brings the Technical Readiness Level of this technology from 3 (laboratory validation) to 5 (validation in a relevant environment, here the actual subsurface).

- To achieve this impact, the following results should be realized:
  - Understanding geochemical, geomechanical, mineralogical and microbiological reactions occurring in geological stores in the presence of hydrogen.
  - Understanding the scalability of the demonstrated approach if replicated across Europe and the requirement for hydrogen infrastructure and renewable power sources.
  - Detailed techno-economic assessment of future scenarios for Europe to achieve widespread deployment of underground renewable hydrogen storage by 2050.
  - Understanding the value chain and the need for further study and development to establish positive business cases (covering technology development, operation, location, system integration and other aspects).

- Realizing these results will lead to a roadmap to establish full scale hydrogen storage pilots in depleted gas fields in Europe.

RESEARCH ACTIVITIES AND STRUCTURE

WHAT ARE WE GOING TO DO?

1. EVALUATE **H_2 STORAGE POTENTIAL IN POROUS RESERVOIRS** IN EUROPE AND **MAP** THEIR **LOCATION** IN RELATION TO **H_2 PRODUCTION** AND **DEMAND SITES**, AND **TRANSPORT INFRASTRUCTURE**

2. **GEOCHEMISTRY**
INVESTIGATE EXPERIMENTALLY THE EFFECTS OF GEOCHEMICAL REACTIONS OF H_2 WITH ROCK AND FLUIDS IN RESERVOIRS

3. **MICROBIOLOGY**
INVESTIGATE EXPERIMENTALLY THE EFFECTS OF MICROBIOLOGICAL ACTIVITY IN RESERVOIRS IN THE PRESENCE OF H_2

4. **H_2 FLOW BEHAVIOR**
INVESTIGATE EXPERIMENTALLY THE DIFFUSION, DISPERSION, AND FLOW OF H_2 IN RESERVOIRS

5. **INTEGRITY & DURABILITY**
INVESTIGATE EXPERIMENTALLY THE INTEGRITY AND DURABILITY OF RESERVOIR ROCKS AND WELL MATERIALS EXPOSED TO H_2

6. **DEVELOP** AND **APPLY** INTEGRATIVE **MULTI-SCALE MODELING** TO ESTABLISH **GUIDELINES** FOR **SUITABILITY ASSESSMENT**

7. **PERFORM** A **TECHNO-ECONOMIC ASSESSMENT** OF **SCENARIOS FOR H_2 STORAGE** AND **DEVELOP** A **ROADMAP TOWARDS DEMONSTRATION** AND **IMPLEMENTATION** IN EUROPE

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QUANTIFYING THE H_2 STORAGE POTENTIAL IN EUROPE

WHICH RESERVOIRS, WHERE, AND HOW MUCH?

- Goal: the hydrogen storage potential of porous reservoirs that have a high chance of being developed (potentially including underground gas stores, depleted oil- and gasfields and aquifers) in Europe will be inventoried and quantified, and their location will be mapped in relation to hydrogen production sites, demand centres, and transport infrastructure.

- Research activities include:
  - Mapping and quantifying the capacities of potential sites of hydrogen production from renewables, existing and planned infrastructure for transport, and demand centres for hydrogen to perform the hydrogen system modelling.
  - Mapping and calculating the storage potential (theoretical capacity, performance) in porous reservoirs that have a high chance of being developed in Europe as input for the hydrogen system modelling, and for the classification of candidate sites.
  - Realizing a database of potential underground hydrogen storage sites that contains data on their key characteristics where available (location, capacity, performance, depth, mineralogy, fluid composition, bacterial populations, type of caprock, presence of faults).
  - Developing a classification scheme with selection criteria for identification of suitable geological reservoirs, and for developing the test matrix for the experimental work.

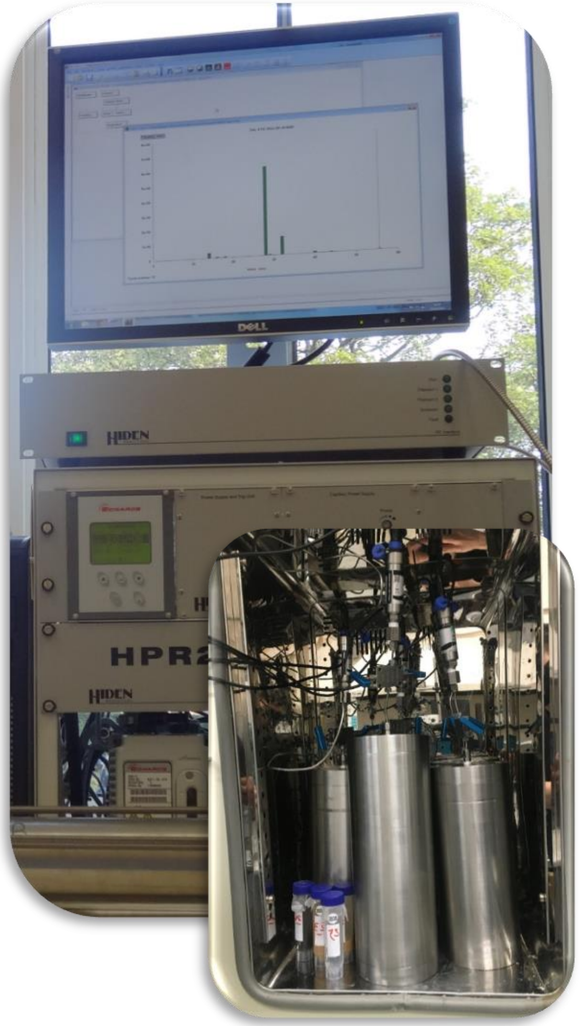
- The results of these research activities will support all other activities in the project with information and data.

SUBSURFACE GEOCHEMICAL REACTIONS WITH H_2

EXPERIMENTS ON GEOCHEMICAL REACTIONS OF H_2 WITH ROCK AND FLUIDS IN RESERVOIRS

- In close collaboration with HyUSPRe's industry partners, experiments will be performed at subsurface reservoir conditions to:
  - Address the uncertainties in the reaction rates of key minerals such as pyrite, pyrrhotite, calcite and anhydrite with hydrogen under a range of storage reservoir pressures and temperatures to benchmark geochemical models.
  - Assess the risk and impact of H_2S generation from the hydrogen driven reduction of pyrite to pyrrhotite. Risks of H_2S as a production stream contaminant and as an agent of increasing chemical reactivity due to changing formation water pH will be addressed.
  - Quantify potential pore space reduction and loss of mechanical integrity through hydrogen / natural gas / reservoir fluids / rock geochemical interactions.
  - Understand and quantify potential caprock integrity loss and its time related evolution.

- Since the large majority of candidate reservoirs (operational gas storages in reservoirs and producing gas fields nearing depletion) are situated at depths ranging between 500-3500m, experiments will be conducted at temperatures ranging between 20°C and 115°C, pressures between 50 bar and 350 bar and salinities between 2.5% and 30% NaCl-equivalent. Both pure hydrogen storage and hydrogen mixtures will be considered containing up to 20% CO_2 and/or methane,



K. Edlmann, University of Edinburgh, 2021

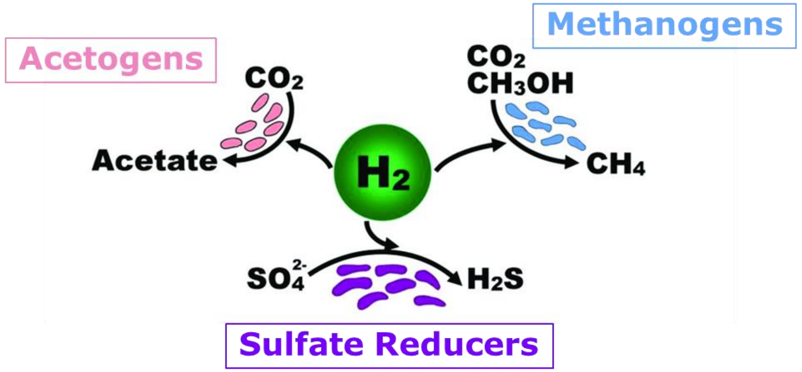
MICROBIOLOGICAL ACTIVITY IN THE PRESENCE OF H_2

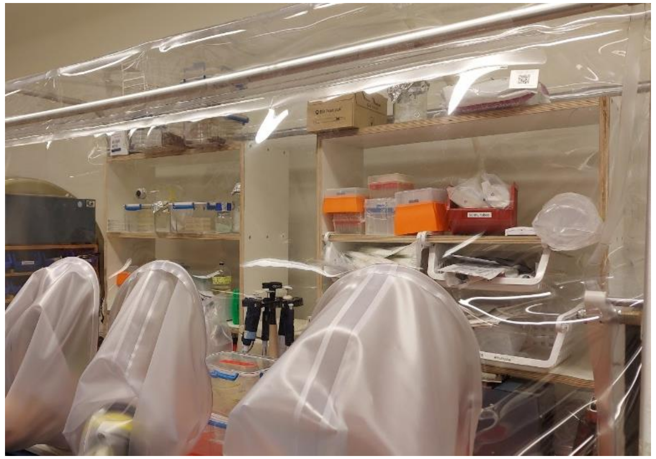
EXPERIMENTS ON SUBSURFACE MICROBIAL INTERACTIONS WITH H_2

- Goal: determination of the potential detrimental impact of microbes on subsurface hydrogen storage by:
  - Assessing the risks of loss of H_2 through microbial metabolic processes (methanogenesis, sulfate-reduction and acetogenesis).
  - Generation of H_2S through microbial sulfate-reduction.
  - Loss of H_2 injectivity due to near well bore plugging by bio-based solids (microbes, Extracellular Polymeric Substances - EPS, FeS).

- Activities include:
  - Establishing the window of viability of microbial metabolisms (see top right image).
  - Quantifying kinetics of microbial growth & activity & generation of bio-based solids.
  - Investigating competition dynamics between different microbial metabolisms.

- Overall objective of the experimental studies is to provide the input parameters for the integrative multi—scale models that will enable the simulations, and therefore the prediction, of risks associated with microbial activities for underground hydrogen storage in porous reservoirs.





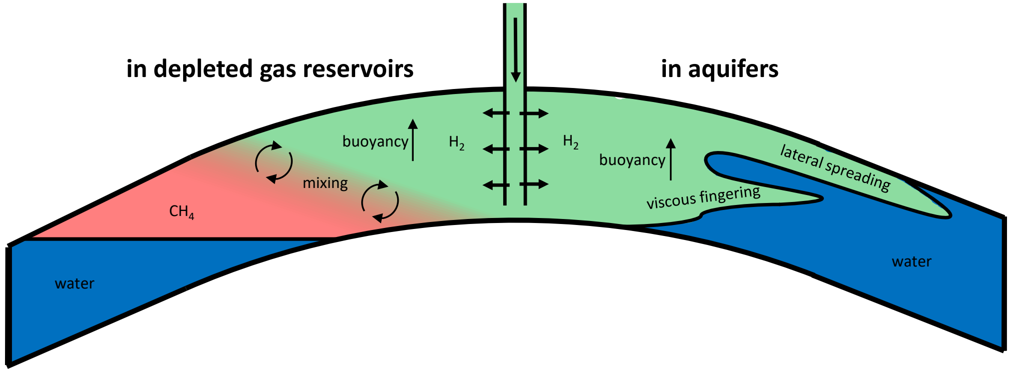
D. Machado de Sousa, Wageningen University, 2021

FLOW AND MIXING OF H_2 IN RESERVOIRS

EXPERIMENTS ON DIFFUSION, DISPERSION, FLOW AND MIXING BEHAVIOR OF H_2 IN RESERVOIRS

- Experimental work aims at improving capabilities to accurately predict the flow behavior of hydrogen in the reservoir by:
  - Measuring the effective molecular diffusion coefficients and mechanical dispersivities for the binary system H_2-CH_4 under reservoir conditions and a typical range of flow velocities.
  - Determining the relative permeability curves for the hydrogen-brine system under drainage and imbibition for selected reservoir rock types under reservoir conditions using both unsteady state and steady state methods.

- Overall objective of the experimental studies is to provide the input parameters for the integrative multi—scale models that will enable the simulations, and therefore the prediction of risks associated with coupled flow and microbial activities for underground hydrogen storage in porous reservoirs.



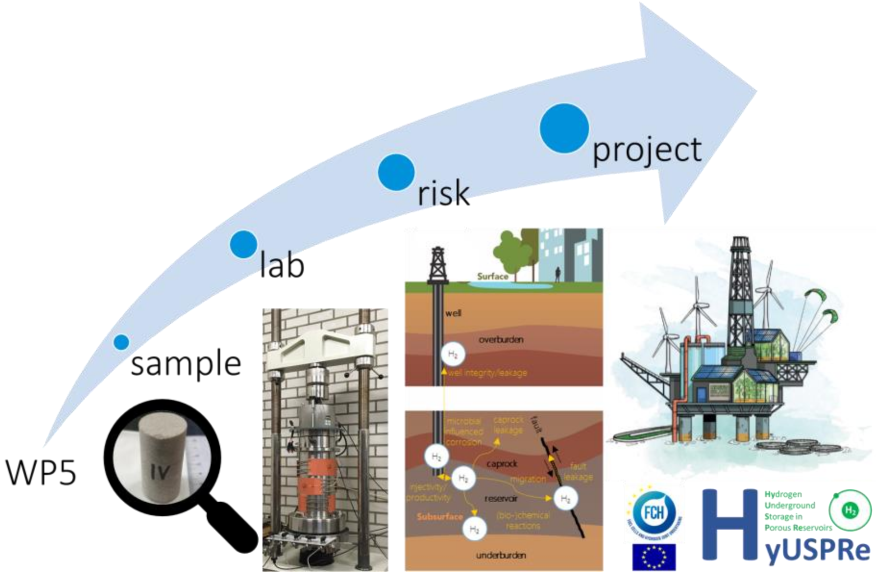
B. Hagemann, Clausthal University of Technology, 2021

DURABILITY & INTEGRITY OF WELLS AND ROCKS

EXPERIMENTS ON ROCKS AND WELL MATERIALS EXPOSED TO HYDROGEN AND CYCLIC LOADING

- Activities will focus on evaluating the integrity and durability of rocks, well materials, and wellbore interfaces under cyclic H_2 injection and withdrawal.

- Specific objectives include:
  - Review, analysis, compilation and extension of relevant experimental data of well materials (cement, steel, elastomers).
  - Review, analysis, compilation and extension of relevant experimental data of reservoir and sealing rock formations.
  - Experiments on scaled down well systems with casing cement rock interfaces to evaluate long term integrity.
  - Evaluation of the effects of microbially influenced corrosion (MIC) at high H_2 partial pressure conditions.
  - Assessment of implications for hydrogen containment, reservoir injectivity/productivity, hydrogen quality.
  - Formulate best practices for mitigation of loss of durability, integrity & efficiency of H_2 storage system.



J. ter Heege, TNO, 2021

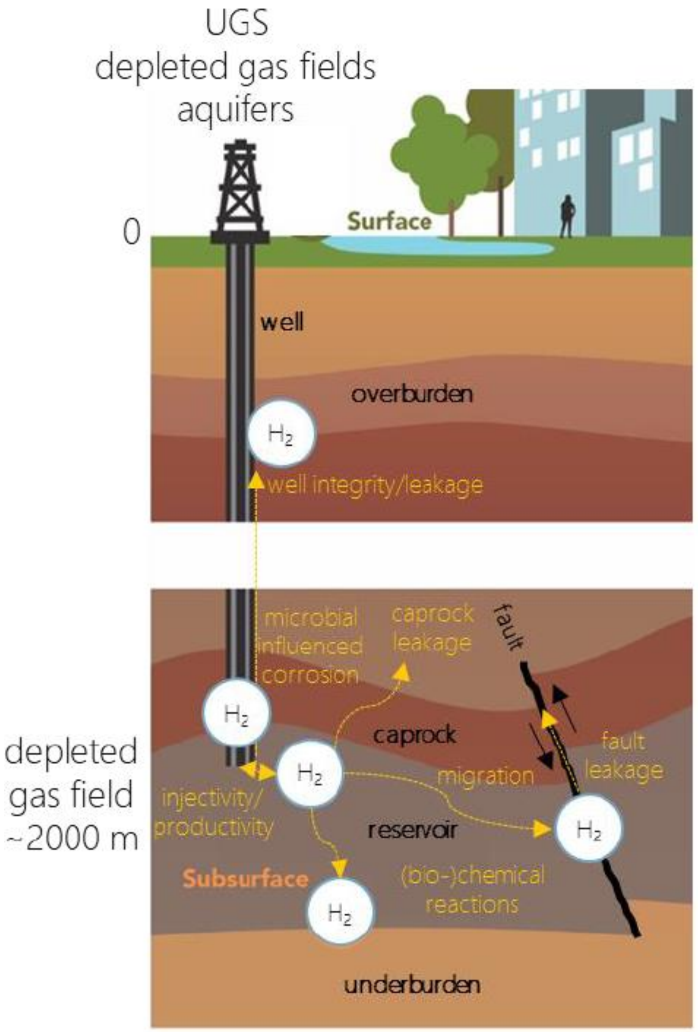
- **Sample**: Characterize processes, mechanisms, and input parameters.
- **Lab**: Test samples at relevant subsurface conditions, and at critical conditions of risks.
- **Risk**: Feed laboratory data into risk assessment. Quantify probability and impacts of risks.
- **Project**: Implications for loss of durability, integrity & efficiency of H_2 storage systems; prioritize mitigation.

MODELS & GUIDELINES FOR SUITABILITY ASSESSMENT

METHODS, TOOLS AND BEST-PRACTICES FOR SITE-SPECIFIC FEASIBILITY ASSESSMENTS

- Research activities focus on:
  - Developing an integrated reservoir and well system modelling approach to assess performance, durability and integrity of potential hydrogen storage sites.
  - Formulating guidelines for the decision-making process in reservoir suitability assessment.

- Specific objectives include:
  - Improvement, extension and validation of a state-of-the-art open-source reservoir simulator for the purpose of assessing multiphysical phenomena and overall performance of hydrogen storage in porous reservoirs.
  - Assessment of the overall performance, integrity and durability of the reservoir and well system of at least 3 representative suitable sites by applying the developed reservoir simulator and a geomechanical model of well systems.
  - Definition of a step-by-step approach for the decision-making process in reservoir and site suitability assessments for hydrogen storage with the goal to better steer the choice of materials, re-use of existing wells and facilities, and more generally, to raise awareness of the risks involved and how to manage them.



J. ter Heege, TNO, 2021

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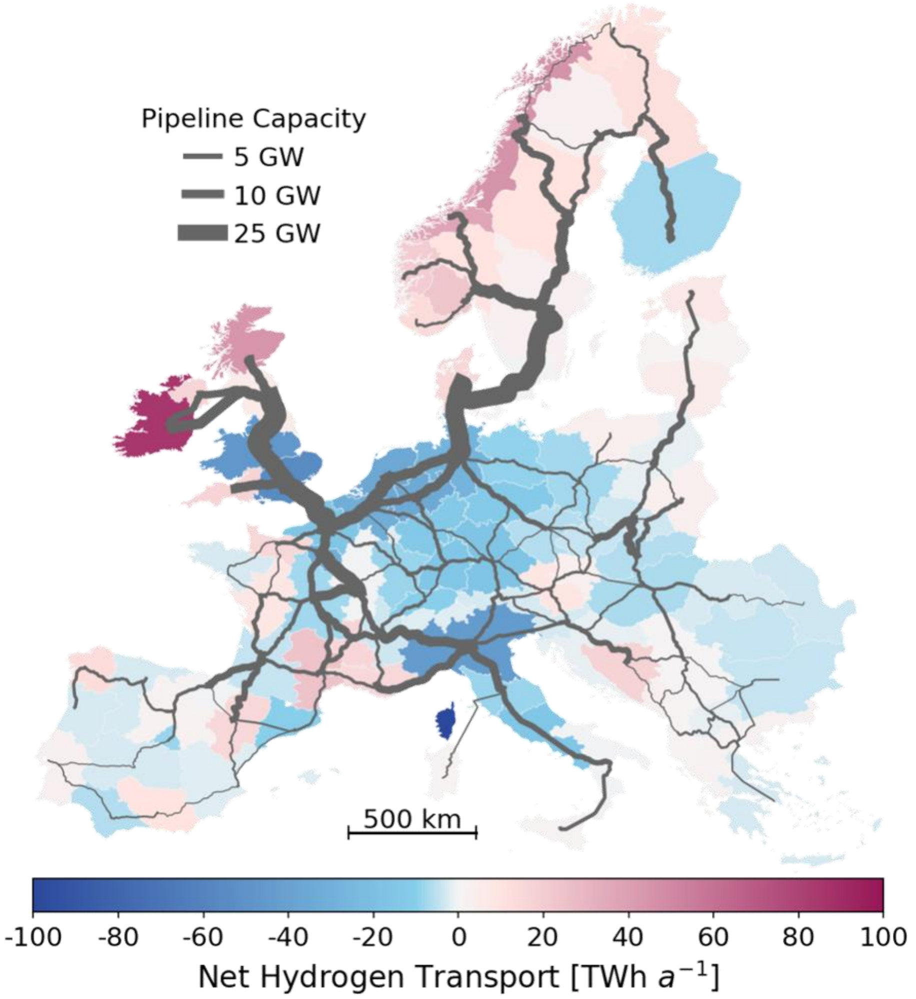
TOWARDS A ROADMAP FOR H_2 STORAGE IN EUROPE

INFORMED BY COUPLED ELECTRICITY-H_2 SYSTEM SCENARIO MODELING AND TECHNO-ECONOMICS

- This research theme is aiming at:
  - Integration of techno-economic performance characteristics of hydrogen storage in porous reservoirs into an open-source energy system model to assess economic feasibility and the role of hydrogen storage within a future decarbonized European energy system.
  - Developing a roadmap for deploying renewable hydrogen underground storage by 2050 by building a step-wise plan for pilots, upscaling and replication in Europe.

- Research activities include:
  - EU-scale coupled electricity-hydrogen system scenario modelling.
  - Analysis of equipment requirements and capital and operating costs for underground hydrogen storage.
  - Calculation of the levelized cost of hydrogen for the chosen scenarios.
  - Analysis of the environmental, regulatory and market-specific risks and barriers for widespread implementation of underground renewable hydrogen storage.



Caglayan, D. (2020): A Robust Design of a Renewable European Energy System Encompassing a Hydrogen Infrastructure. Dissertation. RWTH Aachen. Schriften des Forschungszentrums Jülich. Reihe Energie & Umwelt / Energy & Environment 523, xxii, 312 S.

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