GEOS

Multiphysics Exascale Open-Source

TU Delft • March 7, 2023

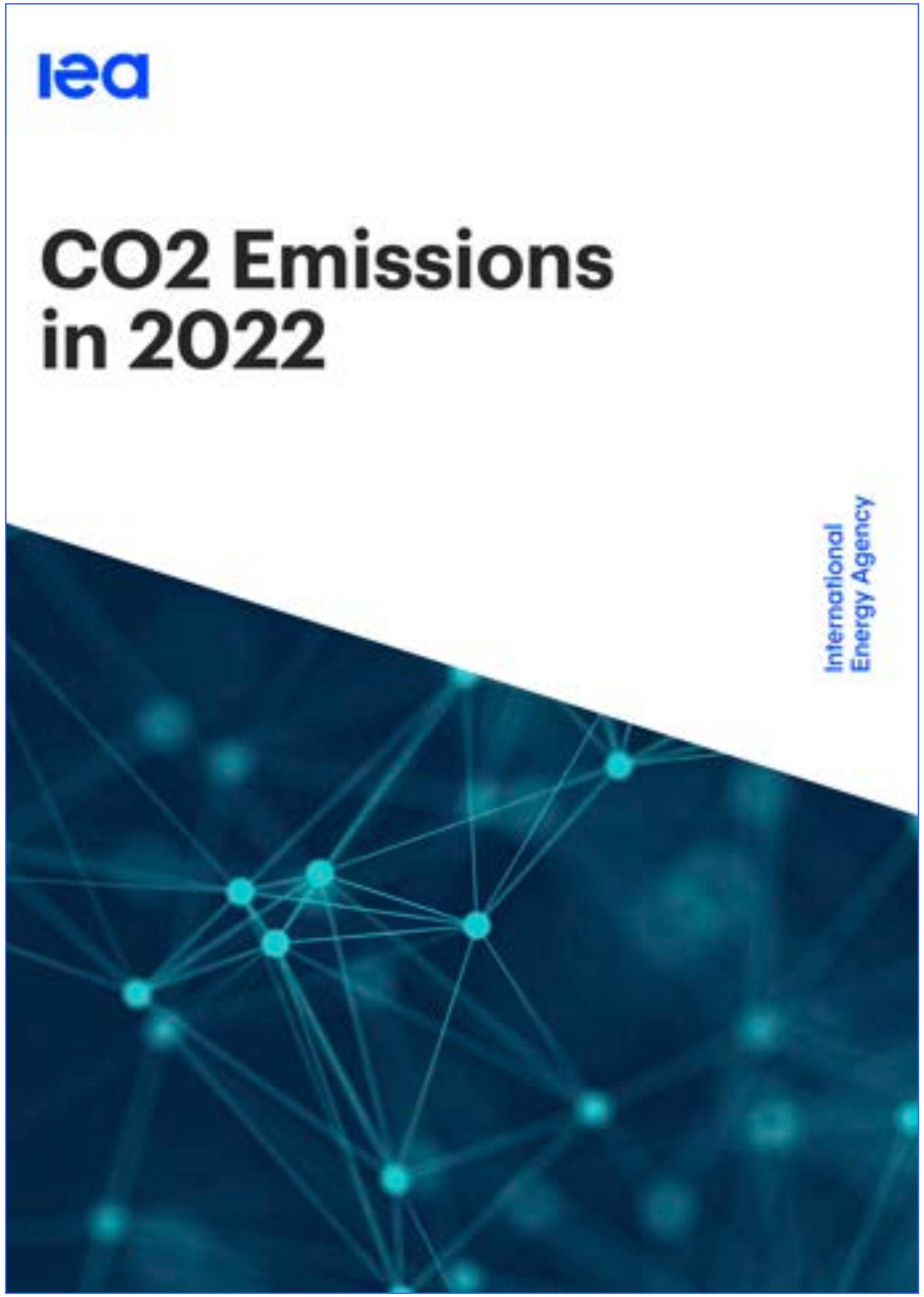
Herve Gross, Ph.D.
R&D Project ManagerTotalEnergies

Given on behalf of all GEOSX developers

TotalEnergies

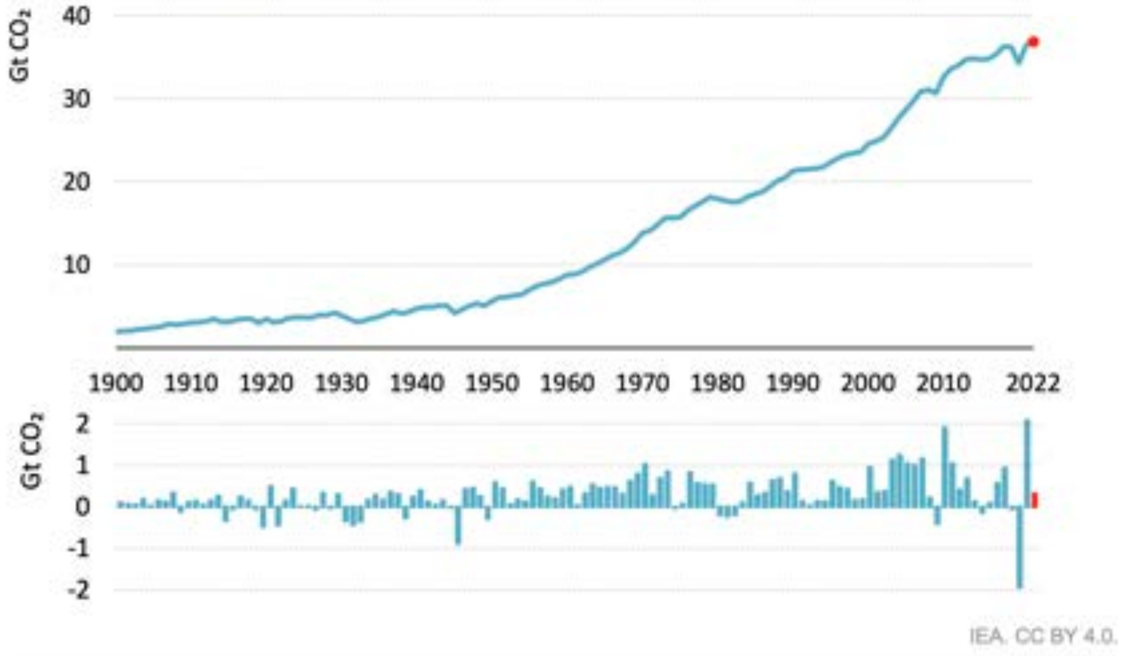
Stanford University

Lawrence Livermore National Laboratory



https://www.iea.org/reports/co2-emissions-in-2022

Figure 1: Global CO_2 emissions from energy combustion and industrial processes and their annual change, 1900-2022

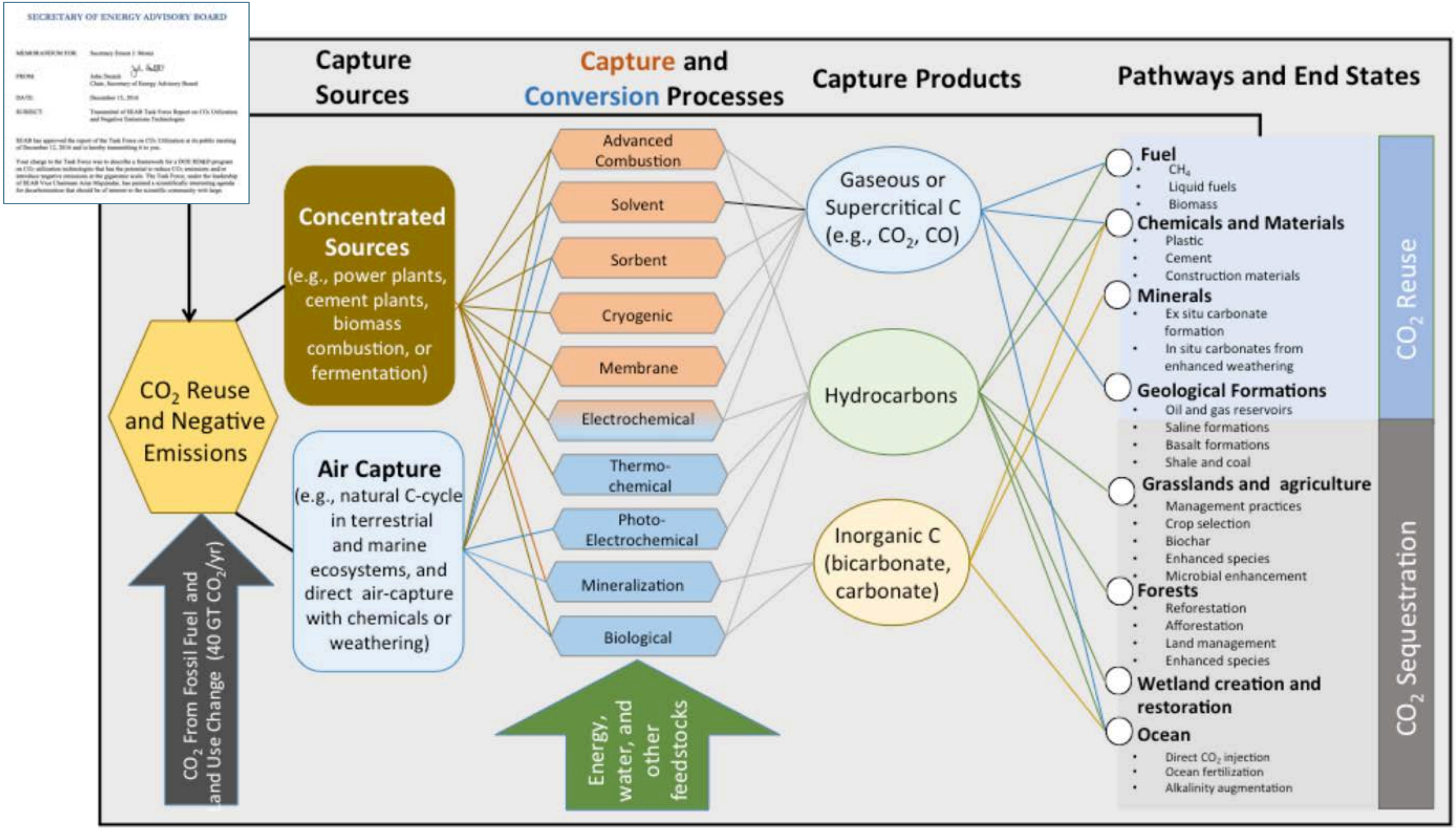


Global energy-related CO2 emissions grew by 0.9% or 321 Mt in 2022, reaching a new high of over 36.8 Gt. […] Last year's growth was much slower than 2021's rebound of more than 6%.

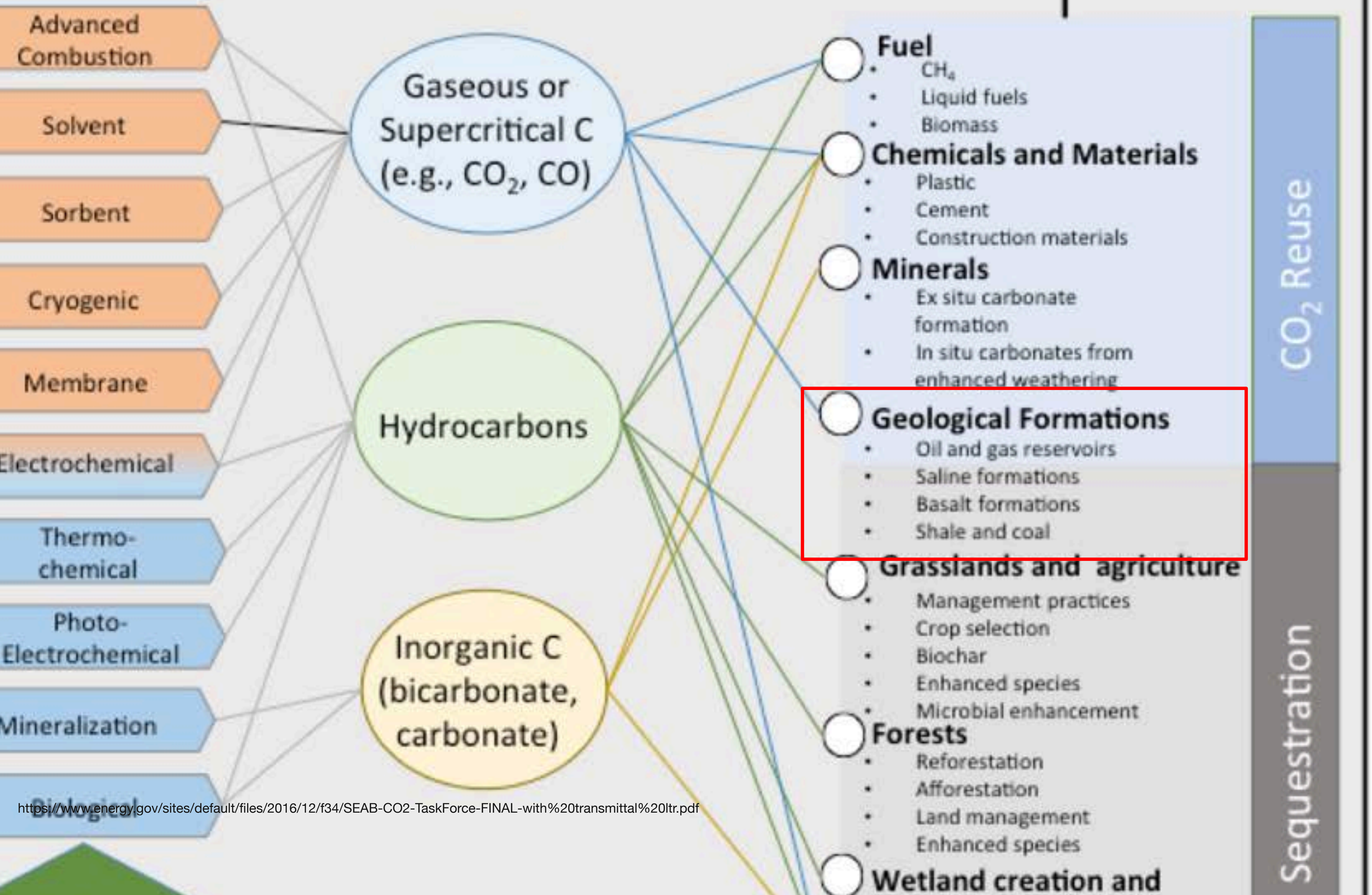
CO2 growth in 2022 was well below global GDP growth of 3.2%, reverting to a decade-long trend of decoupling emissions and economic growth.

Large-scale CO2 capture projects in industry and transformation, actual vs. Net Zero Scenario, 2020-2030

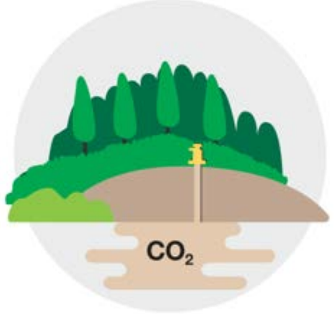
Open



https://www.energy.gov/sites/default/files/2016/12/f34/SEAB-CO2-TaskForce-FINAL-with%20transmittal%20ltr.pdf



https://www.energy.gov/sites/default/files/2016/12/f34/SEAB-CO2-TaskForce-FINAL-with%20transmittal%20ltr.pdf



35

MtCO2/yr

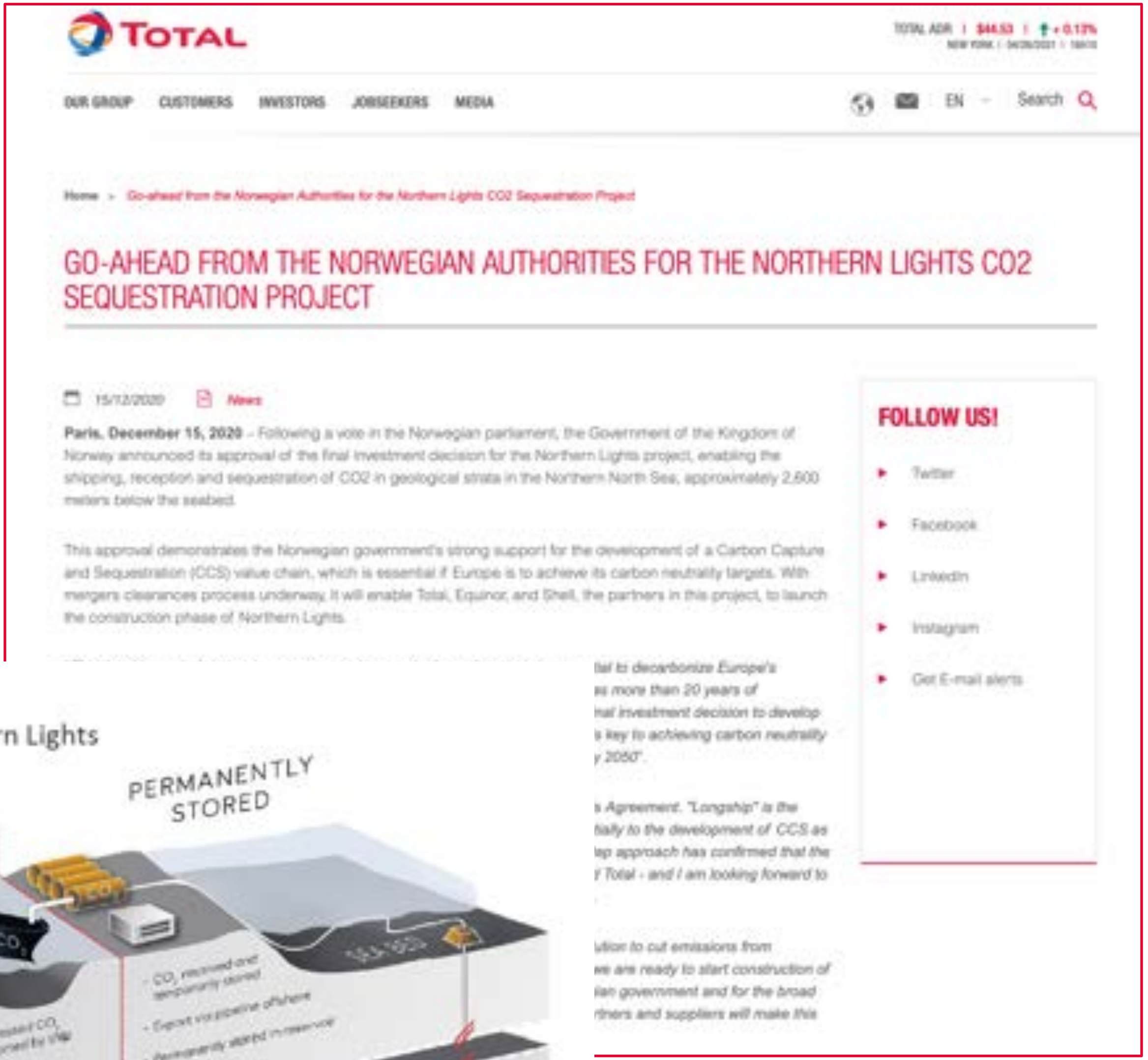
2020

2,800+

MtCO2/yr

IEA
Sustainable
Development
Scenario

2050



TOTAL

TOTAL ADR | $44.53 | +0.13%

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Home > Go-ahead from the Norwegian Authorities for the Northern Lights CO2 Sequestration Project

GO-AHEAD FROM THE NORWEGIAN AUTHORITIES FOR THE NORTHERN LIGHTS CO2 SEQUESTRATION PROJECT

15/12/2020 News

Paris, December 15, 2020 – Following a vote in the Norwegian parliament, the Government of the Kingdom of Norway announced its approval of the final investment decision for the Northern Lights project, enabling the shipping, reception and sequestration of CO2 in geological strata in the Northern North Sea, approximately 2,600 meters below the seabed.

This approval demonstrates the Norwegian government's strong support for the development of a Carbon Capture and Sequestration (CCS) value chain, which is essential if Europe is to achieve its carbon neutrality targets. With mergers clearances process underway, it will enable Total, Equinor, and Shell, the partners in this project, to launch the construction phase of Northern Lights.

…tial to decarbonize Europe's …s more than 20 years of …nal investment decision to develop …s key to achieving carbon neutrality …y 2050".

…s Agreement. "Longship" is the …tially to the development of CCS as …ep approach has confirmed that the …f Total - and I am looking forward to

…ution to cut emissions from …we are ready to start construction of …ian government and for the broad …rtners and suppliers will make this

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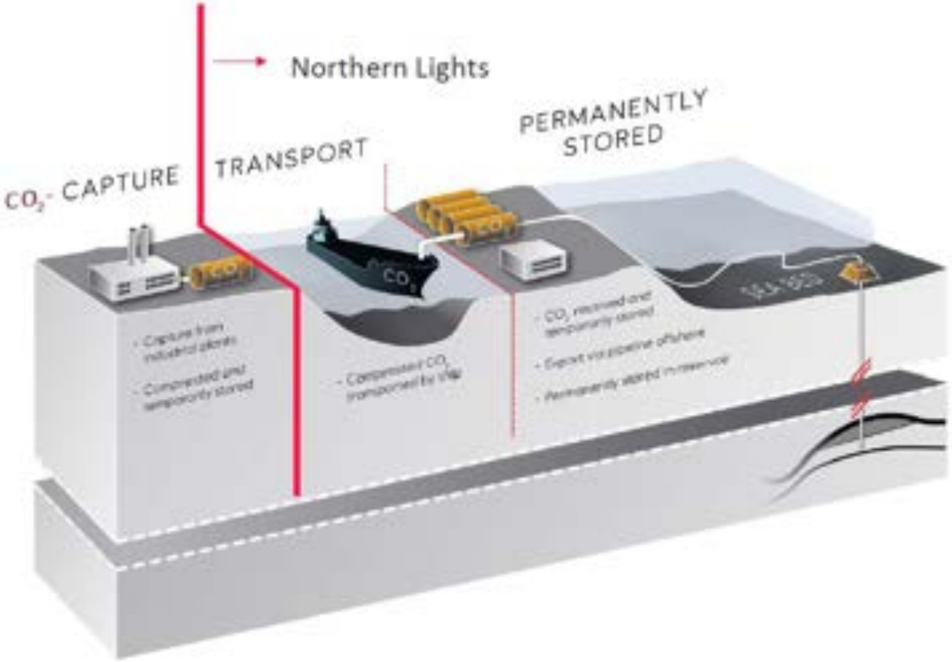
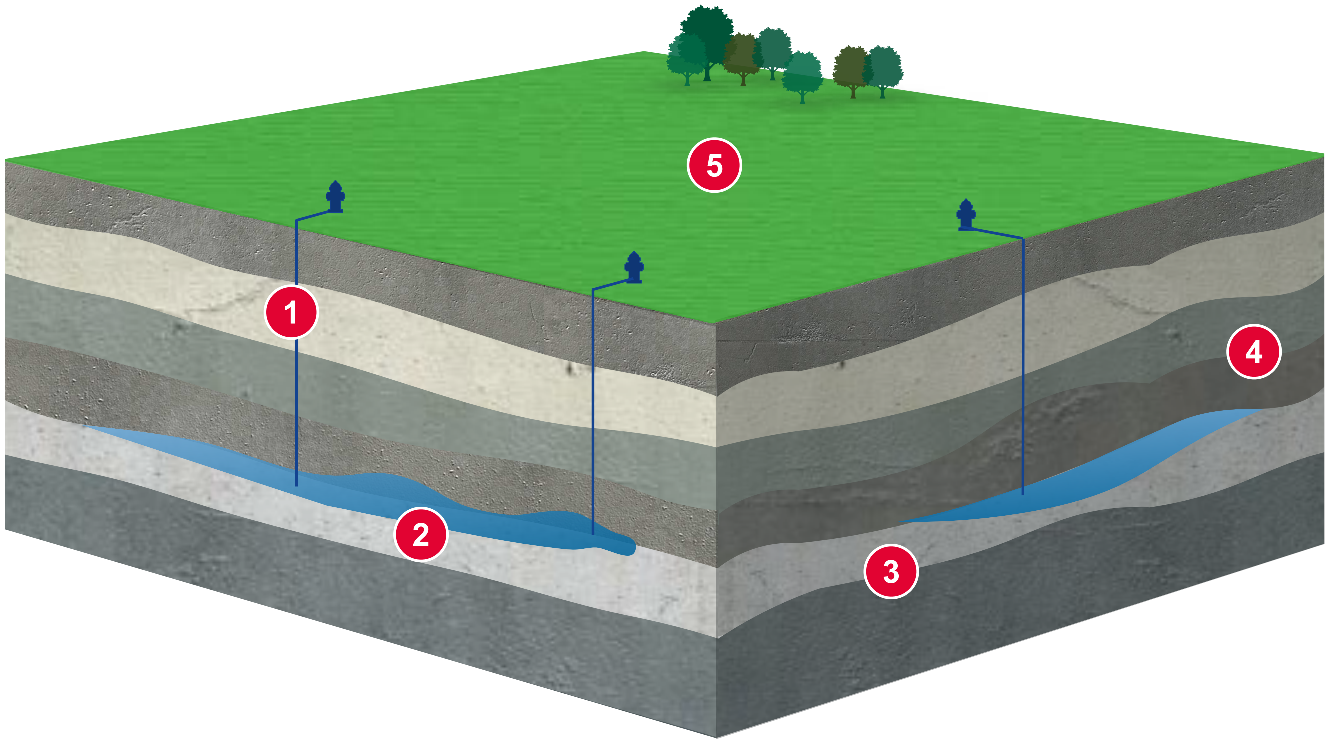


x 3,000

Do we have the right tools?



1 Well integrity/injectivity

2 Pressure/Stress change
Fault Activation

3 CO_2 transport & trapping

4 Seal integrity

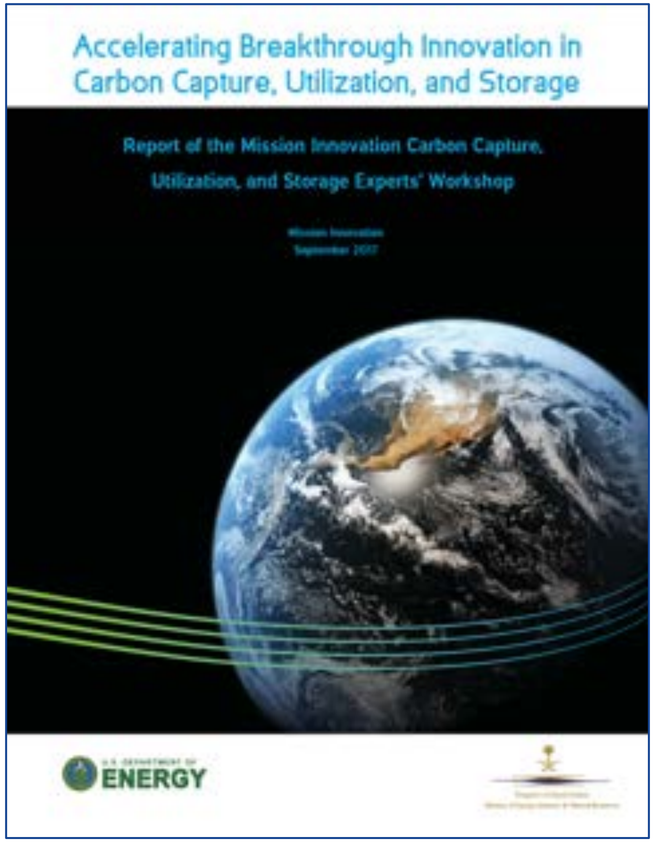
5 Surface deformation
Seismicity

LIMITATIONS

MULTIPHYSICS	GEOMECHANICS + FLOW
LARGE SCALES	98% STORAGE IN AQUIFERS
LONG SIMULATION TIME	POST-INJECTION MATTERS

SOLUTIONS

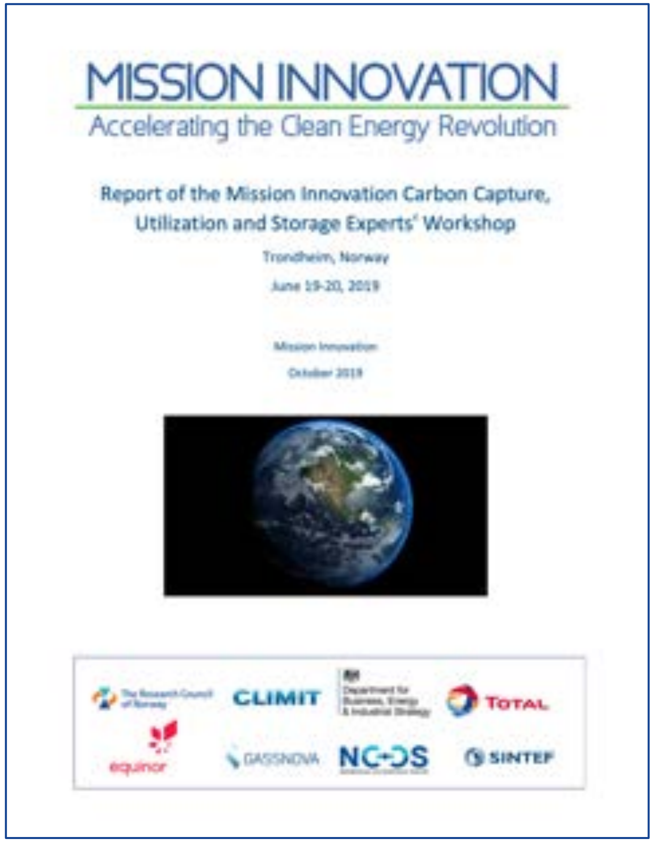
EXASCALE COMPUTERS	2 EXAFLOPS (2023)
FAST ALGORITHMS	SCALABILITY
PORTABILITY	PERENNIAL SOLUTIONS



MISSION INNOVATION CCUS

250 experts including Total
University + Industry

September 2017



June 2019

"HPC effort for CCS should expand beyond traditional reservoir simulation with an emphasis on subsurface pressure and saturation distributions to address the effects on regional hydrodynamics, pressure perturbations, modified stress fields, and deformation at the reservoir and basin scales."

Section 4.5.2

"Establish one or more internationally recognized CO2 storage open-source software as done with climate models. Such open-source software would enable transparency, openness and wider collaboration."

Storage and CO2 networks (topic 3), p.11

TRANSPARENCY AND COLLABORATION

Transparent code & qualification processes for regulators

LGPL 2.1: we can develop important features ourselves — and so can you

Collaboration with partners, universities, third-party vendors

56
Contributors to the code

4,242
Updates since 2018

30
Peer-reviewed publications

100
downloads / week

17
Initiatives using GEOSX

20+
Free test cases to try

Multiphysics

Exascale

Open

FLOW and TRANSPORT
Compositional Multiphase
Fully-implicit, isothermal formulation
Equations-of-state (cubic): PVT, flash
Three-phase extended black and dead oil
Two-phase CO2/brine
Assembled and solved on multi GPU

SOLID MECHANICS
Implicit and explicit time-stepping
Small and large-strain formulations
Advanced Rock models
Isotropic/Anisotropic elasticity
Poroelasticity, poroplasticity
Tightly-coupled & Fractional-step

DISCRETIZATION SCHEMES
Finite volume interface
Cell-centered method (TPFA)
Hybrid Mimetic Method TPFA
Quasi-TPFA inner products
Multi-segmented wells

LINEAR SOLVERS
Unified algebra interface
Hypre, Trilinos, Petsc
Krylov solvers (CG, GMRES, BiCGSTAB)
Preconditioners (AMG, ILU, MGR)
Block matrix and vector support
Serial and parallel direct solvers

CONTACT MECHANICS
Embedded Discrete Fractures
Enriched finite elements
Fault-contact using Lagrange multipliers
Conforming hydrofracture solver
Proppant: slurry, settling, bed build-up

FINITE ELEMENTS
First-order elements and quadrature
8-node hexahedron
6-node wedge
5-node pyramid
4-node tetrahedron

MESH AND DATA I/O
Unstructured 3D (reservoir)
Unstructured 2D (faults/fractures)
Importer for Gmsh, corner-point grids
Importer for LAS format wells
Output: Silo and VTK for VisIt and Paraview

Version 0.2.0
GitHub, Travis CI, Doxygen
LGPL 2.1
LLNL, Stanford, Total

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Matthias Cremon

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Jacques Franc

Massimiliano Ferronato

Claudia Zoccarato

Laura Gazzola

Matteo Frigo

Yuan Tian

Jian Huang

Andrea Borio

GEOS Development Roadmap

2018	2019	2020	2021	2022	2023

Conception

Kick Off

Joshua White
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Panayot Vassilevski
Benjamin Corbett
Matteo Cusini

Lawrence Livermore National Laboratory

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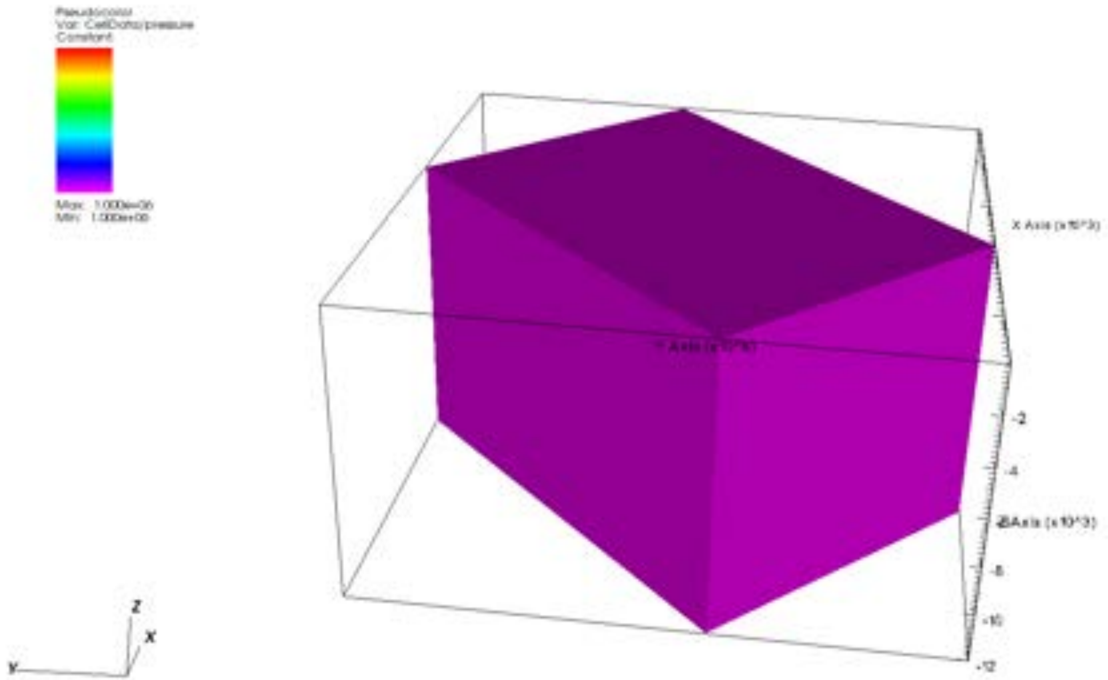
Andrea Franceschini
Antoine Mazuyer
Mohammad Karimi Fard

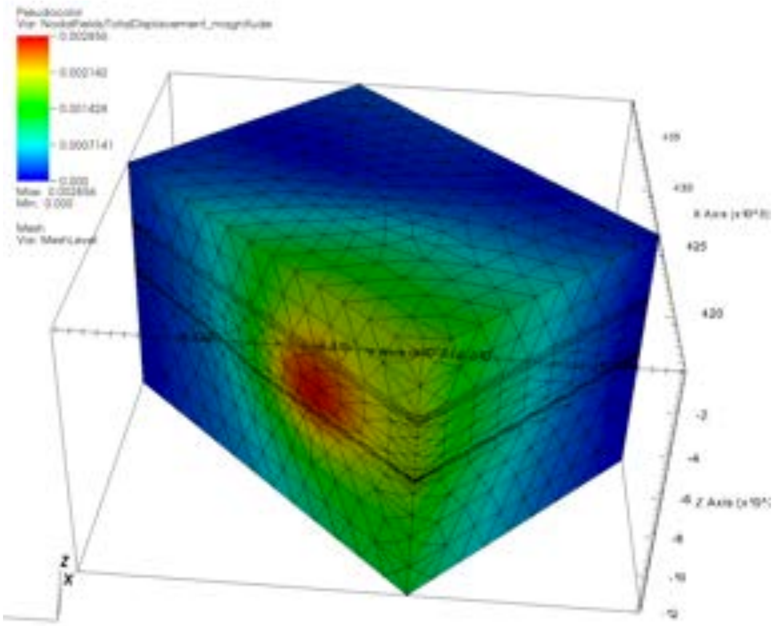
Alexandre Lapene
Herve Gross
Francois Hamon
Philippe Cordier

GEOS Development Roadmap

2018	2019	2020	2021	2022	2023
Conception	HPC infrastructure				
Kick Off	Poroelastic Compositional				



Pressure [Pa]

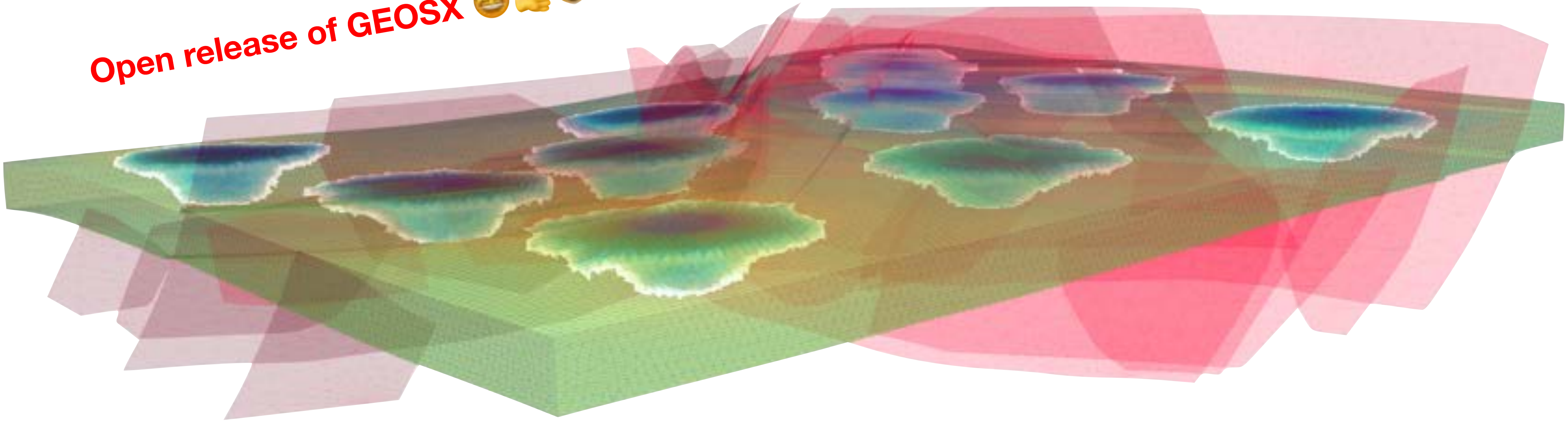


Total Displacement Magnitude [m]

GEOS Development Roadmap

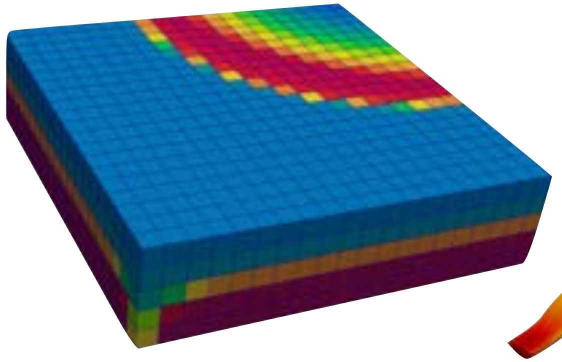
2018	2019	2020	2021	2022	2023
Conception	HPC infrastructure	First CCUS simulations			
Kick Off	Poroelastic Compositional	First GPU benchmarks			

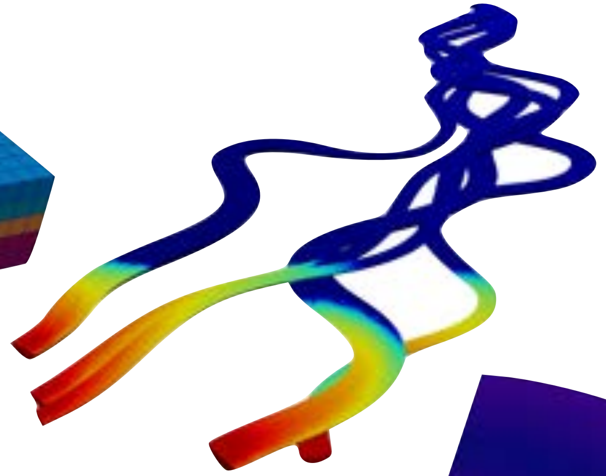
Open release of GEOSX 🤩👍😻🤪

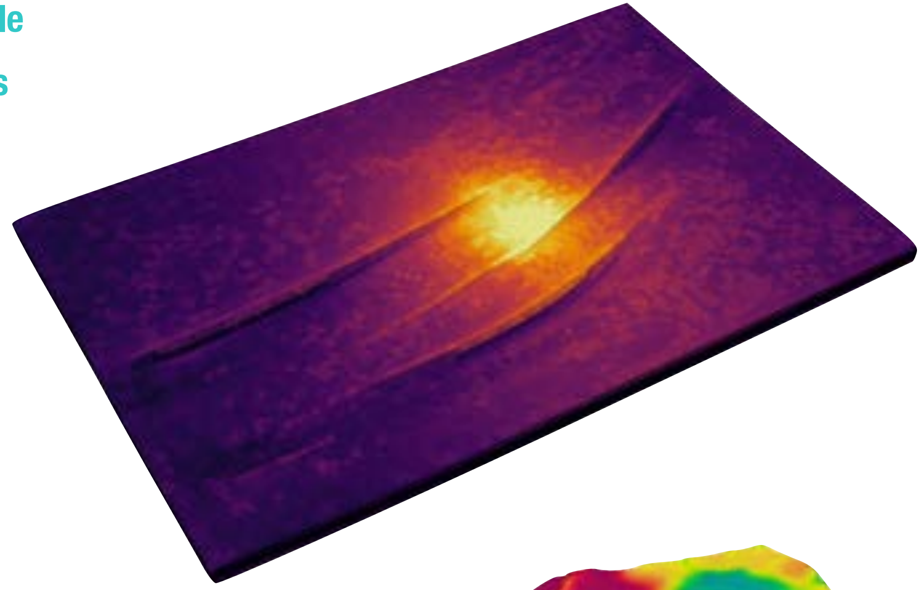


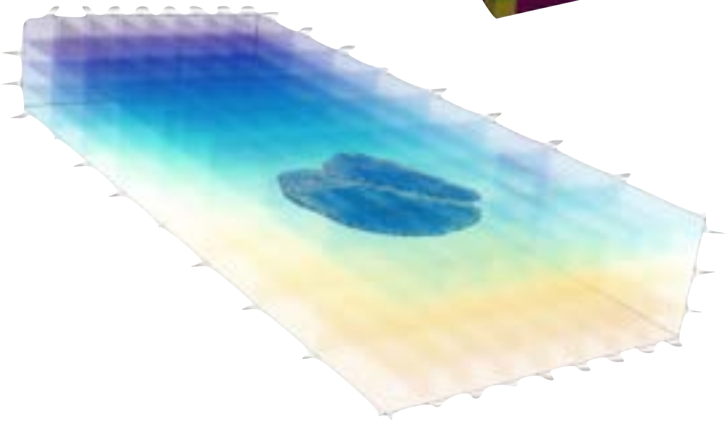
GEOS Development Roadmap

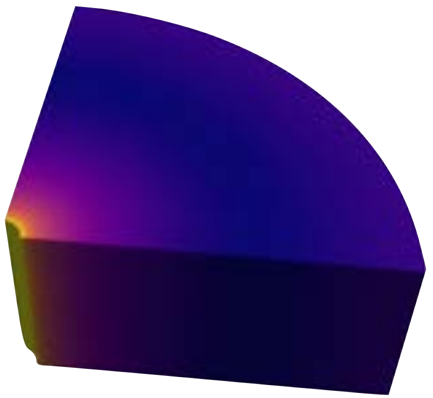
2018	2019	2020	2021	2022	2023
Conception	HPC infrastructure	First CCUS simulations	CCUS Basin scale		
Kick Off	Poroelastic Compositional	First GPU benchmarks	Fault mechanics		

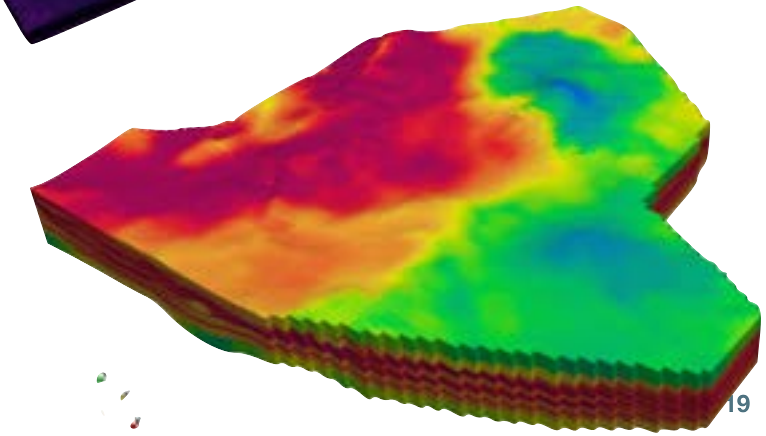






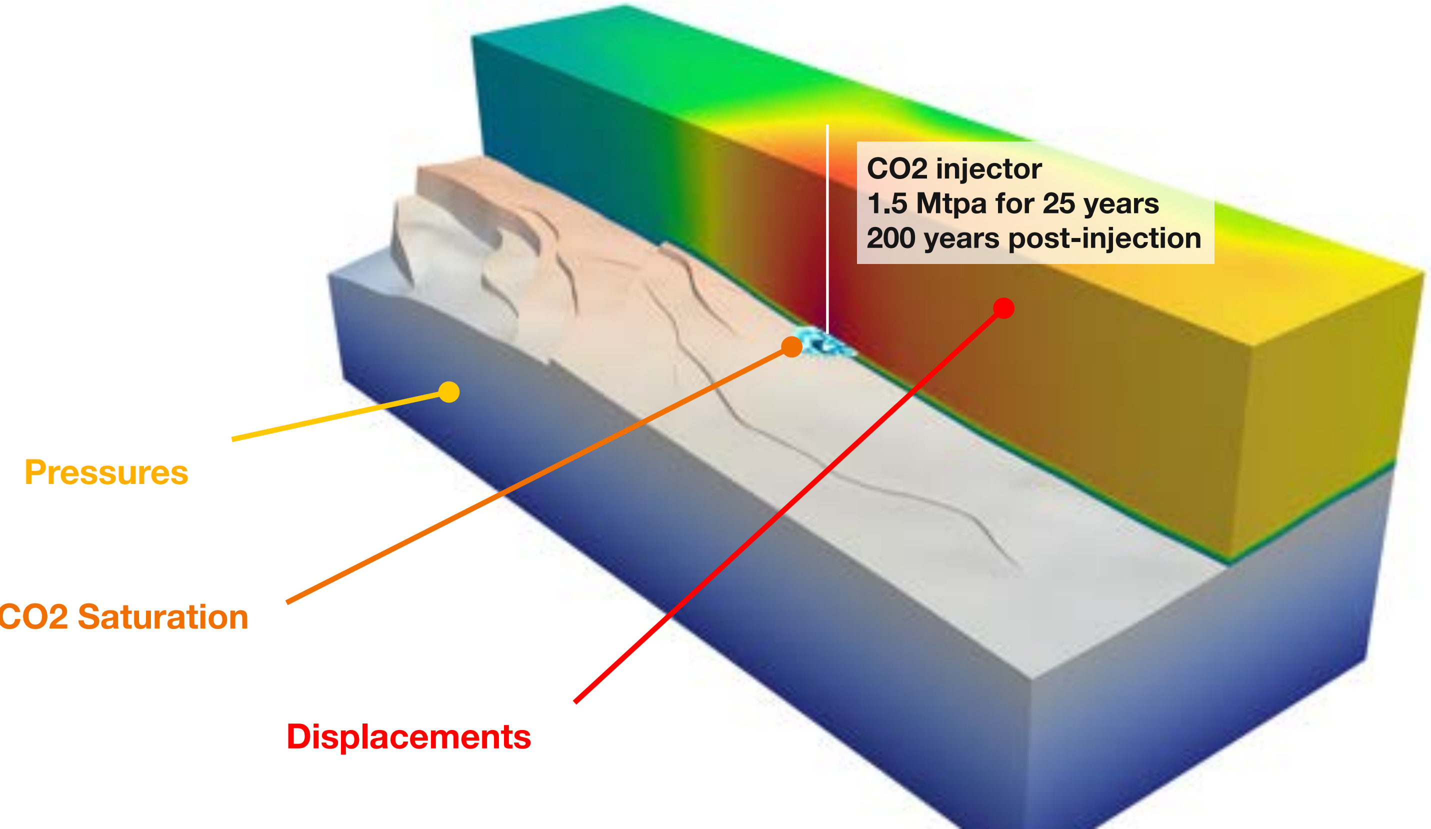




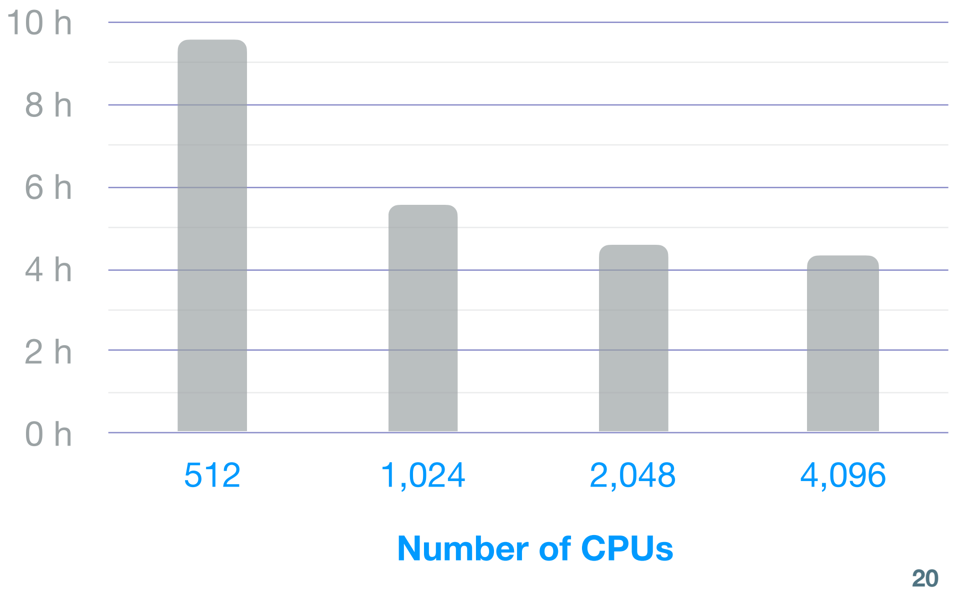


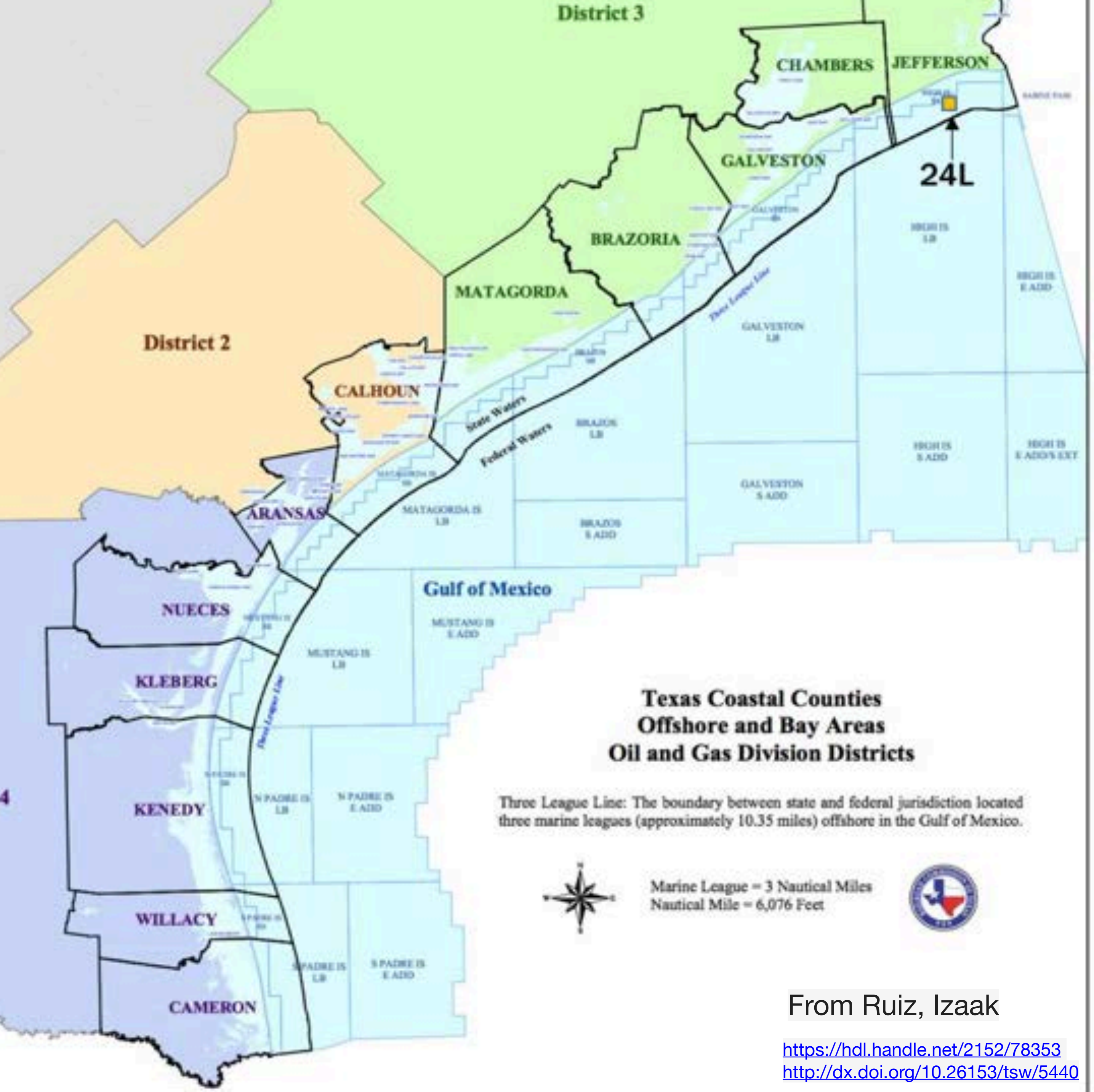
GEOS Development Roadmap

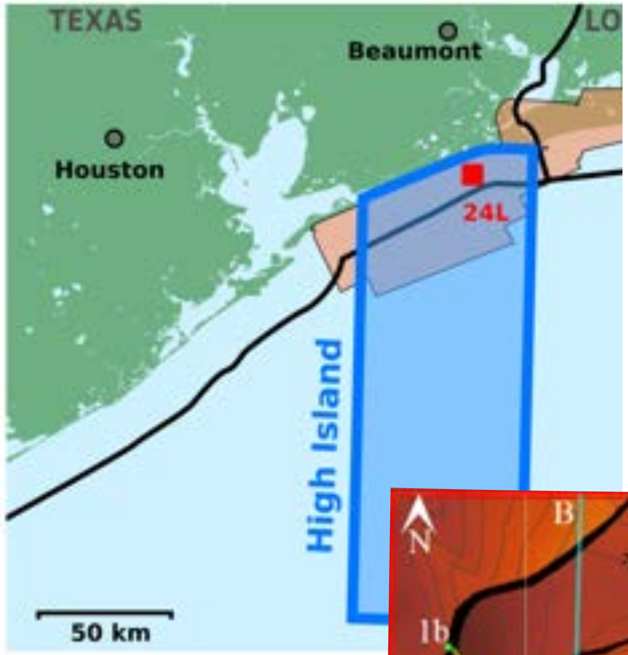
2018	2019	2020	2021	2022	2023
Conception	HPC infrastructure	First CCUS simulations	CCUS Basin scale	Real field applications	
Kick Off	Poroelastic Compositional	First GPU benchmarks	Fault mechanics	Exascale testing	

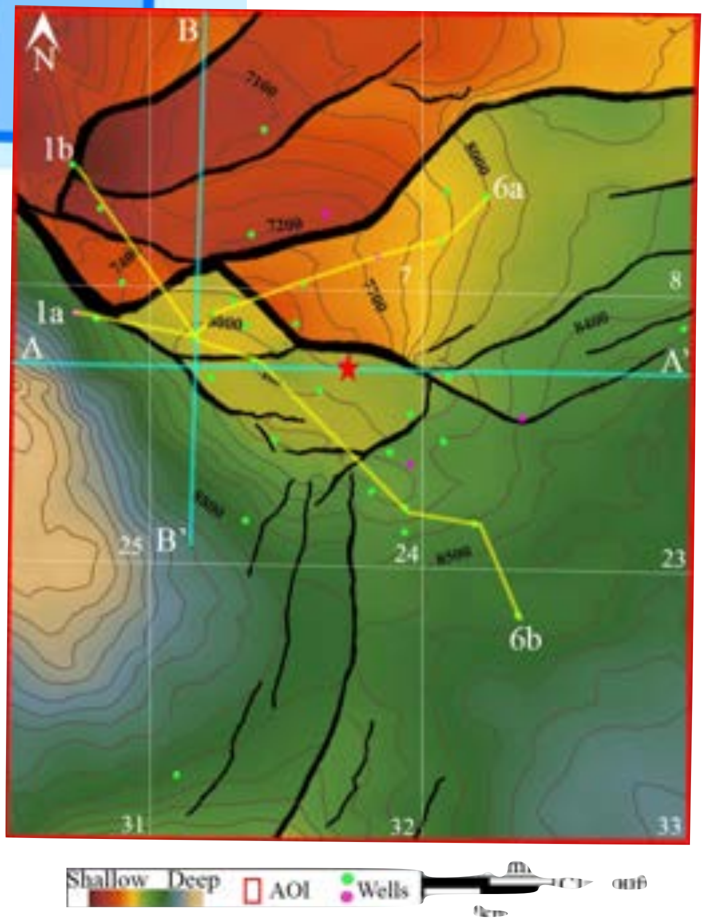


Runtime for the fully-coupled simulations of CO2 storage for 225 years.









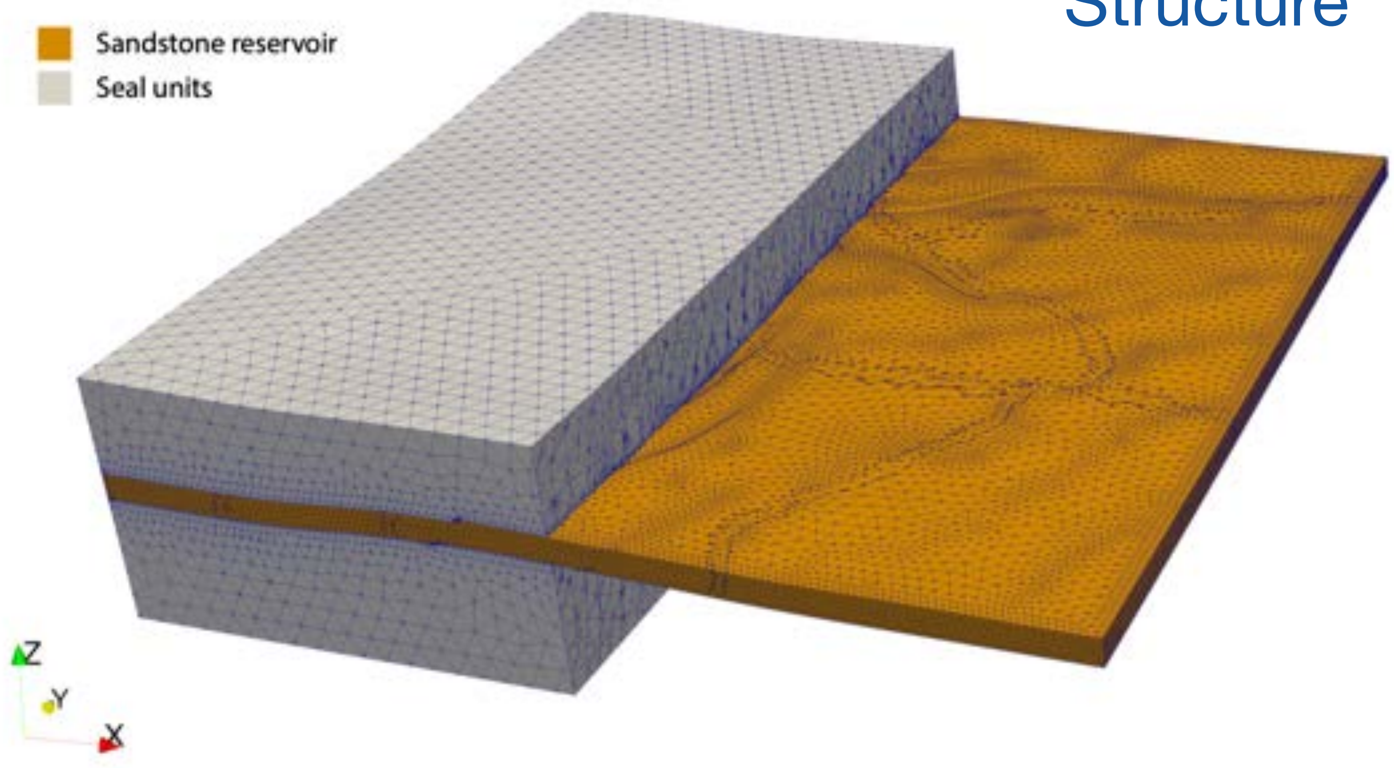
From Ruiz, Izaak

https://hdl.handle.net/2152/78353

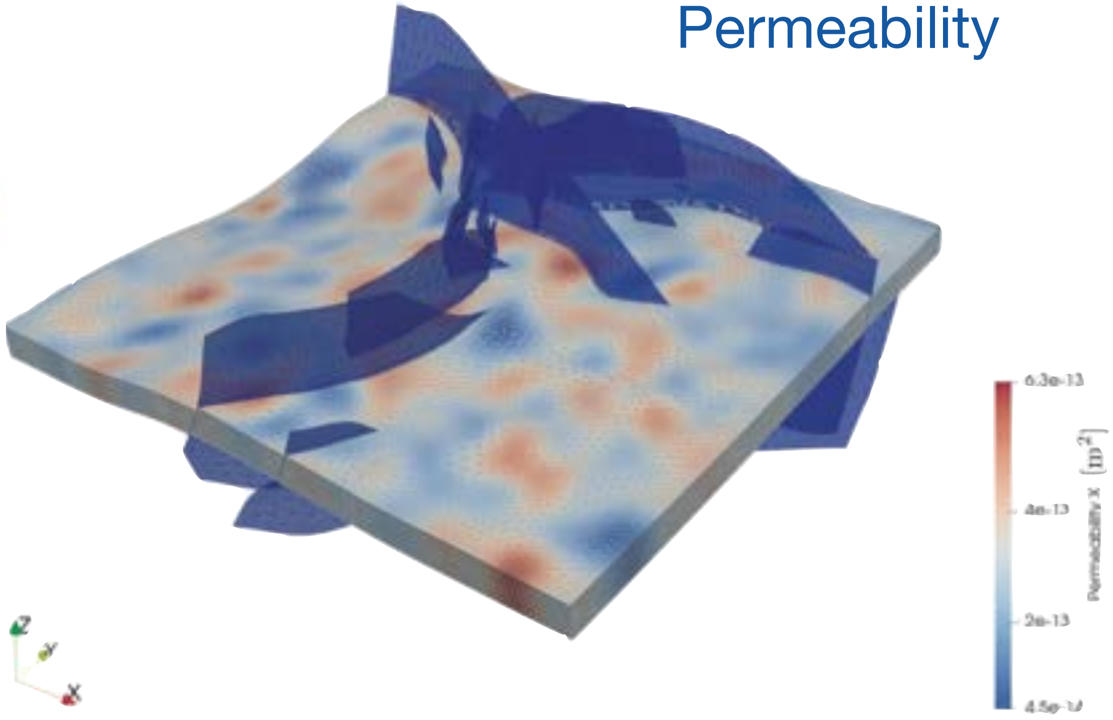
http://dx.doi.org/10.26153/tsw/5440

Poroelasticity at the Reservoir Scale

Structure



Permeability



1.8 M tetrahedral cells, 50m in reservoir layers

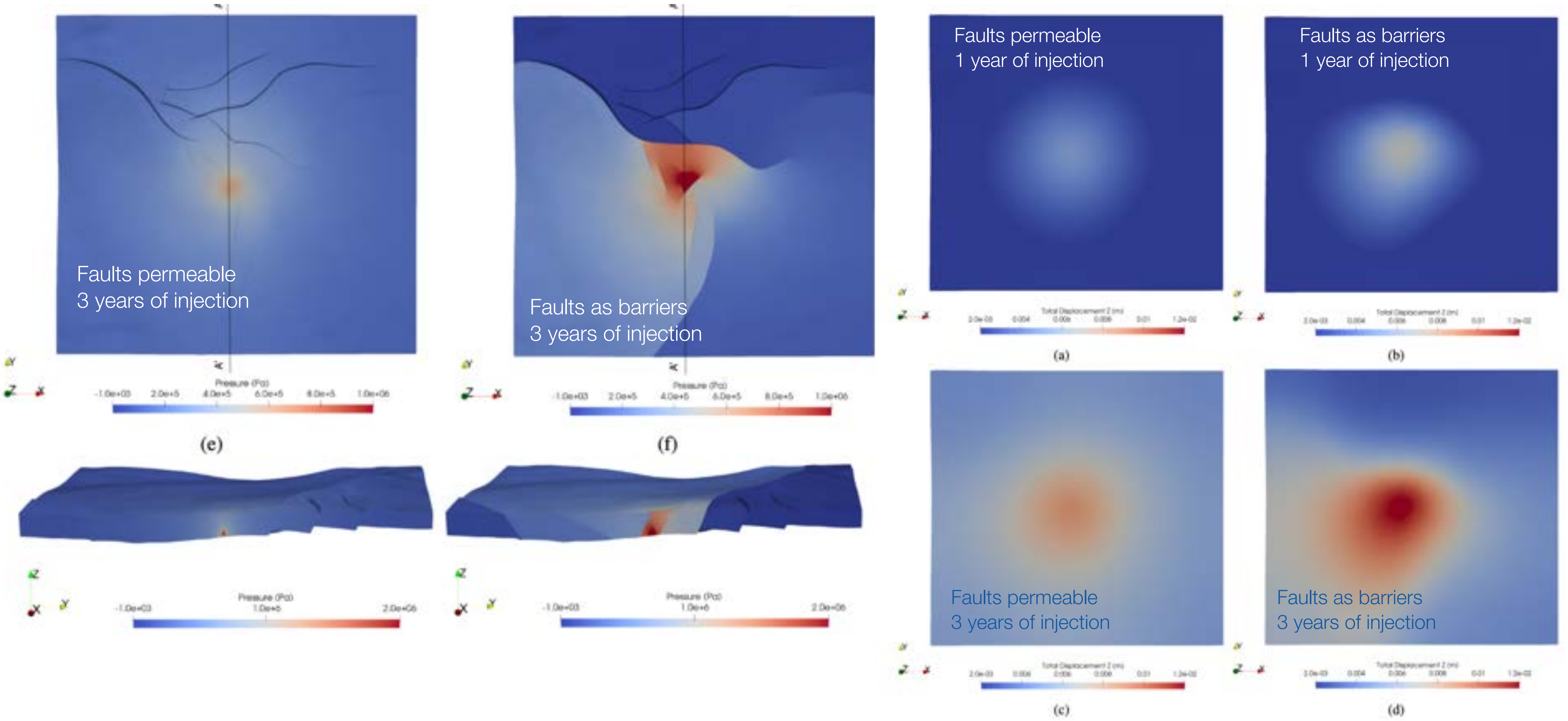
300k nodes

2.7 M degrees of freedom

12 x 15 km

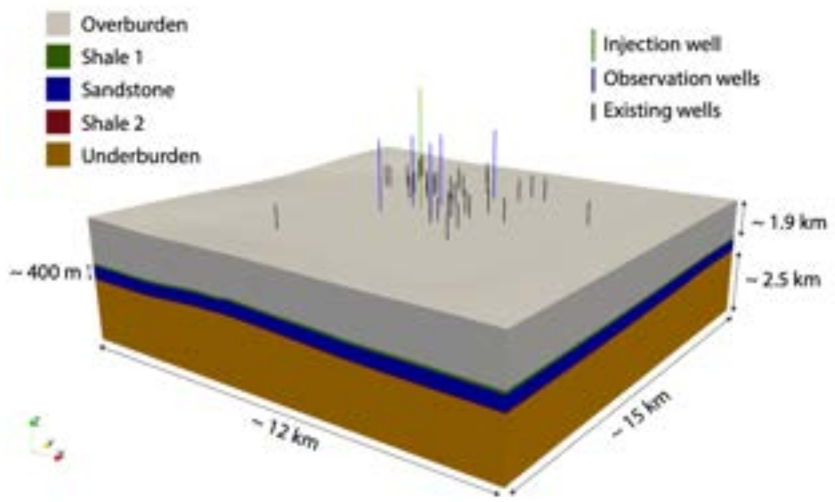
Deformation monitoring feasibility at an offshore carbon storage site
Interim progress report for GCCC, December 2020.
Julia T. Camargo & Joshua A. White

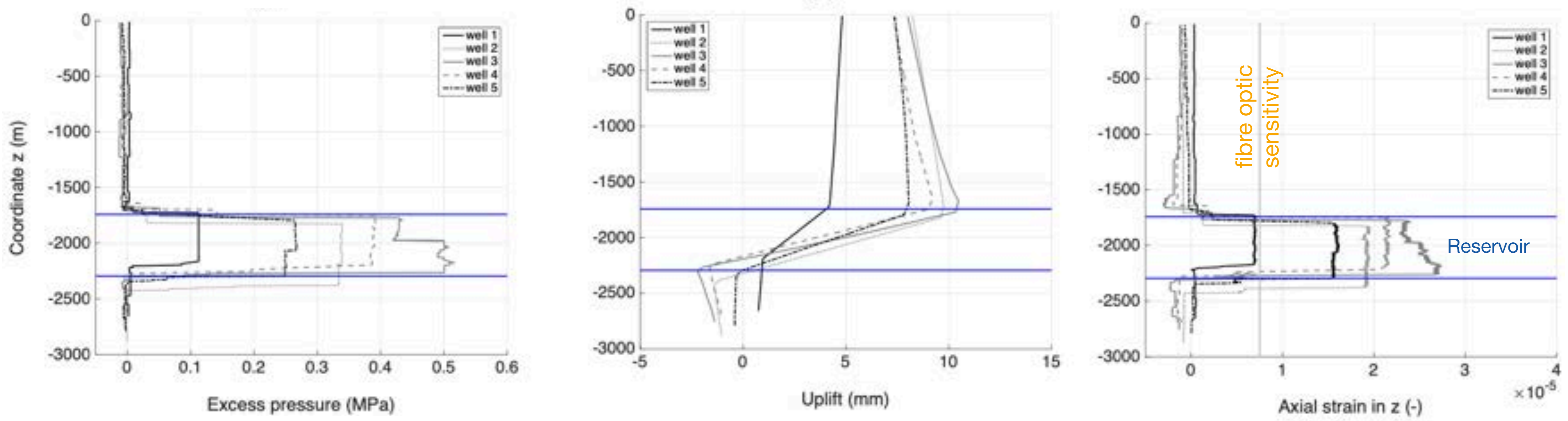
Are the faults permeable?



Is the injection detectable by fibre optic sensors?

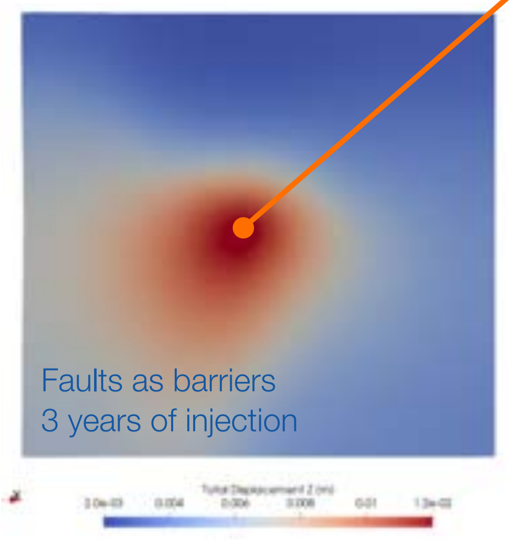
After 3 years, faults acting as barriers



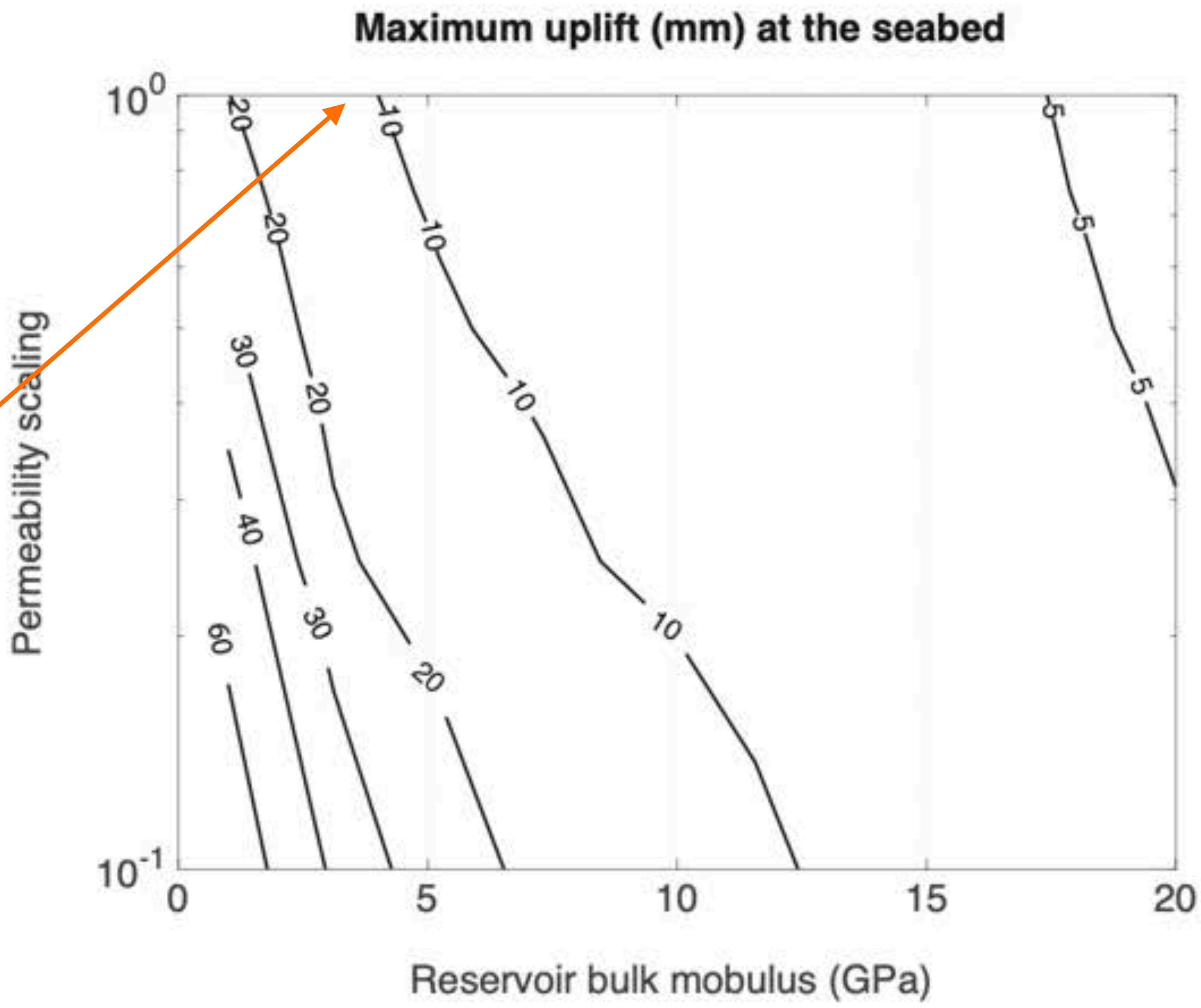


Uncertainty Quantification

What is the risk of uplift at the seabed, based on reservoir properties?



(d)



Uncertainty Quantification

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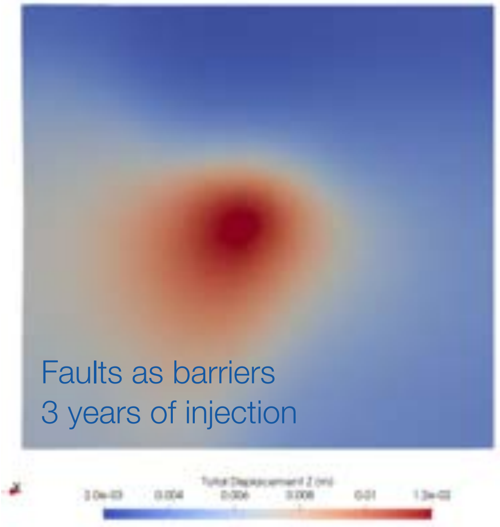
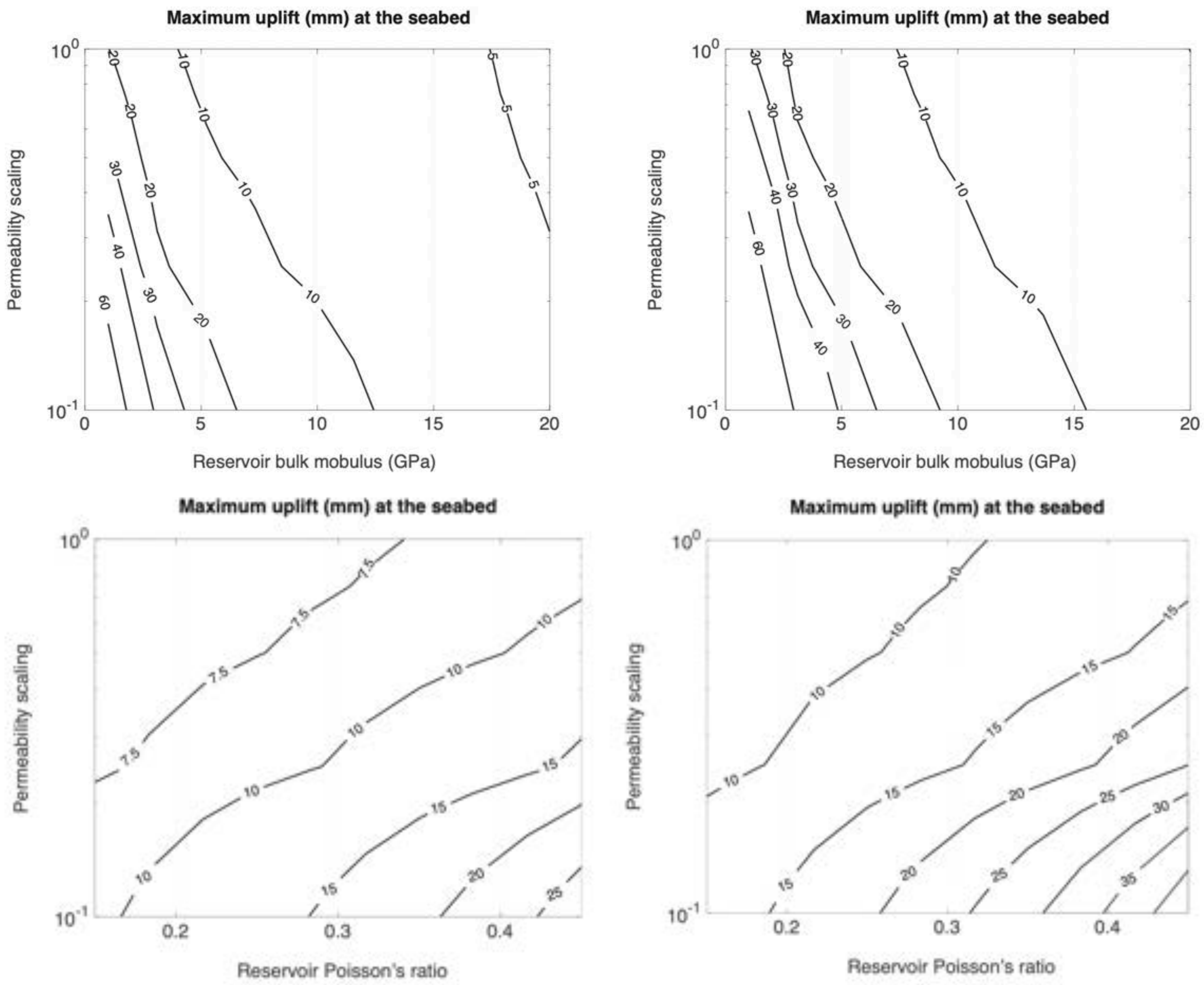
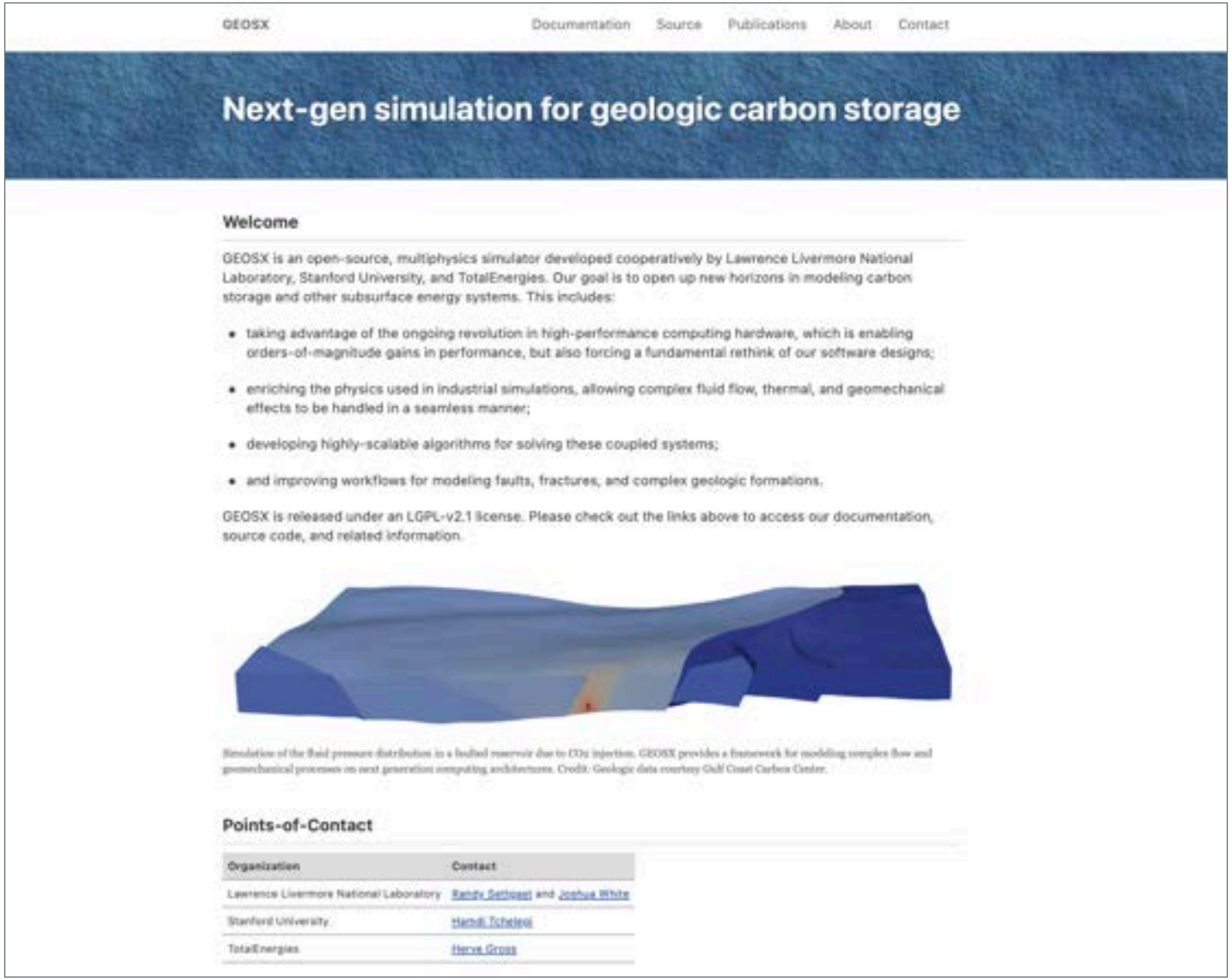


(d)



How can I try GEOS?



GEOSX   Documentation   Source   Publications   About   Contact

Next-gen simulation for geologic carbon storage

Welcome

GEOSX is an open-source, multiphysics simulator developed cooperatively by Lawrence Livermore National Laboratory, Stanford University, and TotalEnergies. Our goal is to open up new horizons in modeling carbon storage and other subsurface energy systems. This includes:

- taking advantage of the ongoing revolution in high-performance computing hardware, which is enabling orders-of-magnitude gains in performance, but also forcing a fundamental rethink of our software designs;
- enriching the physics used in industrial simulations, allowing complex fluid flow, thermal, and geomechanical effects to be handled in a seamless manner;
- developing highly-scalable algorithms for solving these coupled systems;
- and improving workflows for modeling faults, fractures, and complex geologic formations.

GEOSX is released under an LGPL-v2.1 license. Please check out the links above to access our documentation, source code, and related information.

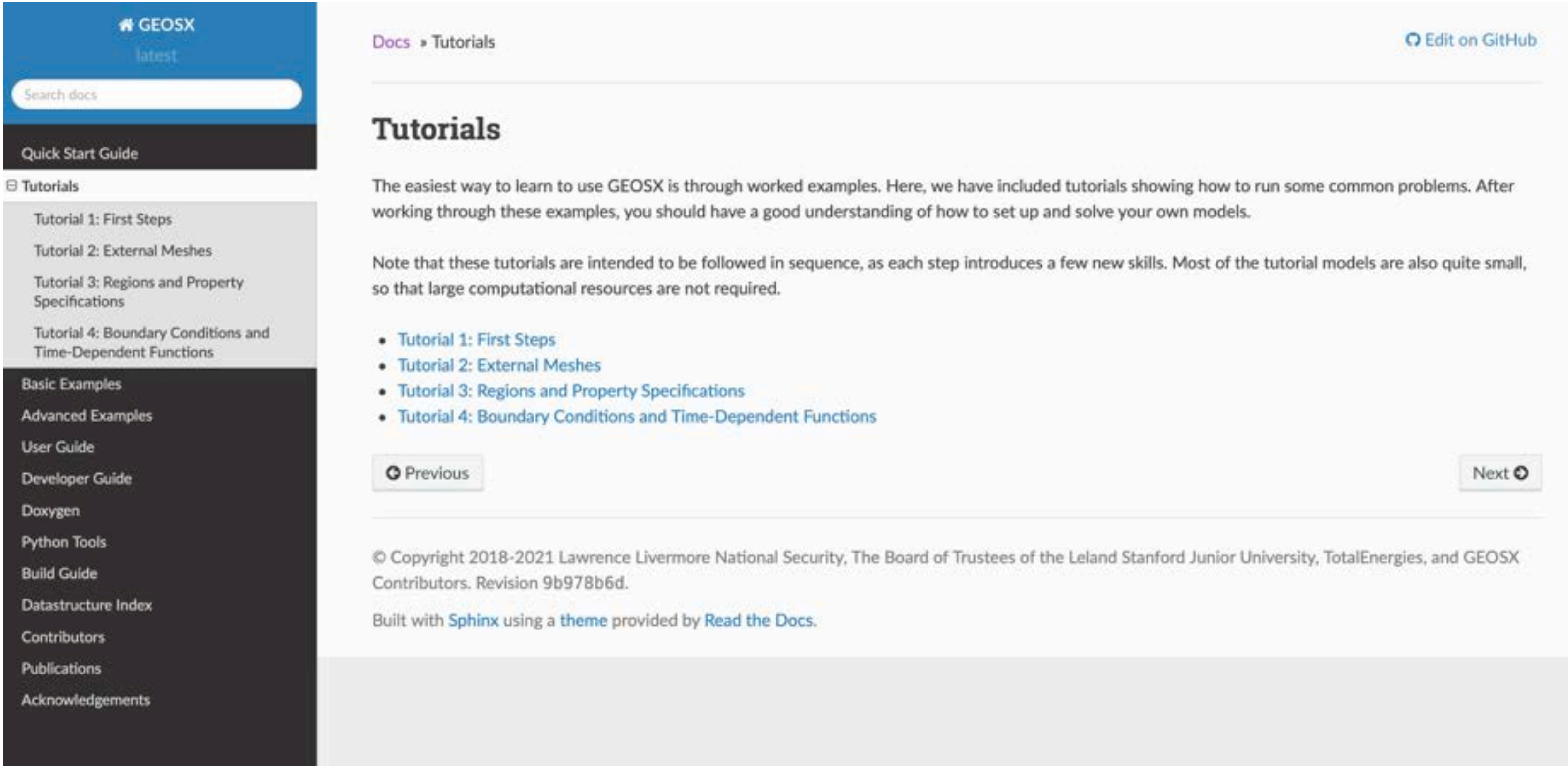
Simulation of the fluid pressure distribution in a faulted reservoir due to CO_2 injection. GEOSX provides a framework for modeling complex flow and geomechanical processes on next generation computing architectures. Credit: Geologic data courtesy Gulf Coast Carbon Center.

Points-of-Contact

Organization	Contact
Lawrence Livermore National Laboratory	Randy Settgast and Joshua White
Stanford University	Hamdi Tchelepi
TotalEnergies	Herve Gross

http://www.geosx.org

http://www.geos.dev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latest
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Tutorial 2: External Meshes
Tutorial 3: Regions and Property Specifications
Tutorial 4: Boundary Conditions and Time-Dependent Functions
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Advanced Examples
User Guide
Developer Guide
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Python Tools
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Docs » Tutorials
Edit on GitHub
Tutorials
The easiest way to learn to use GEOSX is through worked examples. Here, we have included tutorials showing how to run some common problems. After working through these examples, you should have a good understanding of how to set up and solve your own models.
Note that these tutorials are intended to be followed in sequence, as each step introduces a few new skills. Most of the tutorial models are also quite small, so that large computational resources are not required.
Tutorial 1: First Steps
Tutorial 2: External Meshes
Tutorial 3: Regions and Property Specifications
Tutorial 4: Boundary Conditions and Time-Dependent Functions
Previous
Next
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Built with Sphinx using a theme provided by Read the Docs.

GEOSX
latest

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  - Viscosity-Storage-Dominated PKN Hydraulic Fracture
  - Proppant Slot Test
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  - Kirsch Wellbore Problem
  - Cased Elastic Wellbore Problem
  - Deviated Elastic Wellbore Problem
  - Elasto-Plastic Near-Well Deformation
  - Modified Cam-Clay Model for Wellbore Problems
  - Deviated Poro-Elastic Wellbore Subjected to Fluid Injection
  - Deviated Poro-Elastic Wellbore Subjected to In-situ Stresses and Pore Pressure
  - Vertical PoroElasto-Plastic Wellbore Problem
  - Pure Thermal Diffusion Around a Wellbore
  - Cased ThermoElastic Wellbore Problem
- Thermoporomechanics
  - Thermoporoelastic Consolidation

SpringerLink

Home > Computational Geosciences > Article

Original paper | Published: 22 July 2009

A benchmark study on problems related to CO_2 storage in geologic formations

Summary and discussion of the results

Holger Class, Anozie Ebigbo, Rainer Helmig, Helge K. Dahle, Jan M. Nordbotten, Michael A. Celia, Pascal Audigane, Melanie Darcis, Jonathan Ennis-King, Yaqing Fan, Bernd Flemisch, Sarah E. Gasda, Min Jin, Stefanie Krug, Diane Labregere, Ali Naderi Beni, Rajesh J. Pawar, Adil Sbai, Sunil G. Thomas, Laurent Trenty & Lingli Wei

Computational Geosciences 13, 409–434 (2009) | Cite this article

2964 Accesses | 287 Citations | 6 Altmetric | Metrics

Abstract

This paper summarises the results of a benchmark study that compares a number of mathematical and numerical models applied to specific problems in the context of carbon dioxide (CO_2) storage in geologic formations. The processes modelled comprise advective multi-phase flow, compositional effects due to dissolution of CO_2 into the ambient brine and non-isothermal effects due to temperature gradients and the Joule–Thompson effect. The

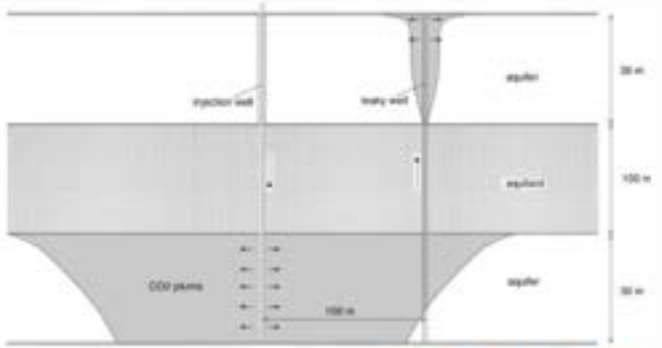
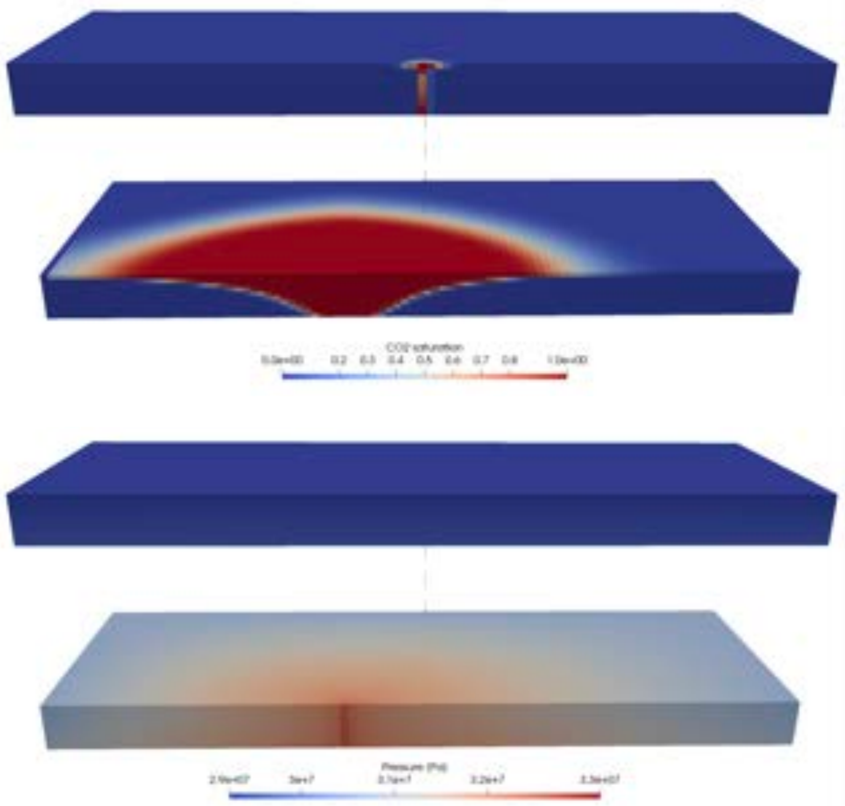
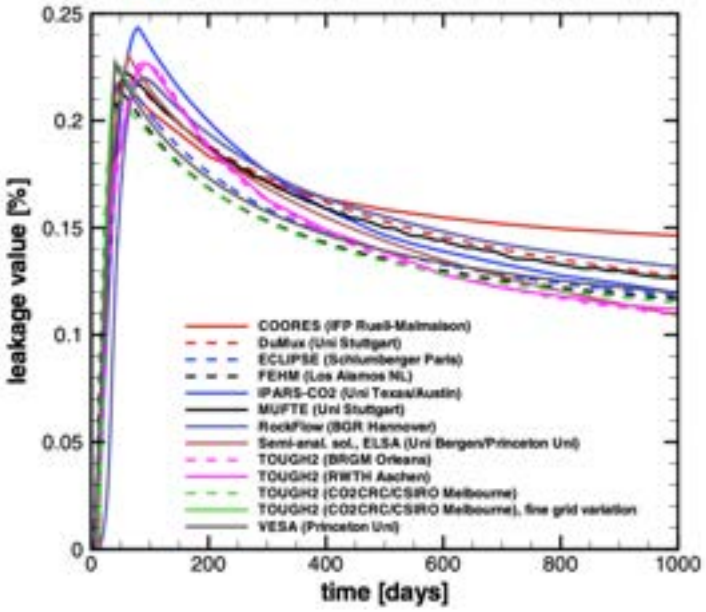
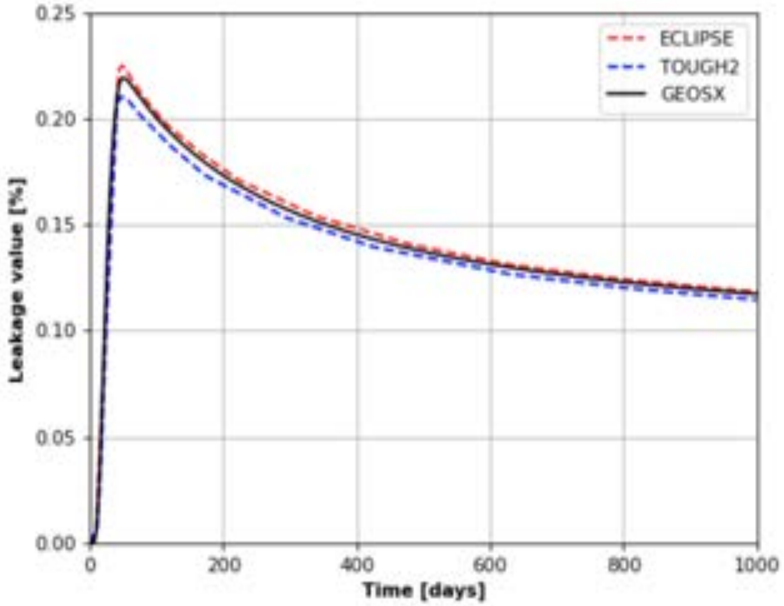


Fig. 5 Leakage scenario (image taken from (Ebigbo, Class, Helmig, 2007)).



Code	Max leakage [%]	Time at max leakage [day]	Leakage at 1000 days [%]
GEOSX	0.219	50.6	0.1172
COORES	0.219	50	0.146
DuMux	0.220	61	0.128
ECLIPSE	0.225	48	0.118
FEHM	0.216	53	0.119
IPARS-CO2	0.242	80	0.120
MUFTE	0.222	58	0.126
RockFlow	0.220	74	0.132
ELSA	0.231	63	0.109
TOUGH2/ECO2N	0.226	93	0.110
TOUGH2/ECO2N (2)	0.212	46	0.115
TOUGH2 (3)	0.227	89	0.112
VESA	0.227	41	0.120





https://geosx-geosx.readthedocs-hosted.com/en/latest/docs/sphinx/advancedExamples/validationStudies/carbonStorage/isothermalLeakyWell/Example.html

Thermoporoelastic Consolidation

Thermoporoelastic consolidation is a typical fully coupled problem which involves **solid deformation, fluid flow and heat transfer** in saturated porous media.

In this example, we use the GEOSX coupled solvers to solve a one-dimensional thermoporoelastic consolidation problem with a non-isothermal boundary condition, and we verify the accuracy of the results using the analytical solution provided in (Bai, 2005)

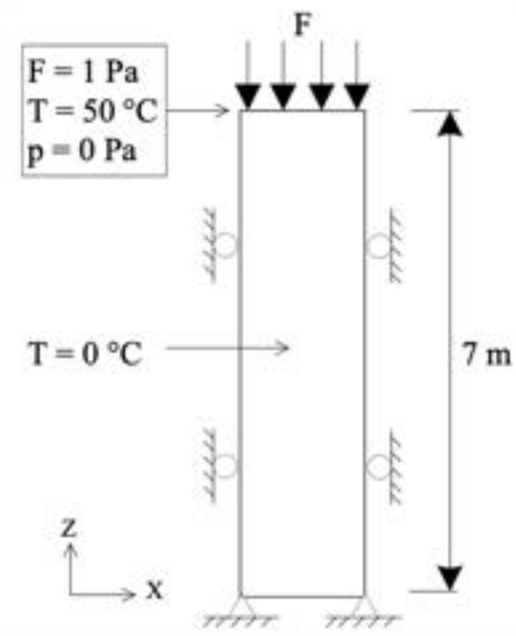
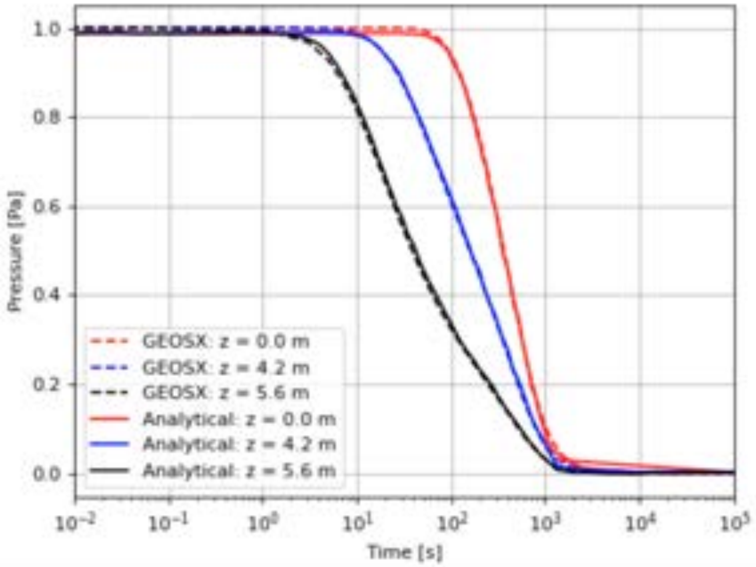
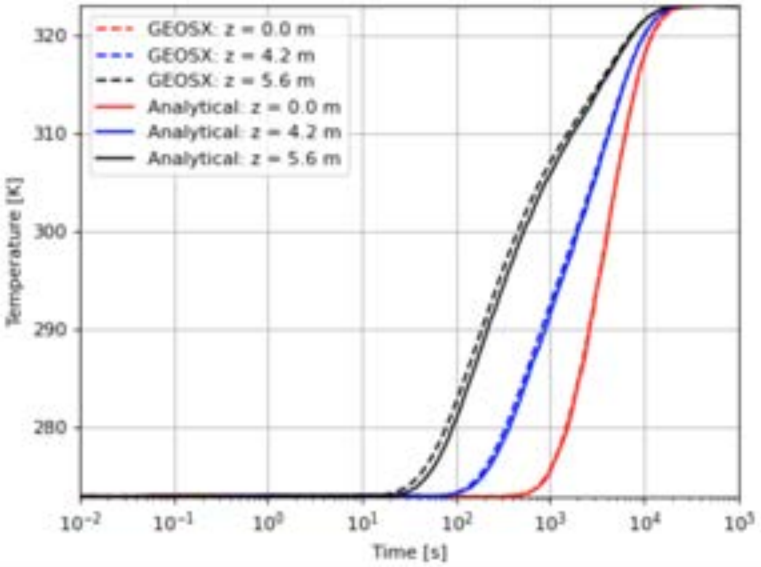
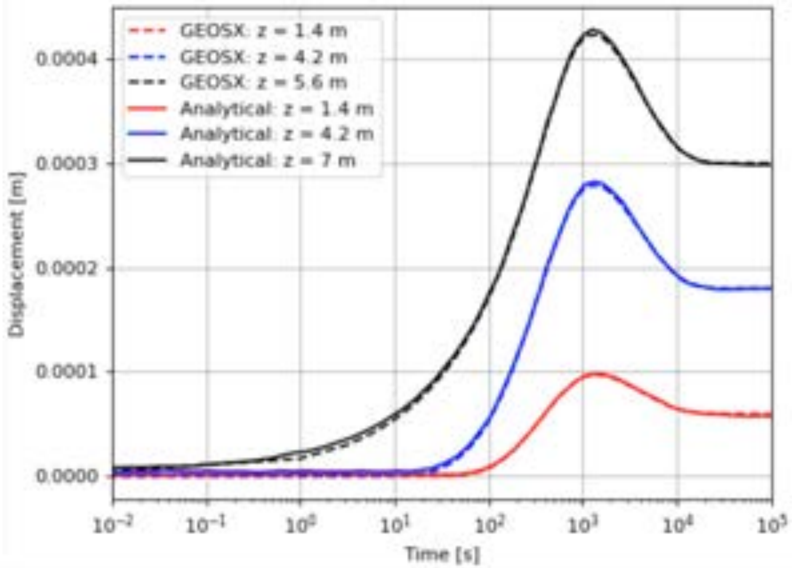


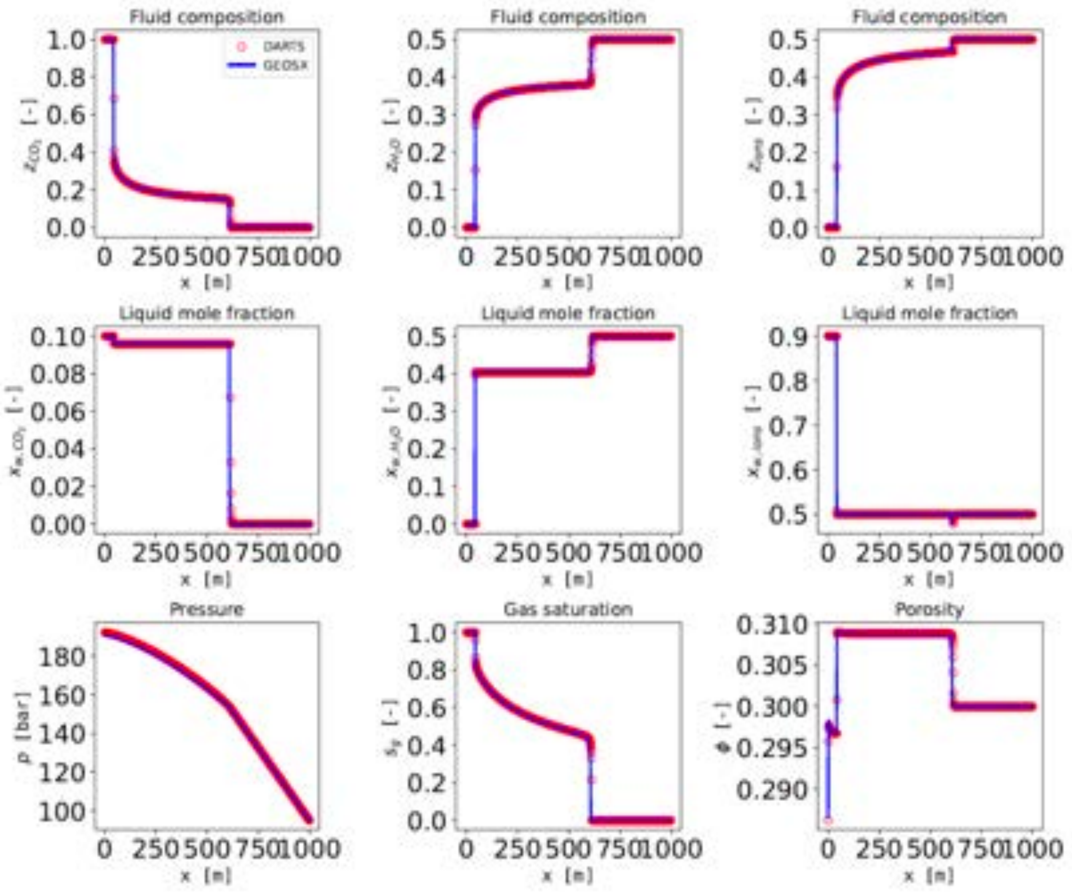
Fig. 62 Sketch of the problem (taken from (Gao and Ghassemi, 2019)).



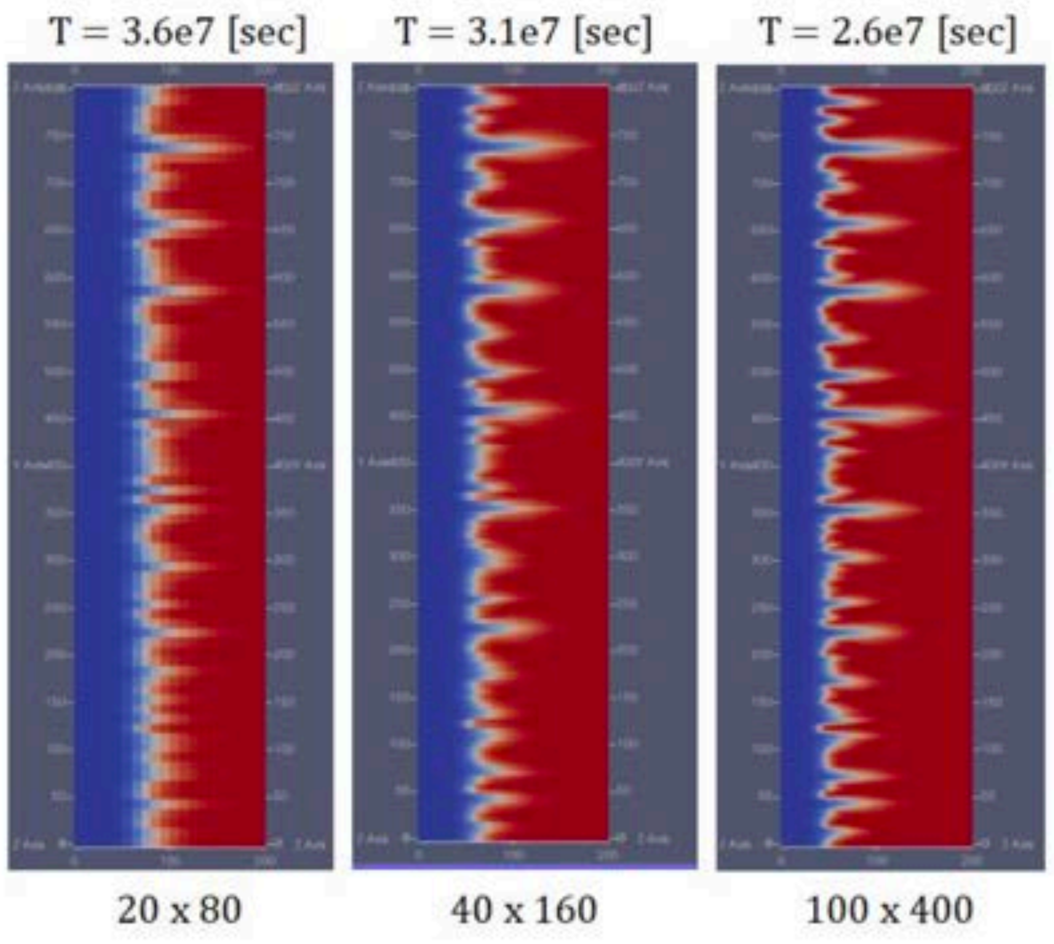




GEOS + DARTS !!

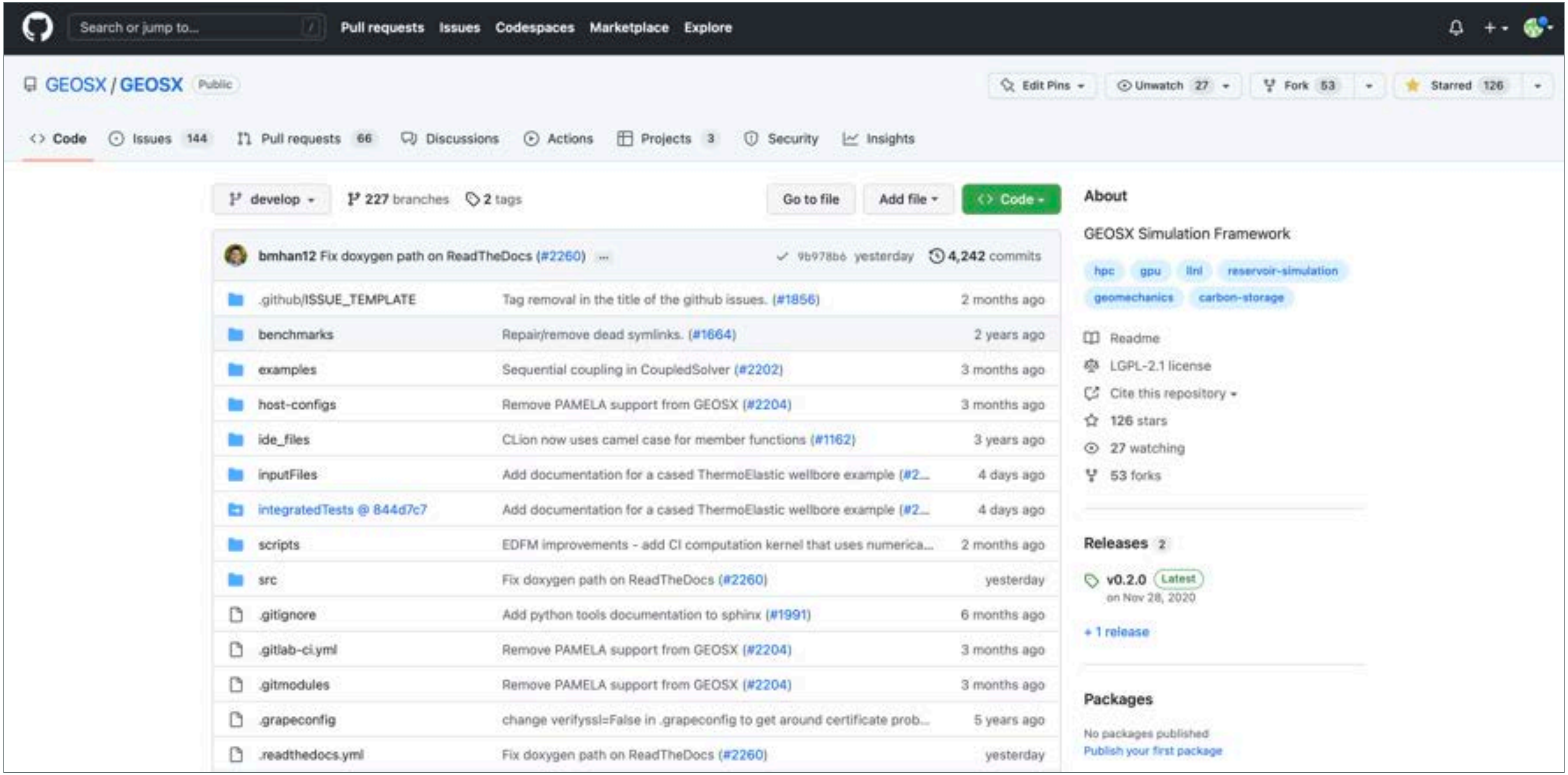


Finite volume flow with porosity alterations using FIM with **OBL from DARTS in GEOS**



Instable dissolution (wormhole) at various mesh resolution using OBL in GEOS

Our GitHub repository



Is there a **documentation webpage** for GEOSX?

- Quick Start Guide
- Tutorials
- Basic Examples
- Advanced Examples
- User Guide
- Developer Guide
- Doxygen
- Python Tools
- Build Guide
- Datastructure Index
- Contributors
- Publications
  - Preprints and Early-Views
  - 2022
  - 2021
  - 2020
  - 2019
- Acknowledgements

Publications

Last updated 23-October-2022

Preprints and Early-Views

2022

Smooth implicit hybrid upwinding for compositional multiphase flow in porous media
SBM Bosma, FP Hamon, BT Mallison, HA Tchelepi
Computer Methods in Applied Mechanics and Engineering
doi:10.1016/j.cma.2021.114288

A Multi-resolution approach to hydraulic fracture simulation
A Costa, M Cusini, T Jin, R Settgast, JE Dolbow
International Journal of Fracture
doi:10.1007/s10704-022-00662-y

Phase-field modeling of rock fractures with roughness
F Fei, J Choo, C Liu, JA White
International Journal for Numerical and Analytical Methods in Geomechanics
doi:10.1002/nag.3317

Scalable preconditioning for the stabilized contact mechanics problem
A Franceschini, N Castelletto, JA White, HA Tchelepi
Journal of Computational Physics
doi:10.1016/j.jcp.2022.111150

A scalable preconditioning framework for stabilized contact mechanics with hydraulically active fractures
A Franceschini, L Gazzola, M Ferronato
Journal of Computational Physics
doi:10.1016/j.jcp.2022.111276

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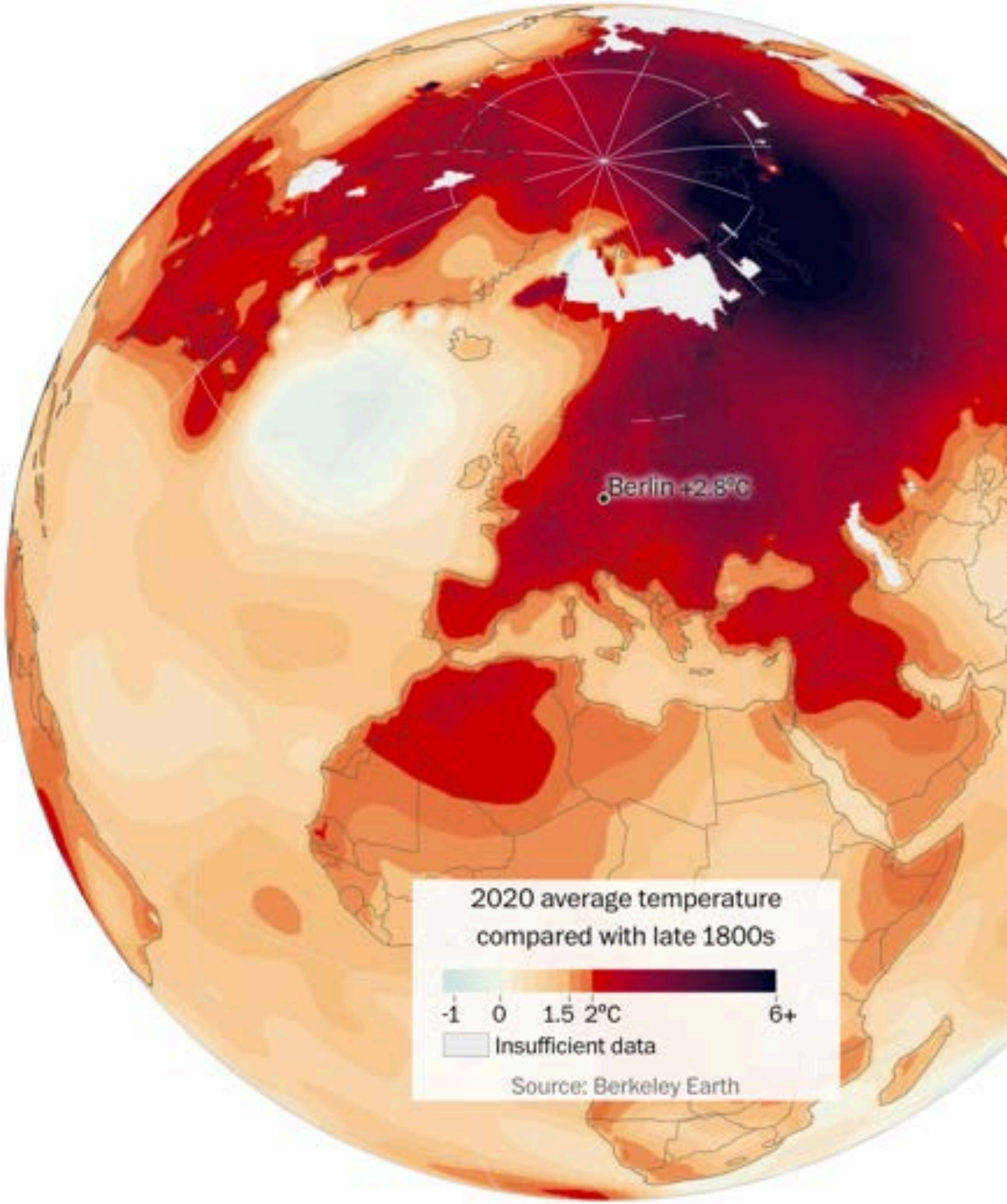

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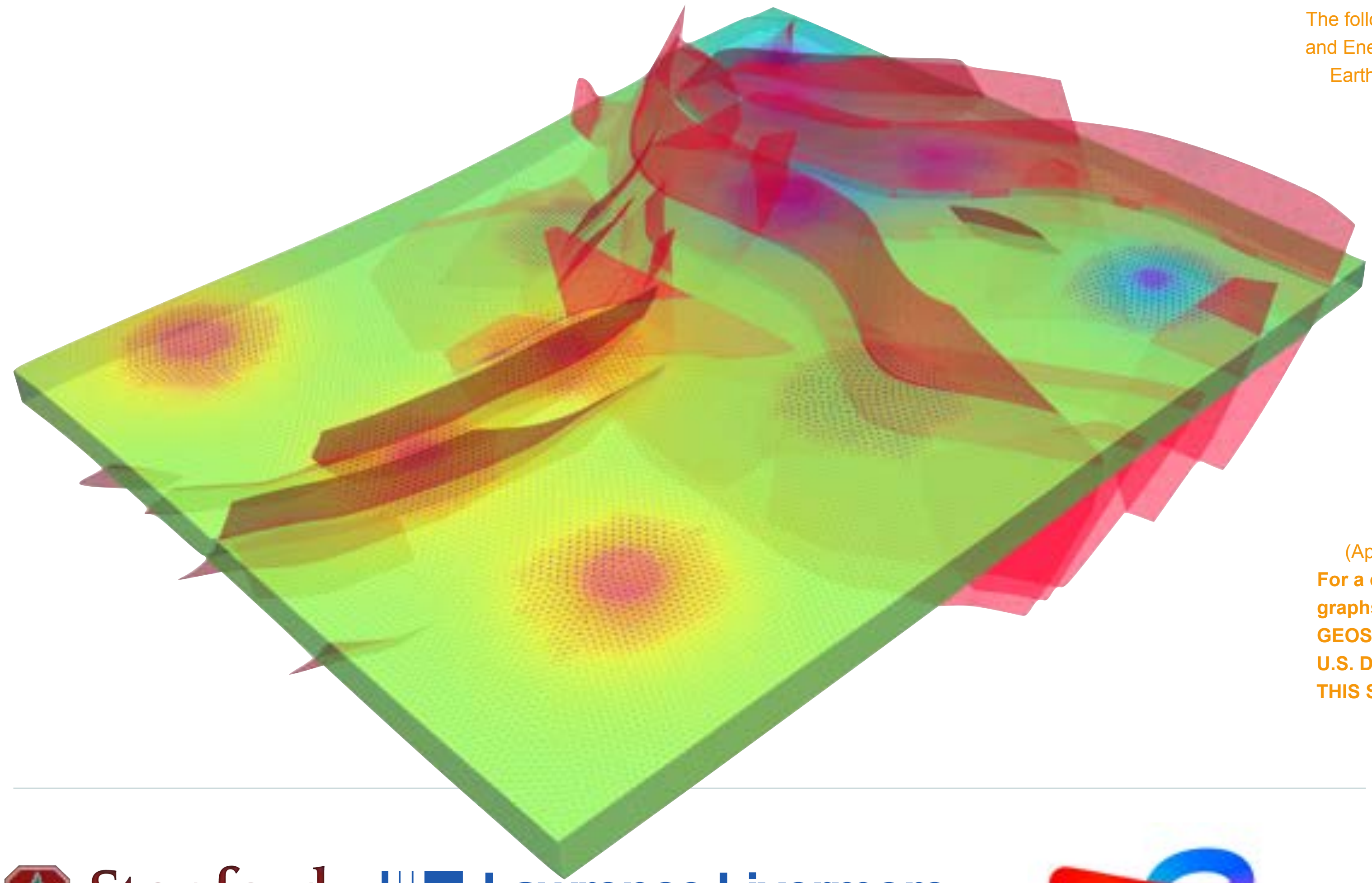

GEOSX is an open source project and is developed by a community of researchers at several institutions. The bulk of the code has been written by contributors from three main organizations: Lawrence Livermore National Laboratory, Stanford University, and Total, S.A..
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For a complete up-to-date list of contributors, see https://github.com/GEOSX/GEOSX/graphs/contributors

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