Stacked Greenfield and Brownfield ROZ Fairways in the Illinois Basin Geo-Laboratory: Co-optimization of EOR and Associated CO_2 Storage

DOE Project Number DE-FE0031700

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U.S. Department of Energy
National Energy Technology Laboratory
2020 Carbon Storage Virtual Project Review Meeting

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Program Overview

- Funding: $4,373,828
  - DOE Share: $3,455,947
  - Cost Share: $ 917,881
- Project Performance Dates: 2/1/19 to 1/31/23
- Project Participants:
  - University of Illinois – Illinois State Geological Survey (Prime)
  - Podolsky Oil Co.
  - Projeo Corp.
  - Indiana Geological and Water Survey

Program Overview

Objectives

DOE Program

- Develop specific subsurface engineering approaches leveraging CO_2 injection field tests and applied research and development, that address research needs critical for advancing CCS to commercial scale

Stacked ROZ Fairways in ILB Geo-Laboratory

- Screen for ROZs using analysis of empirical data and basin evolution modeling
- Characterize stacked brownfield/greenfield siliciclastic ROZs at field laboratory sites
- Conduct injection tests and collect and analyze core and logs at field laboratory sites
- Employ calibrated simulation models and life-cycle analyses for identifying development strategies

Technical Approach
Project Milestones

Milestones provide success criteria for gaging the qualitative and quantitative performance of the project and are decision points to determine if the project should proceed.

BP: Task	Milestone title	Planned completion	Actual completion	Verification method
BP 1 Task 1	Complete project management plan	03/01/2019 (year 1)	03/01/2019	PMP file
BP 1 Task 1	Project kickoff meeting	02/01/2019 (year 1)	11/06/2018	Presentation file
BP 2 Task 4	Finalize plan for data collection and testing at greenfield laboratory sites	07/31/2020 (year 2)	7/31/2020	Report in subsequent quarterly report
BP 2 Task 5	Finalize plan for data collection and testing at brownfield laboratory sites	04/30/2020 (year 2)	11/28/2019	Report in subsequent quarterly report
BP 2 Task 5	Complete testing of fluid and core samples of target CO_2 reservoir(s) from field laboratory sites	03/01/2021 (year 3)		Report in subsequent quarterly report
BP 3 Task 6	Complete strategies for co-optimization of CO_2-EOR and storage in stacked reservoirs (w/ROZs and depleted reservoirs)	01/31/2022 (year 3)		Report in subsequent quarterly report
BP 3 Task 6	Complete fairway maps	10/31/2022 (year 4)		Report in subsequent quarterly report
BP 3 Task 1	Document project results	01/31/2023 (year 4)		Submit final report

Technical Approach

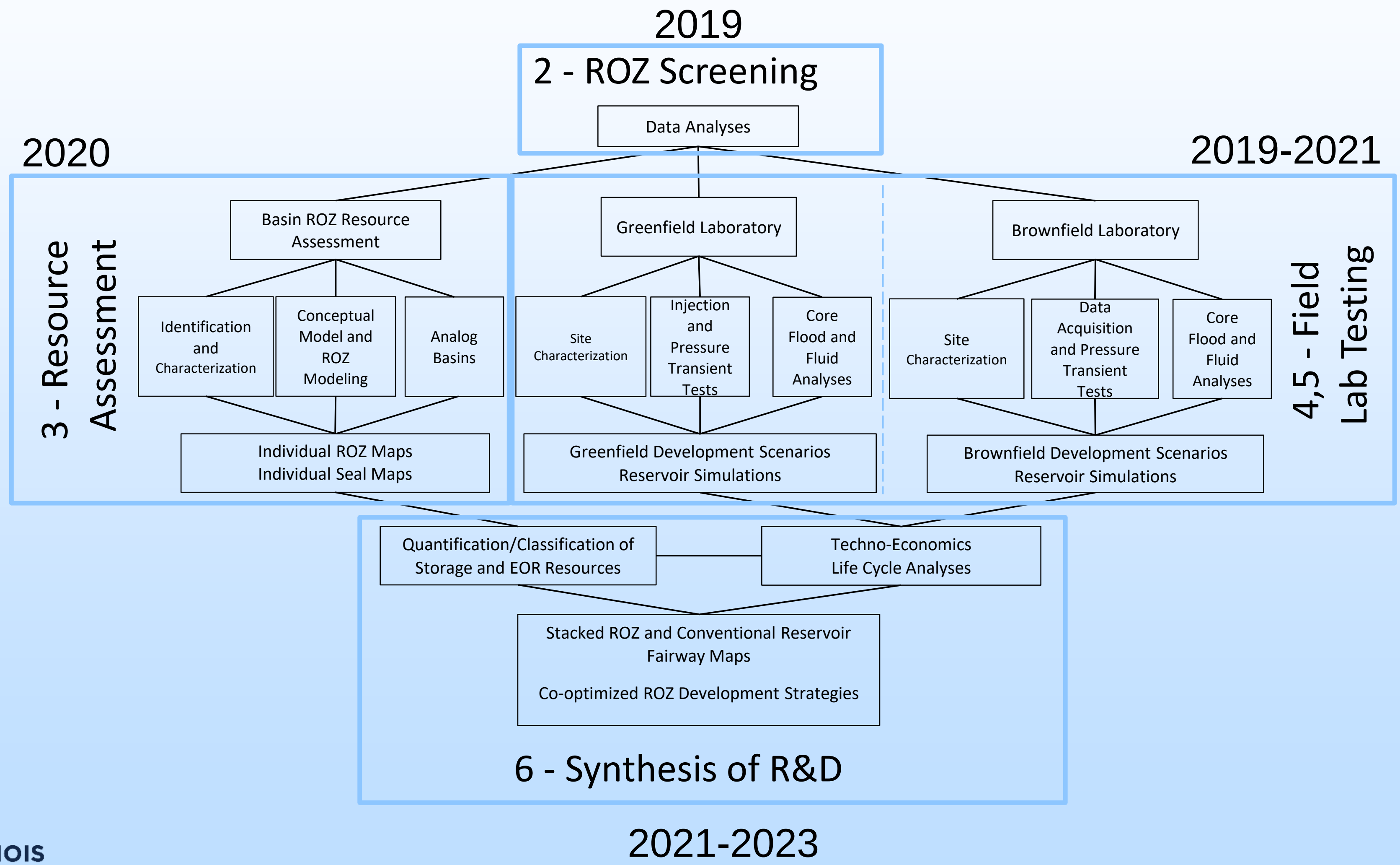
Risk Matrix

The risk matrix is used to identify, assess, monitor and mitigate technical uncertainties and schedule, budgetary and environmental risks associated with the project

Perceived Risk	Risk Rating (Low, Med, High)			Mitigation/Response Strategy
	Prob.	Impact	Overall	
Financial Risks:				
Field laboratory test budget exceeded	Low	Med	Low	If additional cost occurs due to the delay of field personnel or equipment issues, change in duration or number of ROZs tested would be reduced
Cost/Schedule Risks:				
Delay in field activities due to severe weather condition	Low	Med	Low	A project meeting would be held among research team and field personnel to reschedule and reprioritize tasks
Technical/Scope Risks:				
Delay in acquiring data	Low	Med	Low	Assemble and digitize existing ISGS and literature data to provide preliminary estimates and update data when available
Injection test failure due to a well integrity	Low	Med	Low	Identify analogous wells within the field operated by the same company

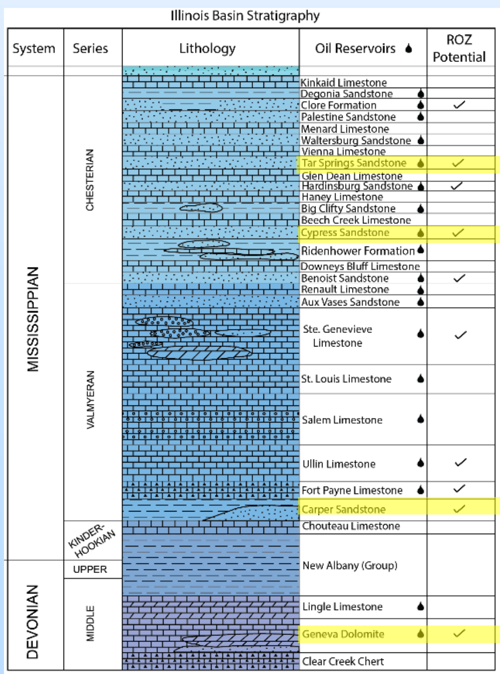
Perceived Risk	Risk Rating (Low, Med, High)			Mitigation/Response Strategy
	Prob.	Impact	Overall	
Management Risks:				
Occasional unavailability of personnel	Med	Low	Low	If staff time is mandatory to keep on schedule, non-project staff will be available to work on project temporarily.
Loss of key personnel	Low	Med	Low	Temporarily allocate tasks among team and initiate hire
Planning and Oversight Risks:				
Well cannot be drilled in year 2 due to rig availability or weather	Low	Low	Low	Greenfield lab schedule will be moved up and switched with the brownfield schedule
EH&S Risks:				
Field laboratory sites in environmentally sensitive areas	Med	Med	Med	Use existing infrastructure and non-invasive sampling and testing techniques
External Factor Risks:				
An operator becomes unavailable to facilitate data collection and testing in the field laboratory	Low	Med	Med	Coordinate with backup operators at other suitable field laboratory sites

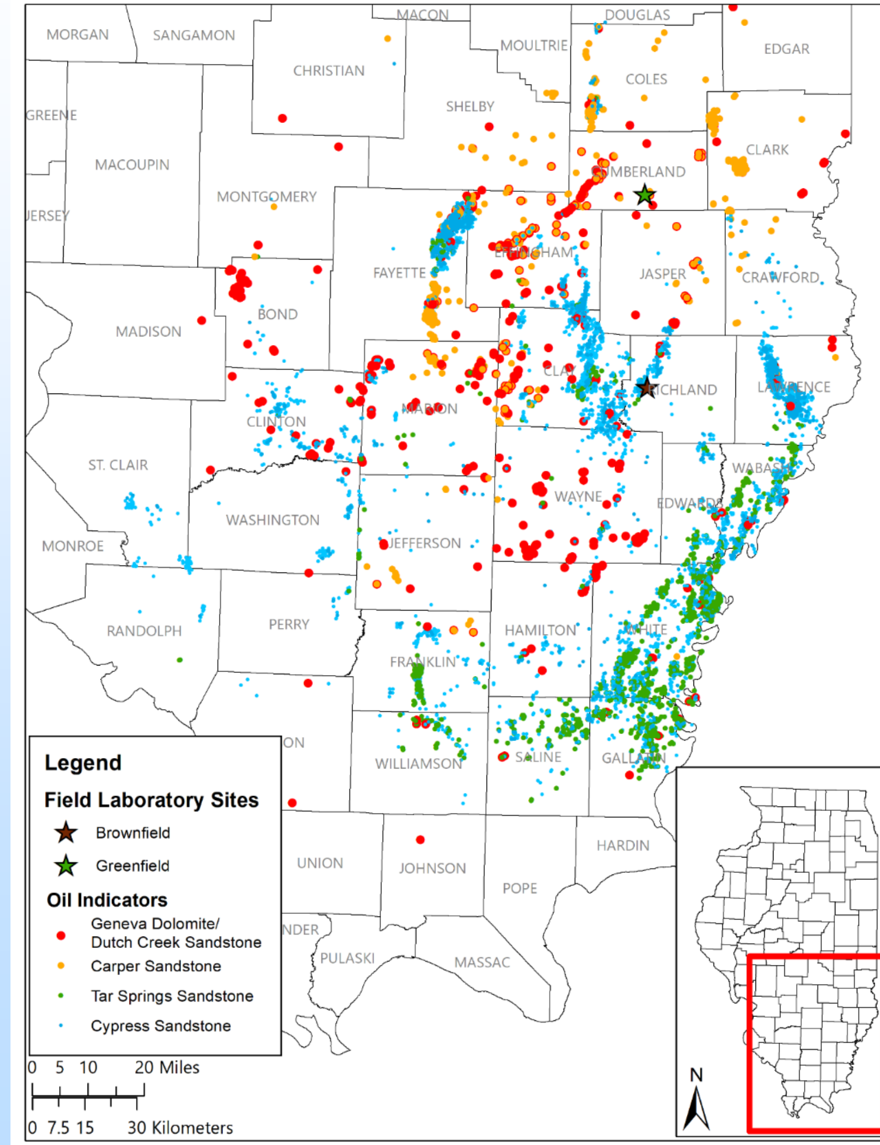
Project Tasks



ROZ Screening

- Selected four formations for regional characterization based on:
  - Geologic properties (porosity, permeability, fairway potential)
  - ROZ indicators (oil shows, core with S_o>0, DSTs with sulfur water – e.g. Trentham and Melzer 2013)
  - Data availability (well logs, core)





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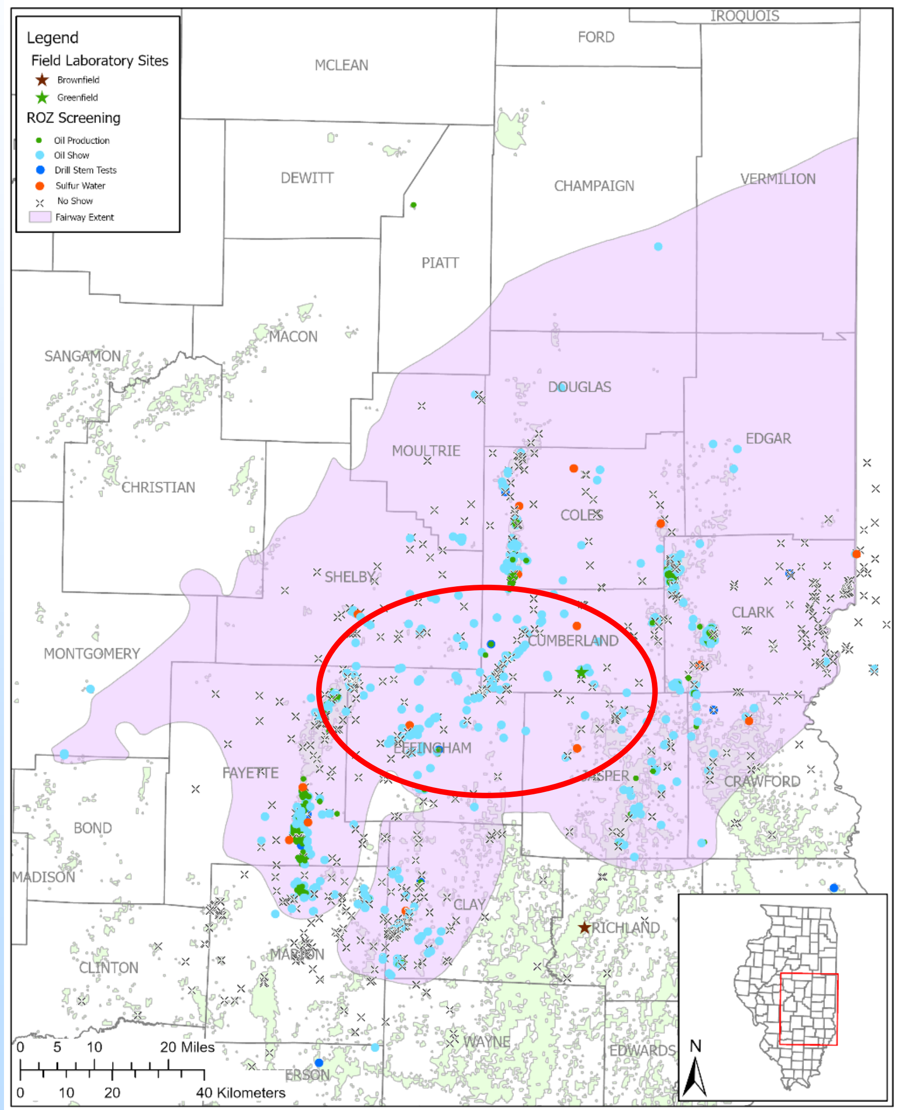
Resource Assessment

Identifying and characterizing ROZs in selected formations

- Identification based on historical data
- Characterization using well log analysis
  - Constrain parameters by formation for log analysis
    - Input: R_w, porosity, *m*, clay properties
    - Output: POWC, OWC, S_{or}
  - Extrapolate OWC and S_{or} to prospect boundaries to estimate OOIPs

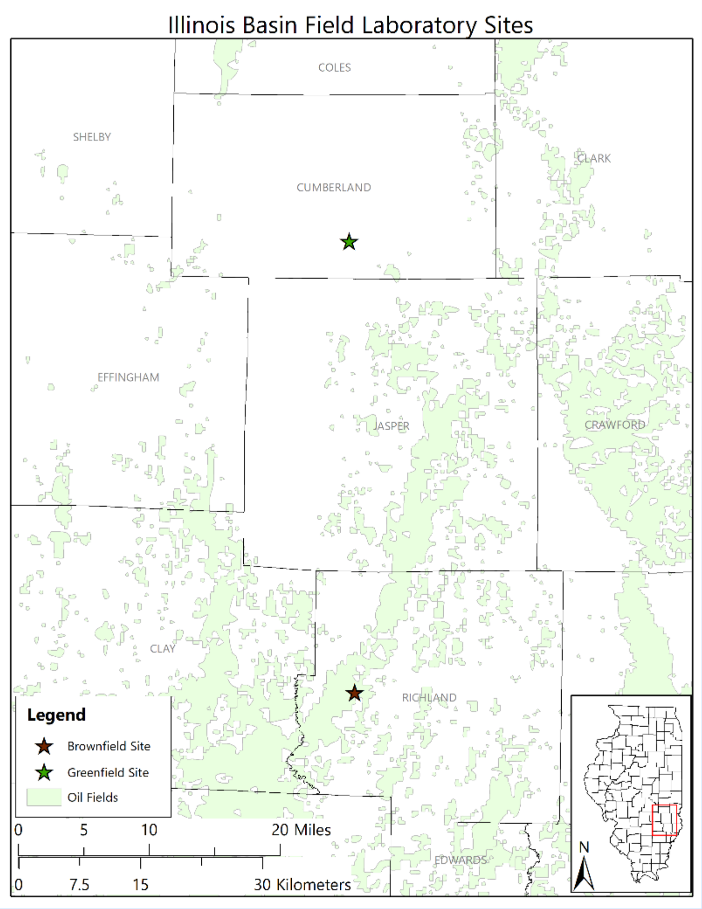
Carper Sandstone



Field Laboratory Tests

Greenfield Site

- Performing pressure transient tests in existing well with validated greenfield ROZ
- Conduct short term CO_2 injection test (huff n' puff) to acquire oil rate change
  - Characterize ROZ
  - Demonstrate efficacy of CO_2-EOR in ROZ
- Field work ongoing through remainder of 2020



Brownfield Site

- Drilled new well for reservoir characterization
  - Collected core and logs to validate Cypress ROZ
    - Correlating with previous field laboratory RST logging
    - Investigating geologic controls on residual oil saturation
    - Refining geologic interpretation
  - Sampled reservoir fluids
  - Performed drill stem test
- Field work completed fall 2019

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Greenfield Test: Challenges

Well: Drilled in 2016 to Carper Ss., ~6 months of pumping with minimal oil production

- Observed fluid production (~200 bbls/day) not possible (15' perforated zone; 0.2 mD)
  - Suspect natural fracture network
- Reservoir simulations indicate single-well CO_2 huff n' puff will increase oil rate to 1-2 bbl/day
  - Injected CO_2 will likely remain in fractures and have limited contact with oil in low permeability matrix
  - High pressure could stimulate production, but quickly depletes once injection stops
  - Uncertainty in fracture/matrix communication hard to quantify

Greenfield Test: Simulations

Base model

- Natural fracture model to match historical water production
- Include negative skin and molecular diffusion

HnP

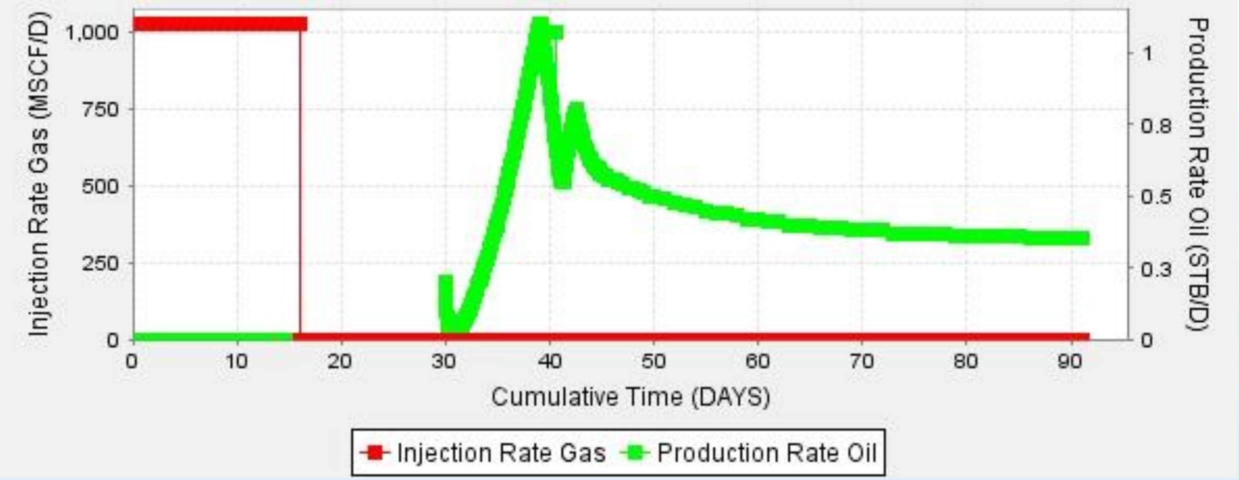
- Analyze sensitivity of injection rate and duration, soak period, water injection on oil response
- Design limits and recommendations

Line drive

- Predict field-scale response

Greenfield Test: Simulations

- Higher rate and volume is desired
- Given 60 t/d, total 1,000 t CO_2, injection duration and soak time had little effect on oil response
- Two cycles of HnP could be beneficial



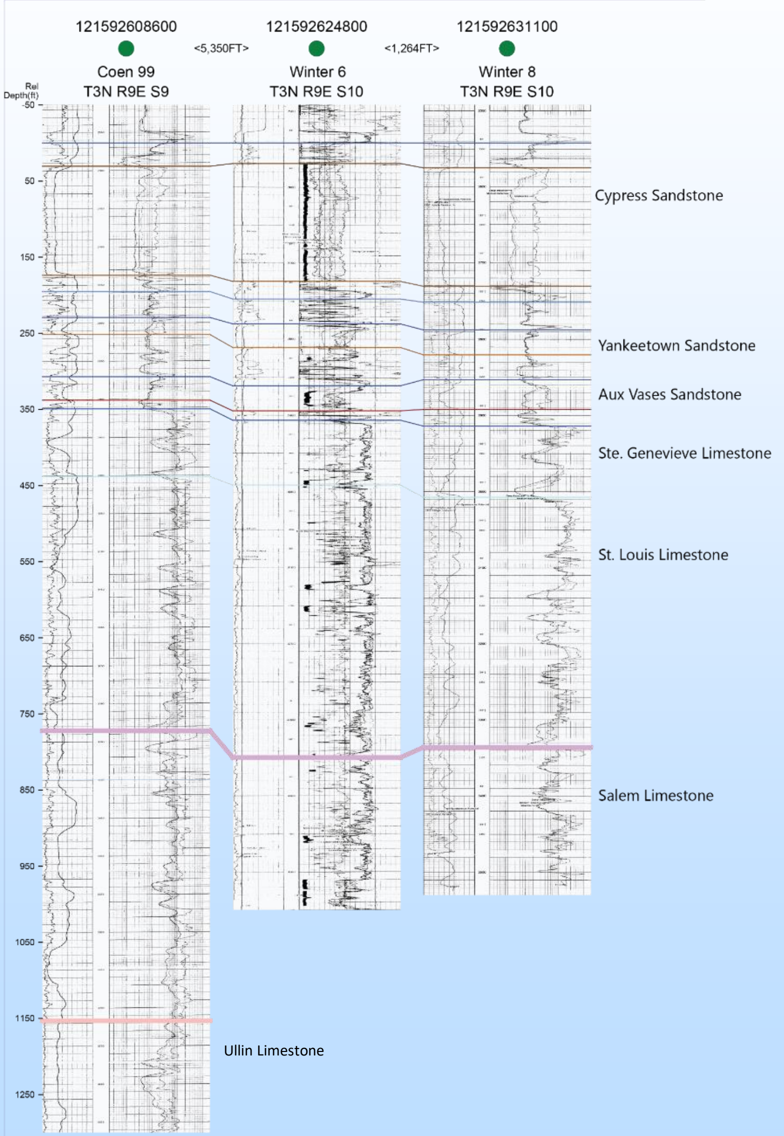
Scenarios	Injection time (d)	Cumulative injection (tonne)	Peak oil rate (stb/d)	Cumulative oil at 1-mont production (stb)
14-day soak	16	960	1.1	15
	8	480	1.1	13
	4	240	1.1	11
7-day soak	16	960	1.2	17
	8	480	1.2	14
	4	240	1.2	12

Greenfield Test: Design

- Pressure transient test
  - Attempt to confirm natural fracture network and determine if it permits communication between units
- Huff n' Puff
  - Design to maximize oil rate increase
    - Use equipment from previous ISGS CO_2-EOR project
    - Inject volume of CO_2 that the budget allows (~1000 tons) at pump capacity (~60 tons/day)
  - Use findings to improve reservoir simulations to see if higher injection rate, more volume, more injectors would yield more oil

Brownfield Lab: Characterization

- Analyzing core and logs collected in 2019
- Correlating and mapping stacked ROZs and conventional reservoirs
  - Seven producing reservoirs; additional formations with oil indicators



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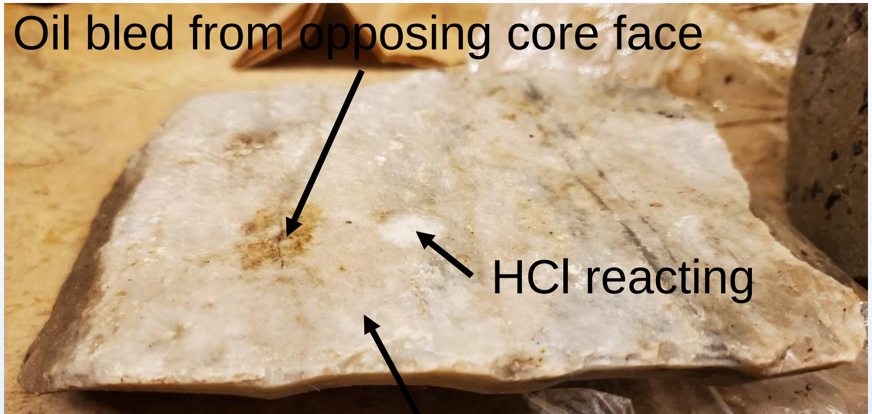
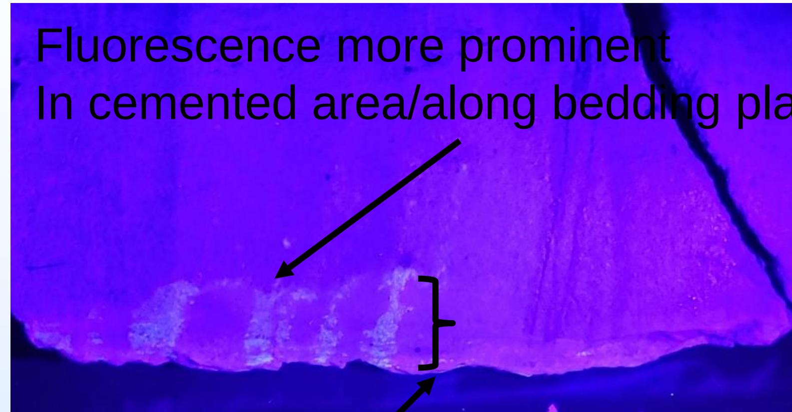
Brownfield Lab: Characterization



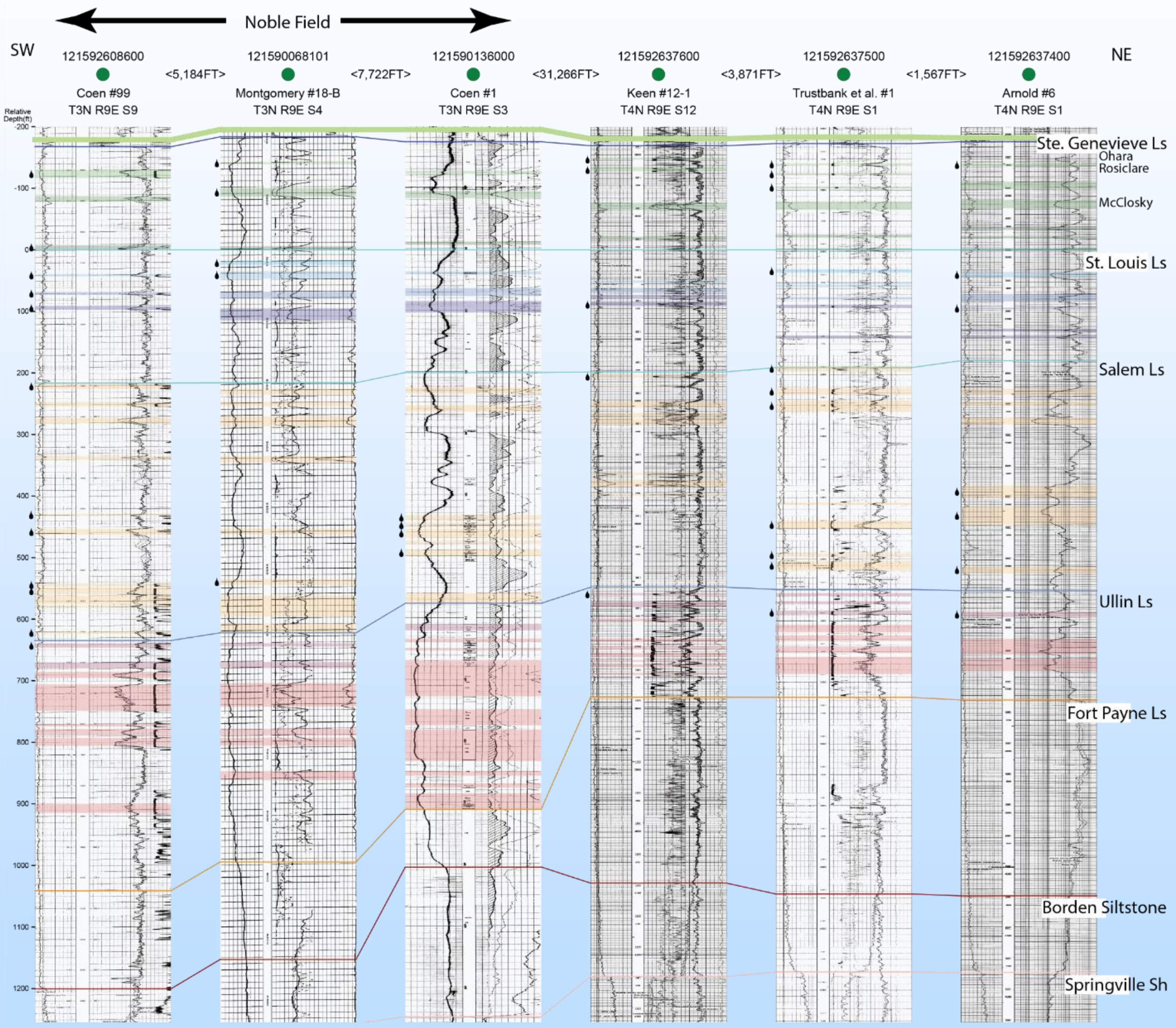


~0.5” halo of calcite cement along fracture

Face of fracture has frosted appearance

Bleeding oil

Brownfield Lab: Characterization



Field Labs: S_O Determination

- Used log analysis to estimate S_o for oil bearing intervals to populate stacked reservoir models
- Greenfield
  - Lower Penn, Cypress, Carper, Geneva have potential greenfield ROZs
- Brownfield
  - Cypress, Aux Vases, Ste. Genevieve, St Louis, Salem, Ullin all produce oil at Noble
  - Calculations rely on modern logs which capture depleted reservoir
  - Compare to dielectric logs at CW10 to validate

Field Labs: Stacked ROZ potential

Greenfield

Data: GR, Induction, Porosity logs ; Core through Carper Ss

Formation	Depth (ft)	Saturated Thickness (ft)	Saturation
Penn	1,650	25	20%
Cypress	2,300	40	30%
Carper	3,550	20	20-30%
Geneva	4,050	40	

*oil saturation occurs over multiple non-contiguous porosity zones

Brownfield

Data: GR, Spectral, Induction, PNL Porosity, Sonic, Dielectric, FMI; Core through Cypress Ss

Formation	Depth (ft)	Saturated Thickness (ft)	Saturation
Cypress	2600	25	40%; 25%
Aux Vases	2900	10	30-40%
Ste. Genevieve	3000	15	30%
St. Louis	3150	15*	30-60%
Salem	3350	40*	20-40%
Ullin	3700	10	40%

Field Labs: Stacked Reservoir Modeling

- Perform pressure pulse modeling to assess reservoir connectivity within stacked formations to determine
  - Model representation of conceptual geology
  - Viability of each formation for CO_2–EOR and associated storage

Approach

- Water injection
- Perform 9-spot pattern modeling
  - A centrally located injector and 8 observation wells
  - 10-, 40-, and 80-acres pattern sizes

Results:

- Reservoir connectivity decreases with increasing pattern size and porosity cutoff in discreet carbonate reservoirs

Synergy opportunities

- Methodologies for finding and characterizing ROZs in mature basins developed as part of this study are applicable in other basins
  - We look forward to comparing the results with findings from the Williston and Powder River Basins
- Siliciclastic ROZs in other basins are expected to have similar characteristics to Illinois Basin ROZs
  - Lessons learned from CO_2 flooding in siliciclastics in the Powder River Basin would be applicable to our ROZs

Project summary

Key Findings

- Selected ILB formations have oil indicators outside of productive areas and potential for ROZs
- Reservoir simulations indicate 1,000 t CO_2 huff n’ puff will increase oil rate to 1-2 bbl/day in 15’ thick, low perm Carper Ss.

Lessons Learned

- Field laboratory research requires extra attention to detail to:
  - Reconcile schedule (project vs. operator vs. weather), meet **all** stated objectives, stay on budget

Future Work

- Complete regional characterization of selected ROZs
- Complete analysis of Brownfield core and logs
- Complete field laboratory research
  - Design injection test for greenfield site

Acknowledgments

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- Through a university grant program, IHS Petra, Geovariences Isatis, and Landmark Software were used for the geologic, geocellular, and reservoir modeling, respectively
- For project information, including reports and presentations, please visit:

  http://www.isgs.illinois.edu/research/ERD/NCO2EOR

Appendix: Benefit to the program

- Goal: The Storage Infrastructure Technology Area research effort is carrying out regional characterization and small- and large-scale field projects to demonstrate that different storage types in various formation classes, distributed over different geographic regions, both onshore and offshore, have the capability to permanently store CO_2 and provide the basis for commercial-scale CO_2 projects. This, working together with the two other research areas, address significant technical challenges in order to meet program goals that support the scale-up and widespread deployment of CCS.
- Benefits Statement: This research will potentially demonstrate CO_2 -EOR and associated storage as an economically feasible option for small-middle size operators in the Illinois Basin and drive demand for CO_2 and investment in infrastructure.

Appendix: Project Overview

Goals

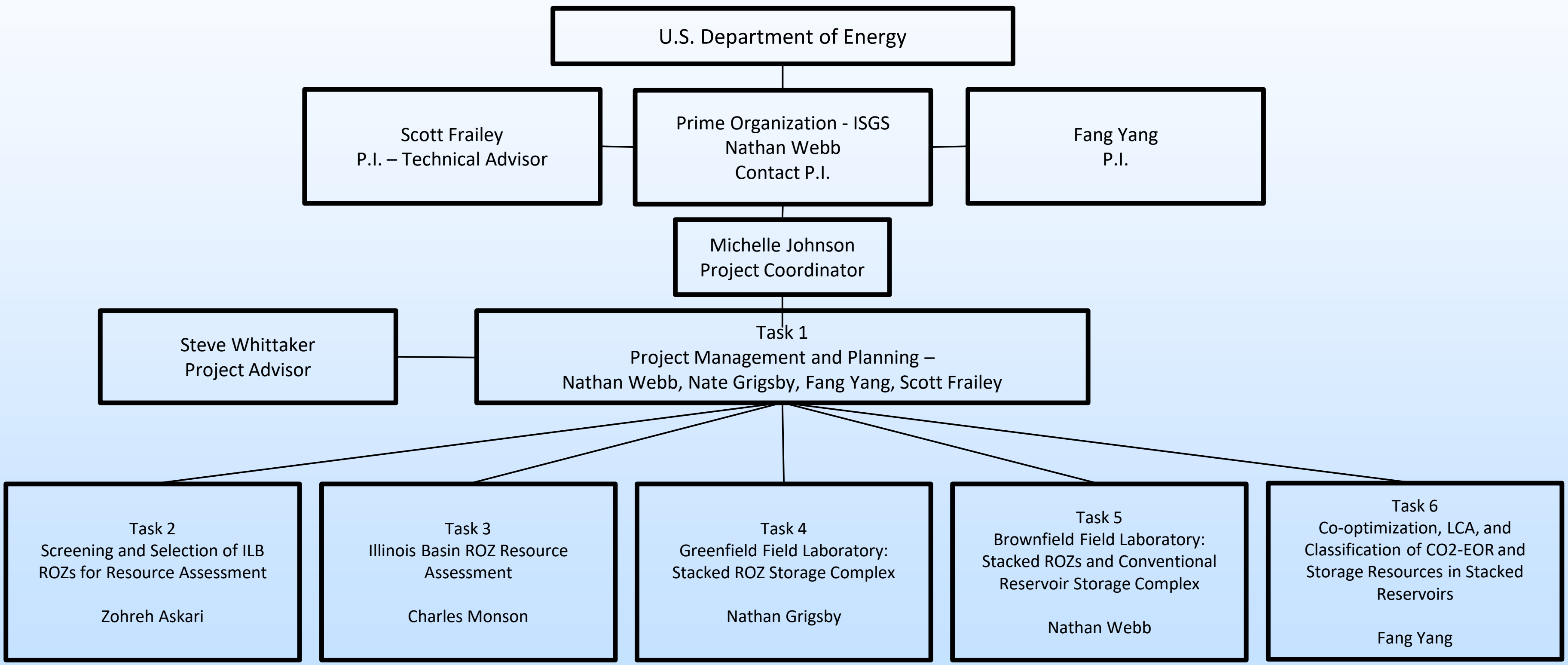
DOE Program

- ROZs:- formation, characterization, and associated storage in conjunction with EOR
- Co-optimizing CO_2-EOR with associated storage in storage complexes that have stacked reservoirs

Stacked ROZ Fairways in ILB Geo-Laboratory

- Identify and characterize primarily siliciclastic ROZs and quantify the CO_2-EOR and associated storage resource using data collected and test results from greenfield and brownfield field laboratory sites
- Design economic development strategies to co-optimize CO_2-EOR and associated storage in stacked storage complexes using reservoir simulations calibrated to field laboratory test results

Appendix: Organization chart



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Appendix: Gantt chart