Modeling CO_2 dynamics in the subsurface

P. Audigane (BRGM) et L. Trenty (IFP)

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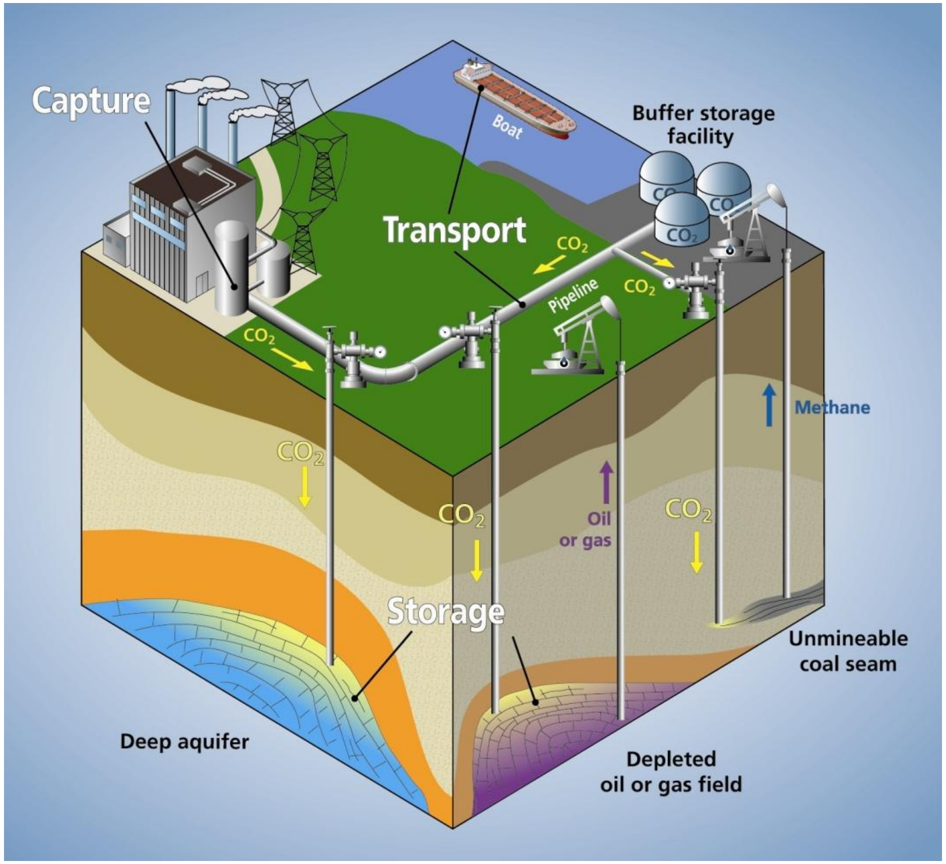
Economic and Environmental issues

Role for CO_2 geological storage modelling



- Select site,
- Optimise CO_2 injection and storage plume,
- Control storage complex,
- Help the surveillance,
- Educate public and authorities

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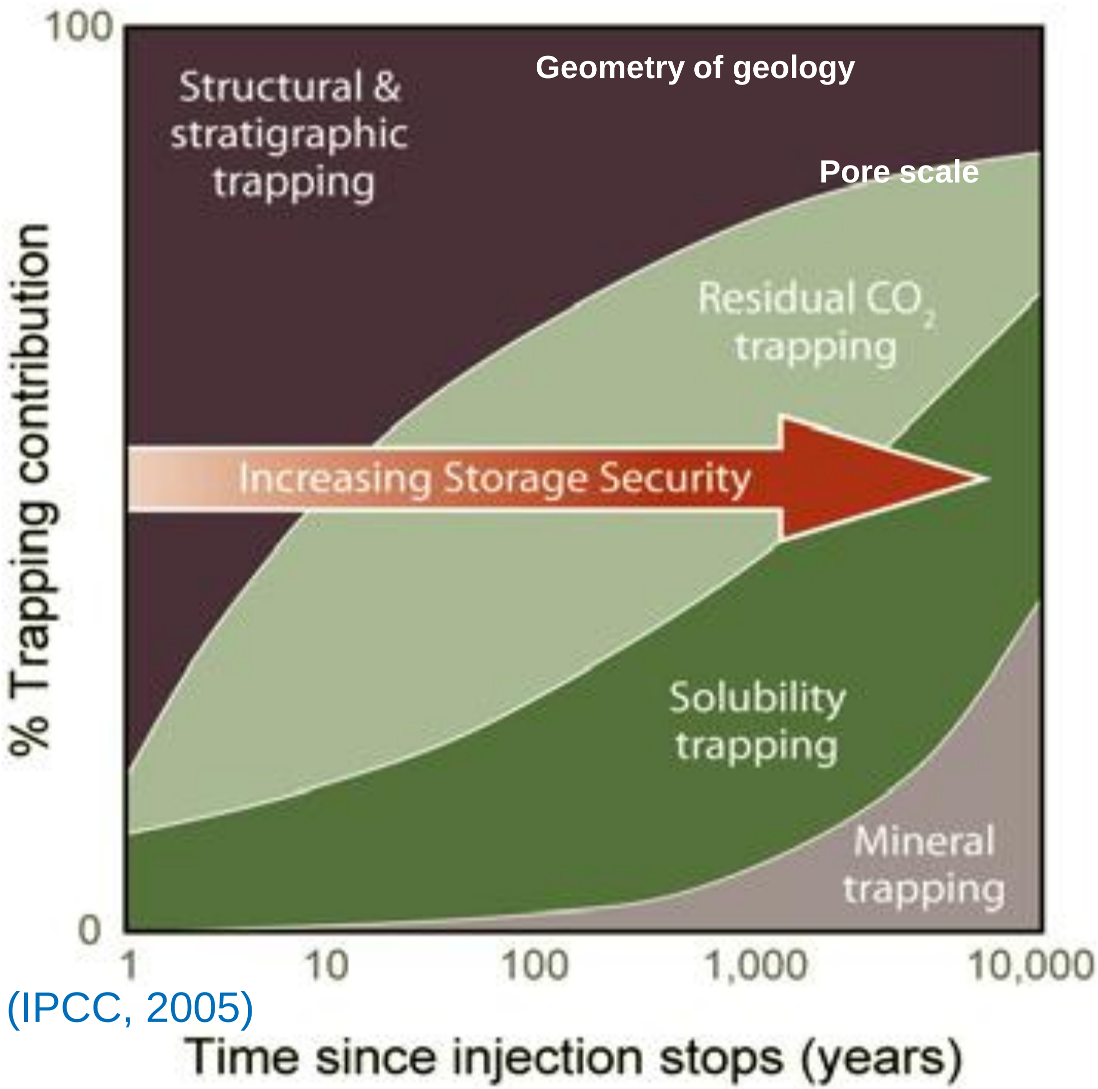
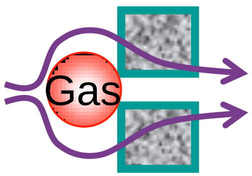
Different trapping mechanisms
Different characteristics time



(IPCC, 2005)

Residual trapping



Solubility trapping

Mineral trapping

Technical challenges: multi-physic approach

Brine | Issues | Free CO_2

CO_2 Supercritical injection

Water dissolution

Pressure increase

Modelling

Geochemical reaction

Geomechanical effect

updating petrophysical properties

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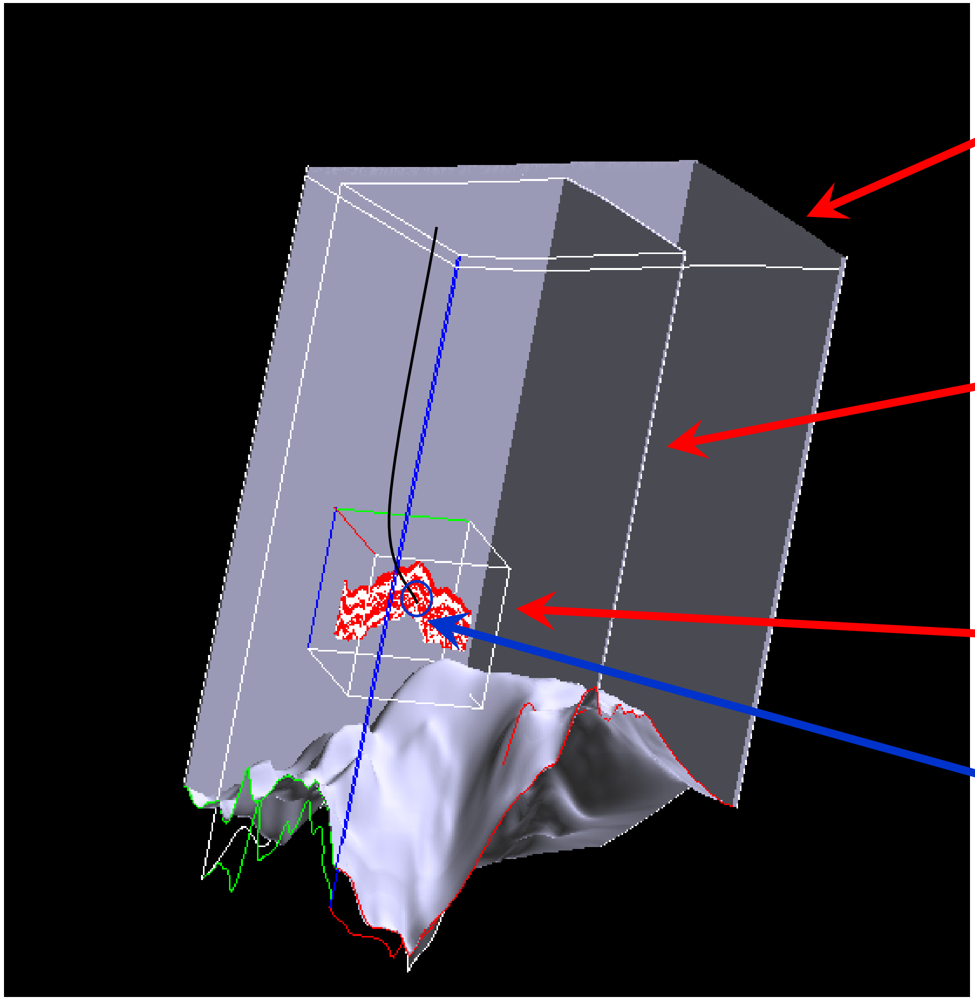
Technical challenges: multi-scale approach



Basin scale

Storage Complex scale

Storage scale

Near wellbore scale

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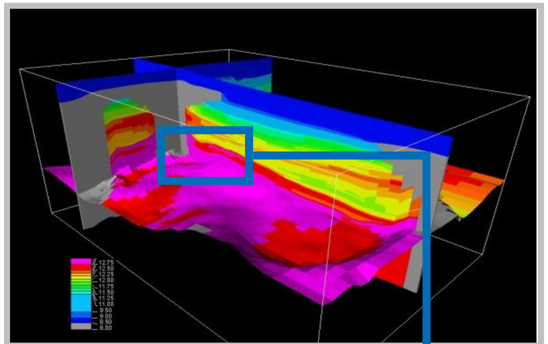
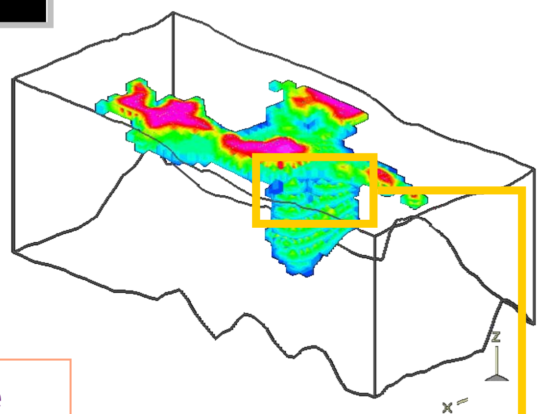
Technical challenges: Integrated modelling



Characteristics hydrogeologic analysis

Basin scale

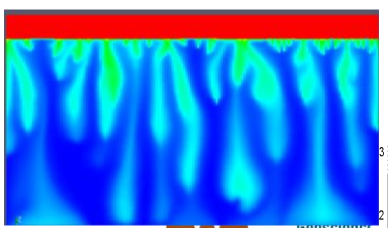


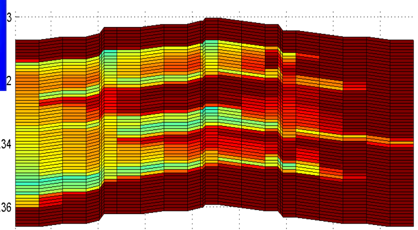
Migration mechanism analysis during injection

Fluid rock interactions analysis

Site scale

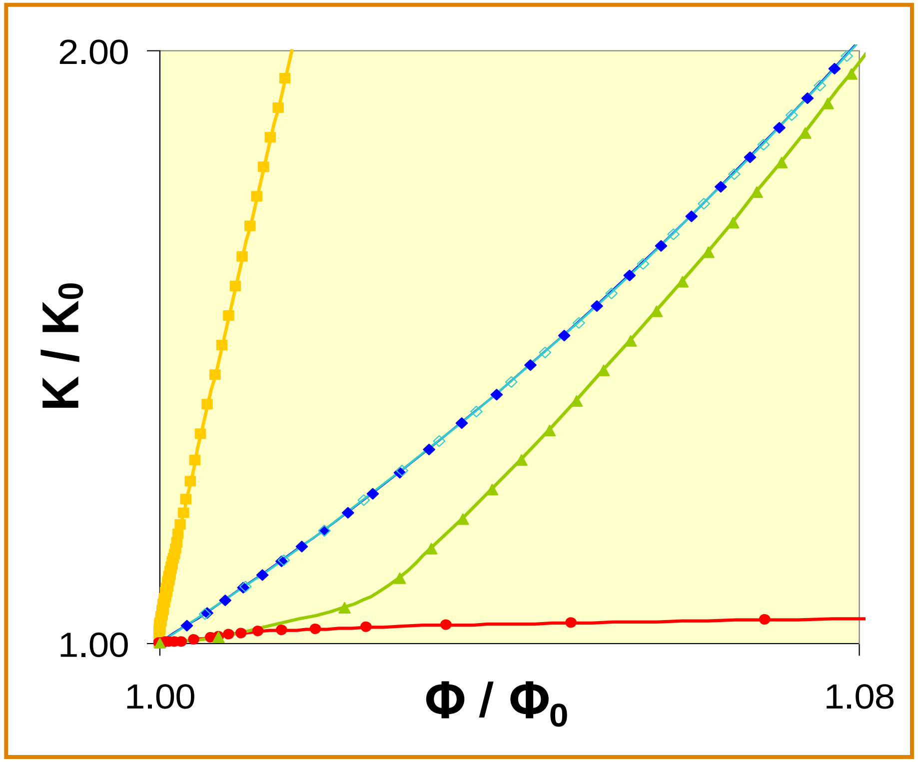
Each scale brings a part of necessary information





Local scale

Application at local scale: upscaling petrophysical data



L. Algive and S. Bekri (IFP - 2009)

- Use of a PNM experimentally calibrated to:
  - various flow rates (Pe)
  - various reaction intensity (PeDa)

low PeDa & low Pe

low PeDa & high Pe

high PeDa & high Pe

high PeDa & low Pe

high PeDa & Pe increasing

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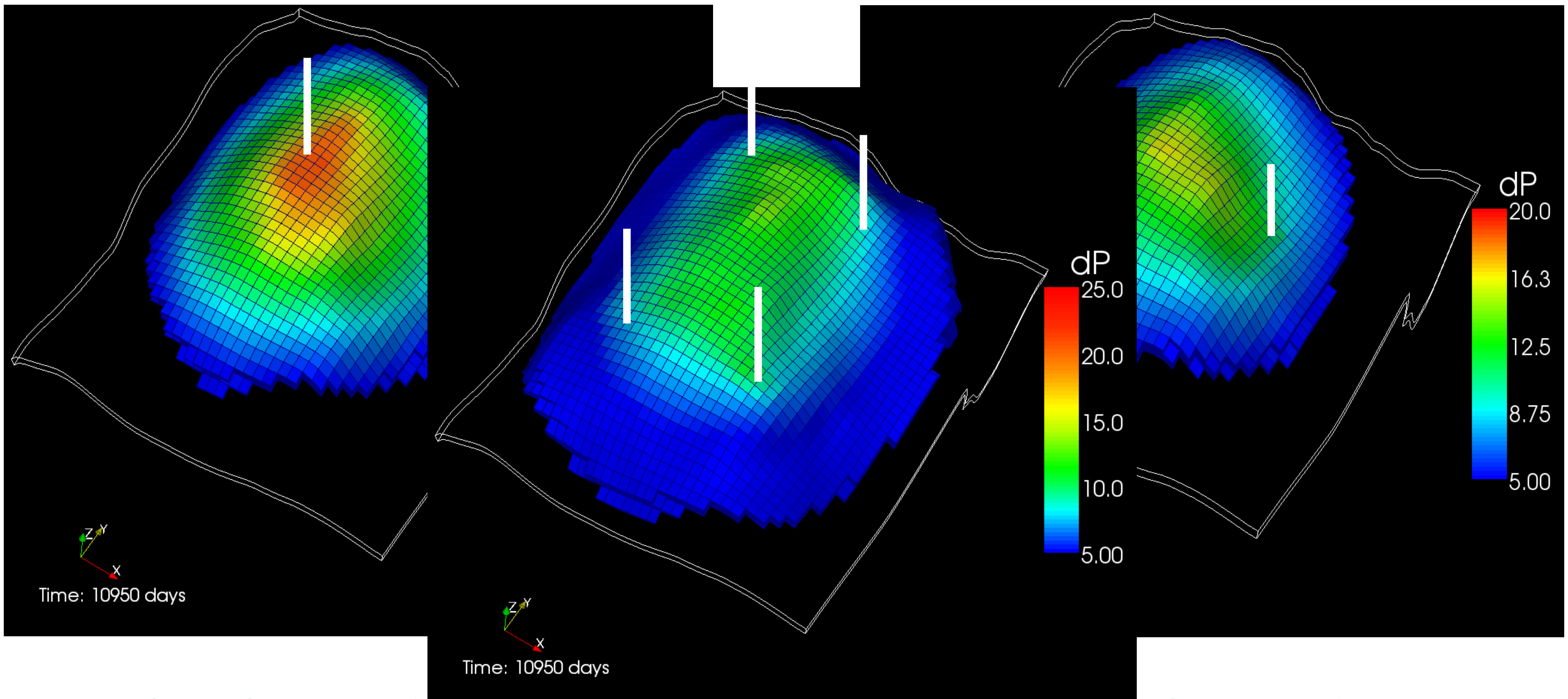
Application at site scale: control over pressure



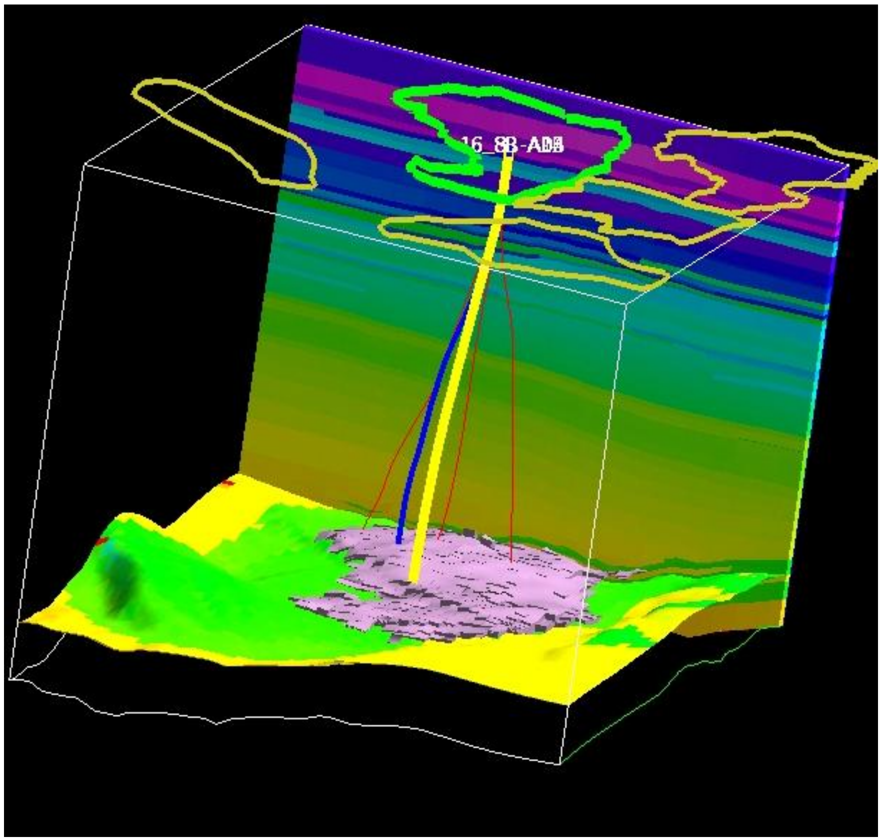
maximum increase of pressure due to injection : 23.5 bar

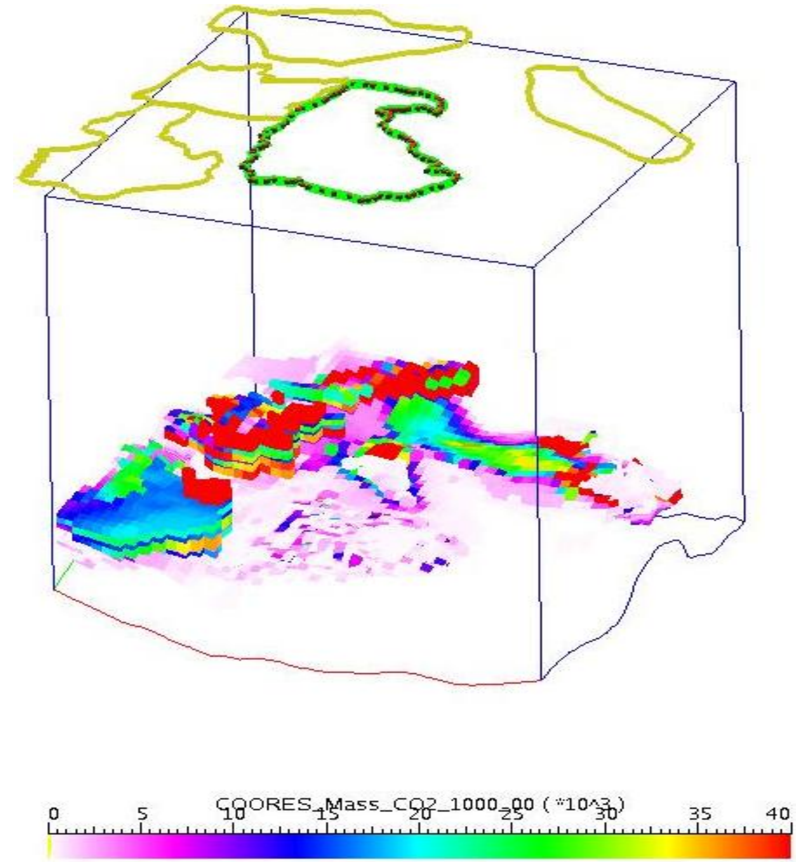
maximum increase of pressure due to injection : 18.4 bar

maximum increase of pressure due to injection : 13.2 bar

N. Maurand (IFP - 2009) - Dynamis

Application at basin scale: check the integrity of the storage





Y. Le Gallo and L. Trenty (GEOGREEN/IFP)

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Listing of numerical codes

Models at a Glance

Name	Affiliation	Developers[1]	Status[2]	Phase transition	Geo-chemistry	Thermal	Solid matrix Deformation	Discretization method (space)	Discretization method (time)	Wells & fractures
Athena	U. of Bergen	Heimsund	○	○	○	○	✗	MPFA (FV)	Implicit	No special treatment
CSLS	Stanford U.	Gerritsen Jessen	○	✓	✗	✗	✗	Pressure: MPFA Flow: Streamline	MMOC along streamlines	No special treatment
Spectral	Stanford U.	(Gerritsen)	✓	✓	✗	✗	✗	Spectral Galerkin	Explicit 4th order	Homogeneous medium
EOS7C	LBNL	Oldenburg	○	✓	✗	✓	✗	FD	Implicit	No special treatment
Dynaflow	Princeton U.	Prevost	✓	✓	○	○	✓	MFEM, VCFV, CCFV	Implicit	No special treatment
Elsa	Princeton U. U of Bergen	Nordbotten Kavetski	○	○	✗	✗	✗	Semi-Analytical	IMPES and fully implicit	1D wells with Darcy flow
FEHM	LANL	Pawar Viswanathan	○	✓	✓	✓	✓	Integrated FV	Implicit	Coupled wellbore flow; Dual porosity
GEM-GHG	Comp. Mod. Grp. U. of Texas	(Bryant)	✓	✓	✓	✓	✗	Adaptive grid, FD	Implicit	Line source/sink wells
MUFTE_UG	U. of Stuttgart U. of Heidelberg	Bielinski Ebigbo	✓	✓	○	✓	✗	Box method (FV)	Implicit or high order schemes	Lower dim. wells/ fractures planned
NUFT/LDEC/ GEMBOCHS	LLNL	Johnson	✓	✓	✓	✓	✓	FD, FE	Transport implicit Deform explicit	Dual porosity
PFLOTRAN	LANL	(Carey)	○	✓	✓	✓	✗	Integrated FV	Implicit	No special modes
STOMP	PNNL Battelle	White	✓	✓	✓	✓	✗	Integral FV	1st or 2nd order backward Euler	Separate subdomains
TOUGH2 ECO2N/EOSM	LBNL	Pruess	✓/○	✓	✓	✓	✗	Integrated FD	Implicit	Multi-continua models
TOUGHREACT	LBNL	(Pruess)	✓	✓	✓	✓	✗	Integrated FD	Implicit	Multi-continua
CO2-PENS	LANL	Viswanathan	○	A systems level code used to integrate the process models into comprehensive systems model						
T2CA	LBNL	Oldenburg	○	A TOUGH2 module for coupled subsurface-atmosphere transport of water, brine, CO2, 1 tracer, air						

Study performed by Geogreen

[1] Developers present at workshop. For complete lists, see the questionnaires at the end of this document. Non-developer presenters are indicated with brackets.
[2] Green checks (✓) indicate 'yes' (or 'publicly accessible' for the status column), grey circles (○) 'still in development', and red crosses (✗) 'no'.

COORES	IFP	_	not free	yes	yes	yes	no
ECLIPSE	SLB	_	not free	yes	no	yes	?
SIMED	TNO	_	not free	yes	no	yes	no

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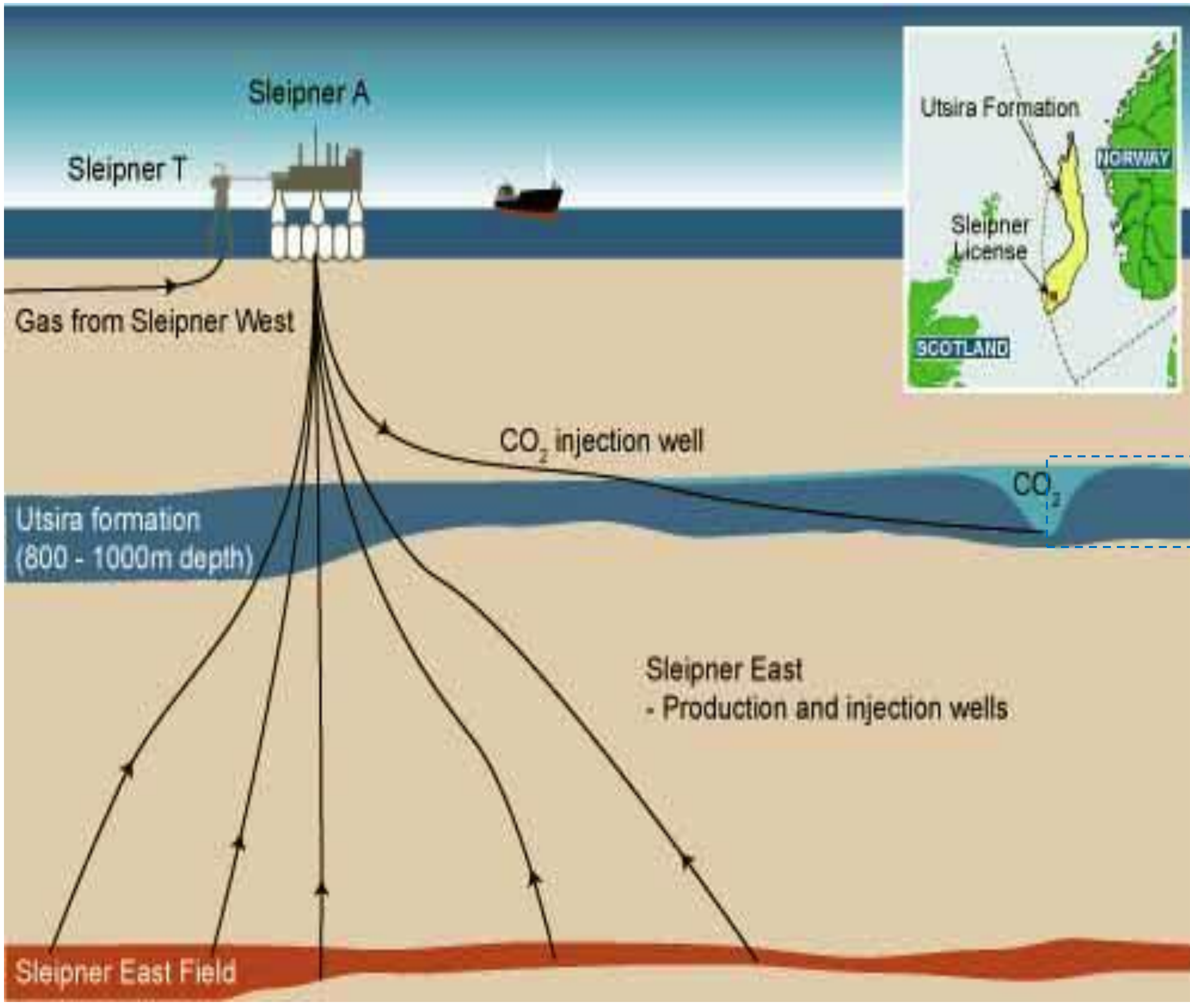
The Sleipner CO2 storage project



2D model
Radial geometry

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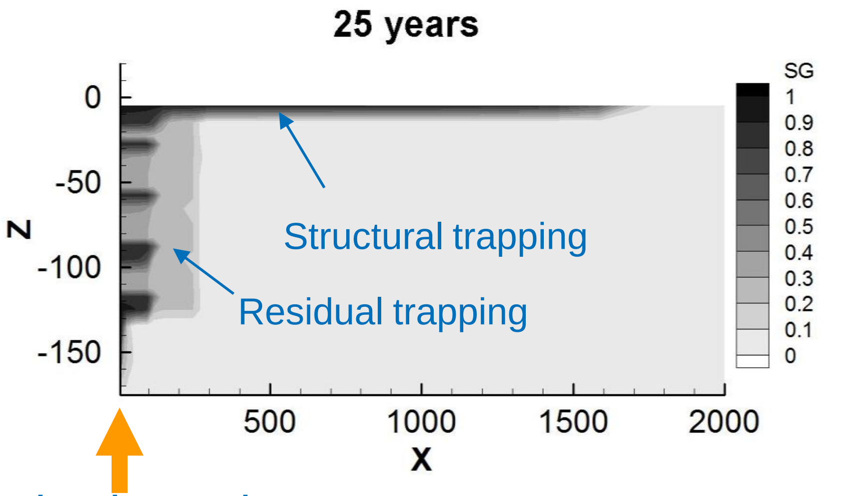
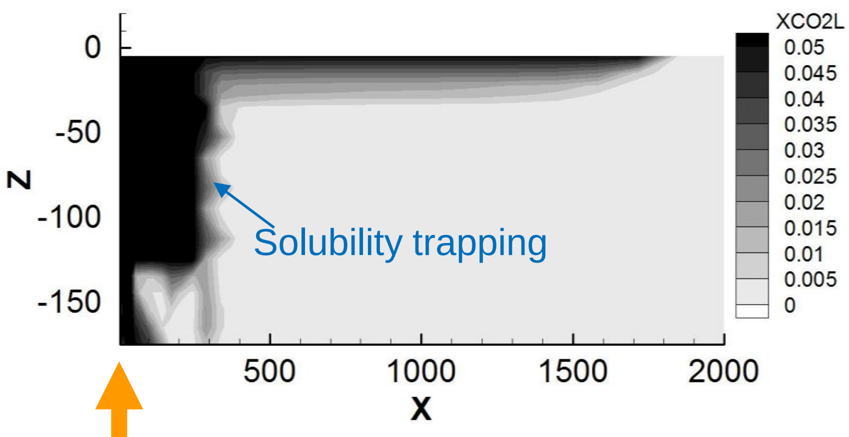
CO2 migration after 25 years of injection



Injection point

Concentration of supercritical CO_2 in the reservoir

Note the accumulations under the Shale layers



Injection point

Amount of dissolved CO_2 in the water (mass fraction)

- Above the injection point maximum saturation is reached
- At the edges we see lower saturation ranges

Audigane et al., 2007, Am. J. Sc.

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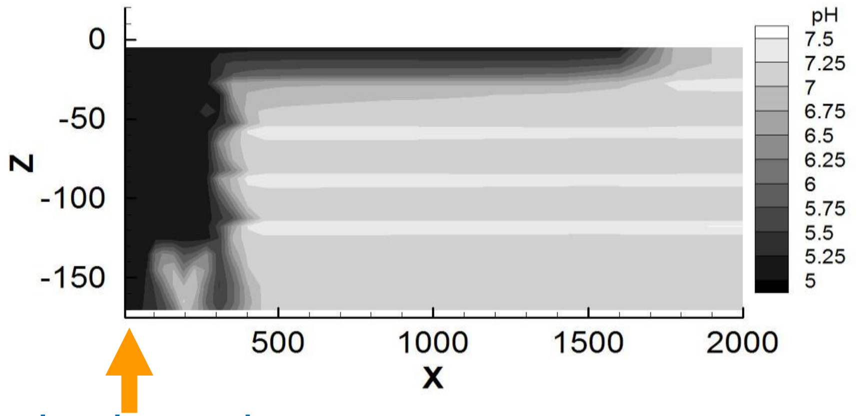
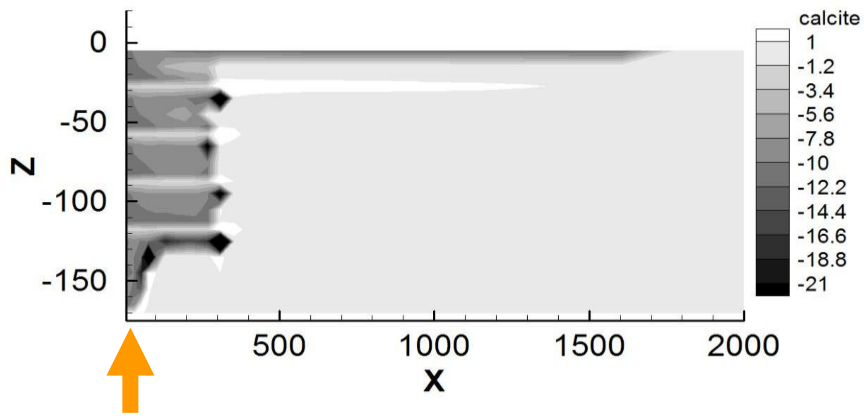
Effects of CO2 dissolution after 25 years of injection

25 years



Injection point



Injection point

The negative sign corresponds to mineral dissolution

pH change of the water due to CO_2 dissolution.

However pH doesn't decrease below 5.13, due to buffering by calcite dissolution.

Calcite dissolution (mol/kg^3) in the acid water.

The dissolution of calcite is less pronounced in the shales than in the sands. However *some calcite precipitates below each shale layer* at the interface between the CO_2 saturated brine and the initial brine, due to mixing of different waters in these regions.

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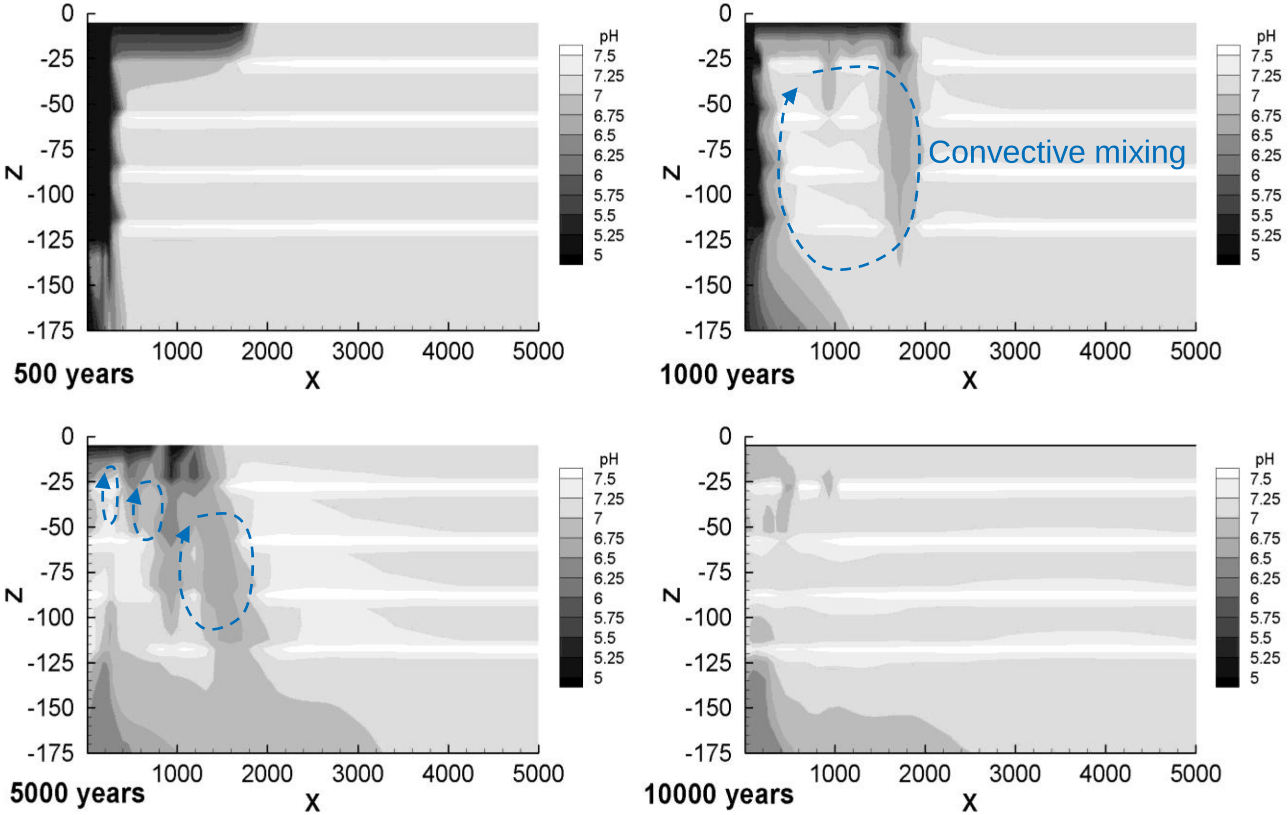
Towards a stabilization of the system…



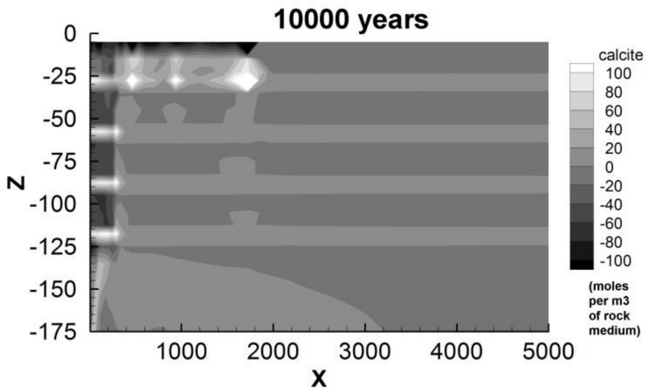
Brine enriched with dissolved CO2 is heavier than the original brine inducing convection and improving dissolution

Dissolution of CO_2 increases the acidity of the brine, but is buffered by carbonate dissolution

Maximum decrease of pH is 5.13

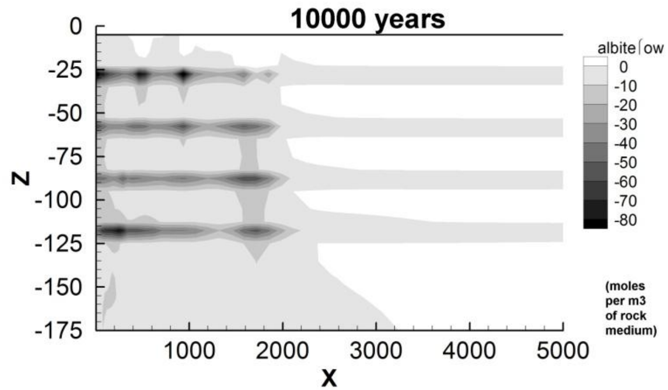
Mineral Trapping

calcite



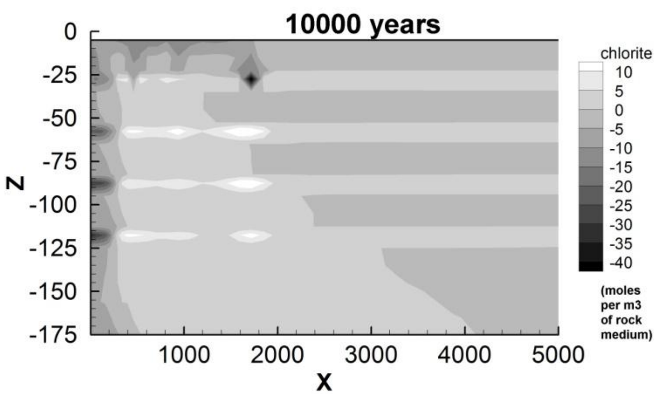
Precipitation of calcite in the shales : consequence of sand-shale cross-flow

albite



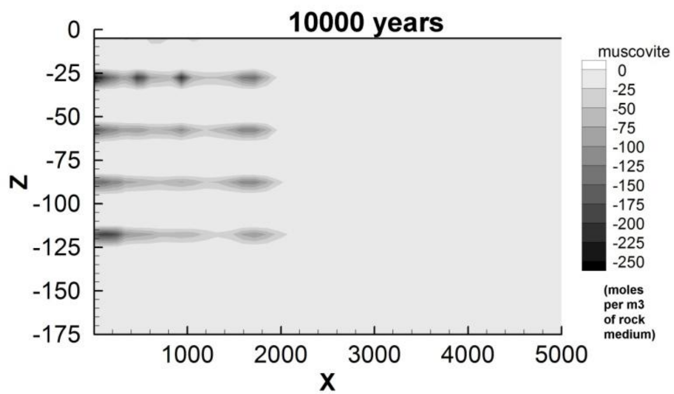
Second CO2 trapping reaction : alteration of albite, leading to the formation of dawsonite and chalcedony

chlorite



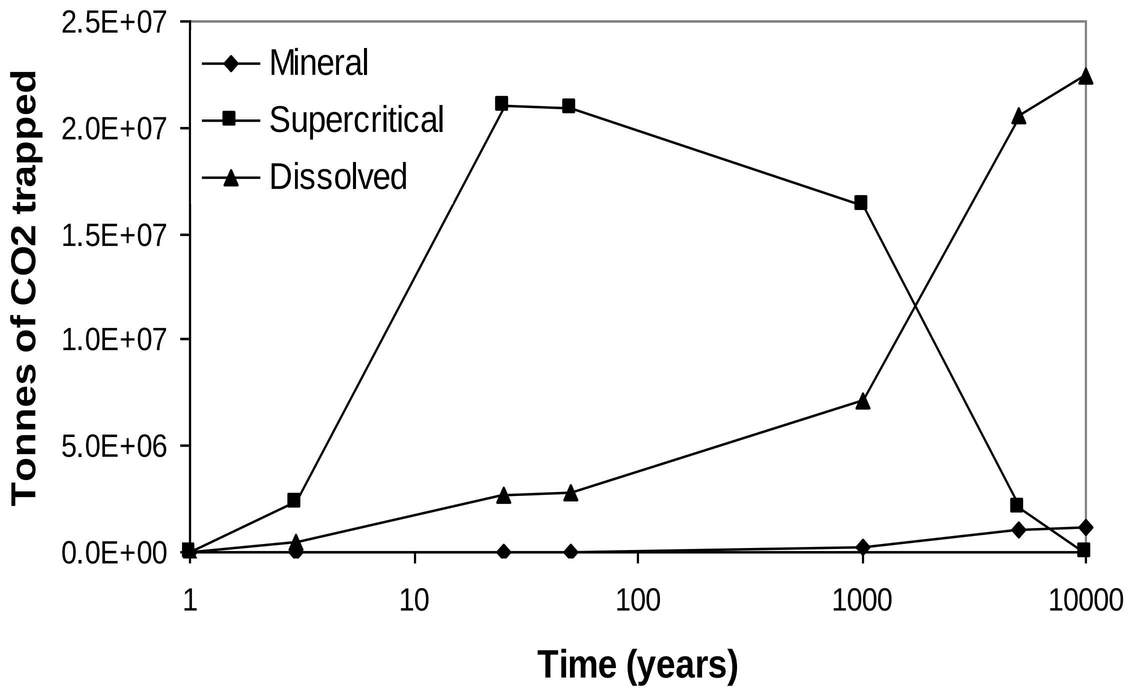
Alteration of chlorite consuming calcite and resulting in the trapping of CO2 into siderite and dolomite

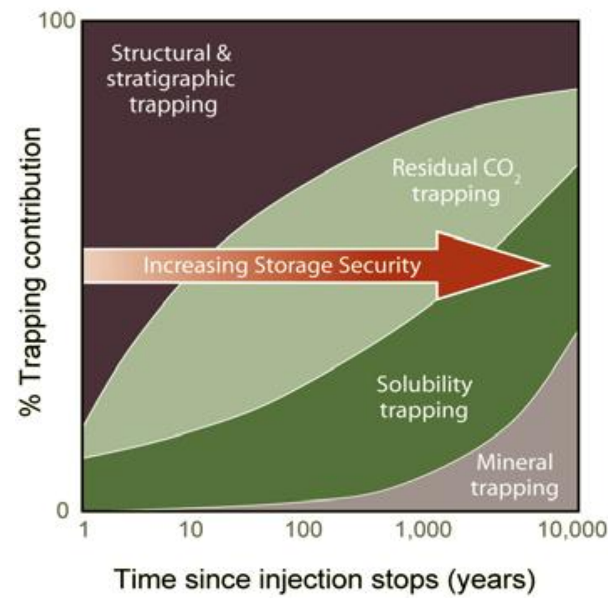
muscovite



Muscovite dissolution favors albite and chlorite dissolution

Amount of CO_2 stored





Total amounts of carbon dioxide present as a free (supercritical) gas phase, dissolved in the aqueous phase, and trapped in carbonated minerals (dawsonite mainly).
Dissolution trapping plays a major role in the long term, while mineral trapping is minor at Sleipner.

Conclusion 1/2

- Numerical modeling is a simplification of very complex systems: Interpretations of such modeling have to be supported by on site measurements for calibration
- The main limitations are the CPU time and memory and data
- Some predictions are provided to assess:
  - Storage efficiency (injectivity and large scale CO2 migration)
  - Storage security (long term fluid rock interaction, over pressure)
  - Trapping efficiency (structural, residual, solubility, mineral)
  - Coupling some processes (geochemical, geomechanical)

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Conclusion 2/2

- New physico-chemical processes to focus on:
  - Near well effect (dry out zone, salt precipitation, cement alteration)
  - Impact of storage to other aquifers
  - Leakage through abandoned well
  - Geochemical kinetic rates of mineral solubility
  - Presence of other gaz (SOx, NOx)

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Actual limitations

- Compromise
  - Detailed multiphase fluid flow description (3D reservoir grid models) incorporating geometry and heterogeneity of the geology
  - Long term simulation
  - Scaling effect of all physical and geochemical processes
- Today solution
  - Use of a combination of different softwares to perform separate simulations for one specific purpose rather than coupling every processes
- Tomorrow solution
  - Platform
  - Parallelism of coupling between geochemistry and hydrodynamics