Panel Discussion : Impacts of microbiological activity in underground storages

Anne-Catherine Ahn[1], Anthony. Ranchou-Peyruse[2,3], Irina Sin[4]

1: Wageningen University and Research, The Netherlands
2: Université de Pau et des Pays de l'Adour, E2S UPPA, CNRS, IPREM, Pau, France
3: Joint Laboratory SEnGA, UPPA-E2S-Teréga, Pau, France
4: Mines Paris - PSL, France

25/05/2023

Geostock

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Hydrogen Storage in European Subsurface

Acknowledgment

The Project is co-founded by European Union

Clean Hydrogen Partnership

Outline

1. Anne-Catherine Ahn - Wageningen University
2. Anthony Ranchou-Peyruse - Université de Pau
3. Irina Sin - Mines Paris
4. Technical Challenges

Microbial H_2 conversions: Background and HyUSPRe experimental results

Anne-Catherine Ahn[1], Adrian Hidalgo-Ulloa[1], Yehor Pererva[1], Bart Lomans[2], Diana Sousa[1]

1: Wageningen University and Research, The Netherlands

2: Shell Global Solutions International B.V., The Netherlands

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HyUSPRe Hydrogen Underground Storage in Porous Reservoirs

Acknowledgment

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H_2 team at WUR

Hydrogen Underground Storage in Porous Reservoirs HyUSPRe

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Diana Sousa

Bart Lomans

Hydrogen Underground Storage in Porous Reservoirs HyUSPRe

HyStoreReact

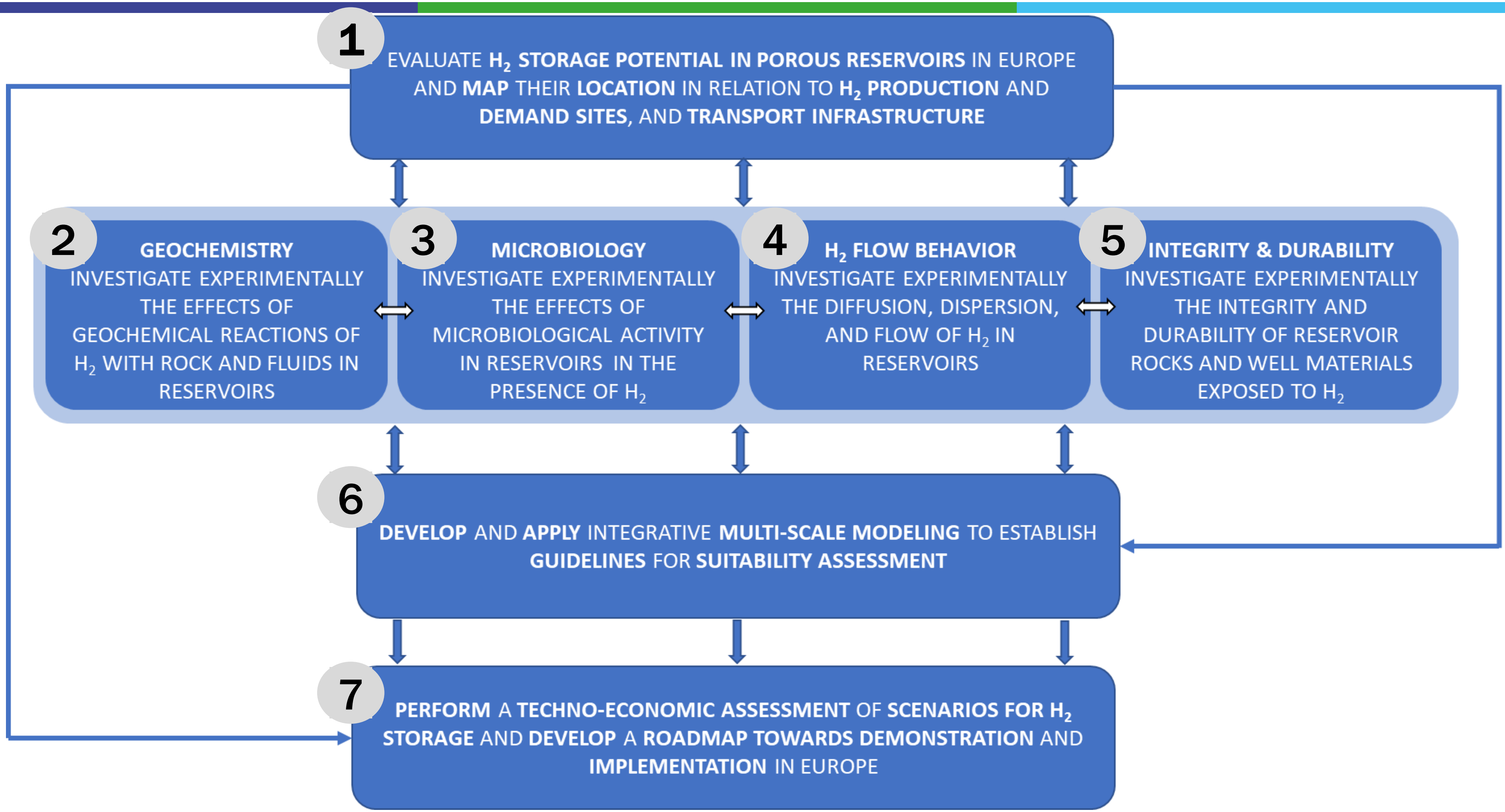
Yehor Pererva

Anne-Catherine Ahn

Ton van Gelder

Adrian Hidalgo

HyUSPre: H_2 underground storage in porous reservoirs

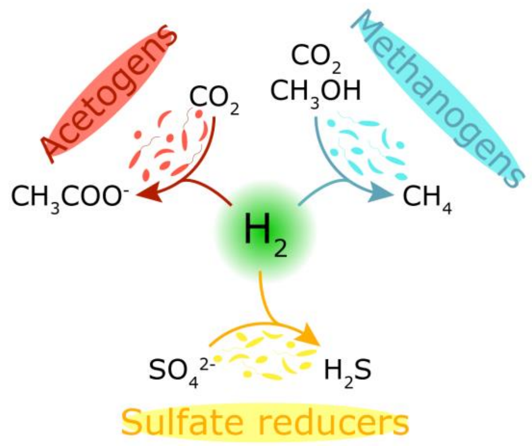


Microbial life in the subsurface

- Subsurface environment harbors extreme conditions:
  - High temperature, pressure and salinity
  - Limited nutrients and energy source
  - Limited pore sizes
- Deep biosphere composes 2–19% of the Earth's total biomass
- Microbial cell number & diversity
  - Cell numbers between 8.65×10^4 - 1.01×10^6/g rock
  - Decreases over the depth
  - Depends on environmental conditions
- Life is possible until at least a depth of 5000 m
- Most microorganisms are in dormant state

Microbial impact on subsurface H_2 storage

- H_2 is an important, easy & high energy source in subsurface where e- donors are scarce
- Potential impact of microbes in H_2 storage:
  - Loss of the stored H_2 through metabolic processes
  - Formation of contaminating products, such as H_2S and CH_4
  - Microbial-influenced corrosion (MIC)
  - Loss of H_2 injectivity due to bio-based solids (biomass, FeS, etc.)



Knowledge gaps:
- ➢ Microbial taxa which are relevant for potential UHS sites
- ➢ Microbial kinetics at high partial H_2 pressures and its dependency on T, P, salinity and pH

Aim of the WP3 in HyUSPre

- Microbial community analysis of target UHS sites

https://www.hyuspre.eu/index.php/downloads/

- Determination of window of viability:

Subsurf... sampl...

Window of viability microorganisms

- Determination o...

Microb... enrichm...

Kinetic data to populate models DuMu^x (TUC) and MoReS-PHREEQC (Shell)

- Bench-marking m...

Synthe... co-cultu... microb...

Competition data to populate models DuMu^x (TUC) and MoReS-PHREEQC (Shell)

- Case studies: Inc... ...ion water

Hydrogen Underground Storage in Porous Reservoirs HyUSPRe

Doc.nr:	HyUSPre-D3.1
Version:	2022.09.30
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Page:	1 of 35

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HyUSPRe
Hydrogen Underground Storage in Porous Reservoirs

Review of the window of viability of the different microbial metabolisms relevant for subsurface H_2 storage application

Prepared by: Ahn, Anne-Catherine, WUR
Hidalgo-Ulloa, Adrian, WUR
Pererva, Yehor, WUR
Lomans, Bart, WUR & Shell
Sousa, Diana, WUR

Aim of the WP3 in HyUSPre

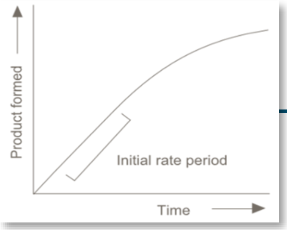
- Microbial community analysis of target UHS sites

- Determination of window of viability:

Subsurface samples → Incubations at relevant P_{H2} & T conditions → Monitoring: Methane, SO_4^{2-}, HS^-, VFAs (acetate, butyrate, etc.), Biomass → Window of viability microorganisms

- Determination of kinetic data:

Microbial enrichments → Incubations at relevant P_{H2} & T conditions →



→ Kinetic data to populate models DuMu^x (TUC) and MoReS-PHREEQC (Shell)

- Bench-marking new-populated models:

Synthetic co-culture of microbes → Incubations at relevant P_{H2} & T conditions → Monitoring: Methane, SO_4^{2-}, HS^-, VFAs, Biomass → Competition data to populate models DuMu^x (TUC) and MoReS-PHREEQC (Shell)

- Case studies: Incubations at specific site’s condition of formation water

Sampling & relevance of environmental samples

- Partners provided environmental brine samples:

-29 porous reservoir samples from 4 partners

-2 salt cavern samples from 2 partners

→ Including potential UHS target sites and actual UHS pilots

→ Ability to use environmental microbial communities for experiments

HyStoreReact

power to hydrogen

Fieldwork: H_2 storage test in salt cavern

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After 6 months H_2 storage test phase, liquid and filter samples, and cores were retrieved

Plan:

-Incubations at different temperatures at low pressure and at the site's conditions at high pressure

-Microbial community analysis of filter and core samples

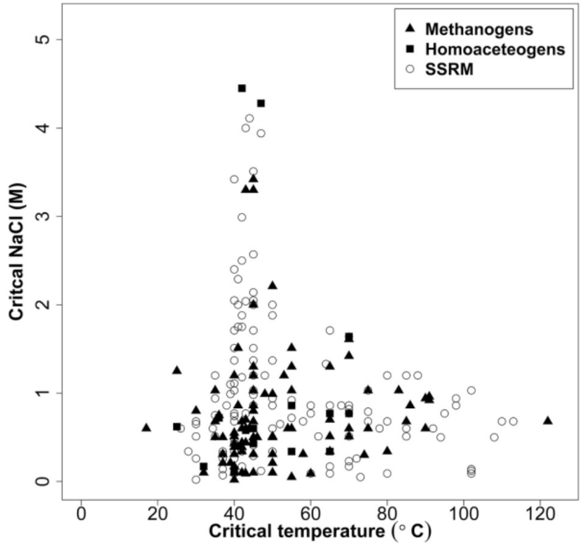
HyStoreReact

hystock power to hydrogen

Window of viability of microorganisms

- Current state of knowledge for microbial survivability limits under subsurface H_2 storage conditions:

Parameters	Microbial optimum & limit	Methanogens	Sulfate reducers	Acetogens
Temperature (H_2 storage: 22.5-100°C)	Optimum Limits	15-98°C 122°C	10-106°C 113°C	20-30°C 72°C
Pressure (H_2 storage: 1-50 MPa)	Optimum		0-30/50 MPa	
Salinity (H_2 storage: 0-5 M NaCl)	Optimum Limits	0-0.77 M NaCl 3.4 M NaCl	0-0.4 M NaCl 4.2 M NaCl	0-0.4 M NaCl 4.4 M NaCl
pH	Optimum Limits	4-9.5 4-10	4-9.5 1-10	NA 3.6-10.7



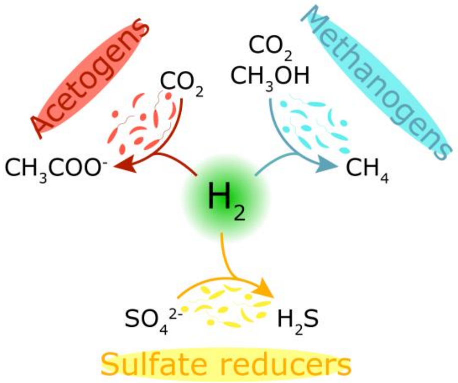
(Thaysen et al., 2021, doi: 0.1016/j.rser.2021.111481)

- Temperature and salinity are the most constraining factors
  - Temperature alone: upper life limit is 122°C
  - Combination of temperature and salinity: >55°C, and >1.7 M NaCl

Window of viability: Incubations

- Environmental samples with 80%H_2/20%CO_2 at 1.7 bar, different temperatures and media

	Sample	T (°C)	P (bar)	pH	Conductivity (mS/cm)	Medium	35°C	50°C	65°C	80°C
Porous reservoirs	A	51	45	7.72	49.24	Sample amended with nutrients/trace	Acetogen	Methanogen	Methanogen	
						Mineral medium (MM)	Methanogen	Methanogen	Methanogen	
						MM with 0.5 M Na^+ + 3mM SO_4^{2-}	SO_4^{2-} reducer	SO_4^{2-}reducer		
	B	51	87	5.95	79.74	Sample amended with nutrients/trace	Methanogen			
						Mineral medium (MM)	Methanogen	Acetogen		
						MM with 0.5 M Na^+ + 3mM SO_4^{2-}	Methanogen + SO_4^{2-} reducer	SO_4^{2-} reducer		
	C	72-107	97-206	ND	ND	Sample amended with nutrients/trace	Methanogen + Acetogen	Methanogen	Methanogen	
						MM with 0.5 M Na^+ + 3mM SO_4^{2-}	SO_4^{2-} reducer + Acetogen	Methanogen	Methanogen	
	D	39-41	56	ND	ND	Sample amended with nutrients/trace	Methanogen	Methanogen		
						MM with 0.5 M Na^+ + 3mM SO_4^{2-}	Methanogen	SO_4^{2-} reducer	SO_4^{2-} reducer	
	E	109	50-150	5.2	217	Sample amended with nutrients/trace		SO_4^{2-} reducer		
						MM with 0.5 M Na^+		SO_4^{2-} reducer	SO_4^{2-} reducer	
	F	103	50-150	5.3	211	Sample amended with nutrients/trace				
						MM with 0.5 M Na^+		SO_4^{2-} reducer	SO_4^{2-} reducer	SO_4^{2-} reducer
Salt caverns	G	45	80-200	6.3	240	Sample amended with nutrients/trace	SO_4^{2-} reducer	SO_4^{2-} reducer + Acetogen		
						MM with 0.5 M Na^+			SO_4^{2-} reducer	
						MM with 2 M Na^+				
	H	20-80	40-275	6.9	219	Sample amended with nutrients/trace				
						MM with 0.5 M Na^+				
						MM with 2 M Na^+				

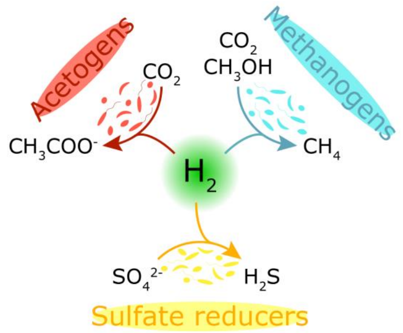


Window of viability: Incubations

- Environmental samples with 100% H_2 at 1.7 bar and different temperatures:

Porous reservoirs: A, B, C, D
Salt caverns: G, H

Sample	T (°C)	P (bar)	pH	Conductivity (mS/cm)	35°C	50°C	65°C	80°C
A	51	45	7.72	49.24	Methanogen	Methanogen	Methanogen	
B	51	87	5.95	79.74				
C	72-107	97-206	ND	ND	Methanogen	Methanogen	Methanogen	Methanogen
D	39-41	56	ND	ND		SO_4^{2-} reducer	SO_4^{2-} reducer	
G	45	80-200	6.3	240		SO_4^{2-} reducer		
H	20-80	40-275	6.9	219				

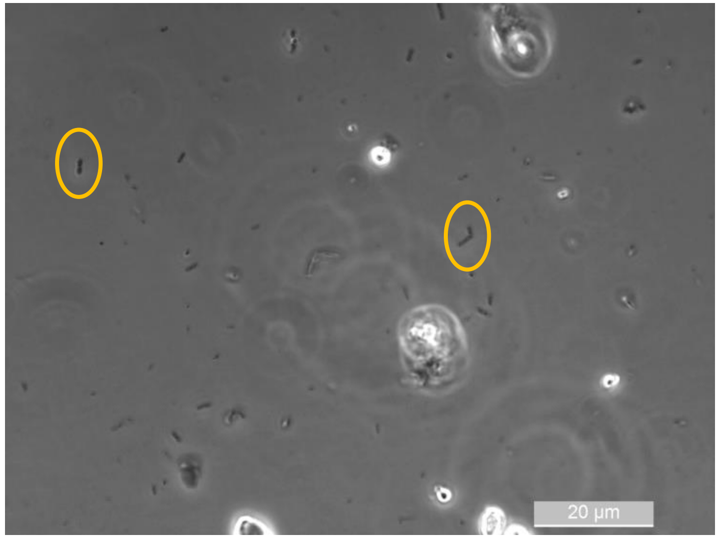


Window of viability: Incubations

- "Master mix" incubation

Medium	35°C	50°C	65°C	80°C
MM with 0.5 M Na^+ + 3mM SO_4^{2-}	Methanogen + SO_4^{2-} reducer	Methanogen + SO_4^{2-} reducer	Methanogen	
MM with 2 M Na^+ + 3mM SO_4^{2-}	Methanogen + SO_4^{2-} reducer	Methanogen + SO_4^{2-} reducer	SO_4^{2-} reducer	

2 mM sulfide produced during 7 months of enrichment



→ 16S rRNA: Peptococcaceae (amongst others)

Redefines the currently known window of viability to the combination of at least >65°C, and >2 M NaCl

Determination of microbial kinetics

- High pressure & temperature reactors:

- <u>In-house systems:</u>

- 3 reactors
- 0.6 L
- 70 Bar (56 Bar op)
- pH/P/°T monitor
- °T (max 350 °C)
- SS 316
- Lining

- <u>Newly arrived systems:</u>

- 4 reactors
- 0.5 L
- 250 Bar (200 Bar op)
- P/°T monitor
- °T (max 350 °C)
- SS 316
- Lining and coating

Conclusions and outlook

- **Window of viability**

- Limits in incubations so far:

  Acetogenesis: 50 °C

  Sulfate reduction: 80 °C

  Methanogenesis: 80 °C

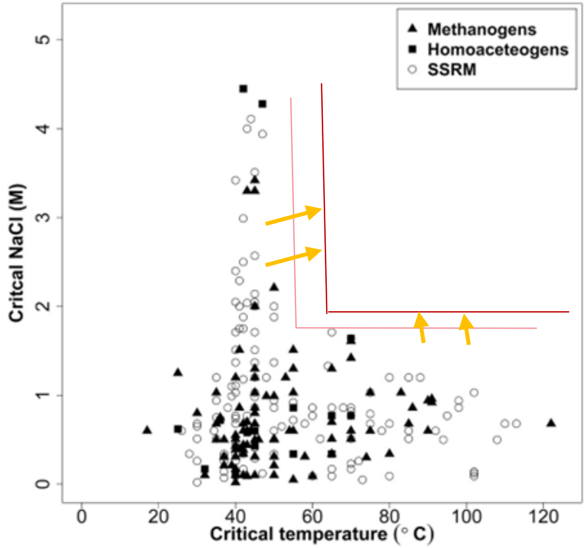
- Sulfate reduction could take place when sulfate was added/present
- Window of viability shifted to at least the combination of 65°C and 2 M NaCl

- **Determination of kinetic data**

- Design and installation of HP/HT reactors
- Determine kinetics of microbial growth & activity

  -Implement results into DuMuX model (TU Clausthal)

  -Predict overall performance of H_2 storage in porous reservoirs



Microbial life in the subsurface

WUR:

- H_2 team: Adrian Hidalgo-Ulloa, Yehor Pererva, Ton van Gelder, Bart Lomans, Diana Sousa
- Microbial Physiology and Molecular Ecology groups at Microbiology

Industrial and project partners:

Co-funded by the European Union

HyStoreReact

Thank you for your attention!

Questions?

Hydrogen Underground Storage in Porous Reservoirs HyUSPRe

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Injection of new gases (H_2 and O_2) in UGS in deep aquifers

J. MURA[1], M. RANCHOU-PEYRUSE[1,2,3], M. GUIGNARD[2], P. G. HADDAD[1], M. DUCOUSSO[1,3], F. CASTERAN[1,3], P. SÉNÉCHAL[4], M-P. ISAURE[1], P. MOONEN[4], M. LARREGIEU[2], I. LEHECHO[2,3], G. HOAREAU[5], A. PETIT[6], P. CHIQUET[3,7], G. CAUMETTE[3,8], P. CÉZAC[1,3] AND **A. RANCHOU-PEYRUSE**[2,3]

[1] UNIVERSITÉ DE PAU ET DES PAYS DE L'ADOUR, E2S UPPA, LATEP, PAU, FRANCE
[2] UNIVERSITÉ DE PAU ET DES PAYS DE L'ADOUR, E2S UPPA, CNRS, IPREM, PAU, FRANCE
[3] JOINT LABORATORY SENGA, UPPA-E2S-TERÉGA, PAU, FRANCE
[4] UNIVERSITÉ DE PAU ET DES PAYS DE L'ADOUR, E2S UPPA, CNRS, DMEX, PAU, FRANCE
[5] UNIVERSITÉ DE PAU ET DES PAYS DE L'ADOUR, E2S UPPA, CNRS, TOTAL, LFCR, PAU, FRANCE
[6] STORENGY – GEOSCIENCES DEPARTMENT, BOIS-COLOMBES, FRANCE
[7] TERÉGA – GEOSCIENCES DEPARTMENT, PAU, FRANCE
[8] TERÉGA – ENVIRONMENT DEPARTMENT, PAU, FRANCE

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Acknowledgment

The Project is co-founded by European Union

Clean Hydrogen Partnership

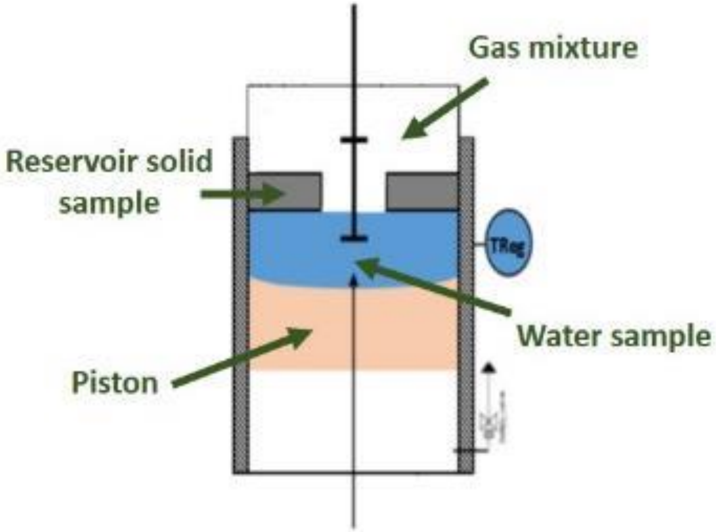
Outline

1. Injection of H_2 (Power-to-gas) and O_2 (biomethane) in the natural gas network
2. Expected arrival of these gases in the UGS
3. Is there a risk to the storage facilities ?
4. How do indigenous microbial communities respond ?
5. Is there an effect on the quality of the stored gas ?

1

Recreating the UGS in situ conditions in a laboratory reactor

Recreating the UGS in situ conditions in a laboratory reactor



→RINGS reactor can work up to 150°C and 150 bars

→Downhole water (containing microorganisms) and rock phases are sampled in the real UGS

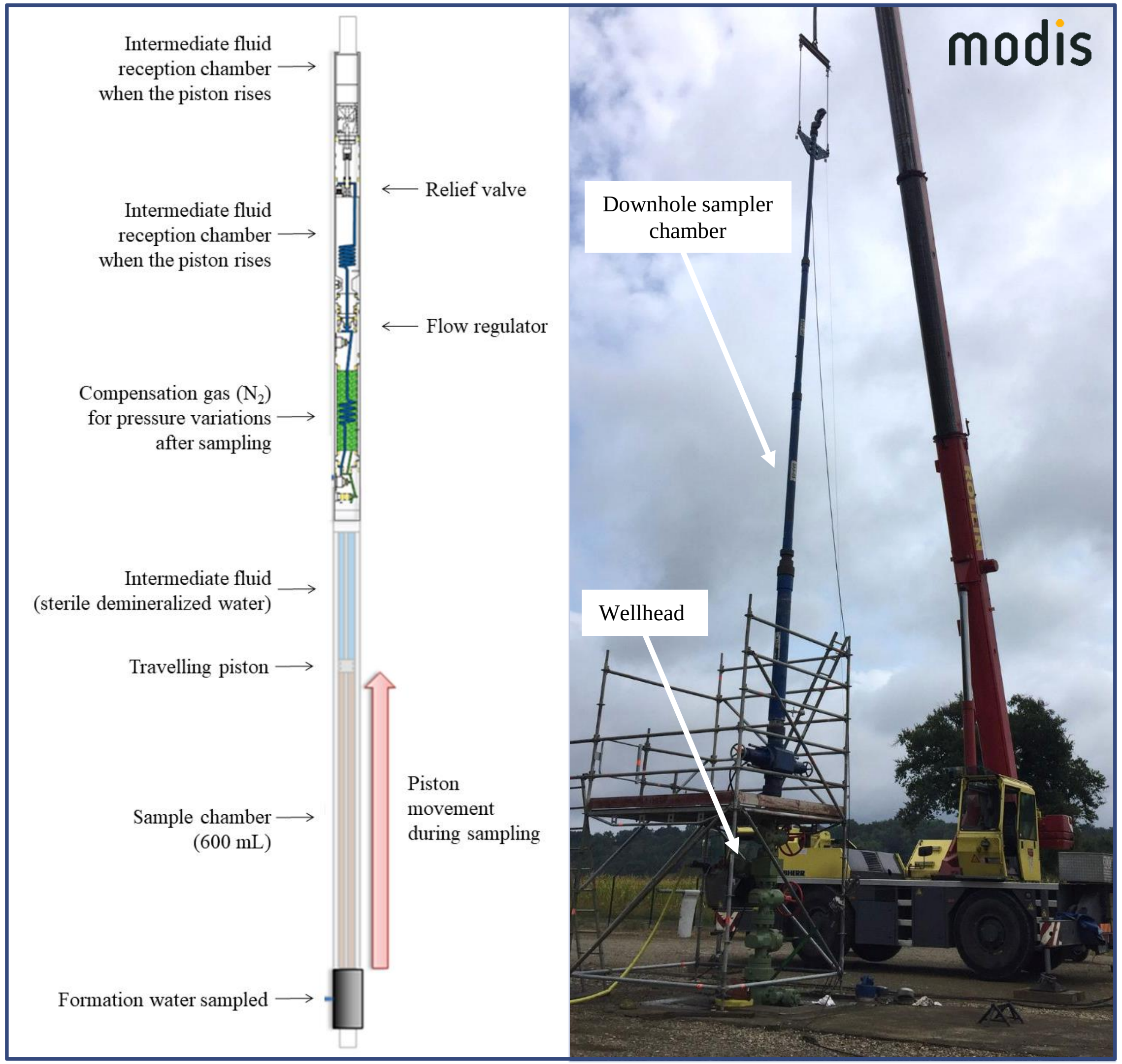
→The initial gas phase is composed of CH_4 (99%), CO_2 (1%) and traces of monoaromatic hydrocarbons (benzene and toluene).

→Deformable reactor (Piston to compensate for the pressure drop)

2

Formation water sampling

Formation water sampling



→ Sampling of the formation water (- 580m to - 1200m)

→ Guarantee the non contamination of the microbial community

→ Control the pressure / depressurization

frontiers | Frontiers in Microbiology

TYPE Original Research
PUBLISHED 04 January 2023
DOI 10.3389/fmicb.2022.1012400

A deep continental aquifer downhole sampler for microbiological studies

Magali Ranchou-Peyruse[1,2,3], Marion Guignard[1], Perla G. Haddad[2], Sylvain Robin[4], Fabrice Boesch[4], Maud Lanot[4], Hervé Carrier[3,5], David Dequidt[6], Pierre Chiquet[3,7], Guilhem Caumette[3,7], Pierre Cézac[2,3] and Anthony Ranchou-Peyruse[1,3]*

3

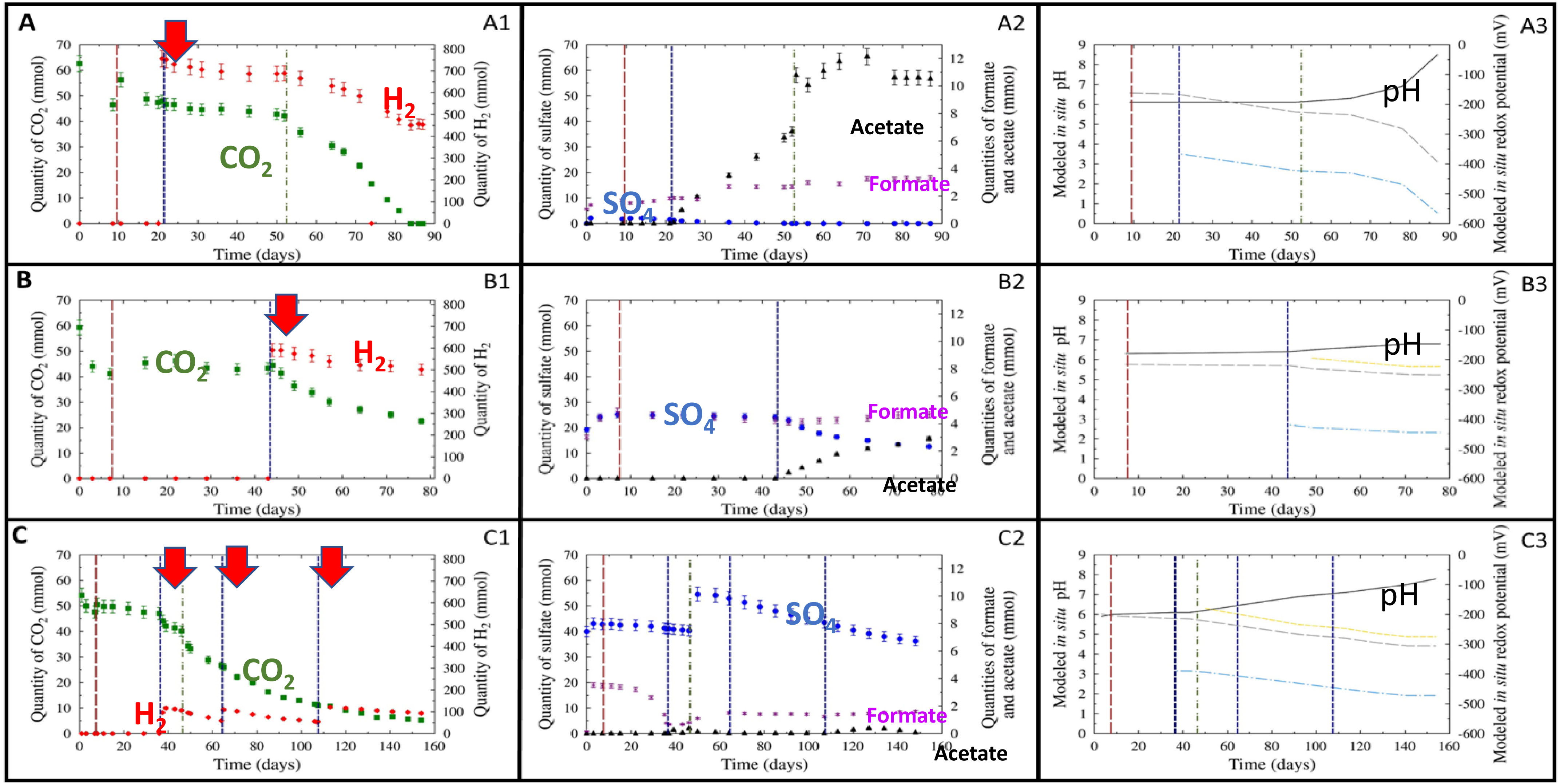
Three aquifers tested for the injection of H_2

Three aquifers tested

Aquifer 1
+ 10% H_2

Aquifer 2
+ 10% H_2

Aquifer 3
+ 3 x 2% H_2



4 Microbial communities monitoring

Microbial communities monitoring

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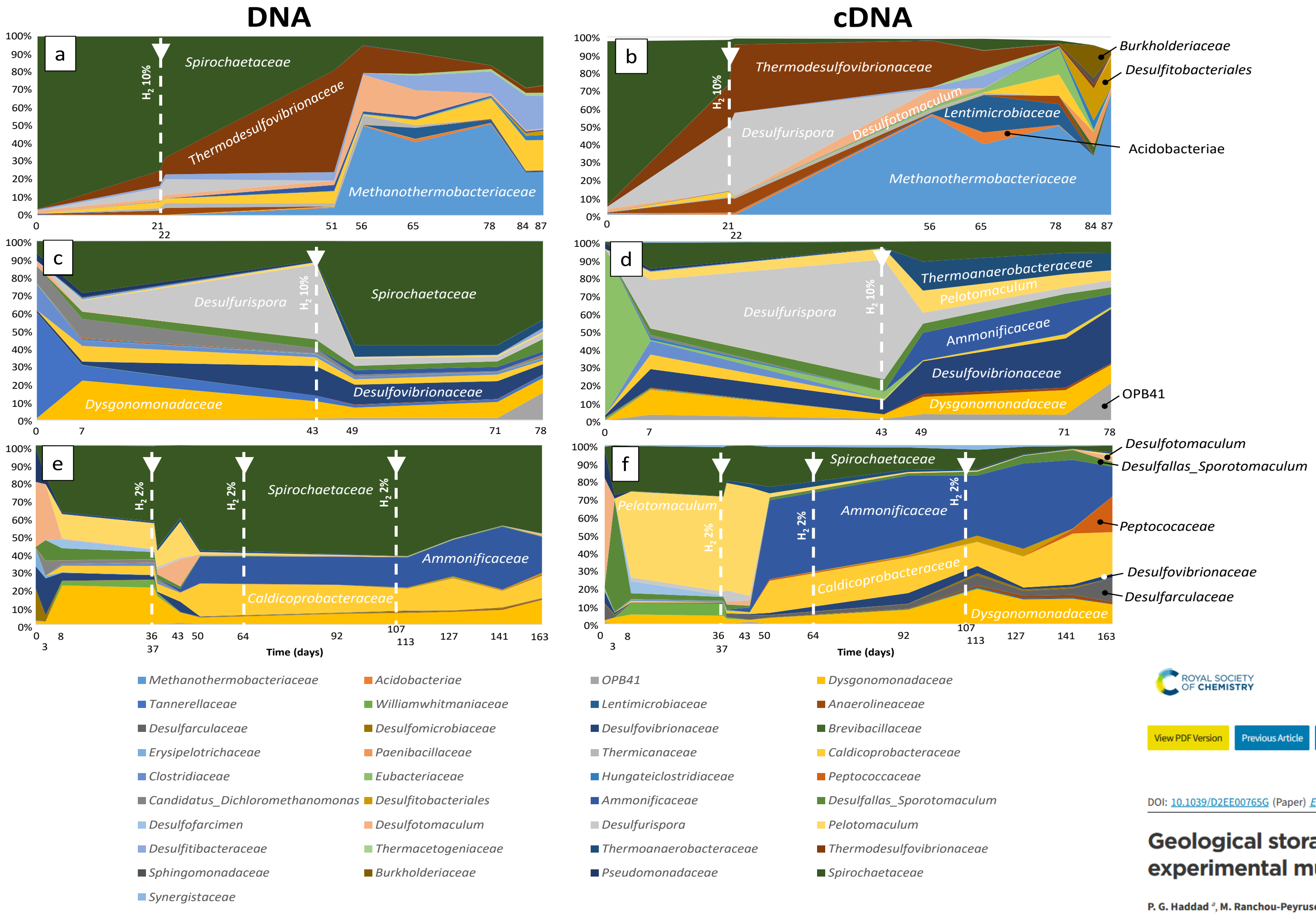
Aquifer 1

Aquifer 2

Aquifer 3



→ A community initially dominated by fermenters and sulfate-reducers

→ The Ammonificaceae family includes sulfate-reducers

→ Formate production (assumed by (homo)-acetogens)

→ Methanogenesis does not necessarily take place

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DOI: 10.1039/D2EE00765G (Paper) Energy Environ. Sci., 2022, 15, 3400-3415

Geological storage of hydrogen in deep aquifers – an experimental multidisciplinary study

P. G. Haddad [a], M. Ranchou-Peyruse [abc], M. Guignard [c], J. Mura [a], F. Casteran [ab], L. Ronjon-Magand [c], P. Senechal [d], M.-P. Isaure [c], P. Moonen [de], G. Hoareau [e], D. Dequidt [f], P. Chiquet [bg], G. Caumette [bh], P. Cezac [ab] and A. Ranchou-Peyruse [*bc]

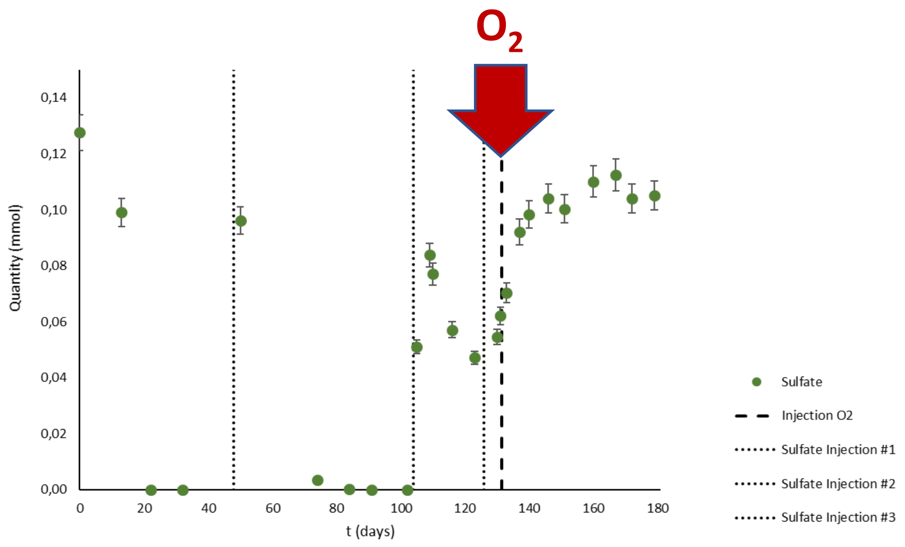
+ Comparative study of three H_2 geological storages in deep aquifers simulated in high pressure reactor (in process)

storengy TERĒGA UNIVERSITÉ DE PAU ET DES PAYS DE L'ADOUR

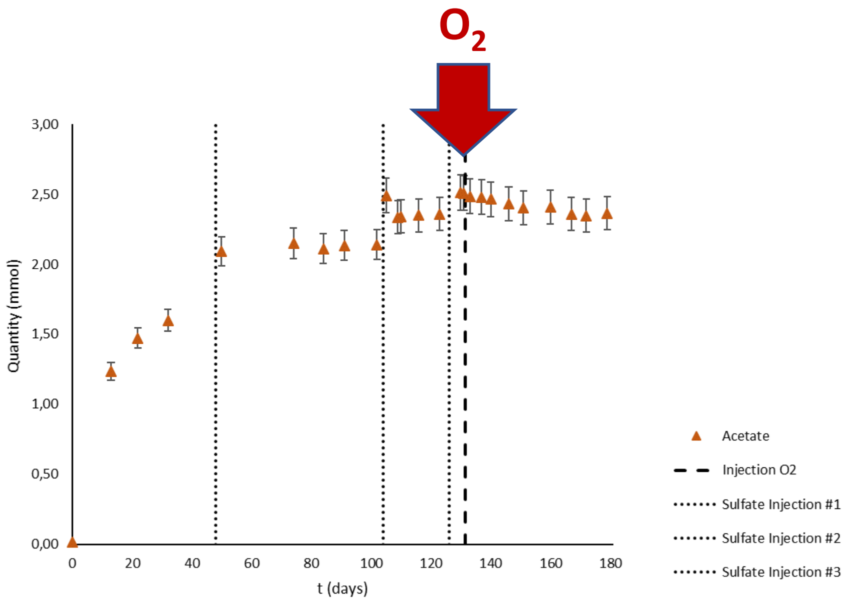
5

An aquifer tested for O_2 injection (1% & 100 ppm)

An aquifer tested for 1% O_2 injection (=10 000 ppm) ➔ changes observed on the water



Sulfate evolution



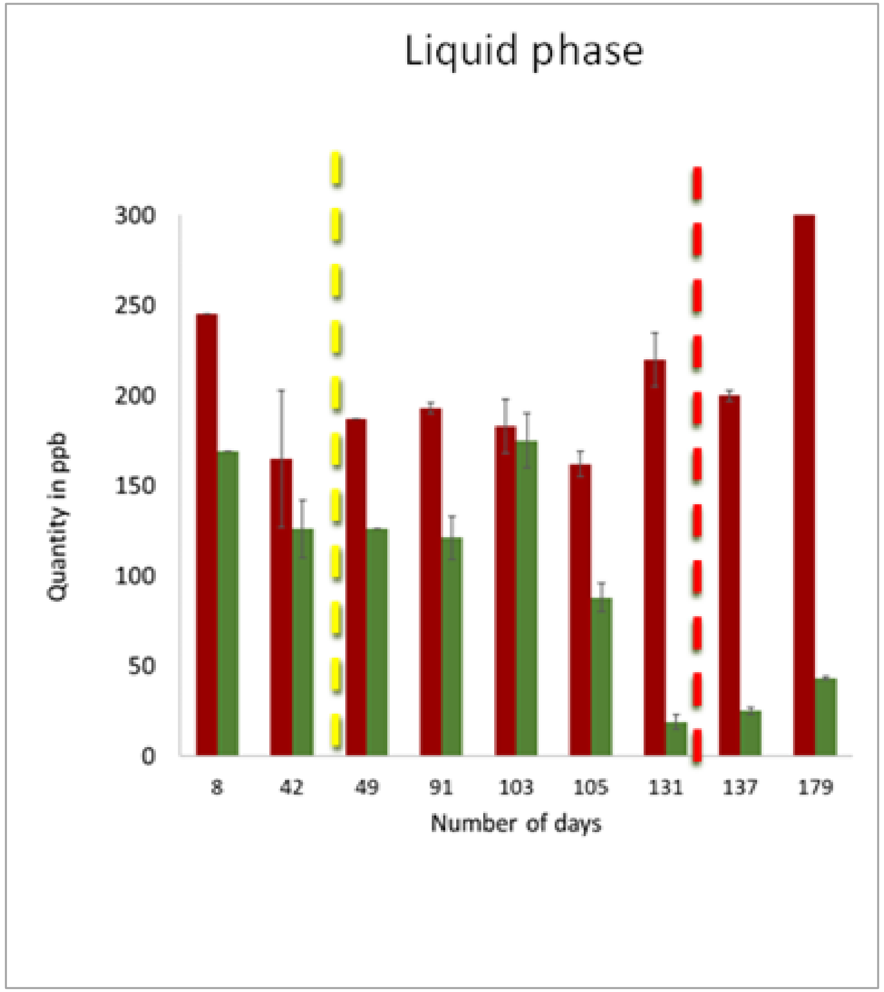
Acetate evolution

→ sulfate was consumed by sulfate-reducers

→ O_2 injection stopped the sulfate consumption (death or inhibition of sulfate-reducers)

→ Acetate is produced from micro-organisms at the beginning of the experiment

An aquifer tested for 1% O_2 injection (=10 000 ppm) ➔ changes observed on the water



→ Decrease of toluene before O_2 injection

→ 1% O_2 injection stopped the toluene disappearance

An aquifer tested for 1% O_2 injection (=10 000 ppm) ➔ changes observed on the microbial community

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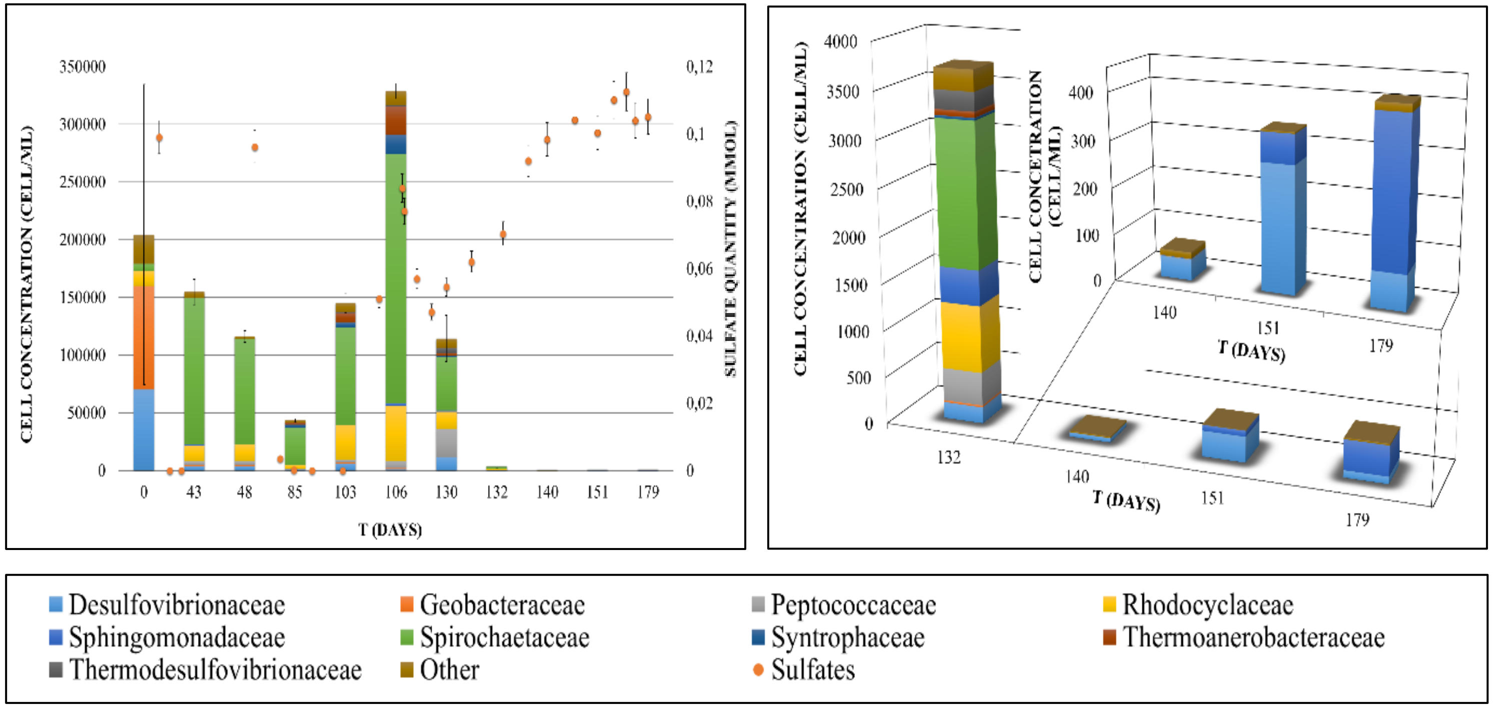

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Science of The Total Environment

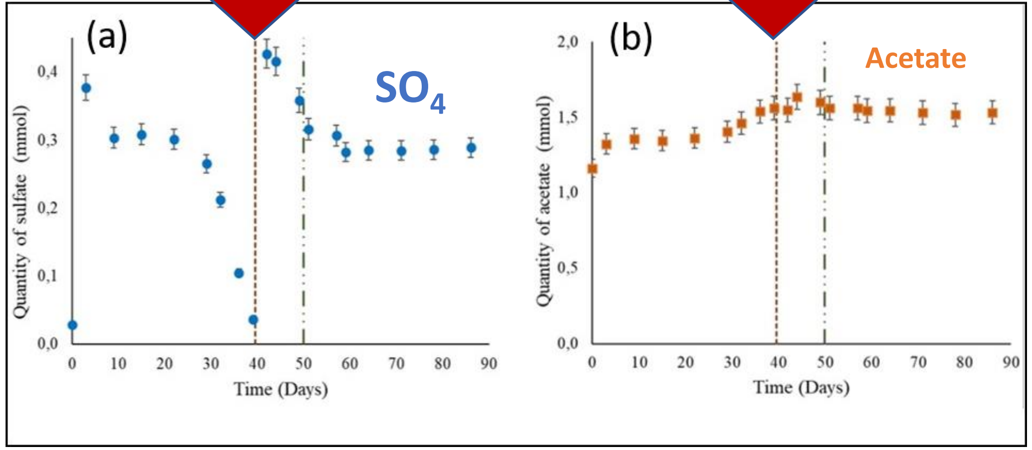
Volume 806, Part 3, 1 February 2022, 150690

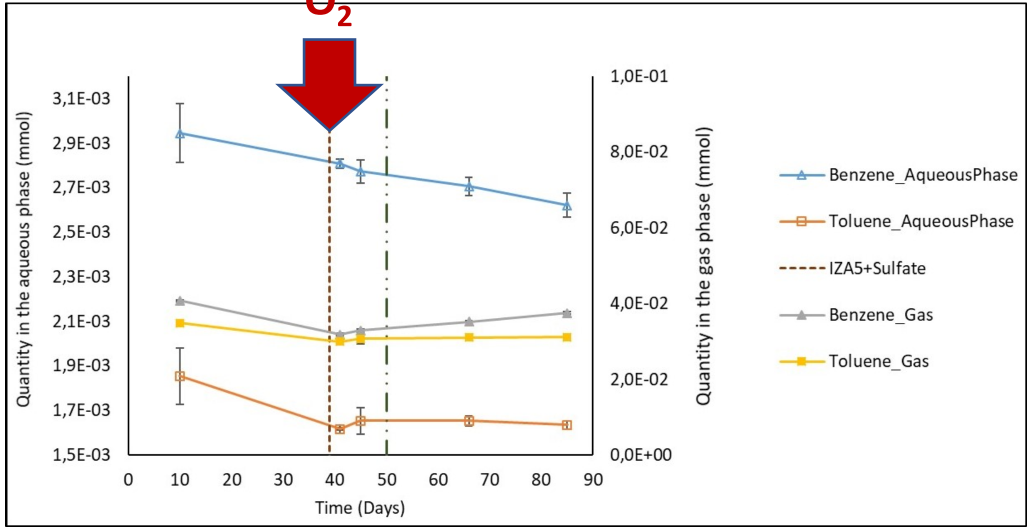
Biological, geological and chemical effects of oxygen injection in underground gas storage aquifers in the setting of biomethane deployment

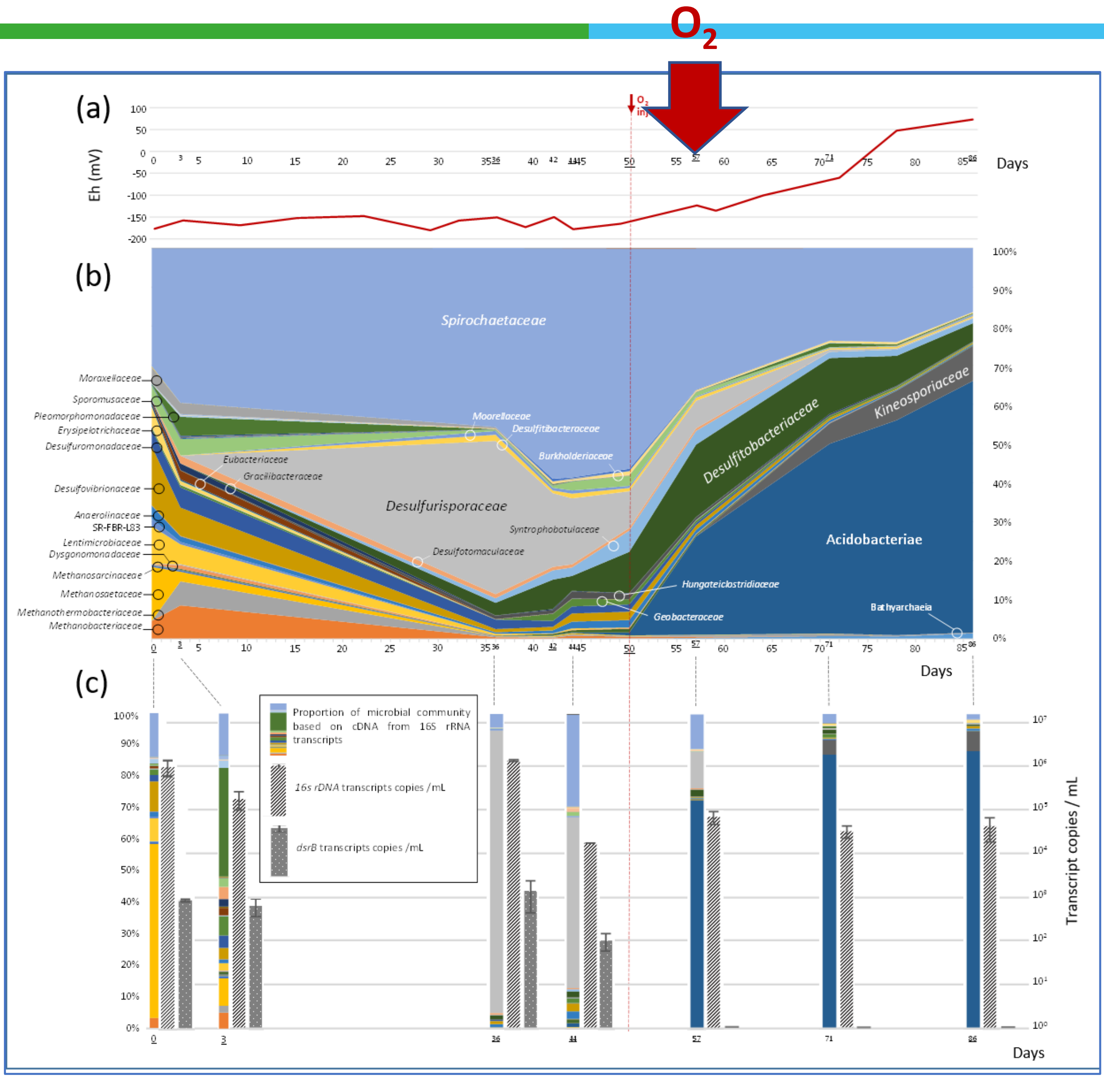
Perla G. Haddad [a], Jean Mura [a], Franck Castéran [a b], Marion Guignard [c], Magali Ranchou-Peyruse [a b c], Pascale Sénéchal [d], Marie Larregieu [c], Marie-Pierre Isaure [c], Isabelle Svahn [e], Peter Moonen [d], Isabelle Le Hécho [b c], Guilhem Hoareau [f], Pierre Chiquet [b g], Guilhem Caumette [b g], David Dequidt [h], Pierre Cézac [a b], Anthony Ranchou-Peyruse [b c]

➔ Negative effect of the 1% O_2 injection on the microbial community = hyperoxic conditions = toxicity

An aquifer tested for 100 ppm O_2 injection
➔ changes observed on the microbial community







Physicochemical and microbiological effects of geological biomethane storage in deep aquifers: introduction of O_2 as a cocontaminant (submitted)

Thank you !

Reactive transport modelling for underground gas storage

Irina SIN

Mines Paris - PSL, France

26/05/2023

Acknowledgment

The Project is co-founded by European Union

Outline

1. Reactive transport
2. Phase equilibria
3. Gas storage: oxygen reactivity
4. Extension to other gases

1 Reactive transport

Reactive transport code HYTEC since 1996

HYTEC

Flow

(Un)saturated, multiphase
Non-isothermal
Double porosity
Anisotropy

Thermodynamics

Phase equilibria, EOS
Non-ideal gas, solution
Multicomponent mixtures
Thermodynamic properties

Transport

Aqueous and gaseous
Advection, diffusion, dispersion
Particle transport

Biogeochemistry

Acid/base, redox
Precipitation, dissolution
Microbiological reactions
Isotopic fractionation

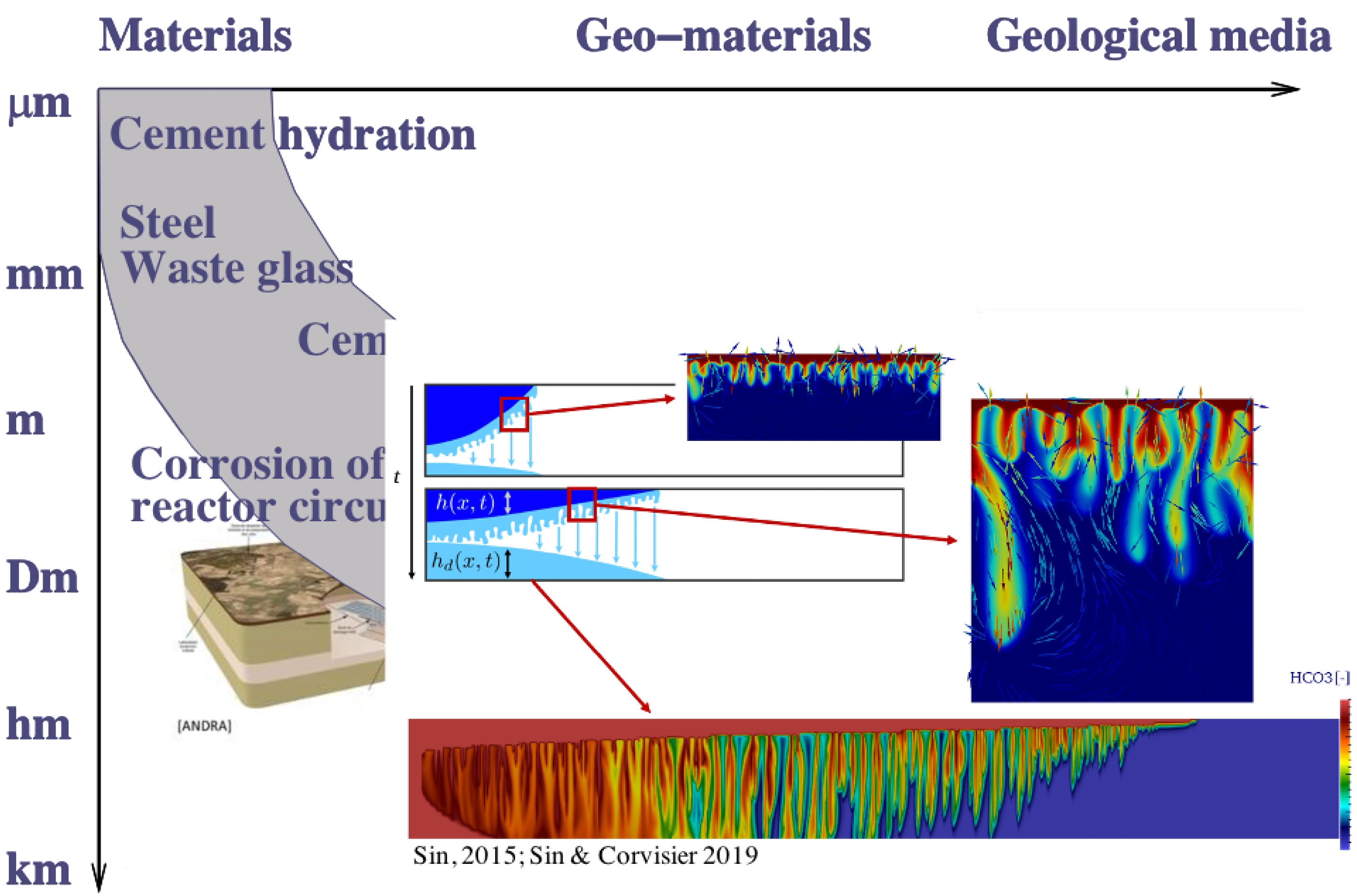
Mechanics

- **HYTEC**=**T**hermo+**H**ydro+**C**hemistry
- **CHESS** - geochemical core of HYTEC
- (Un)structured mesh
- History matching
- Coupling with mechanics
- Water balance
- Variable porosity
- Chemical and mechanical clogging

References

- van der Lee et al., Comp & Geos, 2003
- Sin, Lagneau and Corvisier, Adv. in Water Res, 2017
- Seigneur et al., Adv. in Water Res, 2018

Reactive transport code HYTEC since 1996



2

Phase equilibria

Phase equilibria

Assymetric approach

$$f_i^g = P y_i \varphi_i = K_i^H \gamma_i x_i = f_i^l$$

- φ is the fugacity coefficient calculated by EOS models: e.g. cubic EOS – Peng-Robinson (1978)

$$P = \frac{RT}{v - b^{\mathrm{PR}}} - \frac{a^{\mathrm{PR}}(T)}{v\left(v + b^{\mathrm{PR}}\right) + b^{\mathrm{PR}}\left(v - b^{\mathrm{PR}}\right)}$$

- K^H is the corrected Henry's constant

$$K_i^H(T,P) = K_g^{H,0}\left(T, P^{sat}\right)\exp\left[\frac{\left(P - P^{sat}\right)V_i^{\infty}}{RT}\right]$$

- γ_i is the activity coefficient (B-dot, SIT)

$$\ln\gamma_i = -\frac{AZ_i^2\sqrt{I}}{1 + 1.5\sqrt{I}} + \sum_j [C_j]\epsilon_{ij}$$

Advantages

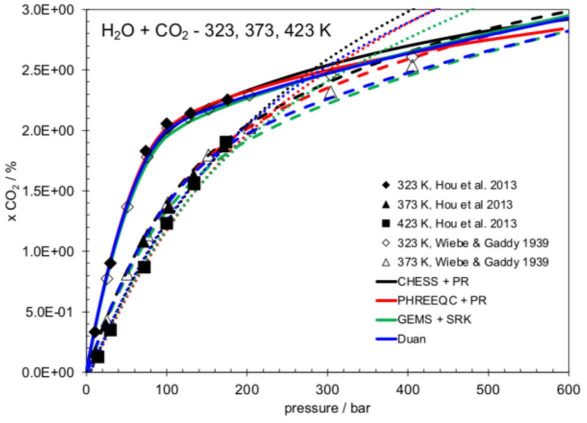
- Activity models adapted for aqueous geochemistry.
- K^H, BIP and EOS parameters adapted to non-ideal gases regarding P and T.
- Analytical solution for the PR-type EOS models.
- Group contribution structure, easy application for mixtures.

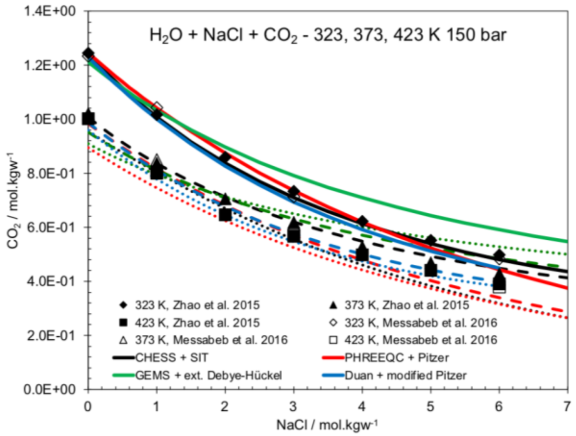
Required data

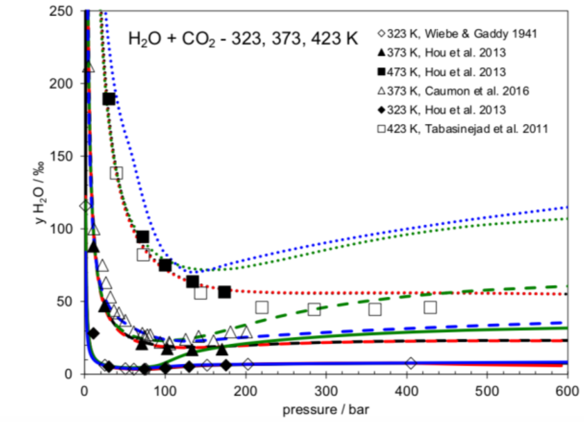
- φ: critical temperatures and pressures T_c, P_c, Z_c, Ω, mixing rule, binary interaction parameters
- K^H: Henry's constants at saturated vapor pressure, molar volumes for pressure correction
- γ_i: Debye-Hückel and B-dot general parameters, binary interaction parameters for solutes (SIT)
- Experimental lab of CTP&Geosciences, Mines Paris - PSL
- ANR GAZ ANNEXES, SIGARRR, FLUIDSTORY

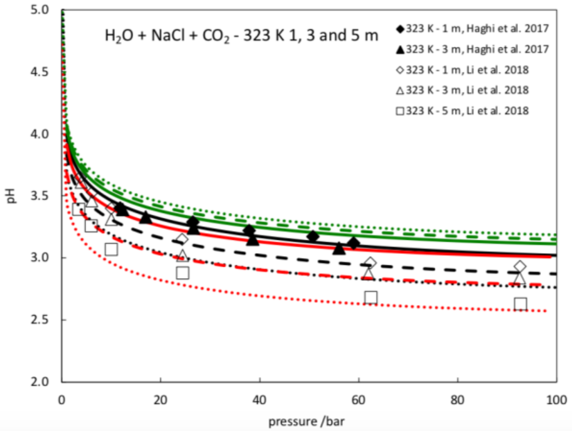
Phase equilibria

Solubility/reactivity of CO_2 in water and NaCl-brine



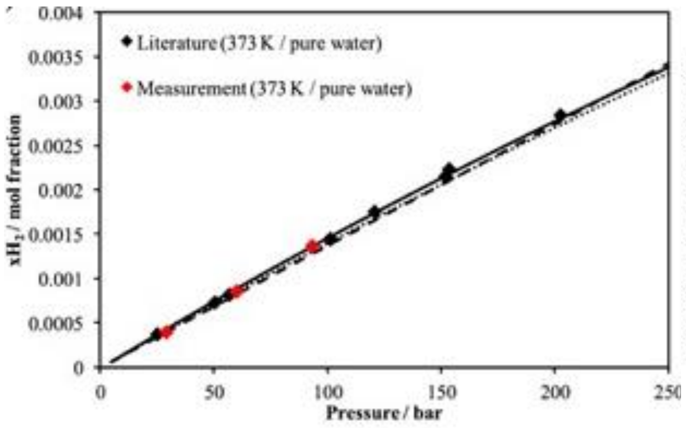


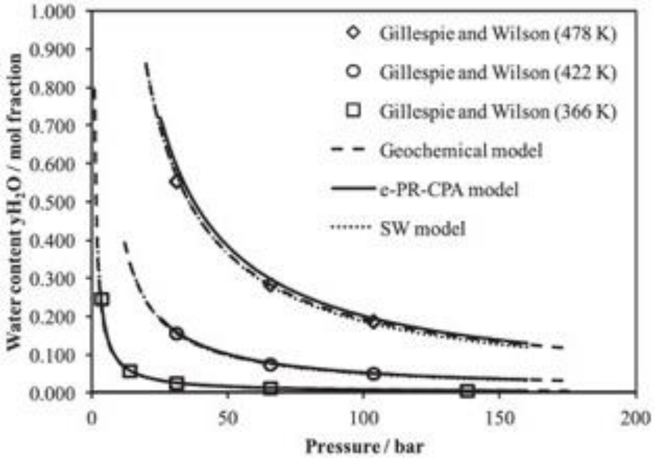


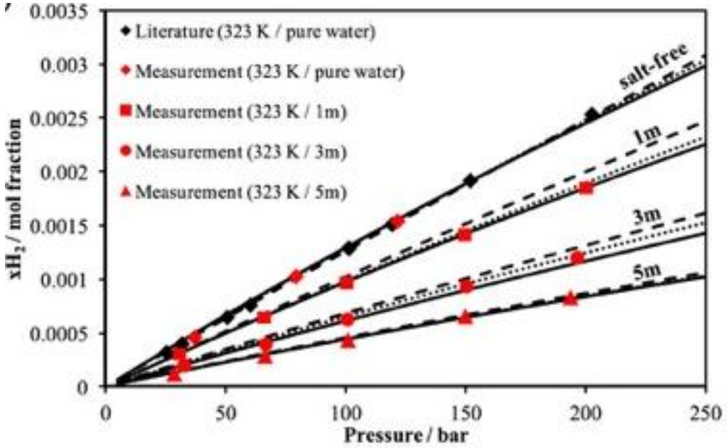


FluidSTORY project, Chabab et al., 2019, Sin and Corvisier 2019

Solubility of H2 in water and NaCl-brine







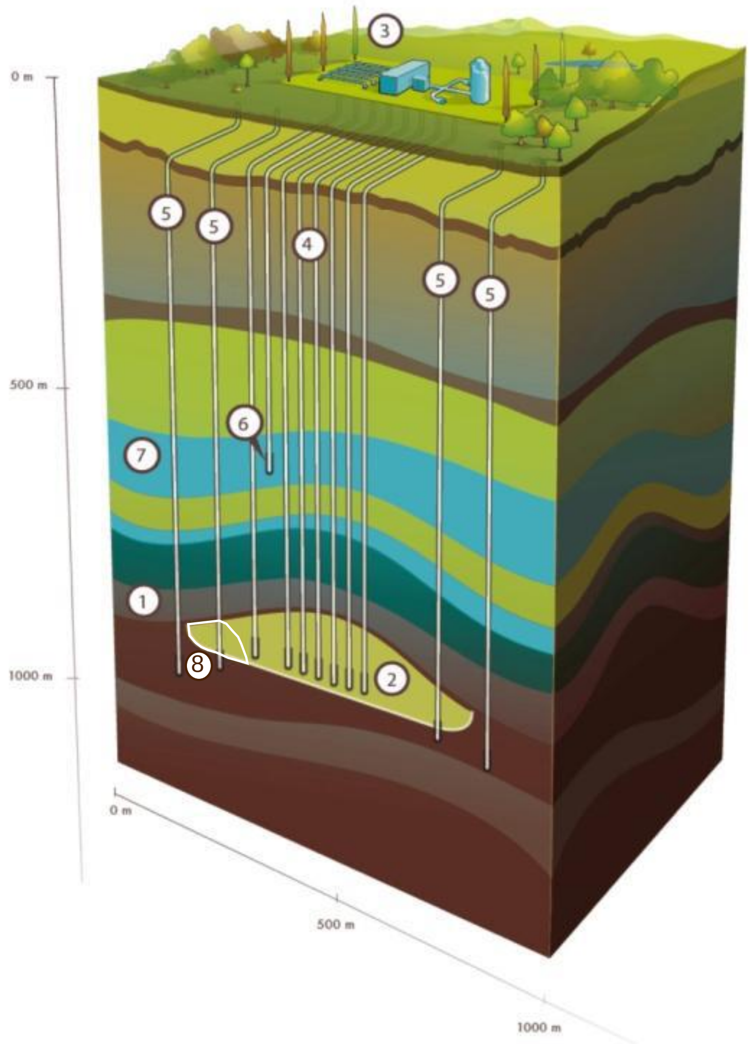
Database: CO_2, O_2, N_2, H_2, CH_4, H_2S, Ar, SF_6, C_2H_6, C_3H_8, C_4H_{10}, CO, He, Kr, Ne, NO, N_2O, Rn, SO_2, Xe

Rostock'H project, Carnot MINES, Chabab et al., 2020

3

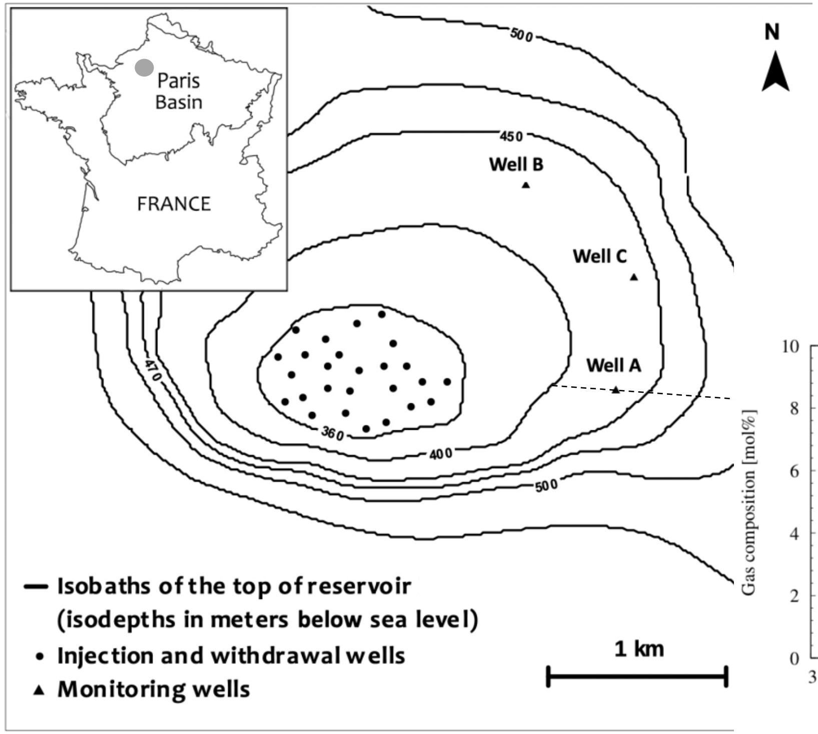
Gas storage: oxygen reactivity

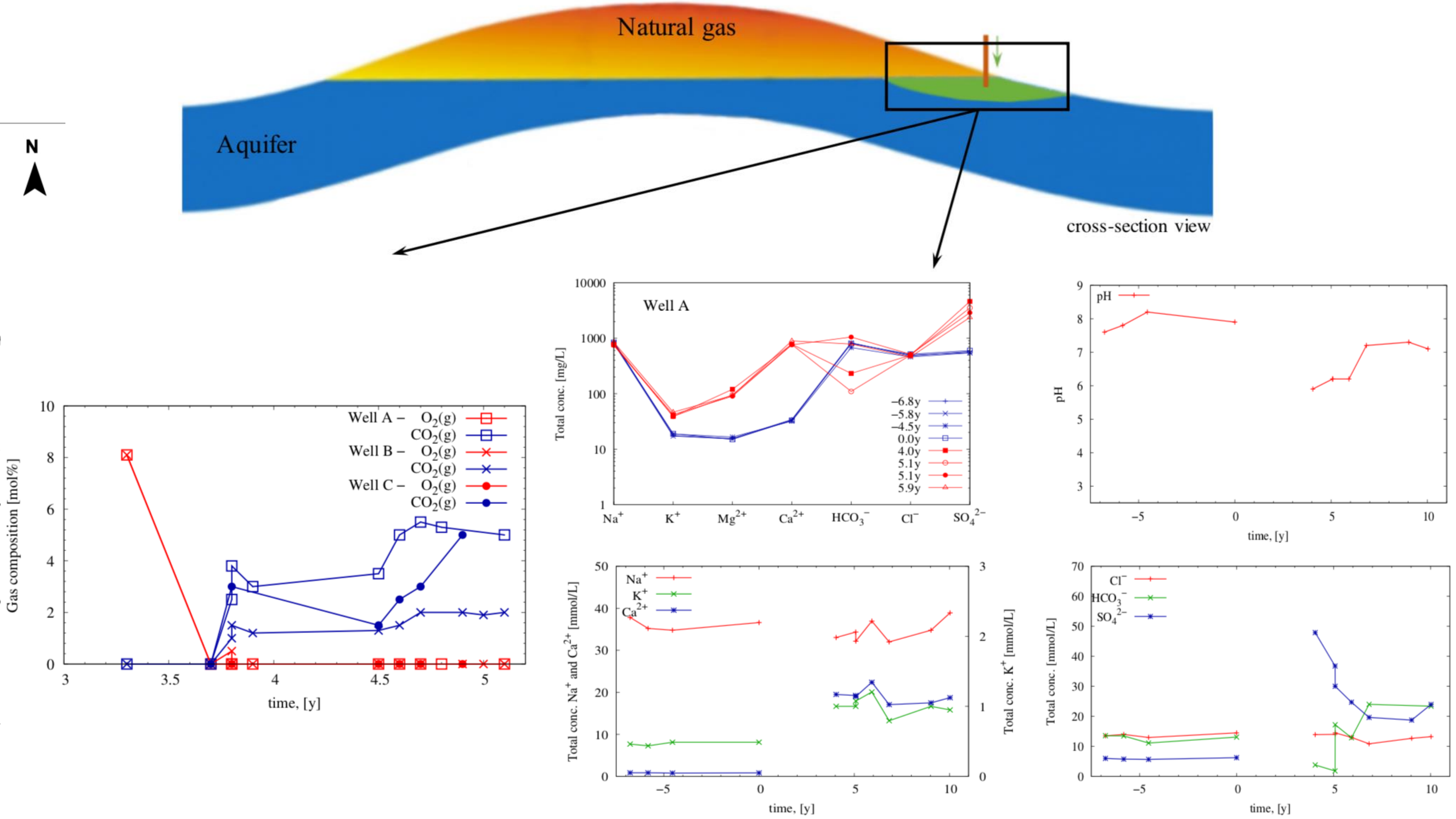
Air injection into a sandstone reservoir (the Paris Basin)



1) Caprock
2) Reservoir
3) Surface facilities
4) Injection and withdrawal wells
5) Monitoring wells
6) Monitoring wells of the upper aquifer
7) Upper aquifer
8) Cushion gas with O_2-depleted air

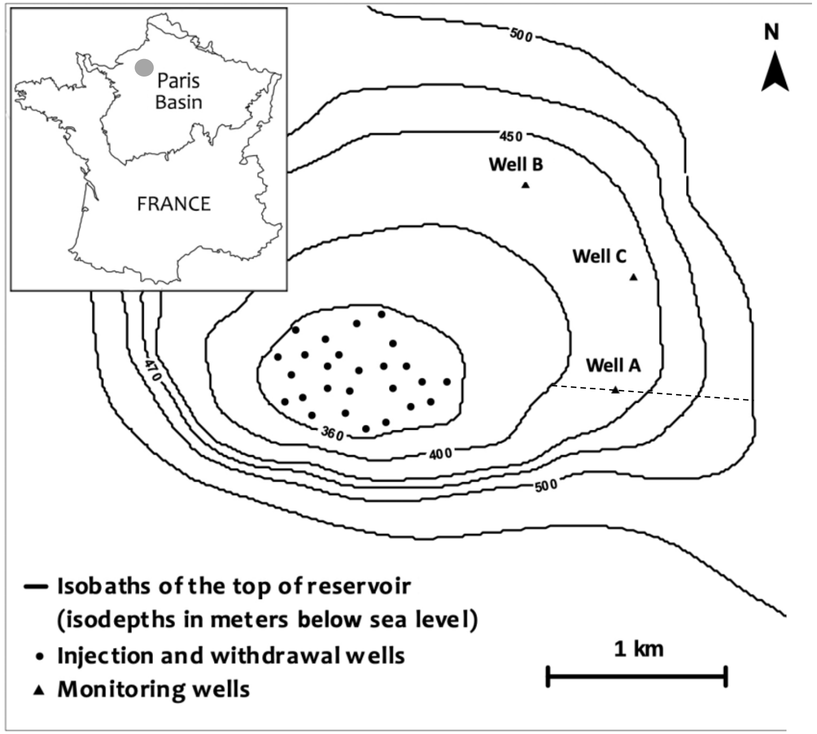
Air injection into a sandstone reservoir (the Paris Basin)

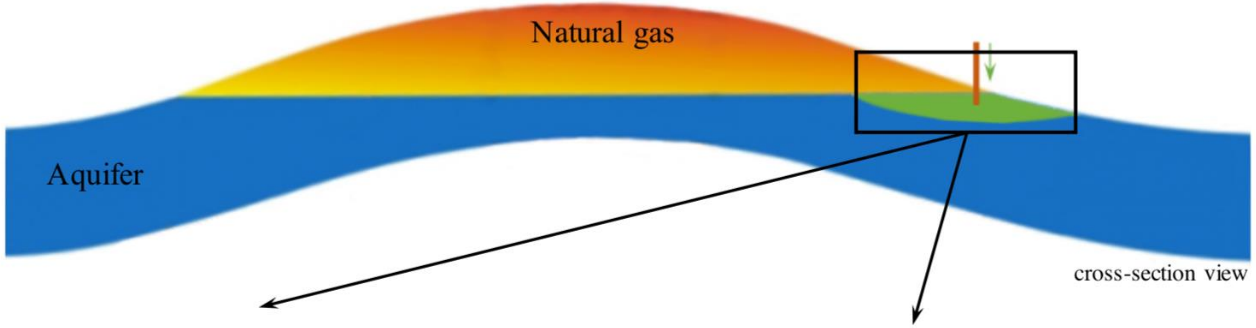


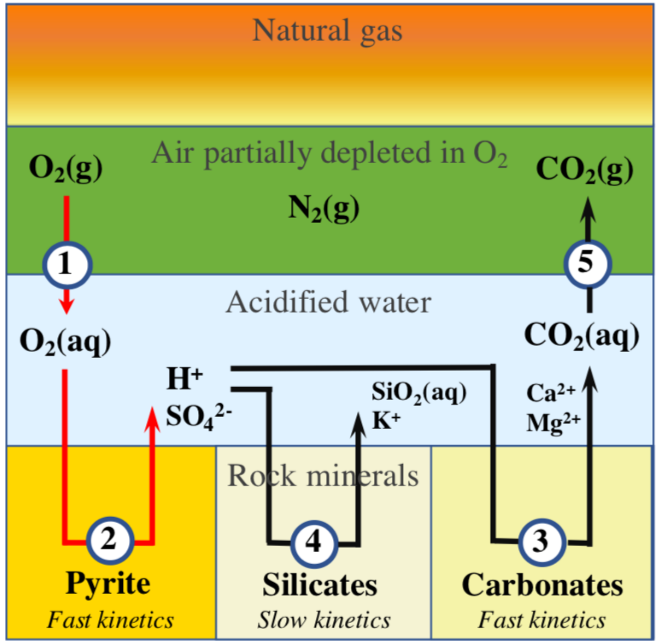


▶ What are the key mechanisms? What impact on the aquifer?

Gas-water-rock interactions







- Cushion gas: N_2, Ar, O_2
- Phase equilibrium of gases + $H_2O(g)$

$$O_2(aq) \rightleftharpoons O_2(g)$$

- Pyrite oxydation

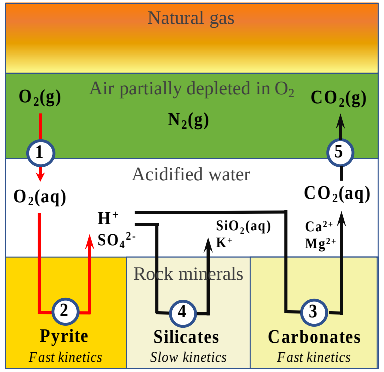
$$\text{Pyrite} + 3.75O_2(aq) + 2.5H_2O \longrightarrow \text{Goethite} + 2SO_4^{2-} + 4H^+$$

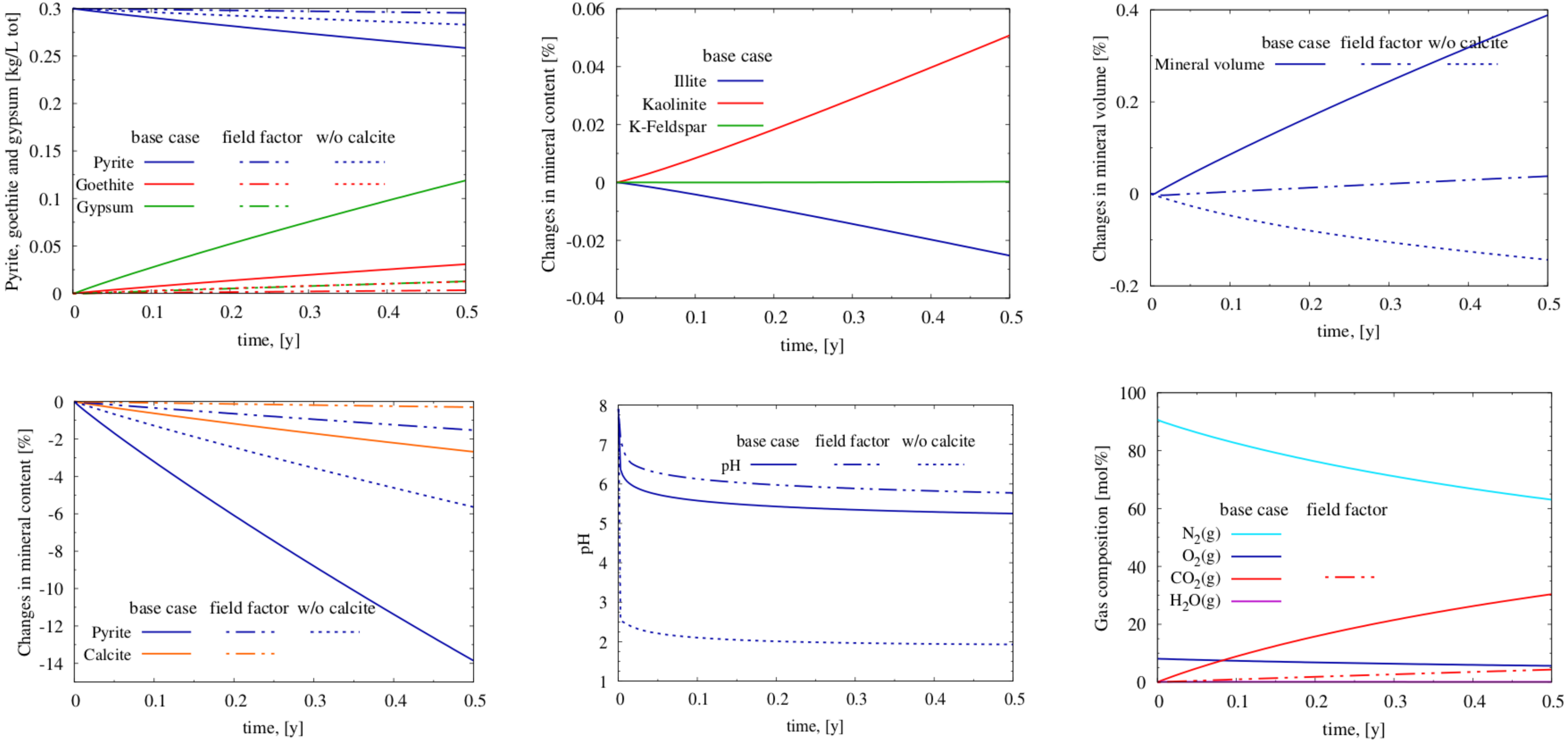
- Dissolution of calcite
  $\text{Calcite} + 2\,H^+ \longrightarrow Ca^{2+} + CO_2(aq) + H_2O$
- Exsolution of CO_2

$$CO_2(aq) \rightleftharpoons CO_2(g)$$

- What are the key mechanisms? What impact on the aquifer?

Gas-water-rock interactions: batch modelling





+ Available data (borehole water sampling and gas composition before and after injection) are used to establish the model.
+ Representation of major mechanisms vs site data.
- Closed system → production of CO_2 is overestimated.
➢ Reactive transport model is needed.

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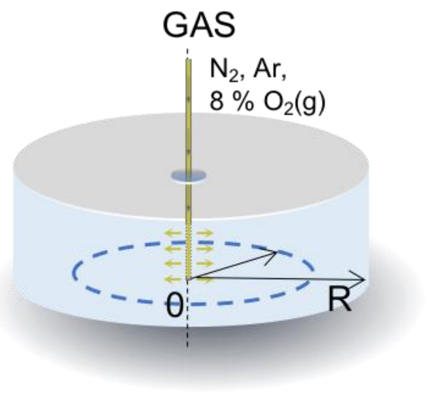
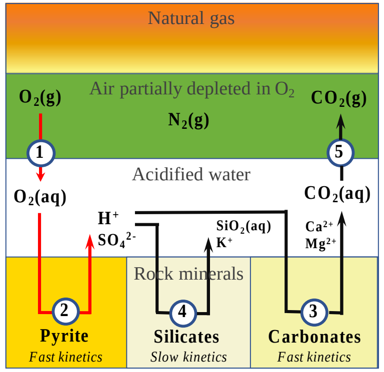
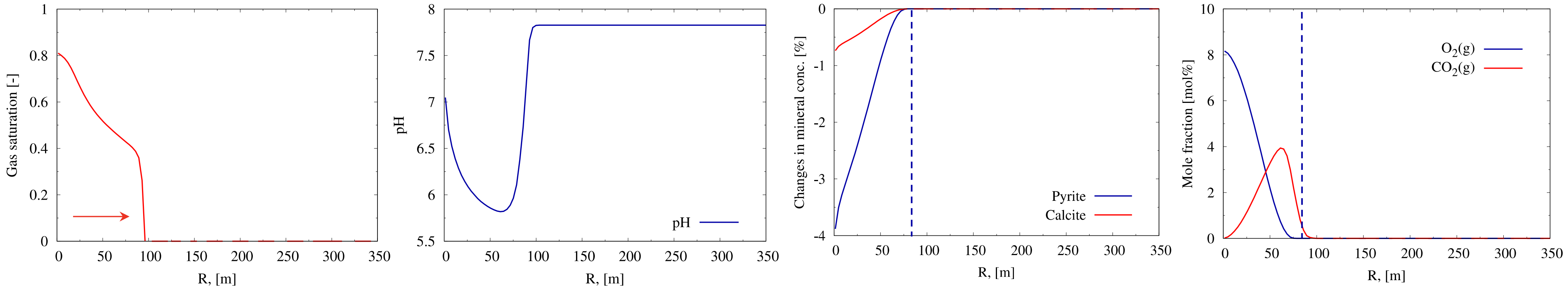
Radial 1D reactive transport model

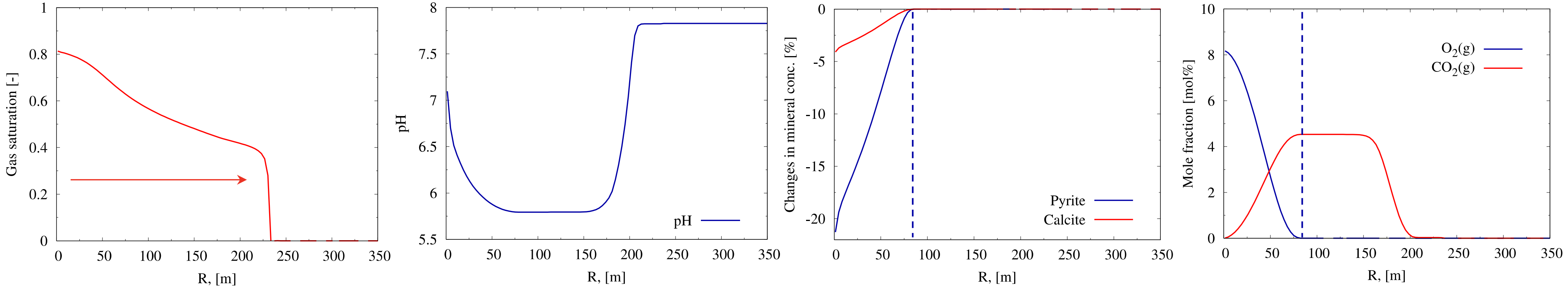




30 days

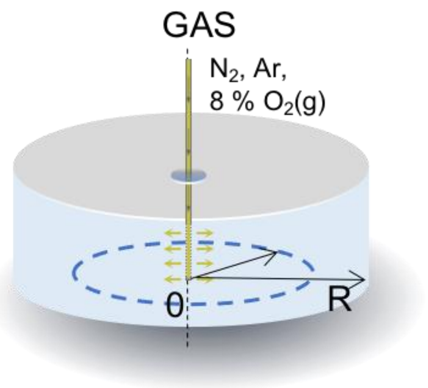


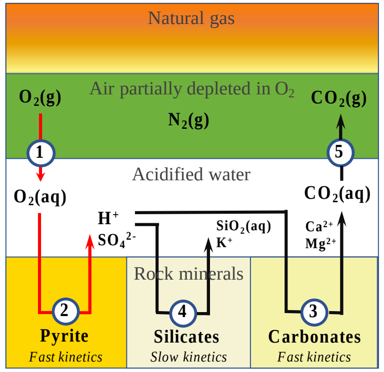
0.5 yr



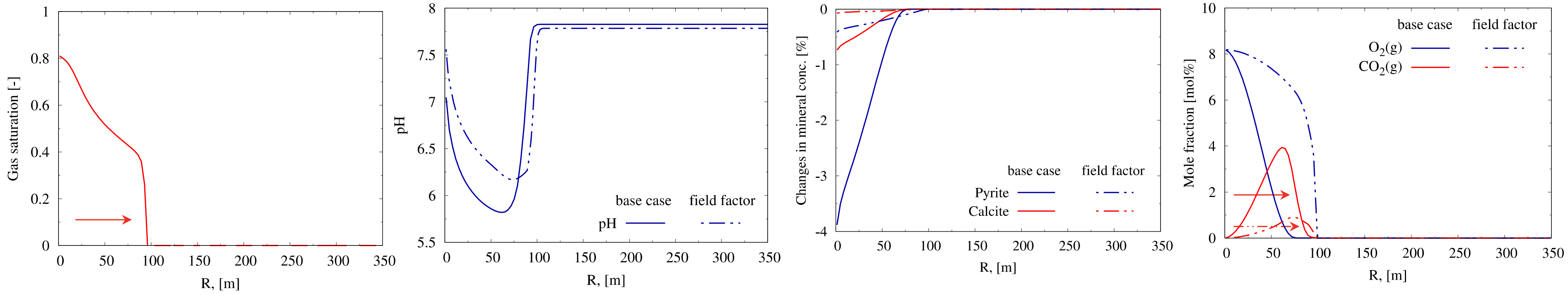
- Dissolution of pyrite/calcite → goethite/gypsum
- ! 22% of pyrite is dissolved. Rapid O_2 consumption (same profiles at 30 d and 0.5 yr)
- ! CO_2 accumulation grows with time, > 4 mol%
- ➢ A slower kinetics is needed

Radial 1D reactive transport model

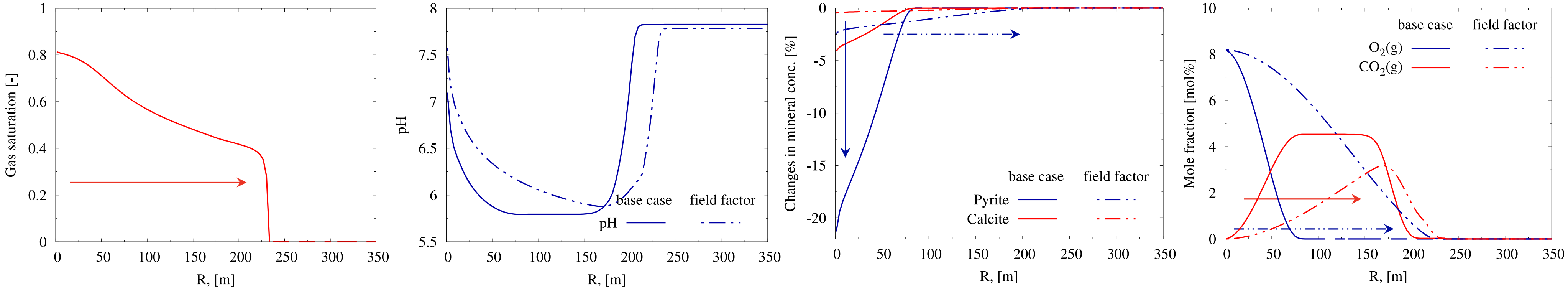




30 days

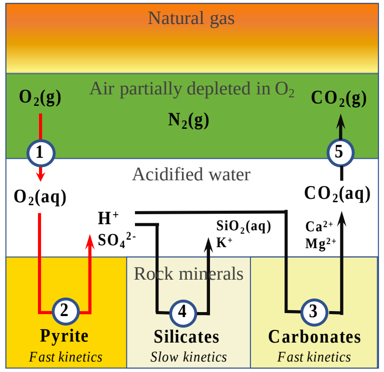


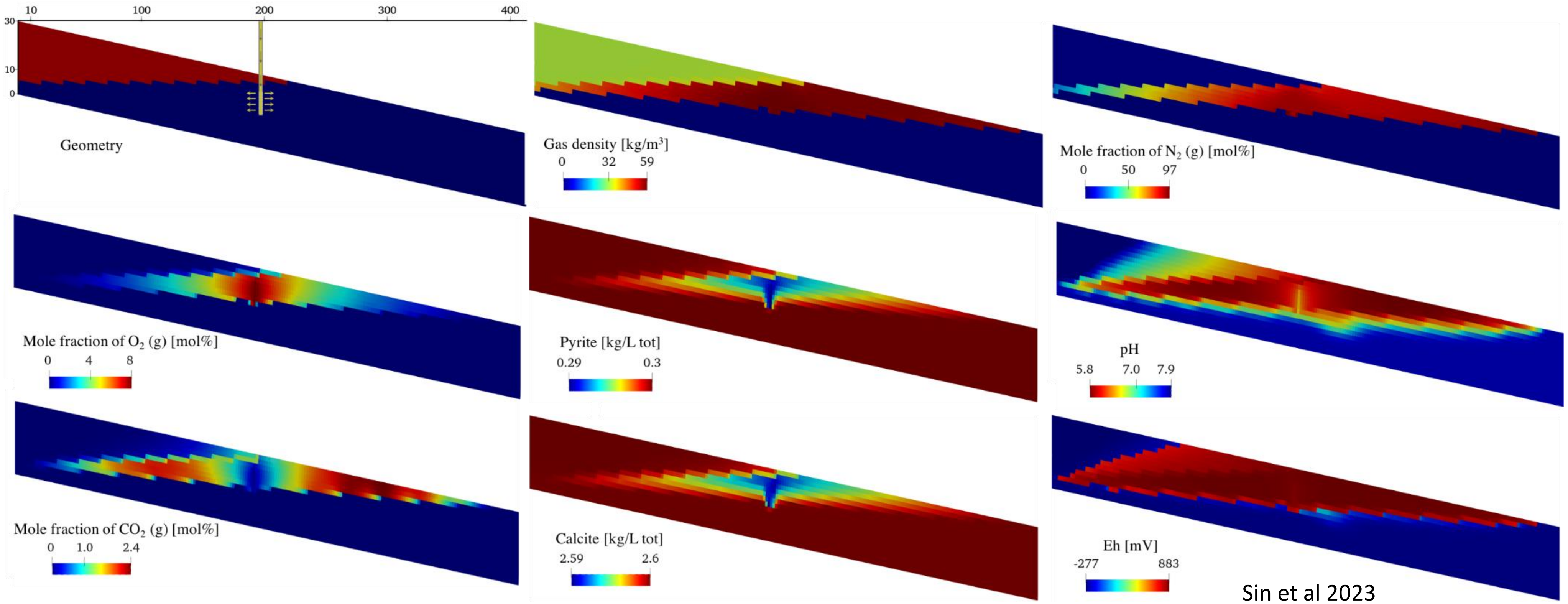
0.5 yr



- Slower kinetics → ~2% of pyrite is dissolved.
- Slower O_2 consumption → O_2 can be transported further → pyrite oxydation not only at near-wellbore zone.
- Damköhler number is analysed, confirms the results.
- CO_2 accumulation still grows with time, ~ 3 mol%
- ➢ Radial 2D reactive transport model is needed…

Reactive transport model at reservoir scale





Sin et al 2023

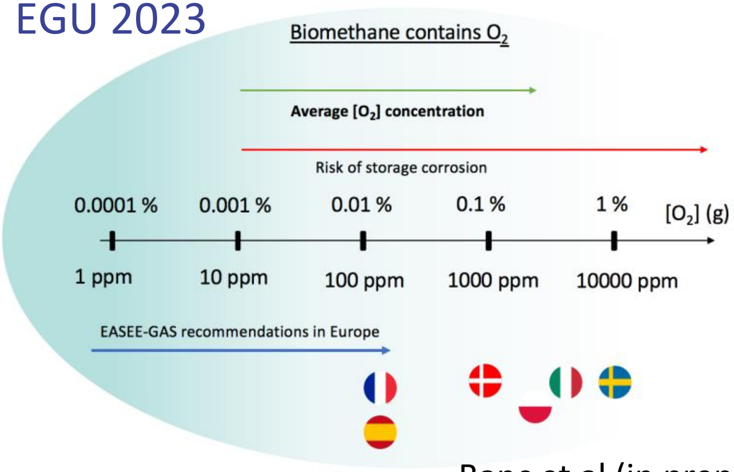
- + Pyrite kinetics is a key factor: Damköhler number derived for O2 reactivity and pyrite kinetics explains gas changes.
- + The multiphase reactive transport model was built based on the field data. From batch to reservoir scales.
- ! Importance of reactive transport -> geometry/scale changing is game changing
- + This workflow can be applied for gas storage facilities (compressed air, biomethane, H_2)

4 Extension to other gases

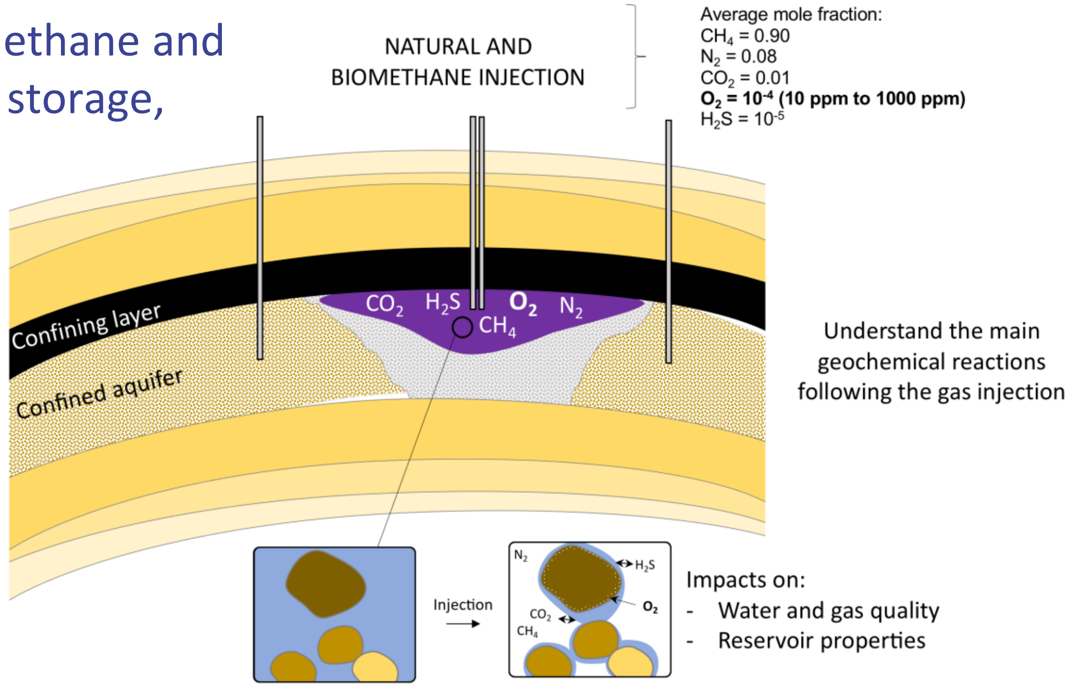
Extension to other gases

- **Biomethane and natural gas**

Evaluation of the geochemical impact of biomethane and natural gas mix injection in sandstone aquifer storage, EGU 2023



Banc et al (in preparation)



- **Hydrogen**
  - Additional complexity: microbial activity, parametrization of models.
  - Modelling experiments (Haddad et al 2022 etc) with Monod like laws
  - Upscaling, integrating to the storage model

HYTEC and consortium PGT

PGT Pôle Géochimie Transport
Reactive Transport Group

Since 2000, **PGT**

- shared funding
- shared scientific research
- shared expertise

PGT V 2020 - 2023

Thank you !

Technical Challenges

Acknowledgment

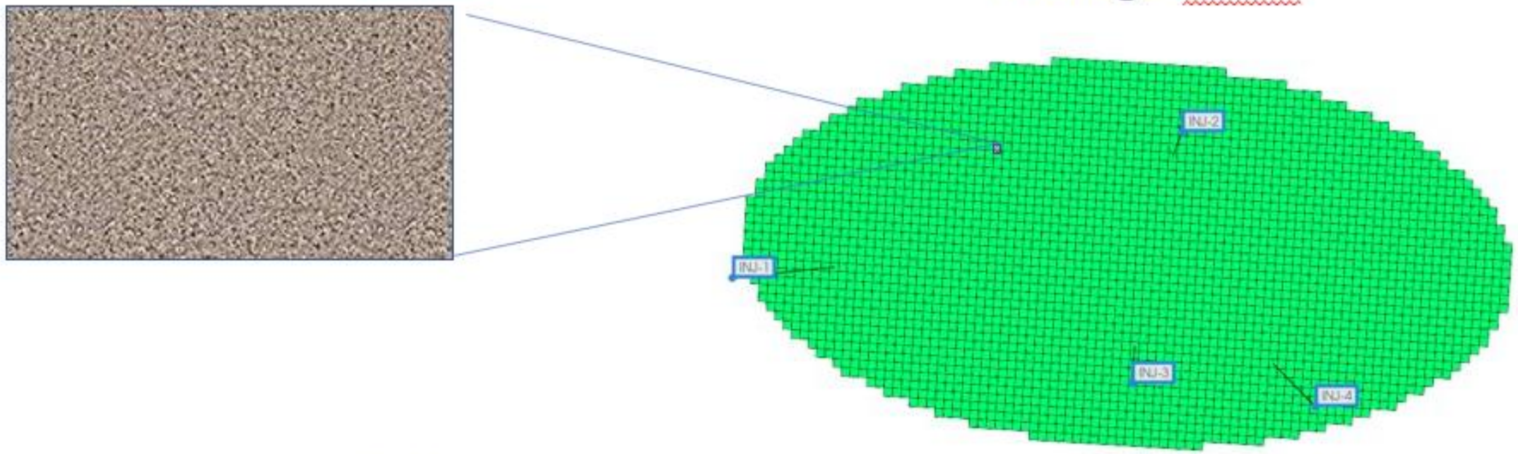
The Project is co-founded by European Union

Clean Hydrogen Partnership

06/06/2023

Technical Challenges

Representativeness of laboratory tests, compared to field observation

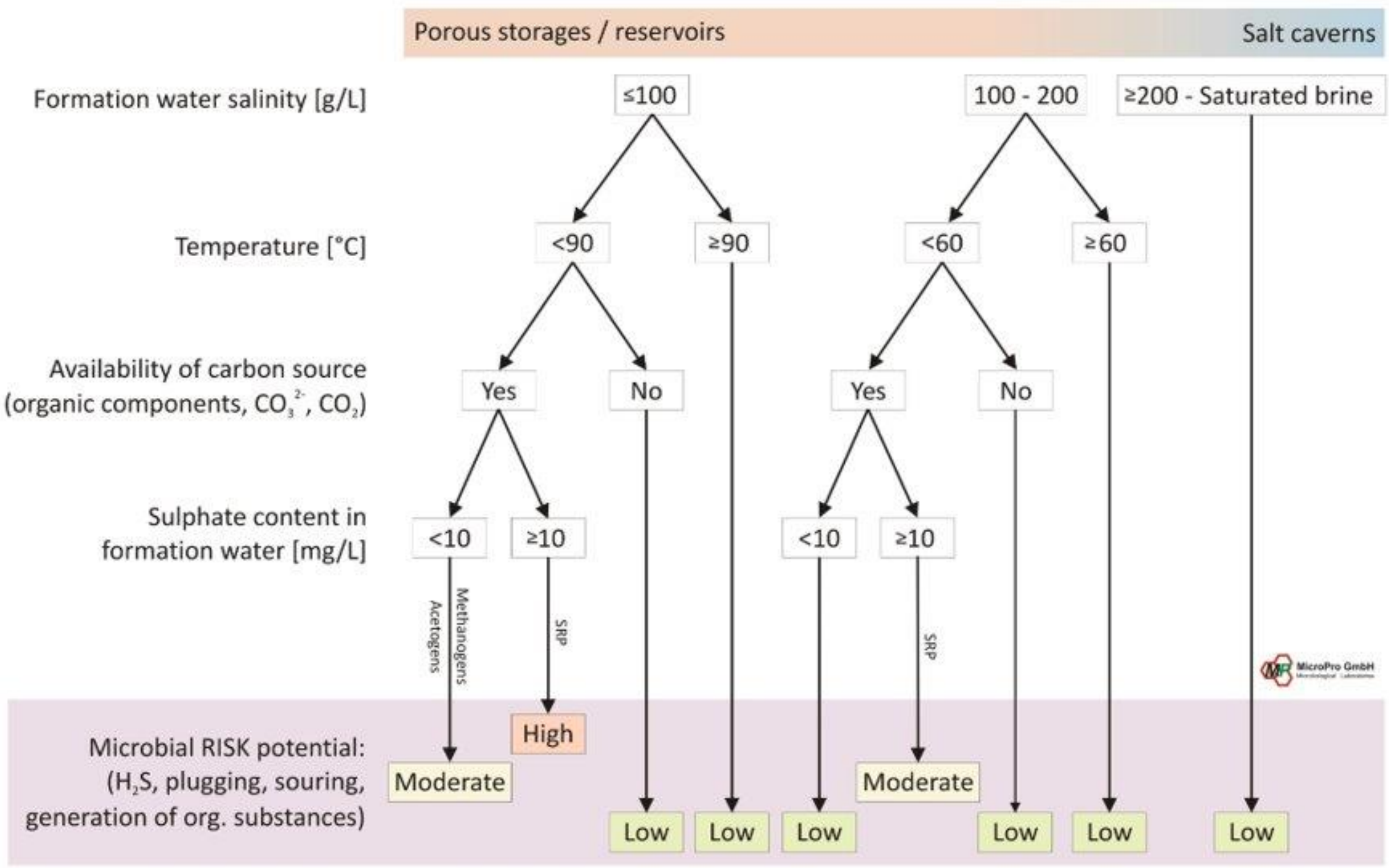
Experiment	grid block scale	Storage scale
		
Volume =1.5 10^{-3} m^3	50*50*10=25 10^{+3} m^3	~370 10^{+6} m^3
Rock / Fluid ratio = 11 / 89	80 / 20 if porosity = 20%	
Optimal growth conditions	**Starving conditions**	

Upscaling factor to damp the reactivity between laboratory and storage conditions

Technical Challenges

Bacteria Reactivity Assessment Risk depending on storage type / Definition of the most favorable environment for hydrogen storage

Simplified chart for the assessment of microbial risks



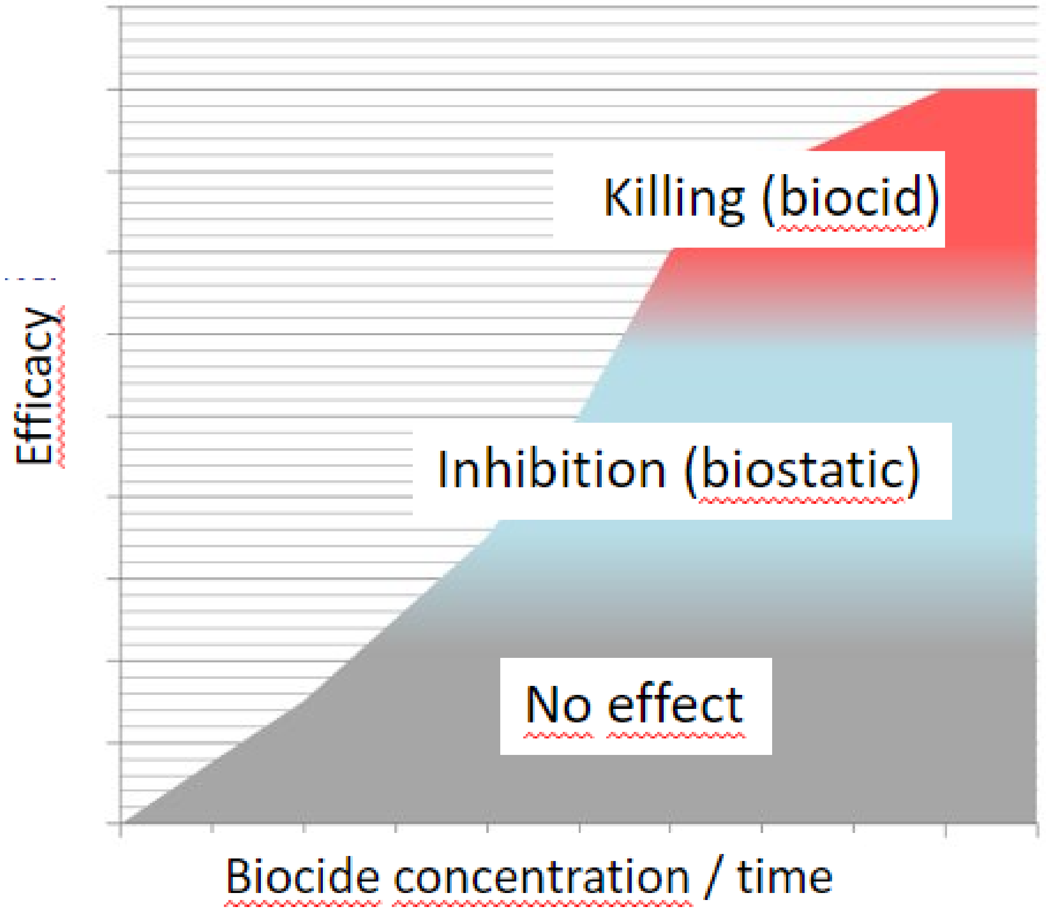
Risk assessment
Low risk (almost no microbial activity or extremely limited)
Moderate risk (though there is inhibition for some microbial groups, there are development of some microorganisms)
High risk (conditions are optimum for many microorganisms in UGS)

Technical Challenges

Mitigations solutions for environment that are less favorable

Biocides in porous reservoirs:

- are diluted in porous storages with increasing distance from the injection well
- become ineffective if the concentration falls below the effective concentration due to dilution
- can be degraded or even serve as nutrients themselves
- do not distribute ideally in the pore space, as the liquids do not migrate evenly in the layer



Hystories project consortium

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Thank for your attention !