Research Under the U.S.-China Clean Energy Partnership

A CAS-NETL-PNNL Research Collaboration

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China-Australia Geological Storage Symposium

Beijing, China

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Outline

- Background of the Partnership
- Overview of the three primary research focus areas
- Details on progress under focus area 1:
  High Volume CO_2 Sequestration and Utilization
  - Task area 1: Examining Preferential Flow Mechanisms of Candidate Storage Formations in China
  - Task area 2: Modeling CCS Deployment in China
- Summary

U.S.-China Clean Energy Partnership
Overview

- Focus: significantly reduce environmental emissions and improve efficiency of fossil fuel conversion
- Approach:
  - 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
- Historical Timeline:
  - June 2010: Official Partnership kickoff in Beijing
  - August 2010: Partnership officially transitioned under Annex VI of the Protocol for Cooperation in the field of Fossil Energy Technology Development and Utilization between U.S. Department of Energy and China Ministry of Science and Technology

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Three Focus Areas

Area 1: High volume CO_2 sequestration and utilization

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

Area 2: Advanced syngas conversion technologies – Removal of contaminants and CO_2 from warm syngas

Area 3: Advanced syngas conversion technologies – Synthetic natural gas catalyst & CO_2 adsorbent integration

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Focus Area 1:

High Volume CO_2 Sequestration & Utilization

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

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Focus Area 2:

Removal of Contaminants and CO_2 from Warm Syngas

- Scope: Characterize warm syngas composition and evaluate syngas process improvements leading to enhanced contaminant and CO_2 removal
- Objectives:
  - Develop absorbents and process integration to remove impurities and CO_2 from warm biomass/coal syngas and provide clean feed streams with preferred composition to downstream chemical synthesis reactions
  - Produce high concentration CO_2 stream for long-term storage
- Progress Highlights:
  - Early results of $Na_2Mg(CO_3)_2$ double salt shows promising CO_2 capture effectiveness
  - Successful 100-hr test on integrated warm syngas cleanup process

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Focus Area 3:
SNG Catalyst & CO_2 Adsorbent Integration

- Scope: Develop optimized methods for syngas conversion to synthetic natural gas (SNG) with CO_2 separation
- Objectives:
  - Develop highly-stable methanation catalysts
  - Develop novel reactors to fully integrate methanation, WGS, and CO_2 capture for improved process efficiency and economics
- Progress Highlights:
  - Proof of concept demonstration for CO_2-sorption enhanced methanation using catalyst and sorbent developed at PNNL
    - 93% methane yield achieved, under process conditions where single reaction equilibrium limitation is 32% methane yield
  - Advanced methanation catalyst developed by CAS and CO_2 sorbent from NETL to be evaluated in combined system at PNNL

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Focus Area 1:

High Volume CO_2 Sequestration & Utilization

- **Task 1: Examining Preferential Flow Mechanisms of Candidate Storage Formations in China**
  - Characterize the heterogeneities common to many candidate CO_2 storage reservoirs in China
  - Investigate and model heterogeneities at the core scale; upscale to reservoir scale to better understand flow paths and control of injection and storage
- **Task 2: Modeling CCS Deployment in China**
  - Focus on assessing the potential of CCS to deploy in China; considering a combination of technical, economic, and other related factors
  - Builds on our research over the past 10 years focused on examining the deployment potential and implications within a techno-economic and geospatial framework

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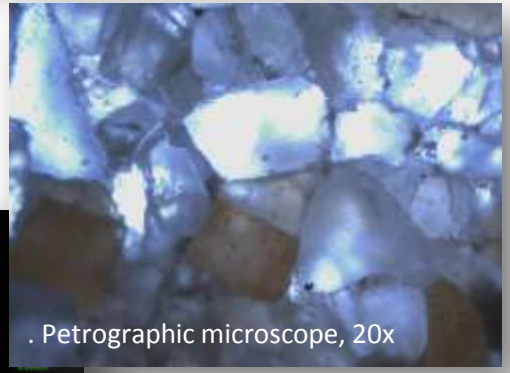
CCS Task 1: Examining Preferential Flow Mechanisms
Core Characterization & Analysis

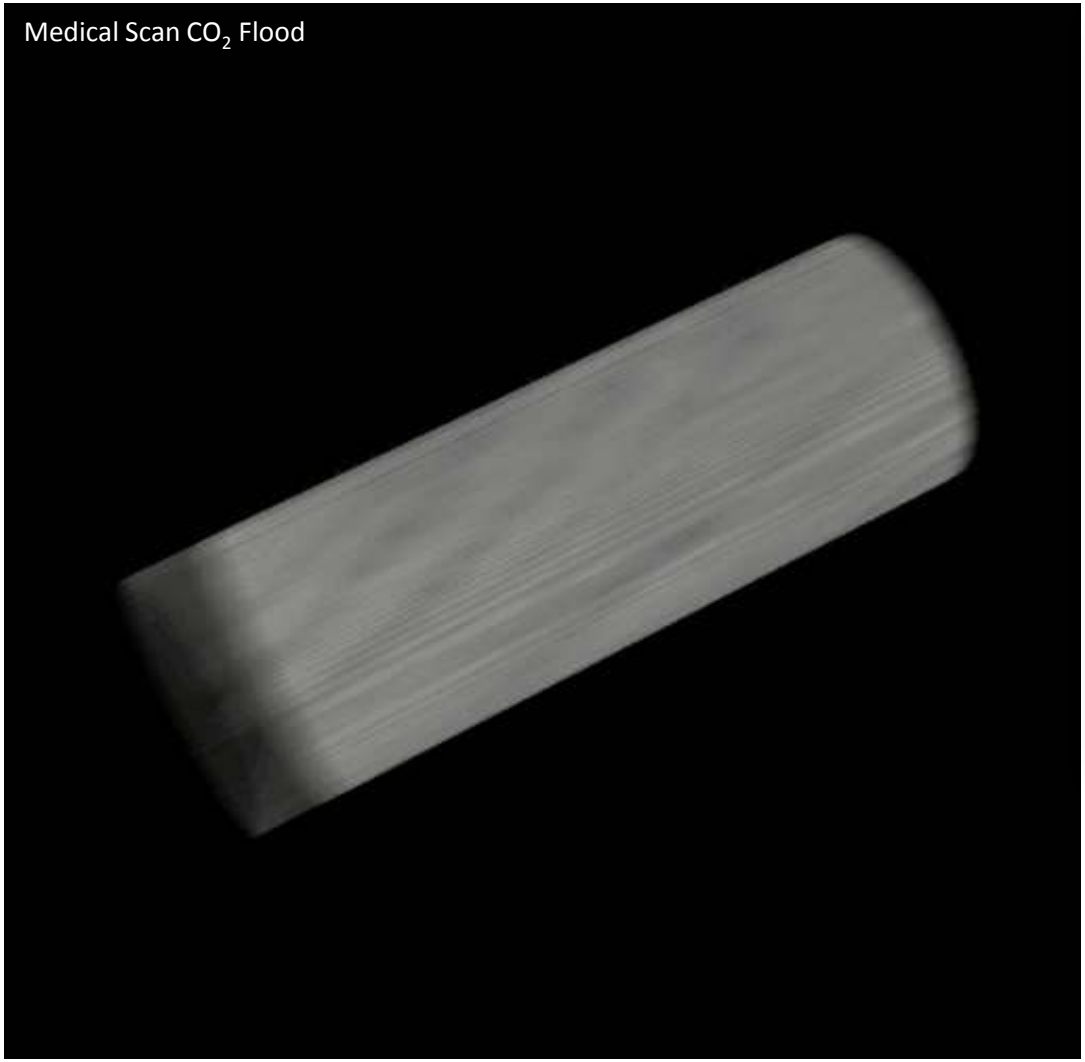
- Complex heterogeneities in reservoir formations may be encountered at all scales
  - pore scale: local grain anisotropy
  - reservoir scale: high permeability
- Characterize and evaluate pore-scale interfacial interactions and up-scaling to core and field scales with experimental and computational tools at NETL, PNNL and CAS, considering:
  - phase behavior
  - CO_2 mineral interactions
  - multiphase flow processes
  - coupling of stress fields and flow


Sandstone core, showing cross bedding.


. Petrographic microscope, 20x


Laser Scanning Confocal Microscope, 20x

CCS Task 1:
CT Scan Animations



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CCS Task 1:

Micromodel Experiments

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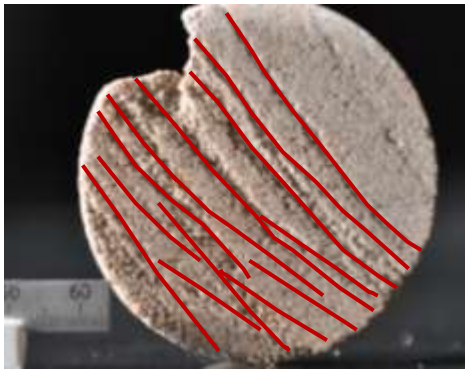
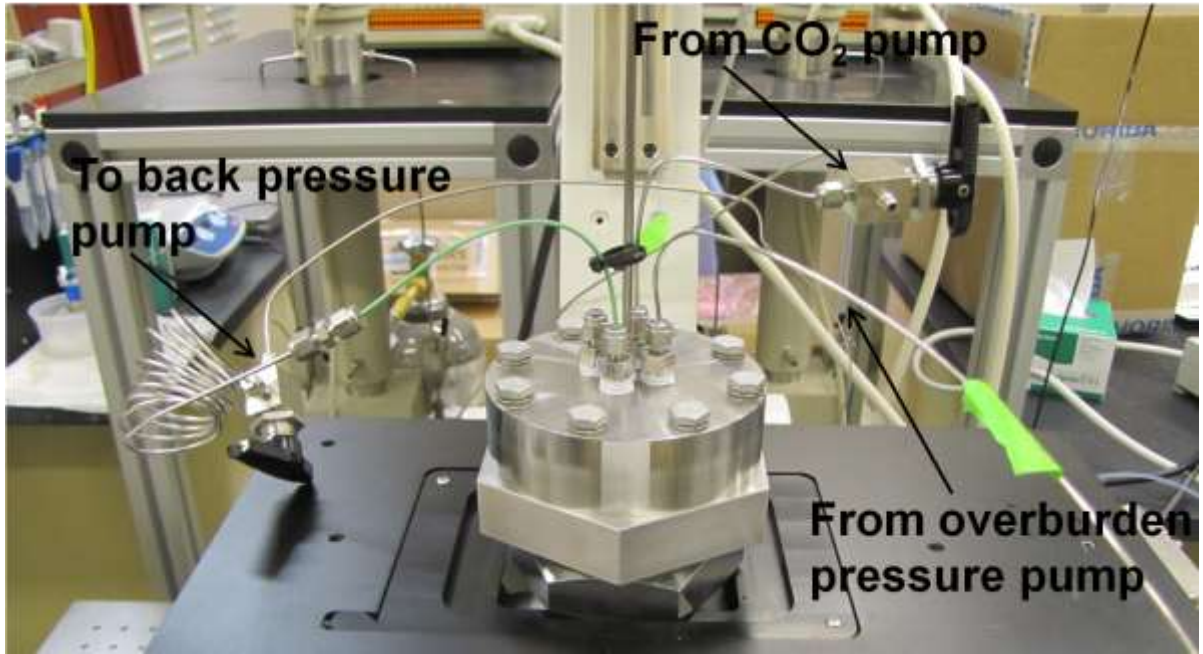
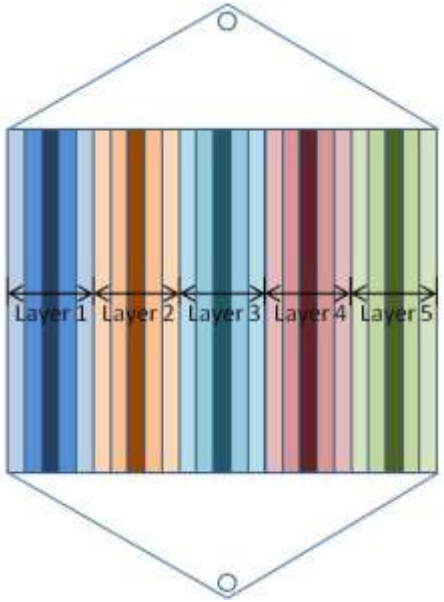
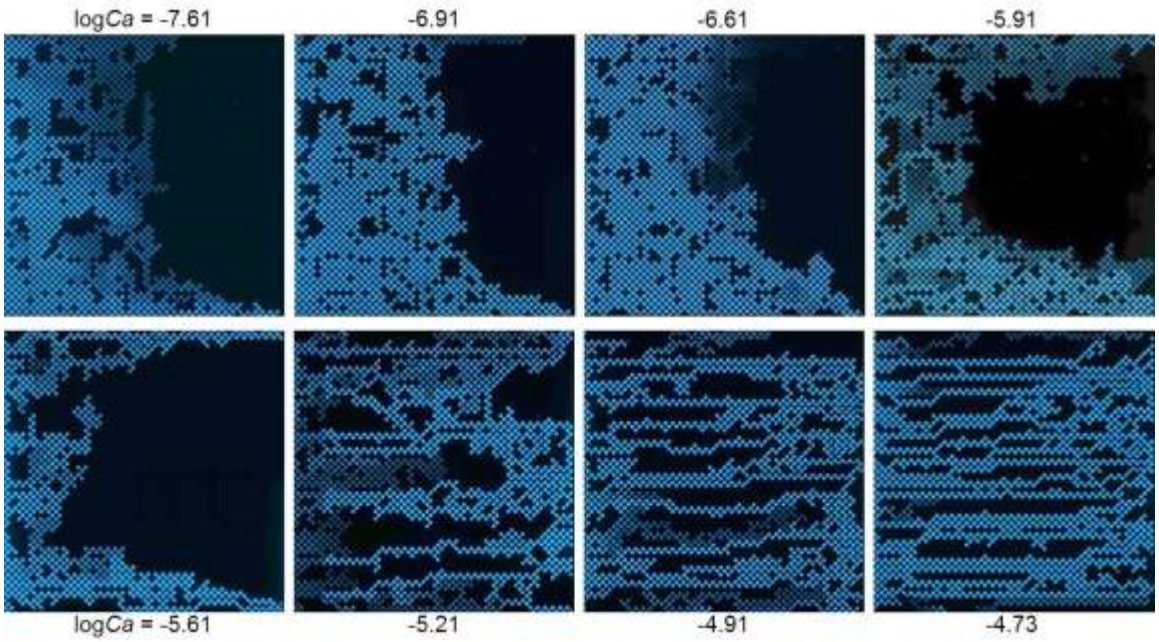
- Multilayer micromodel: Idealized representation of layered Ordos sandstone formation
- Multiple permeability in each layer realized by pore size distribution (grain diameter, pore body, and pore throat, as obtained from tomography)
- Allows direct visualization of $scCO_2$ - brine displacement, mechanistic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

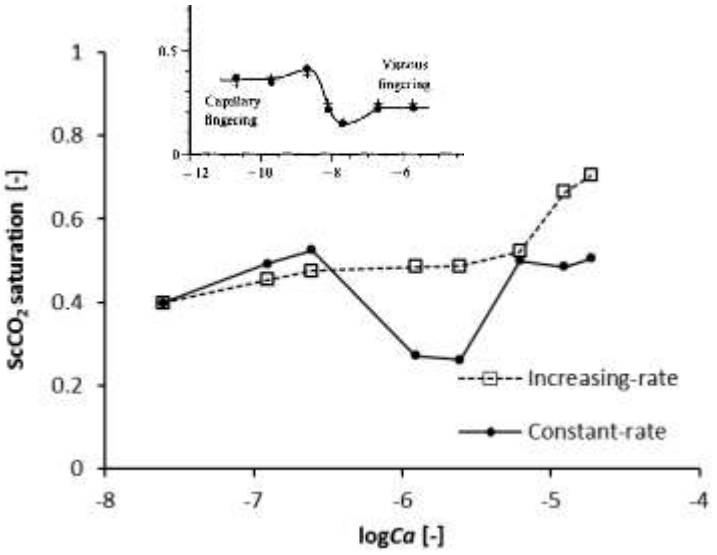




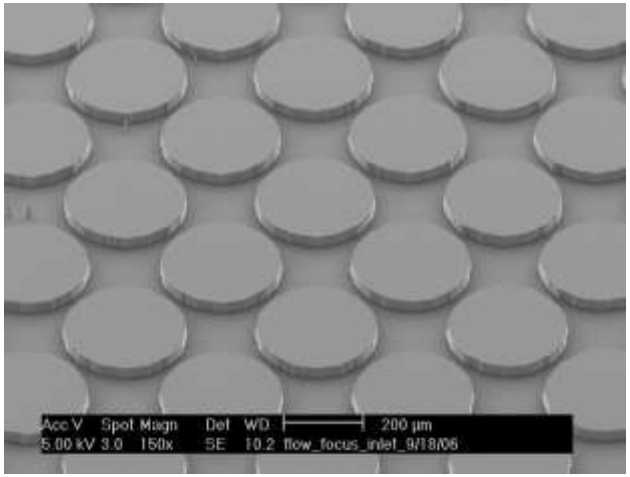


CCS Task 1:
Preliminary Experiments in Homogeneous Models





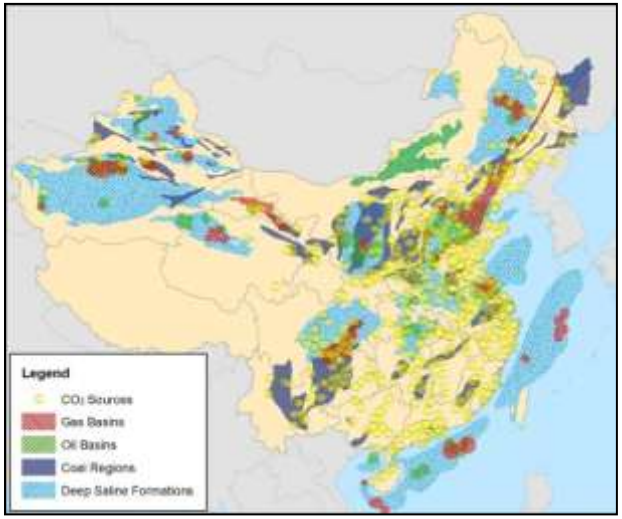
- Experiments show displacement mechanisms change as function of displacement rate:
  - Capillary fingering at low rates
  - Crossover at intermediate rates
  - Viscous fingering at high rate
- Experimental results consistent with theory and numerical modeling (Lenormand et al., 1988)

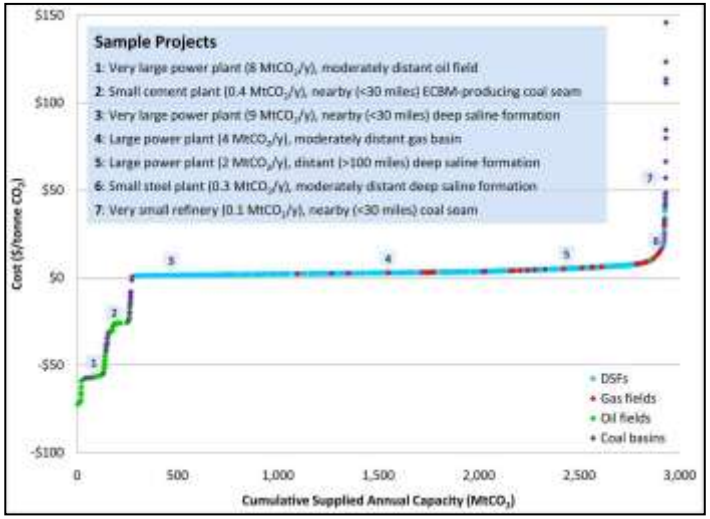


CCS Task 2: Modeling CCS Deployment in China
Builds on Recent Work with CAS-IRSM

Regional Opportunities for Carbon Dioxide Capture and Storage in China

- Inventoried and mapped large CO_2 point sources and candidate geologic CO_2 storage reservoirs
- Analyzed source-reservoir matching with economics of CO_2 transport and storage
- Established potential for cost-effective, large-scale deployment of CCS





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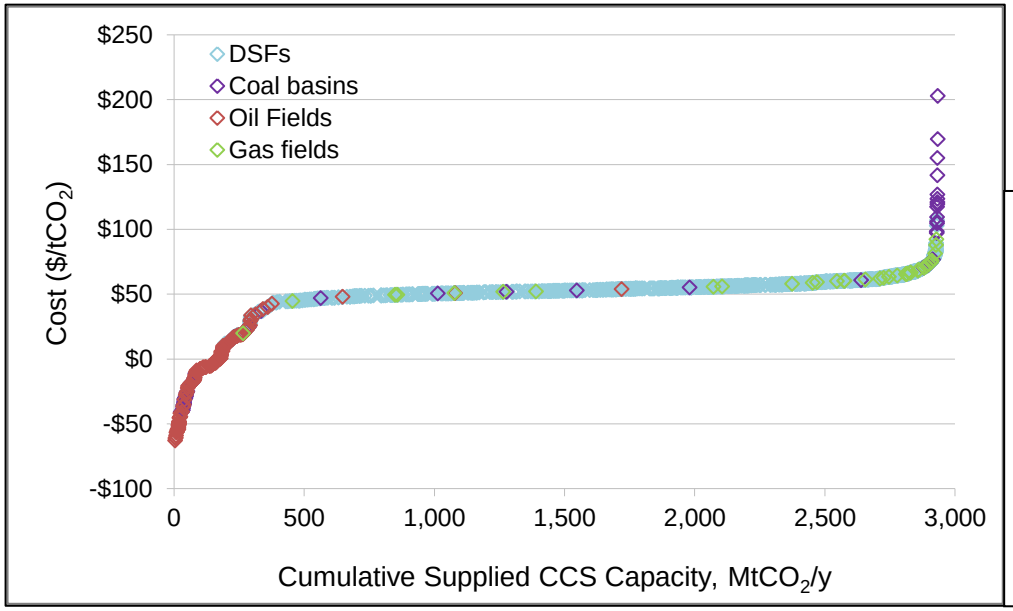
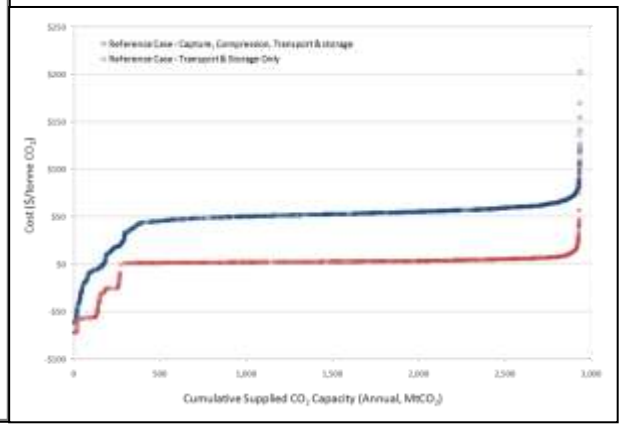
CCS Task 2:
Complete CCS System Cost Curve

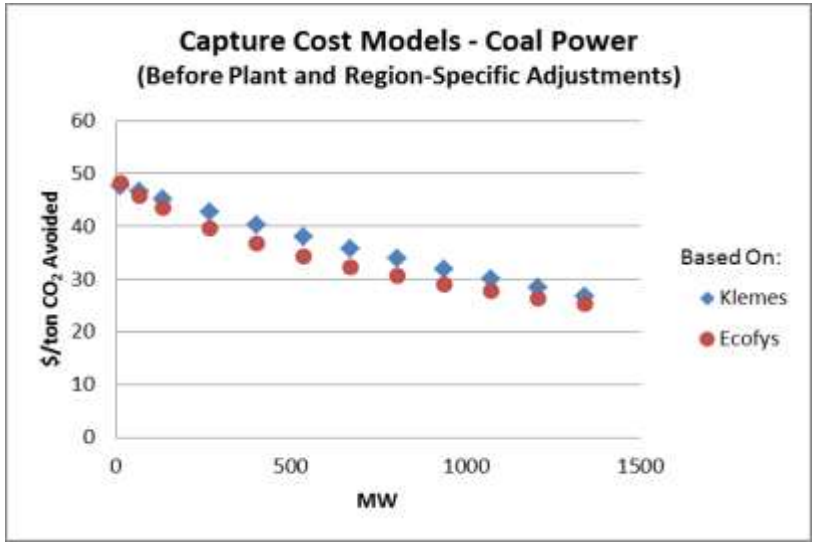
- Includes: Capture, compression, transport, and storage
- Storage costs include: site characterization, CO_2 flowlines, injection and monitoring wells, and other MMV
  - Also production wells, CO_2 recycling plants, and related costs and revenues for enhanced hydrocarbon recovery projects
- All include CAPEX, OPEX, and China cost adjustment factors
- Indicates significant potential for CCS to deploy across China's industries and regions at costs less than \$70/tCO_2

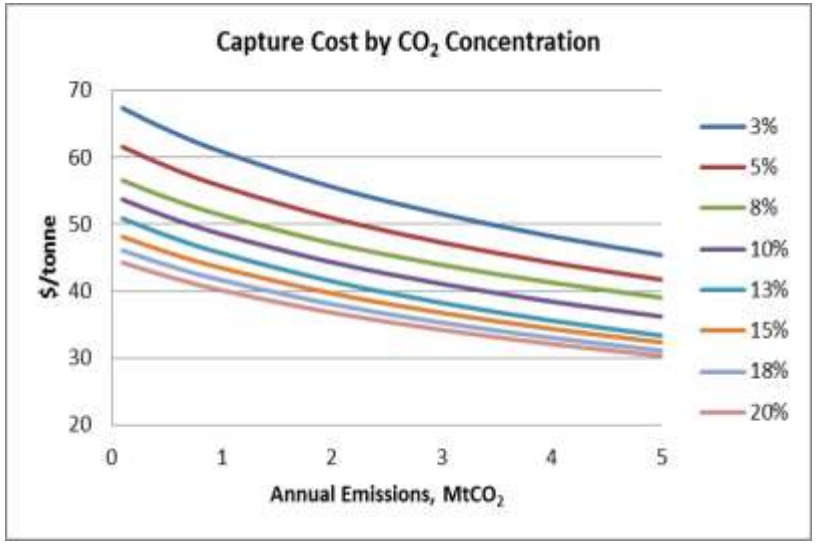




CCS Task 2:
Modeling Capture Costs

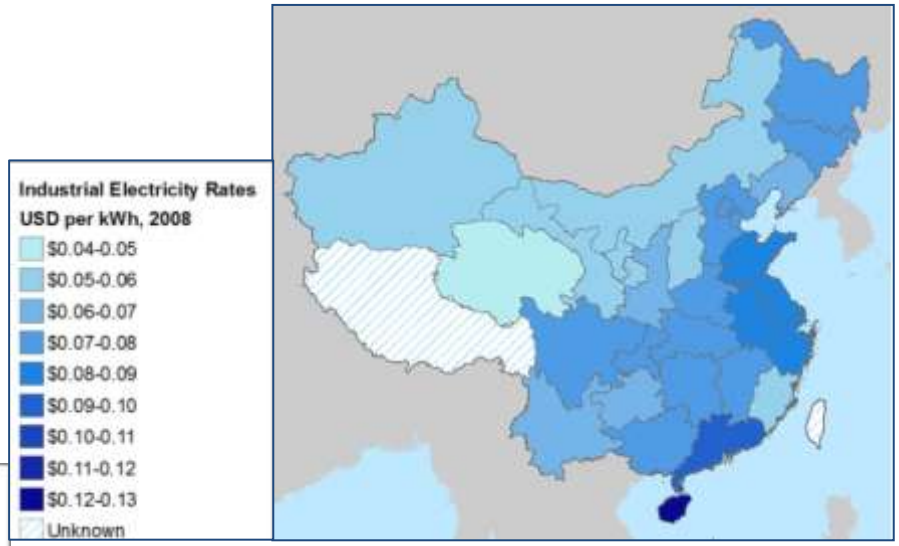
- Applied approach to model representative, *n*th*-unit* capture system costs for 1,623 large CO_2 sources
- Modeled costs based on CO_2 source type, process/fuel, and outlet CO_2 stream concentration
- Resulting costs benchmarked against literature
- Adjusted global cost estimates for China (based on IEA ETP model factors)
  - 90% for capital costs
  - 80% O&M (60% for labor)

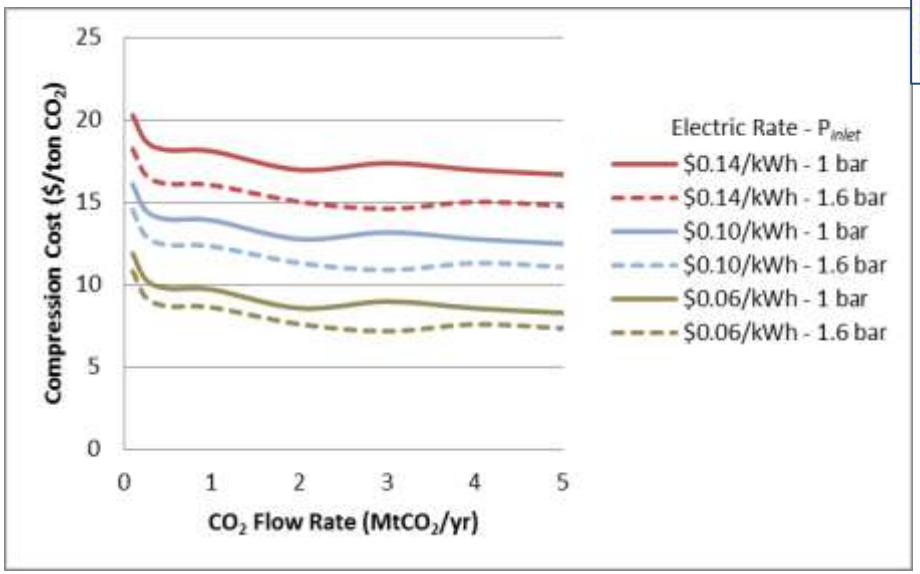


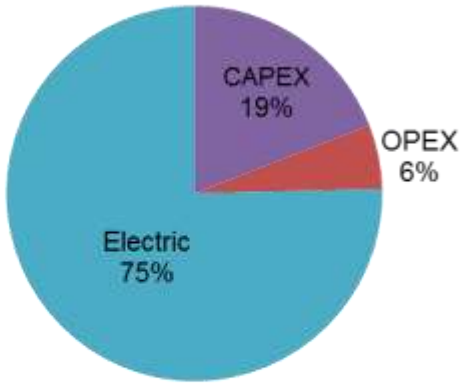


CCS Task 2:
Modeling Compression Costs

- Approach adapted from McCollum and Ogden (2006)
- Assumptions:
  - 5-stage compression
  - 85% capacity factor
  - P_{in}: variable
  - P_{out}: 150 bar
  - Per train limit: 40,000 kW





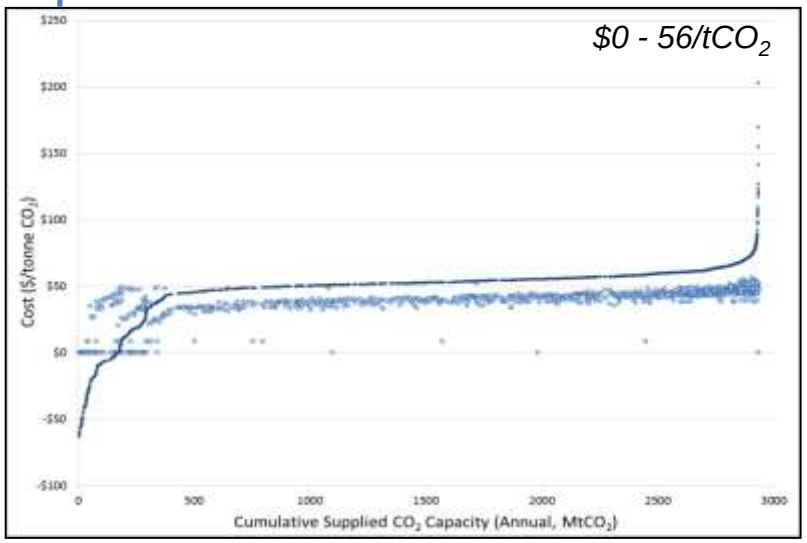


Levelized Cost Split
1 $MtCO_2$/yr; $0.10/kWh

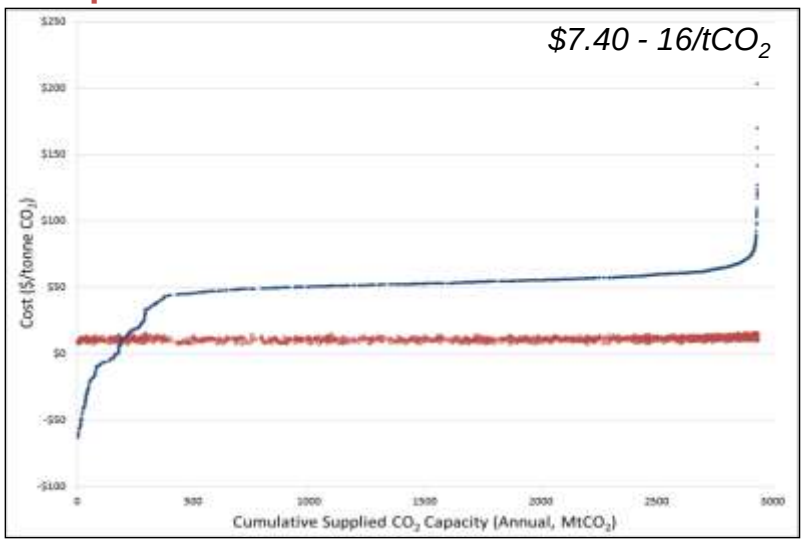
CCS Task 2:

Heterogeneous Nature of the Cost Curve

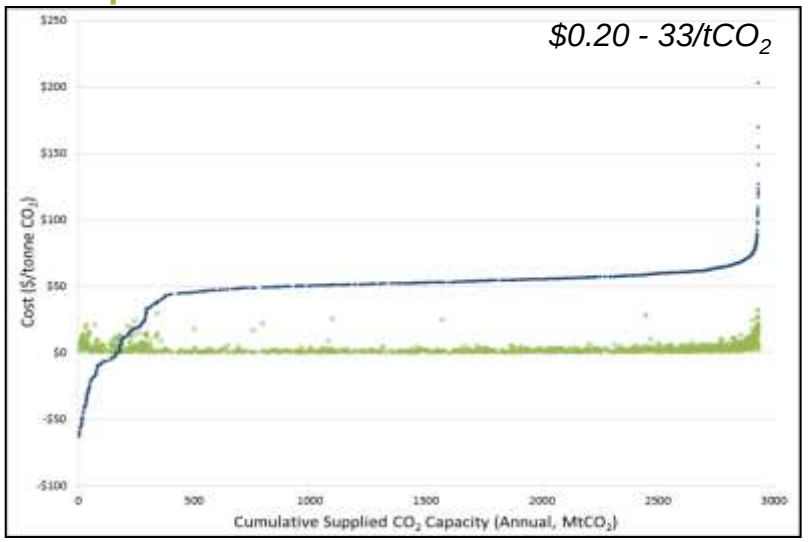
Capture



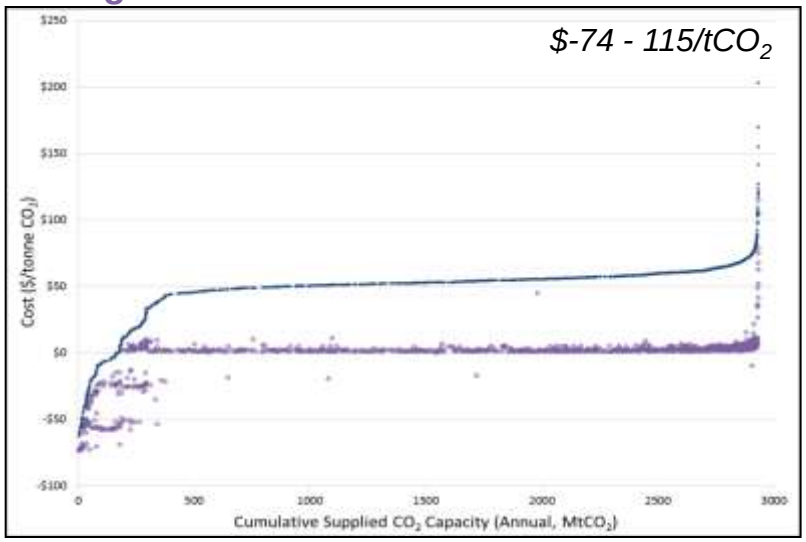
Compression



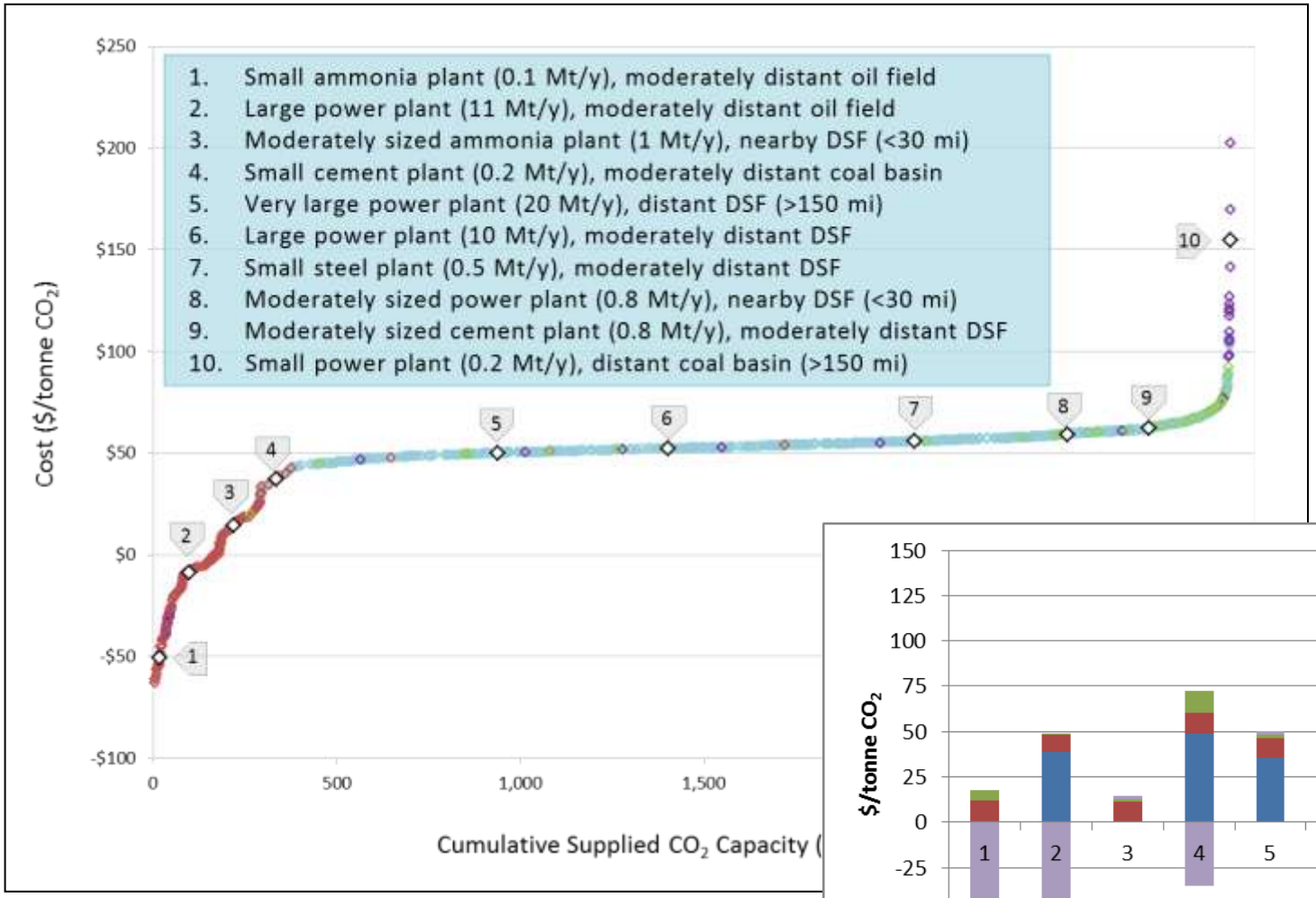
Transport

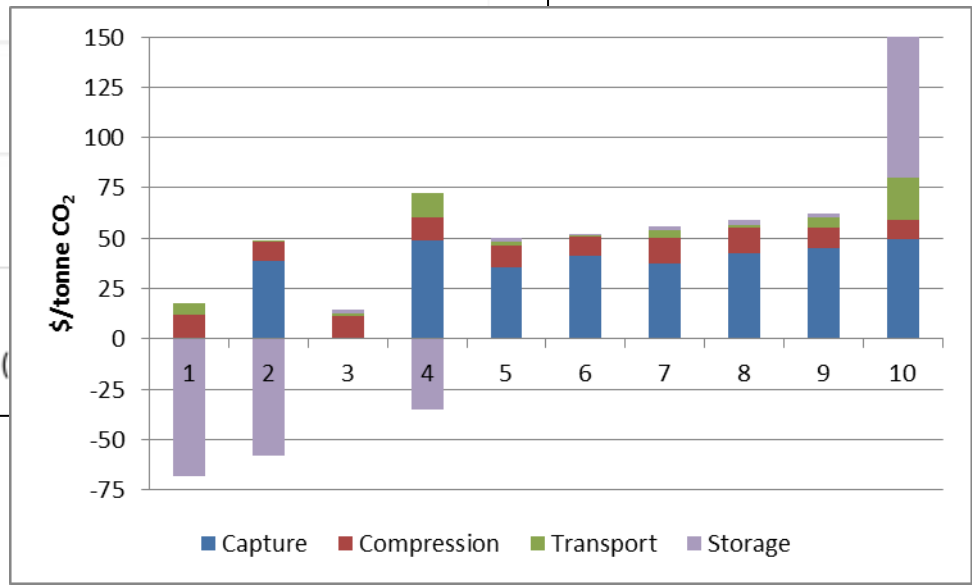


Storage



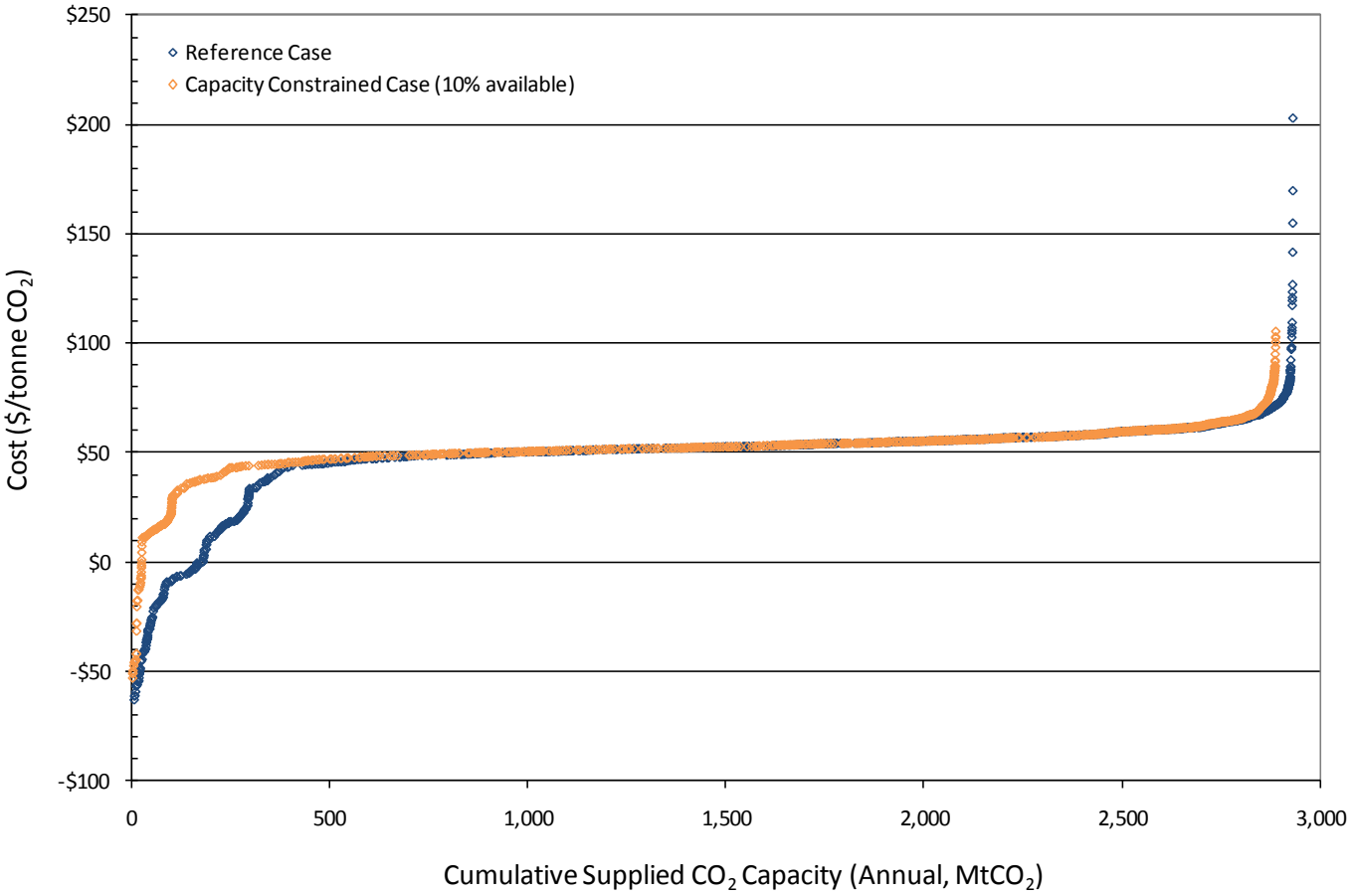
CCS Task 2:
Sample Source-Sink Pairs from the Curve





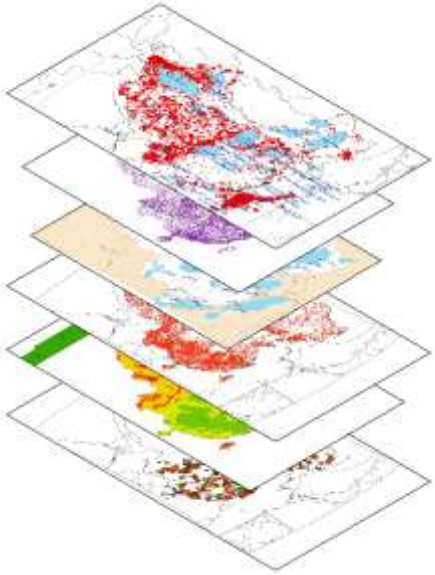
CCS Task 2:
Reduced Capacity Case

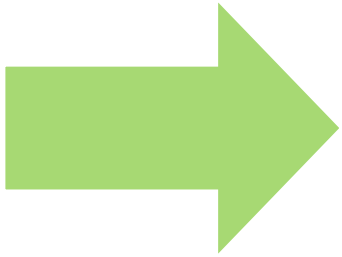
- Examination of limited storage capacity scenarios again suggests adequate CCS potential at reasonable costs for most regions of China

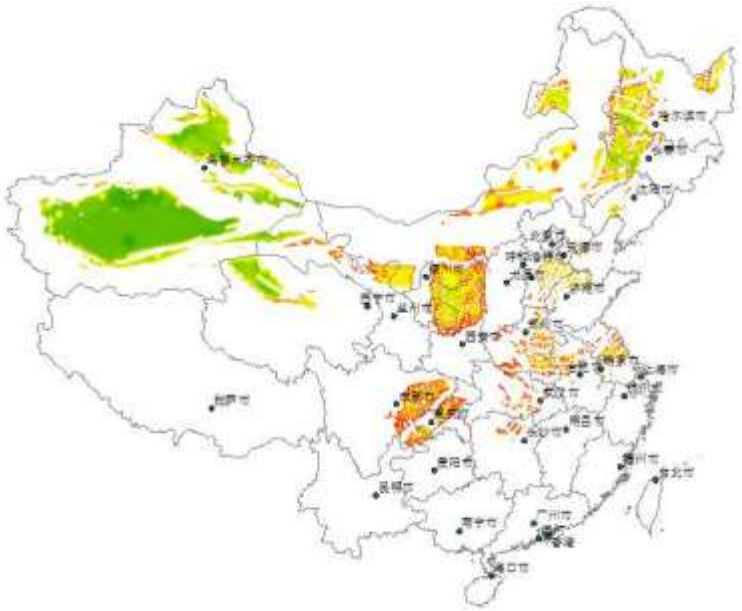


CCS Task 2:
Site Suitability Evaluation Framework

- Developing a preliminary sub-basin scale framework for evaluation of onshore aquifer-based CO_2 storage
- Incorporates multi-criteria geospatial analysis of parameters within the following categories:
  - Storage optimization
  - Storage security, risk minimization
  - Environmental and regulatory compliance
  - Economic and social considerations







U.S.-China Clean Energy Partnership
Summary

- 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 the U.S. and China
- Projects leverage existing capabilities and expertise within each organization
- Significant progress has been made within the first two years

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U.S.-China Clean Energy Partnership

Acknowledgements

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- Chinese Academy of Sciences
- U.S. Department of Energy Office of Fossil Energy

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