Underground hydrogen storage and in-situ gas conversion: *Reactive transport mechanisms on different scales*

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Motivation

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

$$4H_2 + CO_2 \rightarrow CH_4 + 2H_2O \qquad (1)$$

Advantages:

- ☐ Recycling of CO_2 → **CCU process**
- ☐ Worldwide first pilot project in Austria
- ☐ Compatibility with existing gas supply grid

Research:

- ☐ 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

Microfluidic experiments

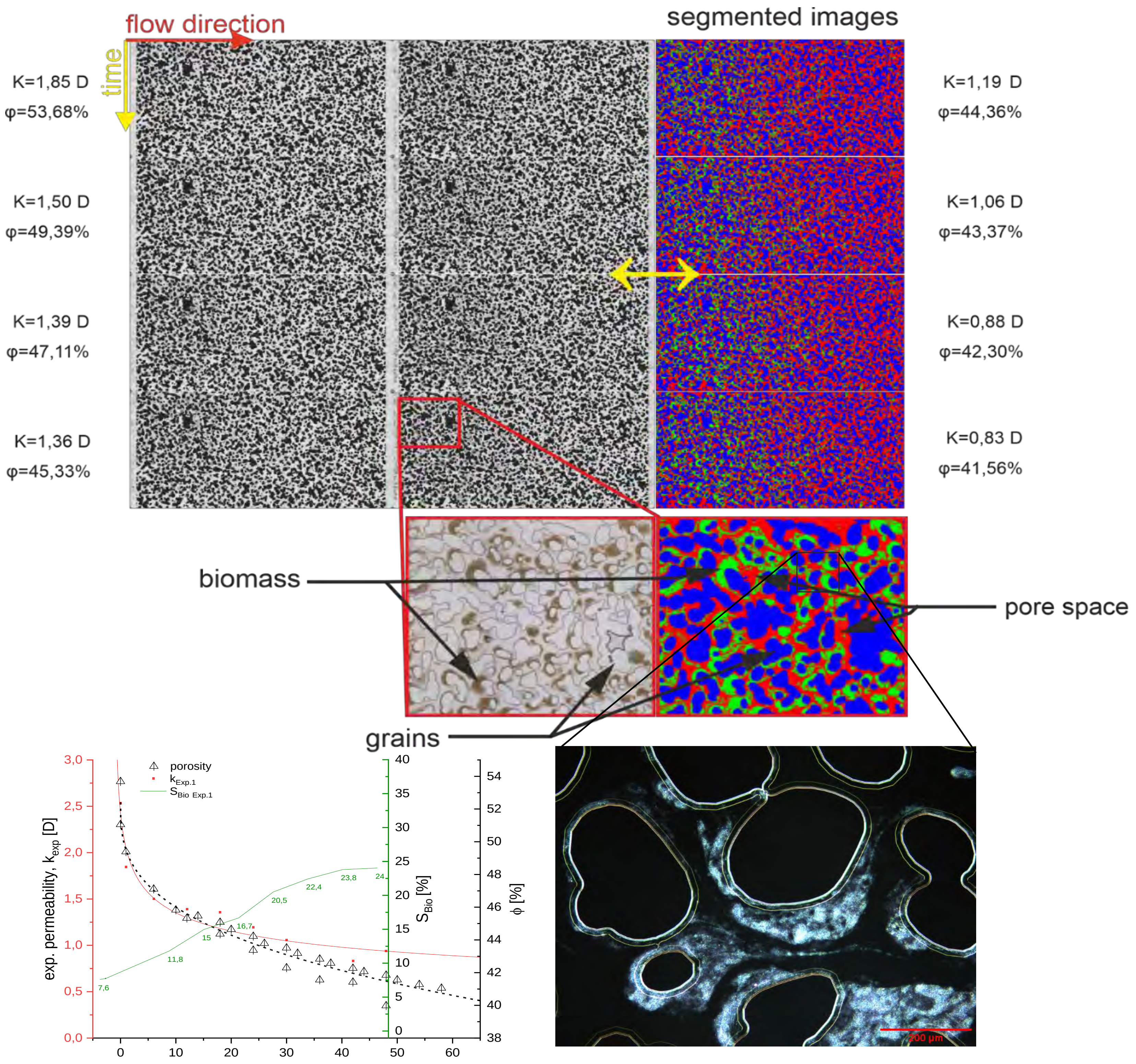

Fig.1: Increase of biomass during a 48-hour single-phase experiment. Starting from the top left corner, the biomass (gray) grows with time, leading to a decreasing permeability and porosity within the micromodel (diagram, bottom right). The top right images show the segmented version of the images on the left. Biomass in green, grains in blue and pore space in red. The close-ups below show significant biomass accumulations on the inlet side of the micromodel. Darkfield microscopy (bottom right) of organic matter. The formation of preferred flow paths can be observed.

- ☐ **Microfluidic-chip**: 2D-artificial proxy for a porous rock matrix (Lab-on-a-Chip)
- ☐ Visualization of biomass, water, and gas-phase under controlled conditions
- ☐ Characterization of hydraulic properties: **K/ϕ-relationship**
- ☐ Description of transport phenomena: accumulation, growth and detachment; Determination of the **intrinsic biomass permeability** with digital twins (Navier-Stokes-Brinkmann formulation)
- ☐ Analysis of critical stress and velocity fields
- ☐ Evaluation of the reactive system using gas chromatography under consideration of controlling parameters (**Pe, Da**)

Core-flooding experiments

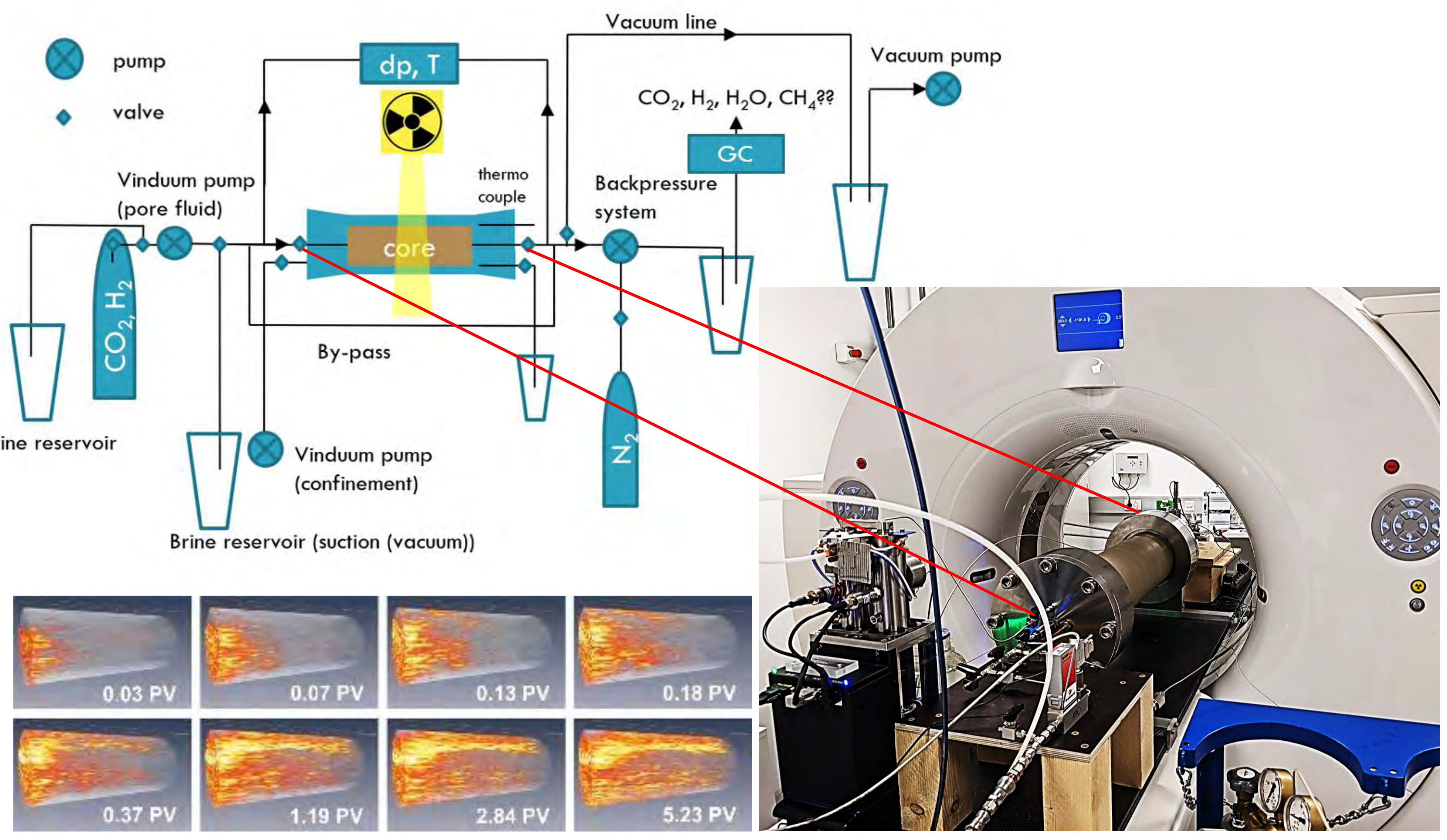

Fig.2: Schematic overview of the experimental setup for core flooding experiments on the meter scale (top), core holder system with a high-pressure metering pump mounted in a medical CT scanner (right), visualization of the gas phase migration (gas saturation profile) during a CO2 injection into a water-saturated core sample (bottom left, S Berg et al. 2013)

- ☐ Investigation on a macroscopic level (**field-relevant** scale)
  - ■ Heterogeneity of the rock matrix → macroscopic phase distribution (gas/brine/biomass)
  - ■ Dispersive effects (diffusion, advection, solubility of the gaseous components into liquid phase)
  - ■ Displacement and transport mechanisms
  - ■ **Gas conversion rates** and microbial growth rates
- ☐ Calibration and refinement of the simulation tool with experimental data (history-matching)
- ☐ X-ray computed tomography imaging (medical CT-scanner), gas analyzation via inline micro-GC unit
- ☐ **Upscaling** of phenomena found on the pore-scale

Continuum-scale simulations

- ☐ Numerical simulations of bio-reactive transport mechanisms during underground hydrogen storage operations in depleted gas reservoirs
  - ■ Injection of H_2 and CO_2
  - ■ Flow through reactors with constant injection and production rates
  - ■ Huff and puff operations with cyclic injection/production via one well
- ☐ Bio-reactive vs. non-reactive simulation scenarios
- ☐ **Sensitivity analysis** of different input and process parameters → What makes the in-situ bio-reactor efficient?
- ☐ Combined work-flow with numerical history-matching of the experimentally obtained results

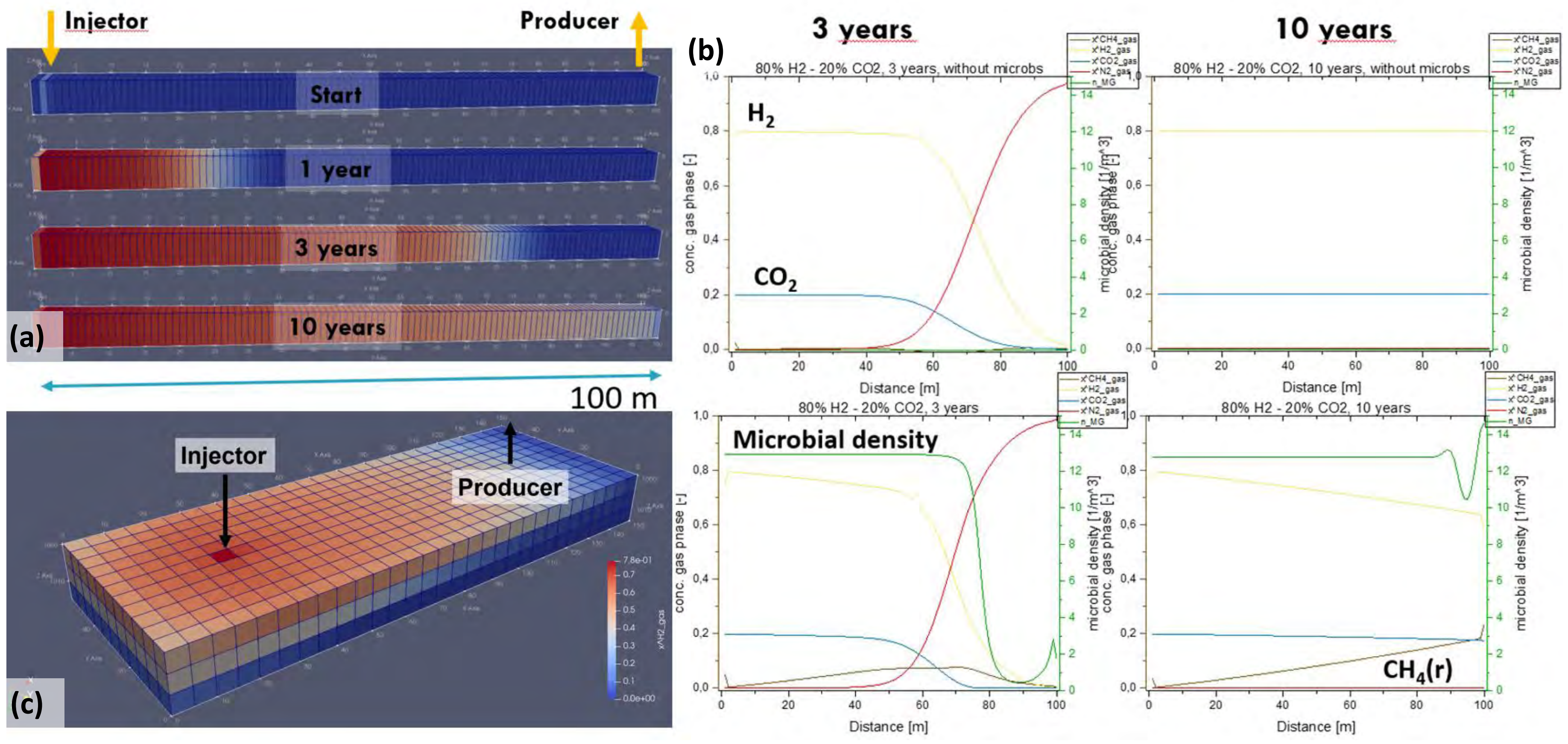

Fig.3: Continuum-scale simulations of bio-reactive transport, co-injection of H_2 (80 mol%) and CO_2 (20 mol%): (a) 1D-simulation model, (b) non-reactive vs. bio-reactive scenarios, gas distribution after 3 and 10 years, (c) 3D field-scale simulation model

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