Integrated Wellbore Integrity Analysis Program for CO_2 Storage Applications: Project Results

DE-FE0026585

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U.S. Department of Energy

National Energy Technology Laboratory

Mastering the Subsurface Through Technology Innovation, Partnerships and Collaboration: Carbon Storage and Oil and Natural Gas Technologies Review Meeting

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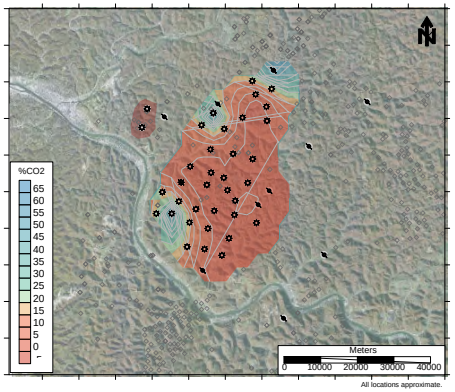
Presentation Outline



1) Technical Status
   - All technical tasks complete, project ends Sept. 2018.
2) Accomplishments to Date
   - Evaluated subsurface conditions at 3 field sites with CO_2 wells.
   - Surveyed 1,500 CO_2 wells at field sites, measured casing pressure in 53 wells, tested 23 wells for sustained casing pressure buildup.
   - Evaluated potential for geochemical cement sealing based on subsurface conditions at the 3 field sites and 4 test study areas.
3) Lessons Learned
   - No significant well defects exhibited in the subsample of wells tested, geochemical cement sealing potential was not very sensitive to subsurface conditions at field sites, tested wells had high construction standards.
4) Synergy Opportunities
5) Project Summary

- Appendix Material

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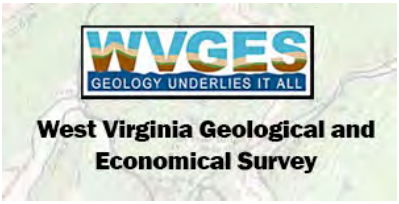
Acknowledgements

- The project was funded by the U.S. DOE / National Energy Technology Laboratory under their program on technologies to ensure permanent geologic carbon storage (Contract DE-FE0026585).
  Project Manager – William O'Dowd, NETL.
- Project team includes Battelle (Lead), Core Energy, West Virginia Geologic and Economic Survey (WVGES), Petroleum Technology Resource Center (PTRC) for SCP testing and well construction analysis Williston Basin.



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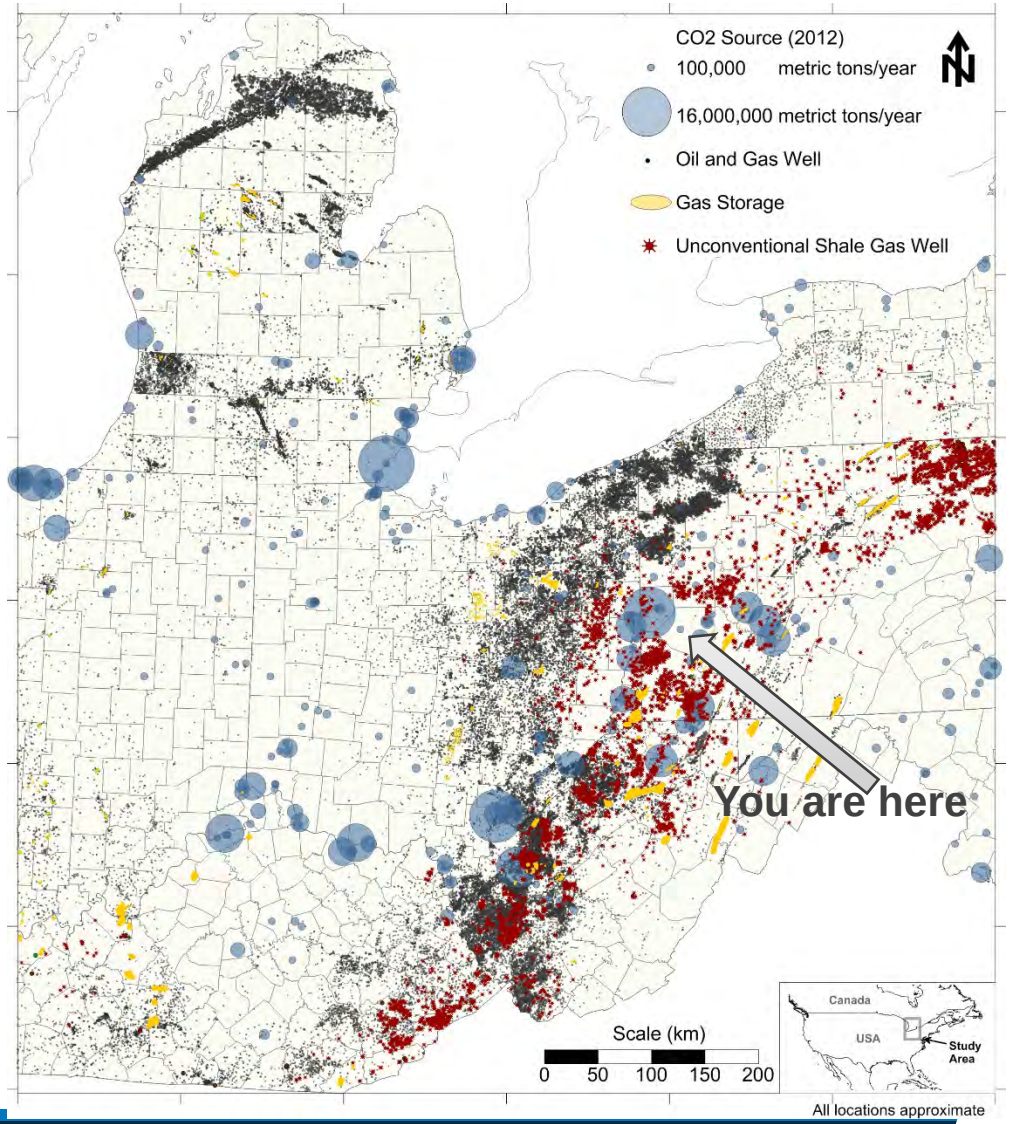
Technical Status- Objectives

- Geologic CO_2 storage may affect legacy oil and gas wells.
- How would exposure to CO_2 in the deep subsurface affect these wells?
- What can we learn from testing and monitoring CO_2 wells?
- Are wells exposed to CO_2 in any better/worse condition than typical oil and gas wells?
- Are subsurface conditions suitable for cement sealing at typical CO_2 storage sites?



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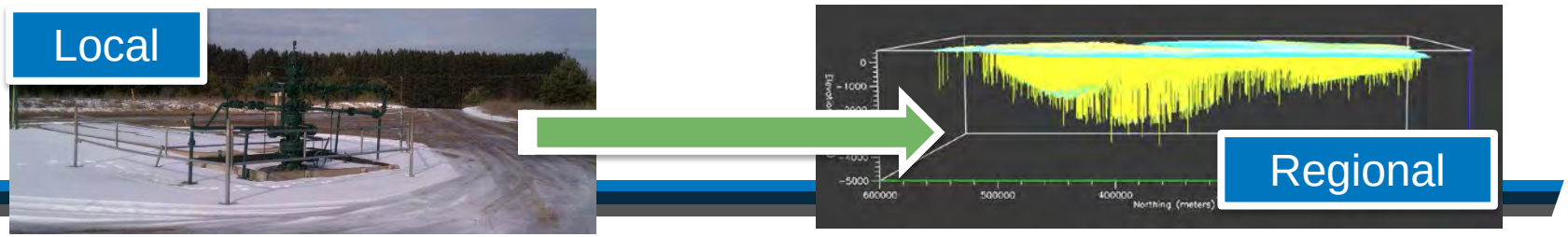
Technical Status- Objectives

- **Objective**: develop & validate a program for identifying and characterizing wellbore integrity in legacy oil and gas wells for CO_2 storage applications based on analytics of well records validated with sustained casing pressure testing.
  1. Determine the nature of well defects, location within the borehole, and severity of the well defects via SCP tests on CO_2 wells.
  2. Integrate results with analysis of wells exposed to CO_2 at study areas in Michigan Basin, Appalachian Basin, & Williston Basin.
- Project results will provide predictive methods to survey, identify, characterize, and manage wellbore integrity for CO_2 storage applications.



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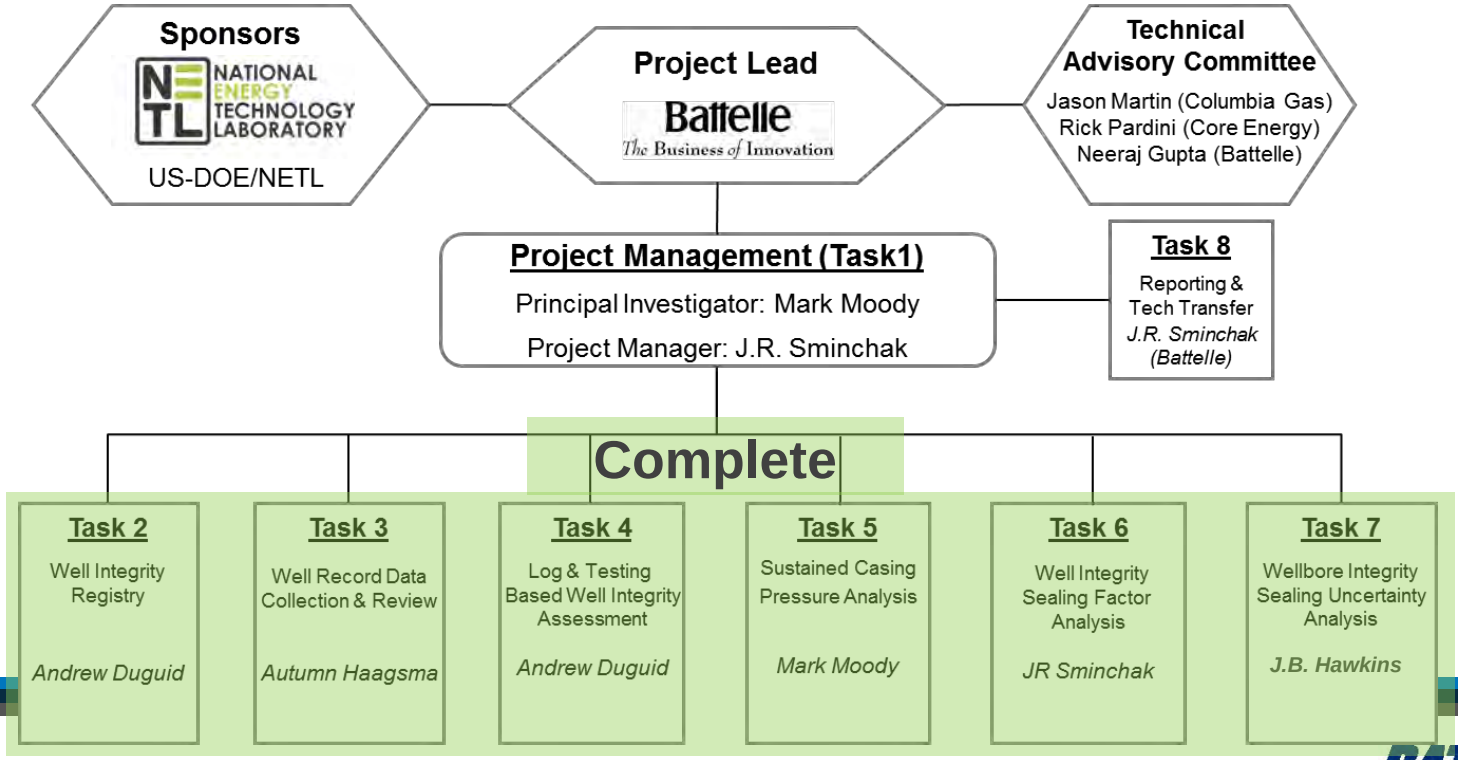
Technical Status- Objectives

- 3 year project from October 2015-September 2018 divided into 6 main technical tasks.
- Project team includes Battelle (Lead), Core Energy, PTRC (well testing in Williston Basin), and the West Virginia Geologic and Economic Survey (WVGES).



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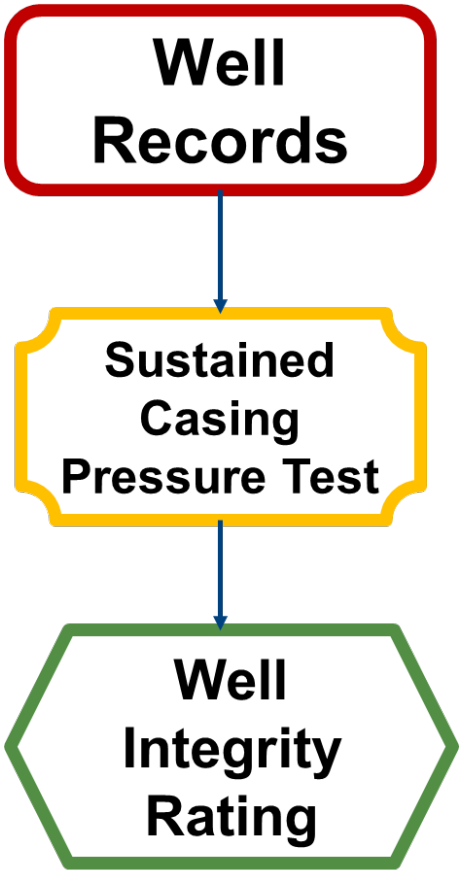
Technical Status- Objectives

- Test selected CO_2 wells at 2-3 sites for sustained casing pressure response.
- Analyze casing pressure buildup to estimate the nature, depth, and severity of well defects. This testing provides direct measurement combined well defects.
- Compare test results to geochemical analysis to understand cement sealing conditions in the subsurface.
- Analyze this information to better understand interactions of legacy boreholes and CO_2 storage in the subsurface.



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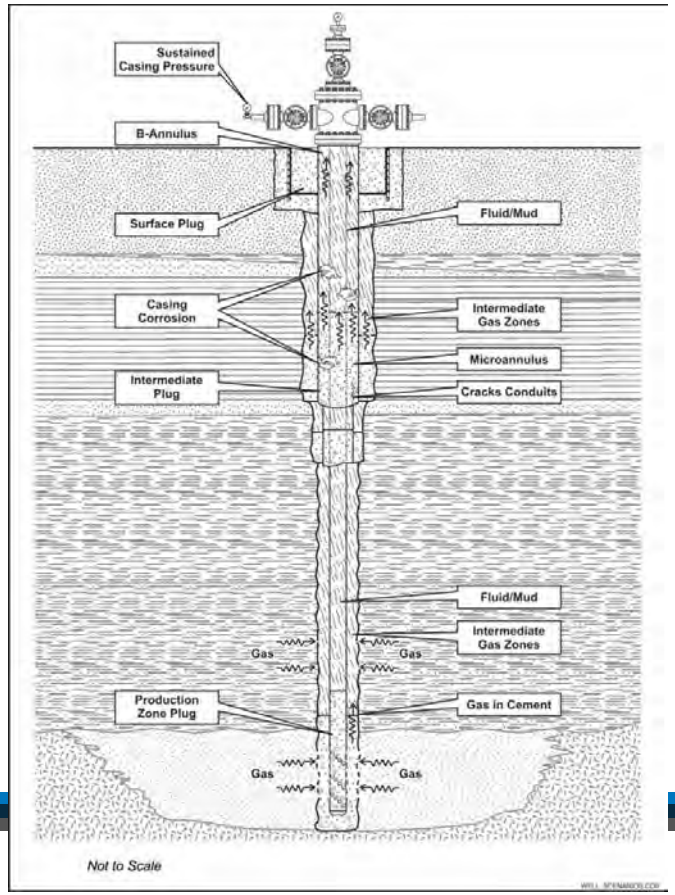
Technical Status- Well Integrity Registry

- Well registry developed to identify wellbore integrity issues, and where and how they occur in the subsurface.
- Many possible types of well defects, combined defects may be expressed as annulus casing pressure at wellhead.



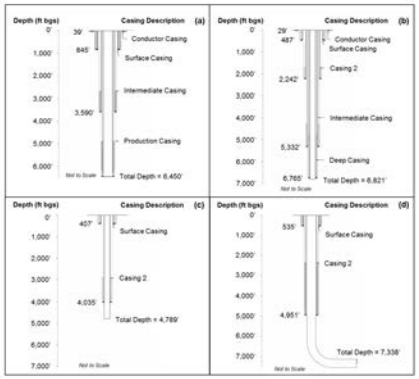
Well Component	Integrity Issue	Description	Causes	When	Leakage Pathway
Casing	Thermo-mechanical cycling	Contraction and expansion of well casing	Differences between properties of materials	Construction, operation, workover, abandonment	Debonding along cement interface (microannulus)
	Wear	Wear to the casing	Casing interactions with wellbore and tools	After drilling, during workovers	Burst, collapse, holes in casing
	Corrosion	Corrosion of casing	Contact with corrosive fluids saturated with CO_2	Construction, operation, workover, abandonment	Holes in casing, cracking
Cement	Degradation	Dissolution or alteration of cement	Contact with corrosive fluids saturated with CO_2	Construction, operation, workover, abandonment	Pores in cement or along degraded cement at interfaces
	Microannulus and cracking	A small gap between casing and cement and cracks in the cement	Casing and cement debond, or bond was never established or was broken	Construction, operation, workover, abandonment	Along casing-cement interface
	Mud contamination	Poor mud removal before cementing	Poor cement job design, poor hole cleanout	During construction	Along interfaces or through bulk cement
	Eccentering	Casing is not centered in the borehole	Poor centralization	During construction	Along casing, cement, or mud interfaces
	Mud channels	Cement slurry fingers through the mud in the annulus	Poor cement job design	During construction	Along mud channel interface or through flowing mud
	Fluid invasion	Invasion of fluids into cement	Poor cement slurry design and loss of hydrostatic pressure	During construction	Poor zonal isolation
Borehole wall (Geologic Processes)	Formation lithology	Borehole breakout and drilling induced fractures	Induced stress greater than maximum of the formation stress	During drilling	Poor cement bond to borehole wall
	Geomechan-ical stresses	Changes in stress field	Pressure gradient changes and creep	Construction, operation, workover, abandonment	Cement and casing damage or failure

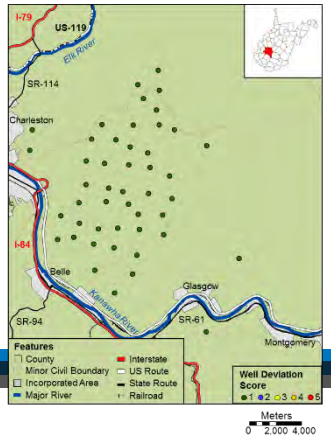
Technical Status- Well Record Data Collection & Review

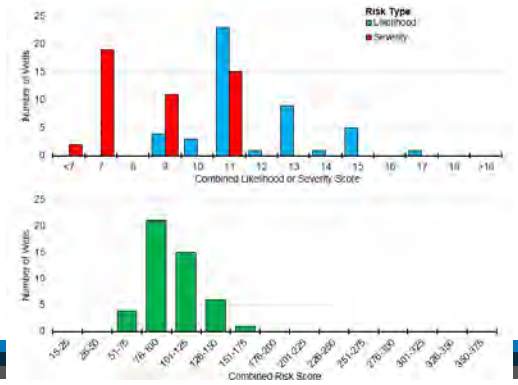
- The 3 field study areas were characterized with a log and testing based process. 5 subtasks defined:

Well Construction	Well Casing	Well Cement	Geologic Processes	CO2 Environments
• Methods • Materials	• Corrosion/wear • Leaks	• Contamination • Defects	• Geomechanical • Geochemical	• Influence of CO2 of cement, casing, etc.

- The 3 field study areas were characterized with this process.







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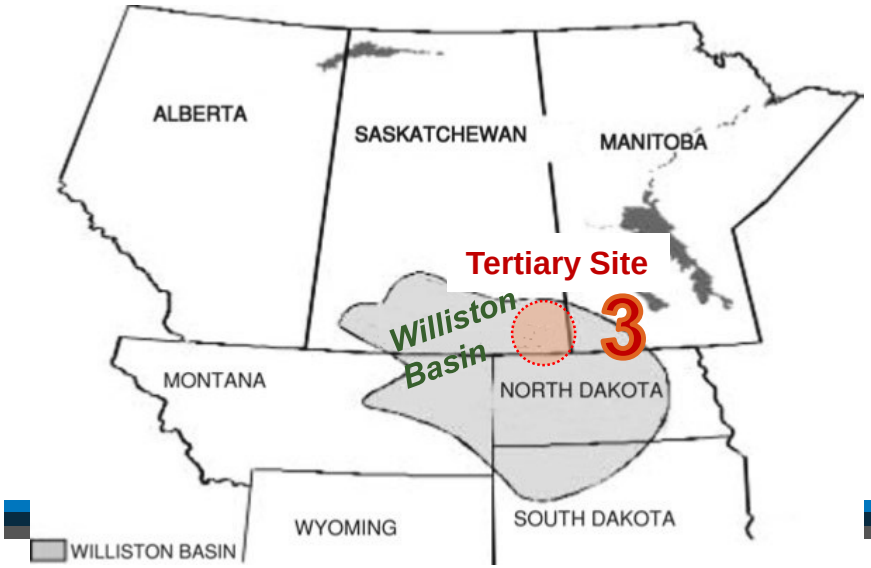
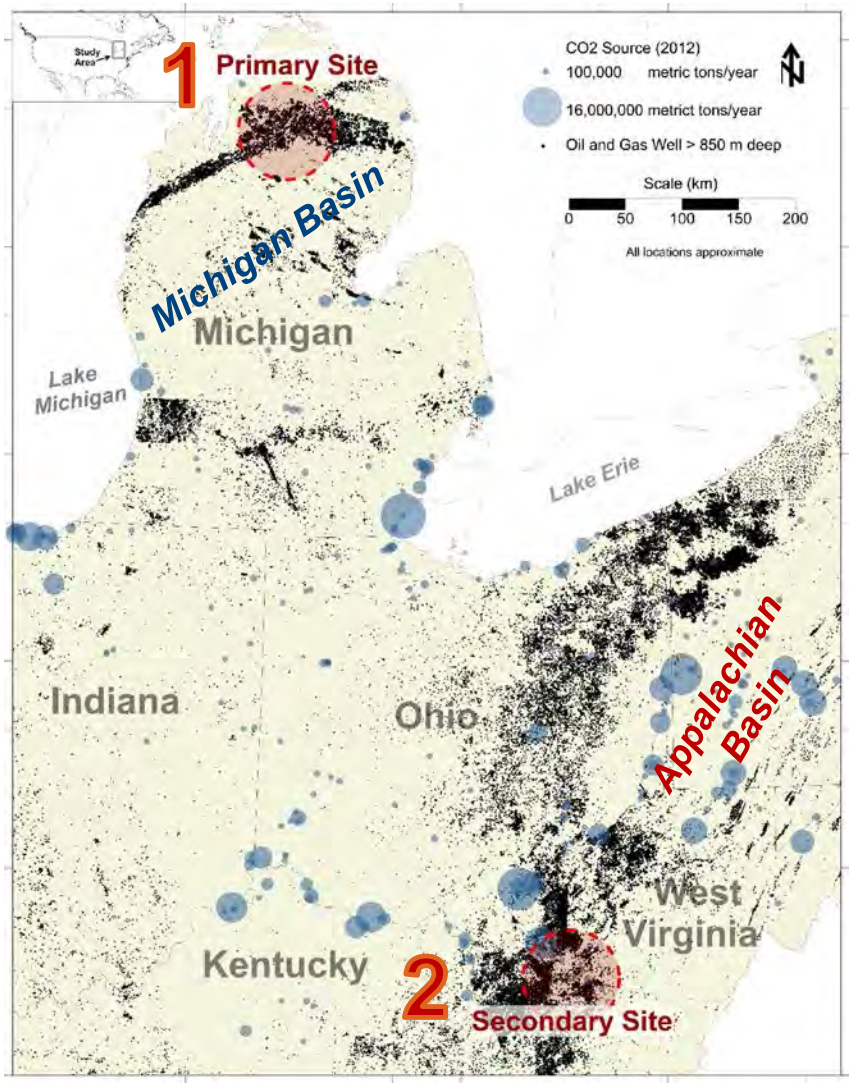
Technical Status- SCP Field Sites

- 3 study areas were examined, because they had existing oil and gas wells exposed to CO_2.
- Study areas were characterized in terms of geology, well construction, field production, & CO_2 exposure.





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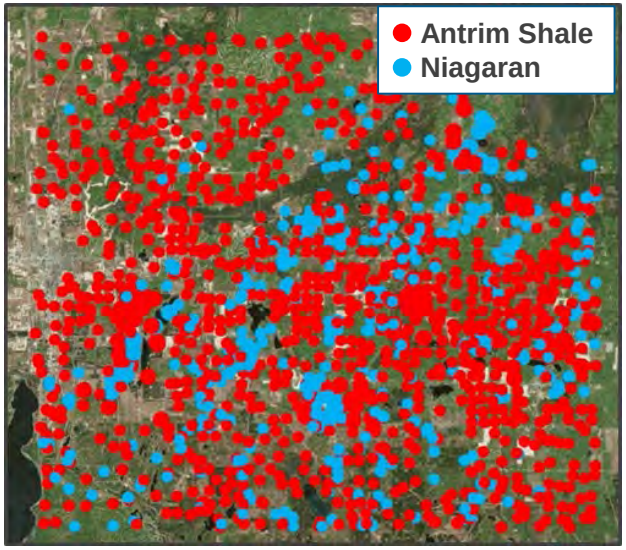
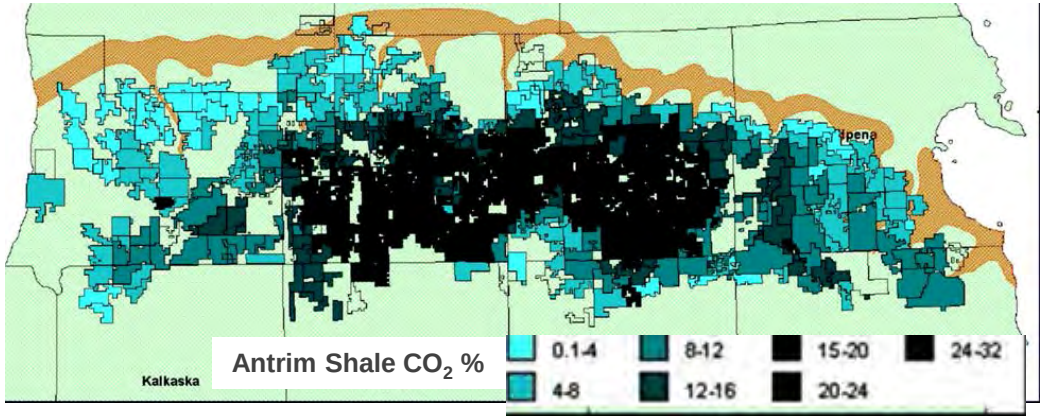
Technical Status- Field Sites

1. Michigan Basin site

- 100's existing wells circa 1960-2016.
- 20-30 wells available in CO_2 EOR fields.
- 5-30% CO_2 in Antrim Shale, 300-500 m.
- 95-99% CO_2 in EOR zone at 1,500-2,000 m.



Antrim Shale CO_2 % in Produced Gas Volume



(Source: Goodman et al, 2014)

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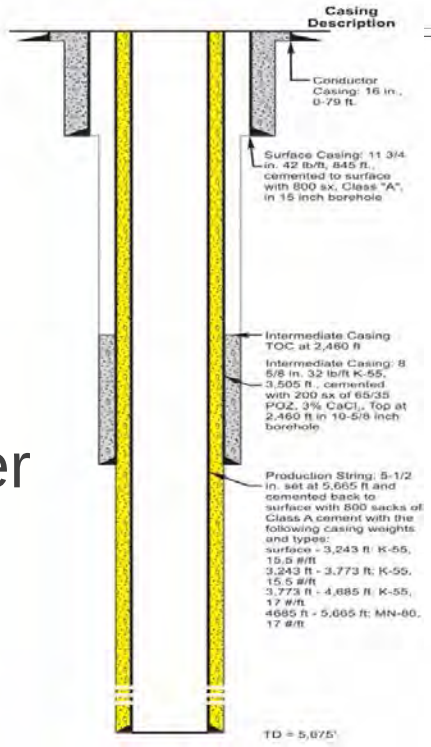
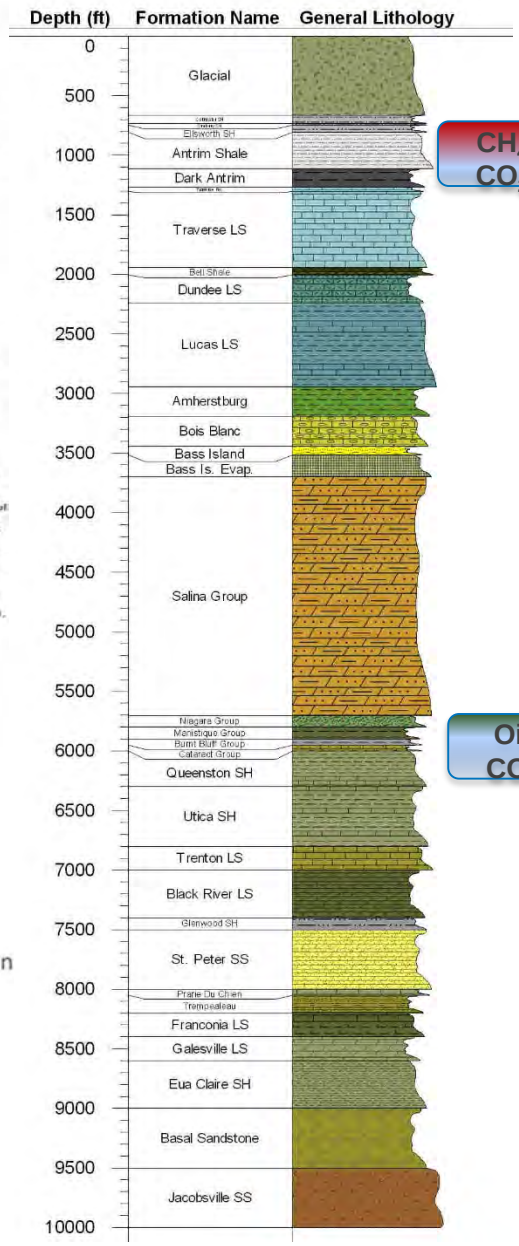
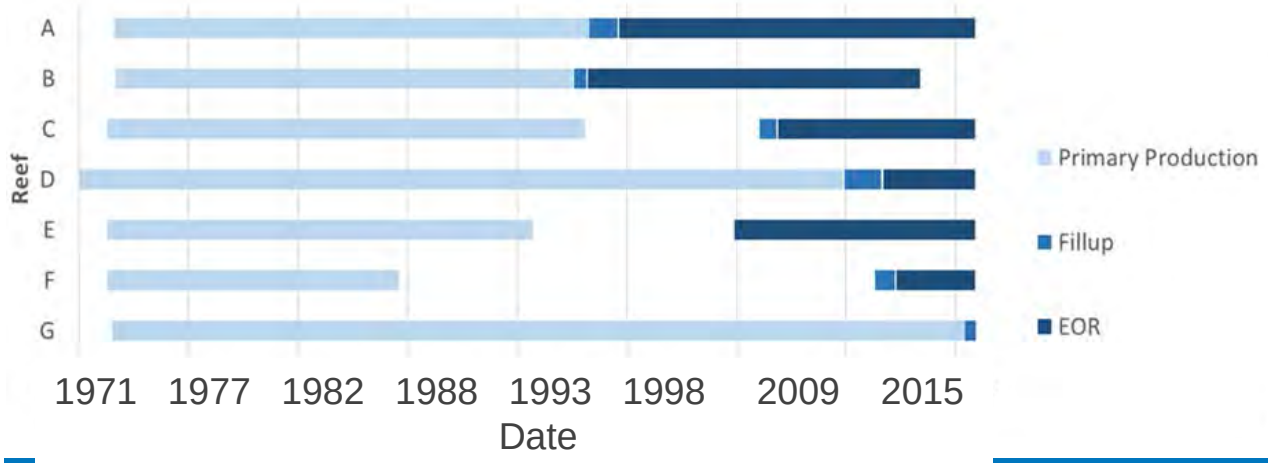
Technical Status

1. Michigan Basin site

- High natural CO_2 levels in a relatively shallow (350 m) shale gas play, and a deeper (1,850 m) carbonate reef CO_2 enhanced oil recovery field.







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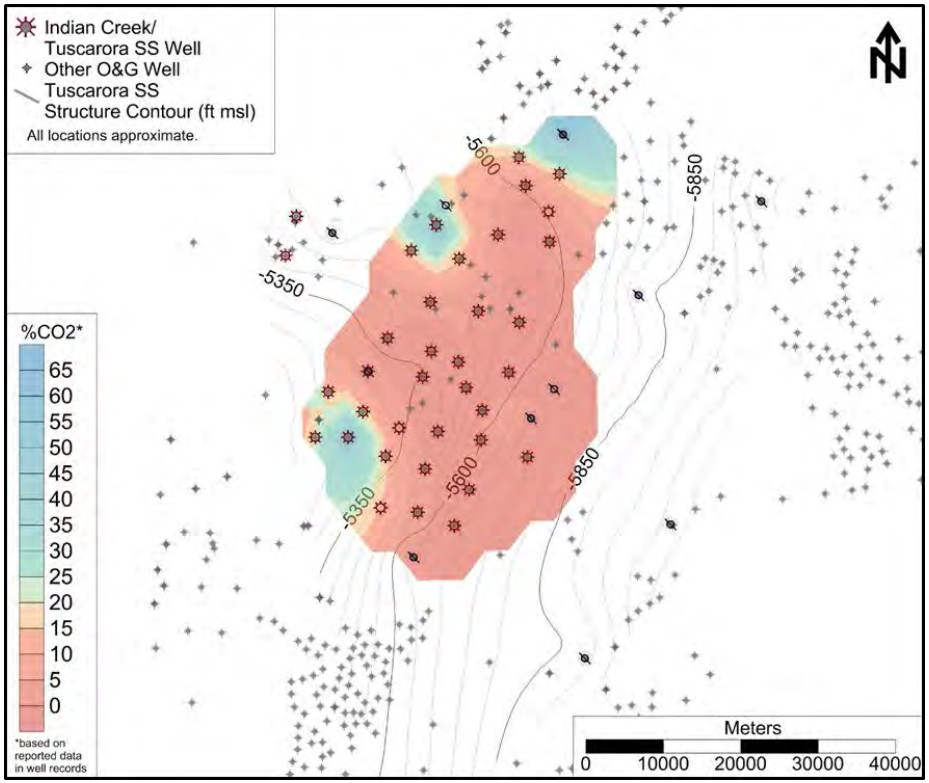
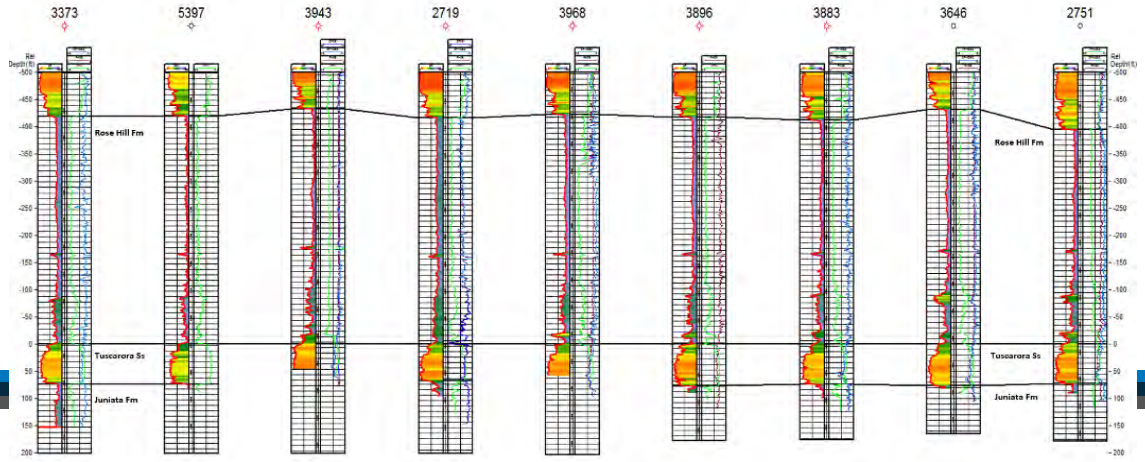
Technical Status

2. Appalachian Basin site

- High <u>natural</u> CO_2 levels in a sandstone reservoir at ~1,900 m depth.
- 20-83% natural CO_2 in areas of the field.
- 58 wells circa 1960-2003.





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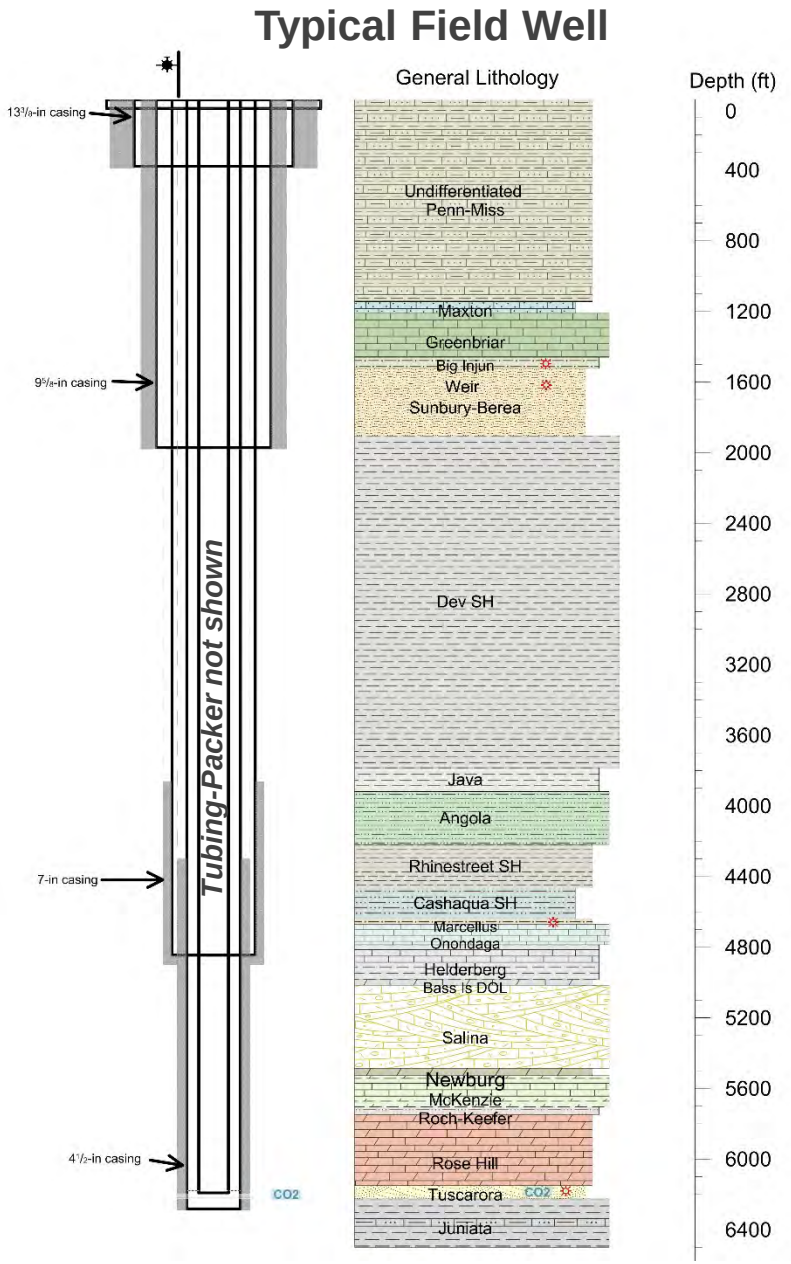
Technical Status

2. Appalachian Basin site

- Wells exposed to natural CO_2 accumulation at depth of 6,200 ft (1,900 m) in the Tuscarora sandstone.



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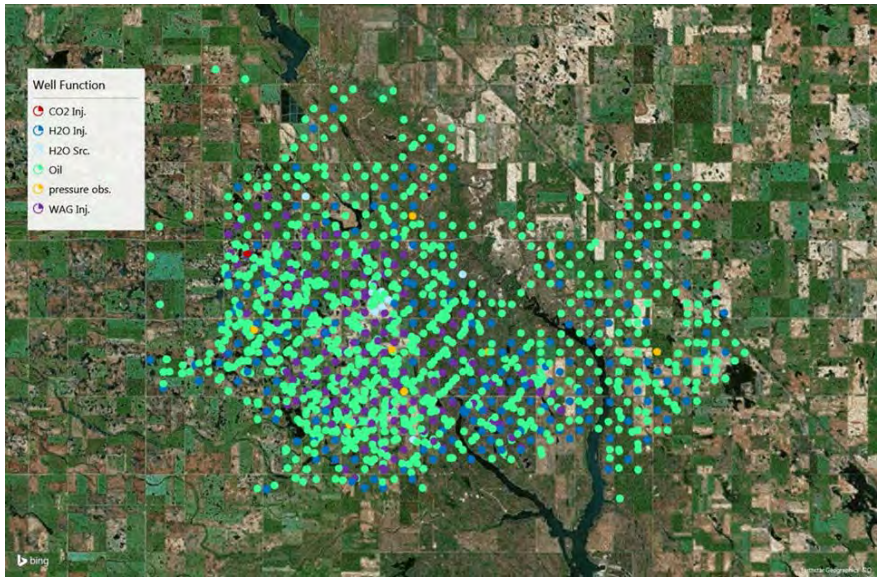
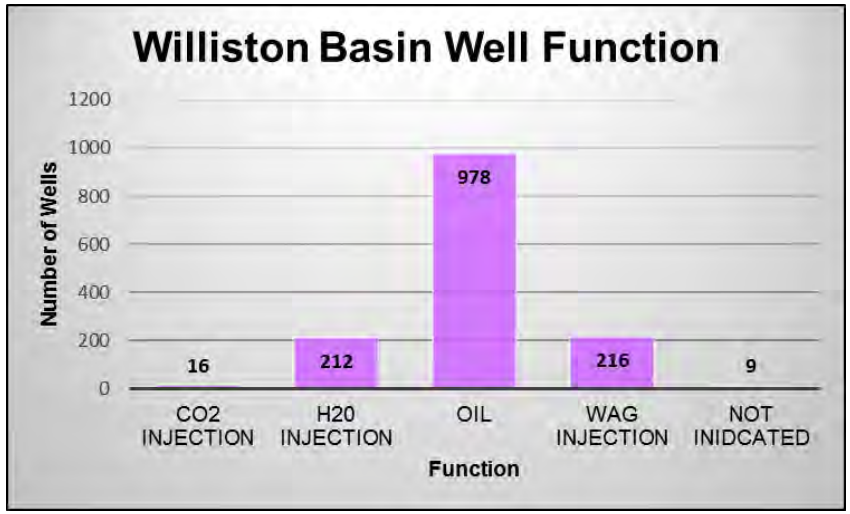
Technical Status

3. Williston Basin site

- ~3,000 wells, and 1,425 were examined in this study.
- The wells were primarily oil producers with select wells used for H_2O or CO_2 injection from 2000-present.
- Well studied site, and previous research was used for most of this sites characterization.





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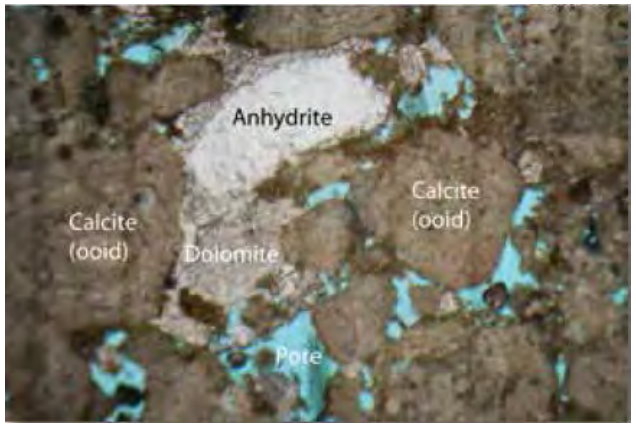
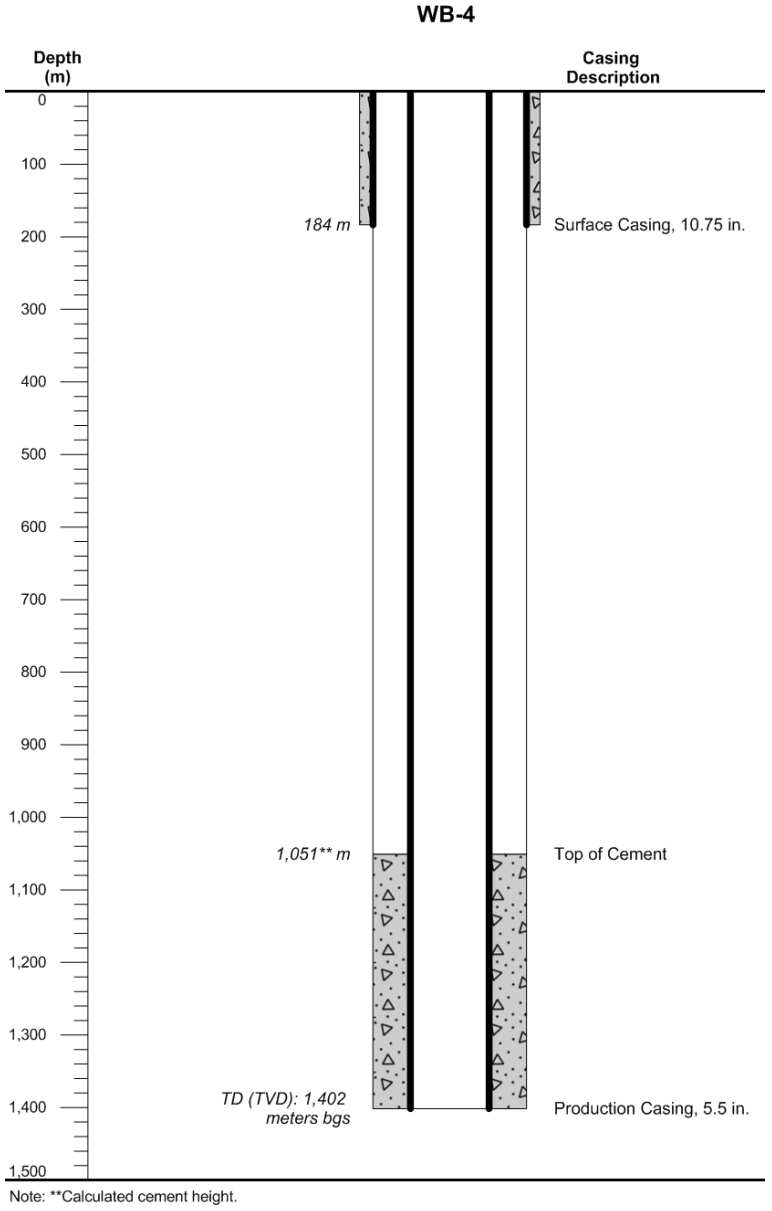
Technical Status

3. Williston Basin site

- Well age ranges from 1950s to 2000s.
- EOR zone at 1,500 m.
- Carbonate reservoir with anhydrite caprock



Williston basin reservoir rock thin section 40X magnification (Braunberger et al., 2012).



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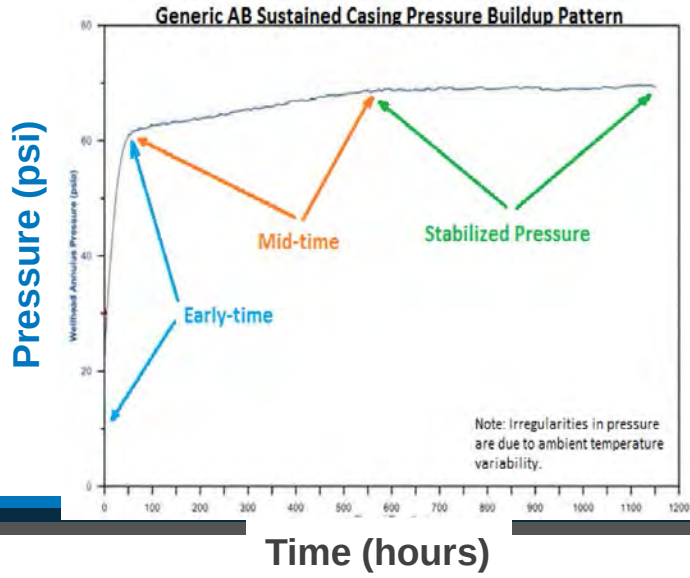
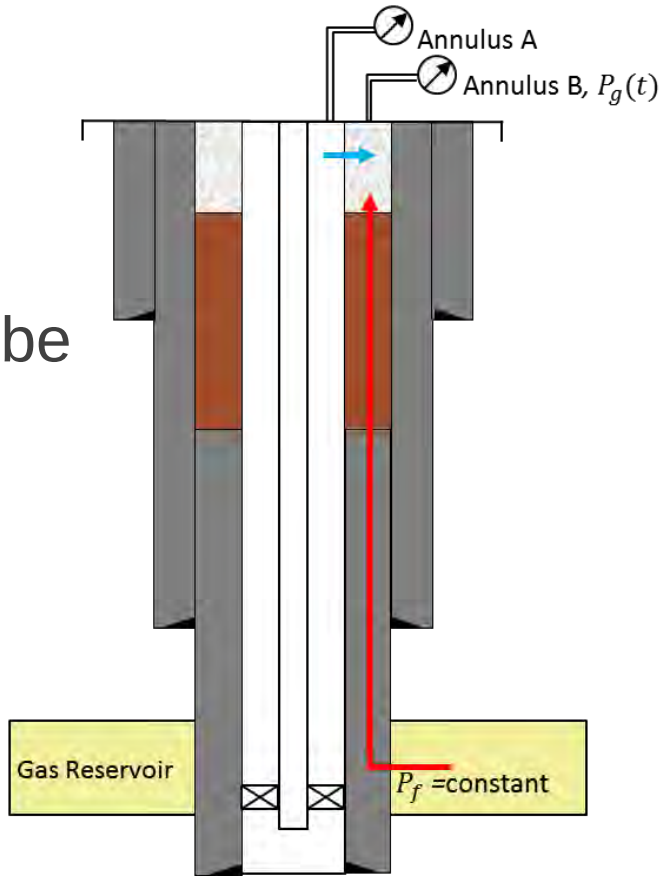
Technical Status- SCP testing

- Well defects may result in “sustained casing pressure” or vent flow gas.
- Gas migrates through casing/cement into deep/production ‘B’ annulus.
- Pressure vs time and rate vs time can be analyzed for information on nature of defect, severity, and location.





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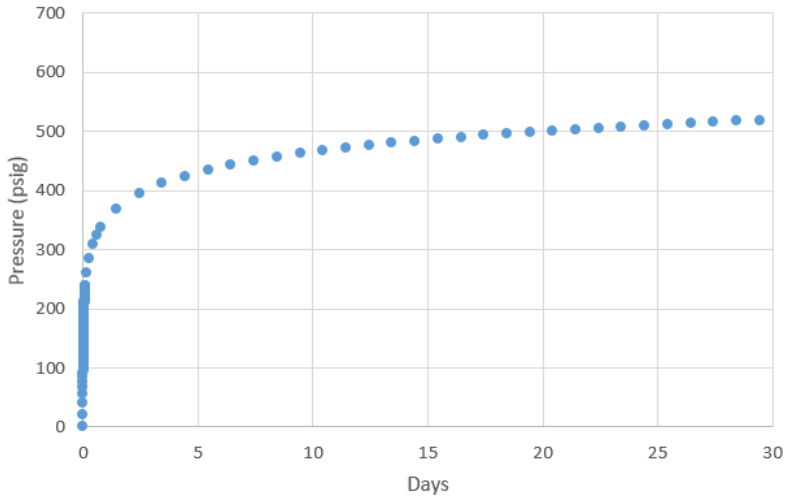
Technical Status- SCP testing

- SCP testing procedure:
  - Confirm wellhead configuration!
  - Measure initial pressure on b-annulus
  - Vent gas and measure gas volume
  - Collect gas sample for analysis
  - Install pressure/temp logger
  - Log pressure build-up (1-8 weeks)
  - Remove logger
  - Analyze results
- No interruption in well operations!

Ex. Pressure Build-Up Monitoring



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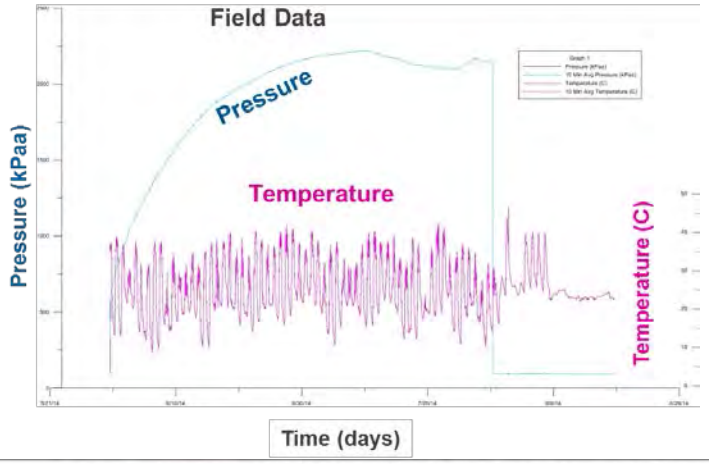
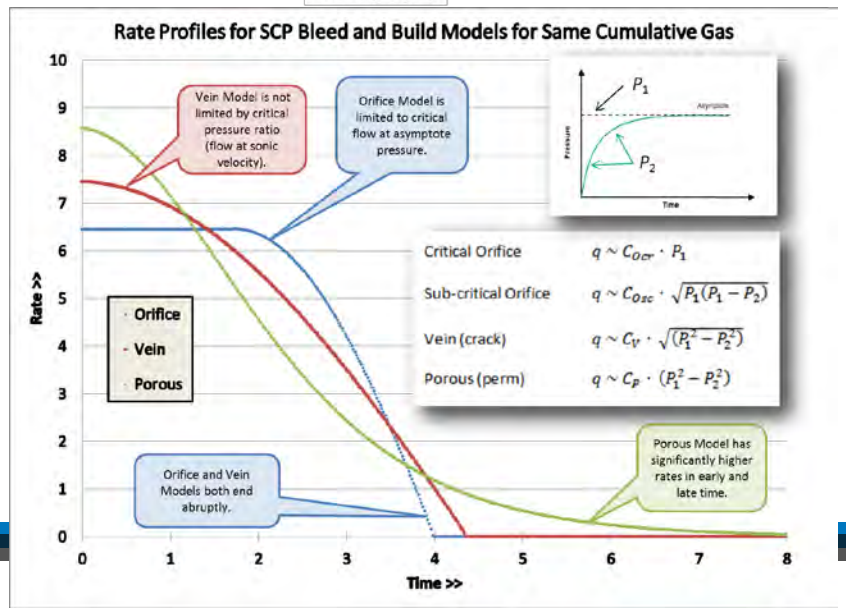
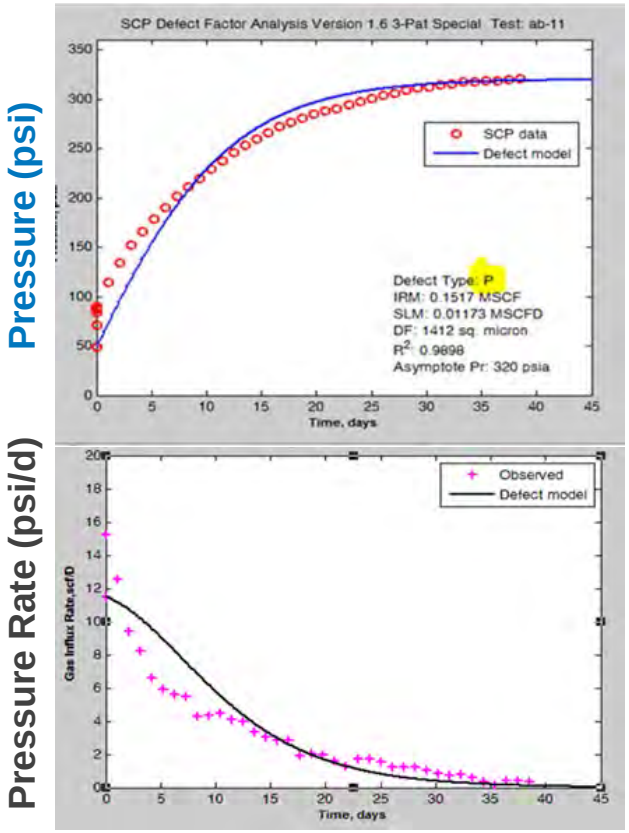
Technical Status- SCP testing

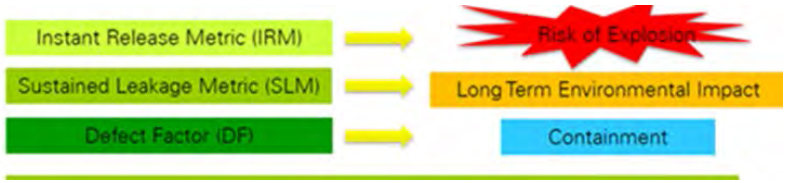
- SCP Rate change model analysis





Rate Change Model





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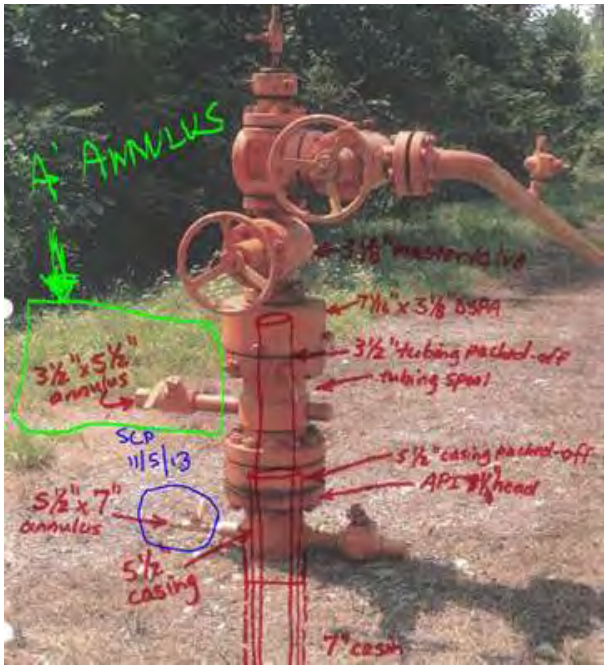
Technical Status- SCP testing

- SCP testing equipment and methods are fairly routine for gas storage field operators.



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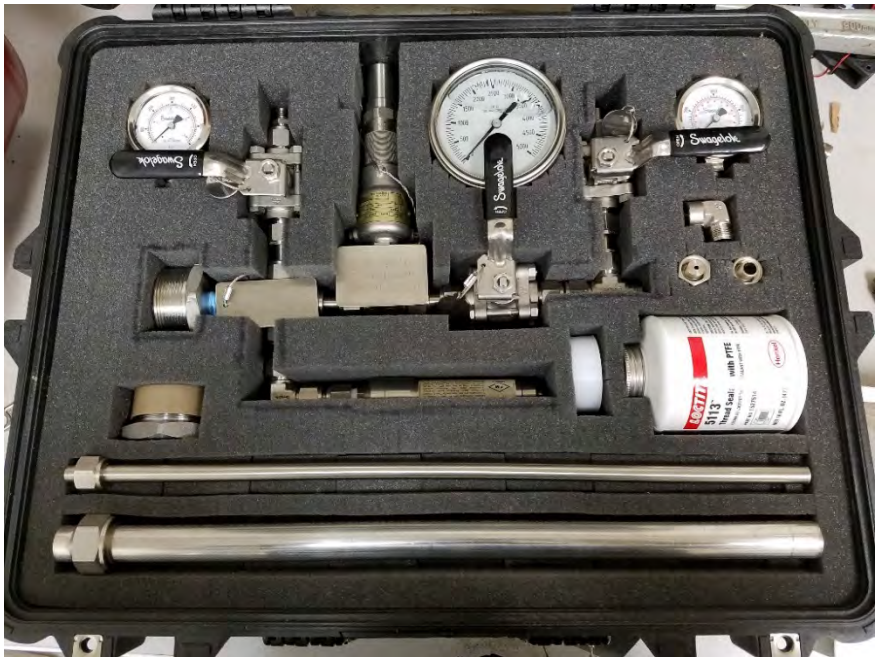
Technical Status- SCP testing

- Sustained casing pressure testing kits were constructed to test wells using methodology by Dotson et al., 2015.
- Allows operators to test many wells exposed to CO_2.



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Technical Status- SCP testing

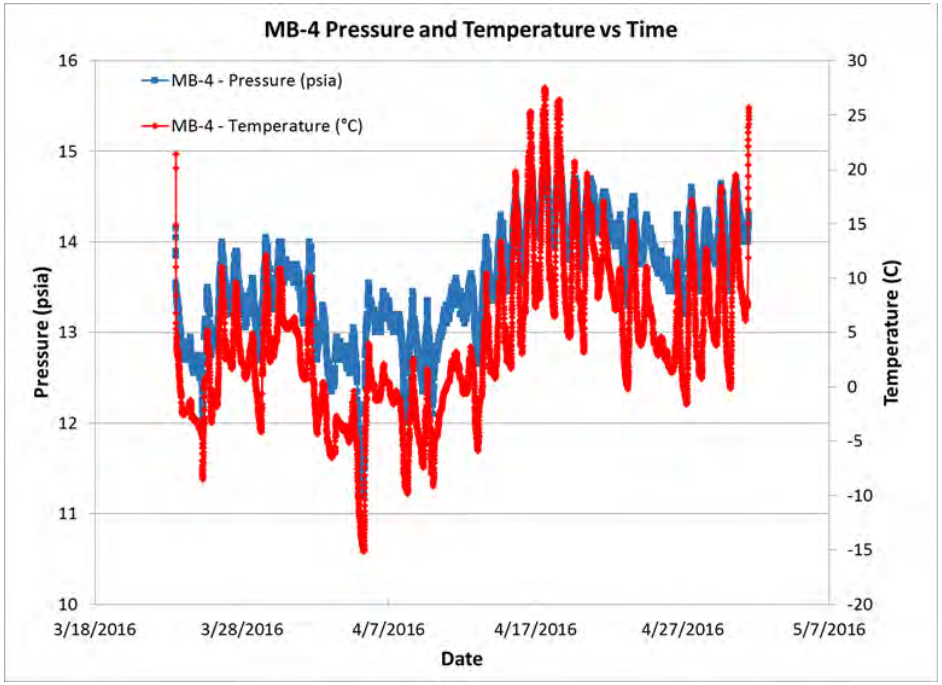
1. MI Basin Site

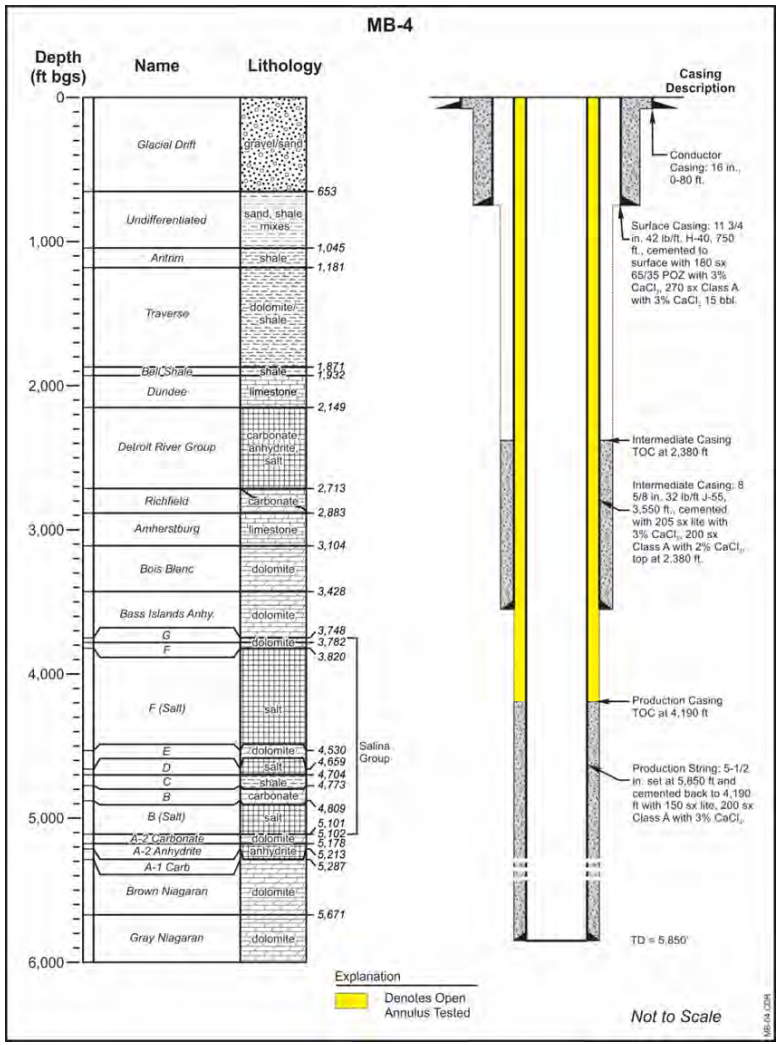
- 23 CO_2 EOR wells circa 1960-2003 were surveyed and measured for casing pres.
- 6 wells identified with some indicators of potential SCP.

Technical Status- SCP testing

1. Michigan Basin Site

- 6 wells were tested for SCP.
- No significant pressure rebound observed, mostly temperature fx.





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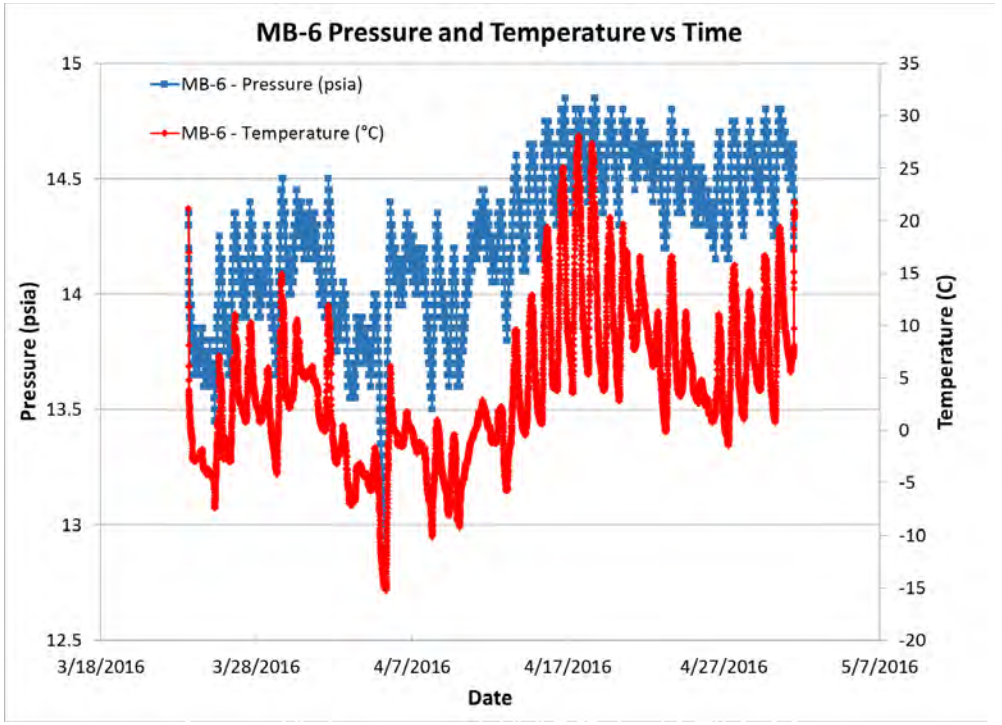
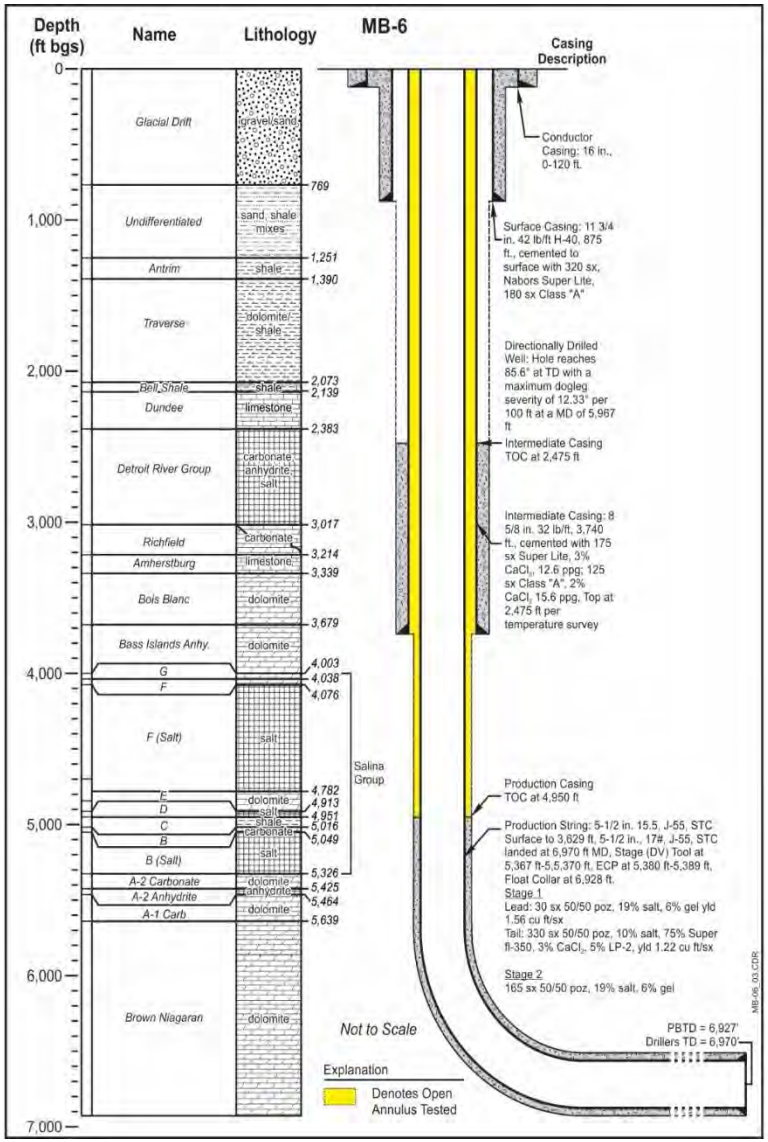
Technical Status- SCP testing

1. Michigan Basin Site

- All pressures were <100 psi.
- Pressure did not rebound to initial levels in many wells.





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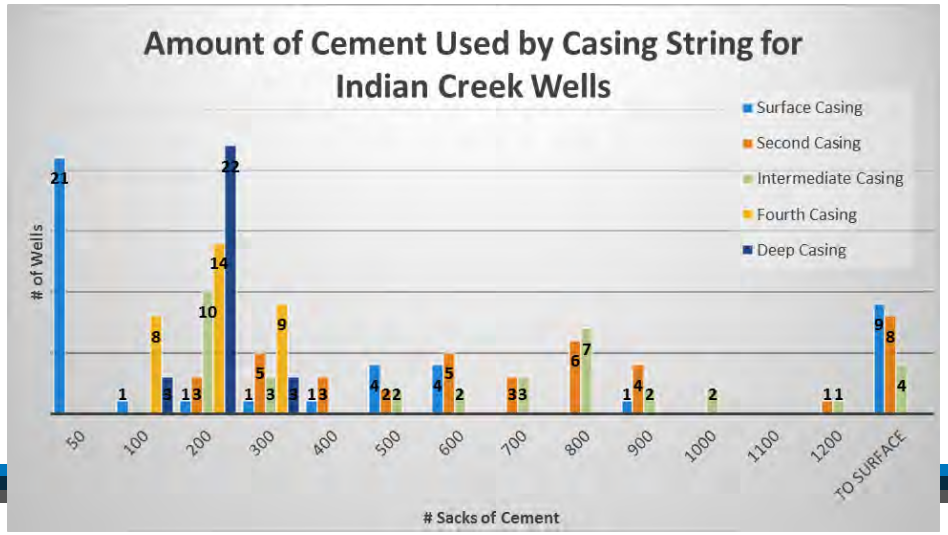
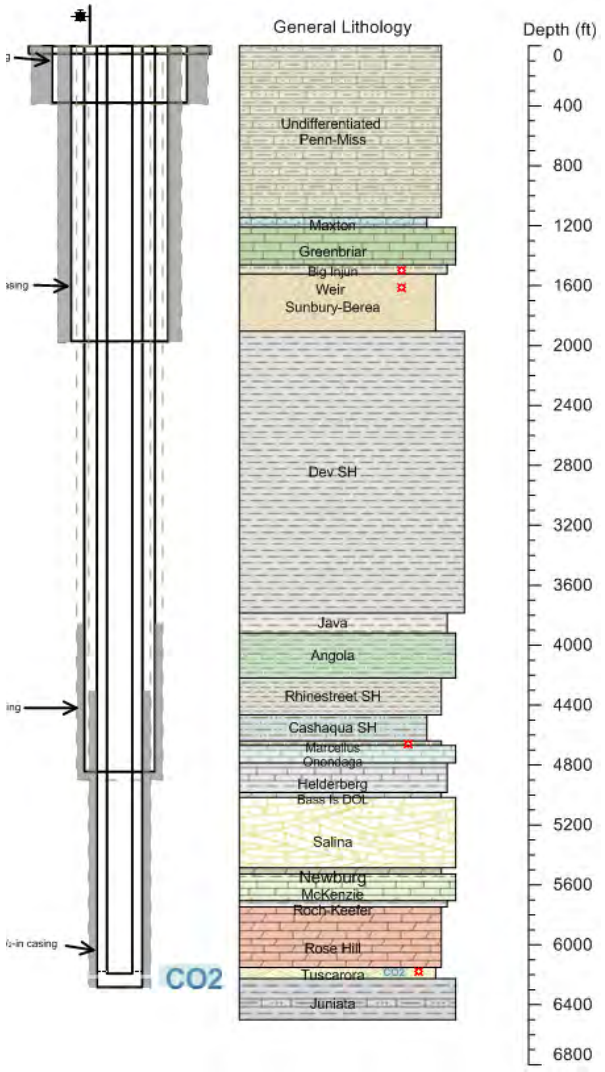
Technical Status- SCP testing

2. Appalachian Basin site- field sold to new operator during the project, and the site was not available for SCP testing.

- Well history/record review/discussions with the field's well technician indicates these wells did not have any more problems than typical oil & gas wells.





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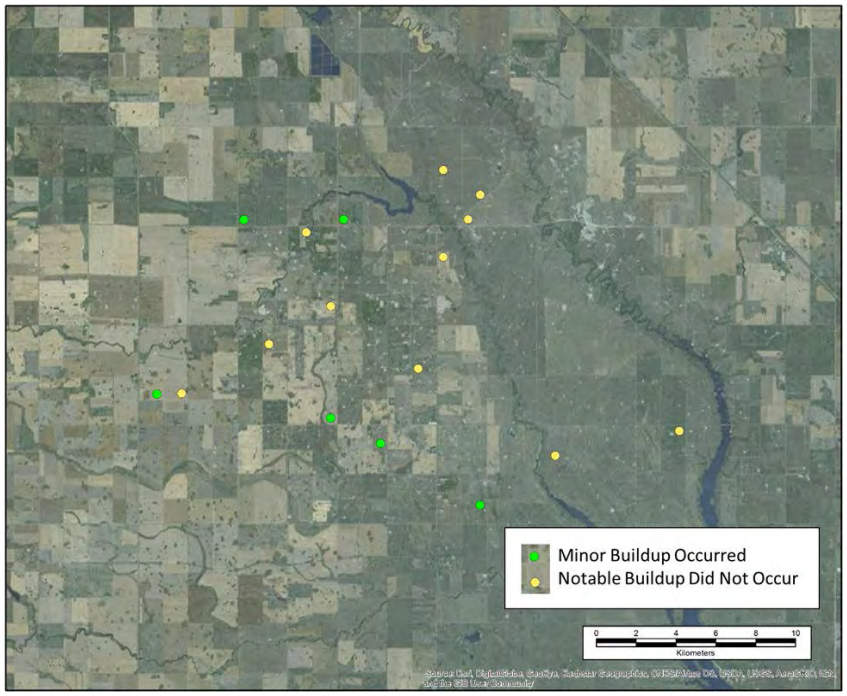
Technical Status- SCP testing

3. Williston Basin site- 1,425 wells were examined.

- 30 wells with history of casing pressure were measured for casing pressure in the field under this study.
- 17 wells were tested for SCP buildup.



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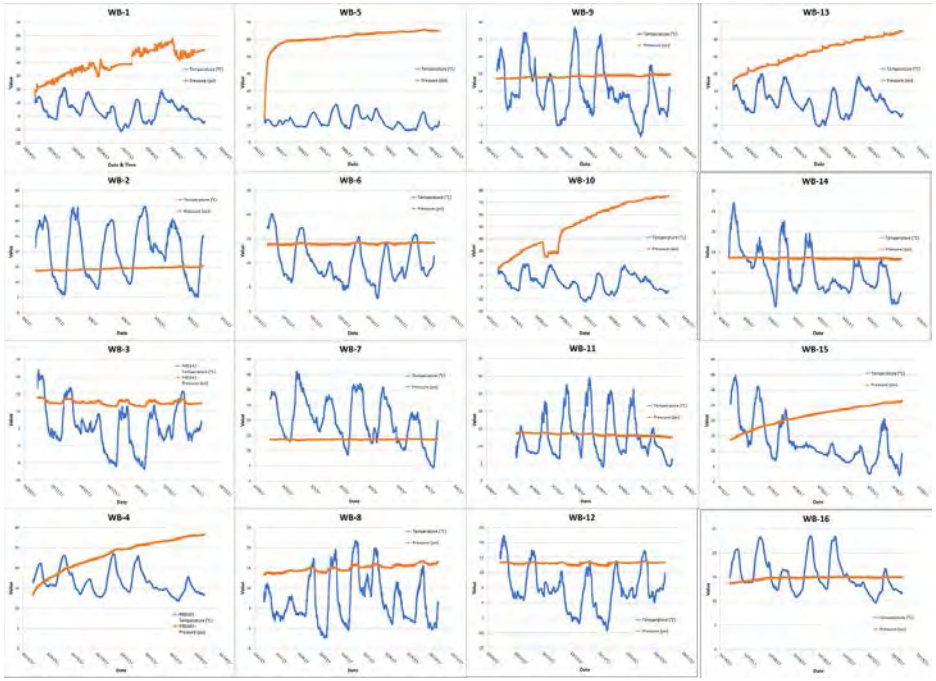
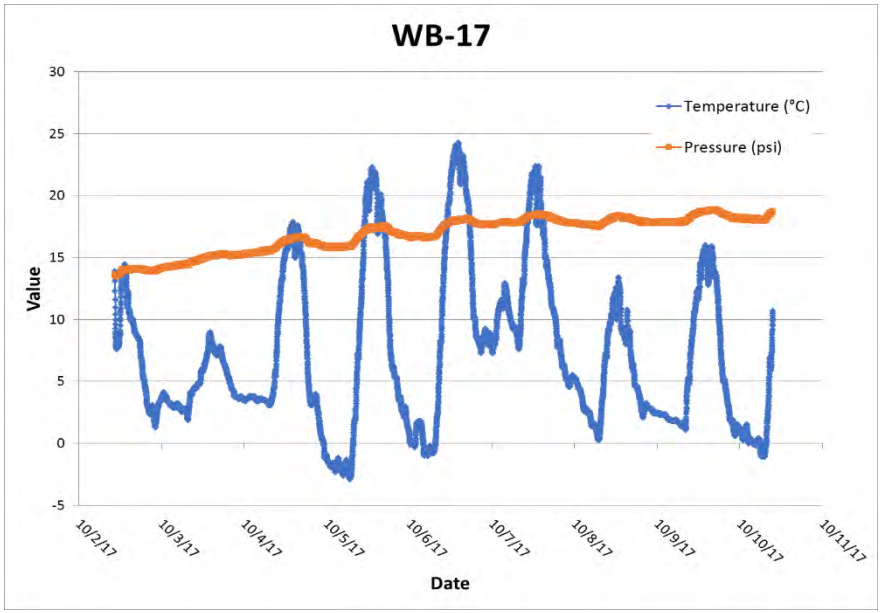
Technical Status- SCP testing

3. Williston Basin Site- The 17 tested wells showed minor pressure buildup less than 100 psi. This suggests wells had zonal isolation, shallow, secondary gas source. 6 wells had some pressure buildup pattern further analyzed.

WB-1 thru WB-16 pressure/temp. buildup



Ex. WB-17 Showing nominal 15-20 psi SCP.



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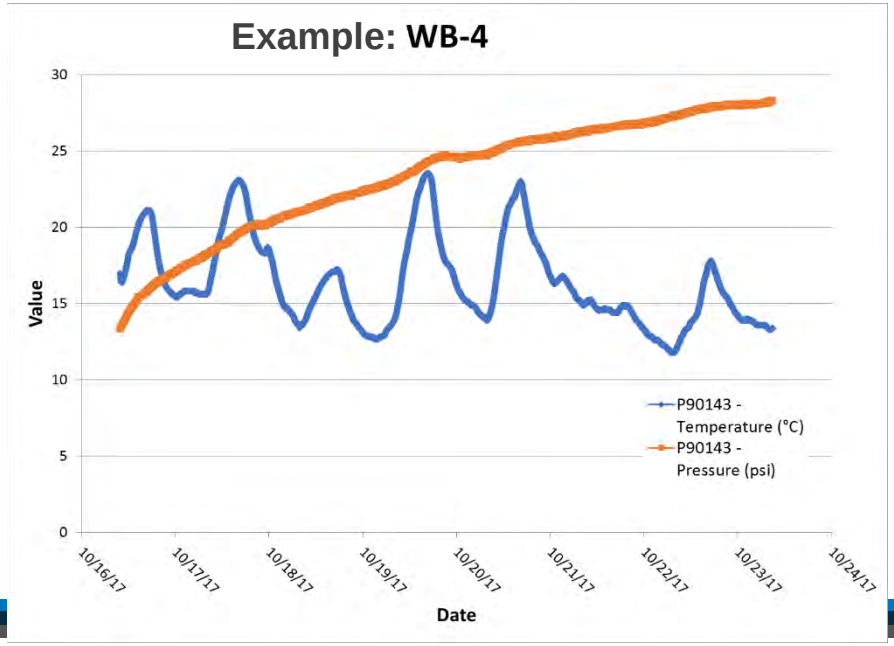
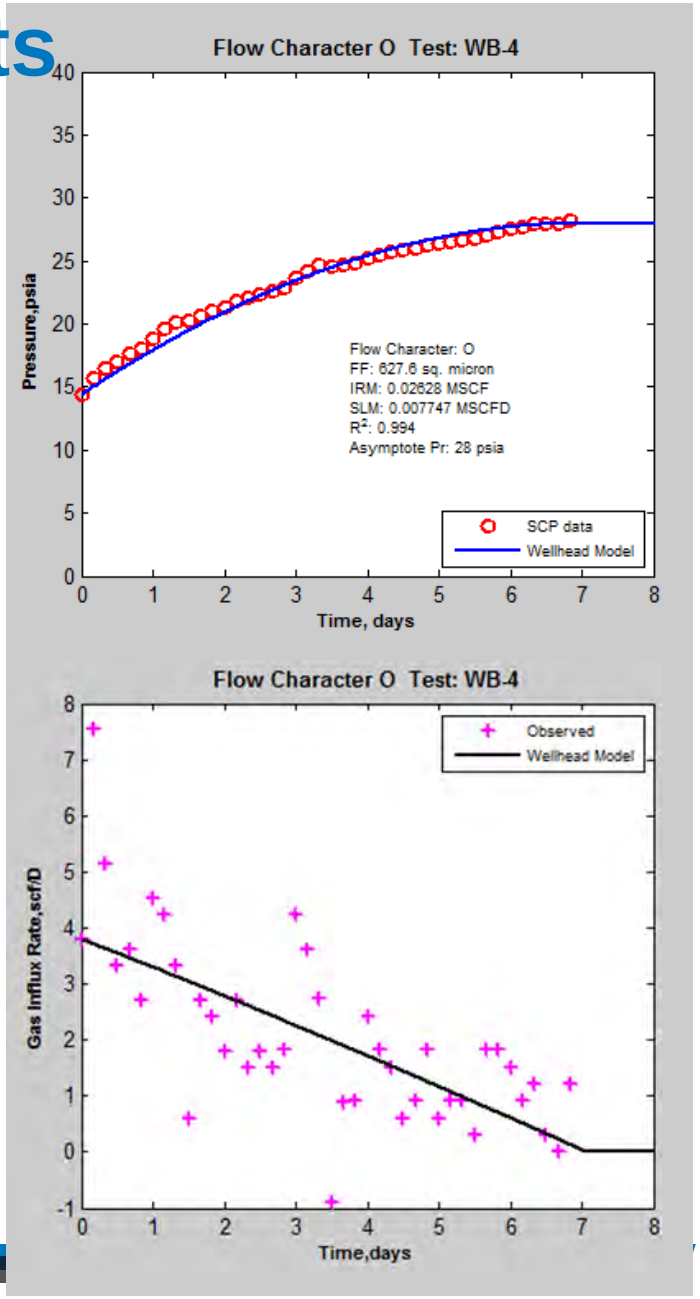
Technical Status- SCP tests

3. Williston Basin Site- Analysis results were inconclusive, supports operator observations that there is low gas flow from a shallow source and likely water present in the casing annulus.





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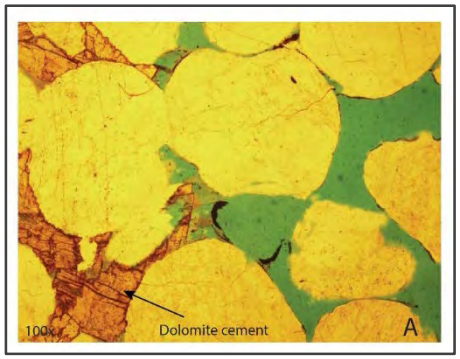
Technical Status- Field Analysis of Geochemical Cement Sealing Conditions

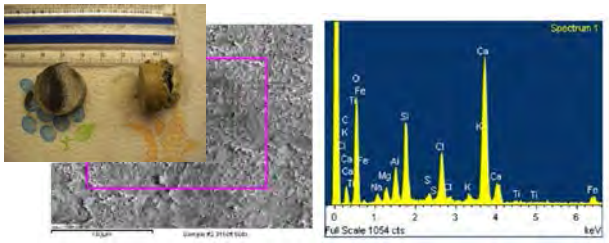
Reservoir/Caprock Mineralogy



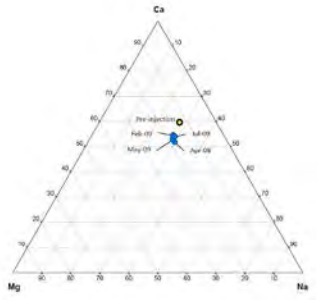
Subsurface cement sealing conditions?

- 1,500 CO_2 wells were reviewed, 53 well casing pressures were measured, and 23 wells were tested for SCP buildup. No positives for SCP well defects were found.
- Therefore, additional task on statistical machine based learning was revised to examine cement sealing conditions.
  - *What construction practices were used in these CO_2 wells that may have ensured wellbore integrity?*
  - *Were conditions right for $CaCO_3$ mineralization in the cement annulus, leading to sealing conditions?*
  - *Are these sealing conditions likely to be present in other oil and gas fields?*

Cement Sample



Brine Geochemistry



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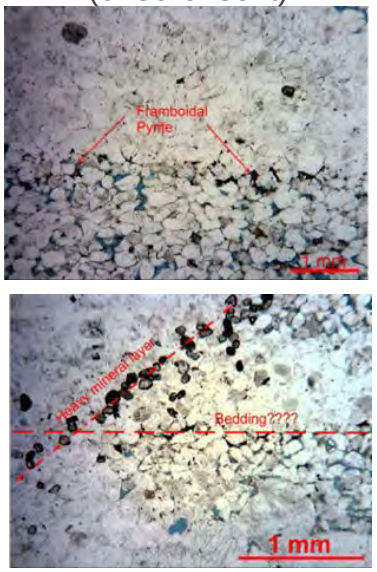
Technical Status- Geochemical Analysis

- Analysis of Subsurface Setting for Cement Sealing
  - Field site conditions vary in depth, age, pressure, temperature, well construction, & CO_2 exposure
  - Reservoirs–sandstone/carbonates, caprock–shale & evaporite
  - Highly saline brine in both Appalachian & Michigan Basins
  - Standard Portland Class A cement used at all 3 sites

Parameter	Appalachian Basin	Michigan Basin	Williston Basin
Field Area (acre)	30,000	3,000	45,000
Reservoir Depth (ft)	6,200-7,000	1,000 & 6,000	5,000
Reservoir Type	Sandstone	Carbonate Reefs	Carbonate
Caprock	Shale/Carbonate	Evaporite	Evaporite
CO_2 Type	Natural gas & CO_2	CO_2 EOR	CO_2 WAG EOR
Temperature (°F)	140	105	145
Discovery Pressure (psi)	2,900	3,000	2,000
Discovery Year	1973	1960	1954
# Wells	58	~45	~3,000

Ex. Tuscarora Sandstone from Appalachian Basin site (6730-6750 ft)



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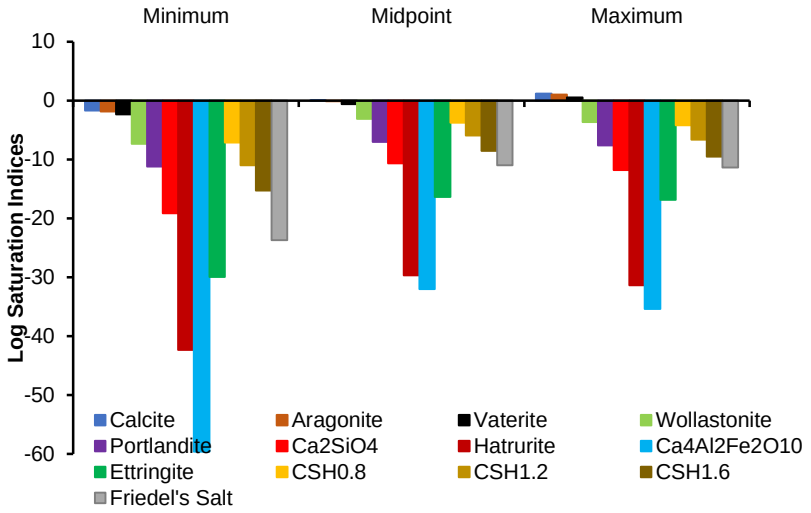
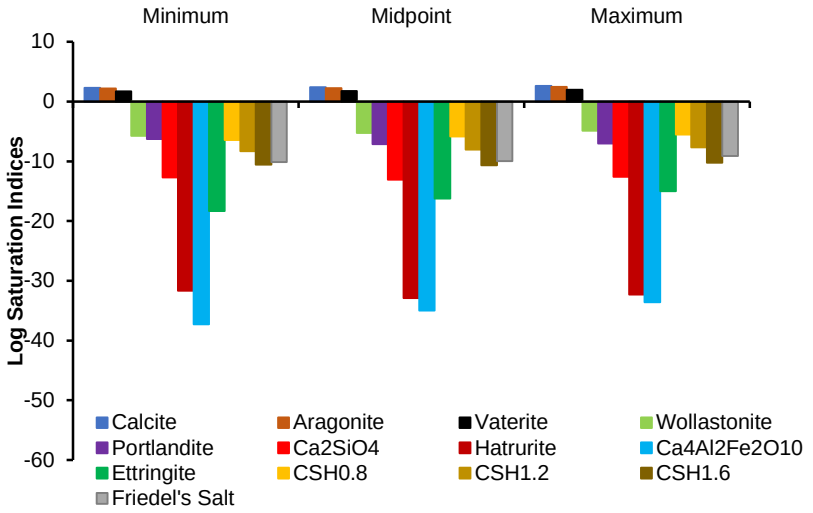
Technical Status- Geochemical Analysis

- PHREEQC modeling for Appalachian and Michigan Basin
  - Equilibrium model – saturation indices at equilibrium
  - Equilibrium phases – moles of minerals precipitated at equilibrium
  - Solid equilibrium phases – effect of solids (reservoir rock, caprock, cement)
  - CO_2 batch – Changes with the addition of CO_2
  - Reservoir conditions batch – pH, pe, P and T varied independently.

- Equilibrium Model – Appalachian Basin



- Equilibrium Model – Michigan Basin



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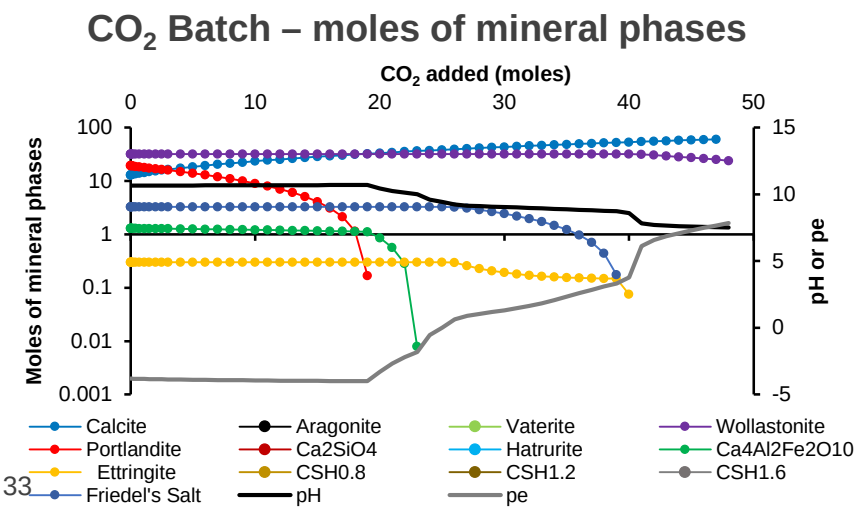
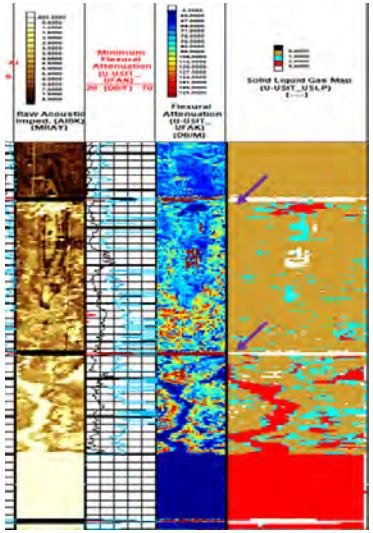
Technical Status- Geochemical Analysis

- Indicator Analysis for CO_2 Cement Sealing Conditions
  - Geochemical modeling completed using combination of models designed to simulate initial conditions, the addition of CO_2, and variations in reservoir properties/conditions
  - Cement is the most reactive component of system, similar to other research on CO_2 interactions with cement
  - Carbonation of cement reactions may seal defects, but most typical defects detectable by logging are >50 mm aperture



Ex. Isolation Scanner Cement Log from MI Basin Site showing 210 mm fracture in cement



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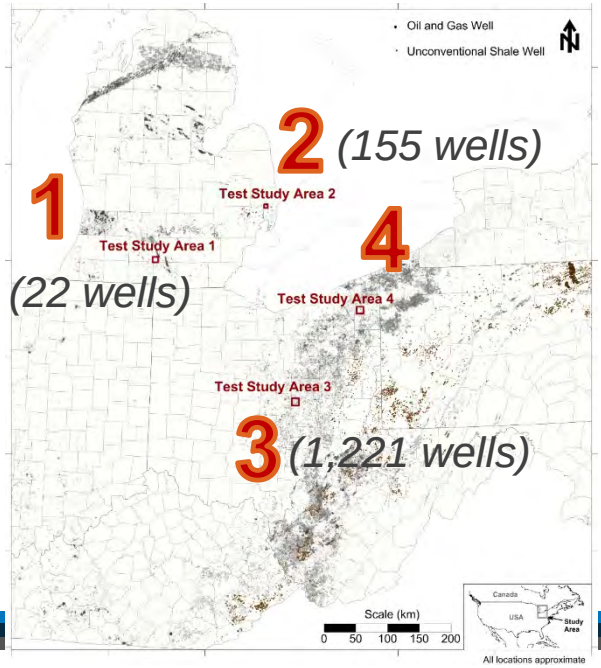
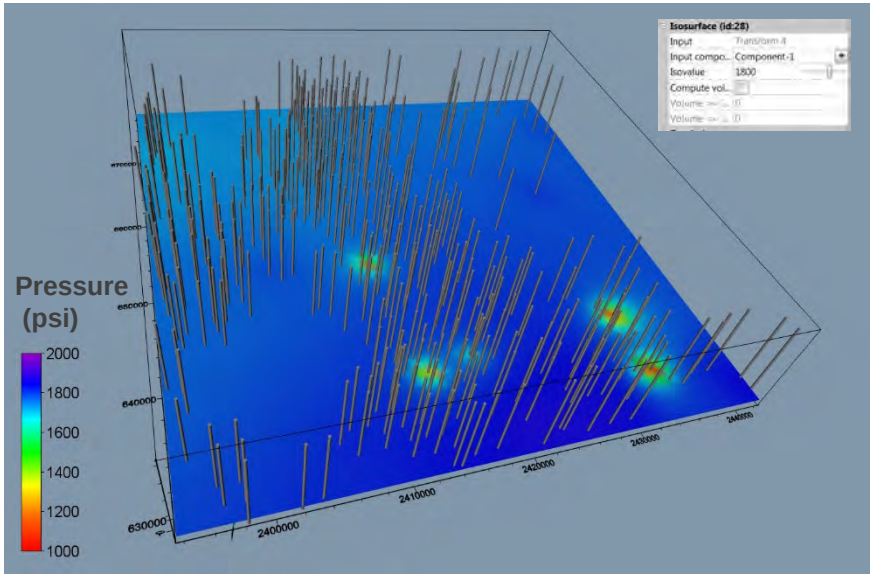
Technical Status- Geochemical Analysis

- Meta models developed based on PHREEQC results and applied to 4 test study areas based on field conditions.
- Models depict cement sealing/calcite precipitation potential in the subsurface across these 4 real life areas.
- Results suggest calcite precipitation has low sensitivity to typical field conditions.



Test Study Area 4 Meta Modeling Sliders (357 wells)



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Accomplishments to Date

- All technical Tasks complete:
  - Task 2- Well integrity registry to identify processes that may affect wellbore integrity at CO_2 storage sites.
  - Task 3- Site characterization of geology, well construction, field history, well status, for test study areas in Appalachian Basin, Michigan Basin, and Williston Basin.
  - Task 4- Log and testing based wellbore integrity assessment
  - Task 5- Completed sustained casing pressure testing and analysis for Michigan Basin site and Williston Basin Site.
  - Task 6- Field analysis of CO_2 cement sealing and well integrity
  - Task 7- Wellbore integrity sealing conditions uncertainty analysis
- Final Technical Report September 2018

Lessons Learned

- 3 field sites with CO_2 wells were examined.
- Surveyed 1,500 CO_2 wells at field sites, measured casing pressure in subsample of 53 wells, tested 23 wells for sustained casing pressure buildup.
- No significant well defects exhibited in the subsample of wells tested, wells exhibited zonal isolation with no indication of significant well defects.
- Task 6-7 modified to evaluate potential for geochemical cement sealing based on subsurface conditions at the 3 field sites and 4 test study areas.
- Geochemical cement sealing potential was not very sensitive to subsurface conditions at field sites.

Lessons Learned

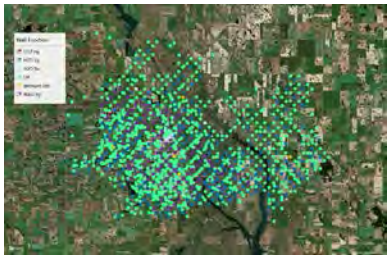
- Results were not expected, we expected to see some defects in wells (like O&G wells tested in other projects).
- Well construction methods that appear to have helped maintain wellbore integrity at the site include:
  - Multiple strings of casing (conductor, surface, intermediate, and deep) were present in the wells, reducing potential for gas migration.
  - Most wells were cemented across or near casing string crossovers reducing pathways for gas migration along the boreholes.
  - More cement was used to cement in the casing strings than many other areas of the Midwest. Casing strings were cemented with several hundred feet of cement (in many cases over 1,000 ft).
- Future work may examine long-term life cycle conditions in CO_2 well with periodic CBLs, SCP tests.

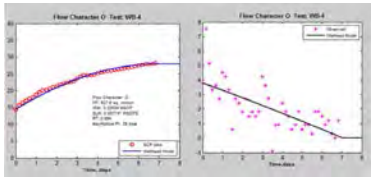
Synergy Opportunities

- Project has significant synergies with other ongoing work on carbon storage technologies (carbon capture & storage), shale gas developments, other CO_2 storage research.
- Provides a better understanding of wellbore integrity in legacy oil and gas wells, a key issue for CO_2 storage in the region's deep rock formations.
- Reduces uncertainty related to siting CO_2 storage projects by providing direct testing of legacy CO_2 wells and relating this to >1 million oil and gas wells in the region.

Project Summary

- This integrated approach brings together analysis of well information with field monitoring and testing:
  - Development of a registry of wellbore integrity factors,
  - Detailed review of fields (Michigan Basin, Appalachian Basin, Williston Basin) with wells exposed to CO_2 in the subsurface,
  - Clear, direct, and cost effective field testing of wells with sustained casing pressure to determine the nature of well defects common to wells exposed to CO_2,
  - Site specific modeling of subsurface conditions for geochemical cement sealing potential in CO_2 wells.





Thanks!

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Appendix

Benefit to the Program

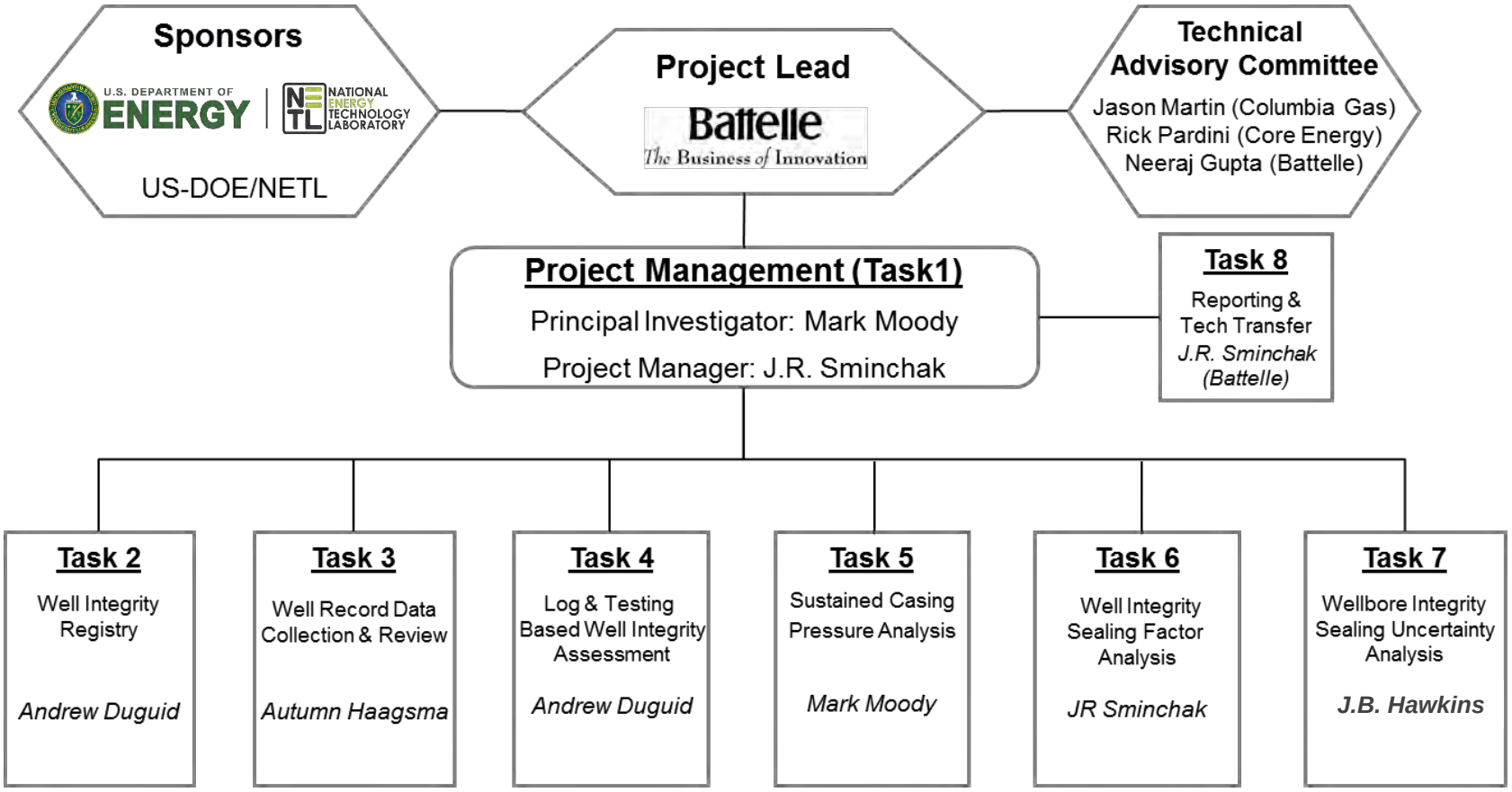
- This project addresses Funding Opportunity 1240 Area of Interest 2: Wellbore Leakage Identification and Characterization.
- The project is designed to establish an effective approach to determining the location/depth, nature, and severity of well integrity issues for wells exposed to CO_2 environments in the subsurface.
- Project results will provide new and improved predictive methods to survey, identify, characterize, and manage wellbore integrity defects for CO_2 storage applications.

Project Overview

- The objective of this project is to develop and validate a program for identifying and characterizing wellbore leakage potential for CO_2 storage applications based on analytics of well records validated with sustained casing pressure field monitoring.
- The project will develop and advance technologies that will significantly improve the effectiveness and reduce the cost of implementing carbon storage.
- Integration of casing pressure test results with geochemical analysis of cement sealing conditions can better define CO_2 well integrity issues.
- Development of an integrated program to identify, survey, measure, analyze, and remediate CO_2 migration in wellbores.
- In addition, the type of well defect (micro-annulus, cracks, cement voids, and incomplete cement coverage) may be better characterized to select to the most appropriate remediation technology.

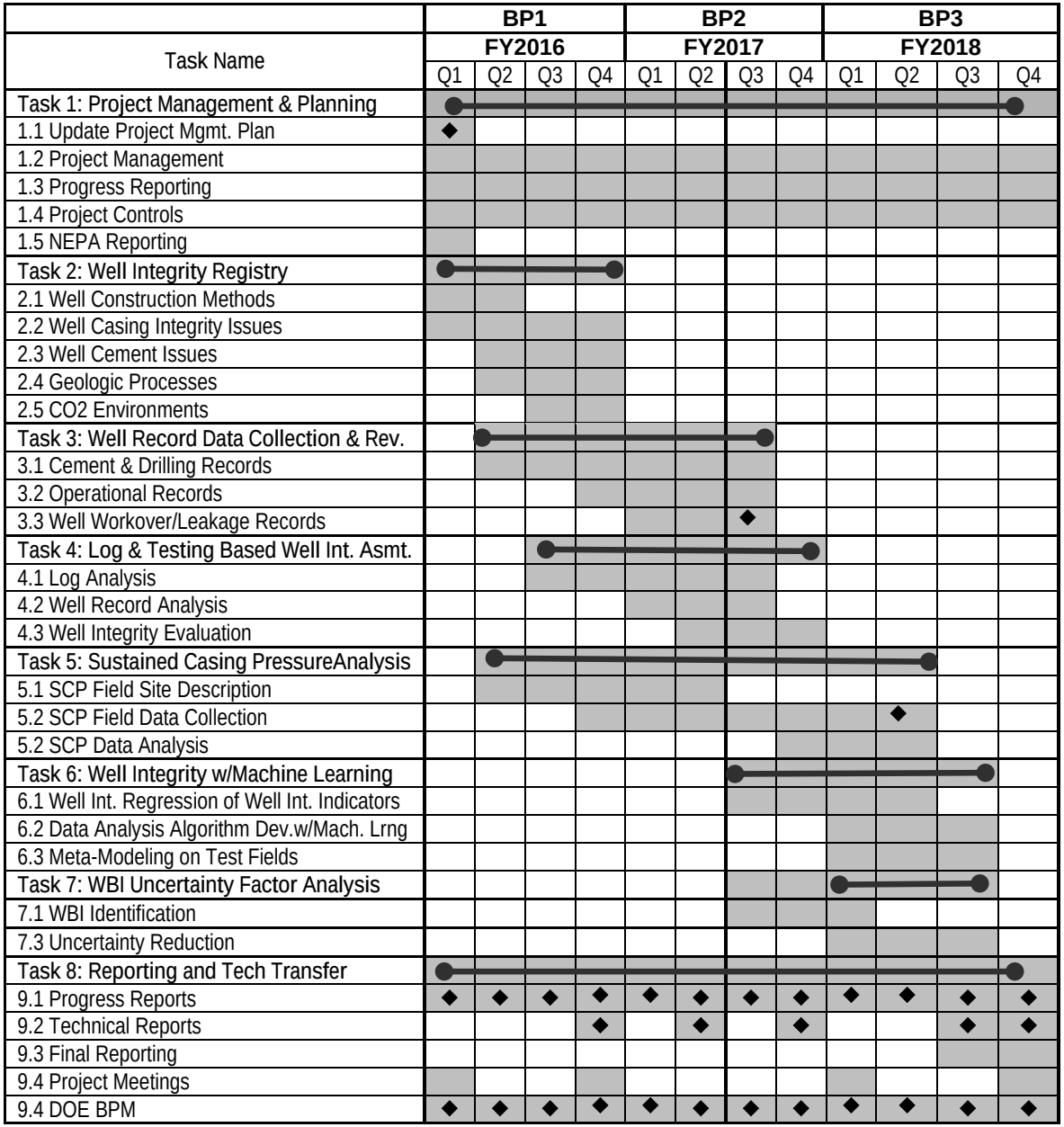
Organization Chart

3-Year Project; October 2015 - September 2018



Gantt Chart

- Project is designed with a sequential series of tasks over 3 years.



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