DE-FE0023314
Area of Interest 1: Geomechanical Research

Development of Geomechanical Screening Tools to Identify Risk: An Experimental and Modeling Approach for Secure CO_2 Storage

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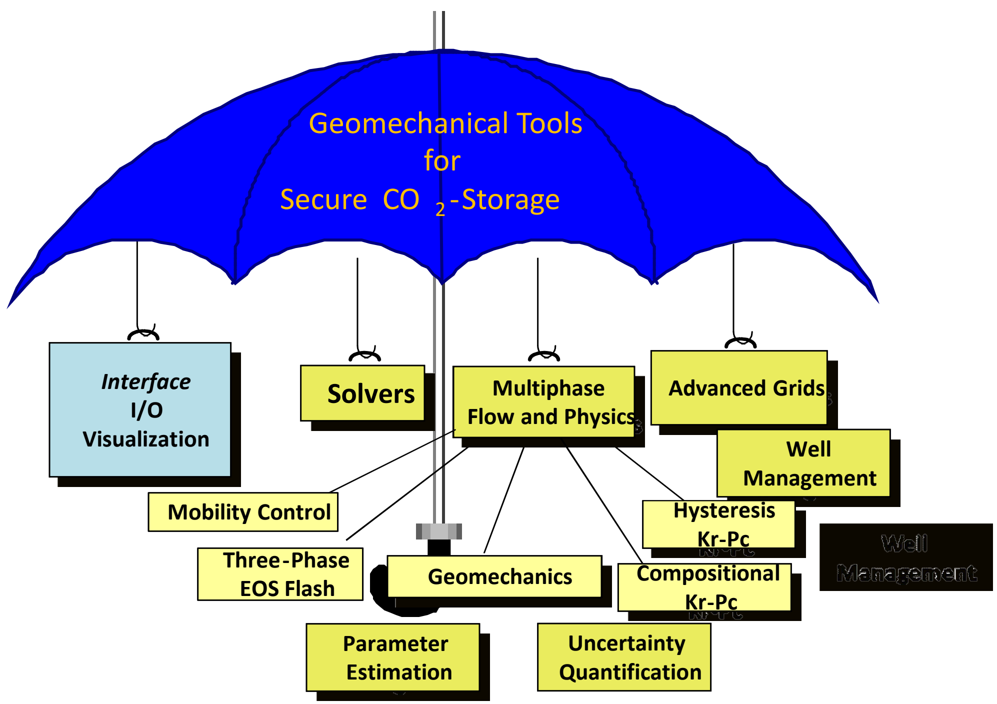
The University of Texas at Austin

U.S. Department of Energy
National Energy Technology Laboratory
DE-FOA0001037 Kickoff Meeting
November 12-13, 2014

Project Goal

DEVELOPMENT OF GEOMECHANICAL SCREENING TOOLS TO IDENTIFY RISK: AN EXPERIMENTAL AND MODELING APPROACH FOR SECURE CO_2 STORAGE



Project Objectives

- To develop a screening tool for improved understanding of geomechanical effects associated with CO_2 injection in the form of a workflow derived from experimental and computational studies conducted for specific CO_2 sites.
  - **Conduct laboratory experiments to study hydro-mechanical rock properties**
  - **Upscale to bridge from laboratory to field scales**
  - **Extend simulator capability to model CO_2 storage field scale studies**
  - **Perform parameter estimation and uncertainty quantification**
  - **Integrate results to generate geomechanical screening tool /workflow**

Benefit to the Program

- Assist in selection of suitable sites for safe CO_2 storage
- Enhance understanding of the effects of $scCO_2$ injection on open and closed faults and fractures
- Support training and education of students who will take part in an interdisciplinary work force
- Contribute to Carbon Storage Program goal of developing and validating technologies to ensure 99 percent storage permanence

Project Management Structure

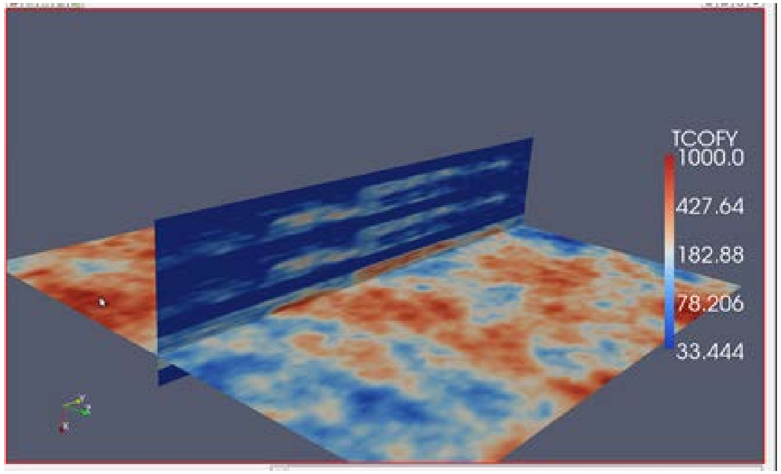
Project Director M.F. Wheeler					
Task 1 Management	**Task 2** Lab. Program	**Task 3** Bridging between Laboratory and Field Scales	**Task 4** Modeling and Field Studies	**Task 5** Uncertainty Quantification and Parameter Estimation	**Task 6** Integrate Results to Generate Geomechanical Screening Tool /Workflow
Task Leader M. Wheeler	**Task Leader** N. Espinoza	**Task Leader** M.F. Wheeler	**Task Leader** M. Delshad	**Task Leader** S. Srinivasan	**Task Leader** M.F. Wheeler
Key Personnel M. Delshad S. Srinivasan N. Espinoza	**Key Personnel** M.F. Wheeler M. Delshad ½ Postdoc 1 student (Y 1&2)	**Key Personnel** S. Srinivasan N. Espinoza ½ Postdoc 1 student	**Key Personnel** M. Wheeler N. Espinoza ½ Postdoc 1 student (Y 3)	**Key Personnel** M. Delshad M.F. Wheeler 1 student	**Key Personnel** M. Delshad S. Srinivasan N. Espinoza Student Postdoc

Methodology

- The project objective will be completed through an experimental and computational program divided into four technical tasks:
  - ✓ Conduct lab experiments to measure the mechanical response to various loadings using rock samples representing CO_2 storage sites
  - ✓ Conduct scale up from lab to field using computational techniques
  - ✓ Complete enhancements to the selected simulator and conduct simulations of two CO_2 storage site case studies
  - ✓ Perform parameter estimation to improve field case study simulations and quantify uncertainty in performance predictions

Expected Outcomes

- Develop an understanding and assessment of geomechanical processes related to CO_2 storage
- Develop computational tools for selection of suitable sites for storage of CO_2
- Train and educate students



Schedule/Milestones

Task Name	Assigned Resource	BP 1				BP 2				BP 3			
		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Task 1 .0 - Project management, planning & reporting	***Wheeler***	○											○
Milestone A: Update Project Management (10/30/2014)		A											
Milestone B: Kick off meeting (11/30/2014)		B											
Task 2.0 -Conduct Laboratory Experiments for Petrophysical and Hydro-mechanical Rock Properties	***Espinoza***	○									○		
Subtask 2.1:Develop Plan for Design of Experimental Apparatus and Rock Property Testing													
Milestone C. Plan for the design of the experimental equipment and the tests to be completed				C									
Subtask 2.2: Experimental Apparatus Fabrication, Setup and Calibration and Sample Acquisition													
Milestone D. List of representative rock samples acquired for testing completed.					D		◆						
Milestone E. Complete triaxial cell setup and initiate testing.							E						
Subtask 2.3: Measurement of basic mechanical properties													
Milestone F. Interim report of measurement of basic rock properties									F				
Subtask 2.4 Measurement of Advanced Mechanical Properties with CO2-Specific Loadings													
Milestone G. Complete report that summarizes the activities, rock testing, and results in Task 2.0.										G			
Task 3.0 -Upscale by Completing Bridge from Laboratory to Field Scales	***Wheeler***			○									○
Subtask 3.1: Computation of effective parameters for flow and mechanics													
Milestone H. Document homogenization and mortar method for flow and mechanics equations for sub-inch and larger scales respectively.									H				
Subtask 3.2: Computation of effective parameters for coupled thermal-geomechanical processes for CO2 Specific Loadings													
Milestone I. Complete report that summarizes the activities and results in Task 3.0 conducted for upscaling lab measurements including a description of the development of homogenization schemes for naturally fractured and heterogeneous rocks.											I		
Task 4.0 - Simulator Development and Modeling CO2 Storage Field Scale Studies	***Delshad***	○											○
Subtask 4.1:Simulator Development with Numerical Schemes for Couples Processes													
Milestone J. Initiate Simulator Development with Numerical Schemes for Coupled Processes					J								
Milestone K. Complete report that describes the enhanced IPARS simulator developed in Subtask 4.1, and include the IPARS module for geomechanics.									K				
Subtask 4.2: Model CO2 Storage Field Sites and Perform Simulations													
Milestone L. Complete reports containing a description of the first selected field site (Site one), the model(s) developed, and the results of the simulations and history matching performed in Subtask 4.2.										L			
Milestone M. Complete report containing a description for the second selected field site (Site two), the model(s) developed, and the results of the simulations and history matching performed in Subtask 4.2.												M	
Task 5.0 -Parameter Estimation and Uncertainty Quantification	***Srinivasan***							○					○
Subtask 5.1: Ensemble Filtering approach for multi-parameter estimation													
Milestone N. Initiate parameter estimation and uncertainty quantification									N				
Subtask 5.2 : Uncertainty Qualification													
Milestone O. Report containing a description of the Task 5.0 computational studies and analyses completed for (1) using the ensemble filtering approach for multi-parameter estimation; and (2) uncertainty quantification conducted with the adaptive response surface-based methodology.													O
Task 6.0 - Integrated Results to Generate Geomchanical Screening Tool/Workflow	***Wheeler***										○		○
Milestone P. Report that includes the geomechanical workflow, provides the accompanying documentation/user's guide, and summarizes the activities and results performed in Task 6.0 for the workflow generation.													P

Budget Period Project Success Criteria/and Decision Point

BUDGET PERIOD PROJECT SUCCESS CRITERIA / DECISION POINTS		
Success Criteria at Decision Points		
Date	**Decision Point**	**Success Criteria***
8/31/2015	End of Budget Period 1	Completion of the following milestones: Milestone C Milestone D Milestone J
8/31/2016	End of Budget Period 2	Completion of the following milestones: Milestone E Milestone F Milestone H Milestone N

Technical Approach

- **Task 1.0 – Project Management, Planning, and Reporting**
- **Task 2.0 – Conduct Laboratory Experiments for petrophysical and hydro-mechanical properties of rocks in the presence of CO_2**
  - Subtask 2.1 – Develop Plan for Design of Experimental Apparatus
  - Subtask 2.2 – Experimental Apparatus Fabrication, Setup and Calibration
  - Subtask 2.3 – Measurement of Basic Mechanical Properties
  - Subtask 2.4 – Measurement of Advanced Mechanical Properties With CO_2-specific loadings

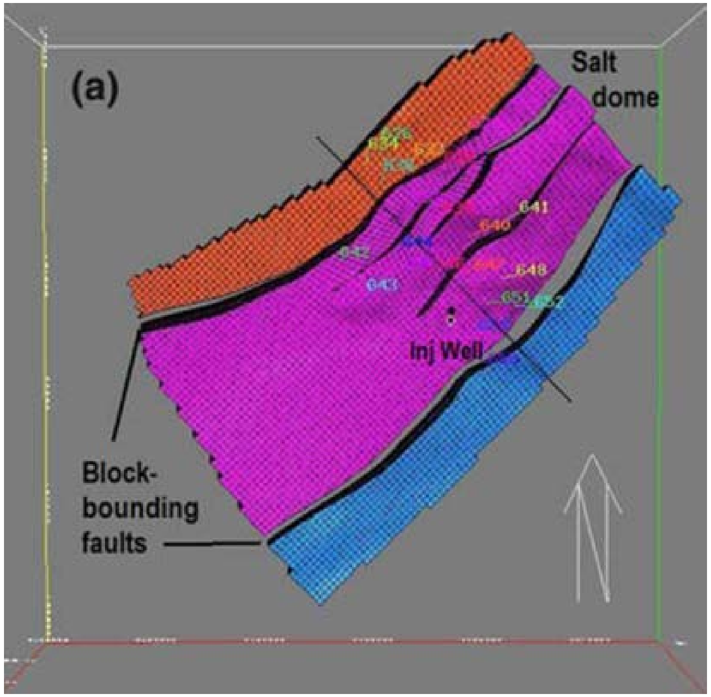
Technical Approach

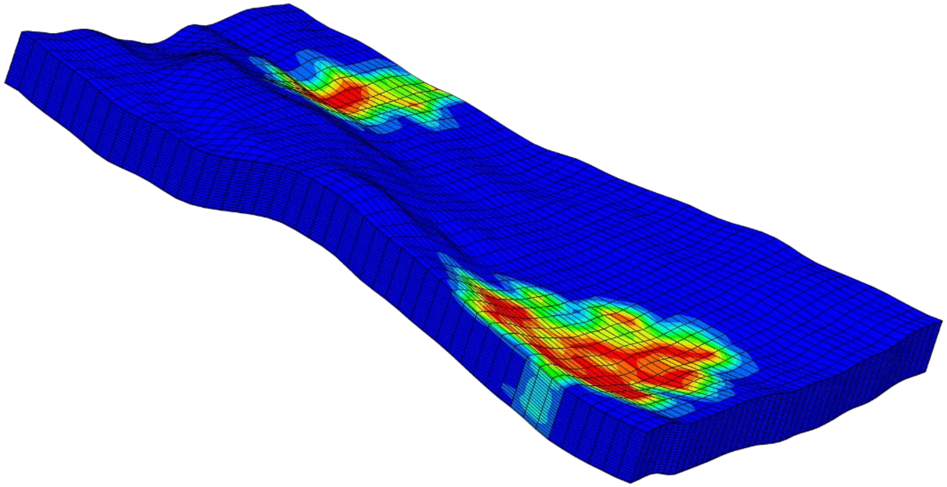
- **Task 3.0 – Upscale to bridge from laboratory to field scales**
  - Subtask 3.1 – Computation of effective parameters for flow and mechanics
  - Subtask 3.2 – Computation of effective parameters for coupled thermal-geomechanical processes for CO_2 specific loadings
- **Task 4.0 - Simulator Development and Modeling CO_2 Storage Field Scale Studies**
  - Subtask 4.1 – Simulator Development With Numerical Schemes for Coupled Processes
    - Subtask 4.1.1 – Multiscale Discretizations for Flow, Geomechanics, and Geochemistry
    - Subtask 4.1.2 – Development of Efficient Solvers and Pre-conditioners
  - Subtask 4.2 –Model CO_2 Storage Field Sites and Perform Simulations

Technical Approach

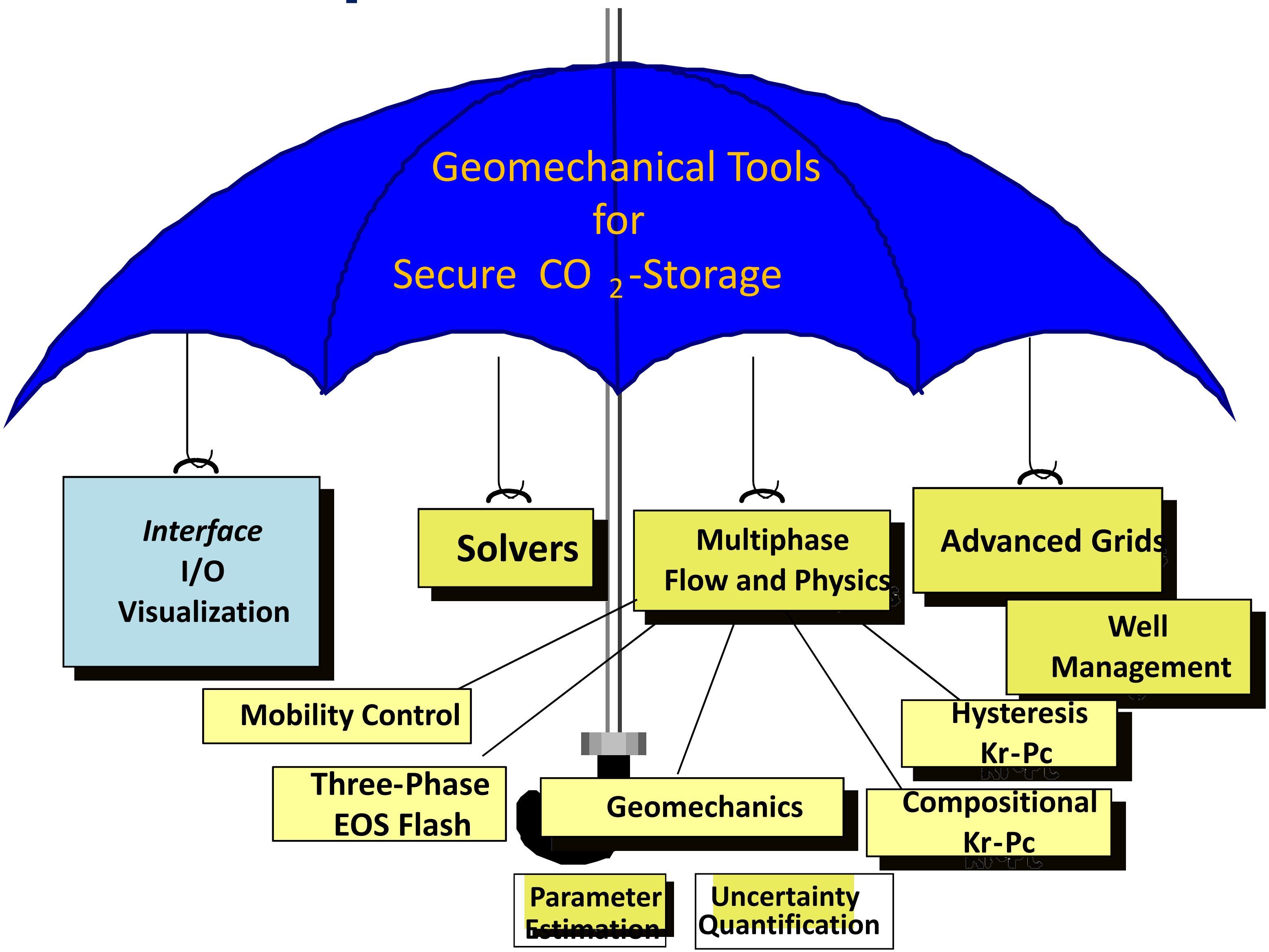
- **Task 5.0 - Parameter Estimation and Uncertainty Quantification**
  - Subtask 5.1 – Ensemble Filtering Approach for Multi-parameter Estimation
  - Subtask 5.2 –Uncertainty Quantification
- **Task 6.0 – Integrate Results to Generate Geomechanical Screening Tool /Workflow**

Approach and Technologies





Computational Framework



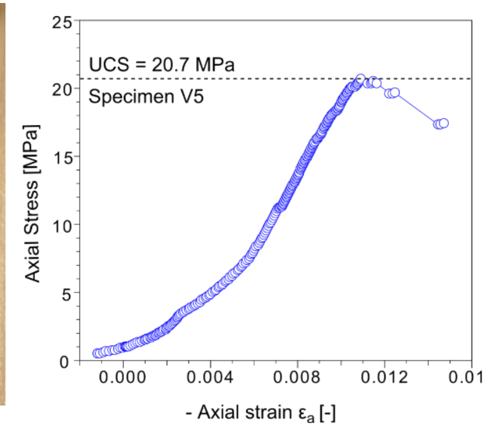
Task 2: Laboratory Experiments

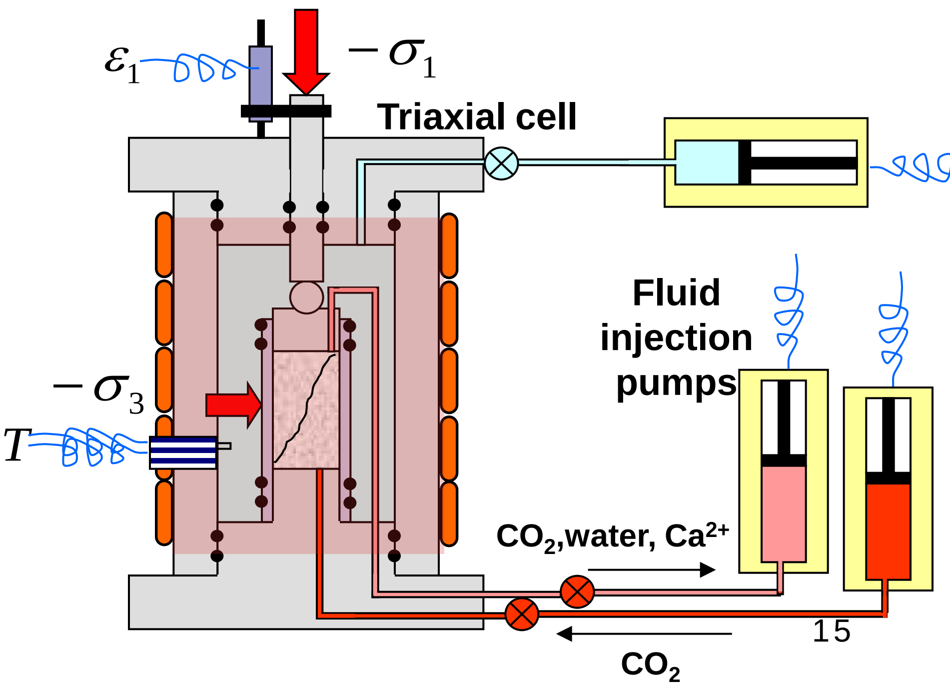
Action items:

•Acquisition of <u>representative rock samples</u> from two CO_2 storage sites: consider lithology, geologic age, and natural fractures among other characteristics

•Design, fabrication and calibration of an experimental device: cylindrical <u>triaxial frame</u> → reliable pore pressure, and fluid injection control, Ø4in, P_p= 20MPa (3000psi), T_{max}= 90° C

•Measure petrophysical and geomechanical properties of reservoir and seal rocks subjected to <u>chemical, thermal, hydraulic, and mechanical</u> loadings





Task 3: Bridge from Laboratory to Field

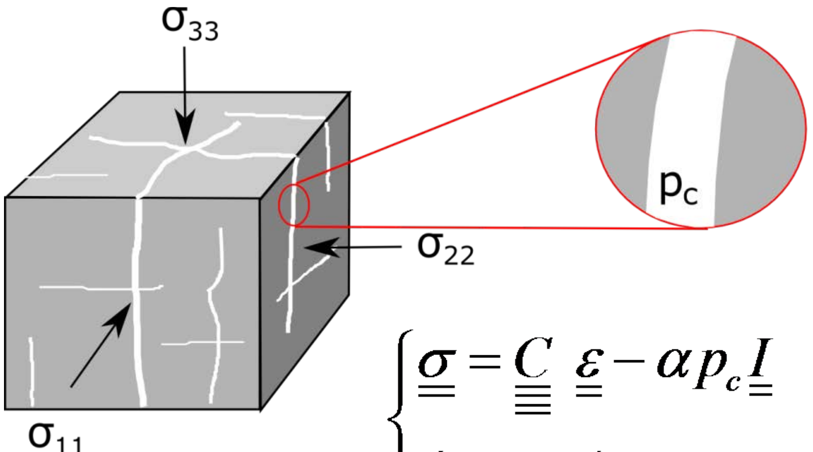
Objectives:

- <u>Upscale measured rock properties</u> (fluid flow and geomechanics) to scale relevant to <u>field processes</u>

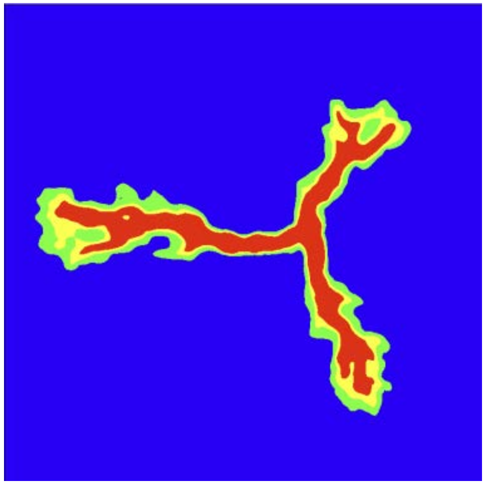
- <u>Development of homogenization schemes</u> combining numerical and analytical approaches, e.g., multiscale mortar method

- Particular emphasis will be put on including <u>natural fractures</u> in effective properties and localization effects

- Obtain field scale <u>constitutive parameters</u> to perform coupled fluid flow and geomechanical numerical simulation



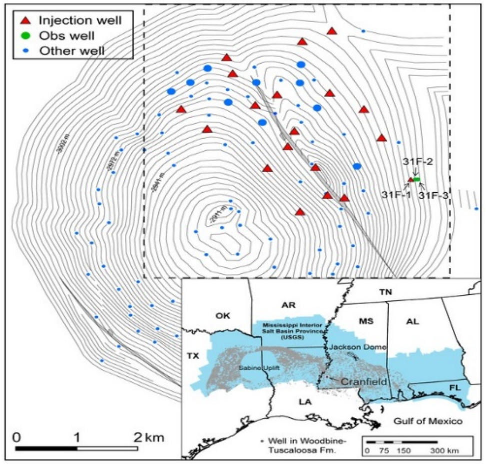
$$\begin{cases} \underline{\underline{\sigma}} = \underline{\underline{\underline{\underline{C}}}}\,\underline{\underline{\varepsilon}} - \alpha p_c \underline{\underline{I}} \\ \phi = p_c / N + \alpha \varepsilon_V \end{cases}$$



Task 4: Simulator Development and Field Scale Studies

Objectives: complete simulator development with numerical schemes for coupled processes

- Develop computational methods for coupled processes based on multiscale discretization techniques for flow, geomechanics and geochemistry
- Development of Efficient Solvers and Pre-conditioners
- Model CO_2 Storage Field Sites and Perform Simulations

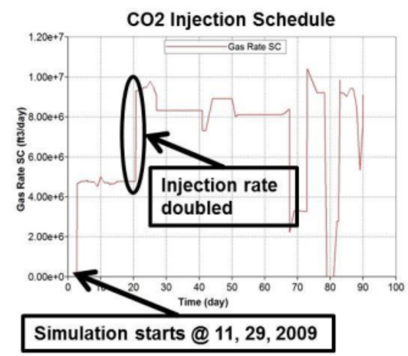


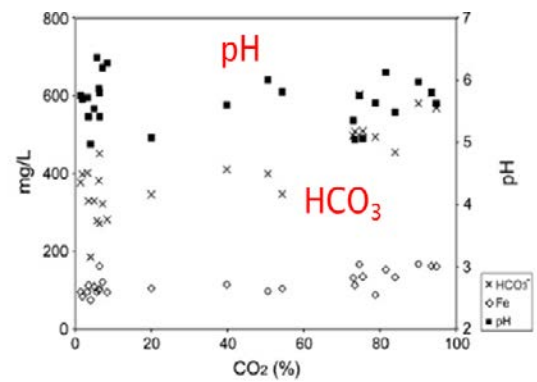
SubTask 4.2: Model Field Sites

Objectives: Complete modeling of two CO_2 storage field scale studies (Site one and Site two), and perform reservoir simulations.

- Candidate Site 1: Cranfield, Mississippi
- Candidate Site 2: Frio pilot study, Texas

- Measure mechanical property from Task 2
- Collect other existing data (seismic, well logs, etc.)
- Study rock dissolution and its effect on weakening the rocks and creating leakage pathways
- Measure impact of geochemical alteration on mechanica properties
- Simulation using the enhanced simulator and tools to study and quantify parameters such as reservoir over pressure, chemical and thermal loading etc.

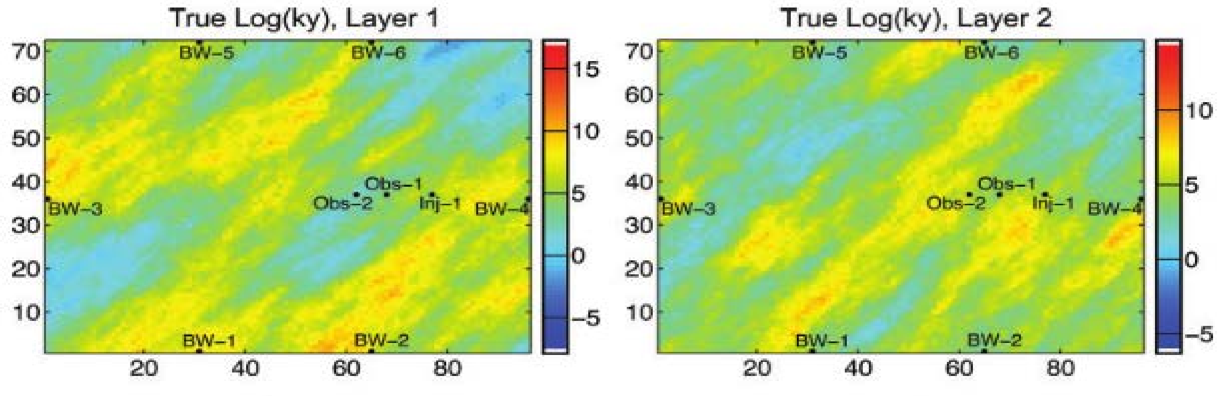




Task 5.0 - Uncertainty Quantification and Parameter Estimation

<u>Objectives:</u> Update input parameters for numerical models such that simulated responses match observations while ensuring:

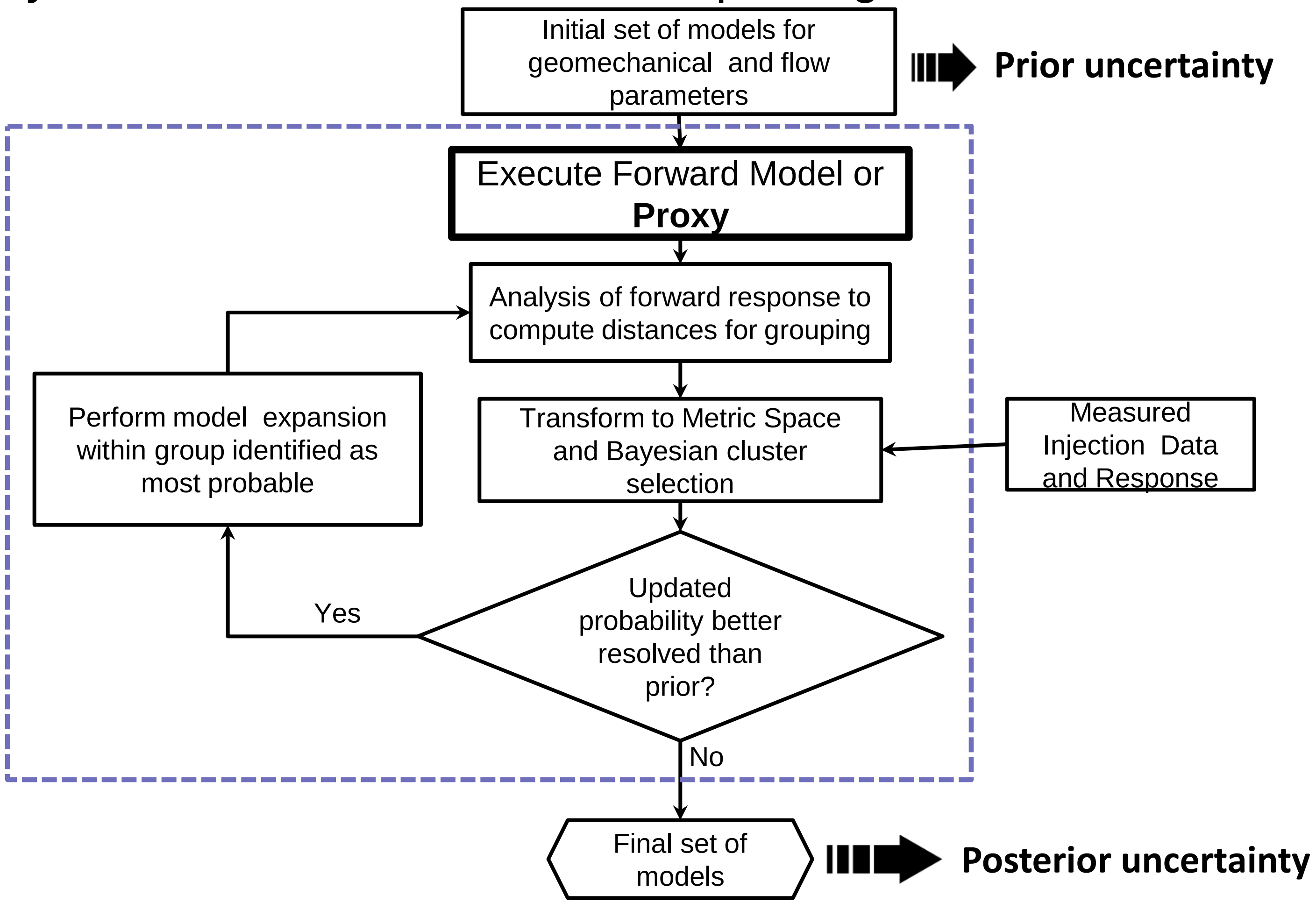
- ✓ Complex relationship between the multi-physics attributes is honored
- ✓ Residual uncertainty in predicting future migration of the CO_2 is faithfully represented



(a) (b)

SubTask 5.1 Multi-parameter Estimation

- Develop a method that is based on ensemble statistics but does not rely on covariance based model updating.



SubTask 5.2 Tools for Fast Risk Assessment

- Use Experimental Design and Response Surfaces to assess model responses critical for risk analysis, for example probability of leakage or risk of contaminating an overlying aquifer (*J*).

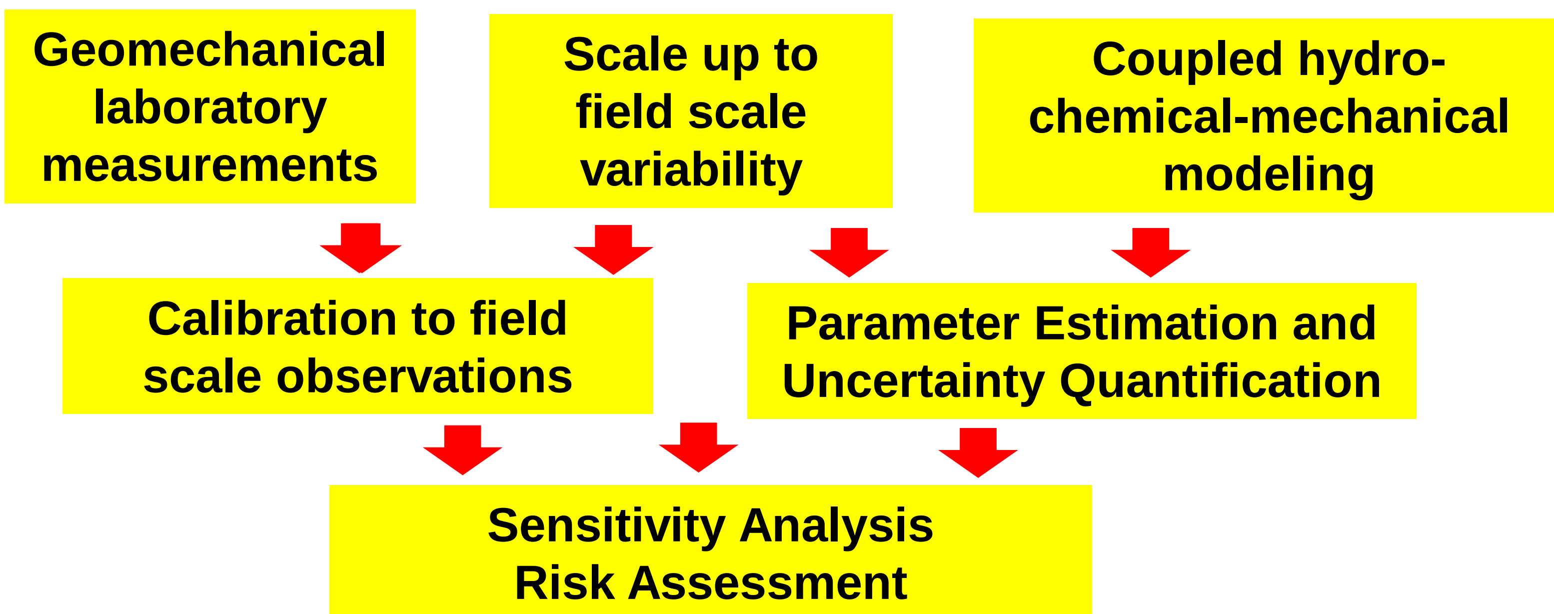
$$\boxed{J = \beta_0 + \beta_1 u_1 + \ldots + \beta_n u_n + \sum_{i<j} \sum_{j=2}^{n} \beta_{ij} u_i u_j + \sum_{i=1}^{n} \beta_{ii} u_i^2 + \varepsilon}$$

  Vectors u are variables such as presence or absence of a major fault, abrupt changes in mechanical or chemical properties of rocks, presence or absence of fractures in the vicinity of wells.

- Adaptive Fitting – Perform importance sampling in parameter space. Execute forward model and assimilate sample if acceptance criterion is met. This adaptive procedure will facilitate the response surface fitting process.

Task 6.0 - Integrate Results to Generate Geomechanical Screening Tool /Workflow

Objectives: Derive a workflow based on project tasks performed - experimental and numerical investigation of geomechanical processes, effects, and conditions related to CO_2 storage and analysis of two CO_2 storage field case studies.



Risk Management

Description of Risk	Mitigation and Response Strategies
Length of experiments for chemical degradation	Use chemicals with higher chemical reaction rates to accelerate laboratory processes
Safety hazards for high pressure tests	Pressure vessels will be shielded with bulletproof polycarbonate plates
Delay in receiving equipment	Can use existing equipment from other laboratories
Unavailability of representative rock samples	Look for analogs/ask Texas Bureau of Economic Geology for cores
Computer resources	Can use CPGE or TACC computing resources
Loss of Project Director	Others PIs are capable to step in
Recruitment of Graduate Students and Post-Docs	Numerous applications are received every year. Anticipate no recruitment difficulties.

Deliverables

Task 1 - Project Management, Planning, and Reporting

- Project Management Plan (PMP)
- Provide the information to update a project-specific fact sheet on the NETL website
- Submit data generated as a result of this project to NETL for inclusion in the NETL Energy Data eXchange (EDX), https://edx.netl.doe.gov/.

Deliverables

Task 2: Conduct Laboratory Experiments for Petrophysical and Hydro-mechanical Rock Properties

- A plan for the design of the experimental equipment and the tests to be conducted shall be developed and submitted to DOE
- A list of representative rock samples acquired for testing to include field locality, rock lithology, geologic age, photo, and nature of any fractures observable in hand sample, shall be provided to DOE
- Quick-look report
  - Summarize the activities, rock testing, and results in Task 2.0 conducted in the experiments for petrophysical and hydro-mechanical rock properties and analyses of measured data
  - The report shall be submitted to the DOE Project Officer no later than fifteen (15) days after the end of the Task/Subtask

Deliverables

Task 3.0 – Upscale by Completing Bridge from Laboratory to Field Scales

- Quick-look report that summarizes the activities and results in Task 3.0 conducted for upscaling lab measurements to CO_2 storage field scale, including a description of the development of homogenization schemes for naturally fractured and heterogeneous rocks

Task 4.0 – Simulator Development and Modeling CO_2 Storage Field Scale Studies

- Quick-look report that describes the enhanced IPARS simulator developed in Subtask 4.1, and include the IPARS module for geomechanics
- Quick-look report containing a description of the first selected field site (Site one), the model(s) developed, and the results of the simulations and history matching performed in Subtask 4.2
- Quick-look report containing a description for the second selected field site (Site two), the model(s) developed, and the results of the simulations and history matching performed in Subtask 4.2

Deliverables

Task 5.0 – Parameter Estimation and Uncertainty Quantification

- Quick-look report containing a description of the Task 5.0 computational studies and analyses completed for (1) using the ensemble filtering approach for multi-parameter estimation; and (2) uncertainty quantification conducted with the adaptive response surface-based methodology

Task 6.0 – Integrate Results to Generate Geomechanical Screening Tool

- Quick-look report that includes the geomechanical workflow, provides the accompanying documentation/user's guide, and summarizes the activities and results performed in Task 6.0 for the workflow generation
- The report shall be submitted to the DOE Project Officer no later than 15 days after the end of the Task/Subtask

Technology Transfer Plan

- Graduate student internships
- Joint industry programs at CPGE and CSM
- Publications/presentations in technical conferences
- Use the developed software(s) and simulator as teaching tools
- Cooperation with interested representatives from industry

Project Impact

- Conception of experimental methods to measure thermo-hydro-chemo-mechanical properties of reservoir rocks
- Method to relate laboratory measurements of rock properties to field scale variability
- Perform advanced coupled numerical simulation to study effect of reservoir overpressure and straining (deformation) on the caprock stresses and strains
- Workflow for assessing risk considering uncertainty in flow, mechanical, and chemical properties of rocks
- Providing guidelines for enhanced monitoring techniques
- Conception of criteria for reservoir rock assessment and injection site selection based on petrophysical properties and natural heterogeneity

Summary

- "Development of Geomechanical Screening Tools to Identify Risk: An Experimental and Modeling Approach for Secure CO_2 Storage:" addresses FOA AOI 1 Geomechanical Research

- Goal/Objectives: To develop a screening tool for improved understanding of geomechanical effects associated with CO_2 injection in the form of a workflow derived from experimental and computational studies conducted for specific CO_2 sites.

- Performance Period: September 1, 2014 - August 31, 2017; 36 mos

- Status/accomplishments to date:

-Completed Project Management Plan

-Completed Kickoff Meeting

- Benefits: Contribute to Carbon Storage Program goal of developing and validating technologies to ensure 99 percent storage permanence

Summary, cont.

- **The project will greatly enhance our understanding of the effects of $scCO_2$ injection on open and closed faults and fractures including the effects of rapid cooling and geochemistry.**

- **Geochemical interactions coupled with mechanical effects such as compaction and upheaval will alter the permeability of the reservoir and sealing formations. These will be studied during the course of the project.**

- **Mechanical, Chemical and Flow processes occur at different spatial and temporal scales. Development of sophisticated numerical tools to represent these effects is a key focus of this project.**