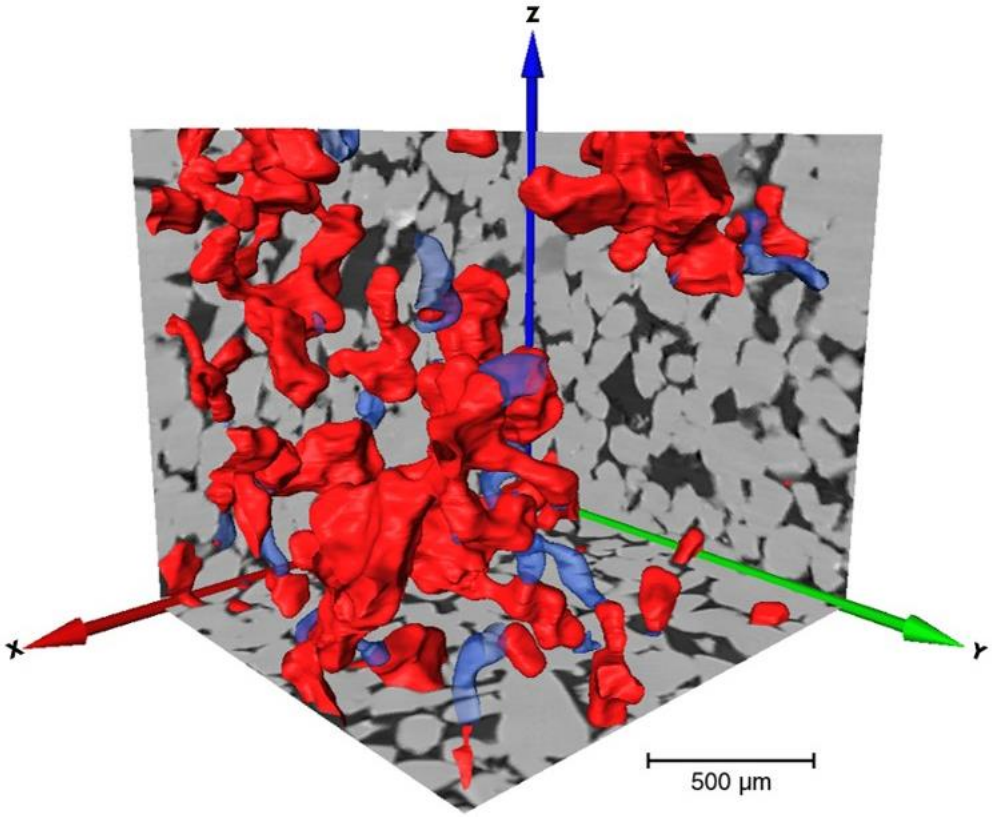
Large Scale Hydrogen Storage; Need, Opportunities and Challenges -

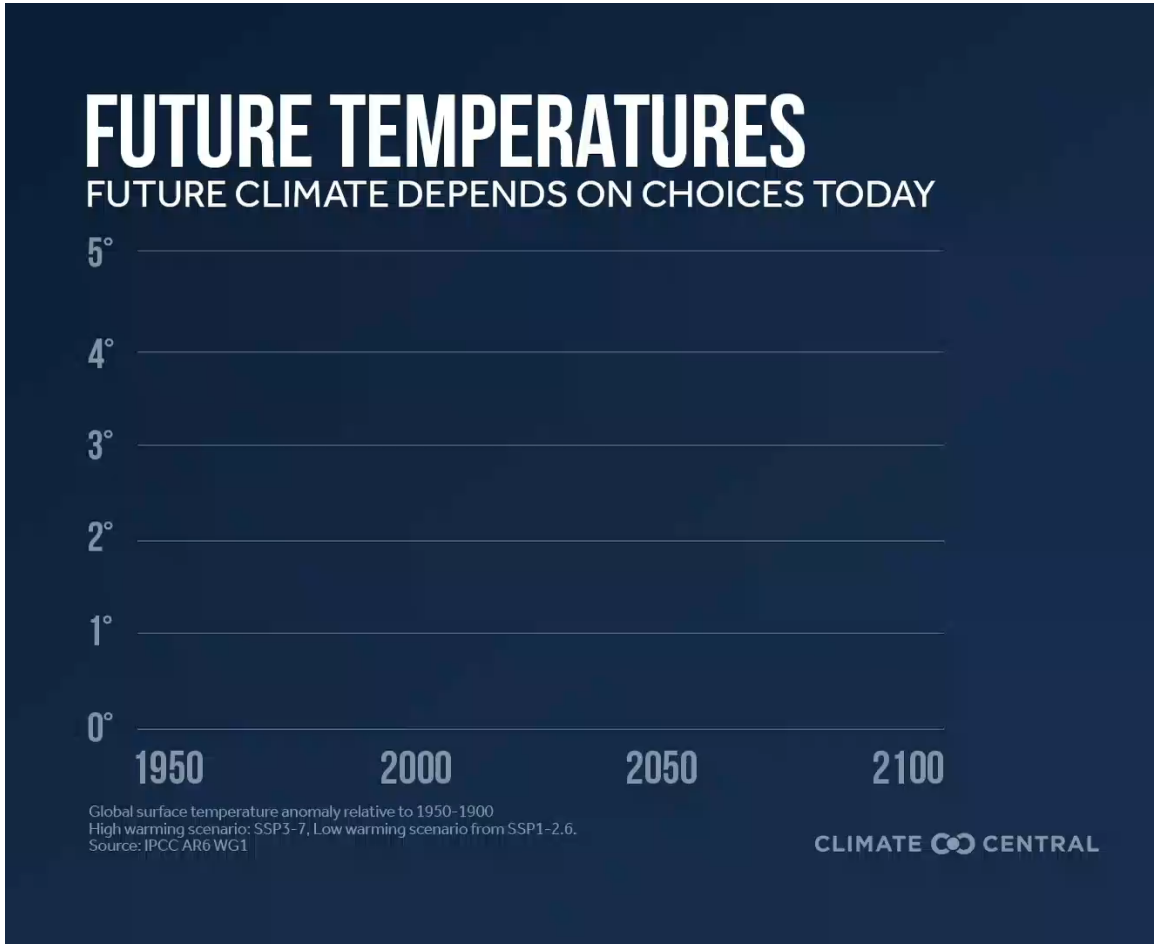
Results from a Recent 3D Visualization study



Presenter: Zaid Jangda
Heriot-Watt University

PAE Symposium
24 June 2023

MOTIVATION

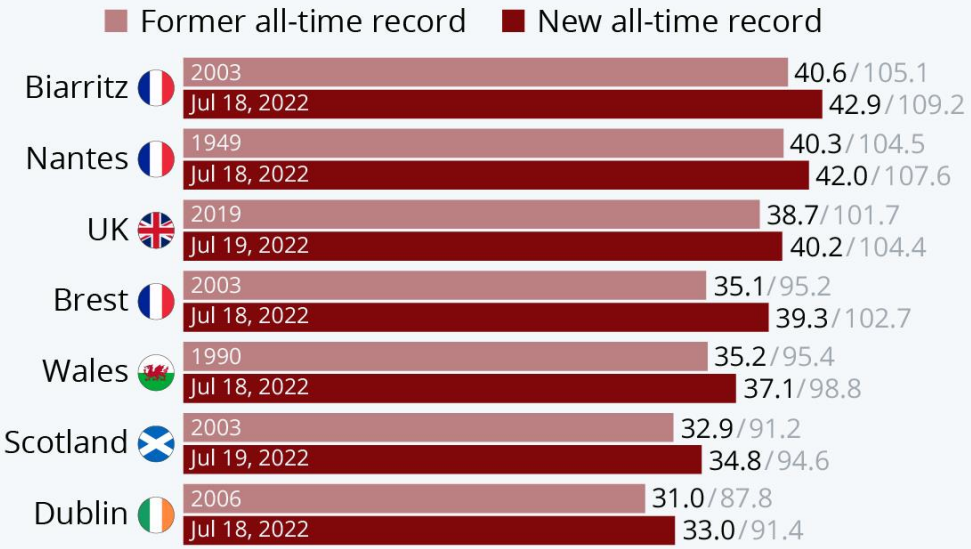


Drastic cuts in carbon emissions are required to keep global warming levels low and prevent an environmental catastrophe

MOTIVATION

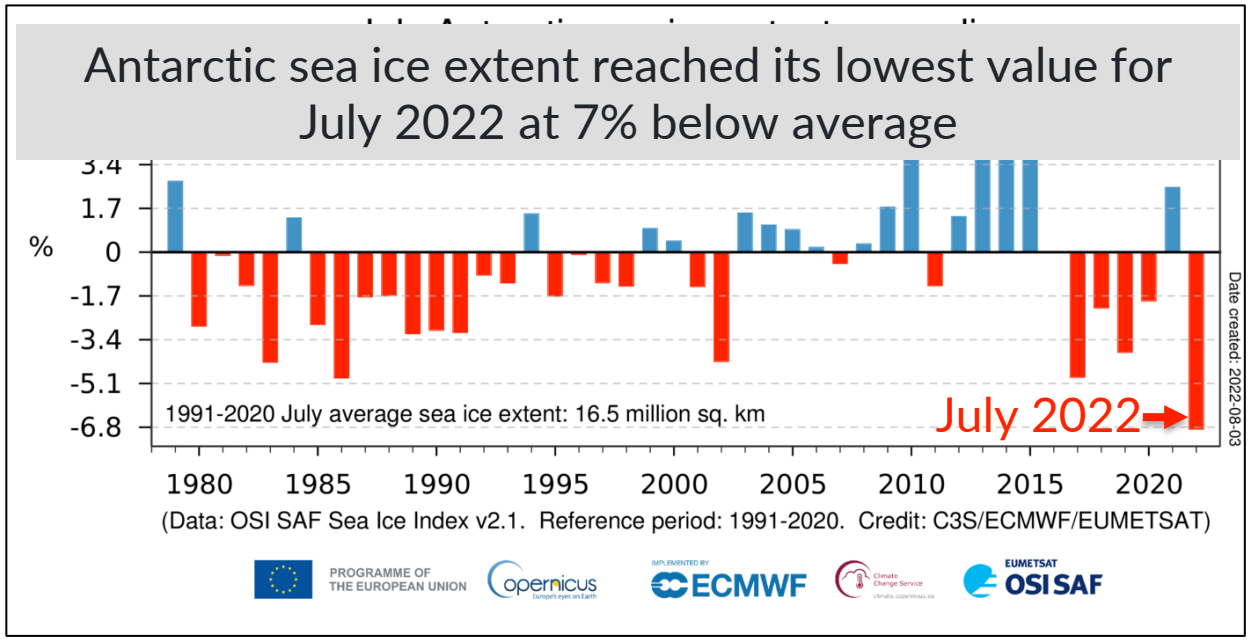
Record-breaking Heat in Europe

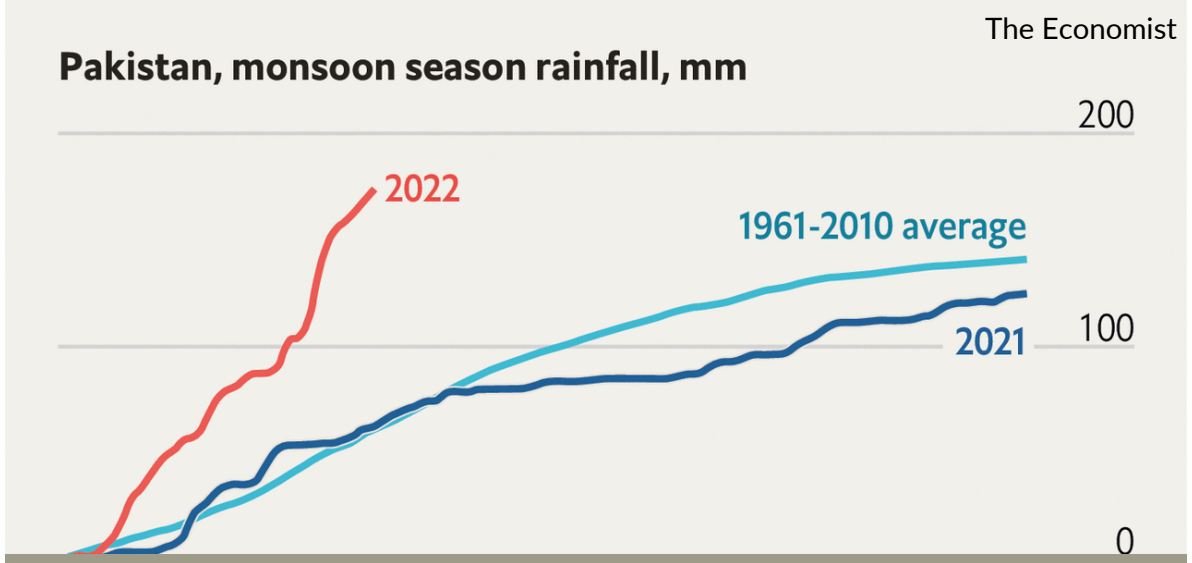
New temperature records compared to former all-time records in European cities/regions/countries (in °C/°F)



New temperature records are preliminary until certified
Sources: Official country meteorological offices, media reports

Europe's Heat Wave Shatters British Records and Drives Wildfires





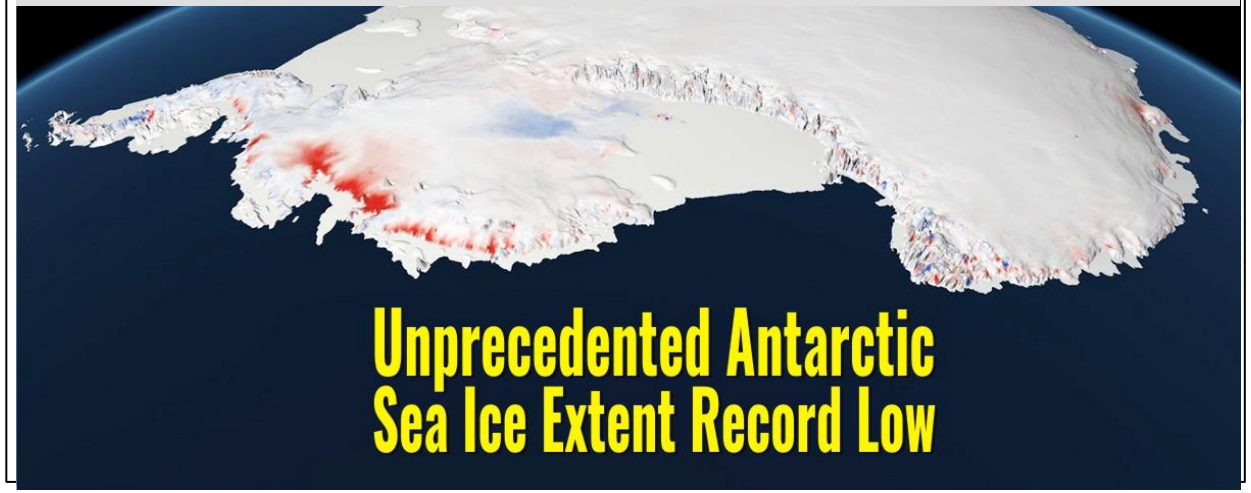
One third of Pakistan is underwater; there has been a 400% increase in average rainfall

MOTIVATION

Record-breaking Heat in Europe

Europe's Heat Wave Shatters British Records and Drives Wildfires

Antarctic sea ice extent reached its lowest value for July 2022 at 7% below average



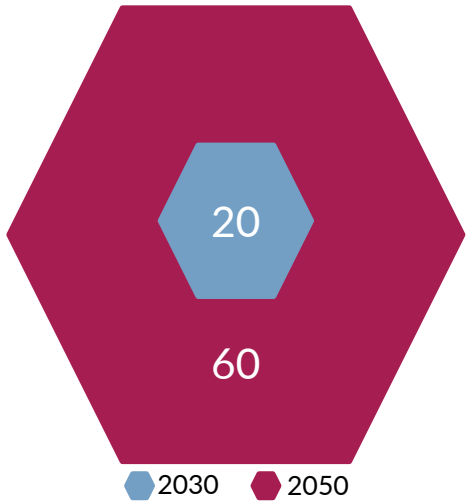
One third of Pakistan is underwater; there has been a 400% increase in average rainfall

MOTIVATION

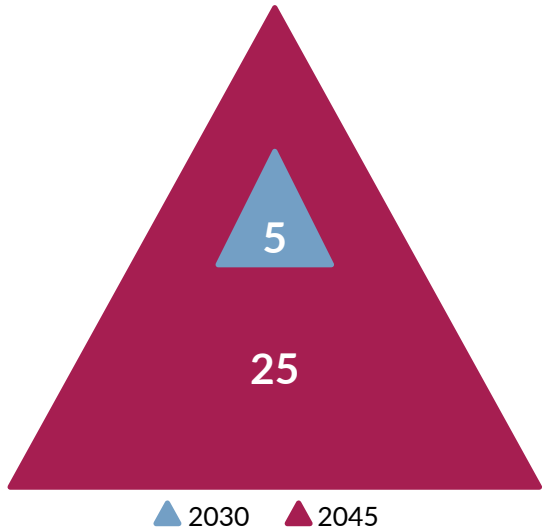
Is Hydrogen the answer???

UPDATED HYDROGEN ENERGY TARGETS

EU H_2 demand (million tonnes)



Scotland H_2 production (GW)



US DoE – Hydrogen Shot

US commitment of $9.5 billion for clean hydrogen

September 2022: European Commission reveals plan for €3 billion hydrogen bank

50% of the industry to transition to **green** hydrogen by 2030 (70% by 2035).

Achieving Clean H_2 at scale by 2050*

- 20% global emissions reductions
- 30 million jobs
- $2.5 trillion in annual revenues

*projection

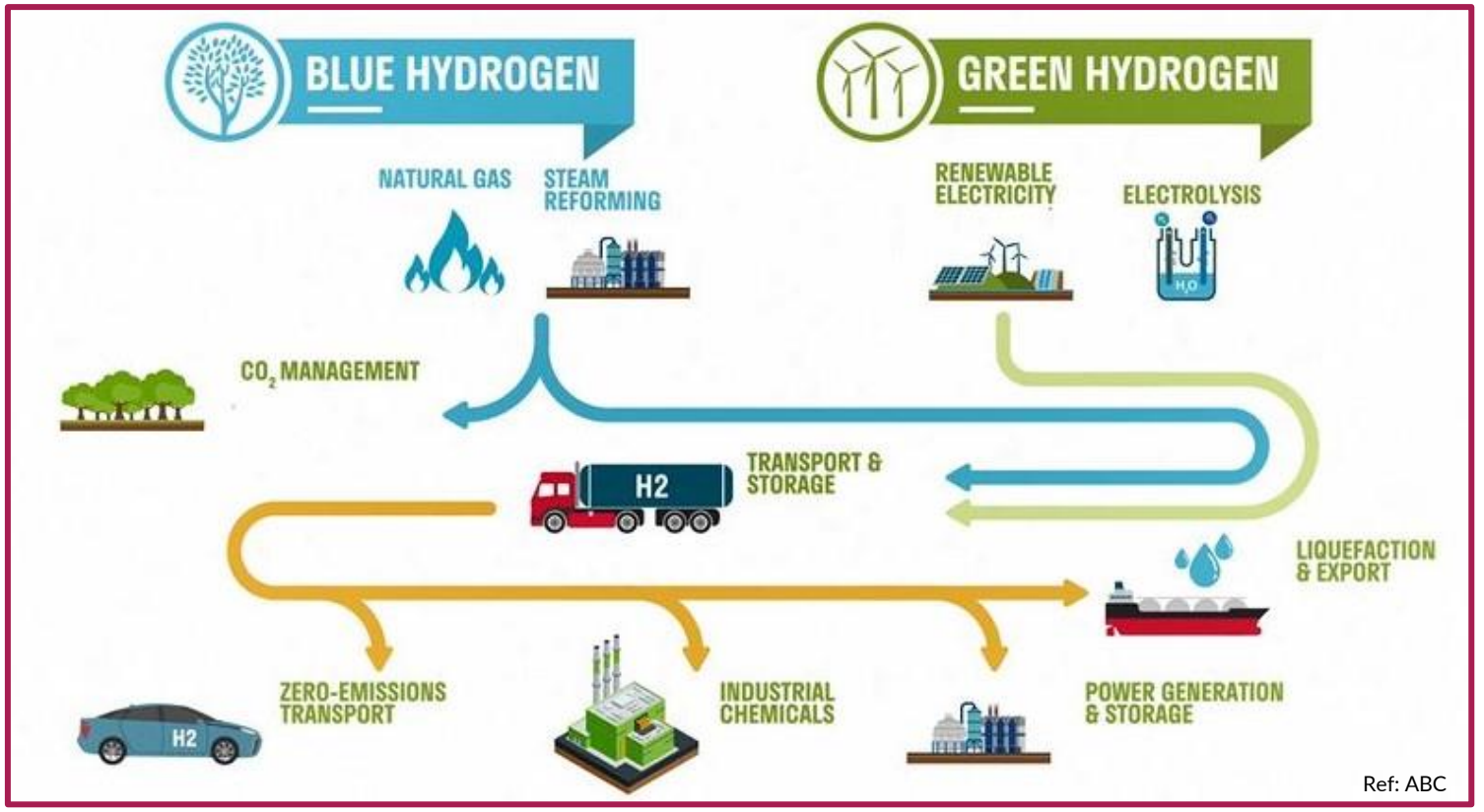
References: EU Commission Hydrogen Strategy, UK Hydrogen Strategy, US DoE

COLORS OF HYDROGEN

The Hydrogen Colour Spectrum

COLOUR	DESCRIPTION: FEEDSTOCK
	Grey: natural gas reforming without CCUS
	Brown: brown coal (lignite) as feedstock
	Blue: natural gas reforming with CCUS
	Green: electrolysis powered through renewable electricity
	Pink: electrolysis powered through nuclear energy
	Turquoise: methane pyrolysis
	Yellow: electrolysis powered through electricity from solar
	Orange: electrolysis powered through electricity from wind

Ref: WRI India



Ref: ABC

GREEN HYDROGEN AND UNDERGROUND HYDROGEN STORAGE (UHS)

There are multiple options available to store green H_2 underground

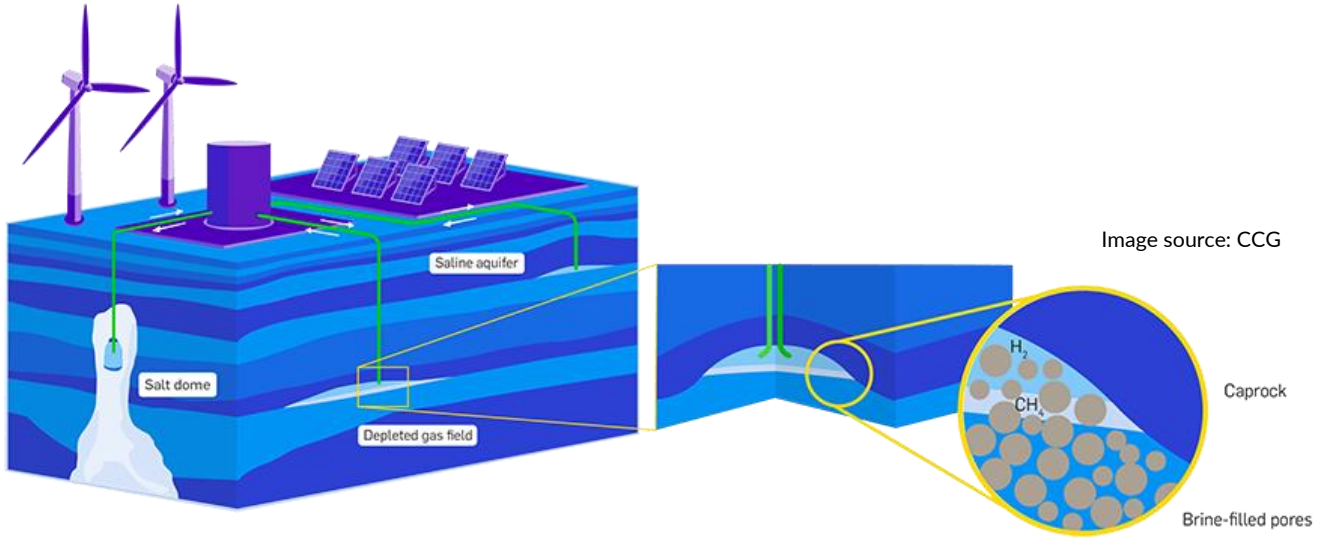


Image source: CCG

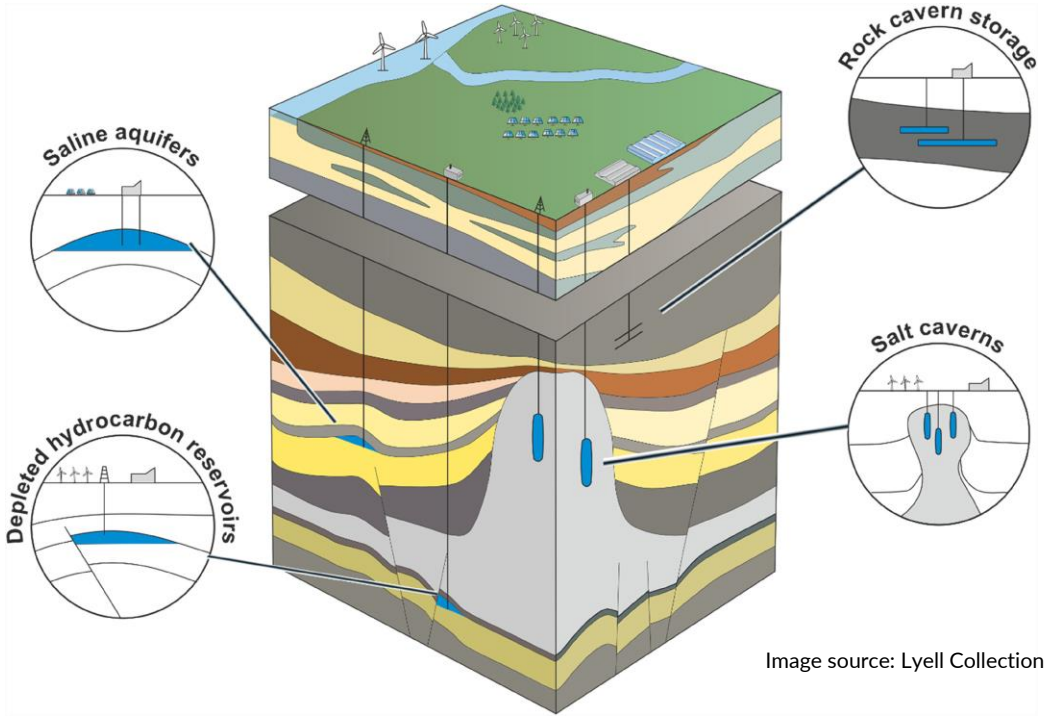


Image source: Lyell Collection

These options differ in terms of capacities

UHS CAPACITIES

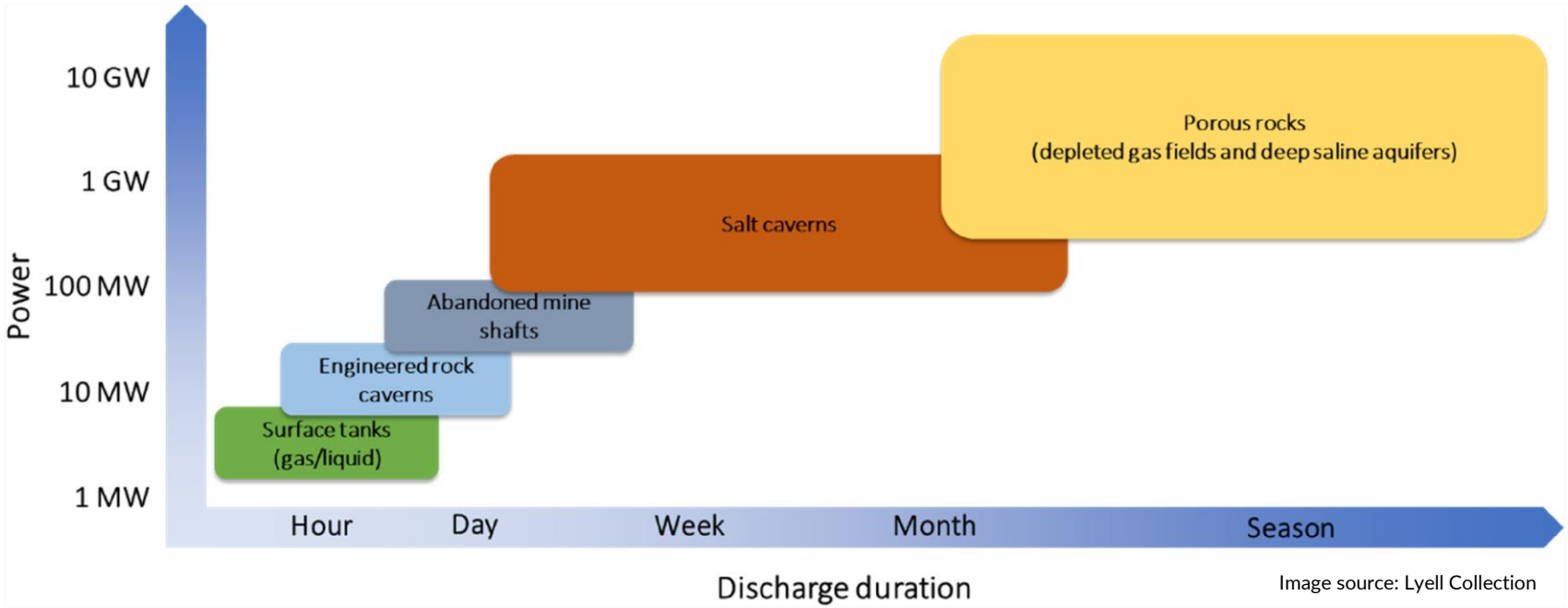
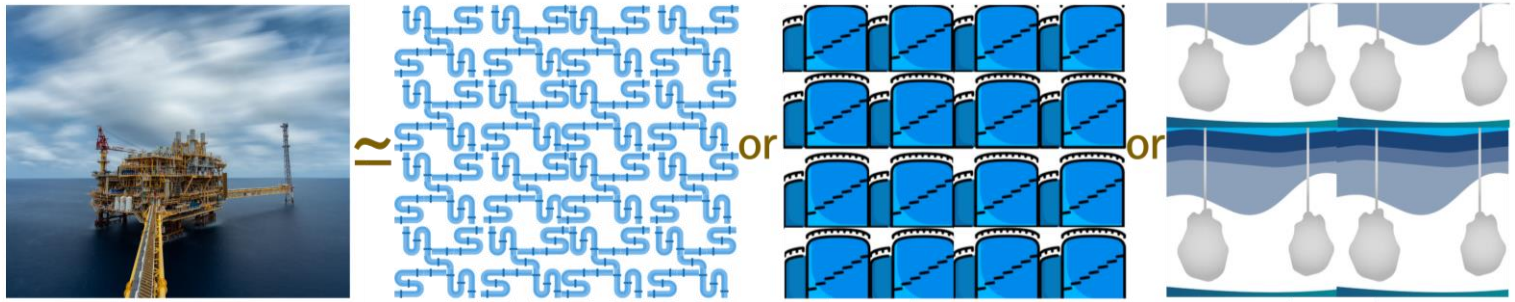


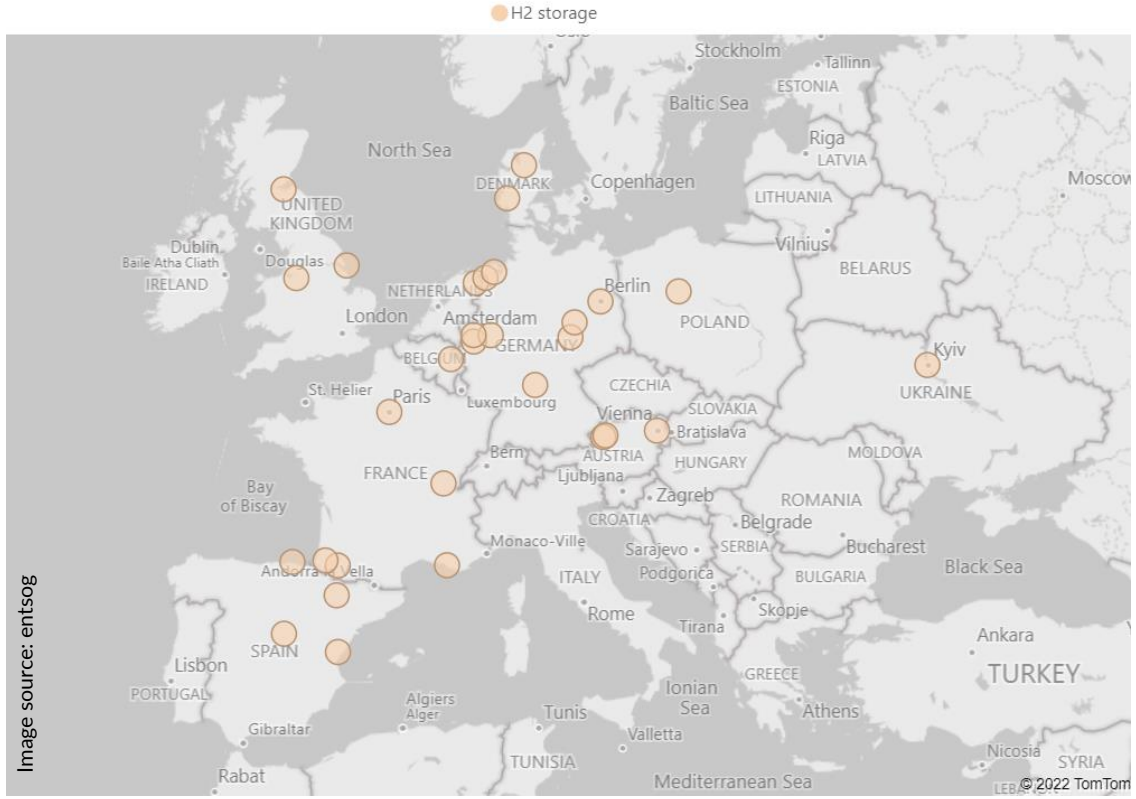
Image source: Lyell Collection



Data courtesy: https://doi.org/10.5194/egusphere-egu2020-10475, www.hyuspre.euwww.hyuspre.eu

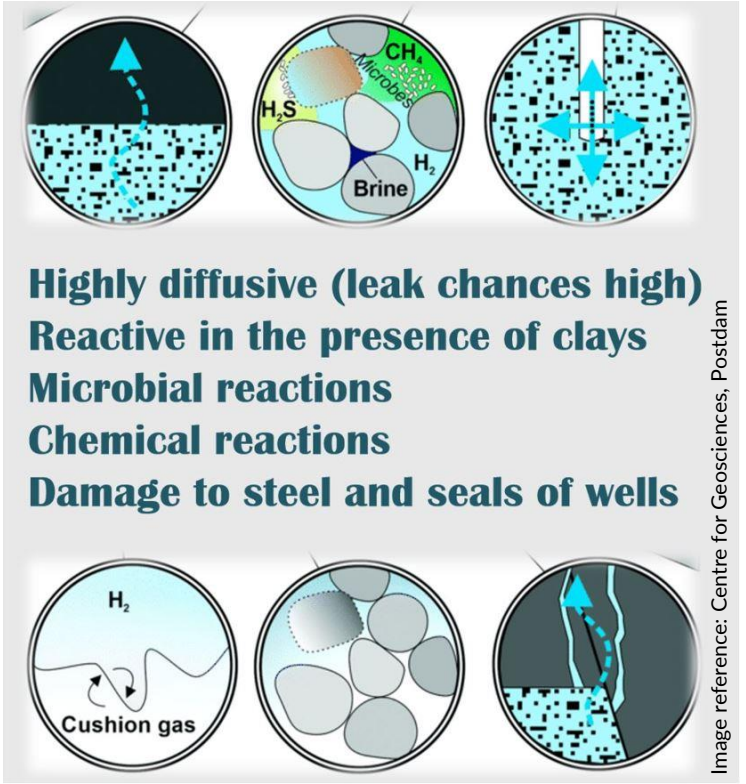
UHS: NEED AND CHALLENGES

An underground hydrogen storage capacity between 250-1000 TWh is forecasted to be required for Europe by 2050.



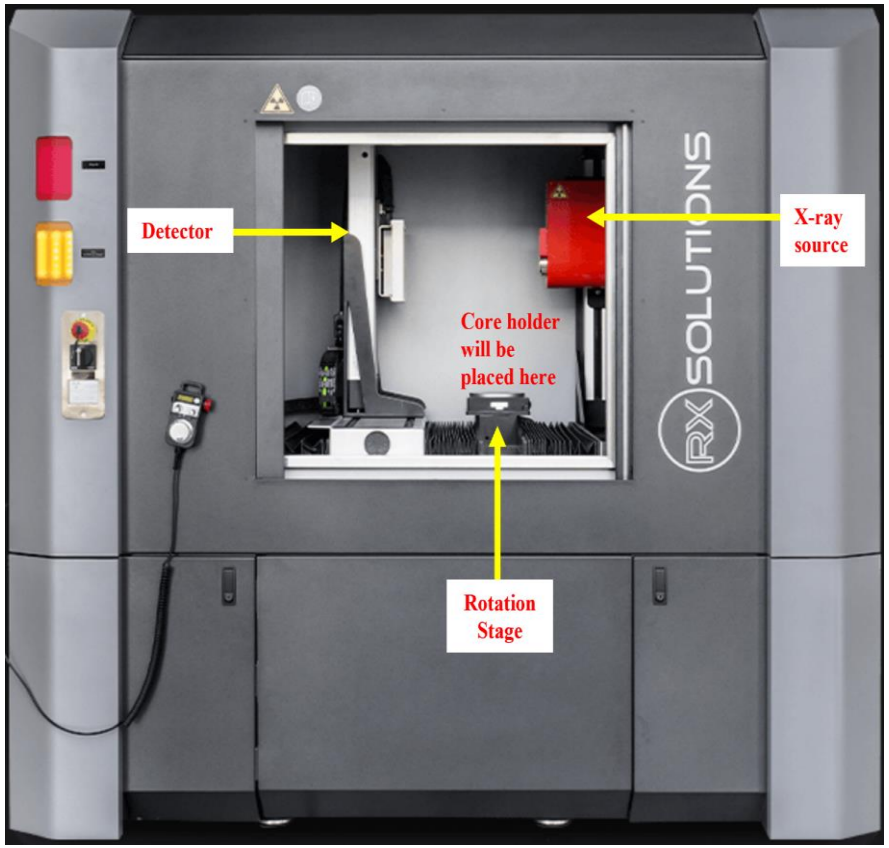
36 projects ongoing in Europe

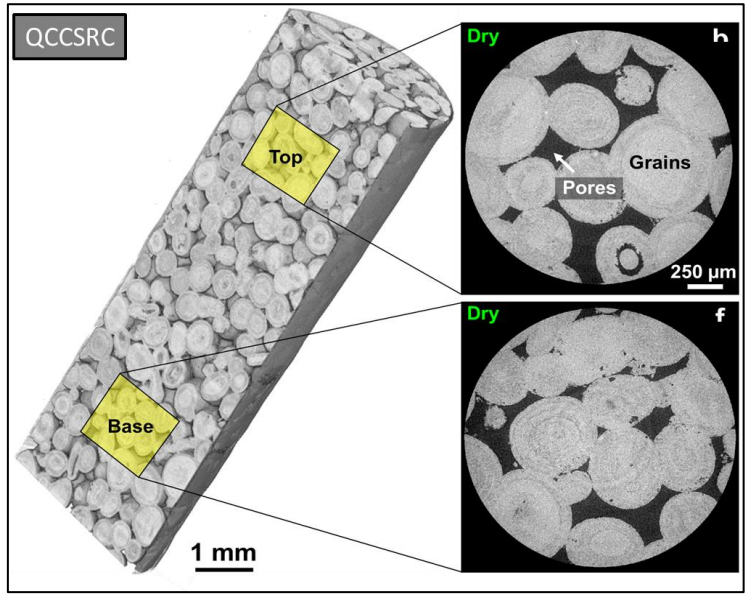
UHS poses its unique challenges due to hydrogen's distinctive physical and chemical properties.

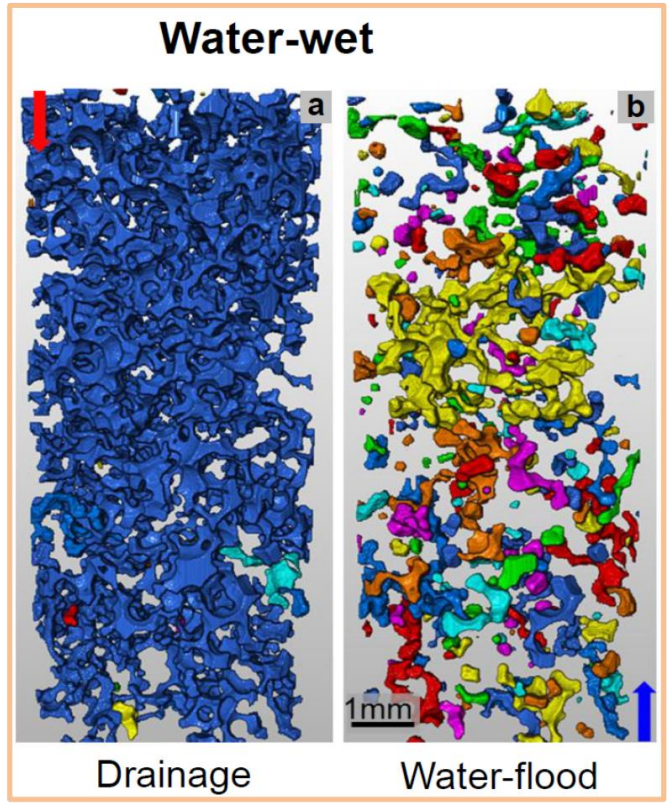


Understanding the pore-scale interactions is essential

HOW CAN 3D X-RAY IMAGING HELP?

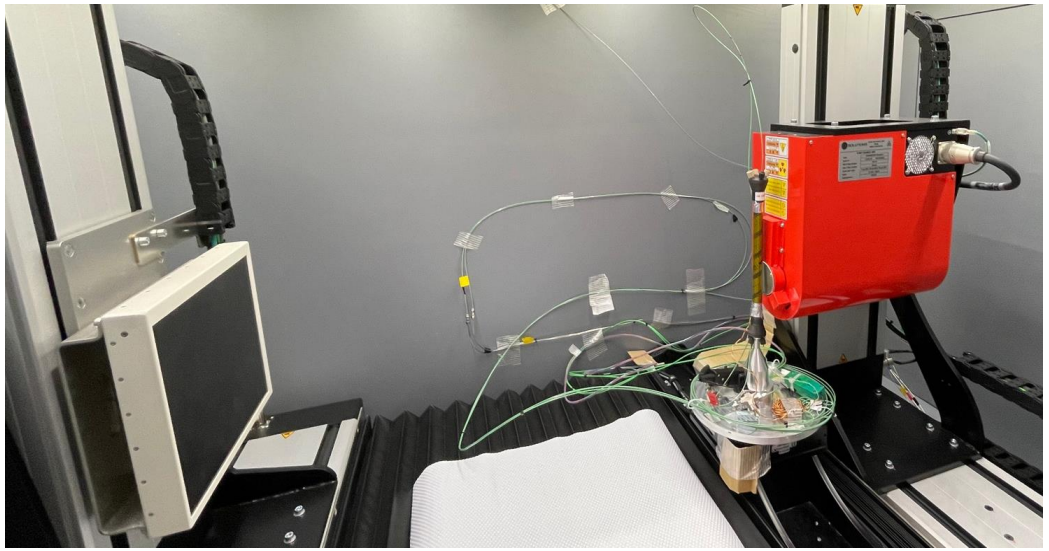


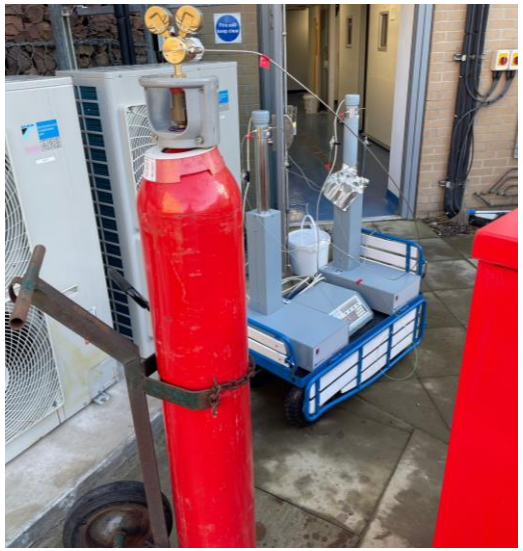




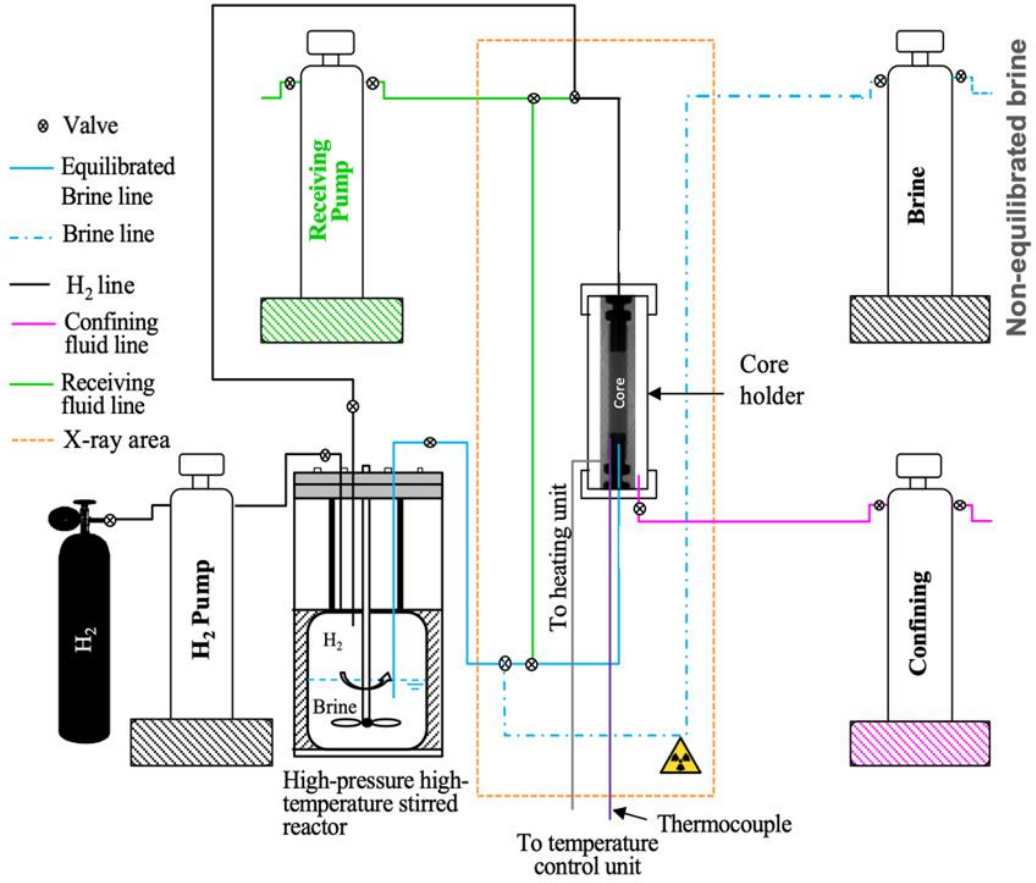
Singh et al., (2016) WRR

IN-SITU FLOW VISUALIZATION EXPERIMENTS WITH X-RAYS





EXPERIMENTAL SETUP



Schematic of the flow system

Flow system inside the micro-CT machine

EXPERIMENTAL DESIGN

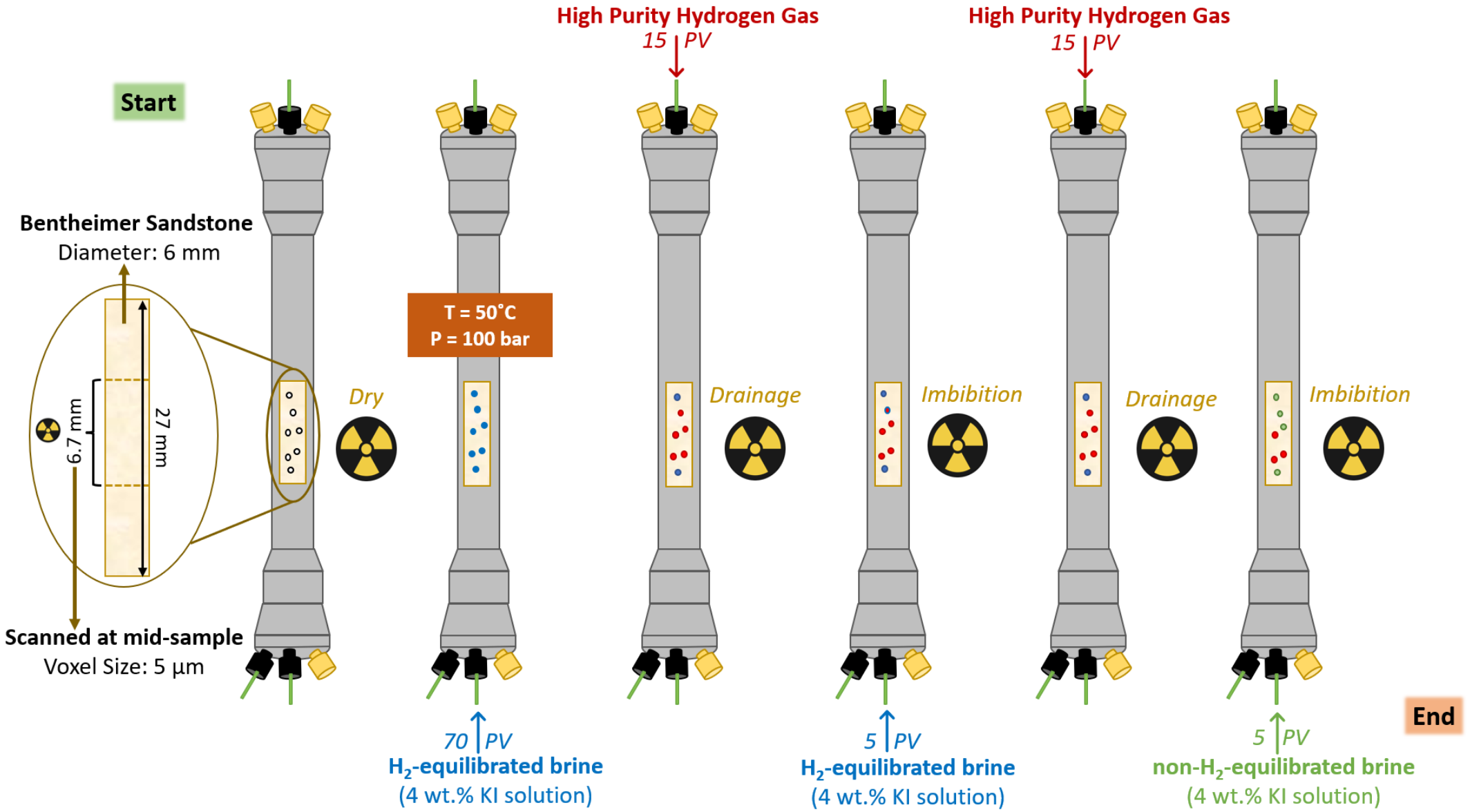
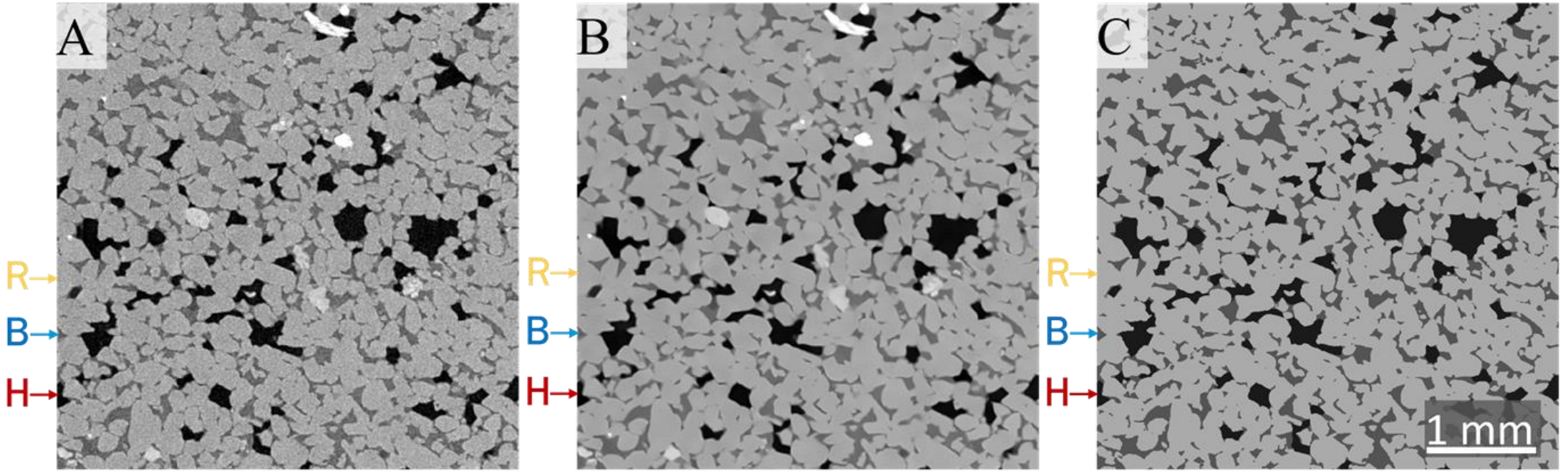


IMAGE PROCESSING



A. Raw Image

B. Filtered Image

C. Segmented Image

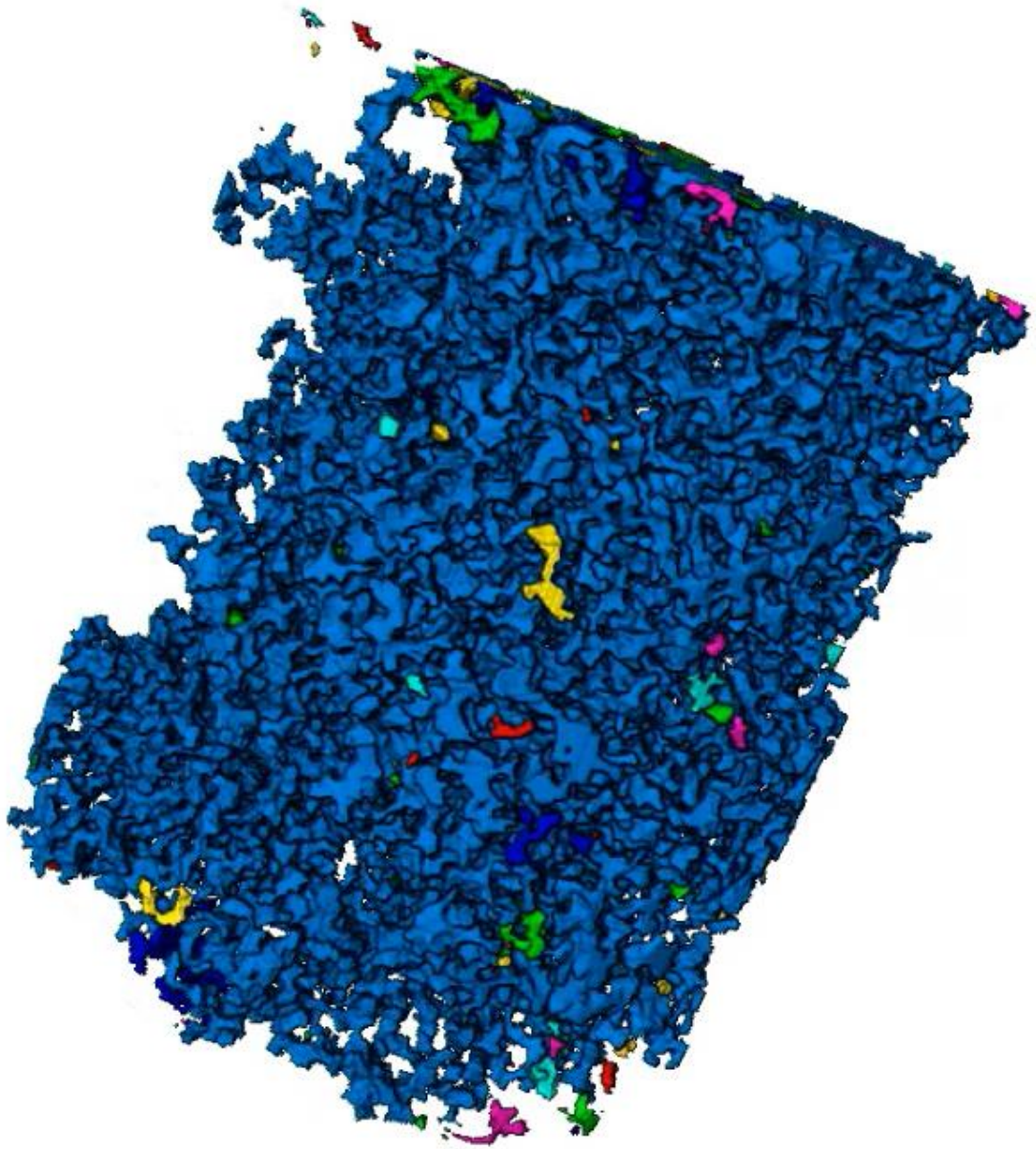
R – Rock B – Brine H – Hydrogen

All image processing done on Avizo (ThermoFisher) software

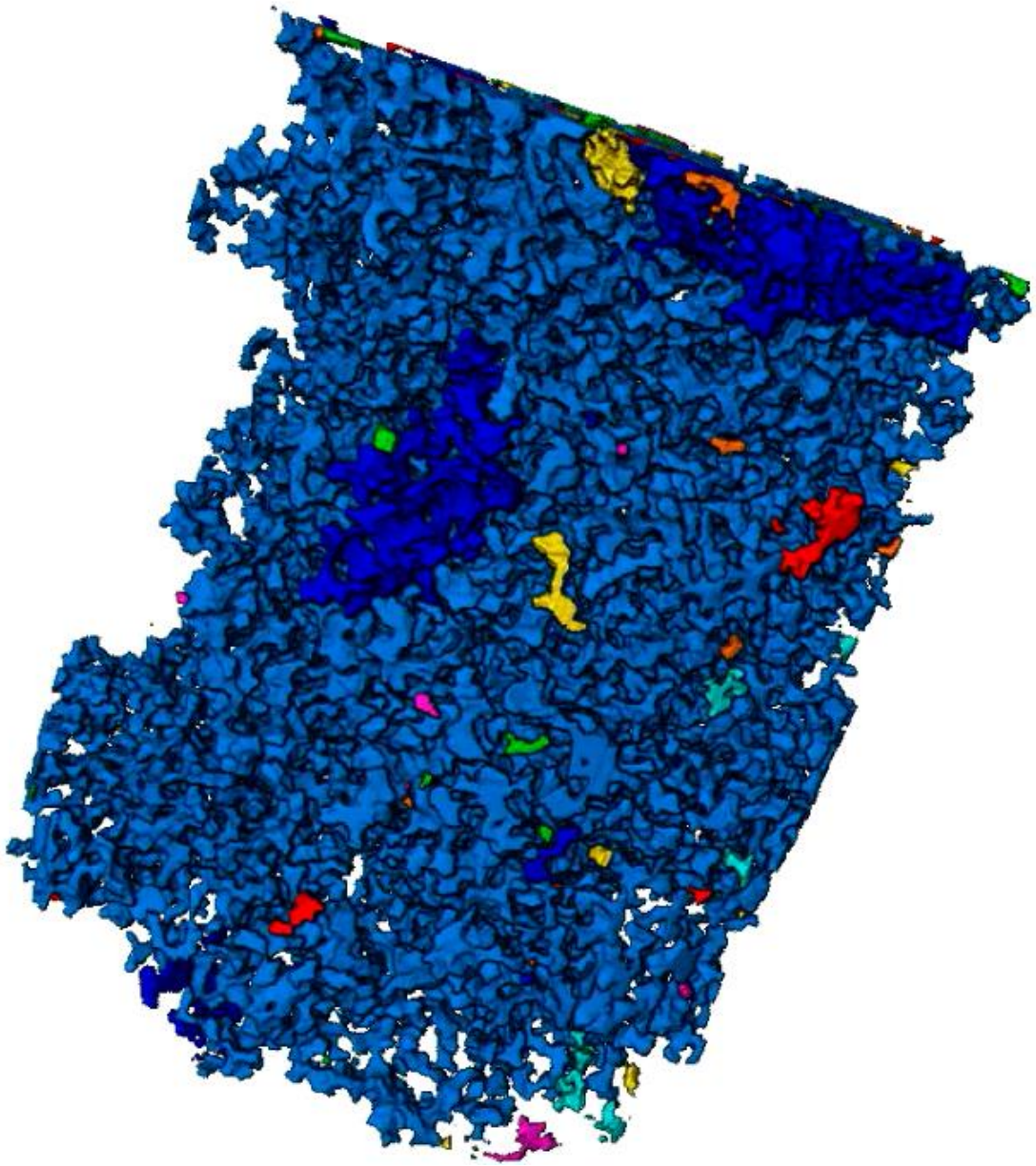
- All raw wet images registered to the dry scan
- Images filtered using Non-Local Means filter
- Images segmented using Watershed segmentation technique plus small spot removal – to accurately segment wetting layers

H_2 phase

Drainage 1

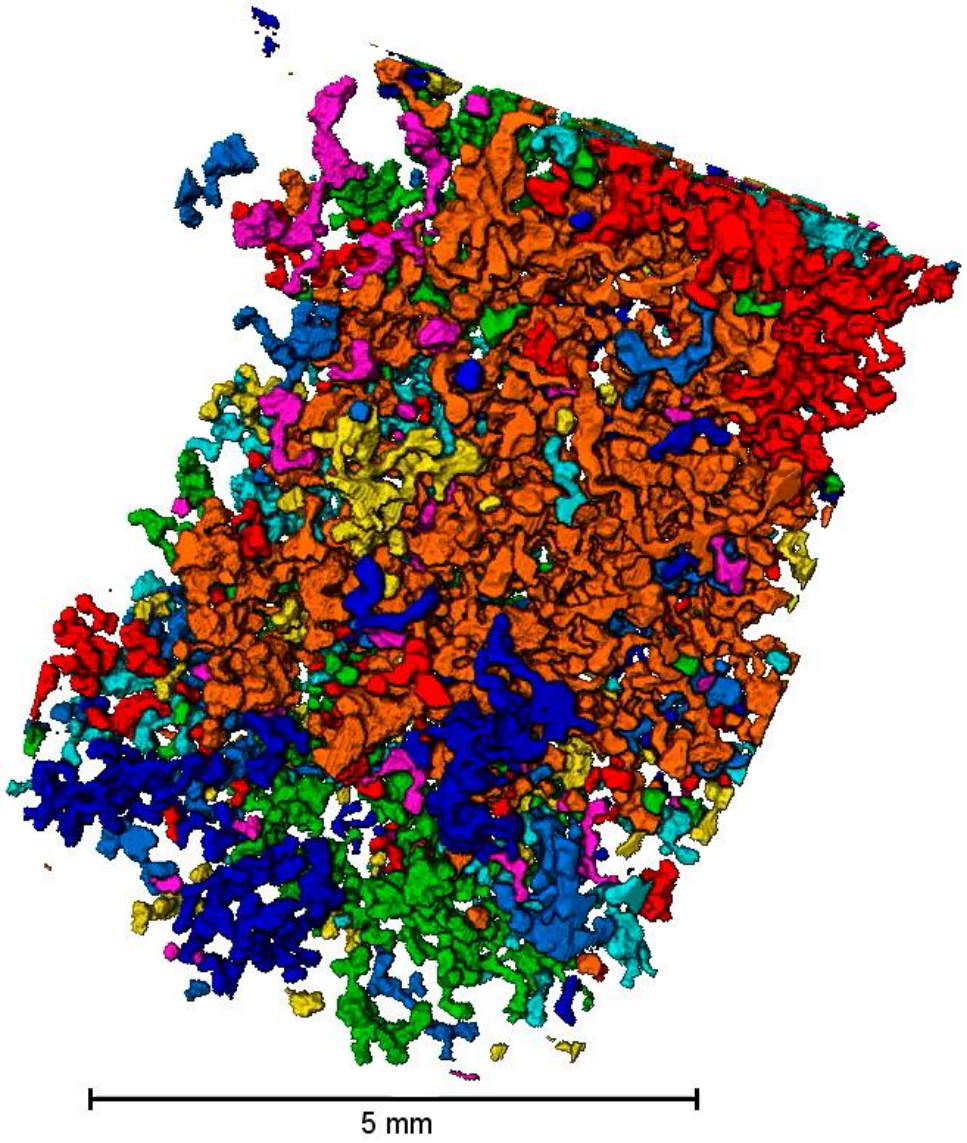


Drainage 2

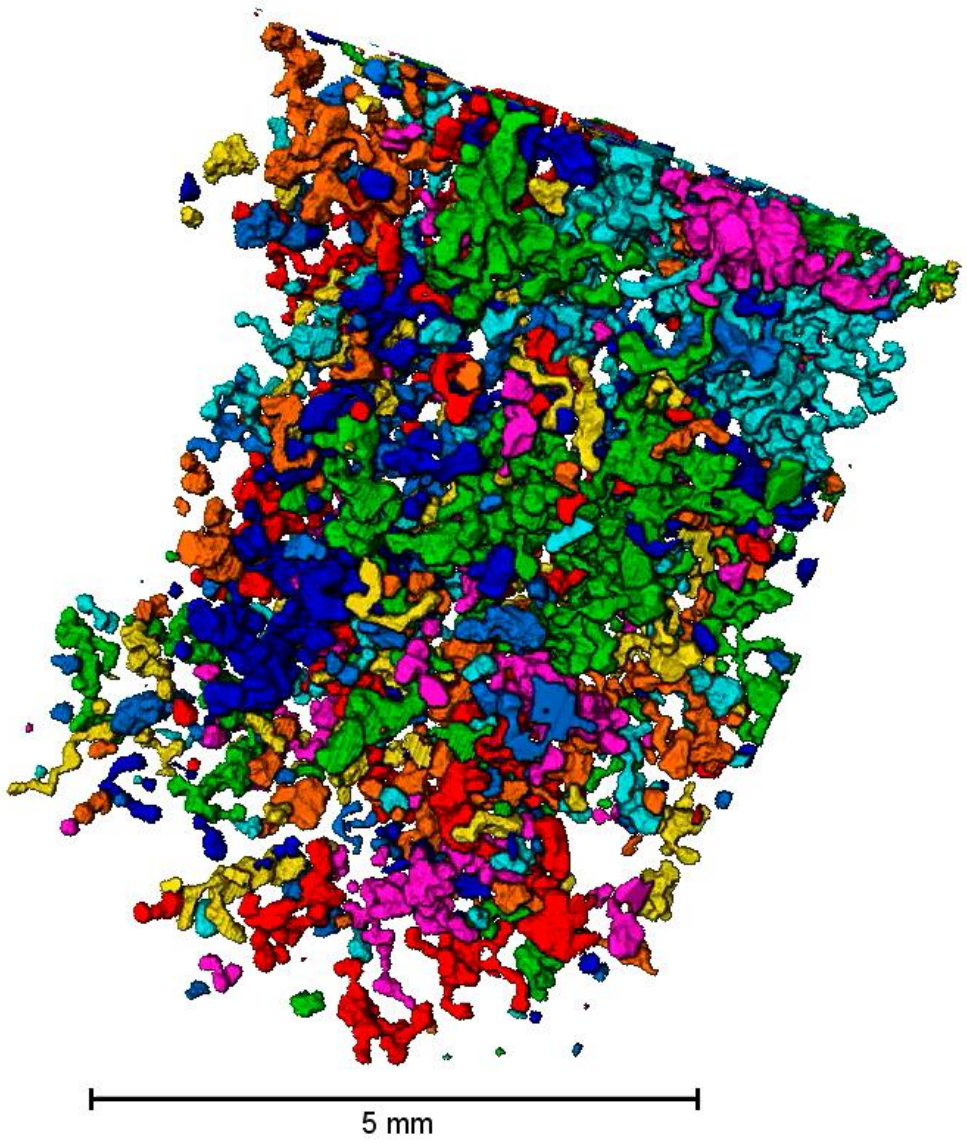


H_2 phase

Imbibition with H_2-eq.brine

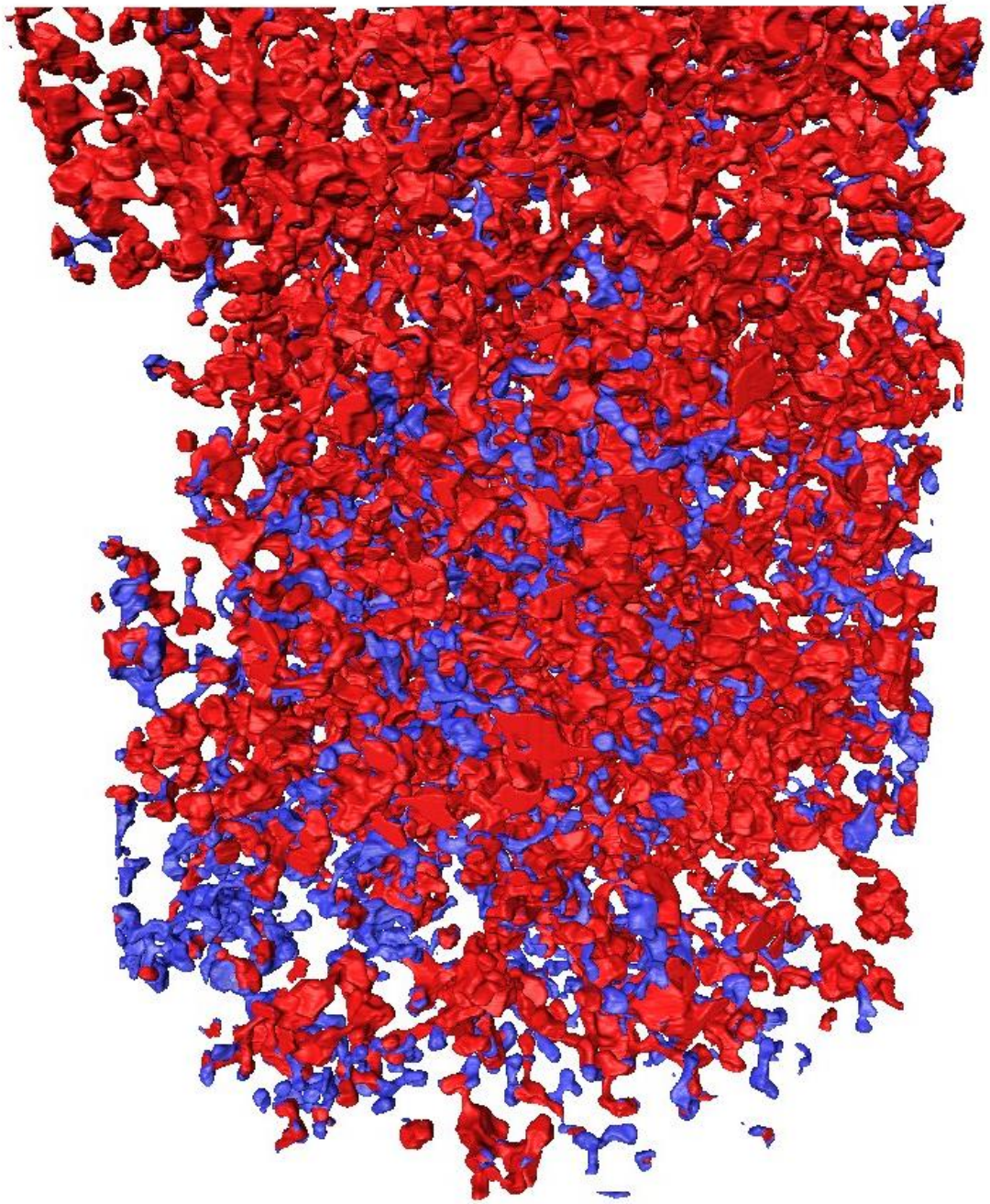


Imbibition with non-H_2-eq.brine



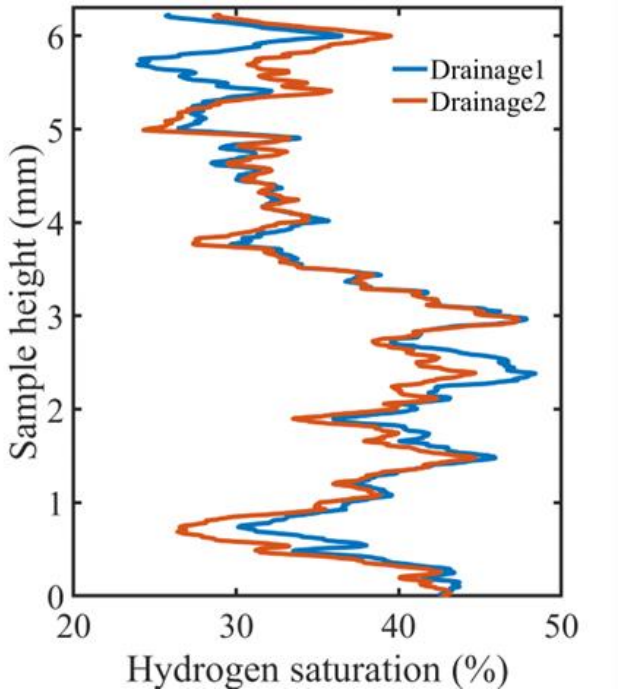
Each color represents a connected ganglia of H_2

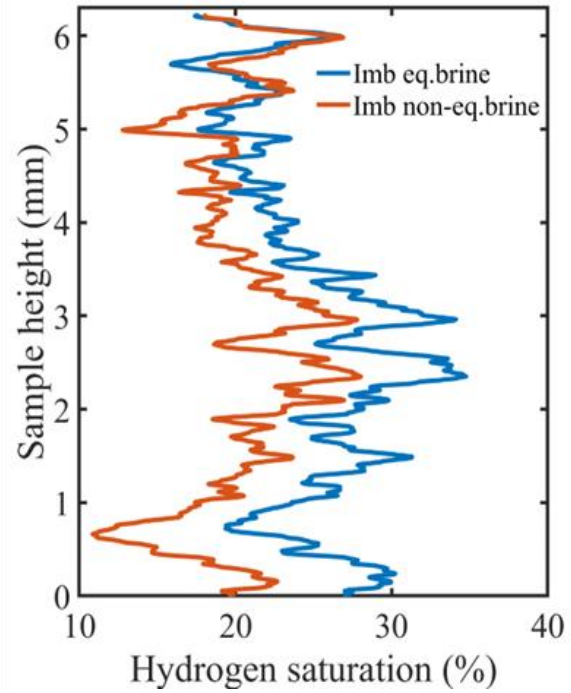
Red: H_2 phase in-place after imbibition with non-H_2-eq.brine

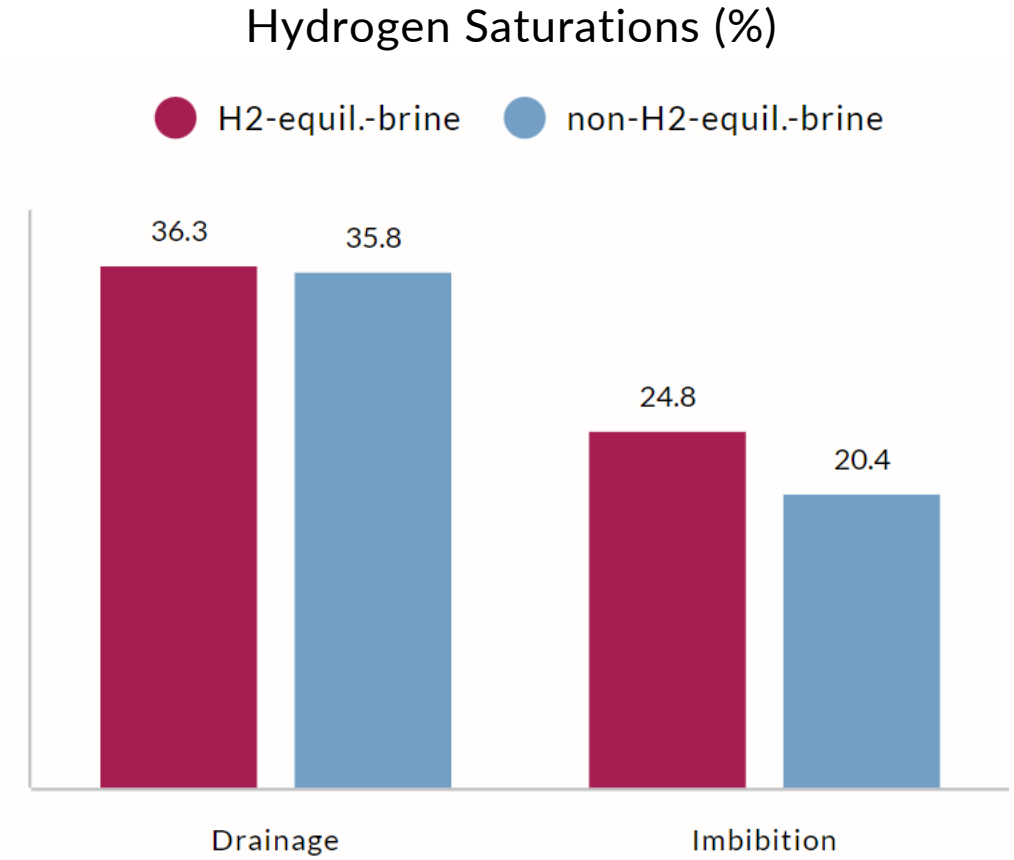


Blue: H_2 phase dissolved in brine during imbibition with non-H_2-eq.brine

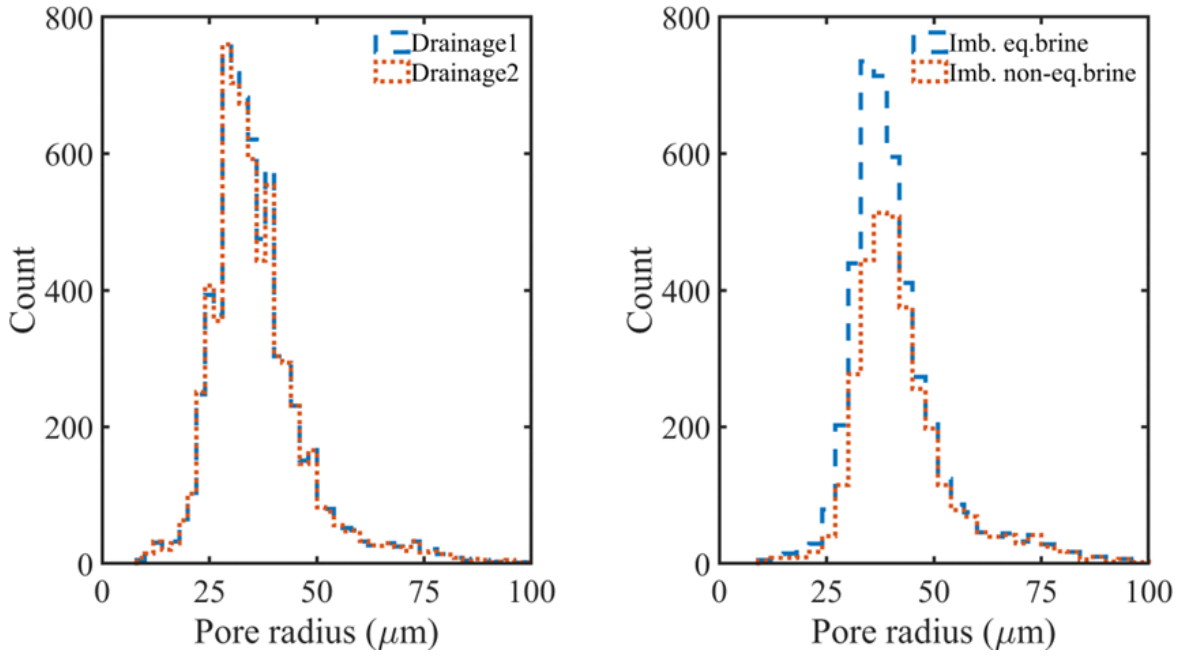
Hydrogen Saturation Profiles

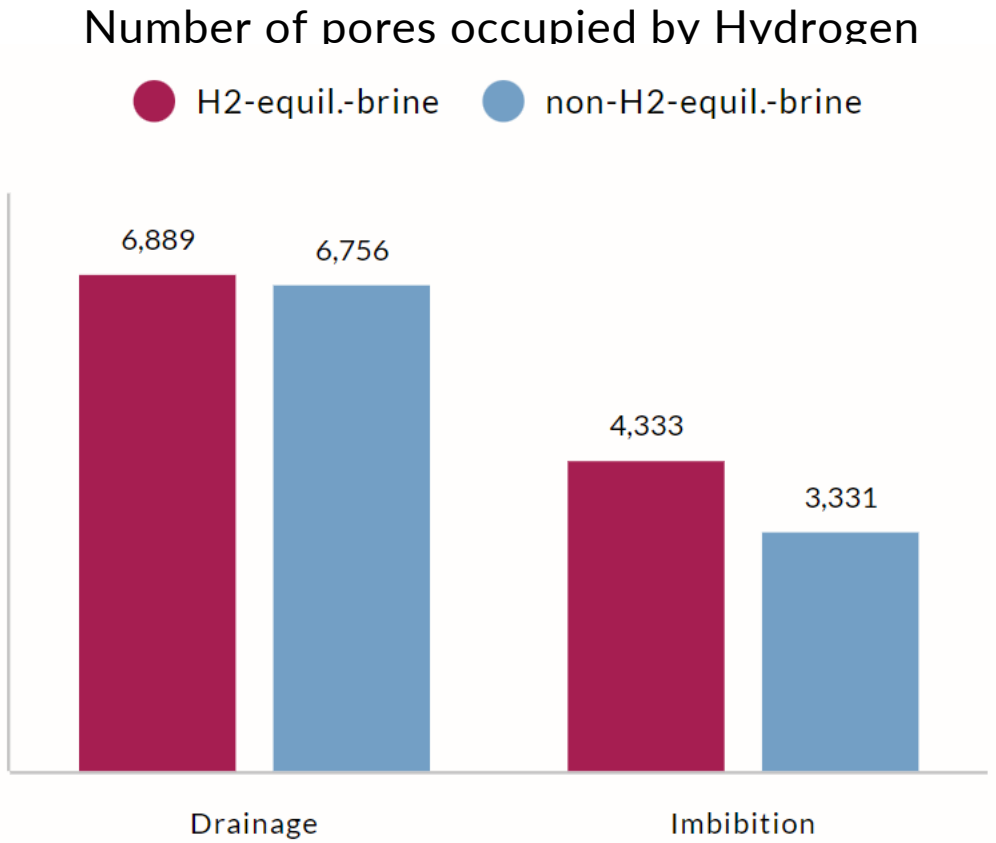






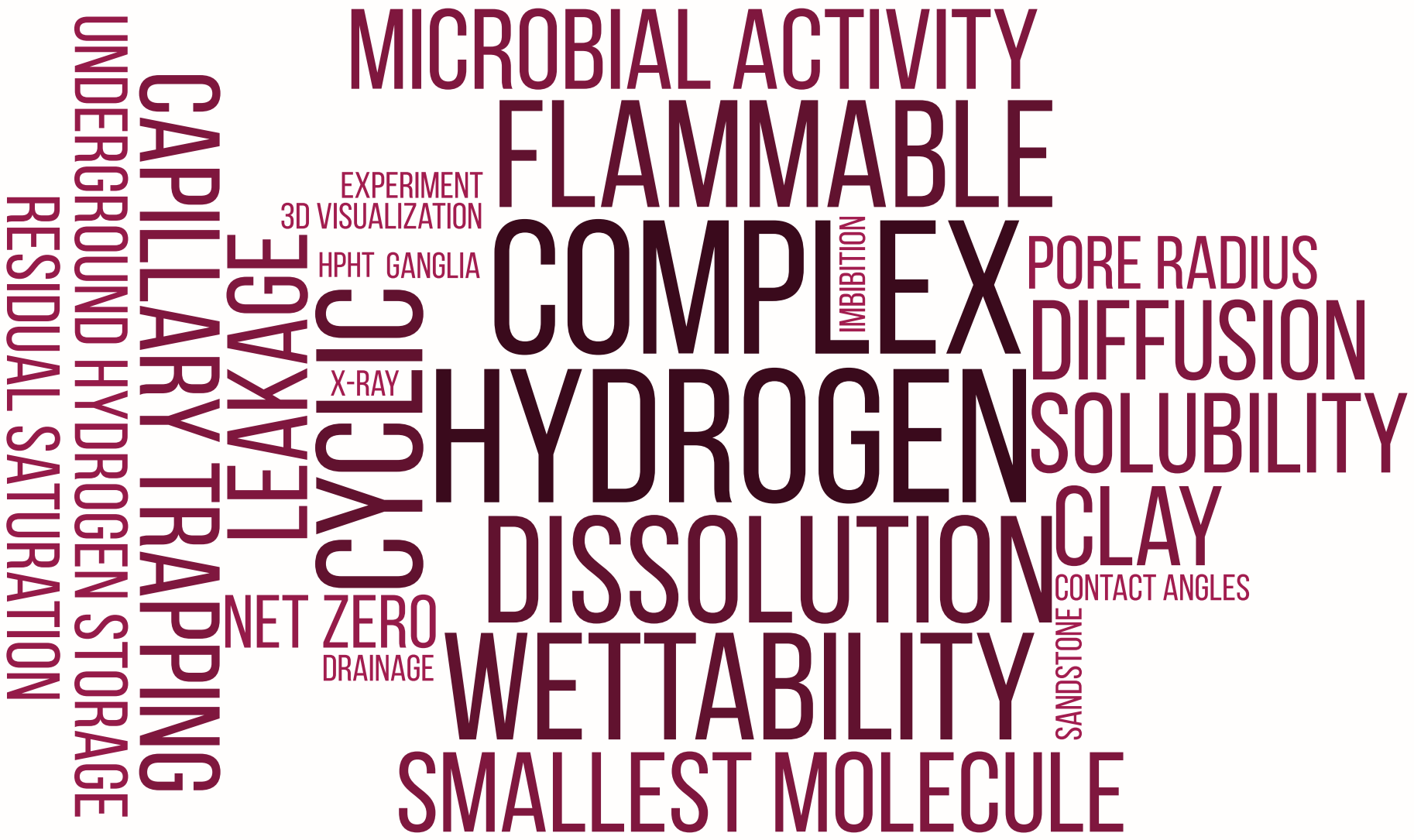
Hydrogen Pore Occupancy





Mean pore radius (μm)

Drainage 1	Drainage 2	Imbibition 1	Imbibition 2
36.3	36.1	41.1	42.9


MICROBIAL ACTIVITY
FLAMMABLE
EXPERIMENT
3D VISUALIZATION
COMPLEX
IMBIBITION
PORE RADIUS
CAPILLARY TRAPPING
UNDERGROUND HYDROGEN STORAGE
RESIDUAL SATURATION
LEAKAGE
HPHT GANGLIA
CYCLIC
HYDROGEN
DIFFUSION
X-RAY
SOLUBILITY
CLAY
DISSOLUTION
CONTACT ANGLES
NET ZERO
DRAINAGE
WETTABILITY
SANDSTONE
SMALLEST MOLECULE

Summary

- 3D-Visualization of hydrogen entrapment at high temperature and pressure conditions
- Hydrogen trapping observed in larger pores
- Possibility of potential dissolution of hydrogen in water
- Less residual saturation observed when imbibition done with non-H_2-equilibrated brine
- Conducted Image and Data Analysis. Results and data are available online
- Studied the effect of rock heterogeneity on hydrogen flow and trapping in the subsurface

THANKS

Contact: zj21@hw.ac.uk

Publication and data are available online as open access:

Jangda et al., Pore-Scale Visualization of Hydrogen Storage in a Sandstone at Subsurface Pressure and Temperature Conditions: Trapping, Dissolution and Wettability (2022)

Publication: Journal of Colloid and Interface Science, https://doi.org/10.1016/j.jcis.2022.09.082.

Data: figshare, https://doi.org/10.6084/m9.figshare.20260968.v1