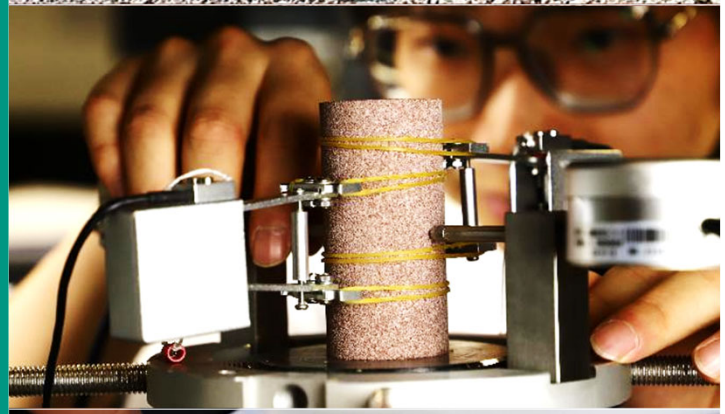
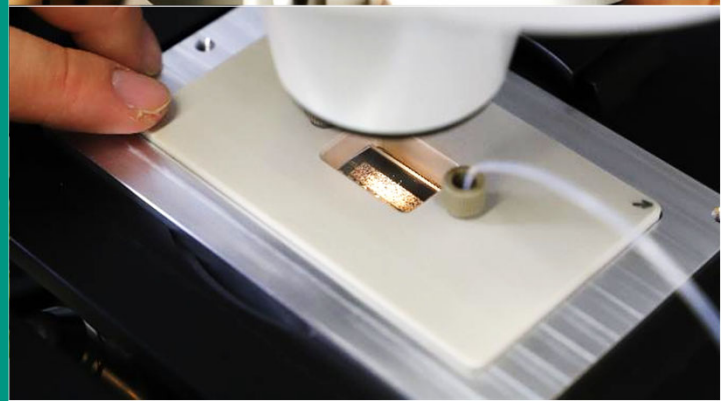
Global Challenges, Geological Solutions and Aspects of Reservoir Quality





Christoph Hilgers

Dr. Olajide Ola Jonathan Adamolekun, Prof. Dr. Agnes Kontny, Dr. Benjamin Busch, Chaojie Cheng, Dr. Jasemin Ölmez, Dr. Katarzyna Dudzisz and team

Institut of Applied Geosciences

Karlsruhe Institute of Technology – KIT, Germany

Accra, 24.7.2026

KIT

THINKTANK INDUSTRIELLE RESSOURCEN-STRATEGIEN

We and me ...

Karlsruhe 1715
KIT since 1825
c. 25.000 students
400 professors, 10.000 staff

studied RWTH & Imperial College, UK
Applied Research RWTH, USA, Australia
Mechanical Eng‘g WZL Quality Management

Professor KIT since 2016
KIT-Center Climate, Environment & Resources CLEAR
President BDG & OGV
German University of Technology in Oman
Shanghai CDZU – Chinese German Center for Environment with Tongji University
R&D: Innovation via KIT Campus Transfer GmbH

Global megatrends
More people & more prosperity

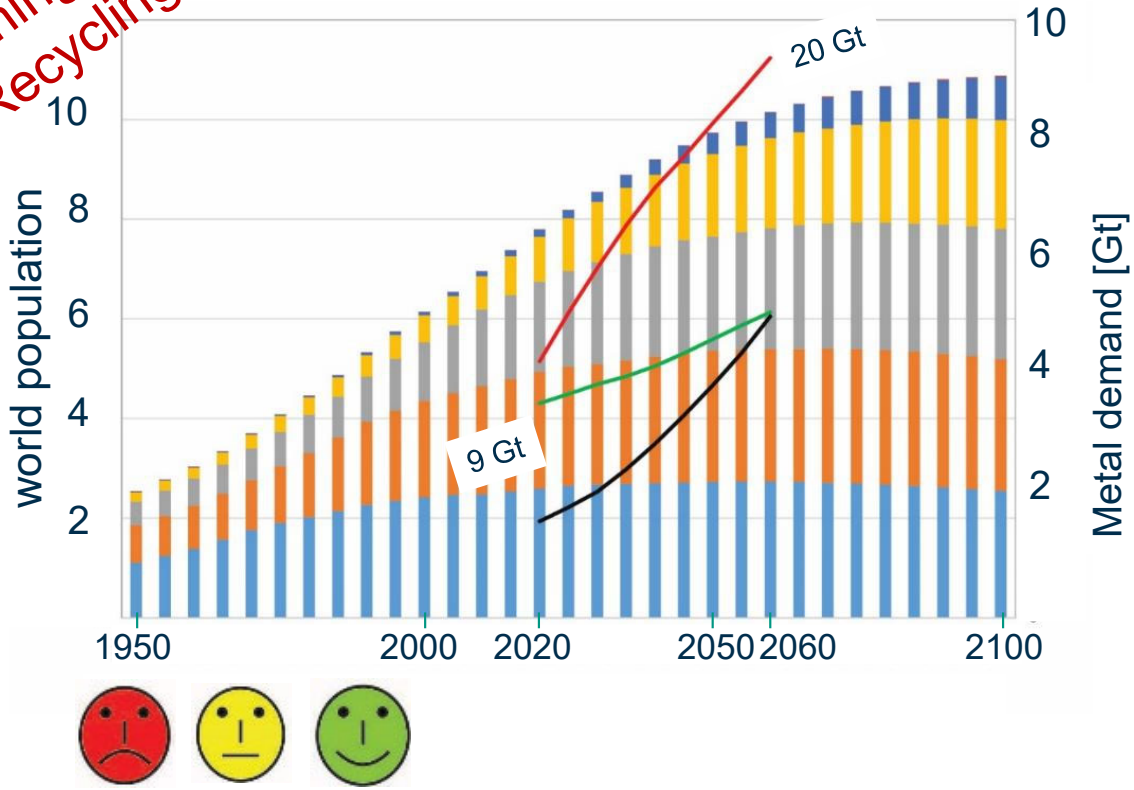
- Hunger:
  821 Mio. $_{2017}$ →733_{2023}
- Housing:
- 1,8 bio.$_{2018}$ → 1,6 bio.$_{2022}$
- Electricity:
  1,2 bio.$_{2010}$ →685_{2020}
- Streets

eMobility & H_2

Digitalization & AI

EU GreenDeal net zero

more Energy
more Mining
more Recycling



Gapminder Tool

image from Hilgers et al. 2021 after OECD, BGS u.a., s.a. Wachstum s. z.B. https://www.worldometers.info/de/, WHO https://www.who.int/news/item/06-07-2022-un-report--global-hunger-numbers-rose-to-as-many-as-828-million-in-2021, OHCR https://www.ohchr.org/en/special-procedures/sr-housing/human-right-adequate-housing

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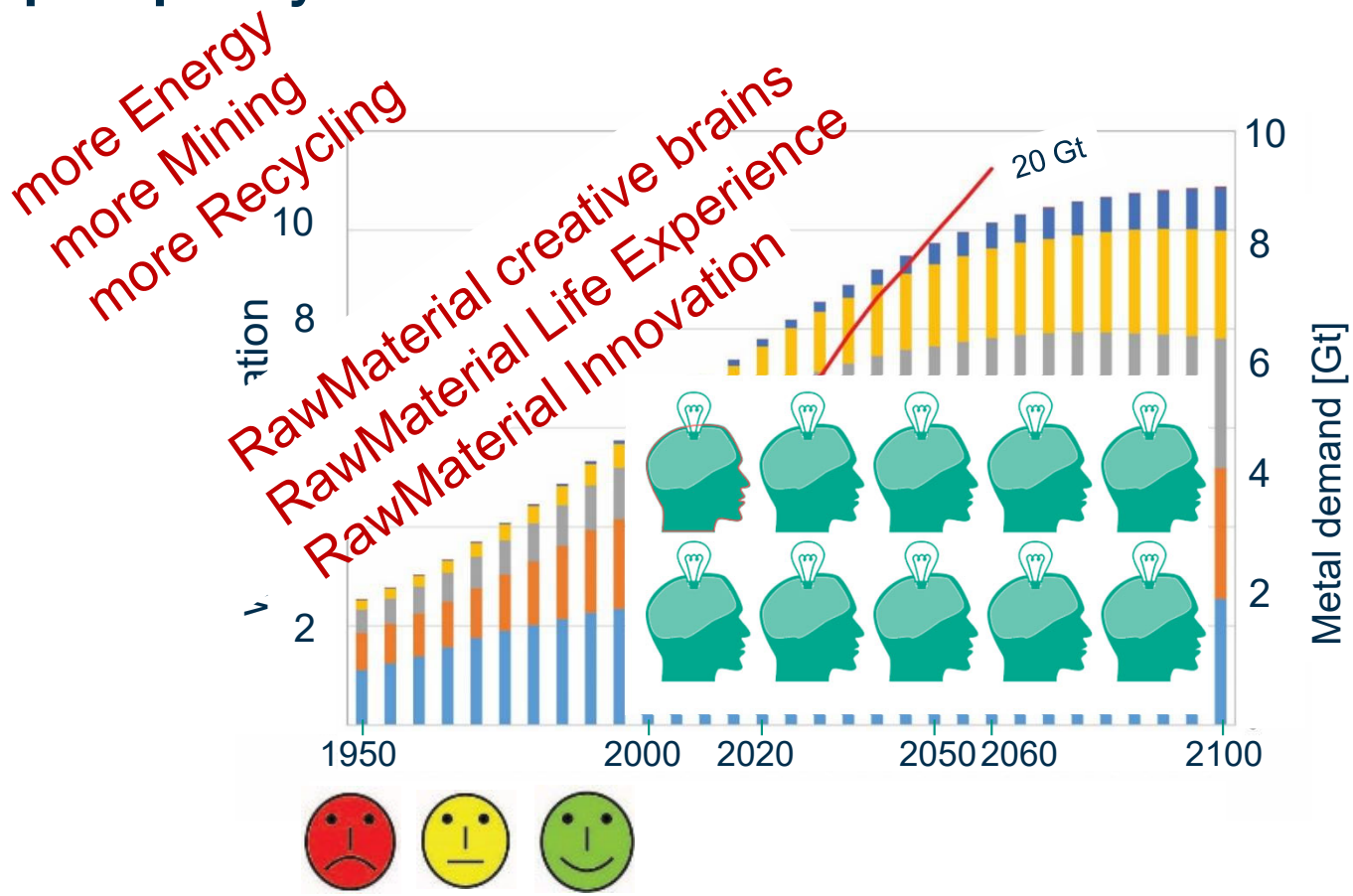

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17 UN-SDGs until 2030

Image English from https://www.un.org/sustainabledevelopment/news/communications-material/, German from https://www.bundesregierung.de/breg-de/themen/nachhaltigkeitspolitik/die-un-nachhaltigkeitsziele-1553514, 1 – from dashboards.sdgindex.org

Global Megatrends
More emissions

Anthropogenic emissions cause climate change

Dilemma

Fuel (& Raw Material) wood, coal, oil, gas

Anthropogenic emissions cause welfare, health, food, …

Paris Agreement: 1,5 °C

image redrawn from NOAA 2023,

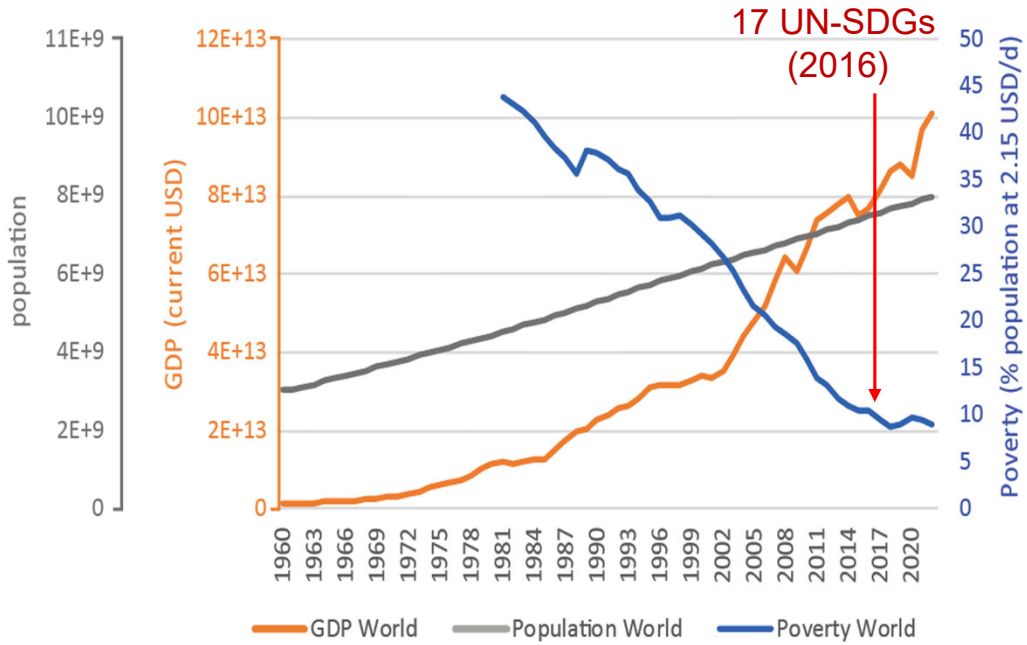
Achievements

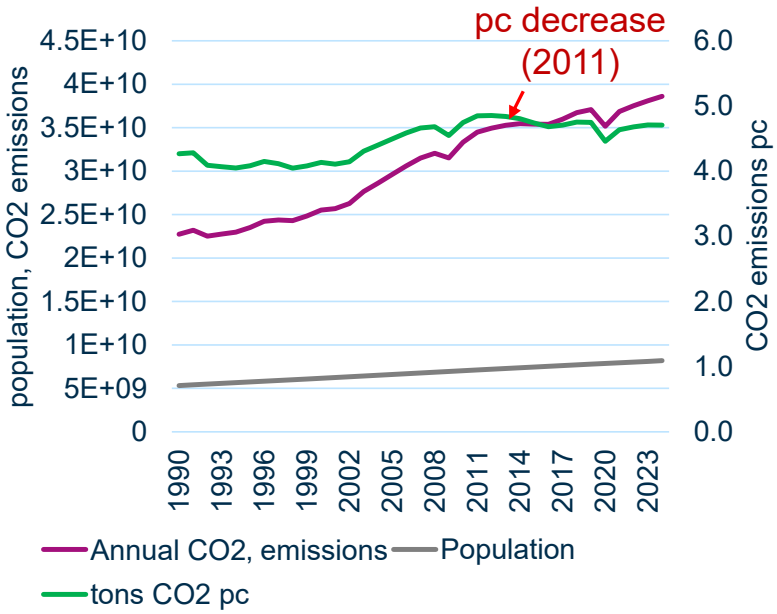
welfare > population

Extreme poverty declined to 10%

CO_2 emissions up to 420 ppm

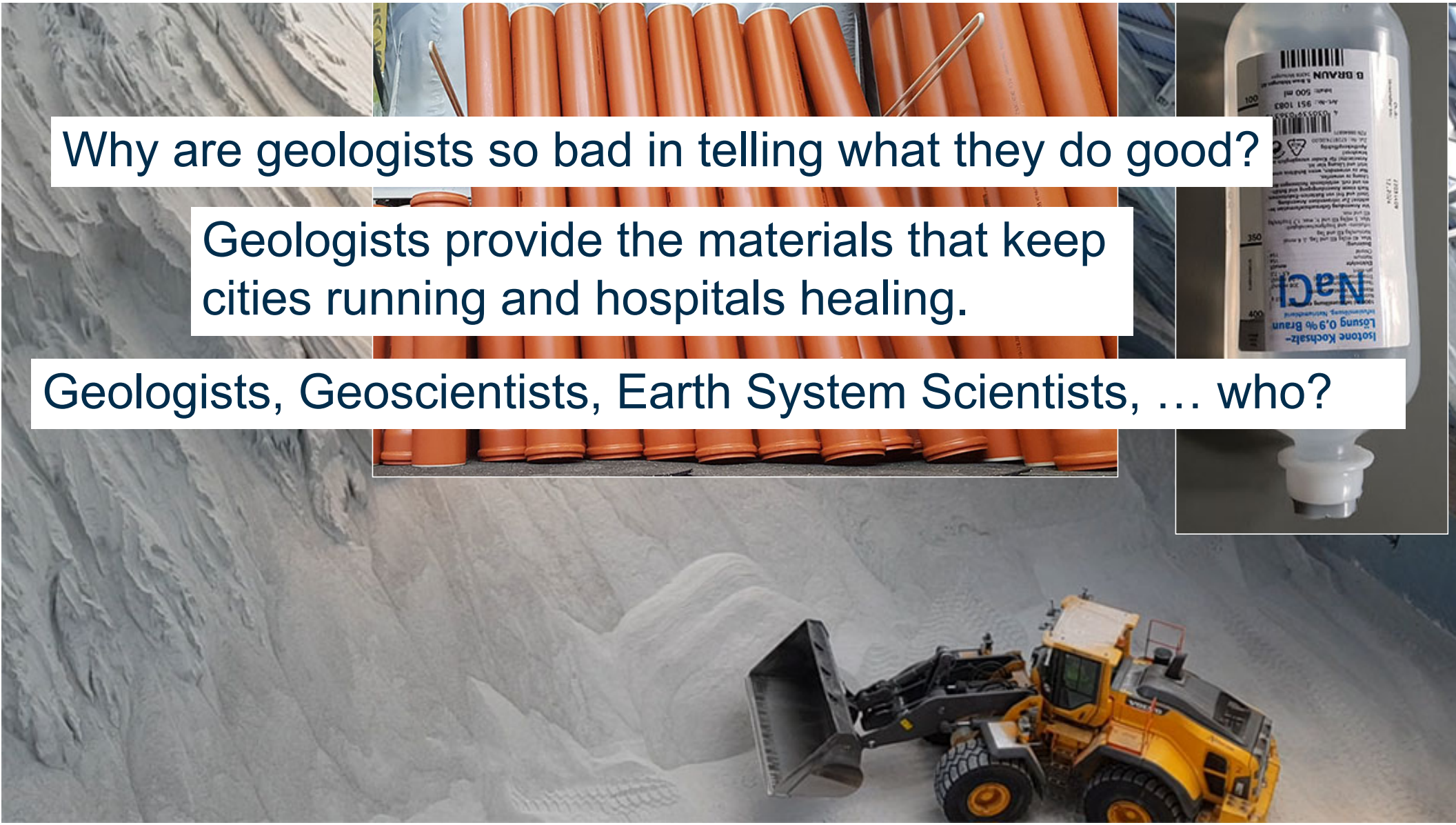
CO_2 emissions per capacity since ~2011 const.

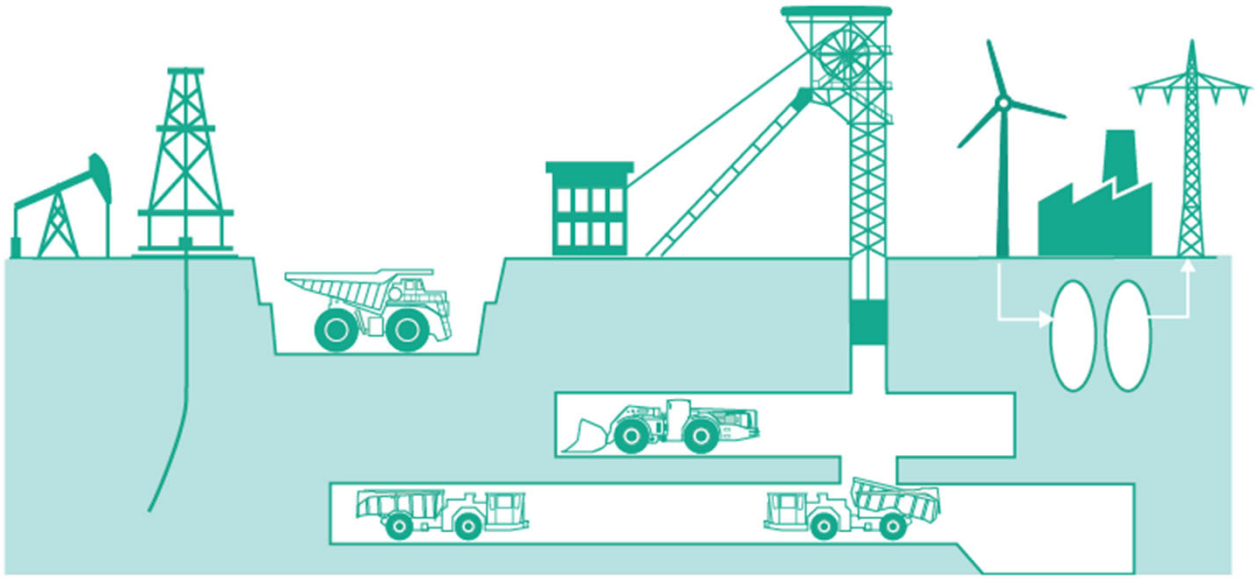




Data from UN and WorldBank

e.g. Hilgers C 2025 Kapitel 1 – Rohstoffbedarf, Energie und Klima. In: Frenz, W. (Hrsg.) Handbuch Rohstoffwirtschaft. S. 57-122, Erich Schmidt Verlag, Berlin, 1145 pp.; Hilgers C, Yildrim M, Ölmez JA 2025. Verordnung über kritische Rohstoffe der EU (CRMA) – Chancen und Herausforderungen. In: Sitzungsberichte der Leibniz-Sozietät der Wissenschaften, Band 166, 21-34

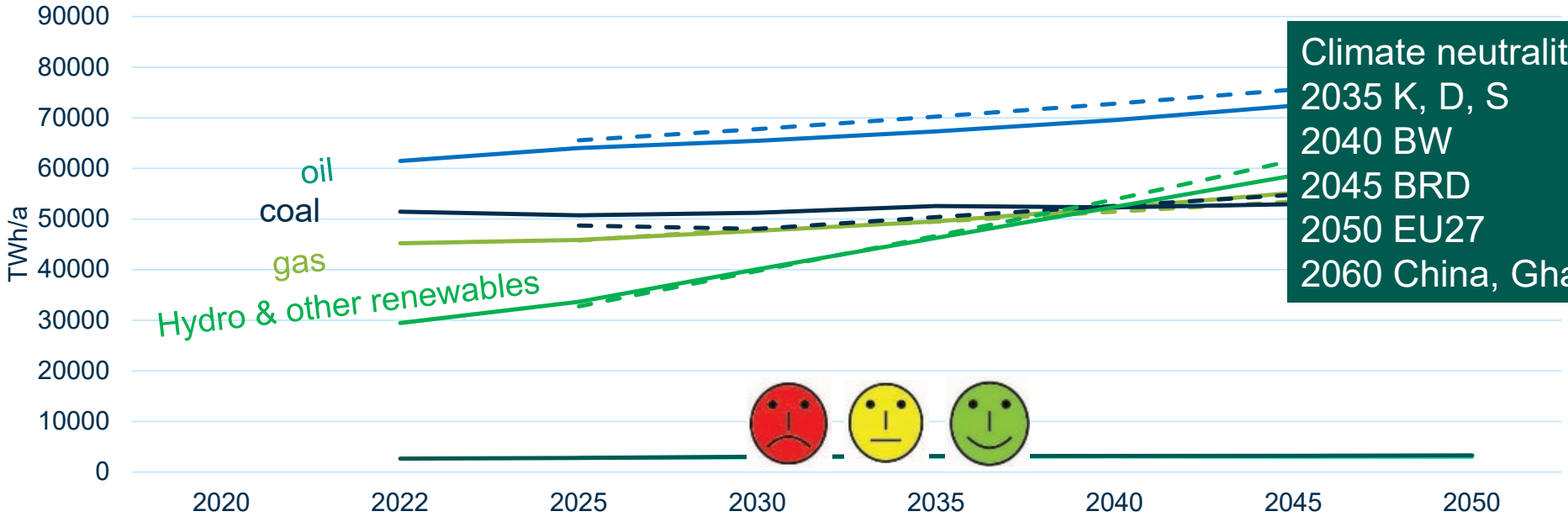

Why are geologists so bad in telling what they do good?
Geologists provide the materials that keep cities running and hospitals healing.
Geologists, Geoscientists, Earth System Scientists, … who?
NaCl
Lösung 0,9 % Braun
B. BRAUN



Energy

Human – Wood/Animals – Wind – Coal – Hydrocarbons –
Nuclear – Wind/Sunlight – …

World and us - Energy(&Material)-demand scenarios



Climate neutrality:
2035 K, D, S
2040 BW
2045 BRD
2050 EU27
2060 China, Ghana

- oil consumption (TWh) 2021
- gas comsumption (TWh) 2021
- coal consumption (TWh) 2021
- nuclear energy consumption (TWh) 2021
- hydroelectricity & other reneables (TWh) 2021
- oil consumption (TWh) 2023
- gas comsumption (TWh) 2023
- coal consumption (TWh) 2023
- nuclear energy consumption (TWh) 2023
- hydroelectricity & other reneables (TWh) 2022

Images after EIA Energy Information Administration 2021 & 2023 International Energy Outlook, reference case
https://www.eia.gov/outlooks/ieo/tables_side_xls.php ; https://www.eia.gov/outlooks/ieo/data.php, s. also EnergData REF and BP Outlook

Germany: scaling storage beyond batteries

e.g. 10 days or more no wind

550 TWh power /a – 1.5 TWh/d

18 d no wind: 26 TWh

→ 50-60 TWh P2Gas H_2

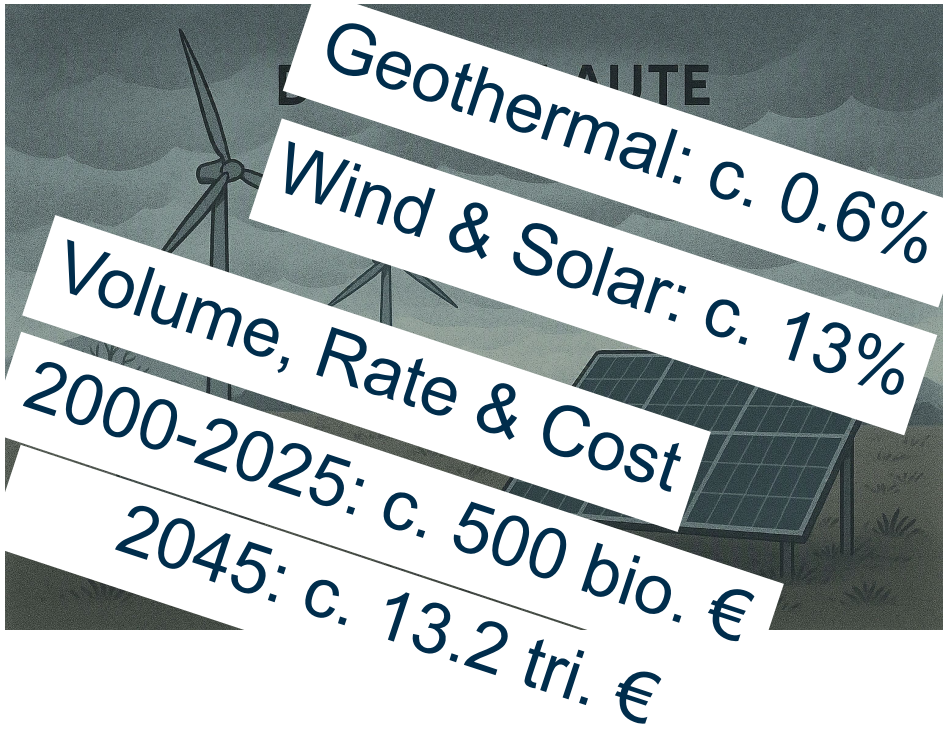
→ 43 TWh natural gas in gas power plants at 60% efficiency = 4.3 bcm gas storage = 43 LNG Ships, 23 bcm German **subsurface** gas storage

→Pumped-Storage Plants Germany: 40 GWh

→2 mio e-vehicles a 60 kWh = 120 GWh, 1/3 V2G = 40 GWh

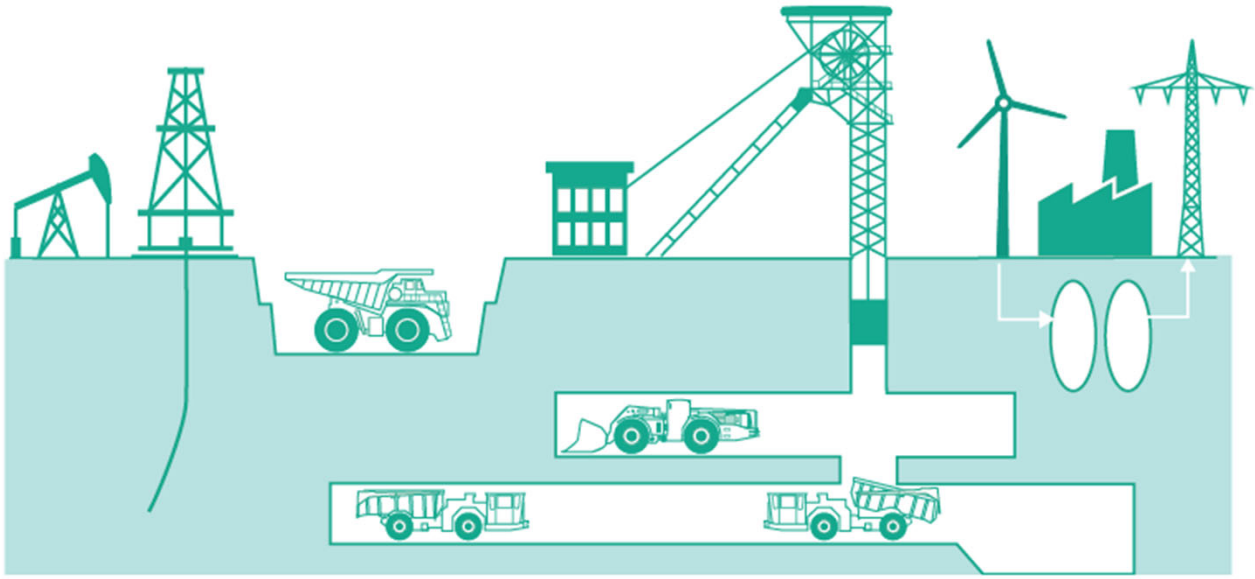
→ 17x all batteries of the world 1.6 TWh

Battery alternatives



PWC 2026 https://www.pwc.de/de/energiewirtschaft/klimaschutzinvestitionen-lohnen-sich.html

1. ~~Raw material supply chains~~
2. ~~Experimental porous microstructure – fracture mechanics coupling~~
3. ~~3D digital rock modeling~~
4. Reservoir quality prediction
5. Why core material
6. Microreactor modeling



Some geology – structural diagenesis (THMCB) for reservoir quality prediction

for people's good life

Doing

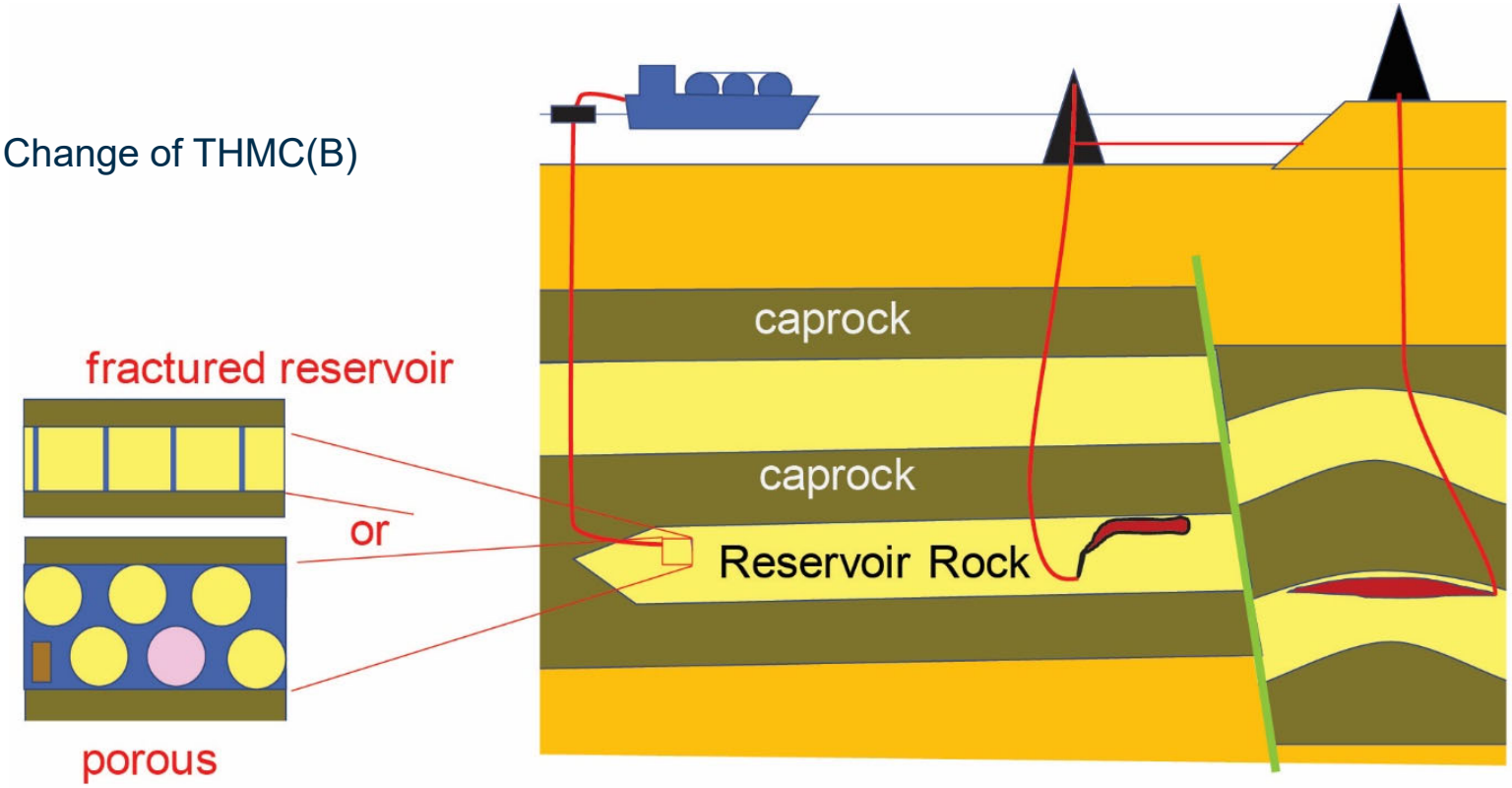
A reservoir

Extraction of groundwater, hydrocarbons, geothermal, CO_2, H_2, Helium

injection for permanent storage (CO_2, toxic waste, nuclear waste, cooled geothermal w.)

injection & extraction for temporary storage

Change of THMC(B)



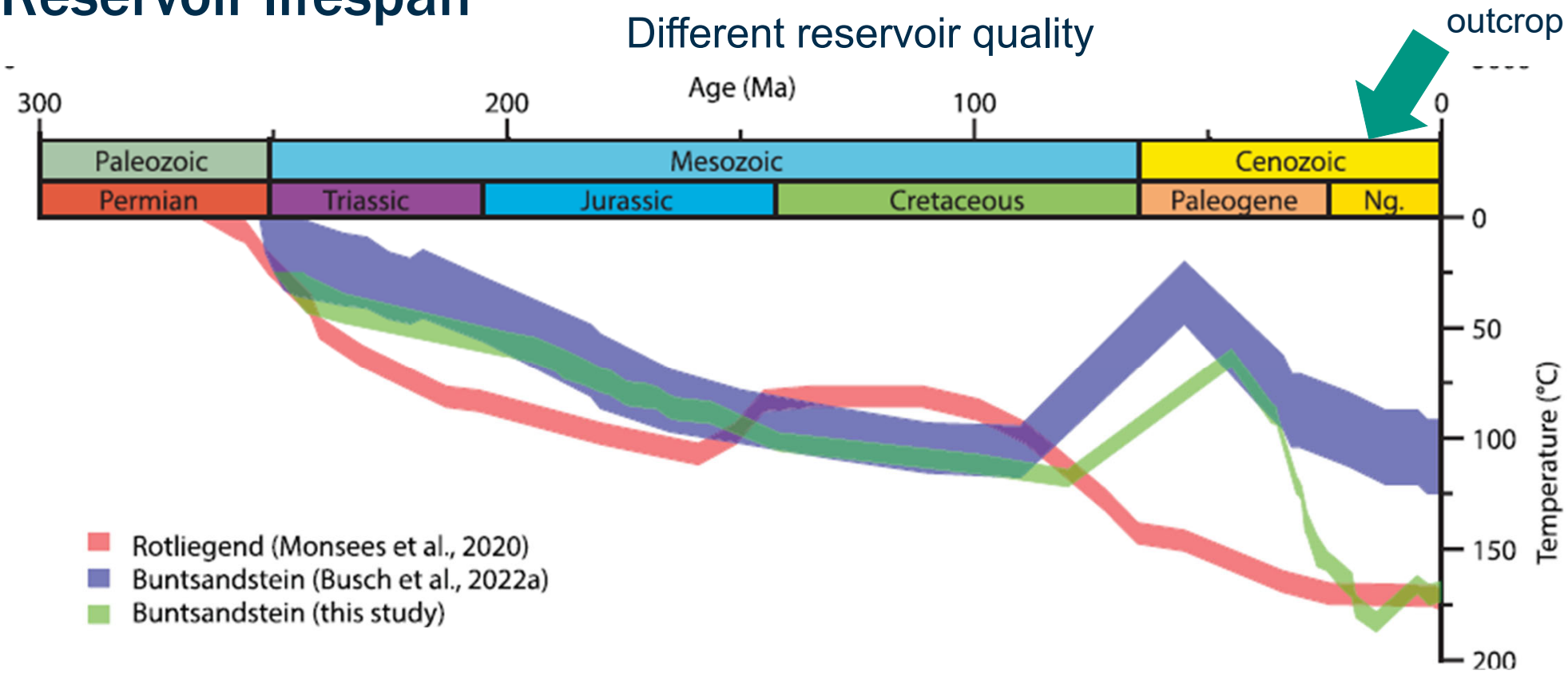
- Hilgers, Schilling 2024, CCS https://sgt.agw.kit.edu/downloads/Publikationen/Hilgers_Schilling_2024_Kohlendioxidabsch.pdf

Reservoir lifespan

Different „cooking time & speed“ of rocks

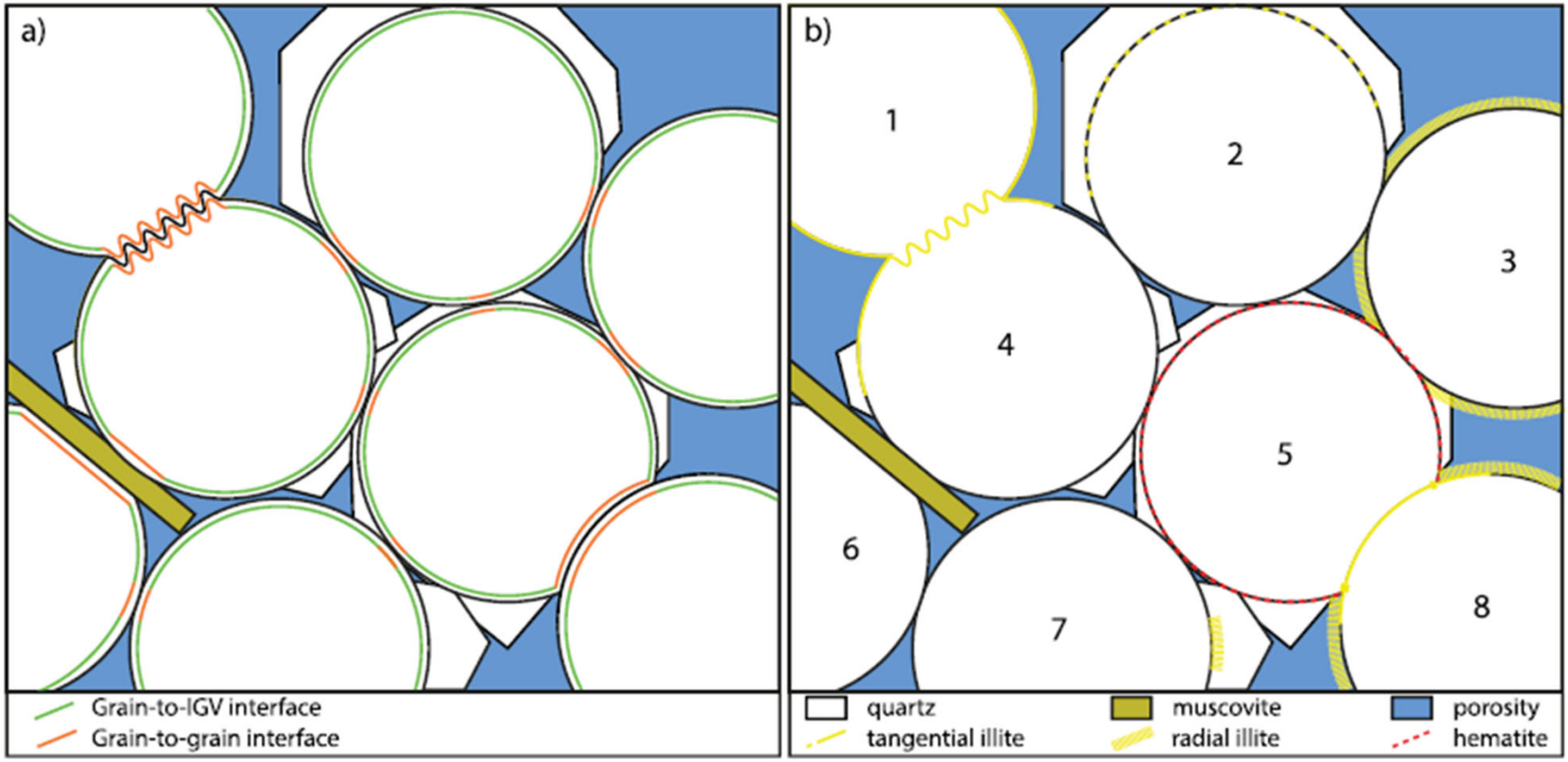
Different minerals &clay coating coverage

Different reservoir quality



Busch, Böker, Hilgers 2024 Geoenergy Science and Engineering, https://doi.org/10.1016/j.geoen.2024.213141

Role of microstructures

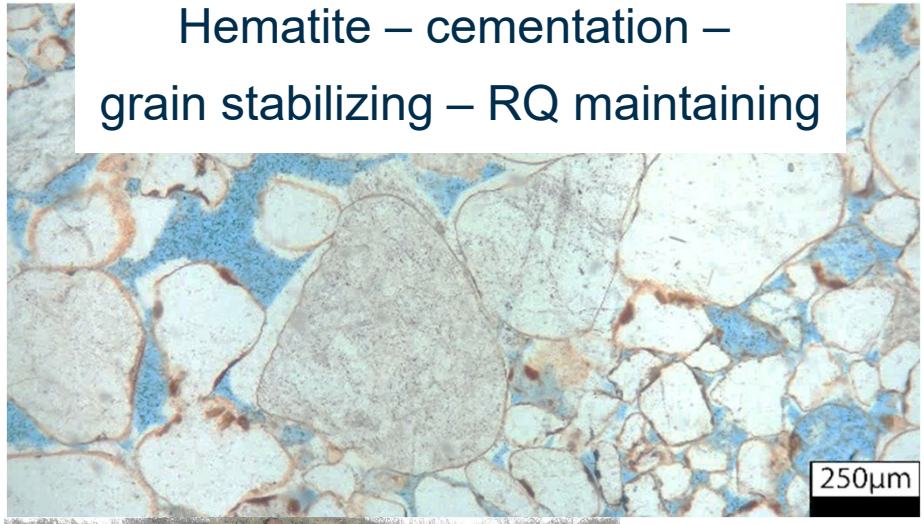


Busch, Böker, Hilgers 2024 Geoenergy Science and Engineering, https://doi.org/10.1016/j.geoen.2024.213141

Mineral coating & compaction effects on reservoir quality
THMC → basin-subsidence → model $\phi-\kappa$

Hematite – cementation –

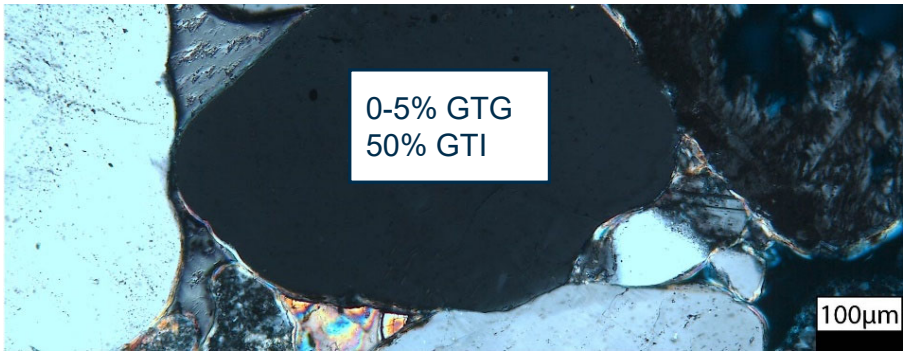
grain stabilizing – RQ maintaining



Bowscar, Cumbria, Northern UK*
Avg. ΦHe = 27 %
Avg. κ = 5118 mD
n = 30

tangential illite – prevents cementation –

Enhances chemical compaction – RQ detoriates



Different „cooking time & speed“ of rocks

Different minerals & clay coating coverage

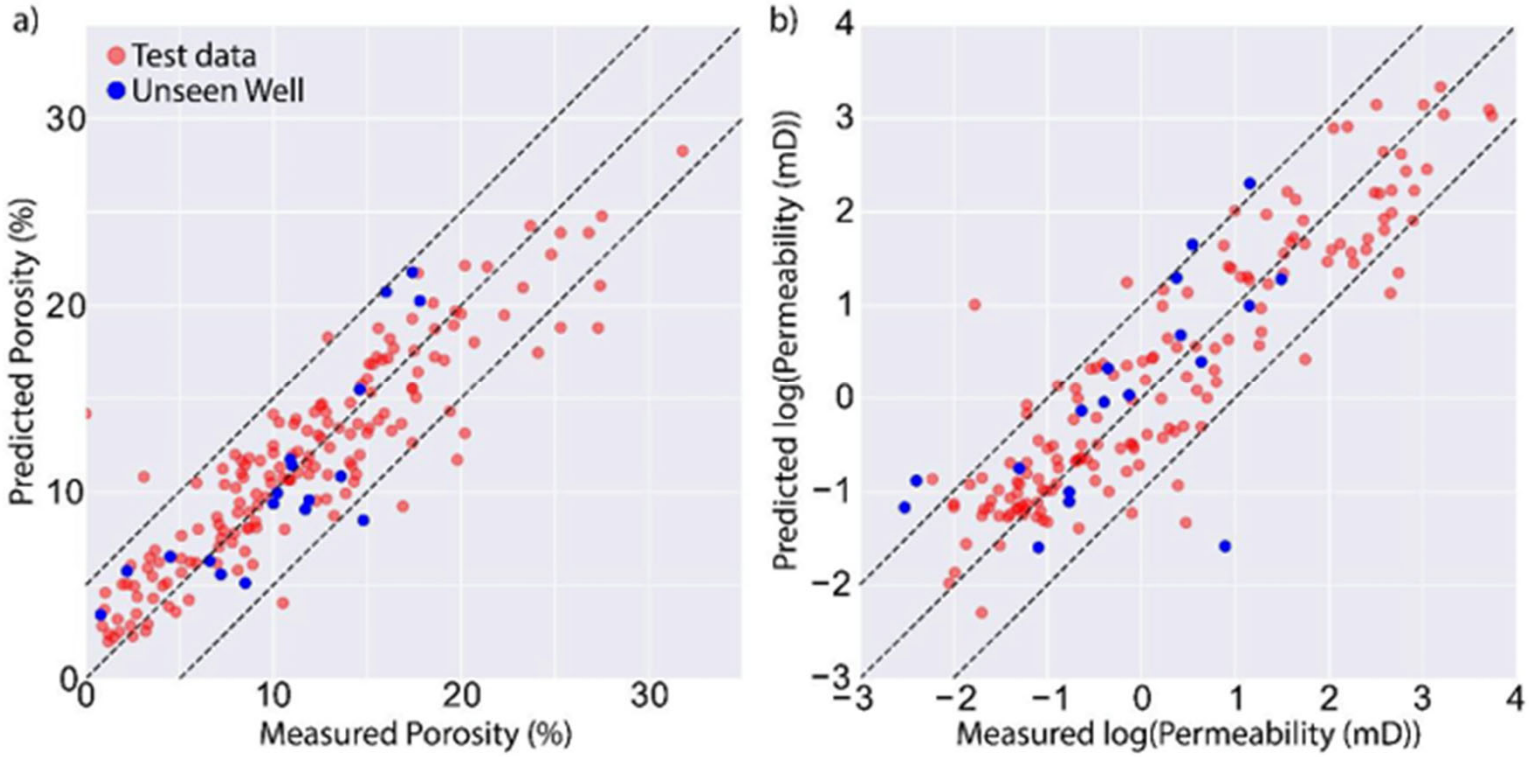
Calculate different reservoir quality

Adamolekun Hilgers et al. 2022 J. Afr. Earth Sc https://doi.org/10.1016/j.jafrearsci.2021.104437
Monsees Hilgers et al 2021 Sciences https://doi.org/10.1007/s00531-021-02036-6

Get rid of core, use cuttings: ML prediction ϕ–κ from point counting

51 wells
875 samples
over 25 years
21 petrographers
510 to 5510 m TVD

Detritral phases
Authigenic phases
Optical porosity
IGV
κ R^2 = 0.82



Sadrihanloo, Busch Hilgers 2026 Energy Geoscience https://doi.org/10.1016/j.engeos.2026.100537

Busch, Hilgers 2026 Artifical Intelligence in Geosciences https://doi.org/10.1016/j.aiig.2026.100202

Ölmez Busch, Hilgers 2025 Energy Geoscience, https://doi.org/10.1016/j.engeos.2025.100461

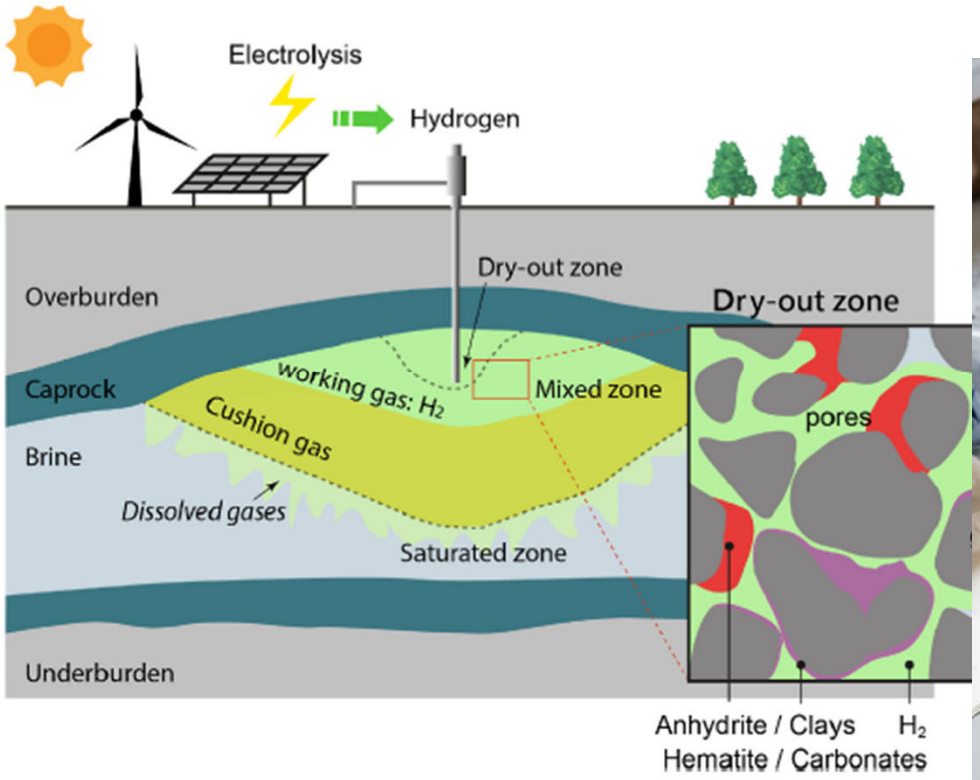
H_2 storage in porous redbed rocks

100°C, 150 bar H2 partial pressure, 4 weeks

Dry H2, saline fluid + H2, saline fluid + He, air

~~Hem to magn, carbonate dissolution~~

200°C, 18 days, hem → magn sandstone



Cheng, Busch, Hilgers, Kontny 2025 International Journal of Hydrogen Energy, https://doi.org/10.1016/j.ijhydene.2025.01.330

Mendes, Cheng, Hilgers, Kontny 2025 Geophys. Res. Lett. https://doi.org/10.1029/2025GL120586, Bruckschlögl et al 2026 Int J of Hydrogen Energy

Experimental Lab: Real-rock micromodel for THMCB

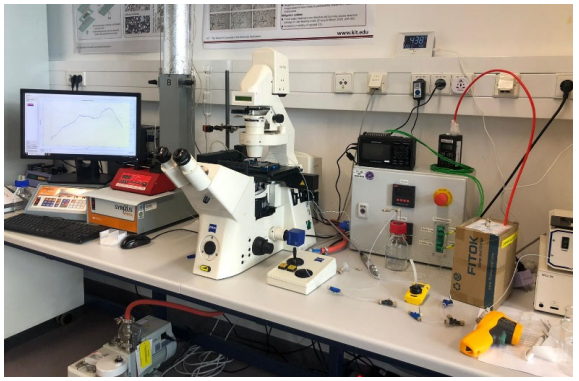
Flow channels and a thin **permeable** rock layer

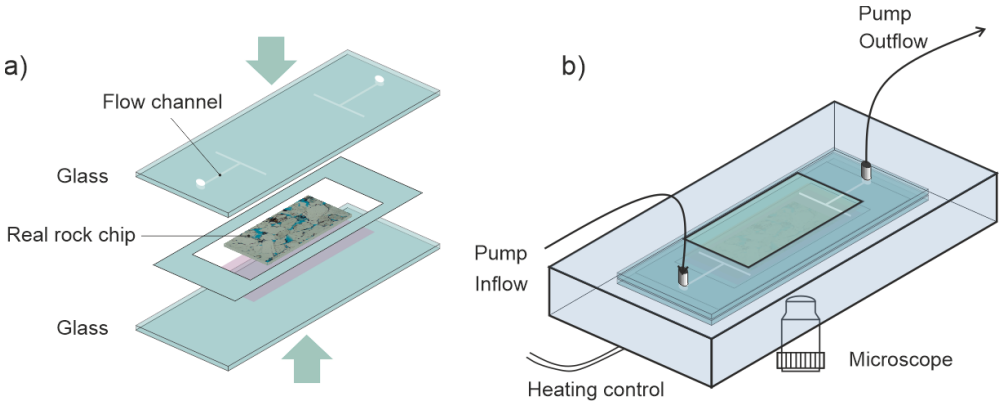
Full boundary constraints and pressure resistance

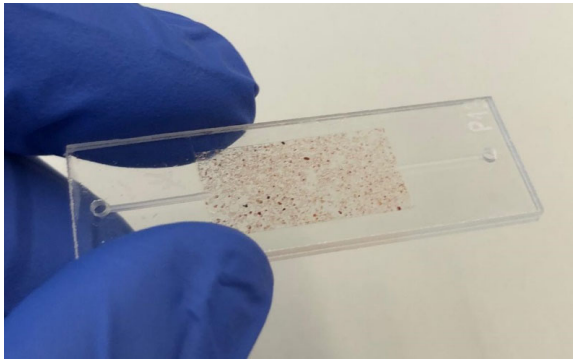
Heating unit and temperature control

Pressure and flow rate measurements

Inverted fluorescence microscope





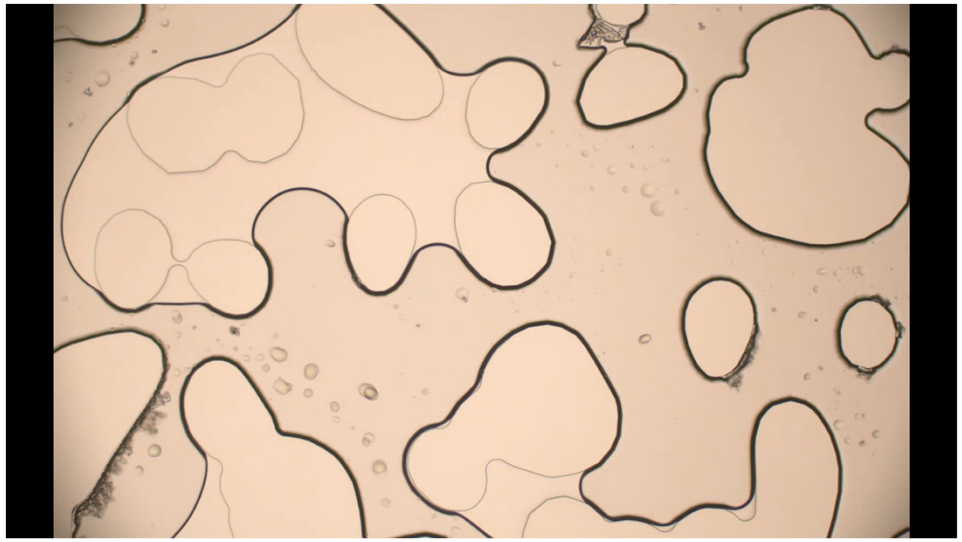


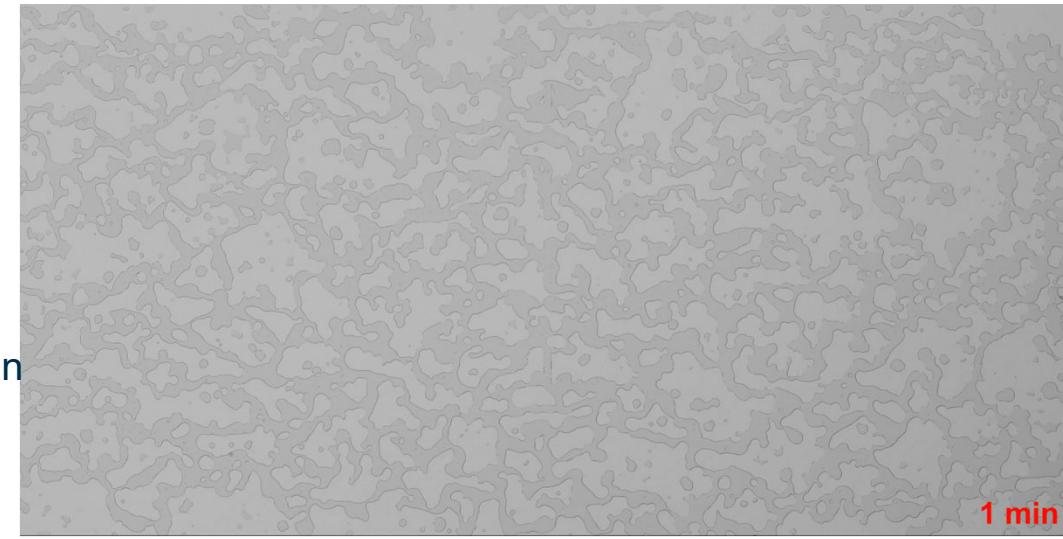
(Cheng et al. 2024)

CO_2 injection & salt plugging

Experiment 6: 60°C, k_{Chip} = 2216 mD, ϕ_{Chip} = 62%

25 wt% NaCl brine, CO_2 injection at 2.0 - 2.5 bar backpressure and a constant flow rate, $Q_{initial}$ = 1.5 mL/min





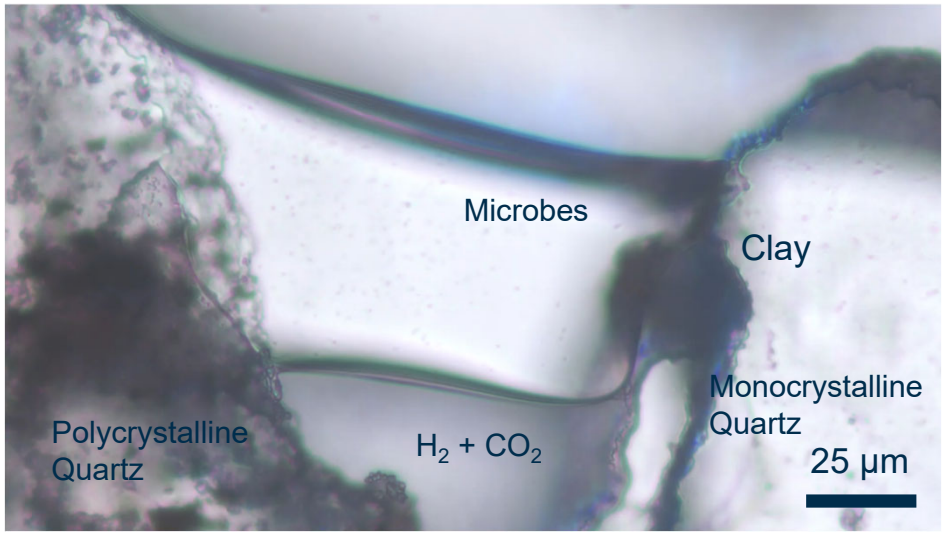
Experiment 6: Reduction of porosity: - 3.1%,

permeability: 99% (10 mD)

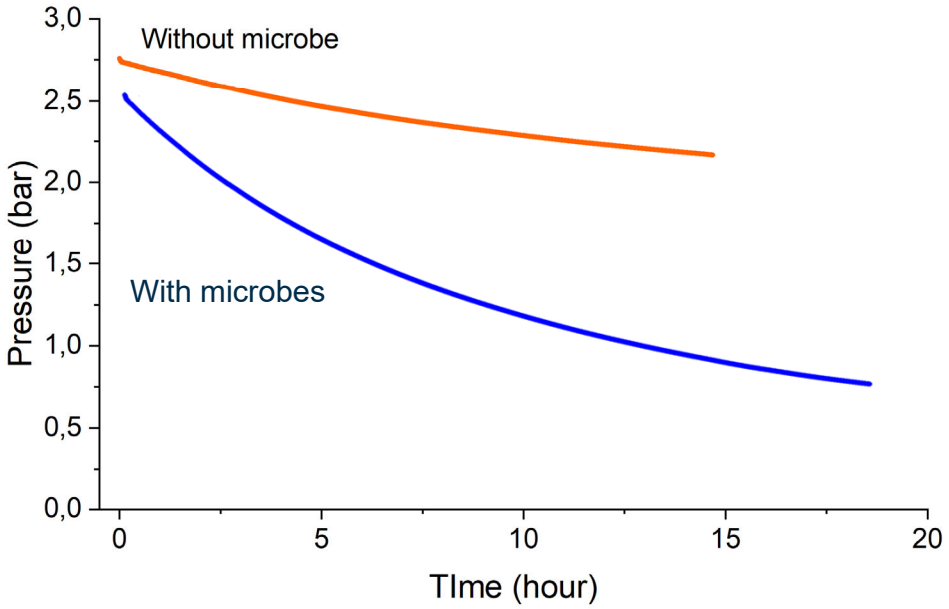
Niftaliyev; Cheng, Nestler; Hilgers (2026) https://data.mendeley.com/preview/tvr6ytz96z?a=63bc60e7-3f80-4ea5-967e-d05ff77e9fd2

Microbial growth in real rock pores

Time-lapse images



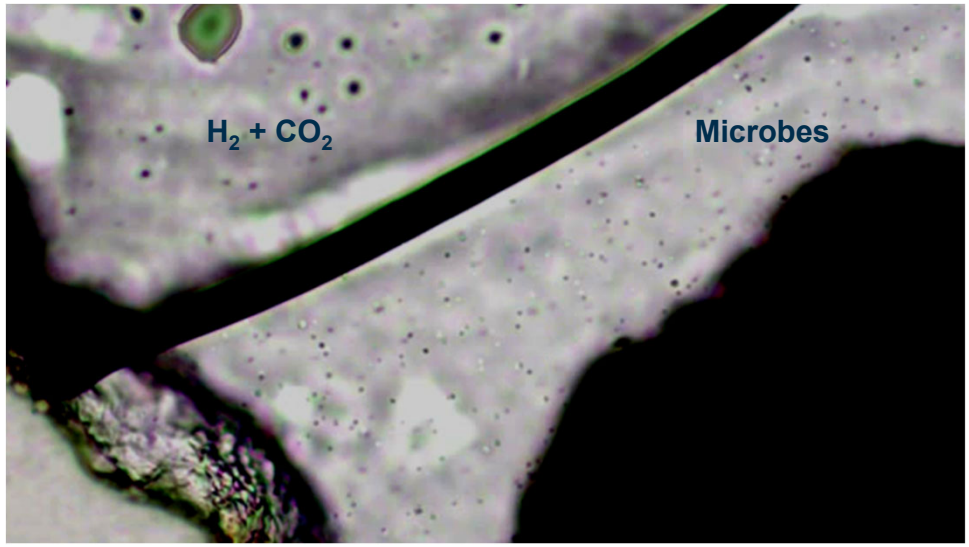
Pressure monitoring



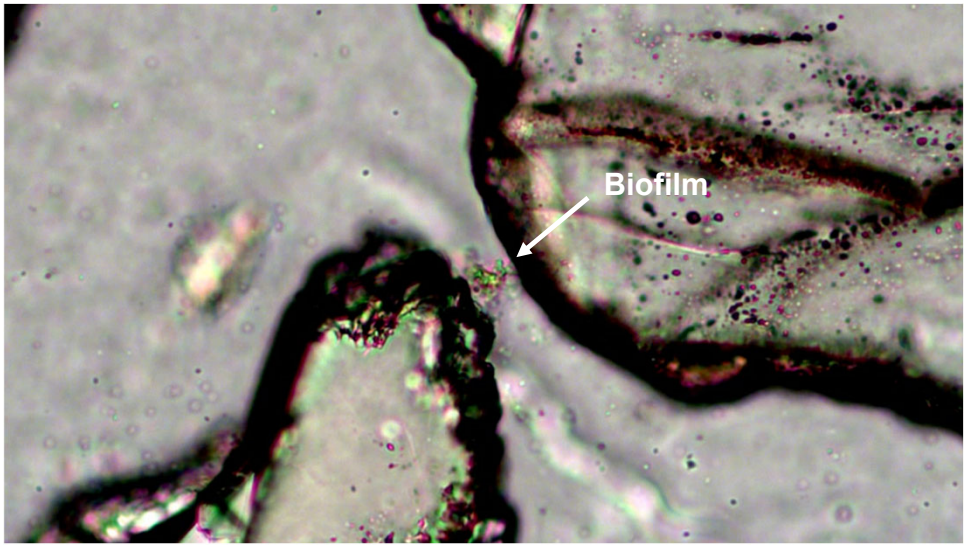
- Methanogenic archaea: Methanothermococcus themolithotroplicous, pure culture
- Static condition: a closed system without supply
- Temperature: 46 °C
- Duration of growth: 19 hours

Microbial growth in real rock pores

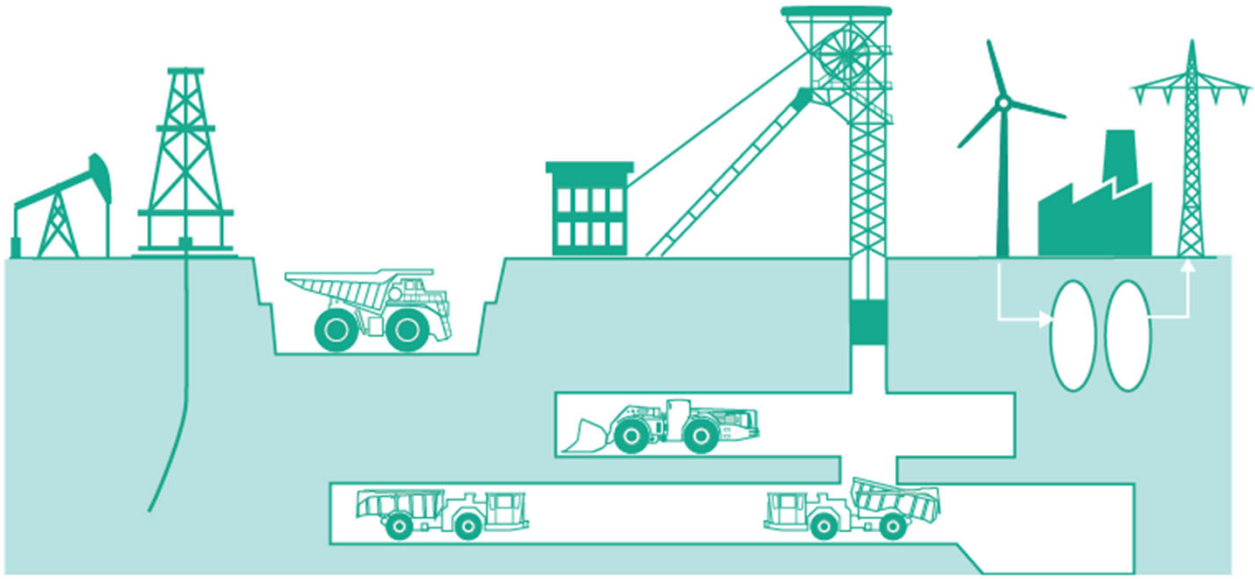
Methanogens (initial)



Biofilm/aggregates in a pore throat



- Methanogenic archaea: Methanothermococcus themolithotroplicous, pure culture
- Static condition: constant gas pressure supply (CO_2 and H_2)
- Temperature: 56°C, Duration of growth: ~5 days

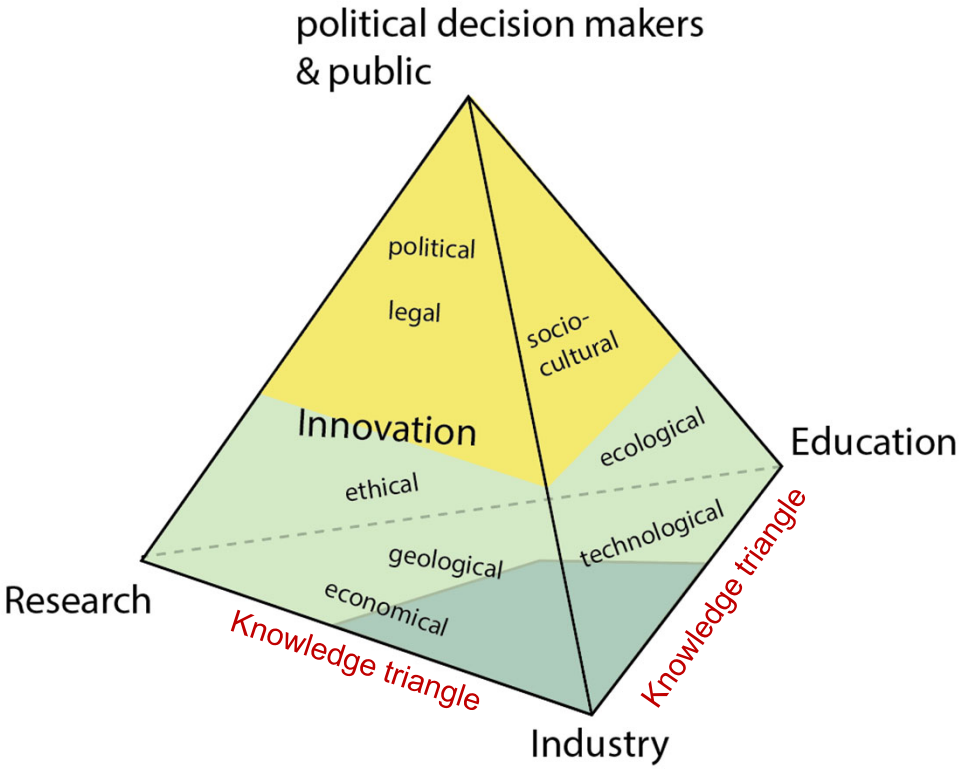


Challenges

...

Challenge: Capacities, Footprint and Handprint

- Space of innovation:

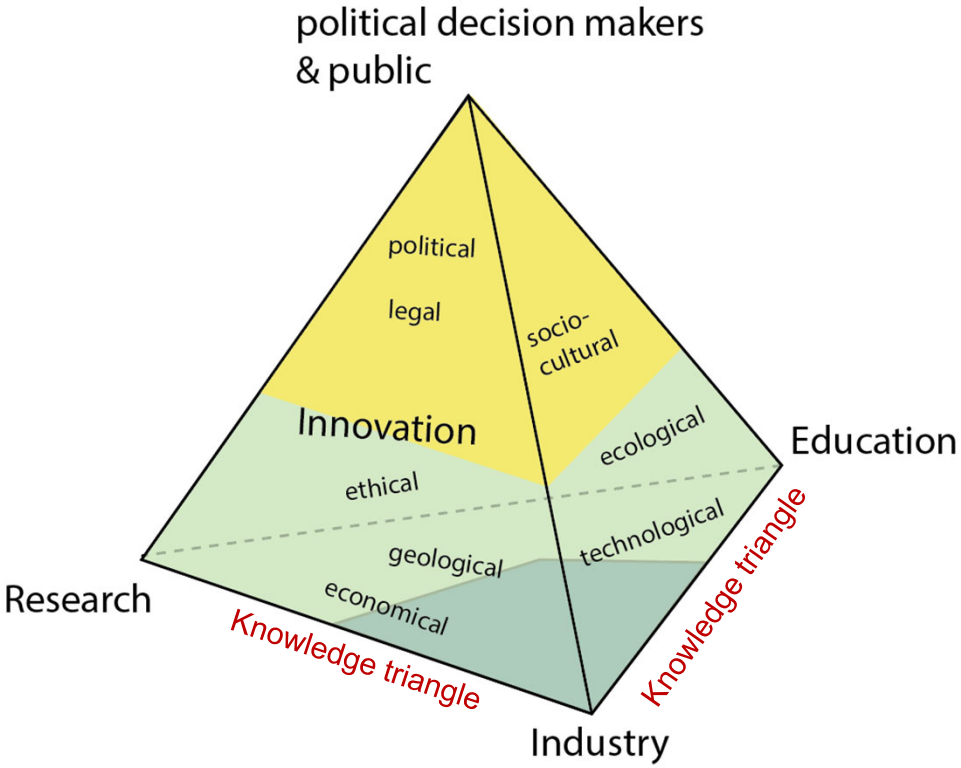


- Space of progress:

(1) Hilgers, Kolb, Becker 2021 Ist die deutsche Nachfrage und das Angebot an Rohstoffen resilient? Download RZ_THINKTANK_Broschuere_Bergbau_Verhuettung_Recycling_DE_Web_Einzelseiten_NEU.pdf (thinktank-irs.de)

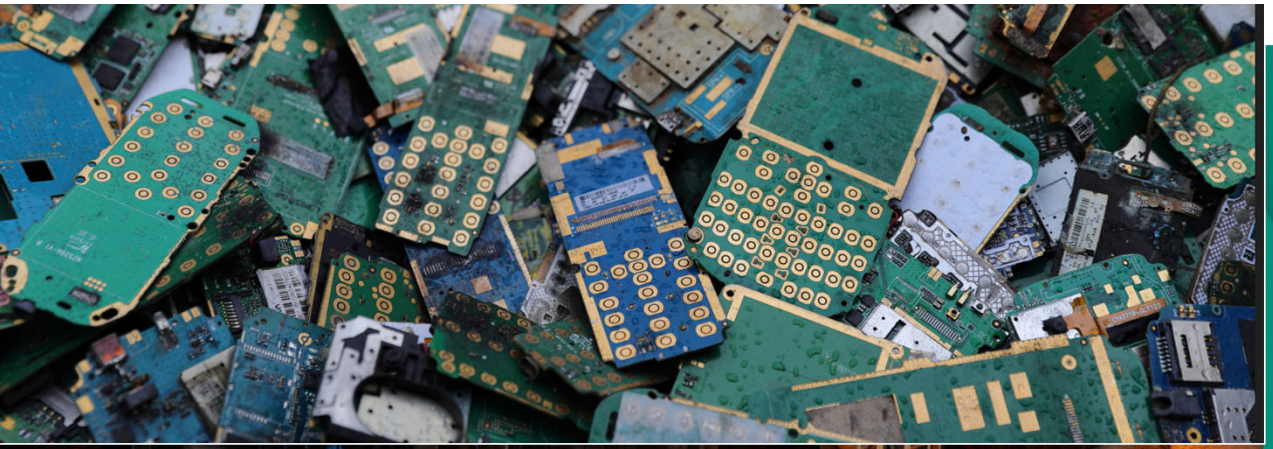
Conclusion

- Space of innovation:



- Shape the Future
- Improved prediction or reservoir properties, T+H,M,C+B-Field/Lab/Model
- Creative ideas & built upon
- Low-emission energy by innovation
  - H_2-storage & natural seeps
  - CO_2-storage & utilization
  - Hydrocarbons as energy & raw material
  - Geothermal
  - Raw material supply chains & resilience

(1) Hilgers, Kolb, Becker 2021 Ist die deutsche Nachfrage und das Angebot an Rohstoffen resilient? Download RZ_THINKTANK_Broschuere_Bergbau_Verhuettung_Recycling_DE_Web_Einzelseiten_NEU.pdf (thinktank-irs.de)



Thank you for your attention!

Karlsruher Institut für Technologie

Karlsruhe Institute of Technology (KIT)
- Christoph Hilgers
- Institute of Applied Geosciences AGW

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76131 Karlsruhe, Germany
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Sustainable use of the environment, above and below ground.

Fotos von Aurubis AG, Hamburg