Science 4 Technology – Poster Exhibition 2024

Department Geoenergy

Chair of Reservoir Engineering

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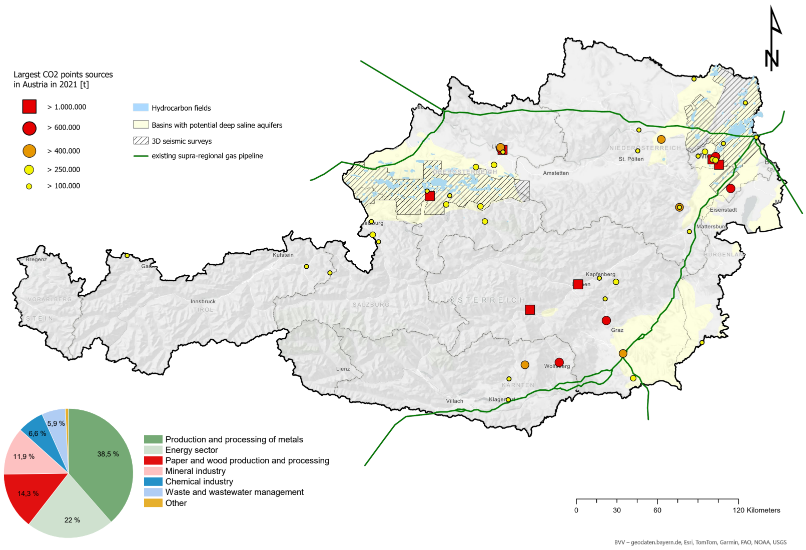
Poster Exhibition 2024

Science 4 Technology @MUL

CO_2 Storage Potential in Austria and its Competitive Subsurface Usage

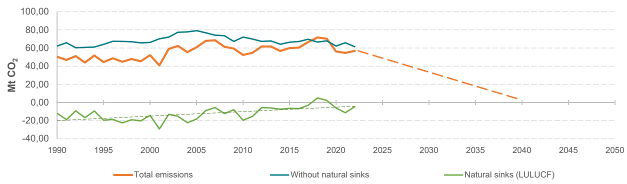


BVV – geodaten.bayern.de, Esri, TomTom, Garmin, FAO, NOAA, USGS

Motivation

- ❑ Austria is committed to becoming **climate net-neutral by 2040**. Reducing the countries hard-to-abate CO_2 emissions will require the substantial application of CCUS to reach this challenging goal. Our work contributes to the Austrian Carbon Management Strategy (CMS)
- ❑ Due to legal regulation and missing public acceptance across Europe, storage sites for CCUS hubs are typically being developed offshore. This is especially challenging for inland countries like Austria where **domestic storage** is **currently not developed** and export of CO_2 can only take off once transport infrastructure is completed
- ❑ Storage capacity in hydrocarbon (HC) fields is limited. CCS might be in competitive subsurface usage with other technologies such as Underground Hydrogen Storage (UHS). Screening storage potentials for both technologies and comparing them to their demands will help with **future subsurface spatial planning**

CO_2 emissions in Austria



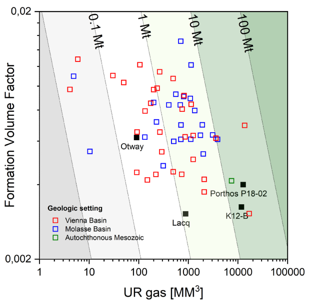
Considerations & Workflow

- ❑ Storage screening in Austrian HC fields: Since storage in depleted saline aquifers will take more development time, storage in HC fields is likely to be developed faster
- ❑ Literature review on existing CCS assessments: We reviewed published literature and contacted companies to gain access to unpublished reports
- ❑ Creation of a database of relevant reservoir parameters: This database serves for a quick estimate of static storage potential and injectivity of the reservoirs
- ❑ Calculating static storage potentials: With displacement efficiency in gas fields and Formation Volume Factor according to reservoir conditions and initial gas composition, see [*Bump et al. (2022)*, *Rupprecht et al. (2018), Okoroafor et al. (2022) and Brix (1993)],* Oil Formation Volume Factor of 1.2 and working to total gas ratio of 50% for H_2 storage*:*

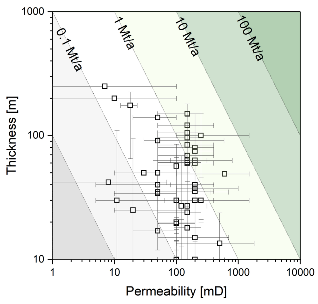
$$M_{CO_2} = \rho_{CO_2} UR_p B$$

M_{CO2}: Field storage capacity
ρ_{CO_2}: CO_2 density at reservoir conditions
UR_p: Ultimate recoverable oil or gas
B: Oil or Gas Formation Volume Factor

CCS capacity screening in depleted gas fields/caps

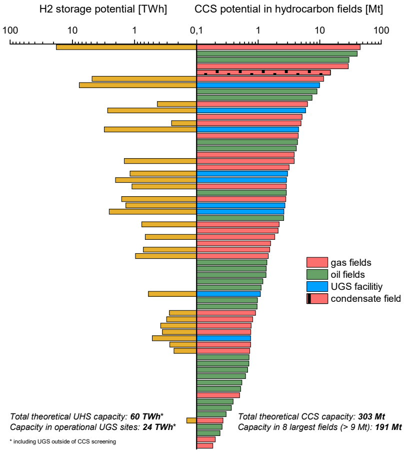


Injectivity screeening



Results & Conclusions

- ❑ CO_2 Storage potentials in hydrocarbon fields are in the order of 303 Mt in total and 191 Mt in fields with individual storage size > 9 Mt. Assuming that storage in oil fields with very high well density is unlikely, this results in a reasonable storage potential in the order of **120 Mt**. H_2 storage potential is in the order of **50 TWh** in depleted gas fields
- ❑ These storage potentials can **bridge crucial time periods** until CO_2 transport networks are developed across Europe
- ❑ The anticipated $\mathbf{CO_2}$ and $\mathbf{H_2}$ storage demands in Austria varies depending on the underlying pathway and scenario but is likely to range from **5 to 10** $\mathbf{Mt_{CO2}}$**/year** *Hochmeister et al. (2024)* and **32 TWh to 56** $\mathbf{TWh_{H2}}$ *Clemens et al. (2022)* for CO_2 and H_2, respectively
- ❑ Both technologies have considerable storage potential in hydrocarbon fields and might meaningfully contribute to the countries climate goals



Total theoretical UHS capacity: ***60 TWh******
Capacity in operational UGS sites: ***24 TWh******

* including UGS outside of CCS screening

Total theoretical CCS capacity: ***303 Mt***
Capacity in 8 largest fields (> 9 Mt): ***191 Mt***

Discussion & Outlook

- ❑ Competitive usage is only to be expected in storages with big capacities as CCS needs certain size for commercial application. Nevertheless, considering continuous development of H2 storage and step by step transformation of conventional underground gas storage (UGS) to H2 storage **reasonable potential is available for both technologies**
- ❑ Future investigations should pursue identification of realistic CO_2 storage potentials in saline aquifers and identify added value of **using** stored $\mathbf{CO_2}$ **as a geothermal working fluid**

References

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DI
Jakob Kulich
Department Geoenergy
Chair of Reservoir Engineering
jakob.kulich@unileoben.ac.at

Univ.-Prof.
Holger Ott
Department Geoenergy
Chair of Reservoir Engineering
holger.ott@unileoben.ac.at

powered by klima+energie fonds

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Subsurface Hydrogen Storage and in-situ Methanation

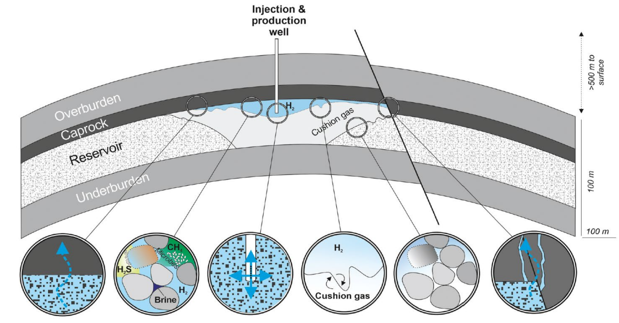
Navigating the Depths through Multiscale Characterization of Reactive Transport for Underground Hydrogen Storage (UHS) and Subsurface Conversion (SC)

Motivation

- Geological hydrogen storage: **Large-scale storage option** for renewable energy with capacities of TWh
- Green hydrogen as a chemical energy carrier with high specific energy density
- Production from surplus energy: wind, solar, hydro-power
- Controlled **in-situ methanation**: microbial conversion of H_2 and CO_2 into renewable (bio-) methane

$$4\,H_2 + CO_2 \leftrightarrow CH_4 + 2\,H_2O$$

- ✓ Recycling of CO_2 → **CCU process**
- ✓ Compatibility with existing gas supply grid

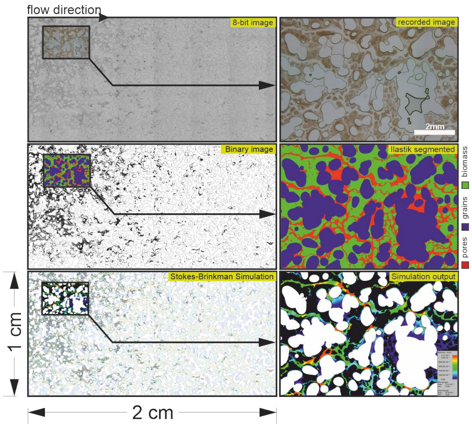


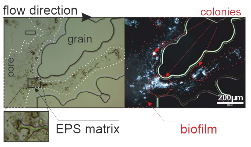
Source: Heinemann et al. (2021). Enabling large-scale hydrogen storage in porous media – the scientific challenges.Energy & Environmental Science.14. 10.1039/D0EE03536J.

Research goals

- Overall goal: gain understanding of **bio-reactive transport mechanisms** to develop a numerical and experimental workflow for the investigation of H_2 subsurface operations
- Ability to predict storage and conversion efficiencies of underground hydrogen operations
- Elaboration of the potential regarding energy storage and CO_2 utilization
- Underground Hydrogen storage vs. in-situ methanation
- Upscaling of phenomena found on the pore-scale

Pore-scale Investigation of Microbial Effects





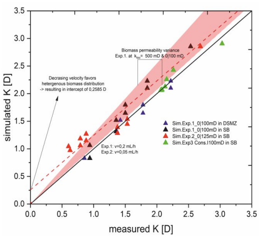


Fig. Advancing understanding of subsurface geo-methanogenesis involves microfluidic experiments studying pore-space modification by methanogenic Archaea. These experiments, conducted in controlled lab conditions, explore biomass accumulation and hydrodynamic alteration. Additionally, Digital-Twins simulate bio-reactive transport parameters, aiding in unraveling the complexities of subsurface methane production. This interdisciplinary approach enhances our insights into environmental processes and energy production methods, facilitating more informed decision-making.

CT-assisted Core-Scale Experiments

Fig. HP/HT Core-flooding setup: Core holder with injection-pumps in medical CT-scanner

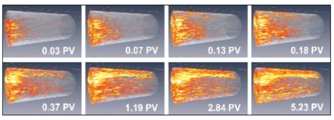


Fig. Spatially and temporally resolved gas saturation front propagation

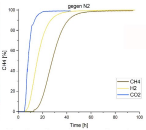


Fig. Gas dispersion experiments

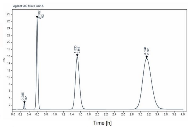


Fig. µGC-module for conversion analytics

Reservoir Scale Simulation of Storage & Recovery

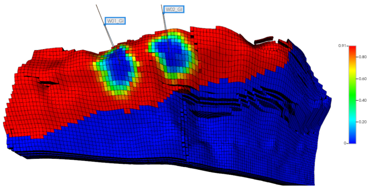


Fig. 3D Reservoir model showing methane evolution and stauration distribution

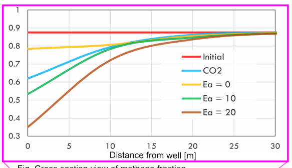


Fig. Cross section view of methane fraction

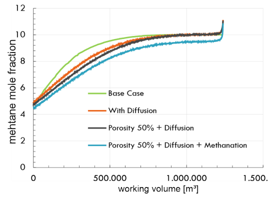


Fig. History-matching of withdrawn geo-methane

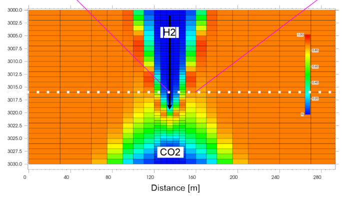


Fig. Methane mole fraction change, cross-section view

Hydrogen Storage in Austria

In cooperation with Austria's leading UHS operator, DGE develops a sensitivity framework to quantify the parameter space relevant to SC by combining numerical experiments with commercial reservoir simulators.

Hydrogen Storage in New Zealand

DGE leads the implementation of UHS reservoir simulation in New Zealand and works with academic and industrial consortium partners to create robust screening criteria for UHS site selection and development.

Laboratory-informed Multiscale Simulation

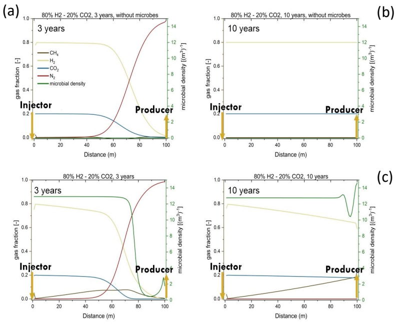


Fig. Bio-reactive mass transport simulation on a continuum-scale. Spatial gas fraction distribution after 3 & 10 years.

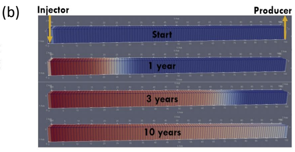


Fig. Pseudo 3D simulation model

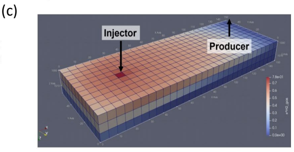


Fig. 3D field-scale simulation model

Fig.: Continuum-scale simulations of bio-reactive transport, co-injection of H_2 (80 mol%) and CO_2 (20 mol%): (a) non-reactive (top) vs bio-reactive (bottom) storage scenarios, compositional differences after 3 and 10 years, (b) Multiseasonal 1D-simulation framework, (c) 3D Field-Scale simulation model.

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Authors: P. Jasek, G. Stiedl, M. Abdellatif
S. Azizmohammadi, H. Ott

Department Geoenergy
Chair of Reservoir Engineering
holger.ott@unileoben.ac.at

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Geological Carbon Dioxide Storage

Motivation

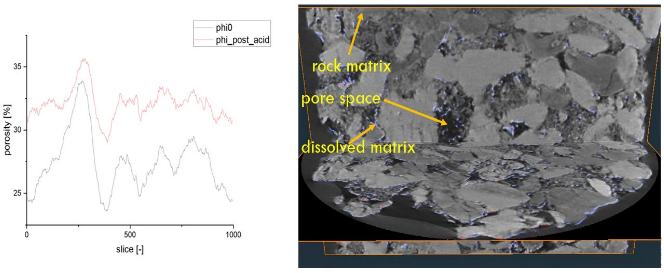
Currently, fossil fuels are the predominant source of primary energy and are expected to continue this dominance in the upcoming decades. **Carbon Capture and Storage (CCS)** emerges as a crucial strategy for **reducing greenhouse gas emissions** into the atmosphere to meet our ambitious climate goals and to drive our society towards a sustainable future. We address this issue at the Chair Of Reservoir Engineering with state-of-the-art experimental research paired with numerical research across all relevant scales. Thereby, we utilize **micro X-ray tomography** and **medical computed tomography** to derive the fluid configuration and changes in the rock matrix. These experiments are a standard tool in **Geoenergy engineering** to study the displacement of miscible and immiscible fluids and to develop a proper understanding of **subsurface flow processes**.

What is important?

- ☐ Required is a suitable **subsurface container**, e.g.: **saline aquifers**, **depleted oil and gas reservoirs**
- ☐ Injection of **dry or undersaturated SC CO_2** into water-bearing formation results in the formation of a dry-out zone as water evaporates from resident brine into the injected CO_2-rich phase
- ☐ Results **in precipitation** which negatively affects hydraulic properties
- ☐ Formation of **carbonic acid** poses certain risks if injected in a carbonate reservoir – **chemical rock-fluid interactions** may change rock strength and hydraulic parameters. **Reactive transport** experiments and simulations provide a link to acoustic properties

Microscale & pore-scale

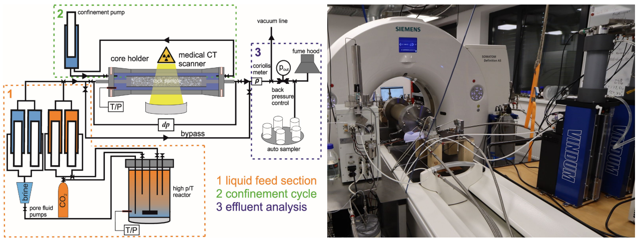
- ☐ Porous 2D microfluidic chip (**Lab-on-a-Chip Approach**) & core flooding on the microscale (captured via µCT)
- ☐ Visualization of the dissolution/precipitation (pore-scale)
- ☐ Characterization of the reduction in hydraulic properties
- ☐ Study principal solute transport mechanisms
- ☐ Studying the **presence of an intrinsic porosity/permeability** of the accumulated salt



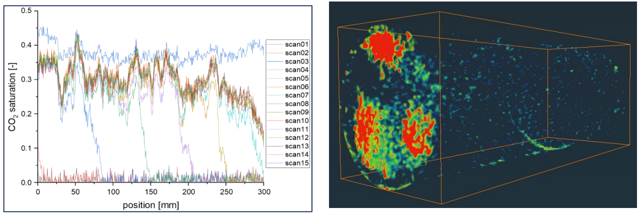
Experimental results derived from µ-CT reactive transport experiments. Left: change in porosity over sample length due to acid injection. Right: corresponding segmented differential image derived from µ-CT scans with labelled changes in the rock matrix.

Continuum-scale experiments

- ☐ Primary displacement mechanisms – CO_2/brine
- ☐ **Real-time monitoring** of saturation state & salt precipitations via medical CT scanner
- ☐ Determination of the **zone of counter-current imbibition** via **meter-scale core flood experiments**, reduction in permeability via differential pressure monitoring



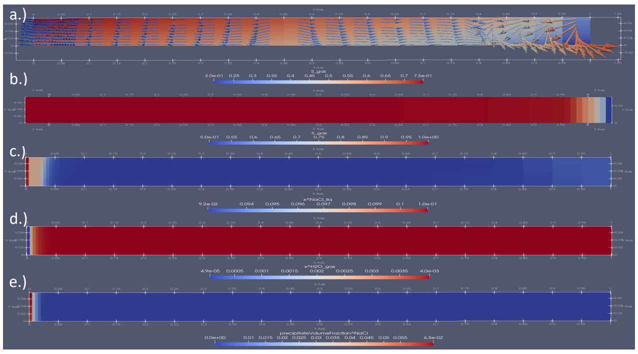
Schematic and image of the experimental setup designed for core-flood experiments.



Saturation profiles derived from medical CT scanner. Left: CO_2 saturation profile versus core length (30 cm). Poor displacement efficiency is visible. Right: segmented medical CT scan. Visualized is the solid salt which came out of the solution due to the evaporation of water from the resident brine due to supercritical gas injection.

Numerical simulations and development

- ☐ Establish **experimental/numerical workflow** to history match with a reservoir simulator
- ☐ Developed a novel numerical module based on **DuMu^X** to describe **evaporation & reaction kinetics** to study dry-out phenomena
- ☐ Upscale numerical results to the wellbore environment
- ☐ Determine the **zone of attraction** and investigate major parameters governing this zone and the fluid transport therein



Simulation results: a.) capillary driven backflow; b.) gas saturation with increased injection rate, dry zone; c.) dissolved salt concentration; d.) water in the gas phase e.) solid salt saturation.

Dipl.-Ing.
Boris Jammernegg
Department Geoenergy
Reservoir Engineering
boris.jammernegg@unileoben.ac.at

Univ.-Prof. Dipl.-Phys. Dr.rer.nat.
Holger Ott
Department Geoenergy
Reservoir Engineering
holger.ott@unileoben.ac.at

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Digital Rock Physics

From Rock Samples to Digital Twins to 2-Phase Flow Simulations

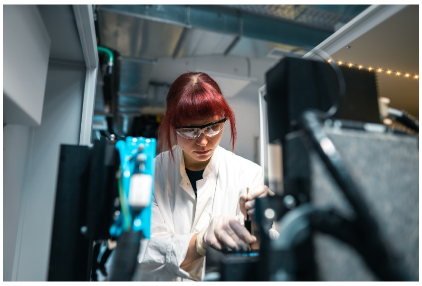
Motivation

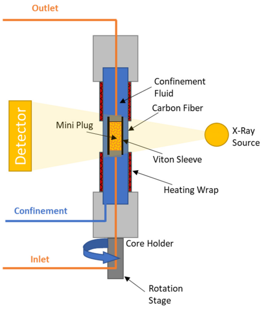
Digital Rock Physics is a rapidly developing field of research with the first major successes in geological field developments. Our focus is on the **enormous potential of the Earth's crust** for energy supply, energy storage and decarbonization through geothermal energy recovery, hydrogen and CO_2 geological storage. These developments require well-calibrated fluid flow, mechanical and reactive transport models.

The underlying flow mechanisms can best be studied at the **rock's pore scale**. In recent years, a Digital Rock workflow has been developed at the Chair of Reservoir Engineering to perform flow simulations on digital rock structures. In this workflow, rock samples are imaged by **micro X-ray tomography** with a resolution high enough to resolve the rock pore structure in detail. Depending on the requirements, scanning is performed with a laboratory instrument or at synchrotron radiation facilities. A series of **data processing** steps, such as reconstruction into 3D volumes, image filtering for noise reduction, image segmentation to distinguish mineral phases and pore space (the porosity), generate a **digital twin** of the original rock structure. On this digital twin, numerical simulations can be performed to extract essential parameters to quantify **multiphase flow** through fluid saturation functions, **mechanical rock properties** and **reactive fluid transport** including chemical rock-fluid interactions.

In particular, the development of very efficient simulation methods, such as the morphological method for multiphase flow simulation, allows us to simulate such parameters very quickly and cost-effectively compared to conventional experimental and numerical methods. The developed workflow has been **successfully implemented in industrial environments**.

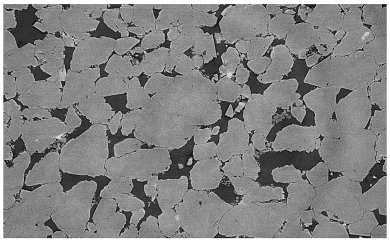
Micro Computed Tomography Imaging





At the Department Geoenergy micro computed tomography (micro-CT) scans are usually done at a **voxel size of 3 µm**, which enables us to **resolve the pore structure** and to **identify different materials** in our rock samples.

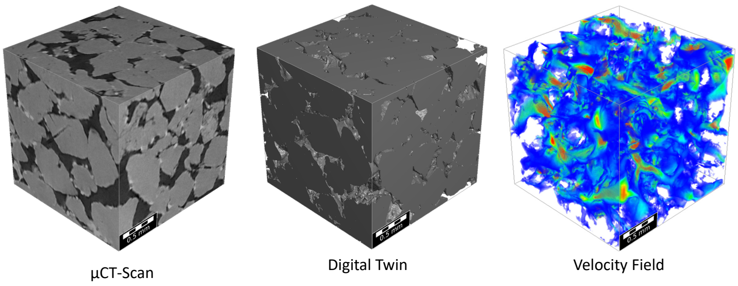
Scans can also be performed during **flooding experiments** at equilibrated conditions, where the rock sample is placed inside a core holder and **flooded with various liquids and gases**, such as **brine and CO_2**.



High resolution Synchrotron Micro-CT image with a Voxel Size of 2.4µm of a Bentheimer Sandstone

Typical Micro-CT Sample of a Berea Sandstone with a diameter of 4 mm

Multi Phase Flow Modeling



µCT-Scan

Digital Twin

Velocity Field

Left: cropped µCT Scan of a Berea Sandstone with a Voxel Size of 3.4µm ; Middle: Segmented Pore Space and Grain – Digital Twin; Right: Simulated Velocity Field with GeoDict®

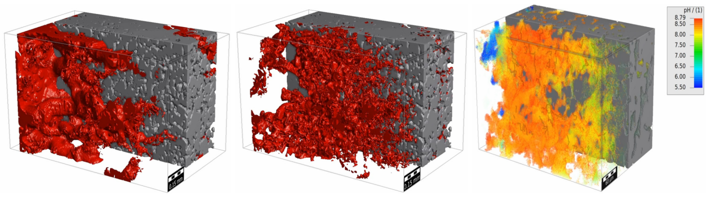
Multiphase flow simulations performed in GeoDict® allow us to research **complex processes** such as **gas-liquid and/or solid-liquid interactions**, within porous media.

For example, the **morphological method** enables us to simulate the **capillary trapping of CO_2**, retention of carbon dioxide in the pore space, which is a crucial factor in **Carbon Capture and Storage**.

Further simulations can provide us with information about:

- ☐ Capillary pressure curves
- ☐ Relative permeability
- ☐ Saturation distribution
- ☐ Displacement patterns
- ☐ Wettability alteration
- ☐ Etc.

Reactive Flow modeling



Left and middle: comparison of different dissolution regimes, wormholing (left) and uniform dissolution (middle). Right: pH value in the sample of interest during the reactive flow simulation

Computation of **dissolution and precipitation of mineral phases** during continuous inflow of reactants. Modeling of **reactive flow** associated with geological carbon storage. Thereby, we simulate the **multiphase flow and transport of chemical species** (e.g. carbonic acid). Results in permeability reduction or enhancement and serves as **link to acoustic properties**.

- ☐ Dry scan (micro-CT) serves as input (digital twin)
- ☐ Calibration of numerical model via reactive flow experiments
- ☐ Derive **K/Φ relationship**
- ☐ 4D rock alteration – **dissolution regime**
- ☐ Describe systems via **dimensionless numbers** (Damköhler number, Péclet number)

Dipl.-Ing.
Boris Jammernegg
Department Geoenergy
Reservoir Engineering
boris.jammernegg@unileoben.ac.at

Dipl.-Ing.
Bianca Brandstätter
Department Geoenergy
Reservoir Engineering
bianca.brandstaetter@unileoben.ac.at

Univ.-Prof. Dipl.-Phys. Dr.rer.nat.
Holger Ott
Department Geoenergy
Reservoir Engineering
holger.ott@unileoben.ac.at

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Chair of Reservoir Engineering

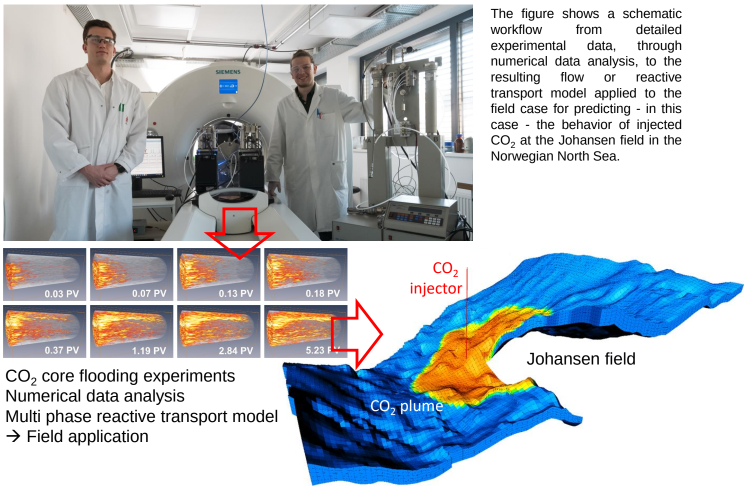
Engineering Future Energy!

Mission Statement

Achieving a sustainable energy future is one of the greatest challenges of our time, in which the Earth's crust with its nearly inexhaustible energy potential plays a crucial role. To achieve both sustainable energy and climate change goals, the development of renewable energy and fossil fuels must be considered together to develop the best path to a decarbonized society.
Reservoir engineering is a key discipline to drive progress in subsurface technology and provide the best possible solutions for energy supply and climate change through research and development. The Reservoir Engineering team is developing future technologies to deliver energy, store it at scale and avoid greenhouse gas emissions. Through research and education, we aim to advance the fields of geoenergy and reservoir engineering and to address the challenges of energy supply and related issues in collaboration with the public sector and energy companies. We focus on economically viable and environmentally friendly methods of energy recovery, gas injection for large-scale energy storage (power-to-gas) and CO2 sequestration (CCS).

State-of-the-art Research Facility

The research focus of the chair is on multiphase flow in porous rocks and on reactive transport and its consequences (feedback) on hydraulic and mechanical rock properties and ultimately on the intended mode of operation. To address these issues, we perform experimental and numerical research on different scales, starting from the fluid-fluid-rock interfaces and the pore scale (nm to mm) to the field scale (m to 100 km) - a pore-to-field approach.



The figure shows a schematic workflow from detailed experimental data, through numerical data analysis, to the resulting flow or reactive transport model applied to the field case for predicting - in this case - the behavior of injected CO_2 at the Johansen field in the Norwegian North Sea.

CO_2 core flooding experiments
Numerical data analysis
Multi phase reactive transport model
→ Field application

Reservoir Engineering
Digital Rock laboratory

Micro Computed
Tomography
Scanner

Microfluidic
Lab on a chip

Men at work

Research Areas

Decarbonization and Energy Transitioning

- ❑ Carbon Capture and Storage (CCS) for climate change mitigation
  - Geological storage performance and security aspects
  - Multiphase flow and reactive CO2 transport
  - CO2 storage capacity and *carbon management strategy* for Austria
- ❑ *Hydrogen storage and in situ methanation* for renewable energy storage
  - Subsurface flow and bio-reactive processes
  - Microbial gas conversion → gas quality, renewable methane
- ❑ *Geothermal energy* as base load renewable energy
  - Geothermal reservoir engineering
  - Aquifer thermal heat storage
- ❑ *Petrocultures* – arts-based science on energy transitioning

Digitalization

- ❑ *Digital Rock Physics* for Multiphase Reactive Fluid Transport in Porous Rock
- ❑ *Stochastic modeling* for experimental data interpretation & field development → uncertainty modeling

Enhanced recovery

CO_2 and chemical enhanced oil recovery (EOR) for cost-effective and environmentally friendly oilfield development

Focus on technical R&D

What do the above technologies have in common and what are the key scientific challenges? When substances such as H2 and CO2, or even heat, are injected into or extracted from the subsurface, the geological reservoir is brought out of chemical, biological or thermodynamic equilibrium. This changes the properties of the geological reservoir in terms of fluid dynamics, geomechanics, etc. in a way that makes it difficult to predict underground processes, e.g. storage capacity and safety in CCS developments or gas conversion rates in microbial hydrogen methanation. The aim of the research is to gain a more comprehensive understanding of such coupled processes and their feedback on operational performance and safety. A better understanding will enable the prediction and design of subsurface processes and thus the control and optimization of operational results.
Multiphase flow and reactive transport models will be developed through experimental and numerical research. These models will be brought to technological maturity as efficiently as possible in order to apply the technologies on the required timescales and thus contribute effectively to the energy transition and decarbonization.

Non-technical engagement in energy transitioning

An increasing proportion of our R&D activities is focused on more conceptual issues, such as the implementation of CCS to achieve climate goals. This includes active participation in the development of the Austrian Carbon Management Strategy, collaboration on the Austrian Assessment Report, and exchange with industry stakeholders. In addition to the technical, political and economic aspects, it is important to change our attitude towards energy and consumption. In cooperation with the University of Applied Arts Vienna, we are investigating our cultural dependence (or rather addiction) and the necessary energy transition that begins in our heads - an art-based science project on petrocultures!

The A Team

Dr. Holger Ott
Head of Department Geoenergy
Head of Chair of Reservoir Engineering
holger.ott@unileoben.ac.at
www.geoenergy.engineering
www.dpe.ac.at