Collaboration with China on Clean Energy Research

Project Number 58159 Task 3

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Pacific Northwest National Laboratory

U.S. Department of Energy

National Energy Technology Laboratory
Carbon Storage R&D Project Review Meeting
Developing the Technologies and Building the Infrastructure for CO_2 Storage

August 21-23, 2012

Presentation Outline

Collaboration with China on Clean Energy Research

- Project overview
- Sub-Task 1: Investigation of CO_2 migration in heterogeneous porous media
- Sub-Task 2: Modeling CCUS deployment in China
- Summary

Benefit to the Program

The Clean Energy Partnership was established by an memorandum of understanding between the Chinese Academy of Sciences, the National Energy Technology Laboratory and the Pacific Northwest National Laboratory in May of 2009 with the goal of significantly reducing the environmental emissions and improving the efficiency of fossil fuel conversion.

In particular, the project focuses on the study of heterogeneities of Chinese sedimentary formations at multiple scales and on the enhancement of modeling of CCUS potential in China.

This project contributes to the Carbon Storage Program's effort of developing technologies that will support industries' ability to predict CO_2 storage capacity in geologic formations to within ±30 percent.

Project Overview

Established under a May 2009 MOU between CAS, NETL and PNNL and transitioned in 2010 under Annex VI of the Protocol for Cooperation in the field of FE Technology Development and Utilization between US DOE/FE and China Ministry of Science and Technology (MOST)

Two sub-tasks:

- Investigations of CO_2 migration in heterogeneous porous media
- Modeling CCUS deployment in China

Highly productive cross-institutional teams

- **CAS:** Xiaochun Li, Ning Wei, Yan Wang, Ying Wang (Institute of Rock and Soil Mechanics);
- **NETL:** Grant Bromhal, Dustin Crandall, George Guthrie, Dustin McIntyre, Bob Warzinski
- **PNNL:** Alain Bonneville, Bob Dahowski, Casie Davidson, Mart Oostrom, Changyong Zhang

NETL NATIONAL ENERGY TECHNOLOGY LABORATORY

Institute of Rock and Soil Mechanics, Chinese Academy of Sciences

Pacific Northwest NATIONAL LABORATORY

Goals and Objectives

- **Scope:** Study heterogeneities of Chinese sedimentary formations at multiple scales; enhance modeling of CCUS potential in China
- **Objectives:** Better understand and evaluate the potential for large-scale CCUS opportunities in China
- **Progress:**
  - Characterization of Ordos Basin core samples achieved;
  - Micro-model development and first analysis completed;
  - CO_2 capture and compression costs in China have been integrated into CCS cost and performance models

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Institute of Rock and Soil Mechanics, Chinese Academy of Sciences

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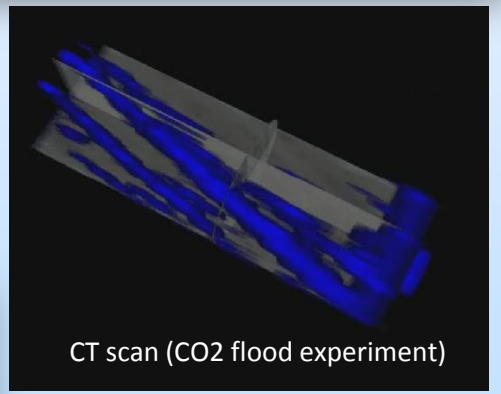
Sub-Task 1: CO_2 migration in heterogeneous porous media

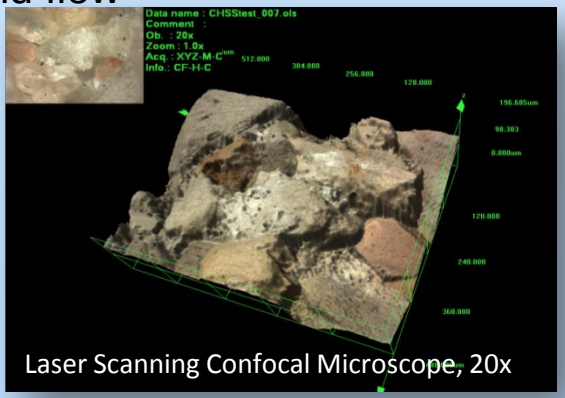
Core Characterization & Analysis

- Complex heterogeneities in reservoir formations may be encountered at all scales
  - pore scale: local grain anisotropy
  - reservoir scale: high permeability

Sandstone core, showing cross bedding.

- Characterize and evaluate pore-scale interfacial interactions and up-scaling to core and field scales with experimental and computational tools at NETL, PNNL and CAS, considering:
  - mineral analysis
  - multi-scale sample characterization & imaging
  - coupling of stress fields and flow
  - CO_2 flooding processes

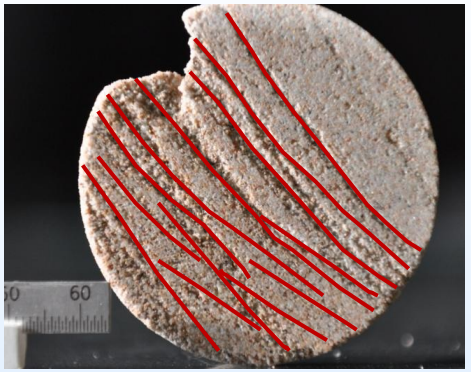

CT scan (CO2 flood experiment)

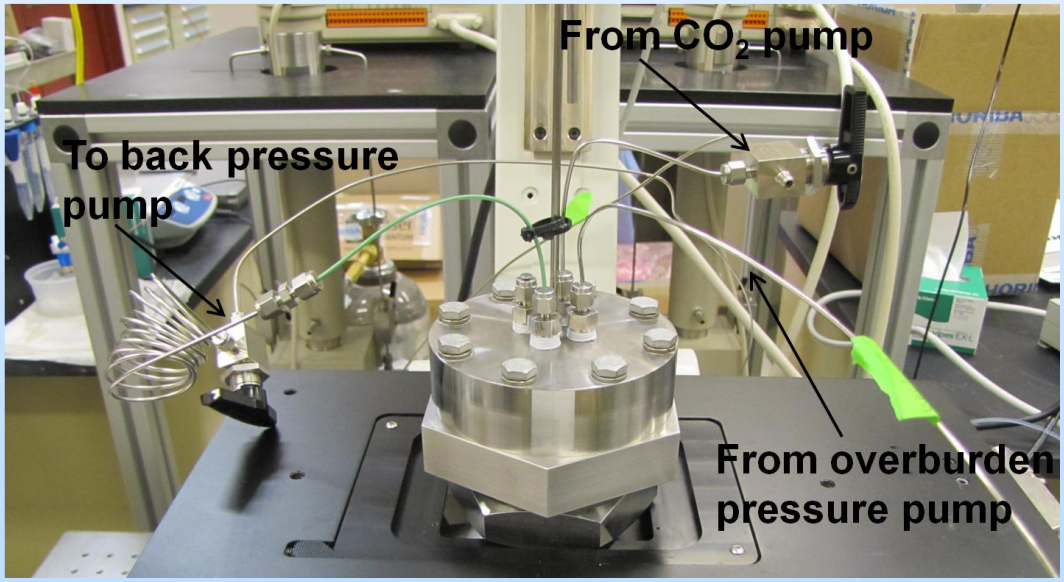


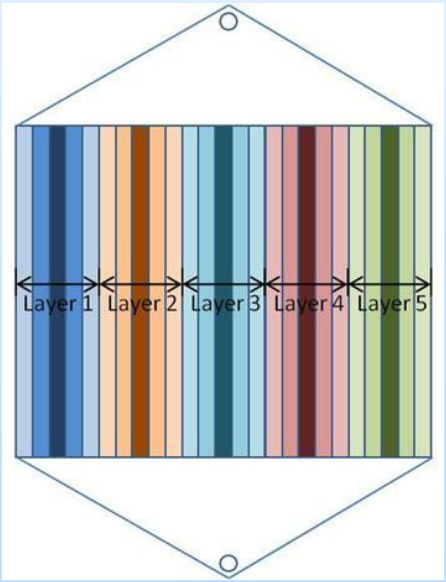
Laser Scanning Confocal Microscope, 20x

Sub-task 1: **Micromodel Experiments**

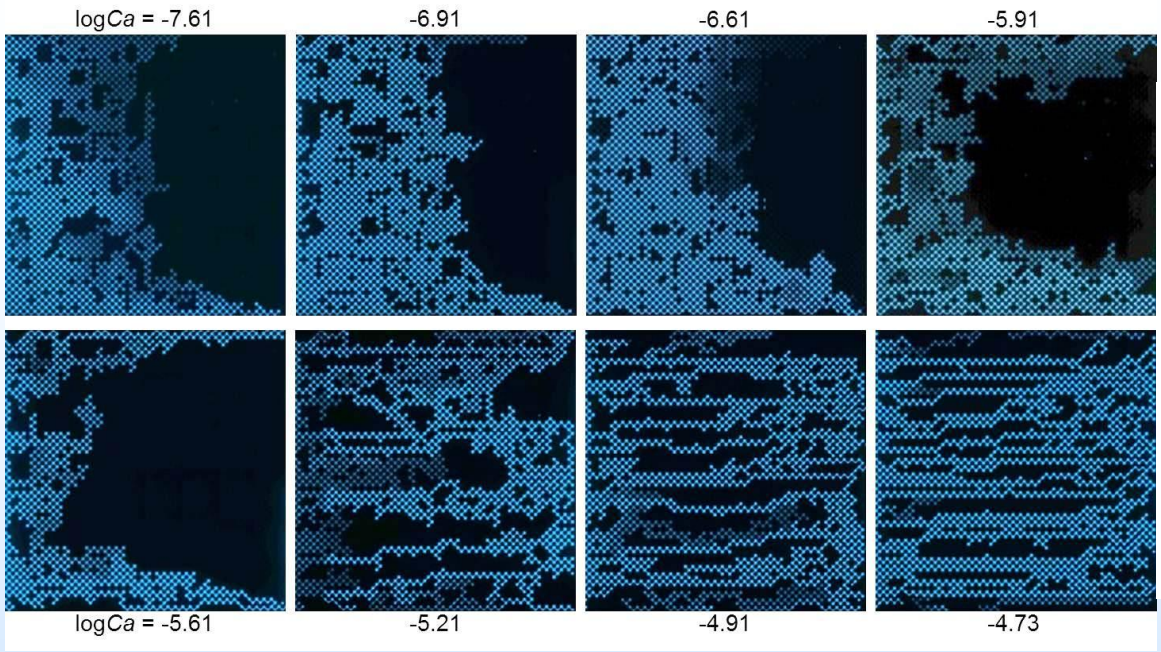
- Multilayer micromodel: Idealized representation of layered Ordos sandstone formation
- Multiple permeability in each layer realized by pore size distribution (grain diameter, pore body, and pore throat, as obtained from tomography)
- Allows direct visualization of $scCO_2$ - brine displacement, mechanistic study of displacement stability, sealing efficiency, and quantification of fluid saturation

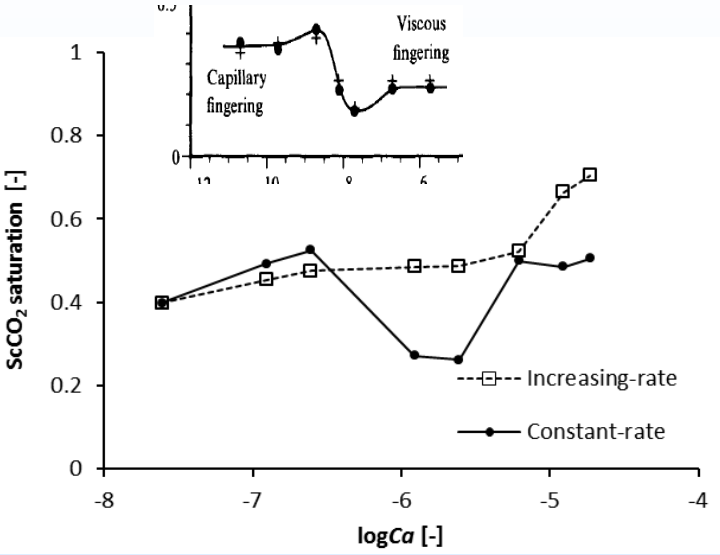




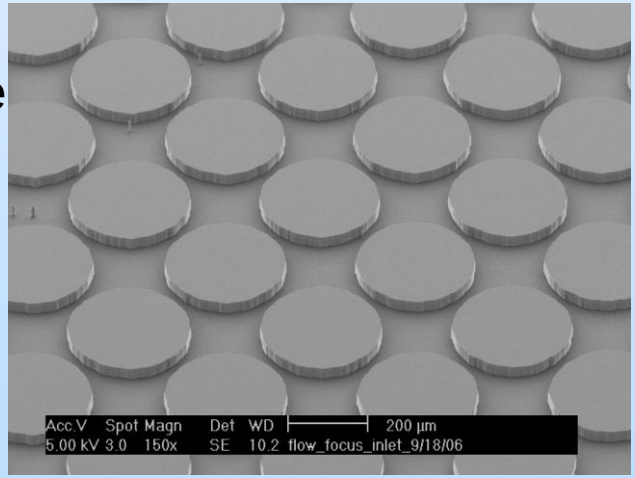


Sub-task 1: **Drainage Experiments in Homogeneous Models**

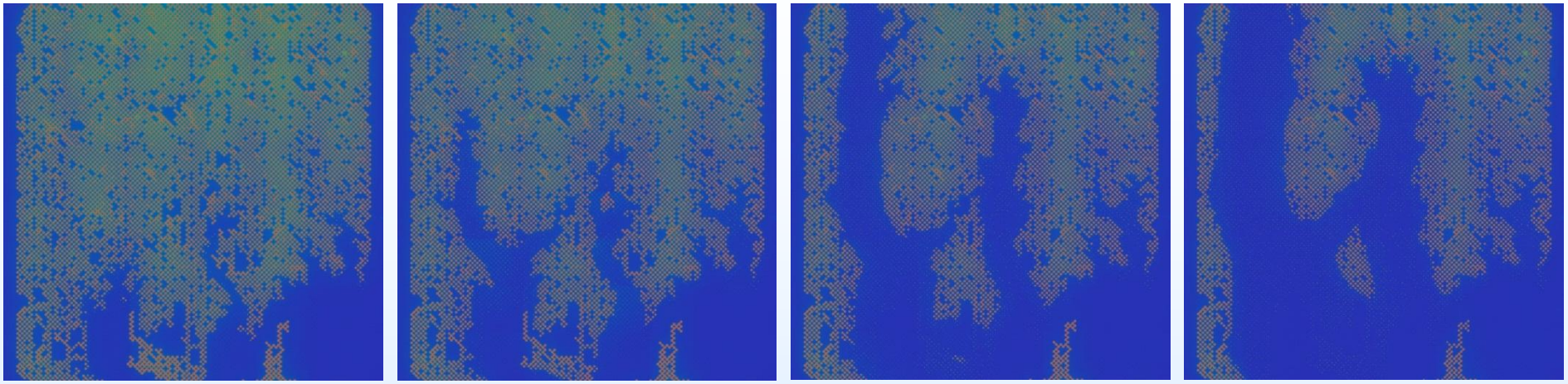




- Experiments show $scCO_2$-water displacement mechanisms change as function of displacement rate during main drainage:
  - Capillary fingering at low rates
  - Crossover at intermediate rates
  - Viscous fingering at high rate
- Experimental results consistent with theory and numerical modeling (Lenormand et al., 1988)



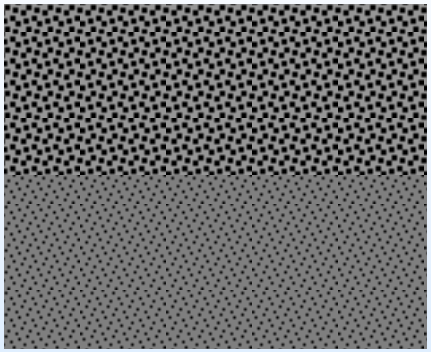
Sub-task 1: **Imbibition Experiments in Homogeneous Models**



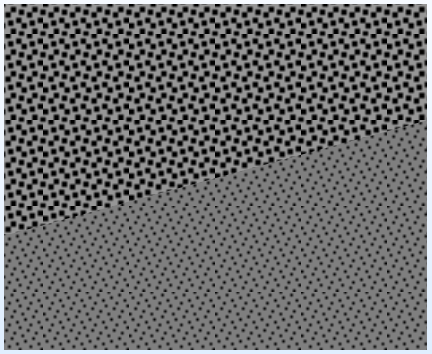
- Preliminary results also showed $scCO_2$ dissolution is controlled by $scCO_2$ pore-level saturation and dissolution fingering is the dominant mechanism during primary imbibition:
  - Preferential dissolution front
  - Multiple dissolution fingers developed over time
- Dissolution behavior is consistent with modeling predictions (Miller and Imhoff, 1996)
- $scCO_2$ entrapment is not caused by pore-level snap-off and bypassing: entrapment instead occurs over larger zones.

Sub-task 1: $scCO_2$ displacement in heterogeneous systems

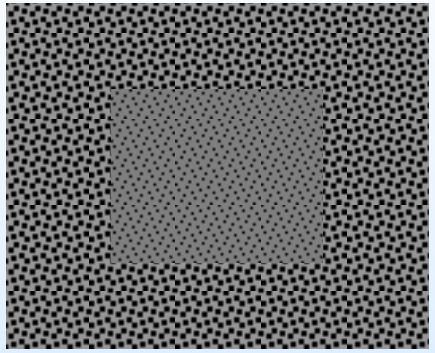
Micromodel Investigation of Impacts of Structural Heterogeneity on Enhanced Oil Recovery



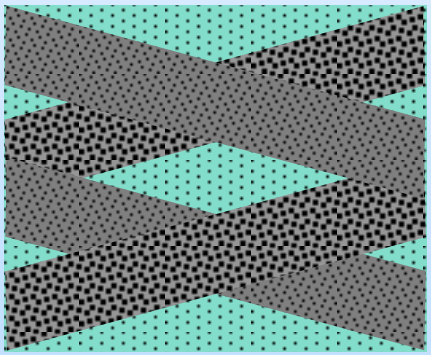
Dual Permeability



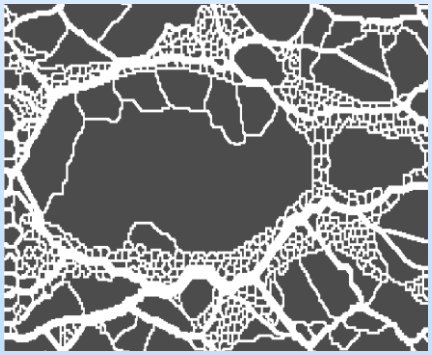
Tilted Dual Permeability



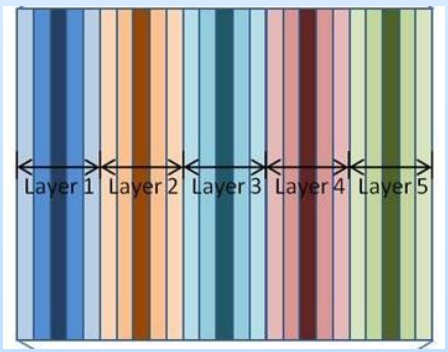
Embedded Low Permeability



Interlaced Low/High Permeability

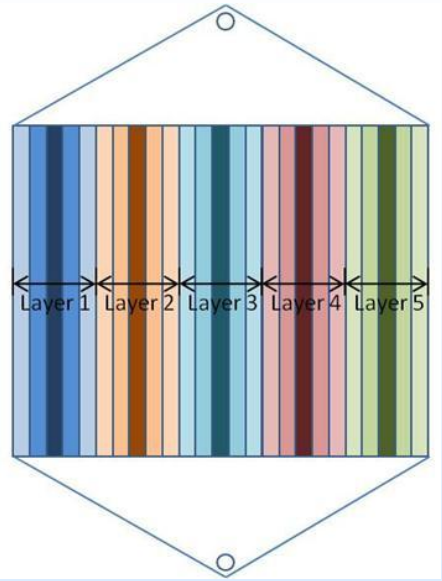


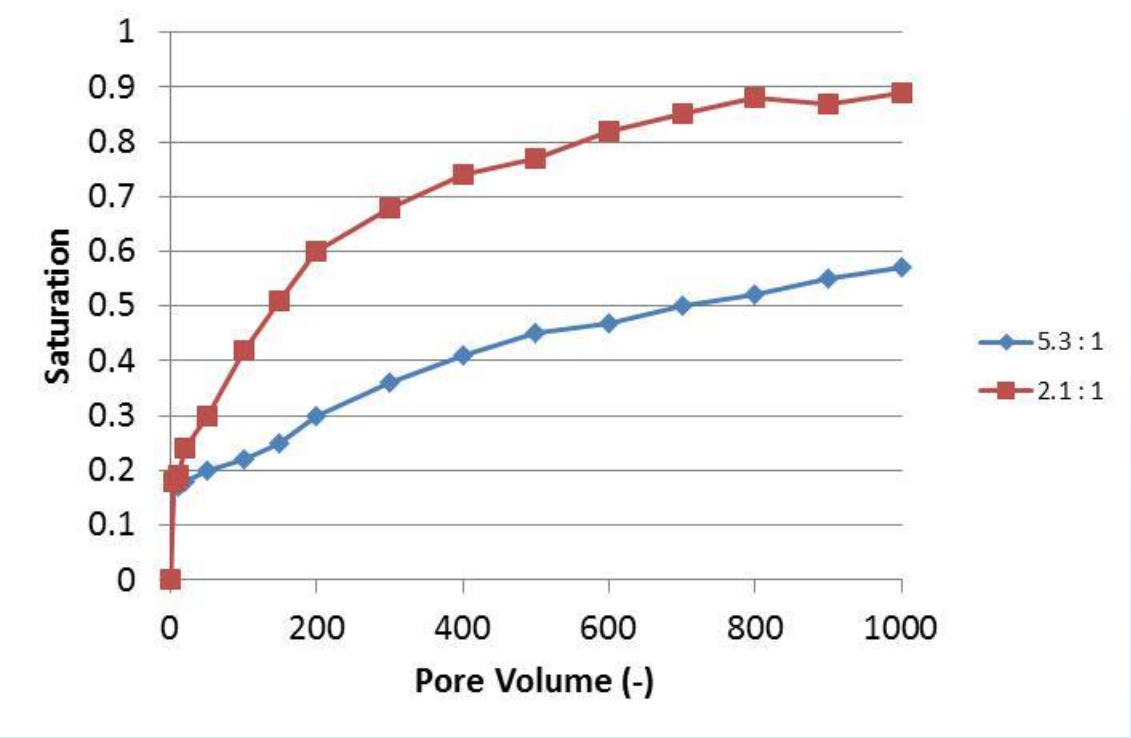
Fractured Sandstone



Ordos Analogue

Example: Ordos Analogue

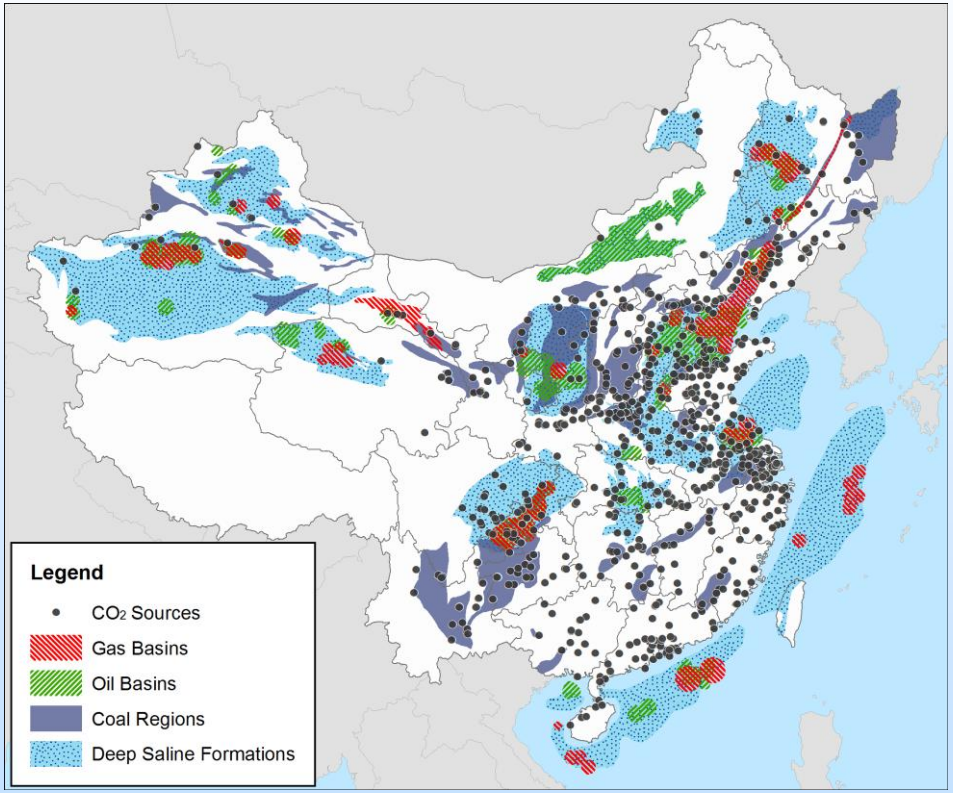




- Dual-permeability models with 5 high-K zones (darkest colors in figure; 20% model area) and 6 low-K zones (80% model area)
- Two different micromodels: Permeability ratio 5.3 : 1 and 2.1 : 1
- Constant injection rate of 50 μL/min
- $scCO_2$ flow primarily through high-K zones.
- $scCO_2$ transport into low-K zones (dissolution / diffusion) is faster for the lower permeability ratio case

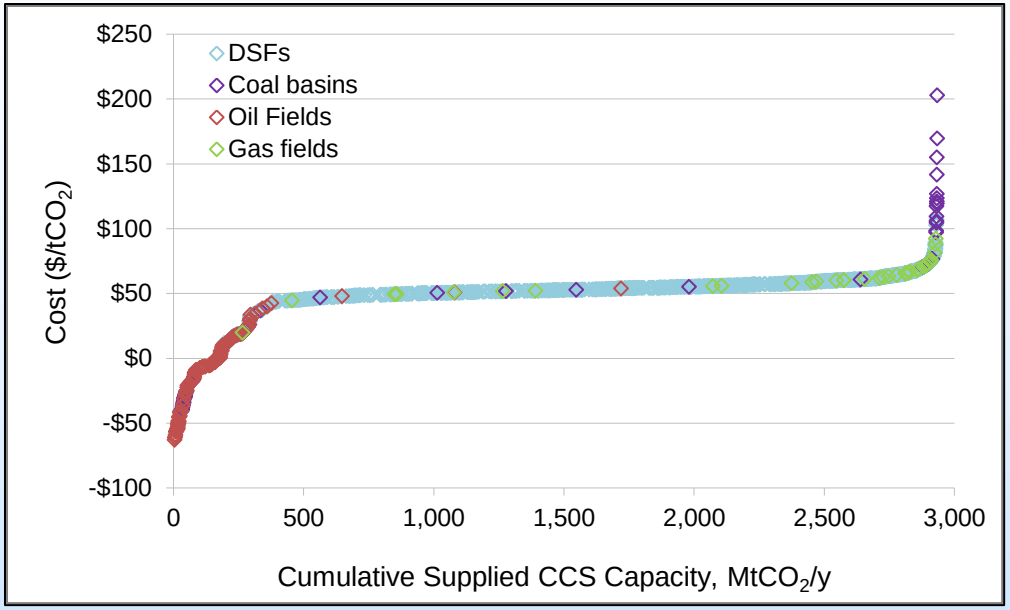
Sub-Task 2: Modeling of CCUS Potential Via Optimized Source-Sink Matching

- Cost-optimized, resource-constrained matching analyses
- 1,623 large CO_2 point sources
- 2,300 $GtCO_2$ theoretical CO_2 storage capacity in 90 candidate geologic formations
- Cost curves developed for to examine CCUS potential and costs across varying industries, geologies, and locations



Produced the First Comprehensive CCUS System Cost Curve

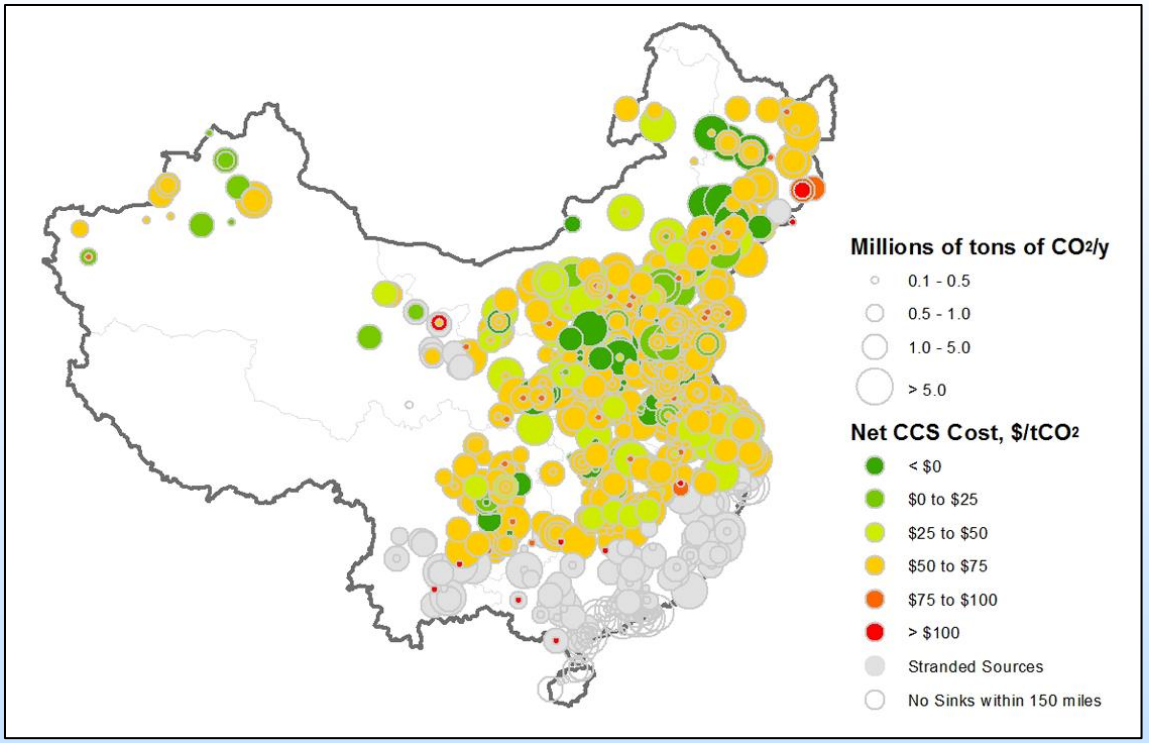
- Integrates CO_2 capture, compression, transport, utilization, storage, and MMV
- N^{th}-unit costs, including CAPEX and OPEX, considering unique characteristics of each source-sink pair



- Storage costs include: site characterization, CO_2 flowlines, injection and monitoring wells
- CO_2 utilization focuses on enhanced hydrocarbon recovery options, revenues, and costs
- Indicates significant potential for CCUS to deploy across China's industries and regions at costs less than \$70/tCO_2

Distribution and Variation of CCUS Options

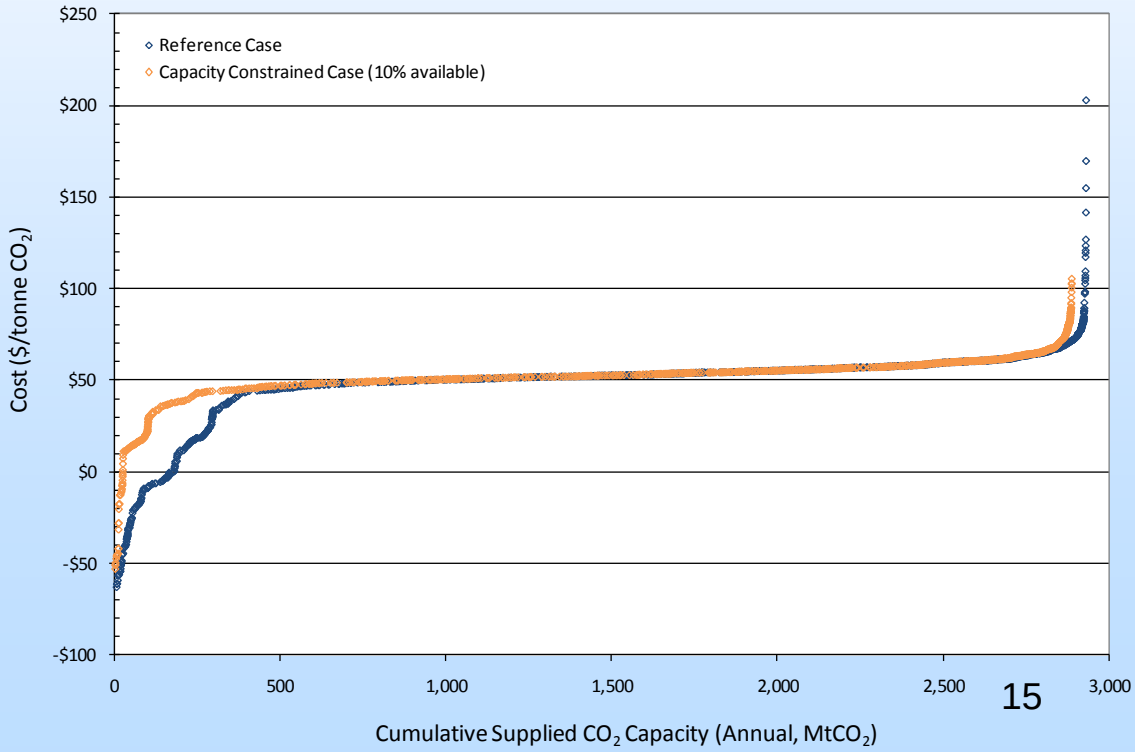
- Strongest demand for CO_2 storage in the eastern part of China
- Limited but growing demand in north and west
- Lack of sufficient onshore CO_2 storage capacity in highly industrialized southern coastal region; near offshore storage options may prove important



Examining Impacts of Resource Uncertainties on Deployment Potential

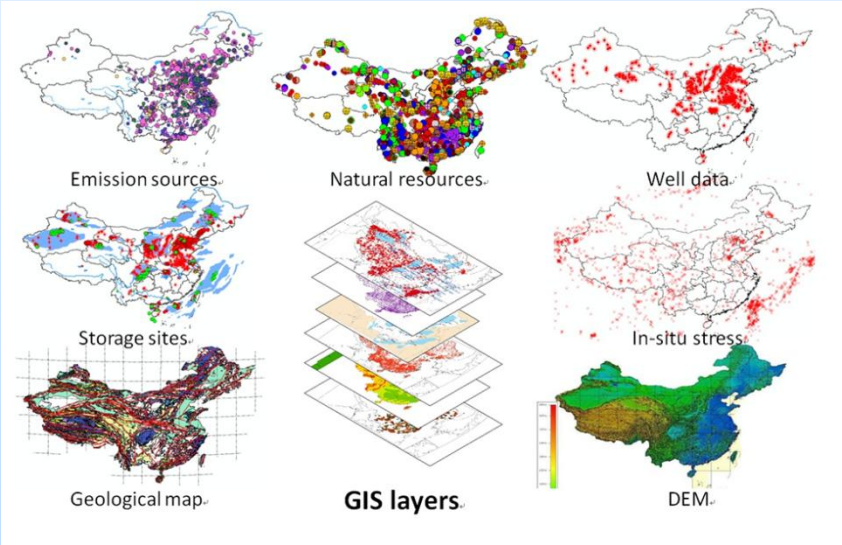
Significant challenges and uncertainties remain regarding achievable CO_2 storage capacities in China

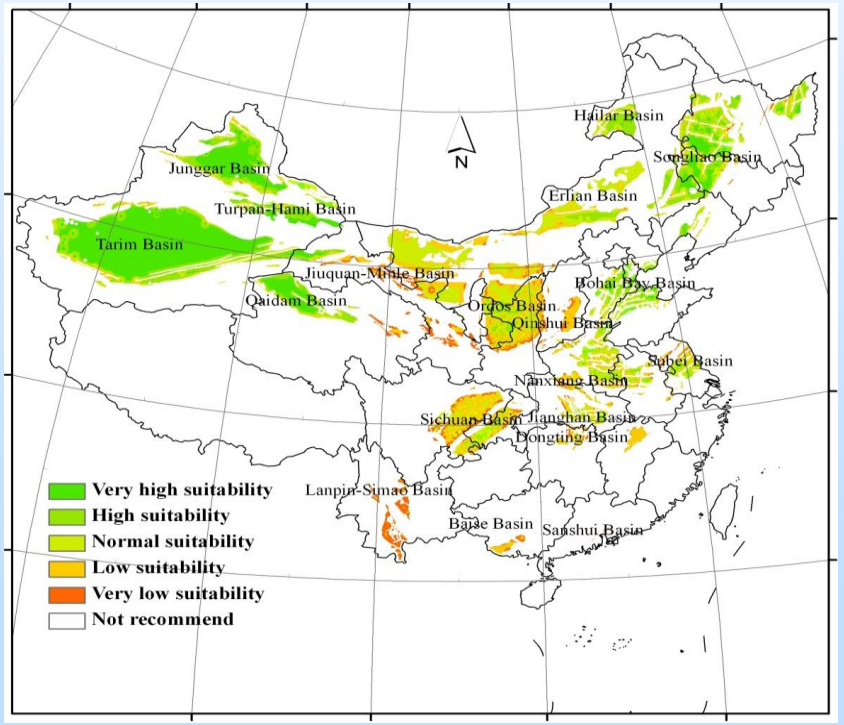
- Examination of reduced storage capacity scenarios suggests adequate CCUS potential at reasonable costs for most regions of China
- Limited but important exceptions (e.g., onshore southern coastal region already capacity constrained)
- Modeling results help prioritize needs for more detailed evaluations



Site Screening using Multiple Decision Variables and User-Specified Weighting

- Multivariate geospatial analysis allows for semi-quantitative storage site screening
- Working to add and refine underlying datasets
- Moving toward interfacing more directly with cost curve modeling





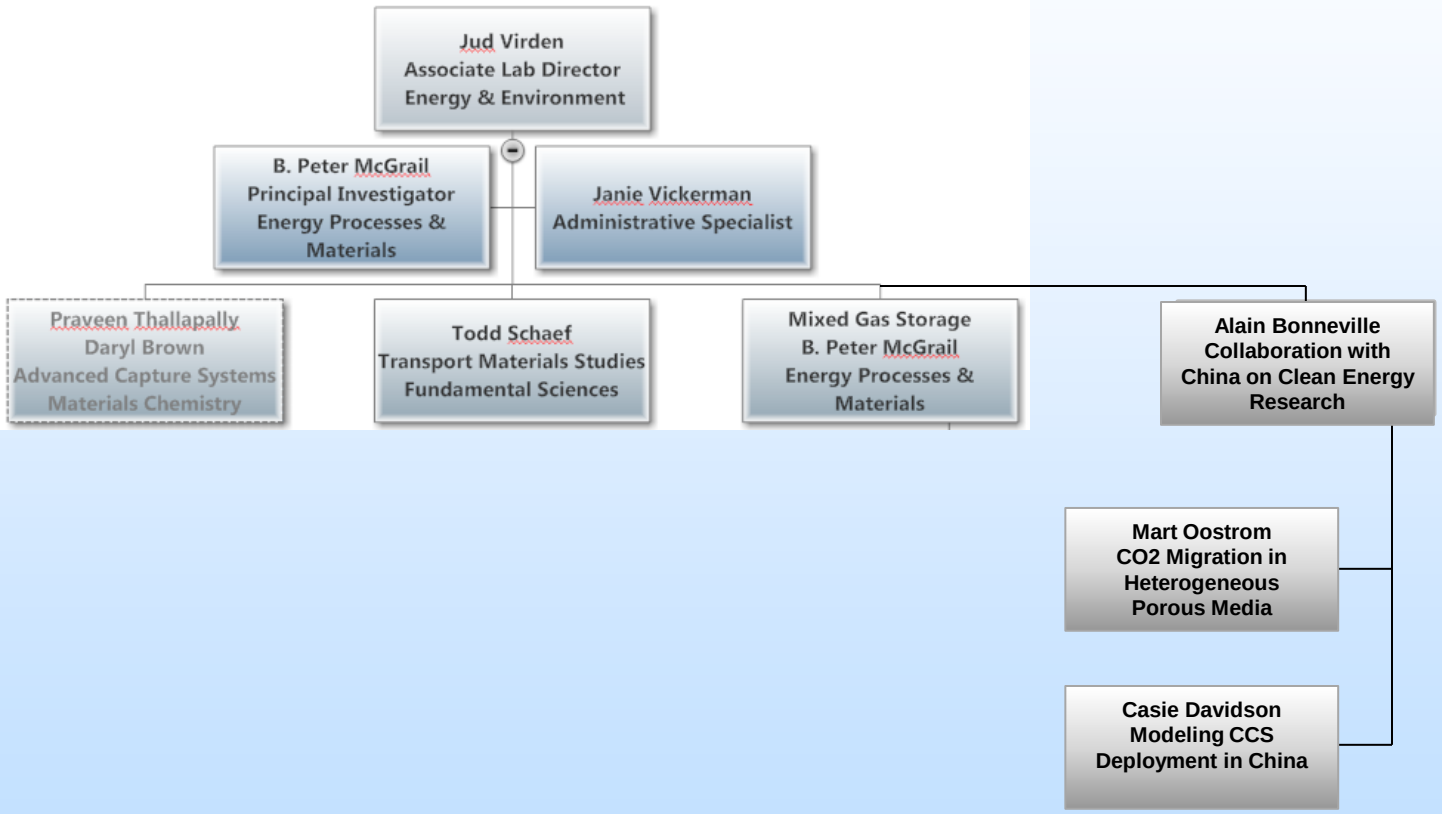
Accomplishments to Date

- CAS, NETL, and PNNL have forged a strong collaborative research partnership focused on improvements in efficiency of fossil fuel conversion and reductions of environmental emissions
- Technical areas and scope have been jointly defined based on common S&T interest between U.S and China
- Projects leverage existing capabilities and expertise within each organization
- The first two years have shown significant technical progress including numerous papers and presentations, in particular:
  - Complete characterization of Ordos sandstone models and realization of several pore-scale micro-model experimentations.
  - The first comprehensive cost curve has been produced for the deployment of the entire CCS system chain in China.

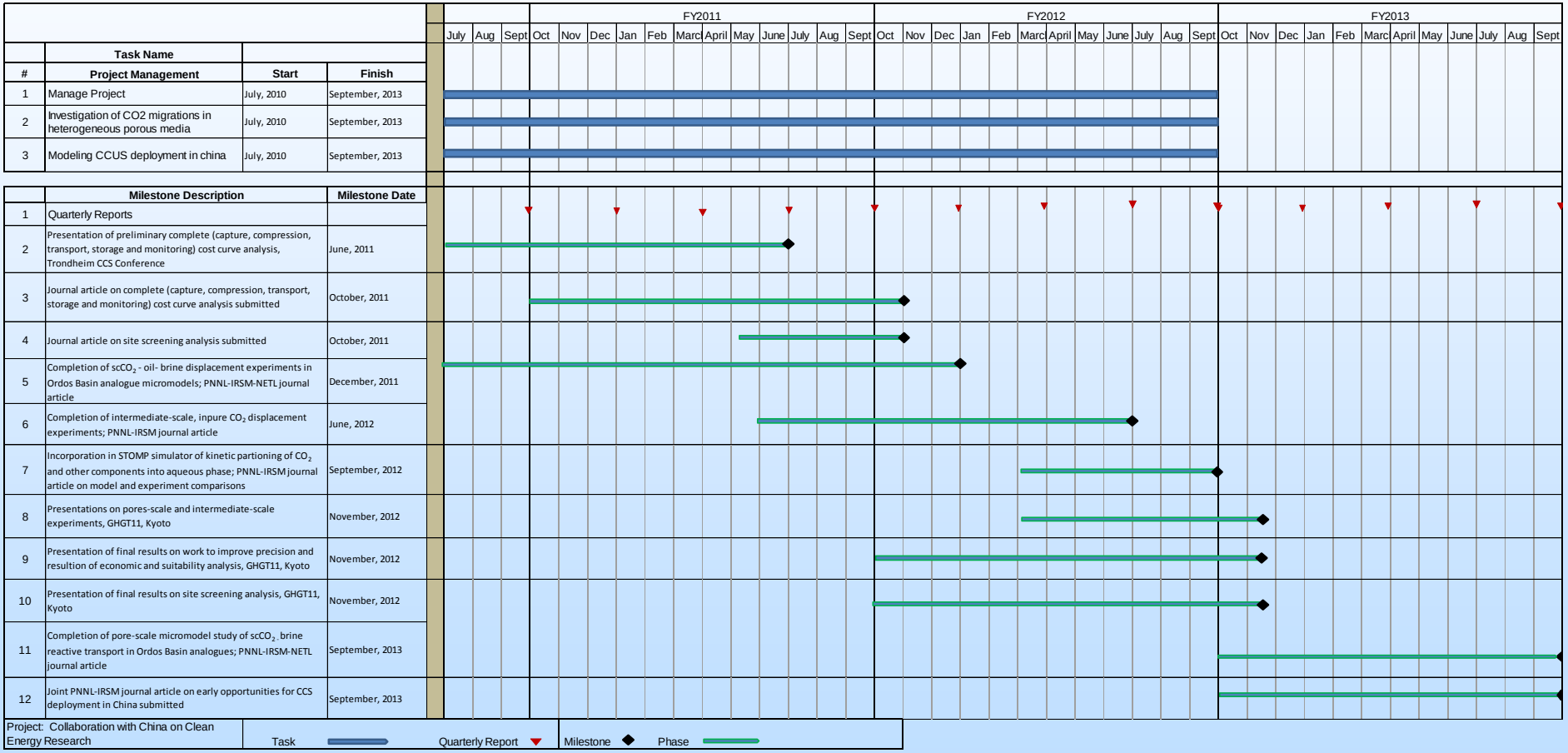
Appendix

– These slides will not be discussed during the presentation, but are mandatory

Organization Chart



Gantt Chart



#	Task Name Project Management	Start	Finish
1	Manage Project	July, 2010	September, 2013
2	Investigation of CO2 migrations in heterogeneous porous media	July, 2010	September, 2013
3	Modeling CCUS deployment in china	July, 2010	September, 2013

	Milestone Description	Milestone Date
1	Quarterly Reports	
2	Presentation of preliminary complete (capture, compression, transport, storage and monitoring) cost curve analysis, Trondheim CCS Conference	June, 2011
3	Journal article on complete (capture, compression, transport, storage and monitoring) cost curve analysis submitted	October, 2011
4	Journal article on site screening analysis submitted	October, 2011
5	Completion of $scCO_2$ - oil- brine displacement experiments in Ordos Basin analogue micromodels; PNNL-IRSM-NETL journal article	December, 2011
6	Completion of intermediate-scale, inpure CO_2 displacement experiments; PNNL-IRSM journal article	June, 2012
7	Incorporation in STOMP simulator of kinetic partioning of CO_2 and other components into aqueous phase; PNNL-IRSM journal article on model and experiment comparisons	September, 2012
8	Presentations on pores-scale and intermediate-scale experiments, GHGT11, Kyoto	November, 2012
9	Presentation of final results on work to improve precision and resultion of economic and suitability analysis, GHGT11, Kyoto	November, 2012
10	Presentation of final results on site screening analysis, GHGT11, Kyoto	November, 2012
11	Completion of pore-scale micromodel study of $scCO_2$, brine reactive transport in Ordos Basin analogues; PNNL-IRSM-NETL journal article	September, 2013
12	Joint PNNL-IRSM journal article on early opportunities for CCS deployment in China submitted	September, 2013

Project: Collaboration with China on Clean Energy Research

Task | Quarterly Report | Milestone | Phase

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