Optimizing and Quantifying CO_2 Storage Capacity/Resource in Saline Formations and Hydrocarbon Reservoirs

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University of North Dakota

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Developing the Technologies and
Infrastructure for CCS

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Presentation Outline

- Benefit to the Program
- Project Overview
- Technical Status
- Accomplishments to Date
- Summary

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Benefit to the Program

- Develop technologies to improve reservoir storage efficiency while ensuring containment effectiveness.
- Develop best practice manuals (BPMs) for monitoring, verification, and assessment; site screening, selection, and initial characterization; public outreach; well management activities; and risk analysis and simulation.
- The research project is seeking to optimize carbon dioxide (CO_2) storage resource and containment in geologic formations by establishing field methodologies focused on quantifying and enhancing storage resource in saline formations and hydrocarbon reservoirs associated with enhanced oil recovery (EOR). These methodologies will better enable stakeholders to estimate, predict, and optimize storage resource and demonstrate long-term CO_2 storage in these formations. This project addresses the goals listed above.

Project Overview: Goals and Objectives

- To refine current methods and terms used to estimate CO_2 storage resource in saline formations and hydrocarbon reservoirs.

- Two concurrent areas of investigation (Tasks 2 and 3) will be undertaken to accomplish project goals:

Task 1: Project Management

Task 2: Optimizing and Quantifying CO_2 Storage Resource in **Saline Formations**

Task 3: Optimizing and Quantifying CO_2 Storage Resource in **Hydrocarbon Reservoirs**

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Project Overview:
Goals and Objectives (continued)

Task 2 Objectives

- Perform a literature review and update and expand the Average Global Database (AGD) with saline formation reservoir properties.
- Develop regional- and formation-scale geologic models using Schlumberger Carbon Services (Schlumberger) Petrel geologic modeling software package for several clastic and carbonate depositional environments (i.e., reservoir classes) and up to seven defined structural frameworks based on available real-world data.
- Perform CO_2 storage injection simulations on the models, using Computer Modelling Group Ltd. (CMG) GEM and CMOST software packages, to identify local and regional pressure buildup effects on reservoir storage resource, injectivity, storage efficiency, and plume footprint for the different reservoir classes.
- Perform simulations on the different regional models to determine ways to enhance storage resource and storage efficiency by using different well configurations, horizontal wells, and water extraction wells.
- Refine current methodologies and coefficients used to optimized CO_2 storage resource.

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Project Overview: Goals and Objectives (continued)

Task 3 Objectives

- Perform a literature review on current CO_2 EOR projects to develop a database with reservoir and CO_2 flooding properties for the different cases and reservoir types.
- Conduct reservoir evaluations on current and hypothetical CO_2 EOR projects to better define when an EOR project with incidental CO_2 storage changes to a) an EOR and CO_2 storage project and b) a CO_2 storage project with incidental hydrocarbon recovery.
- Develop pattern-sized geologic models and perform simulations to determine the effects that different reservoir/depositional types have on sweep efficiency, utilization factor, and CO_2 retention.
- Evaluate different types of injection strategies with respect to their ability to optimize utilization factor, storage permanence, and hydrocarbon recovery in different reservoir classes.
- Develop more refined methods for estimating CO_2 storage resource in hydrocarbon reservoirs and the terms used to estimate storage resource for different reservoir classes.

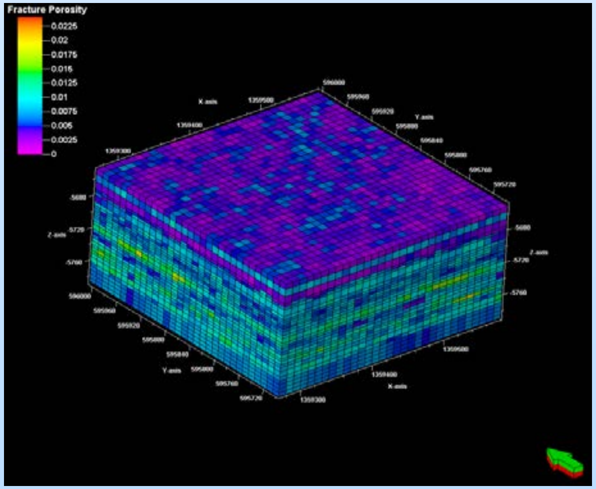
Project Overview:
Goals and Objectives (continued)

- Accomplishment of goals will provide insight into the optimization of CO_2 efficiency, important factors for site selection, the impact of field activities on storage resource, and site-specific effects such as pressure, sweep efficiency, etc.
- Success criteria
  - Completion of literature review of current methodologies
  - Collection of publicly available data for real-world reservoirs
  - Creation of geocellular models for both saline formations and hydrocarbon reservoirs
  - Accomplishment of dynamic CO_2 injection simulations investigating field- and regional-based effects (e.g., pressure)
  - Development of a BPM

Technical Status – Task 2

Approach

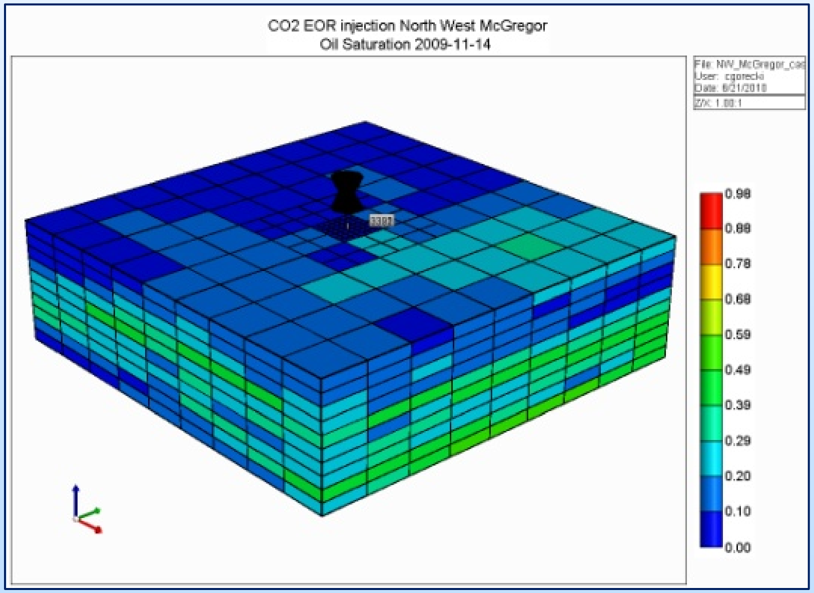
- Literature review
- Build static geologic 3-D models using Petrel
  - Base case properties from publicly available data
  - P10, P50, P90 properties from expanded AGD
  - Ten selected formations covering seven major depositional environments
  - Nine base case models, both regional and formation scale, to capture effects of various depositional environments and heterogeneities
  - Both intracratonic and intermountainous basin deposition systems



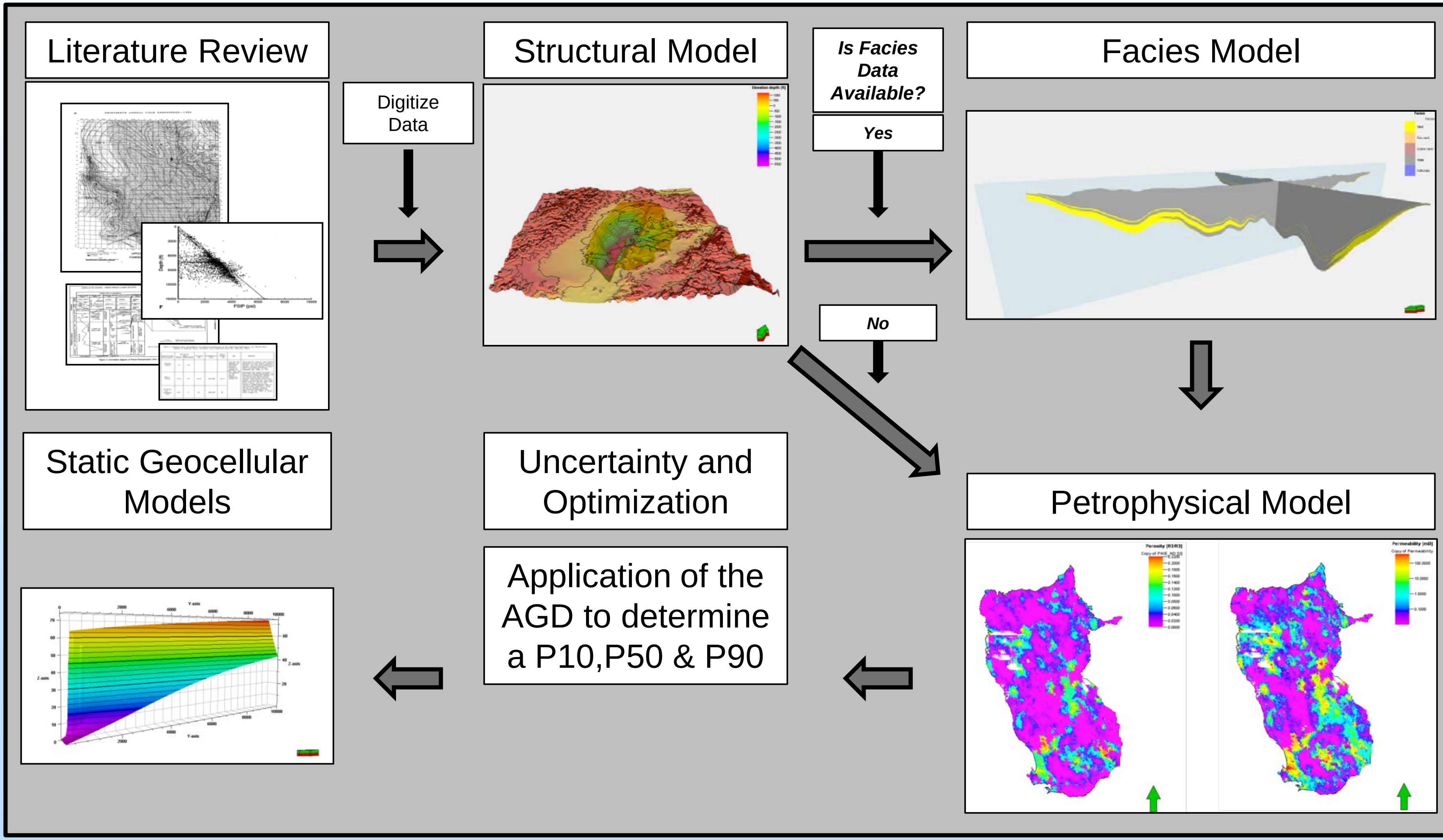
Technical Status – Task 2 (continued)

Approach (continued)

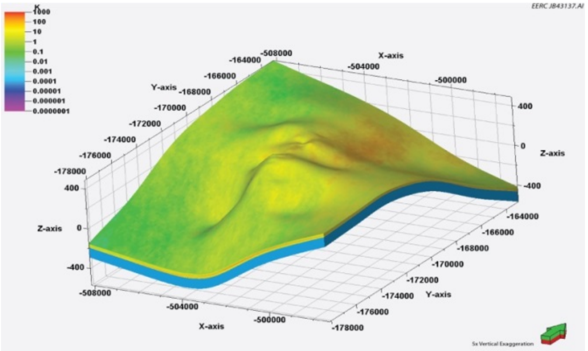
- Perform dynamic simulations using CMG software
  - Validate and optimize geologic models
    - ♦ Upscale base, high, mid, and low cases
    - ♦ Sensitivity analysis and numerical tuning
  - Perform predictive simulations
    - ♦ Pressure buildup
    - ♦ Sweep efficiency
    - ♦ Plume footprint



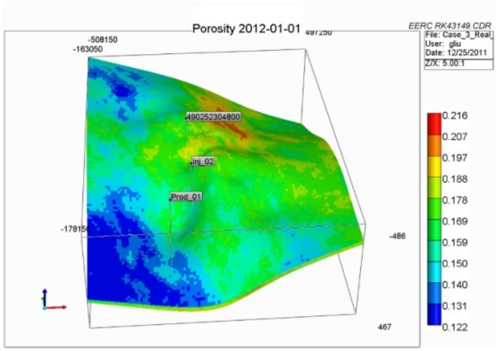
Technical Status – Task 2 (continued)



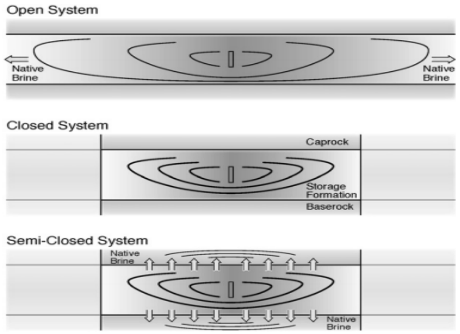
Technical Status – Task 2 (continued)



Geocellular Models with High-, Mid-, and Low-Pore Volume

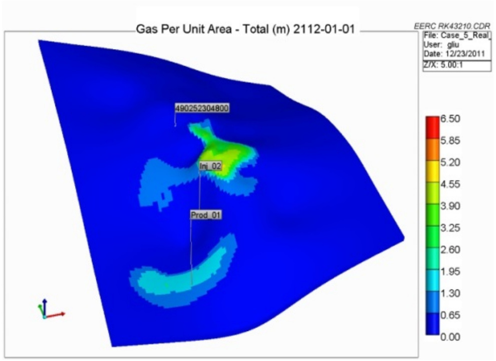


Injection Simulation Design

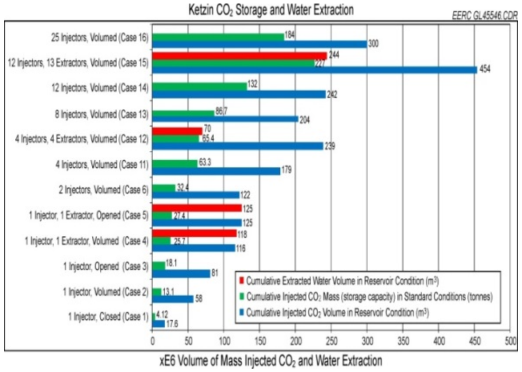


Boundary Condition Explorations

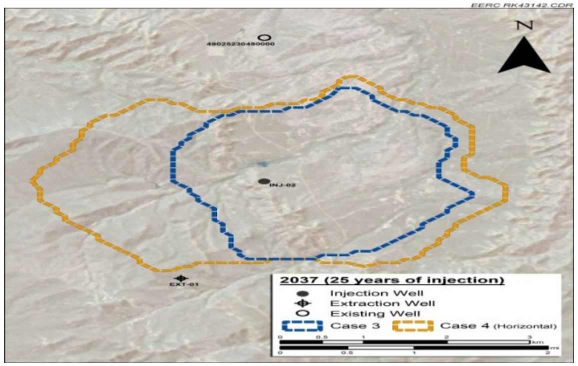
http://esd.lbl.gov/files/research/programs/gcs/projects/storage_resources/journal_3_NETL_zhou_etal_IJGGC.pdf



Operational Storage Capacity Enhancement



Dynamic Storage Capacity estimates



Storage Capacity Comparisons and Analysis

Technical Status – Task 2 (continued)

Transitional Marine Formations (Fms)

- **Broom Creek Fm**
  - Eolian, marginal marine and marine sediments
  - Intracratonic Williston Basin, North Dakota
- **Minnelusa Fm**
  - Eolian and marine sediments
  - Intermountain Powder River Basin, Wyoming

http://www.studyblue.com/notes/note/n/exam-4-deserts-earthquakes--plate-tectonics-/deck/2570065

Technical Status – Task 2 (continued)

Nonmarine Formations

- **Inyan Kara Fm**
  - Predominantly fluvial transitioning to marginal marine sediments
  - Intracratonic Williston Basin, North Dakota
- **Stuttgart Fm**
  - Predominantly fluvial sediments
  - Intracratonic Northeast German Basin, Ketzin, Germany

Image from http://ndstudies.gov/content/williston-basin

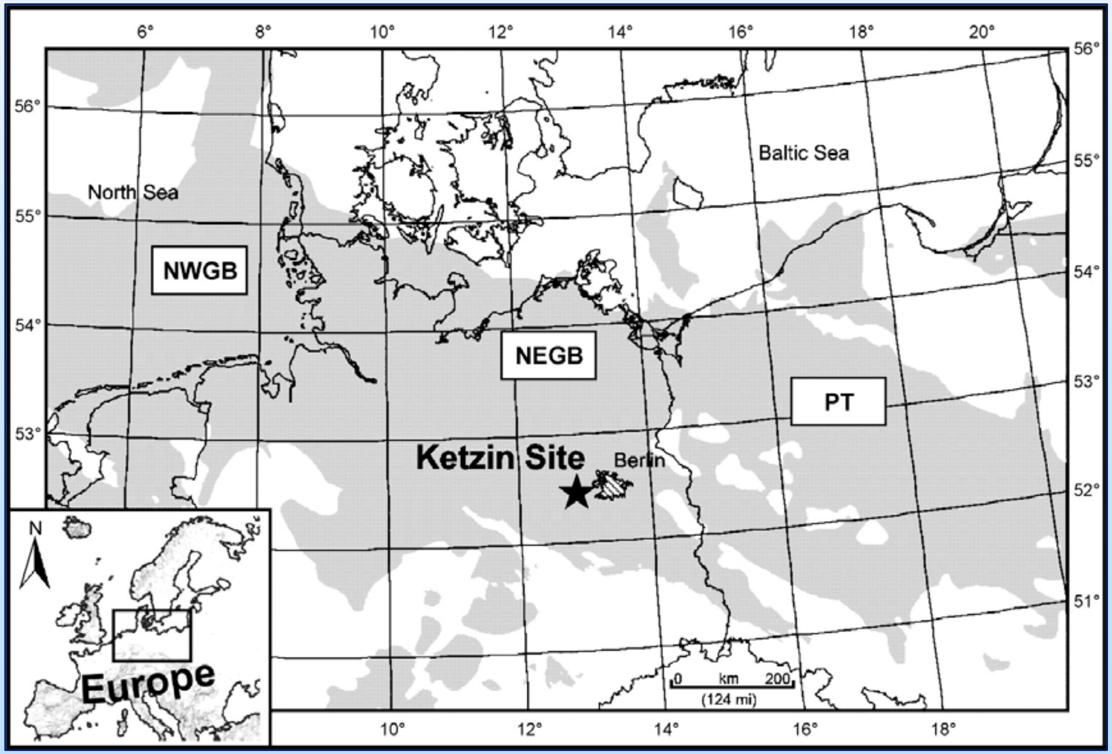


Image from Förster and others, 2010.

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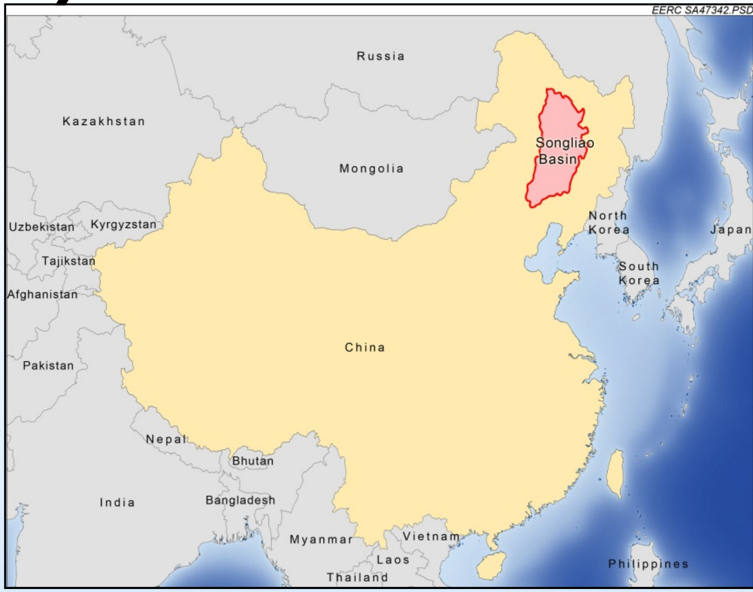
Technical Status – Task 2 (continued)

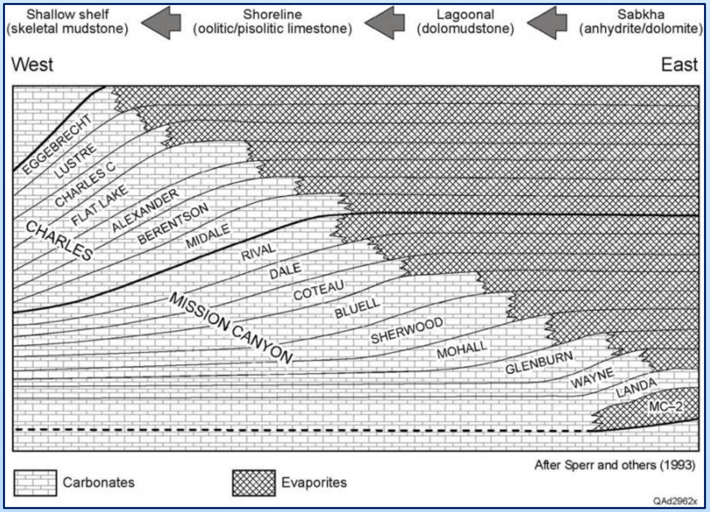


Nonmarine Formations

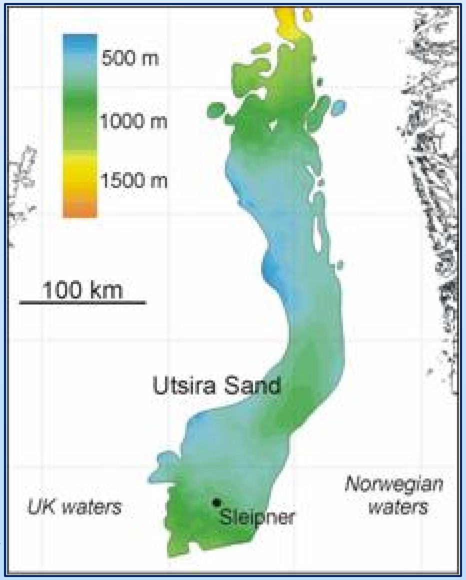
- **Qingshankou–Yaojia Fms**
  - Lacustrine with interbedded deltaic sediments
  - Intermountain Songliao Basin, Heilongjiang Province, Northeast China

Marine Formations

- **Mission Canyon Fm**
  - Carbonate shelf sediments
  - Intracratonic Williston Basin, North Dakota



- **Utsira Fm**
  - Deltaic sediments
  - Intracratonic Norwegian Danish Basin



http://climatex.org/articles/climate-change-info/geosequestration-burying-problem/

Technical Status – Task 2 (continued)

Marine Formations

- **Leduc Fm**
  - Reef and shallow water carbonate sediments
  - Intracratonic regional Western Canada Sedimentary Basin, west-central Alberta, Canada
- **Winnipegosis Fm**
  - Reef structures in marine sediments
  - Intracratonic Williston Basin, North Dakota

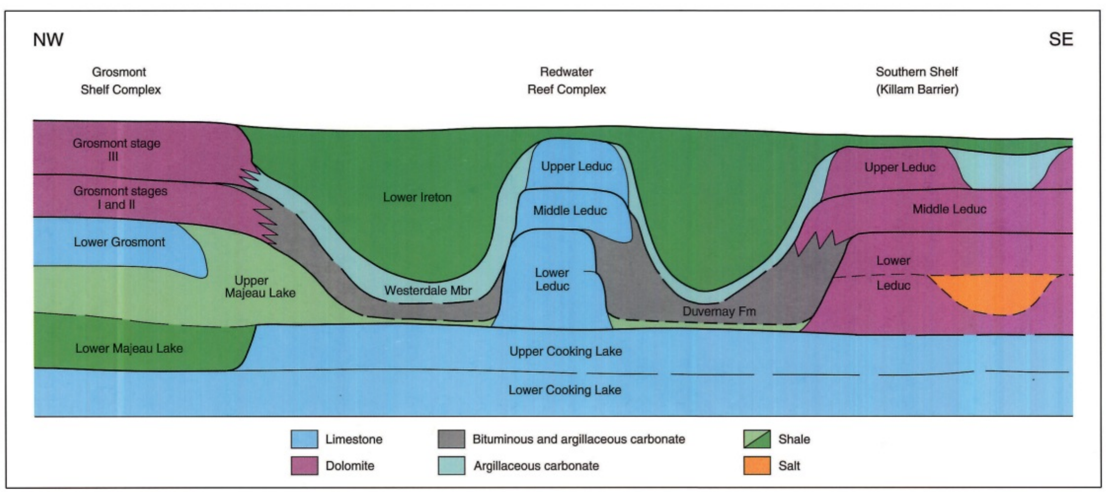


Figure 12.10 Schematic cross section showing stages of reef, shelf and basin-fill development within Woodbend intervals. See Figure 12.7 caption for explanation of the Majeau Lake-Cooking Lake relationship.

Image from Switzer and others, 2012.

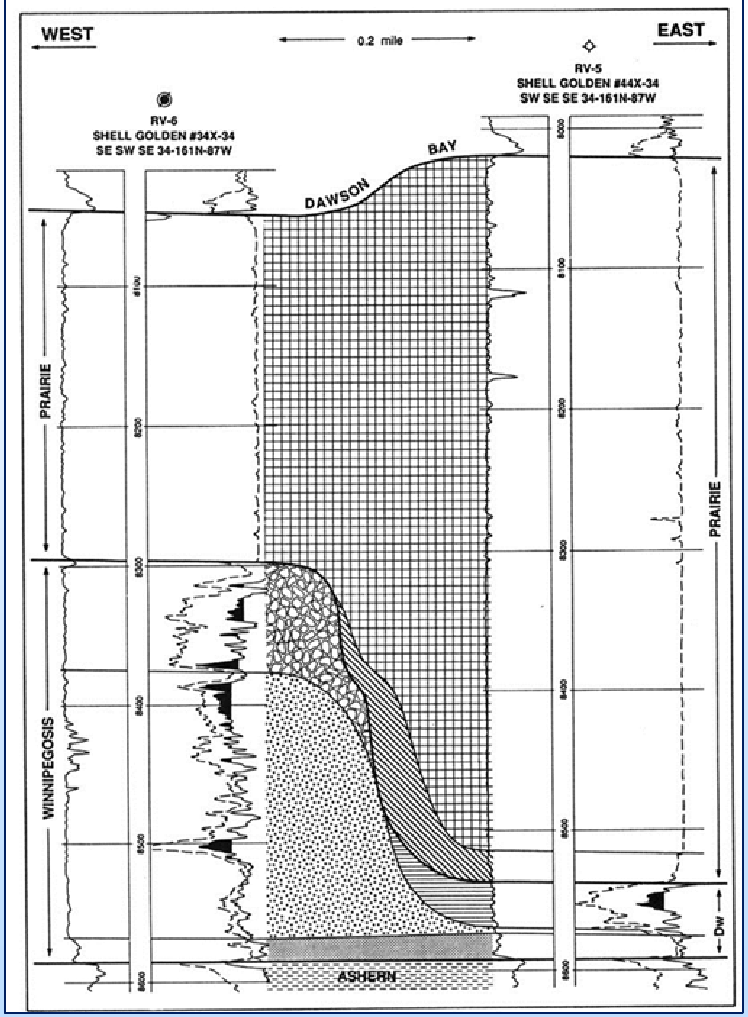


Image from Ehrets and Kissling, 1987.

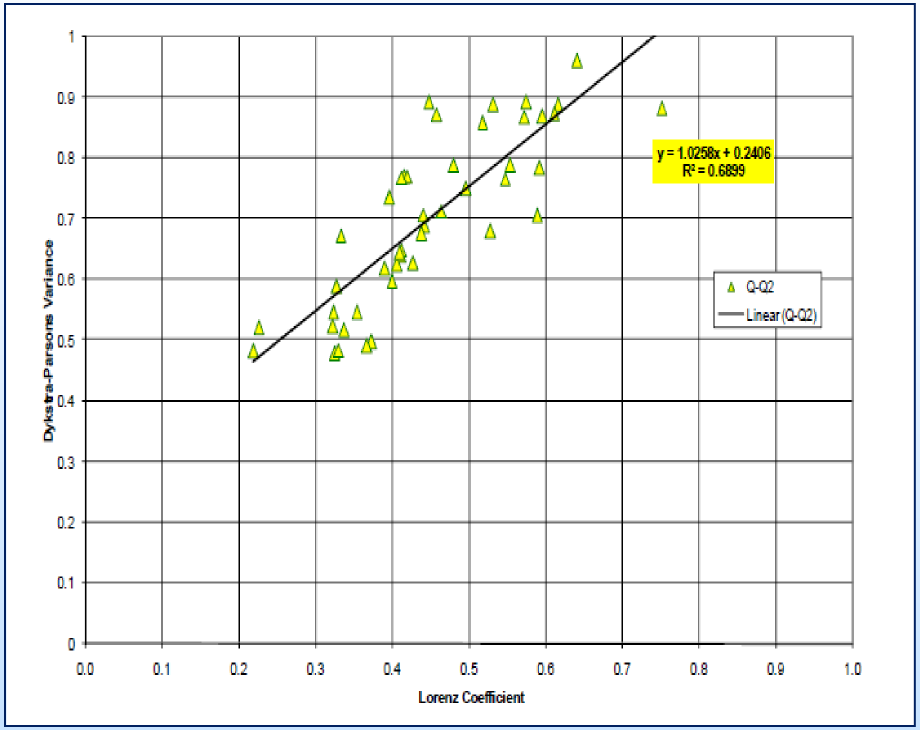
Technical Status – Task 3

Approach

- Literature review
  - Review of existing CO_2 storage resource methodologies for hydrocarbon reservoirs
  - Collection of publicly available data: Oil and Gas Journal EOR survey, technical papers, etc.
  - Initial screening based on specific criteria (e.g., enhanced recovery)
  - Detailed analysis of selected reservoirs
- Evaluation of factors involved in the CO_2 EOR and CO_2 storage relationship
- Hydrocarbon reservoir modeling and simulation
- Evaluation of methodology

Technical Status – Task 3 (continued)

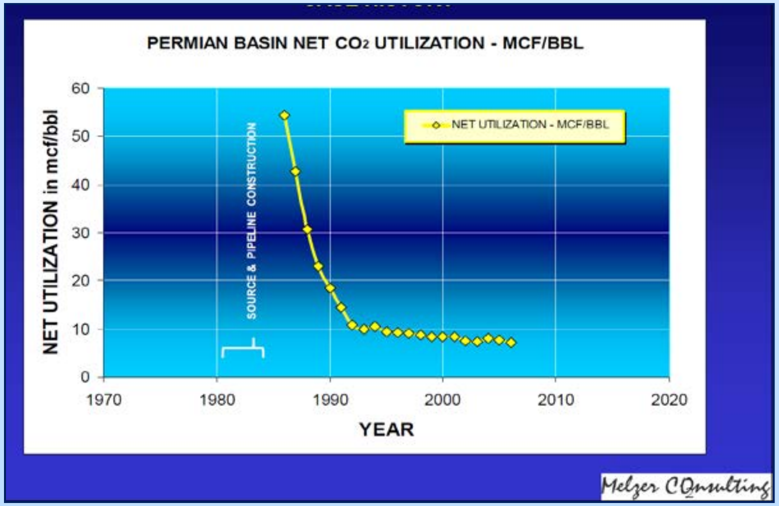
- Develop equation for CO_2 storage resource estimation.
- Perform basic 2-D spreadsheet-based evaluations.
- Compile geologic and reservoir inputs and noted inflection points to study relationship between utilization factor and project stage (CO_2 EOR and CO_2 storage).



Dykstra Parsons vs. Lorenz Coefficient Plot

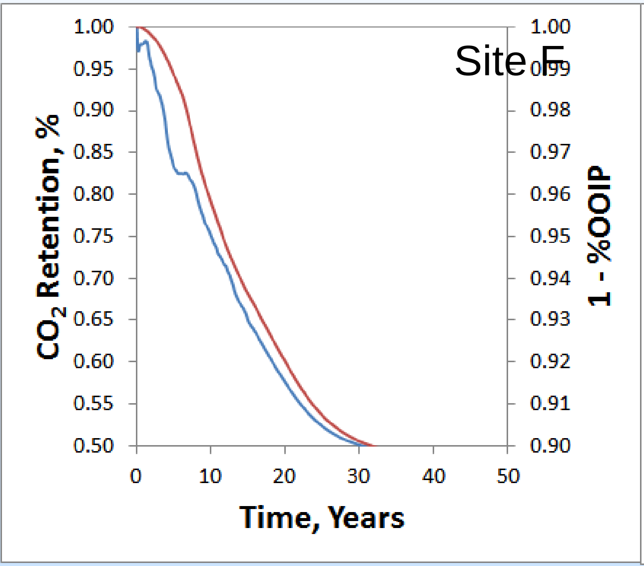
Image from http://etd.lsu.edu/docs/available/etd-10302008040624/unrestricted/Senocak_Thesis.pdf

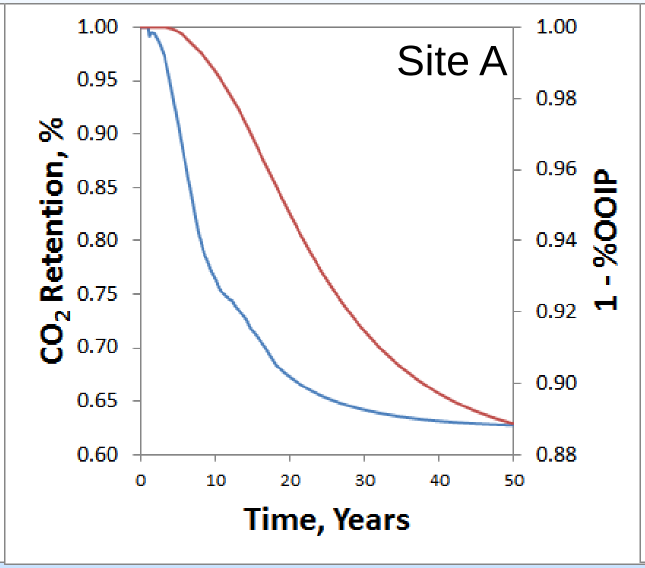
Image from Melzer, S.L., 2006

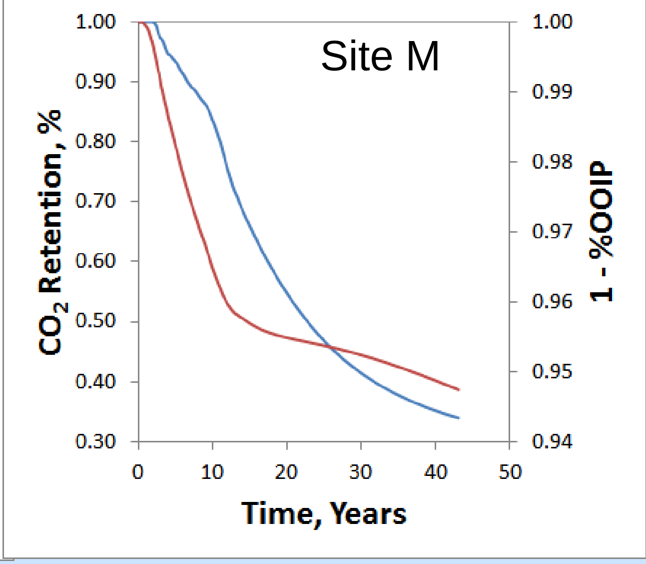


Technical Status – Task 3 (continued)

Evaluating Relationships Between CO_2 Retention and Reservoir Production







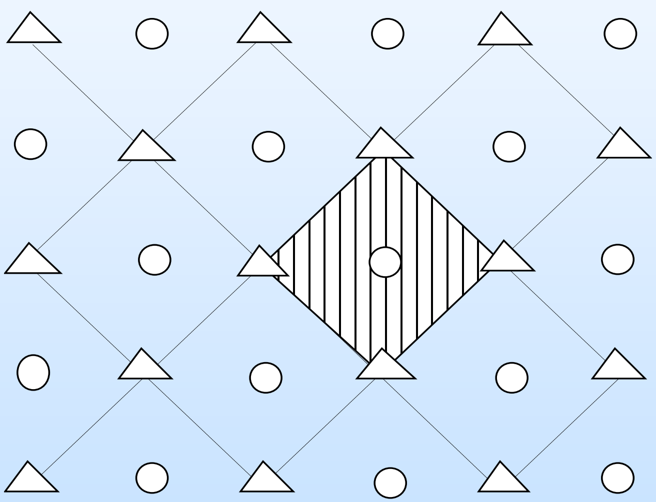
Type 1:
"Mirror"
CO_2 retention and oil production track closely over time.

Type 2:
"Lag"
Time lag between oil production and CO_2 retention.

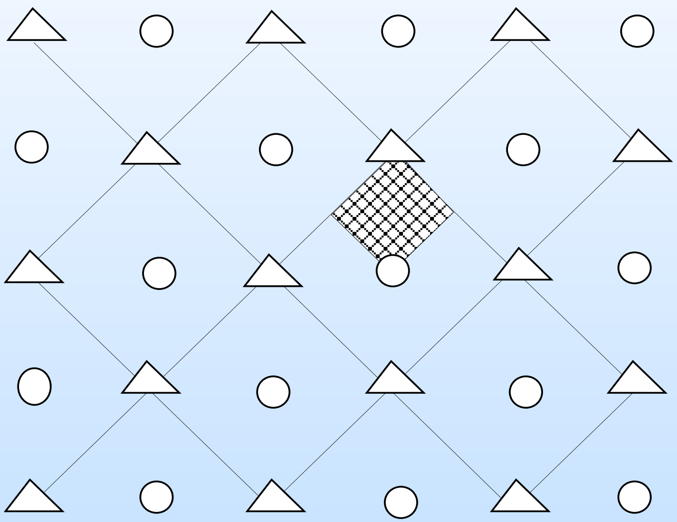
Type 3:
"Crossover"
Greater oil production prior to decline in CO_2 retention.

Technical Status – Task 3 (continued)

- Develop 2-D conceptual geologic models
- Perform intermediate-level reservoir simulation using COZView/COZSim or CO_2 Prophet software



The **AREA** entered as input to the model should correspond to the hatched area.



The partial area (crosshatched) is actually simulated in the model.

Images from CO_2 Prophet Manual

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Technical Status – Task 3 (continued)

- Develop field- to pattern-sized geologic models. (Schlumberger's *Petrel*™)

- Perform dynamic simulations (using CMG's *GEM*™) to understand and optimize:
  - Utilization factor, sweep efficiency, storage permanence, and retention

Technical Status – Task 3 (continued)

- Simulation-based estimates of expected CO_2 EOR efficiency and CO_2 storage capacity for refined storage resource estimations/storage coefficients for EOR/storage projects.

- Simulation-based analysis of potential transition of an EOR project to a CO_2 storage project and CO_2 storage resource.

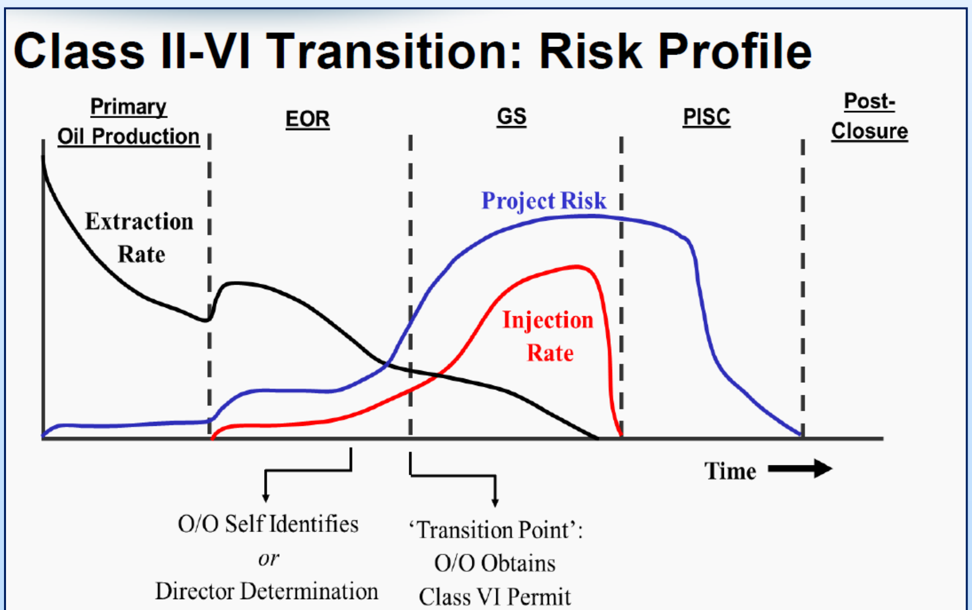

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Image from http://www.spe.org/events/cmtc/2012/pages/schedule/tech%20program/documents/17_Kobelski.pdf

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Accomplishments to Date

Task 2

- Literature review complete.
- Publicly available data have been collected, catalogued, and analyzed.
- Ten saline formations selected for evaluation, nine geocellular models under development.
- Dynamic simulation reservoir properties gathered.

Reservoir Formation	Status
Minnelusa	Base case complete
Broom Creek	Base case complete
Inyan Cara	Structure model built
Mission Canyon	Structure model started
Leduc	Structure model built; properties compiled for object modeling
Winnipegosis	Structure model built
Stuttgart	Structure model built; property modeling begun
Qingshankou–Yaojia	Base case complete
Utsira	Structure model started

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Accomplishments to Date (continued)

Task 3

- Literature review nearly complete.
- Current oilfield CO_2 storage resource methodologies identified and under review.
- Existing EOR projects and reservoirs identified for detailed investigation.
- Potential equations for hydrocarbon reservoirs developed.

Summary

- Site- and reservoir-specific effects (e.g., pressure response) can have a significant impact on the optimization and estimation of storage resource—current methodologies typically ignore these effects.
- Dynamic CO_2 injection simulation is expected to provide insight into:
  1. Validity of coefficients at the formational level for different reservoir classes and basin types, thus reducing extrapolation for large-scale assessments.
  2. Property distributions for each lithology and depositional environment.
  3. Well optimization techniques for CO_2 storage (configurations, horizontal wells, etc.).
  4. Factors affecting CO_2 retention during EOR.
  5. CO_2 storage efficiency in both saline formations and hydrocarbon reservoirs.

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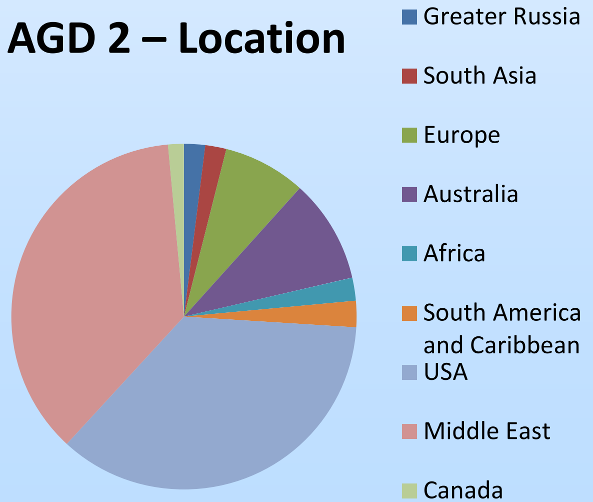
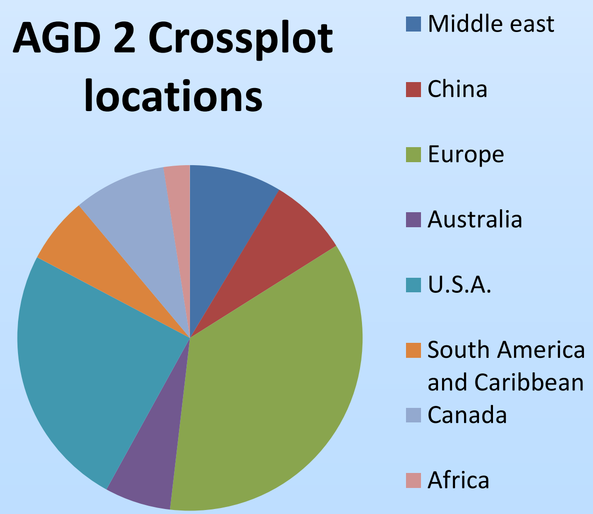
Appendix

AGD

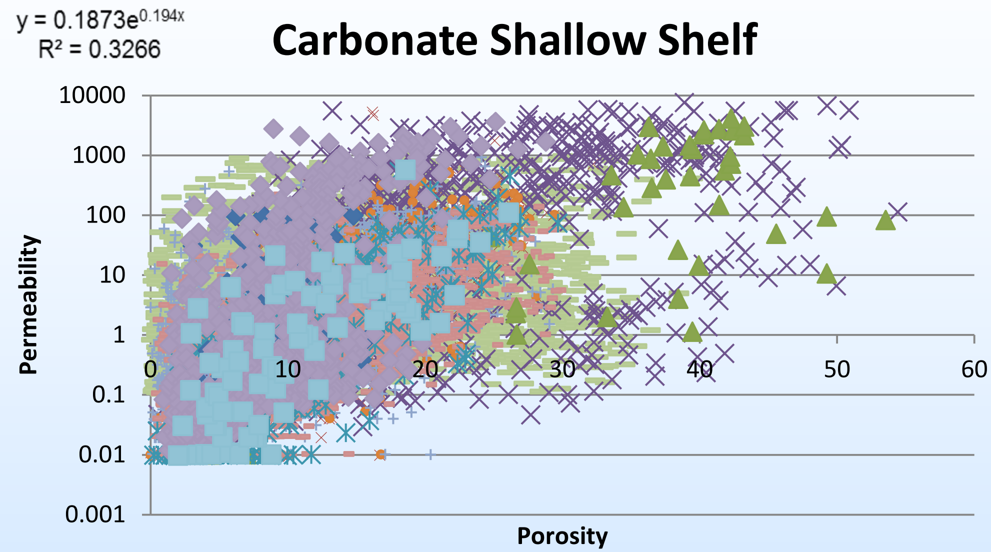
- The AGD was updated with several goals;
  - Better represent global data
  - Increase database organization
  - Incorporate porosity-permeability crossplot data
  - Be distributable
  - Rely less on American Databases
  - Lacustrine and Carbonate Slope environments were added.

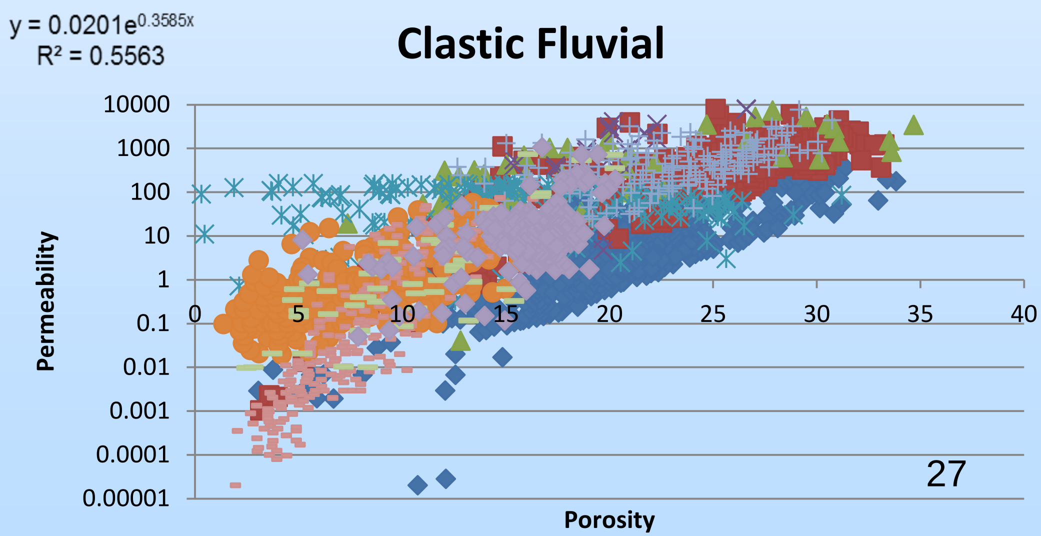




AGD: Porosity-Permeability Relationships

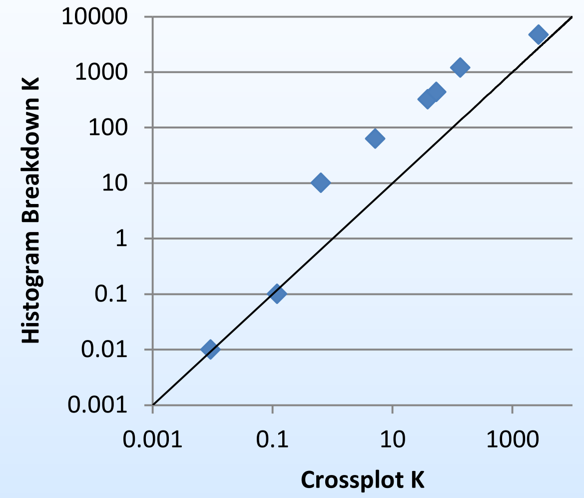
- Nearly 26,000 points were added to the database recording referenced porosity-permeability.
- Data is sorted by depositional environment and sub-facies.

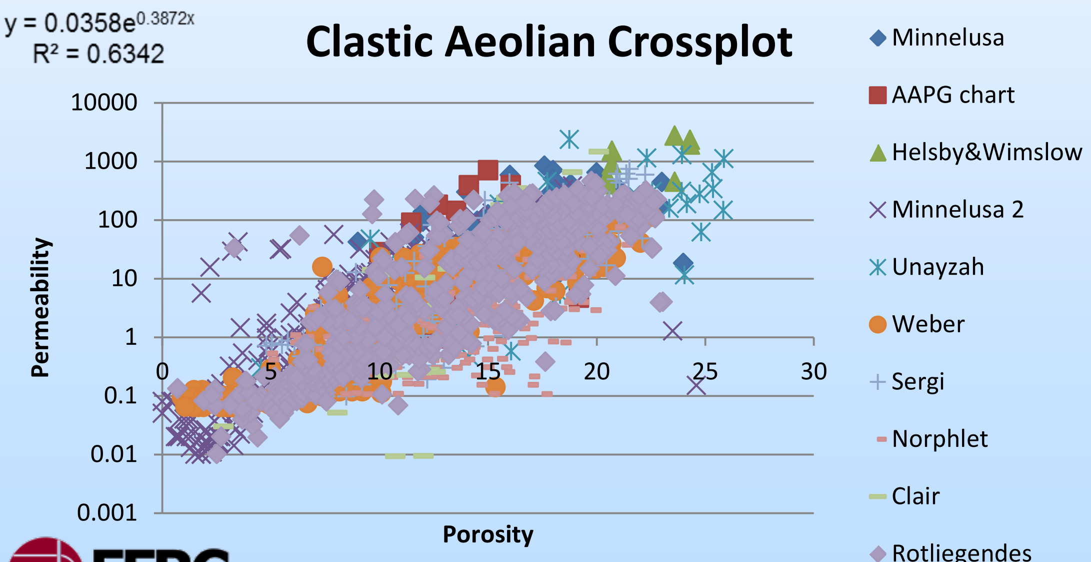




AGD: Findings

- Environments with tighter energy controls provide more consistent (predictable) porosity-permeability relationships.
- Crossplot data appears to produce a more representative dataset with better controls on very low and very high data (Reported histograms oversample mean data)





Aeolian Permeability		
	Crossplot K	Histogram Breakdown K
N=	1503	51
Min.	0.009251	0.01
0.1	0.11964	0.1
0.25	0.639542	10
0.5	5.14	63
0.75	38.82977	320
0.9	135.672	1200
Max.	2735.775	4700
Mean	53.66795	436.398
Stdev	169.1931	977.8442

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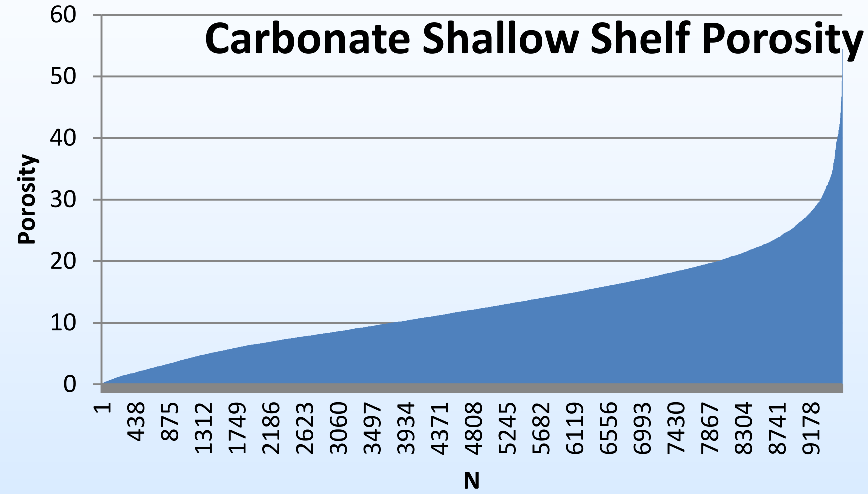
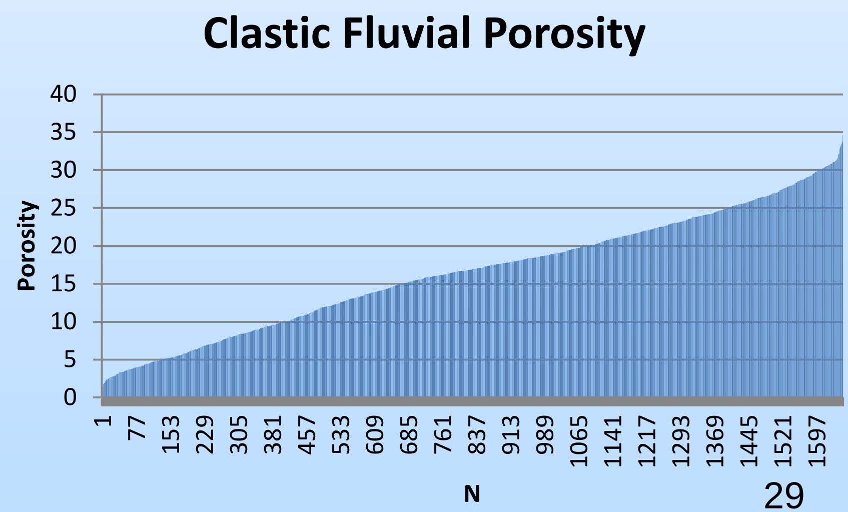
AGD: Statistical Methods

- Depo-environment based quartile statistics for porosity and permeability were developed using two methods;
  - Using the raw porosity-permeability cross plot data
  - Using recombined histogram breakdowns





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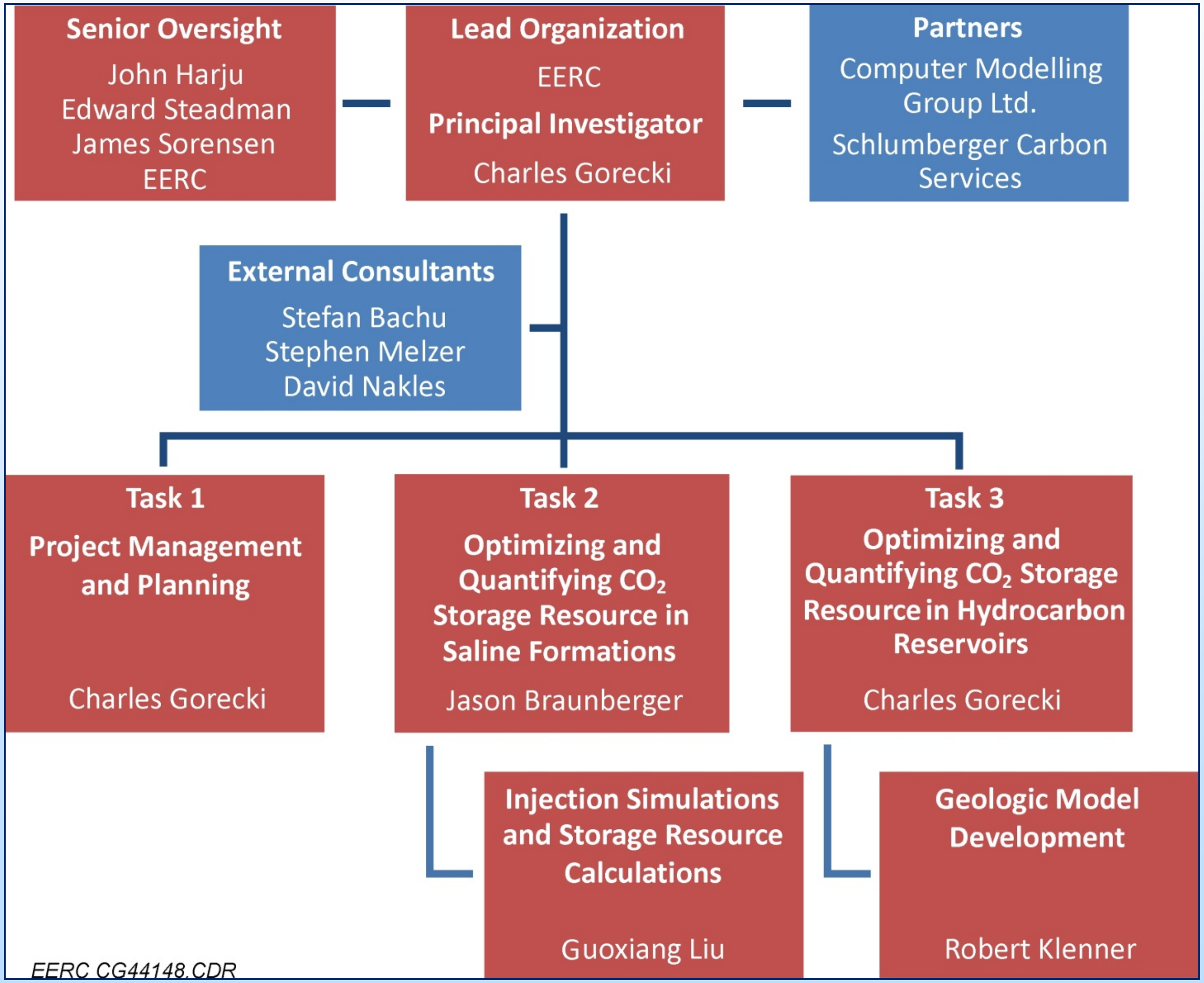
Organizational Chart

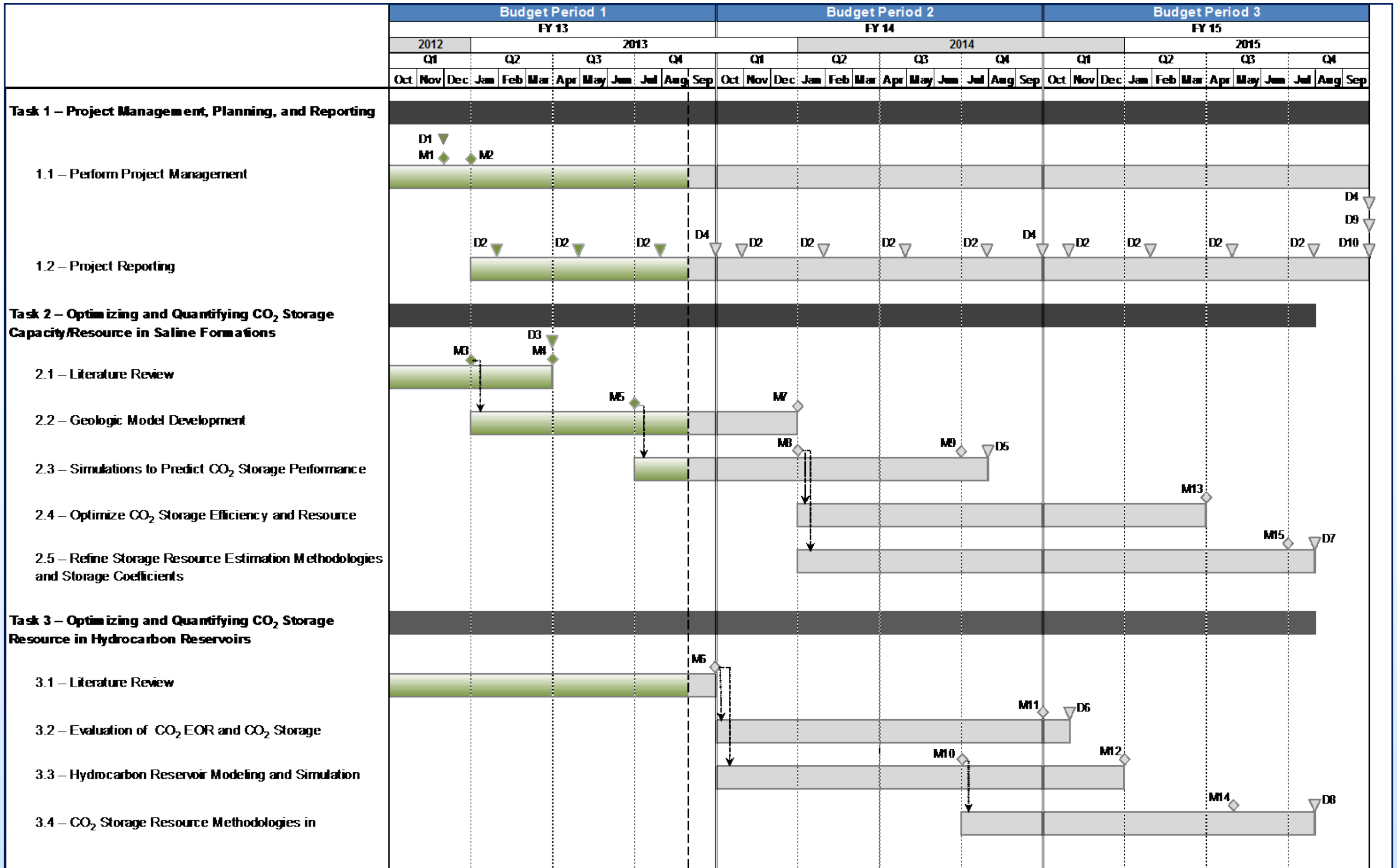


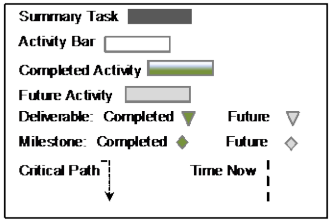
<u>Partners</u>

- Schlumberger and CMG provide software use and technical support.

<u>Consultants assisting with the following</u>:

- Task 2
  - Stefan Bachu
  - David Nakles
- Task 3
  - David Nakles
  - Stephen Melzer





Key for Deliverables (D) ▼
D1 – Updated PMP
D2 – Quarterly Progress/Milestone Report
D3 – Identification of Geologic Formations Selected for Evaluation
D4 – Data Submission to EDX
D5 – Interim Report: Simulation Results for CO_2 Storage Performance
D6 – Interim Report: Balance Between CO_2 EOR and CO_2 Storage
D7 – Manuscript on CO_2 Storage Performance for Submission to Peer-Reviewed Journal
D8 – Manuscript on the Balance Between CO_2 EOR and CO_2 Storage for Submission to Peer-Reviewed Journal
D9 – Best Practices Manual on Optimizing and Quantifying CO_2 Storage Resource in Saline Formations and Hydrocarbon Reservoirs
D10 – Final Report

Key for Milestones (M) ◆
M1 – Updated Project Management Plan Submitted to DOE
M2 – Project Kickoff Meeting Held
M3 – First Saline Formation Selected
M4 – Saline Formations Literature Review Completed
M5 – First Geologic Model Completed
M6 – CO_2 EOR and Associated Storage Literature Review Completed
M7 – All Geologic Models Completed
M8 – First Injection Simulation Completed
M9 – Simulations to Predict CO_2 Storage Performance Completed
M10 – First CO_2 EOR and Storage Simulation Completed
M11 – Reservoir Evaluations Completed
M12 – Field- to Pattern-Sized Geologic Models Completed
M13 – Simulations to Optimize CO_2 Storage Efficiency Completed
M14 – Examination and Refinement of Storage Capacity and Incremental Hydrocarbon Production Completed
M15 – Evaluation and Validation of Estimation Methodologies Completed

Bibliography

No publications to date.

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