Multiscale Modeling of Carbon Dioxide Migration and Trapping in Fractured Reservoirs with Validation by Model Comparison and Real-Site Applications

Project Number DE-FE0023323

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U.S. Department of Energy

National Energy Technology Laboratory

Mastering the Subsurface Through Technology Innovation, Partnerships and Collaboration:
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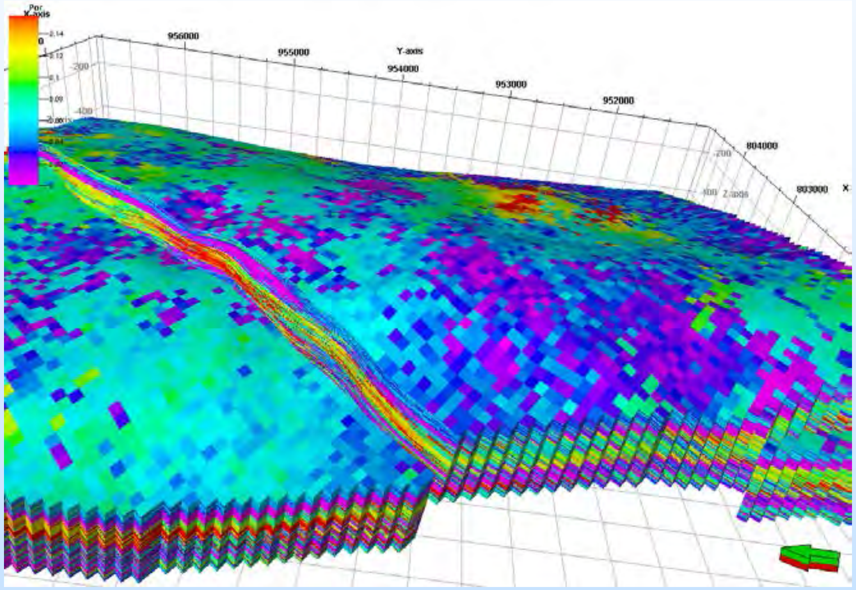
Presentation Outline

- Modeling approach
- Mass transfer functions
- Diffusion
- Vertically-integrated approach
- Key findings

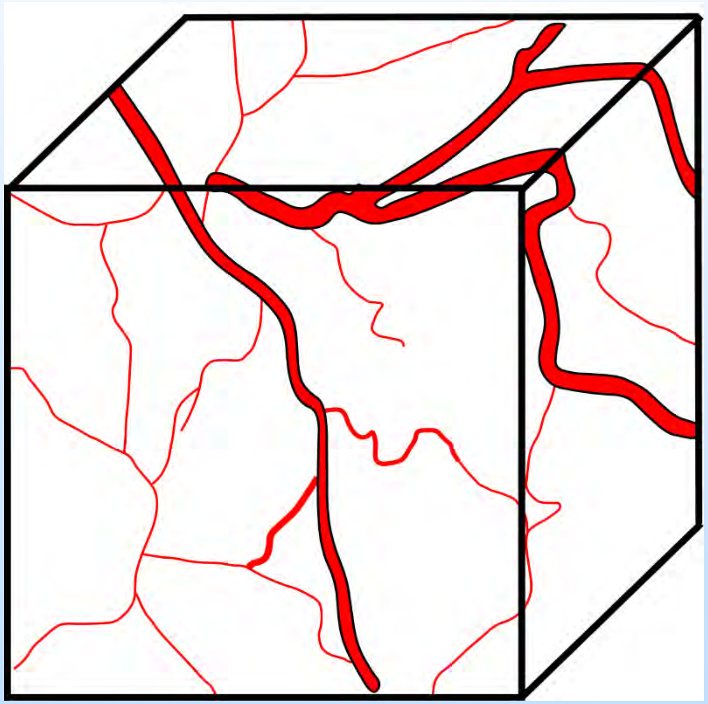
MODELING APPROACH

What are the issues

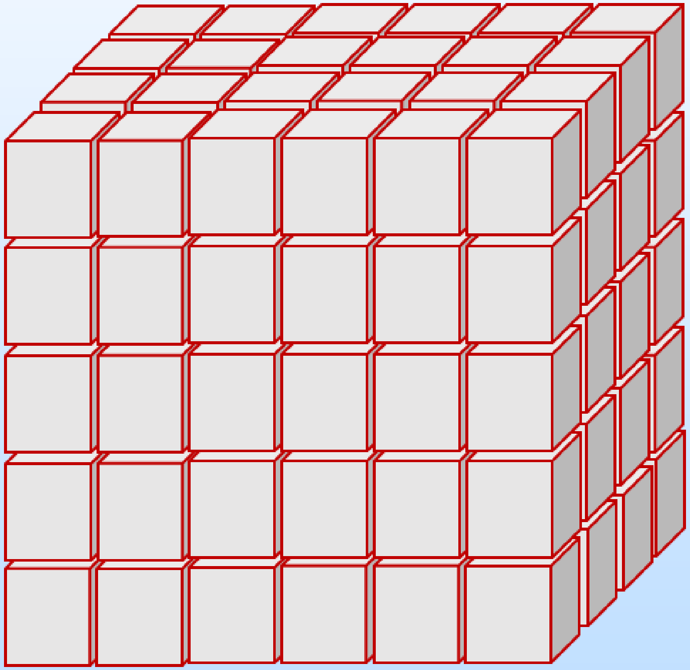


Dual domain concept

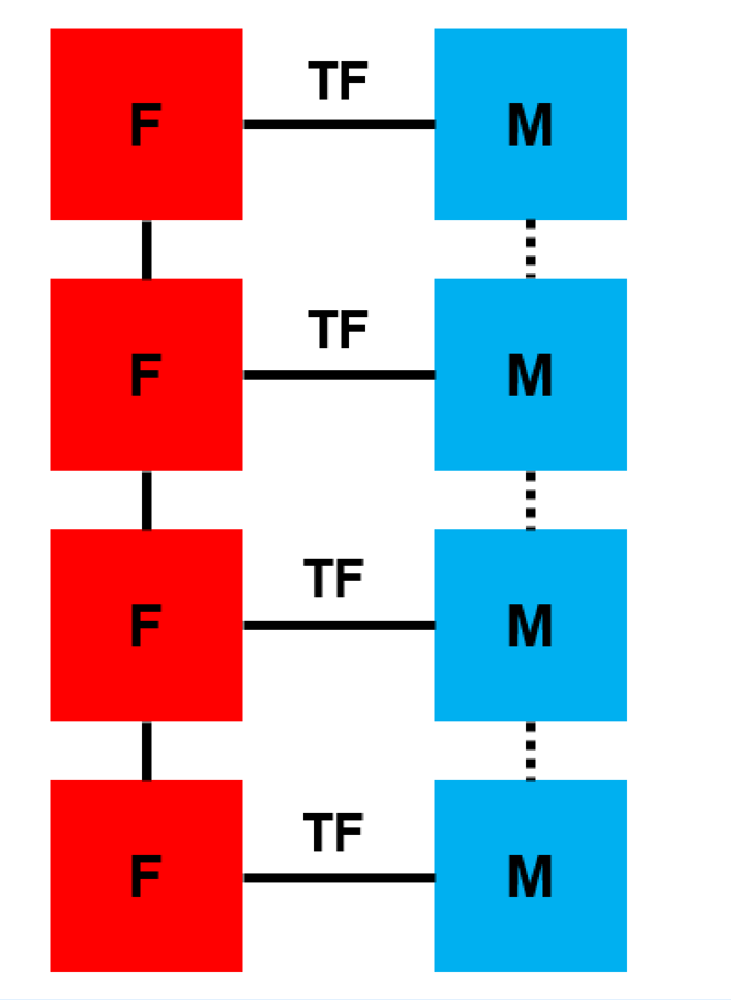
Physical geometry



Idealization: the dual-continuum representation



Modeling approach



F = Fracture grid-block
M = Matrix grid-block
TF = Transfer function

Fracture

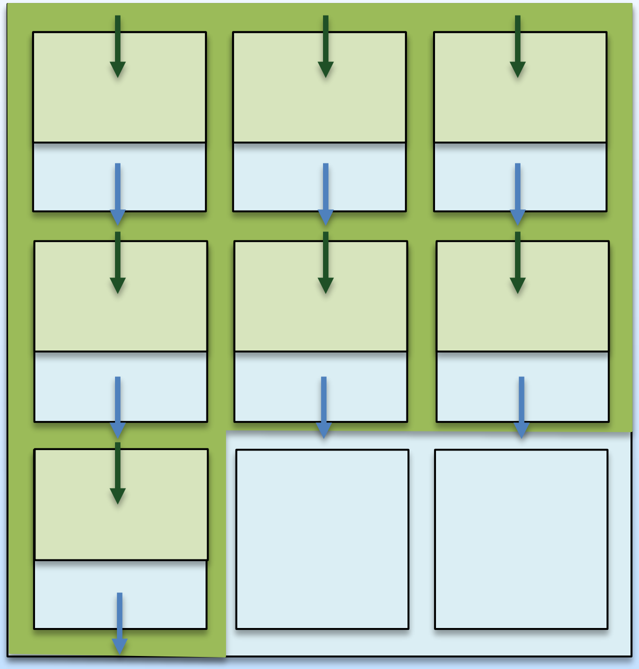
$$\frac{\partial m_\alpha^f}{\partial t} + \nabla \cdot (\rho_\alpha^f \boldsymbol{u}_\alpha^f) = \rho_\alpha^f Q_\alpha^f + T_\alpha^{fm}$$

Matrix

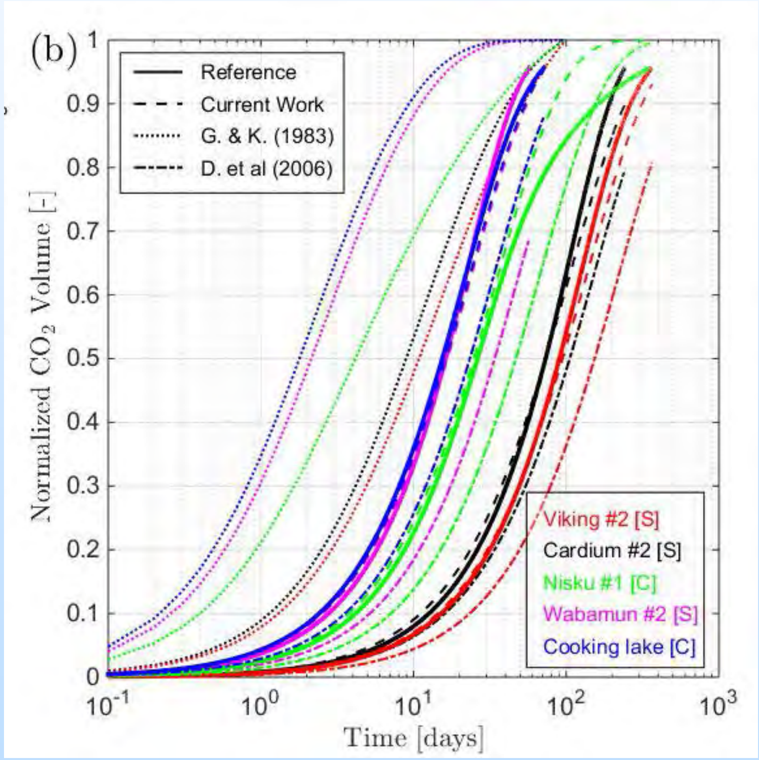
$$\frac{\partial m_\alpha^m}{\partial t} = \rho_\alpha^m Q_\alpha^m - T_\alpha^{fm}$$

MASS TRANSFER FUNCTION

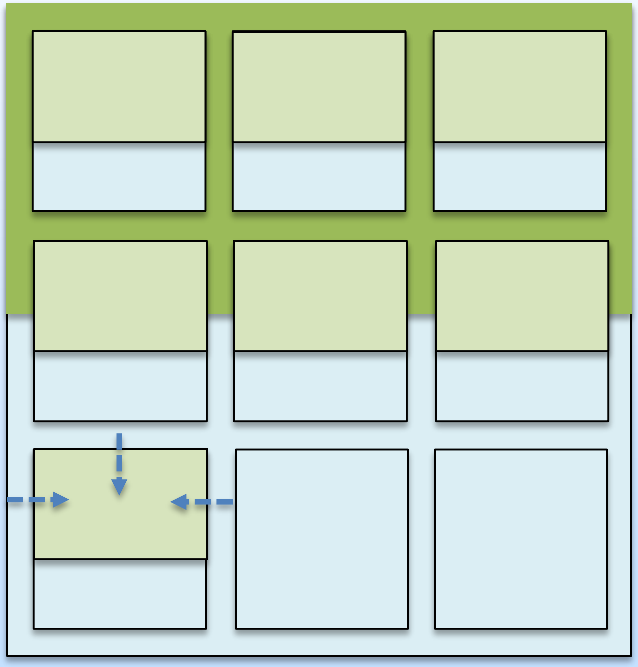
Gravity Drainage

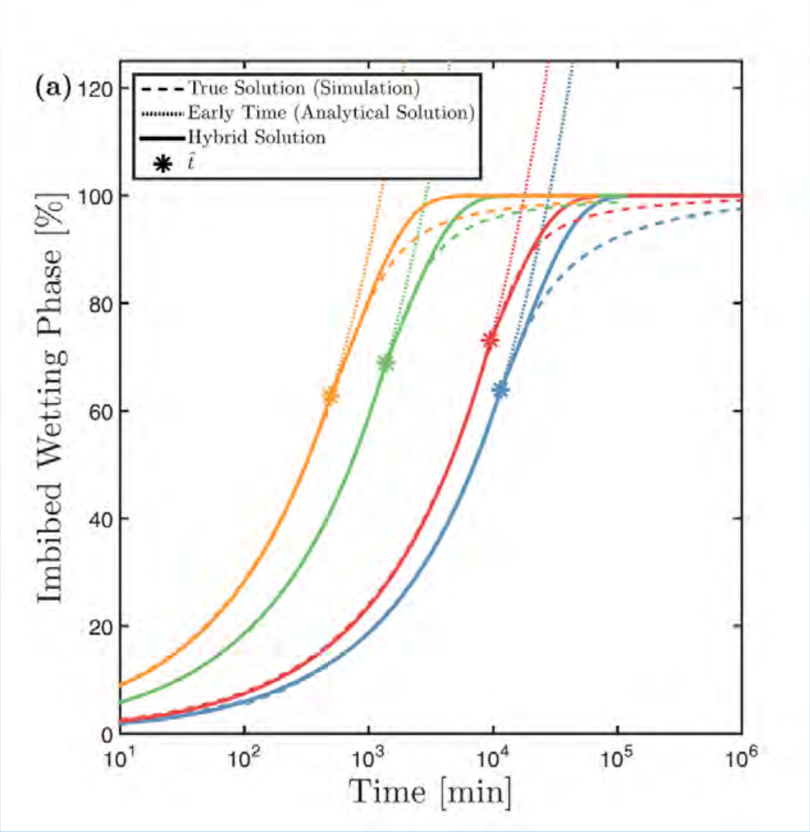


$$V_{CO_2}(t) = V_{CO_2}^{max}\left(1 - e^{-\beta t}\right)$$

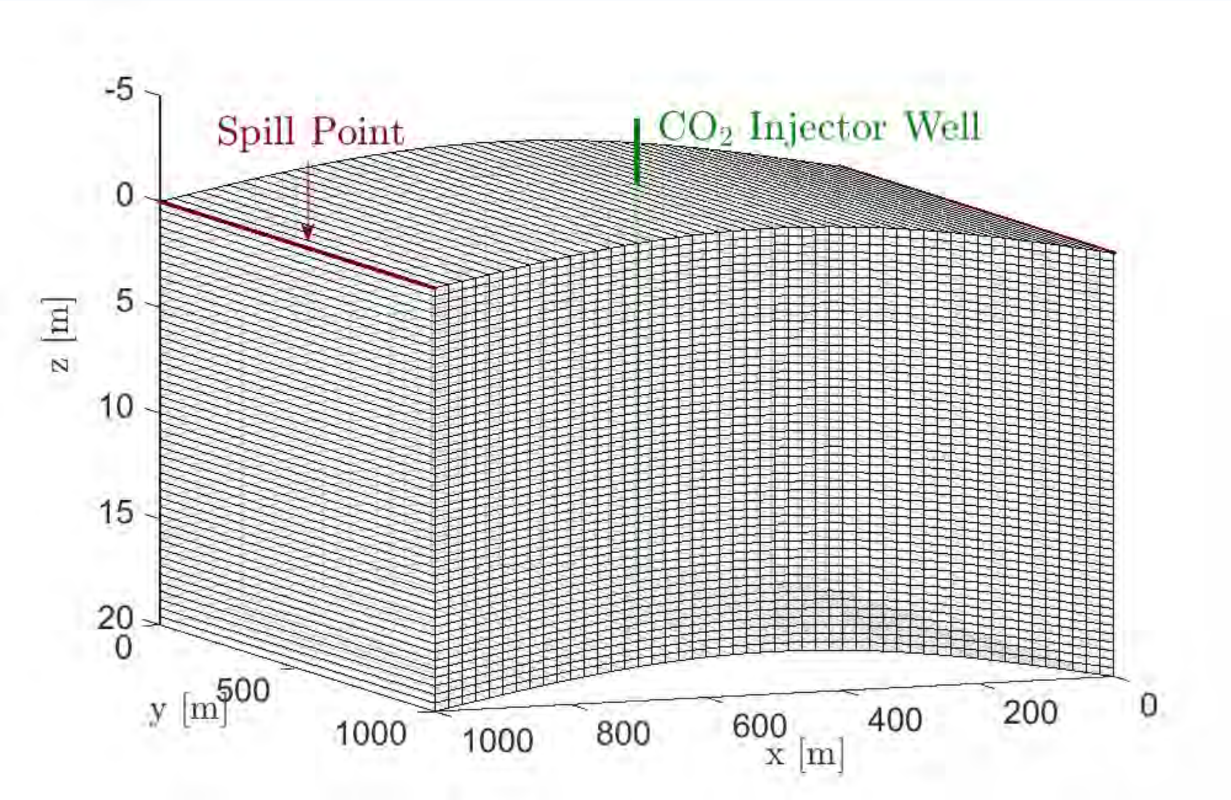


Spontaneous Imbibition





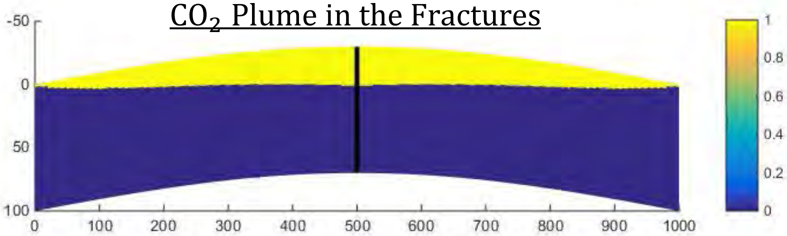
Anticline model



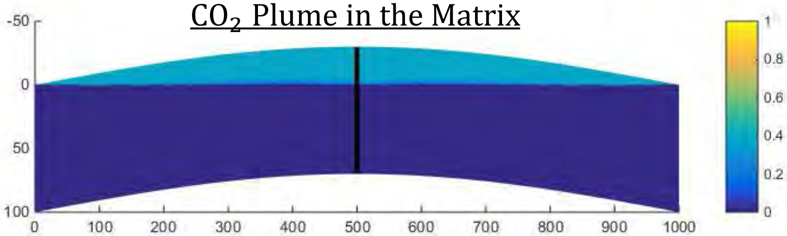
Fractured - Unfractured

Fractured Anticline

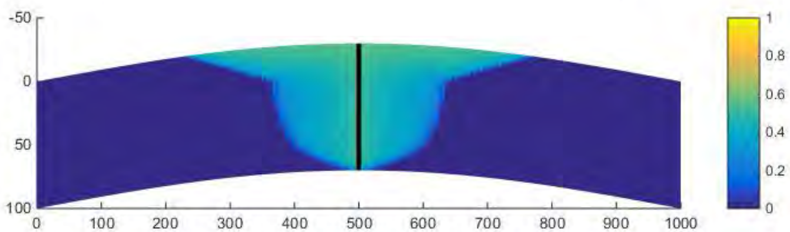
CO_2 Plume in the Fractures



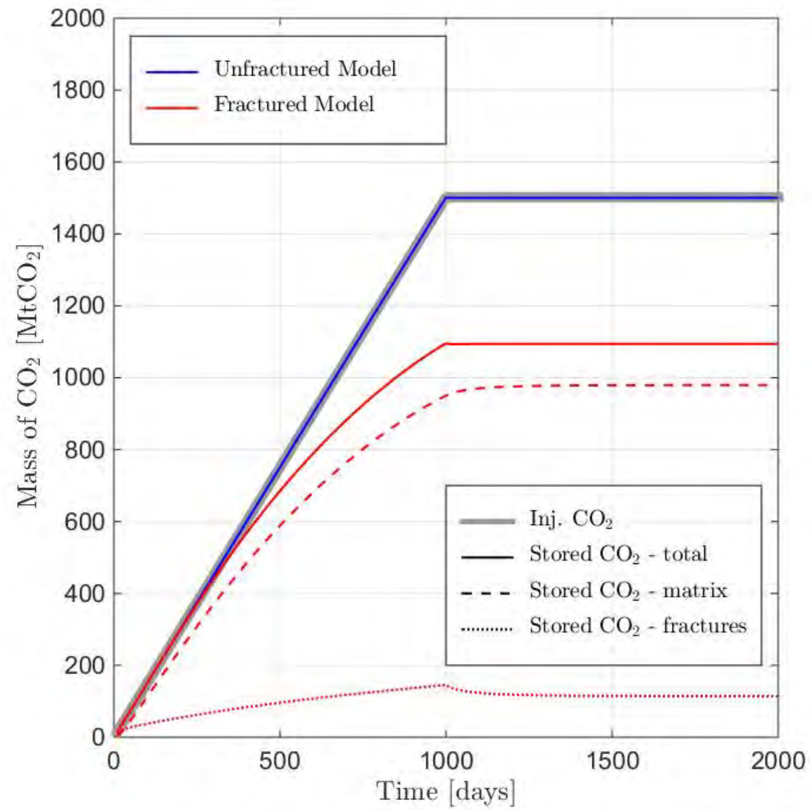
CO_2 Plume in the Matrix



Unfractured Anticline

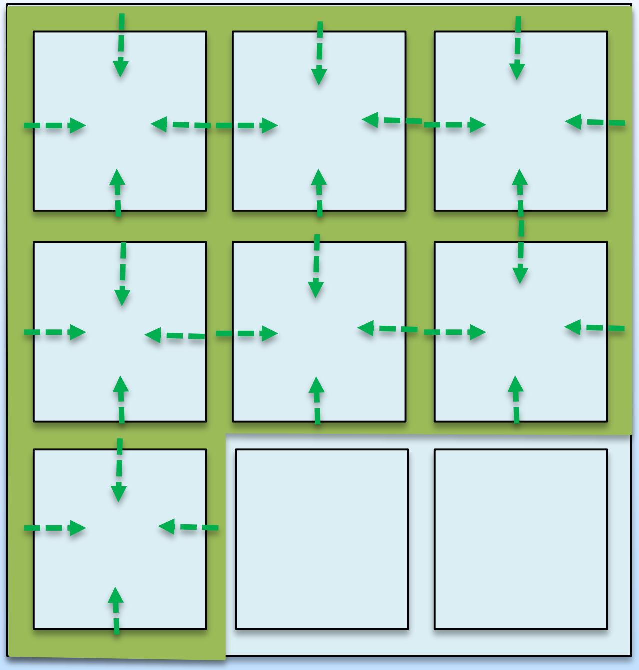


Stored Mass of CO_2

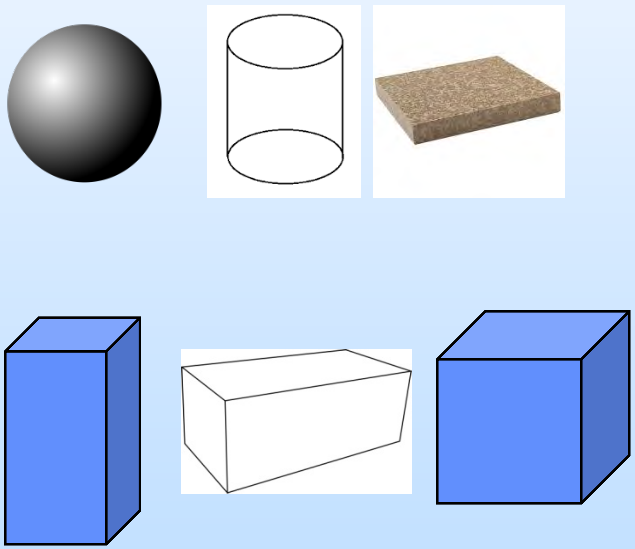


DIFFUSION

Diffusion Mass Transfer



Matrix Shapes



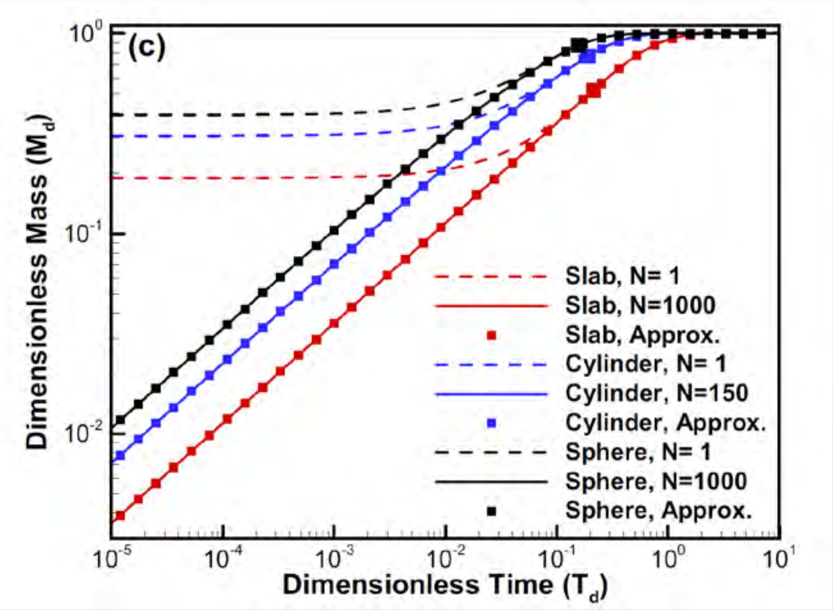
Simplified Approach

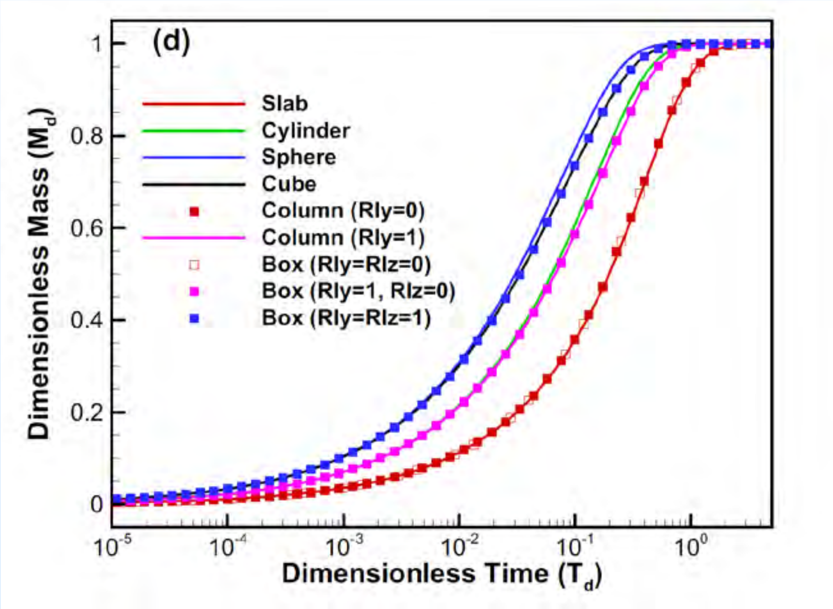
$$M_d = \begin{cases} a_1\sqrt{T_d} + a_2 T_d + a_3 (T_d)^{3/2} & T_d \le T_{d0} \\ 1 - \sum_{j=1}^{N} b_{1j} \exp\left[-b_{2j} T_d\right], & T_d > T_{d0} \end{cases}$$

$$M_d = M_t / M_\infty = C_t / C_0 = C_d$$

$$T_d = Dt/l^2$$

Accuracy/Consistency



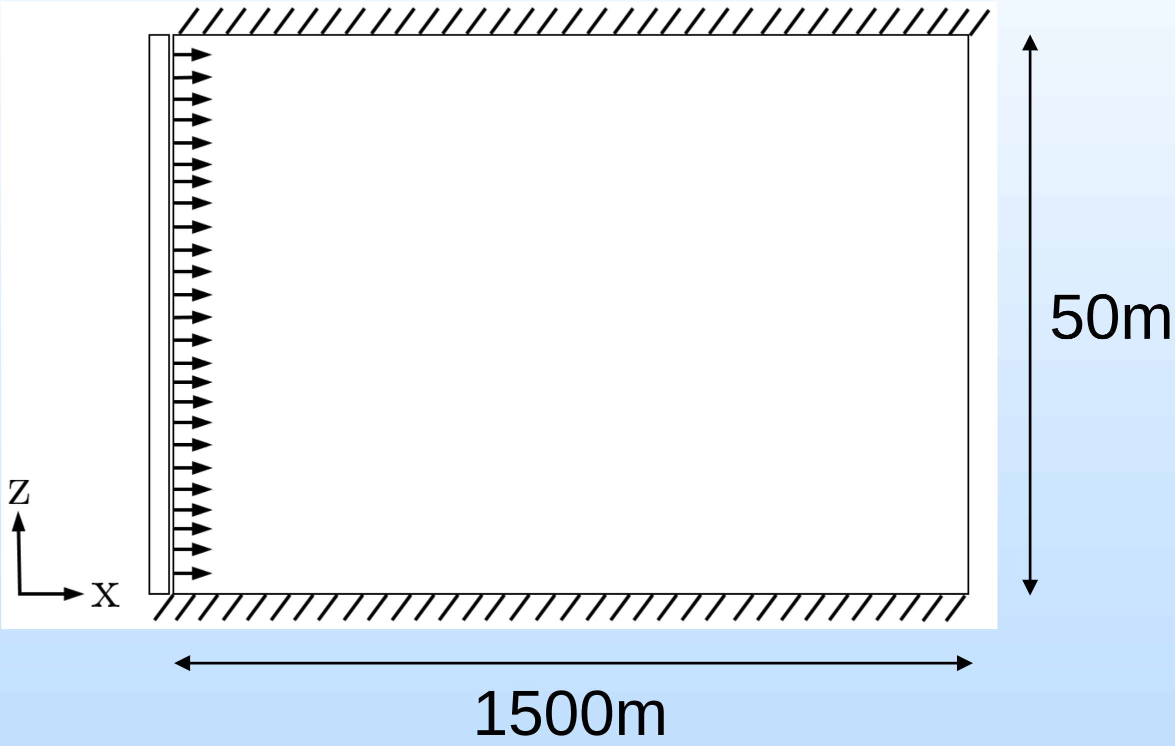


SIMPLIFIED MODEL

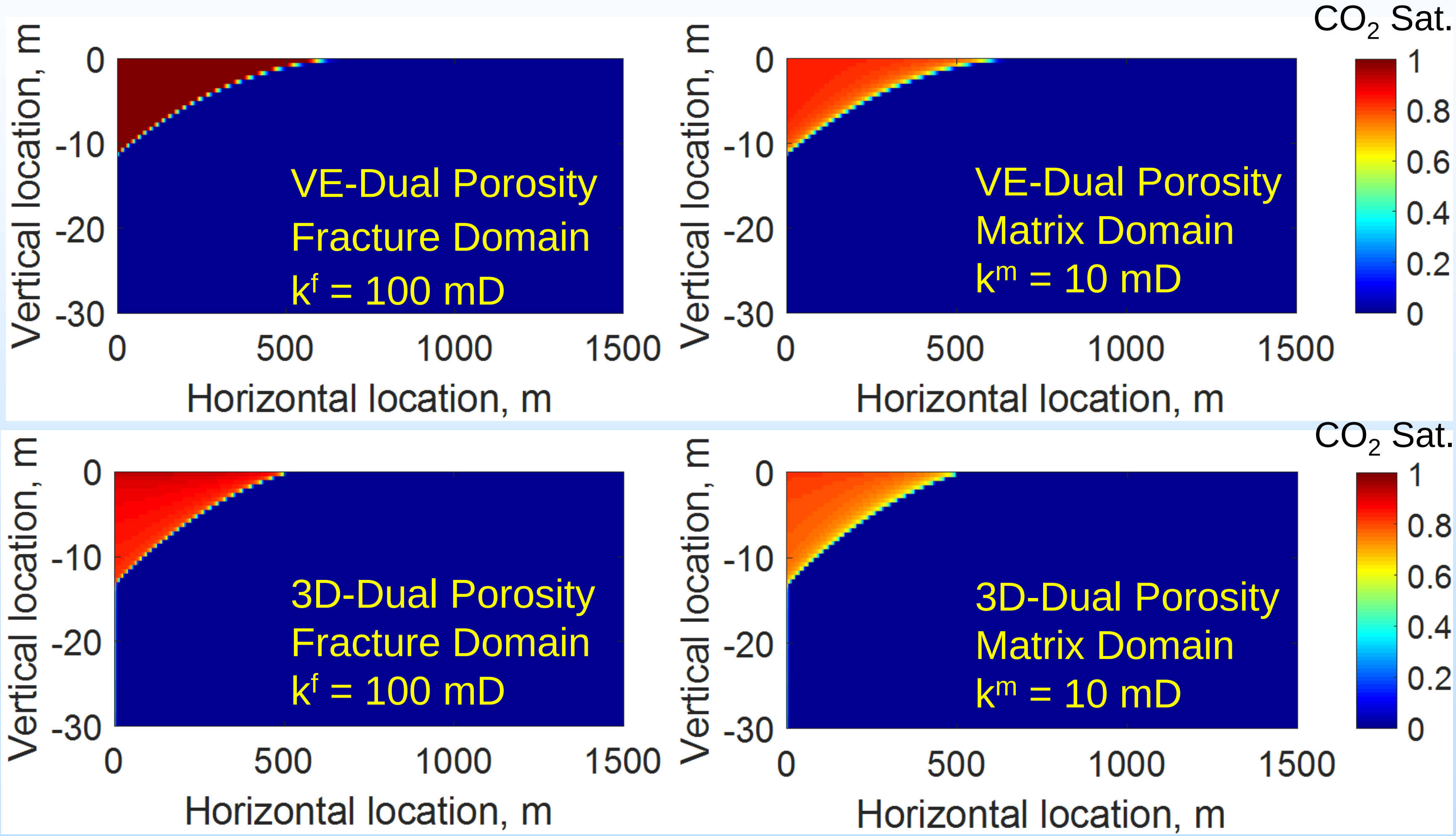
Simplified models

- Fractures:
  - High permeability
  - Low capillary entry pressure
- Vertically-integrated sharp-interface model
- Pressure and saturation reconstruction for mass transfer

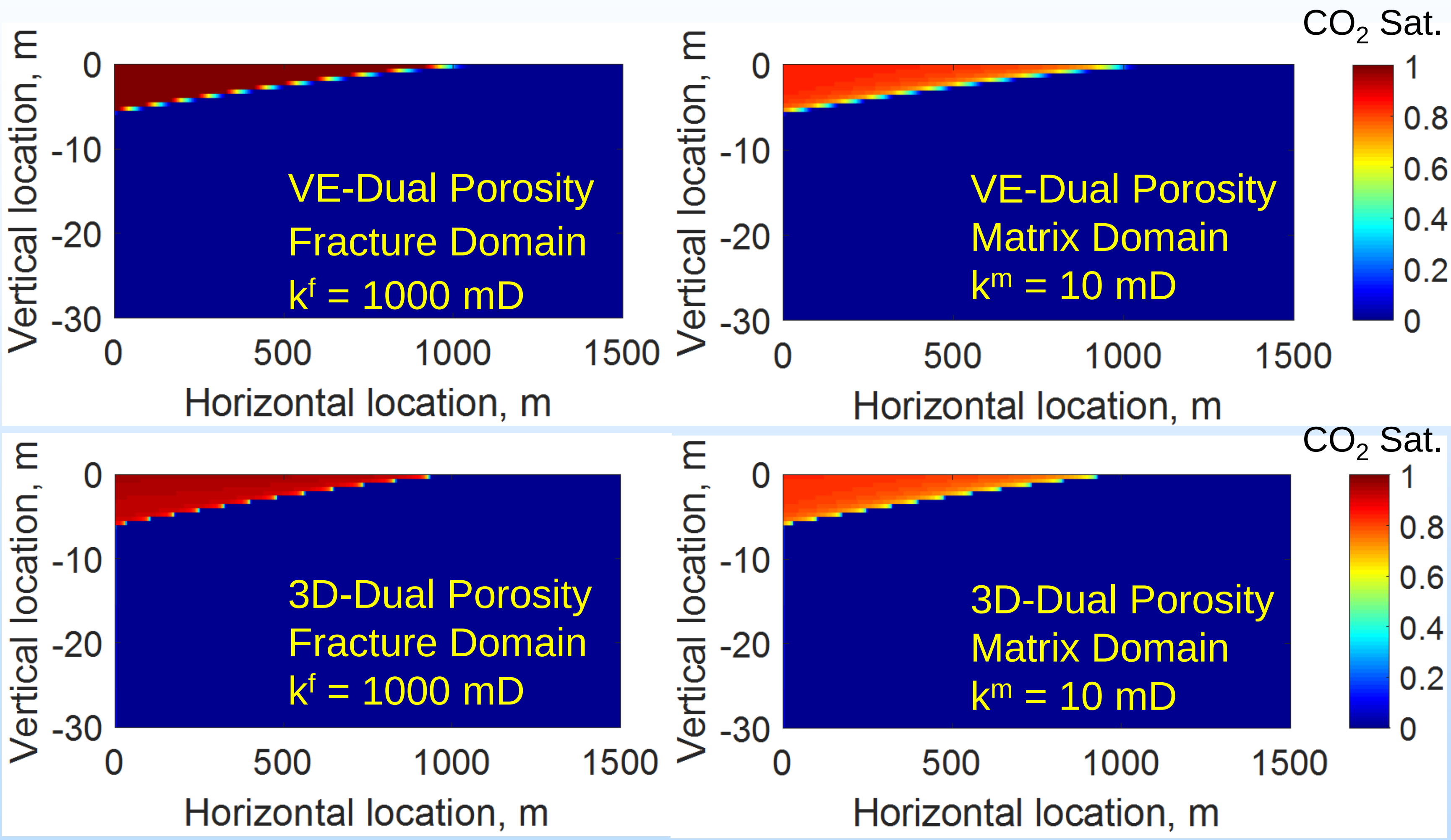
Test Case



100 mD fractures



1000 mD fractures



Key findings

- We can use relatively simple deterministic models to describe mass transfer based on:
  - Diffusion
  - Gravity drainage
  - Spontaneous imbibition
- Vertically-integrated models seem to be applicable

Accomplishments to Date

- Development of transfer function for dual-porosity model for both spontaneous imbibition and gravity drainage
- Implemented and validated single- and two-phase dual-porosity modules and a hysteresis module for MRST
- Updated TOUGH2/ECO2N simulator for better performance for CO_2 storage in fractured media simulations

Accomplishments to Date

- Investigated the impact of matrix block connectivity on CO_2 storage capacity
- Developed analytic solutions for CO_2 storage due to diffusion of dissolved CO_2
- Developed and implemented a vertically-integrated dual-porosity model
- Investigated development of vertically-integrated dual-permeability model
- Conducted sensitivity analyses based on new models

Lessons learned

- More complex is not necessarily better
- Vocabulary matters

Synergy opportunities

- The modeling approaches developed in this project should be useful to other projects studying carbon sequestration in fractured formations

Future Plans

- Continue development of vertically-integrated dual-porosity and dual-permeability models
- Continue to investigate the impact of fracture and matrix block parameters on CO_2 storage capacity
- Apply newly developed modeling approaches to In Salah site

THANK YOU!

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Appendix

Benefit to the Program

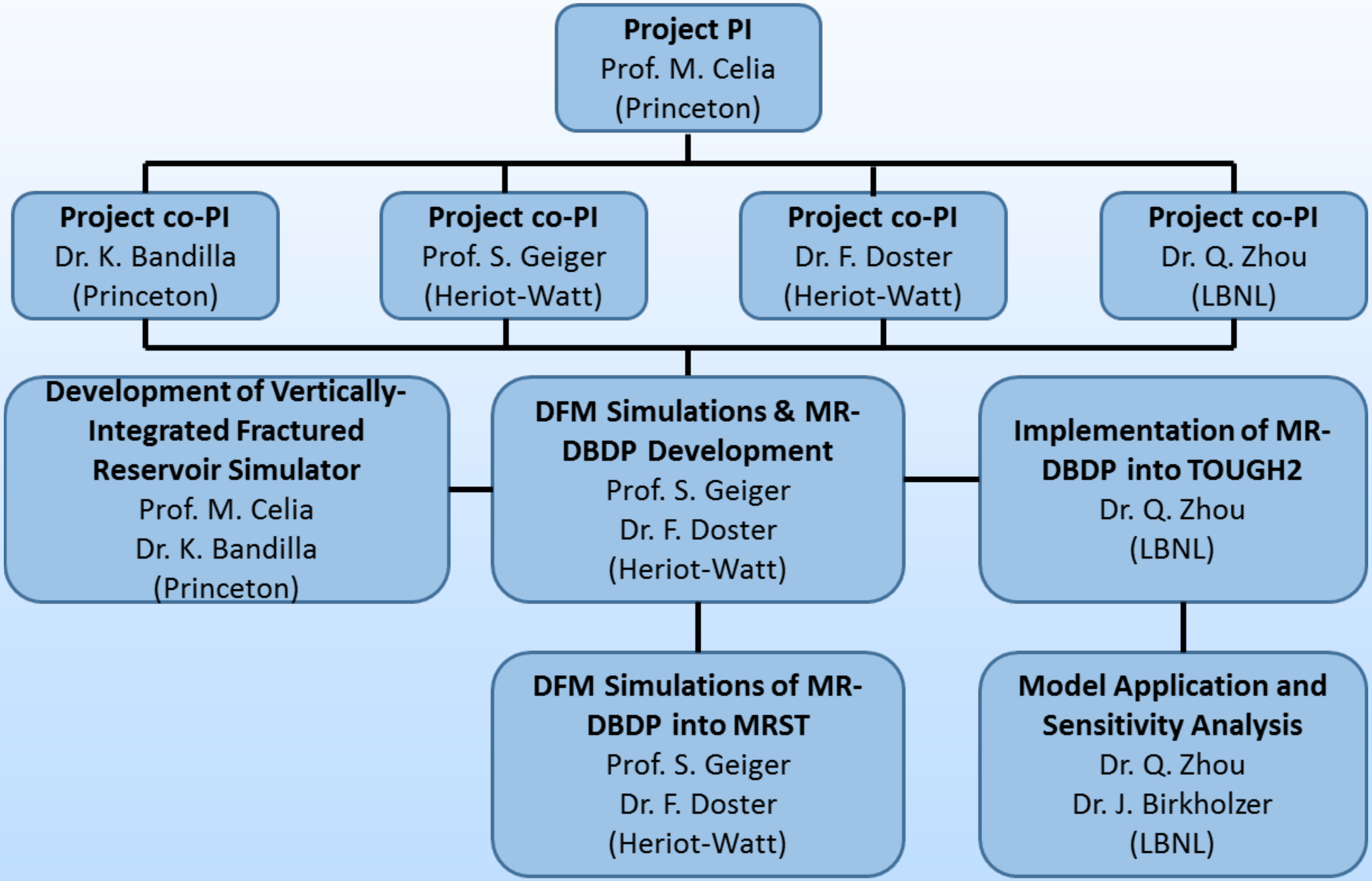
- Goal: Develop new capabilities for carbon sequestration modeling in fractured reservoirs through improvements in the representation of fracture-matrix flow interactions.

- Support industry's ability to predict CO_2 storage capacity in geologic formations to within ±30 percent.

Project Objectives

- Develop new models for interactions of fracture and matrix flow
- Incorporate those models into reservoir-scale simulators
- Conduct sensitivity analyses of trapping efficiency and storage capacity using new model
- Apply new model to In Salah site

Organization Chart



Gantt Chart (BP1-BP3)

light grey: accomplished; dark grey: planned; MS: mile stone

Fiscal Year	BP 1				BP 2						BP 3	
Quarter	1	2	3	4	1	2	3	4	5	6	3	4
Task 1: Project Management, Planning and Reporting												
Subtask 1.1: Updated Project Management Plan	MS											
Subtask 1.2: Project Planning and Reporting	MS											
Task 2.0: Detailed DFM modeling of CO2 and brine				MS								
Task 3.0: Development of MR-DBDP model with analytic transfer function						MS						
Task 4.0: Development of new simulator capabilities												
Subtask 4.1: Development of vertically integrated simulator					MS					MS		
Subtask 4.2: incorporate new MR-DBDP into MRST simulator												MS
Subtask 4.3: incorporate new MR-DBDP into TOUGH2									MS			
Task 5.0: Model demonstration and sensitivity analysis												
Subtask 5.1: Investigation of driving forces												
Subtask 5.2: Sensitivity Analysis								MS				
Subtask 5.3: Storage and trapping in heterogeneous reservoir										MS		
Subtask 5.4: Investigation of injection scenarios												
Task 6.0: Simulator application to In Salah												
Subtask 6.1: Site-specific model development										MS		
Subtask 6.2: Migration and Trapping modeling										MS		
Subtask 6.3: Sensitivity analysis												

Gantt Chart (BP4)

light grey: accomplished; dark grey: planned; MS: mile stone

Fiscal Year	BP 4			
Quarter	1	2	3	4
Task 1: Project Management, Planning and Reporting				
Subtask 1.1: Updated Project Management Plan				
Subtask 1.2: Project Planning and Reporting				
Task 2.0: Detailed DFM modeling of CO2 and brine				
Task 3.0: Development of MR-DBDP model with analytic transfer function				
Task 4.0: Development of new simulator capabilities				
Subtask 4.1: Development of vertically integrated simulator				
Subtask 4.2: incorporate new MR-DBDP into MRST simulator				
Subtask 4.3: incorporate new MR-DBDP into TOUGH2				
Task 5.0: Model demonstration and sensitivity analysis				
Subtask 5.1: Investigation of driving forces				
Subtask 5.2: Sensitivity Analysis				
Subtask 5.3: Storage and trapping in heterogeneous reservoir				
Subtask 5.4: Investigation of injection scenarios				
Task 6.0: Simulator application to In Salah				
Subtask 6.1: Site-specific model development				
Subtask 6.2: Migration and Trapping modeling				
Subtask 6.3: Sensitivity analysis				MS

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