Integrated Wellbore Integrity Analysis Program for CO_2 Storage Applications

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

August 1-3, 2017

Presentation Outline

1) Technical Status
2) Accomplishments to Date
3) Lessons Learned
4) Synergy Opportunities
5) Project Summary

- Appendix Material

1966 Gordon Sand Well

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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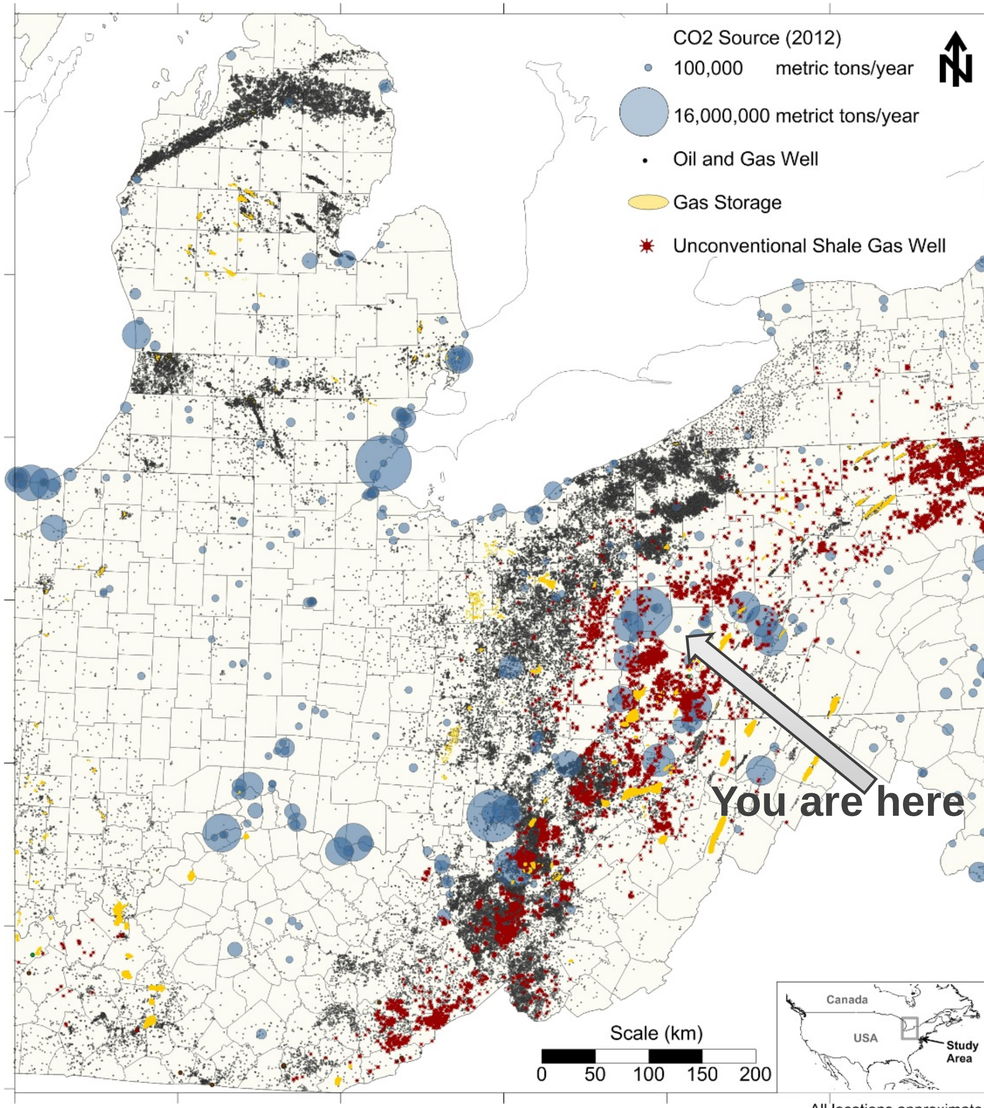
CORE ENERGY, LLC

WVGES GEOLOGY UNDERLIES IT ALL
West Virginia Geological and Economical Survey

Technical Status- Objectives

- Geologic CO_2 storage may affect legacy oil and gas wells.
- For example, there are more than 1 million oil & gas wells in Midwest U.S. since ~1859.
- What is the condition of these wells?
- How would exposure to CO_2 in the deep subsurface affect these wells?
- What can we learn from testing and monitoring these wells?
- Are CO_2 wells in any better/worse condition than typical oil and gas wells?



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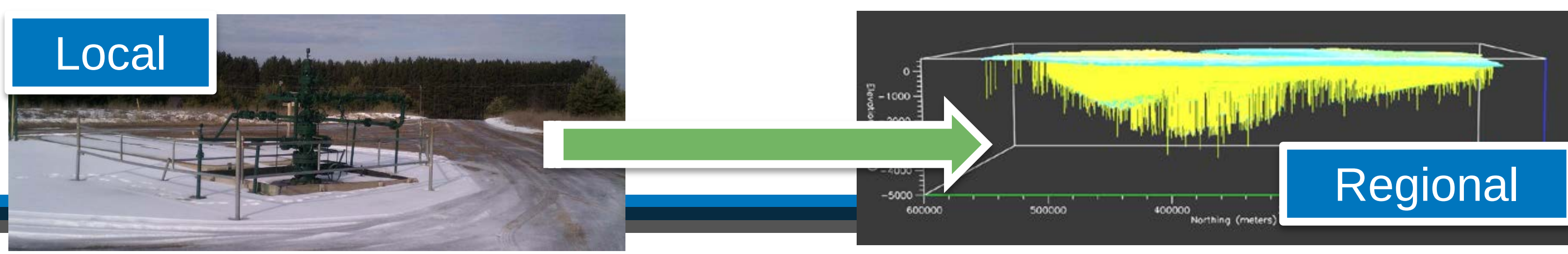
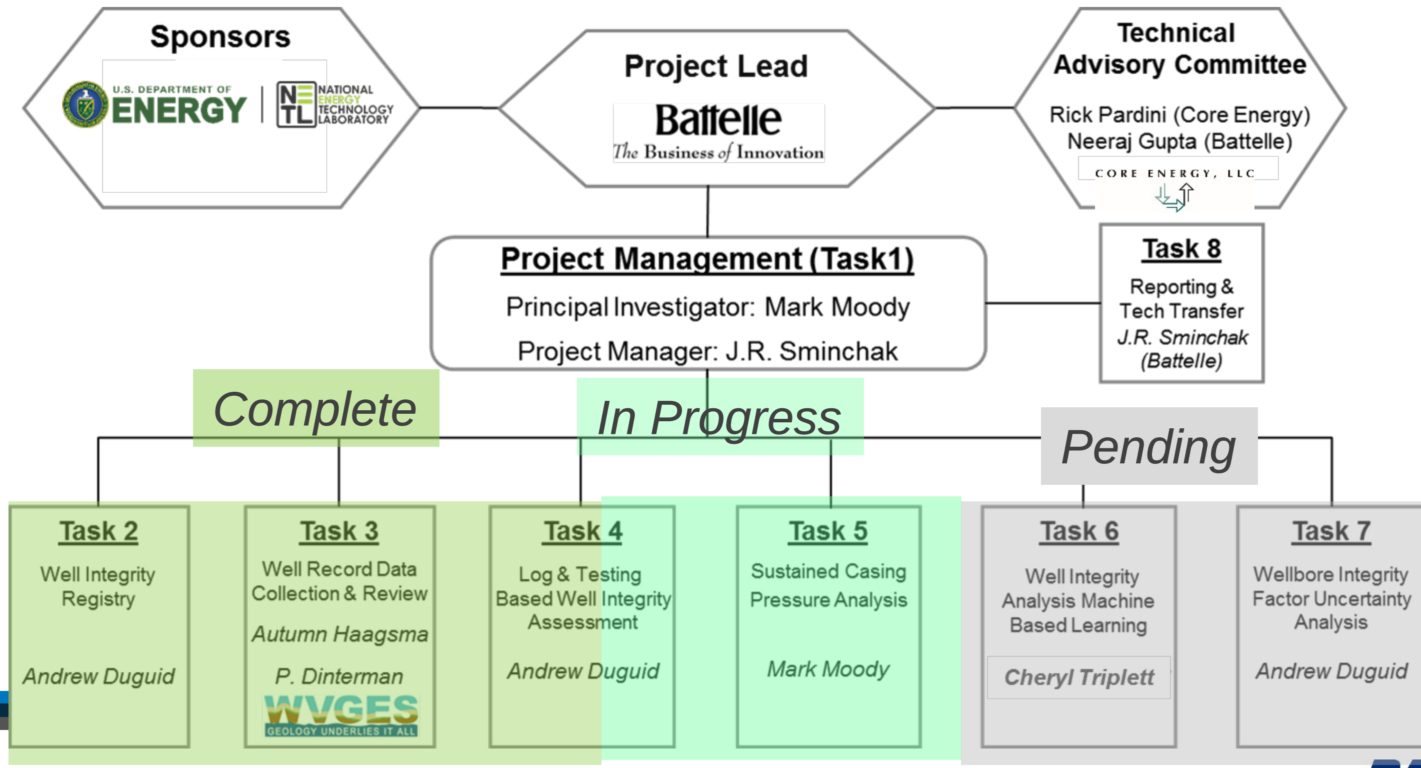
Technical Status- Objectives

- **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.



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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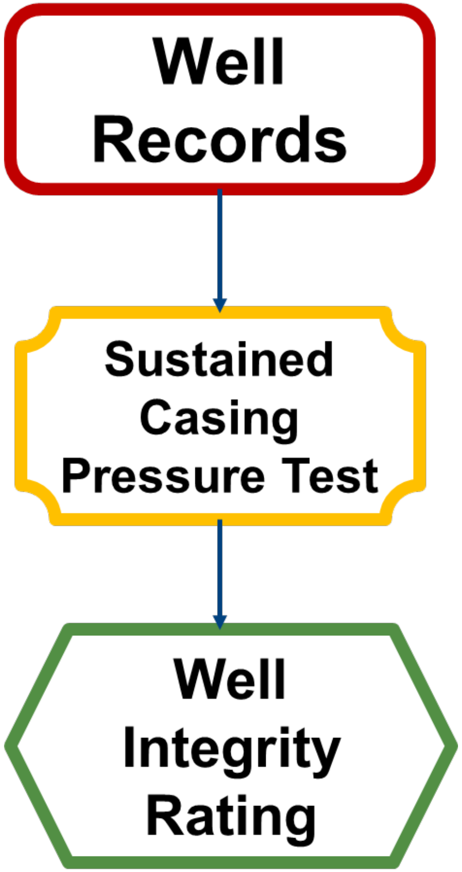
Technical Status- Objectives

- 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 well records with statistical based machine learning to define well construction factors that may be most relevant to CO_2 storage applications.
- Analyze this information to better understand the risks that legacy boreholes may pose for CO_2 storage in the region.



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Technical Status

- Well registry developed to identify wellbore integrity issues, and where and how they occur in the subsurface
- Five 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.

- Information was used to characterize the three study areas

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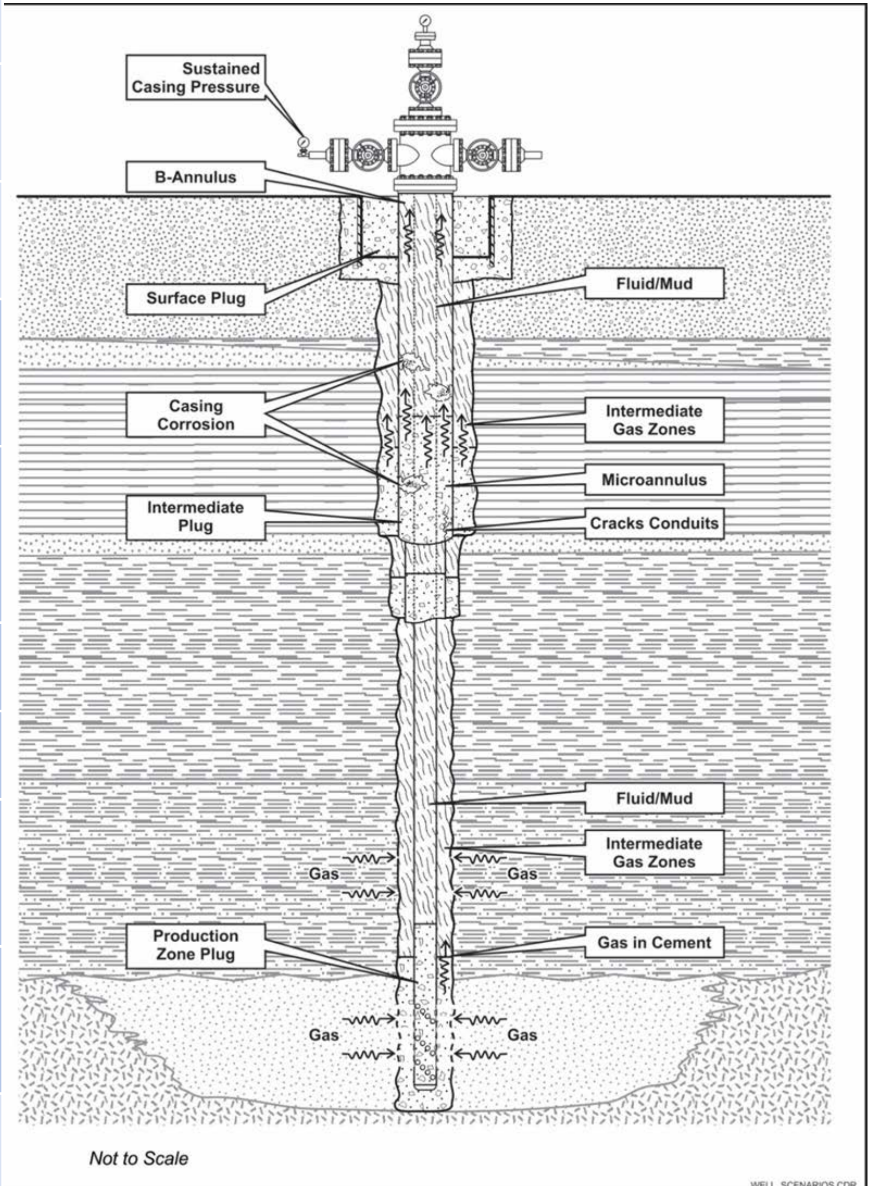
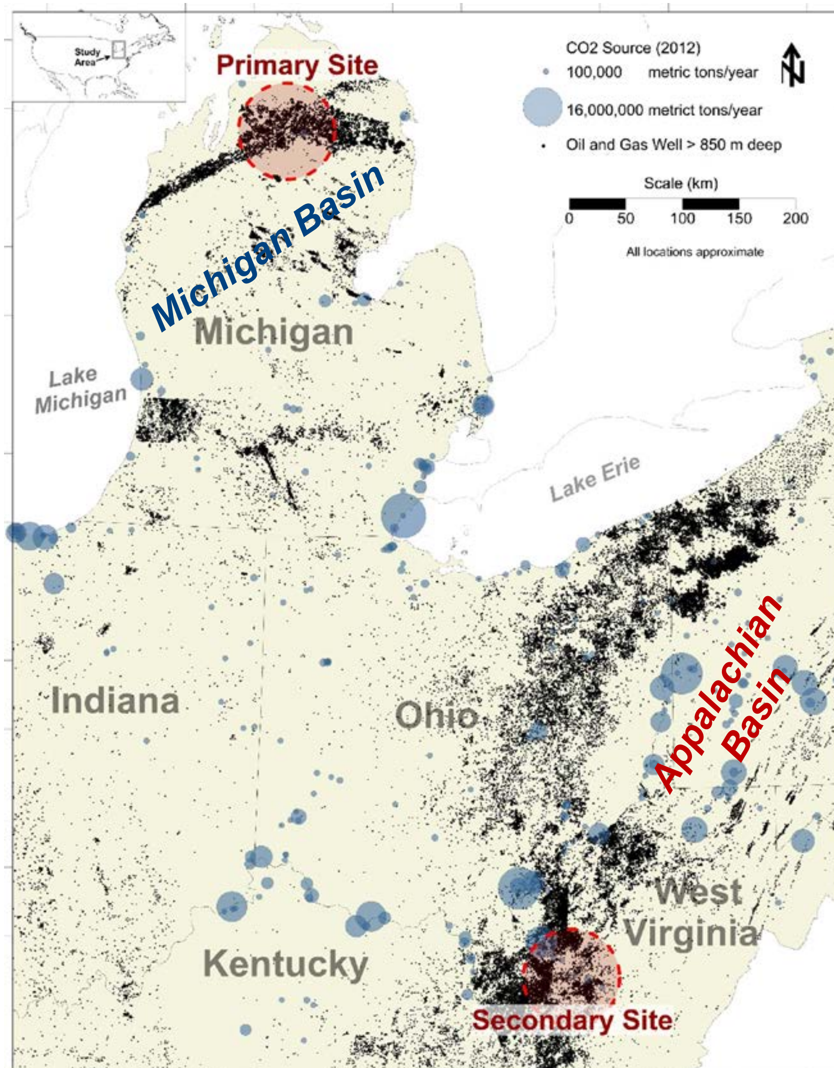
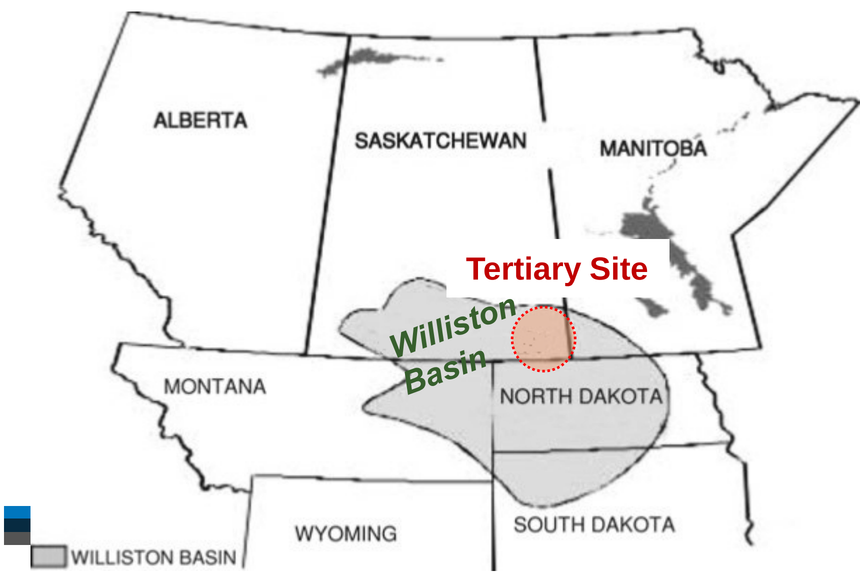
Well Component	Integrity Issue	Description	Causes	When	Leakage Pathway
Casing	Thermo-mechanical cycling	Contraction and expansion of well casing	Differences between properties of materials	Construction, operation, workover, abandonment	Debonding along cement interface (microannulus)
	Wear	Wear to the 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

- 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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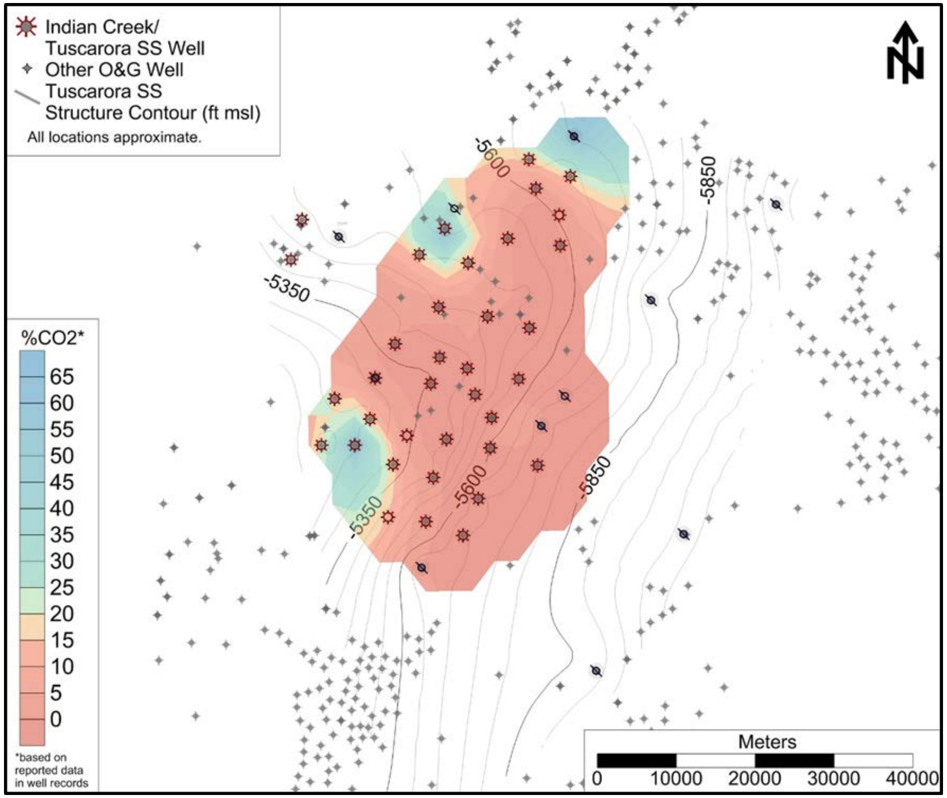
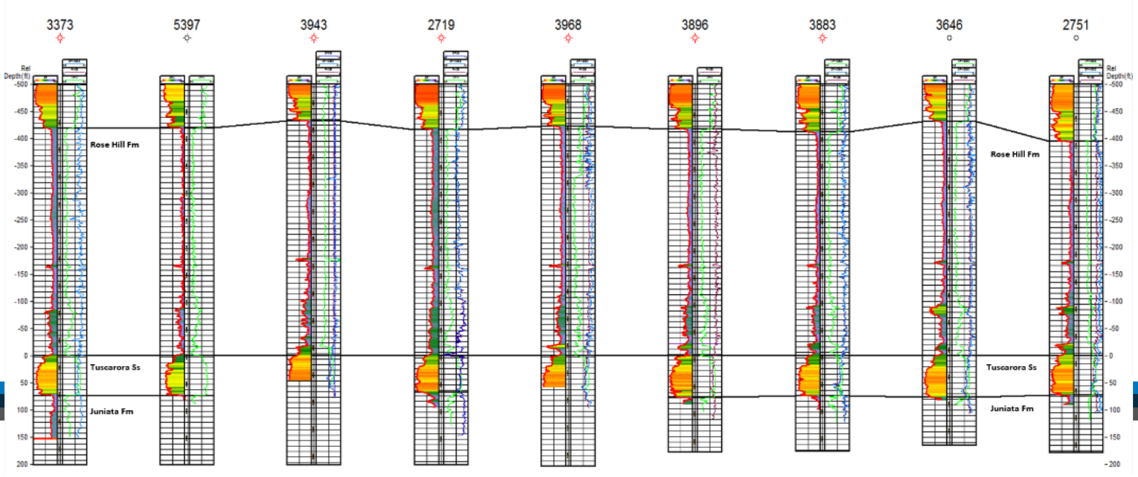
Technical Status

- **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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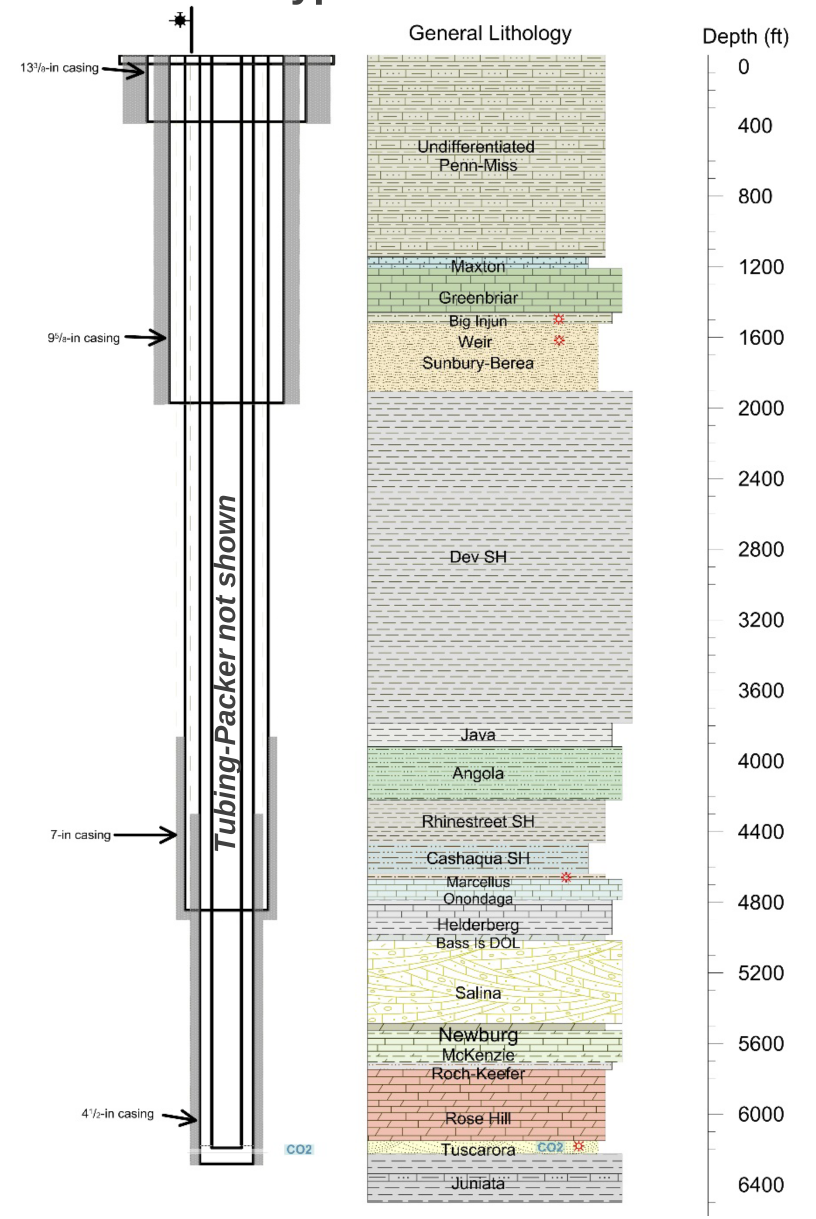
Technical Status

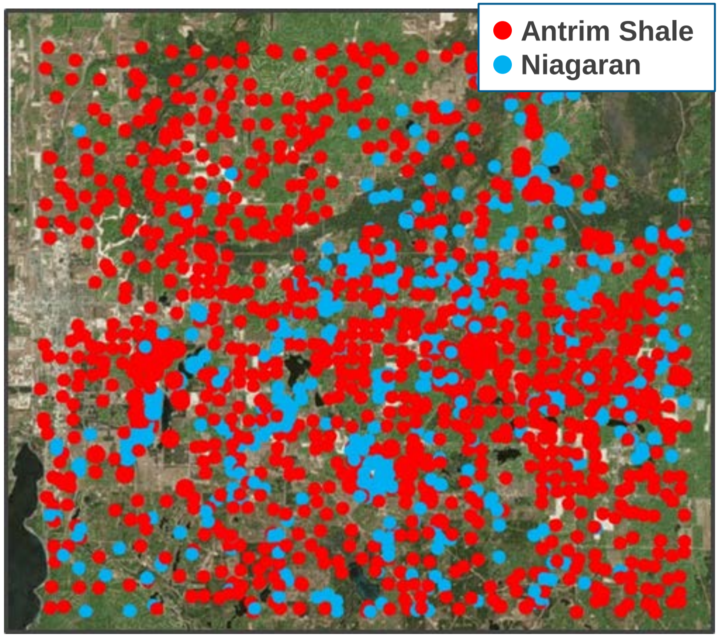
- **Appalachian Basin site**
- Wells exposed to natural CO_2 accumulation at depth of 6200 ft (1900 m) in the Tuscarora sandstone.

Typical Field Well

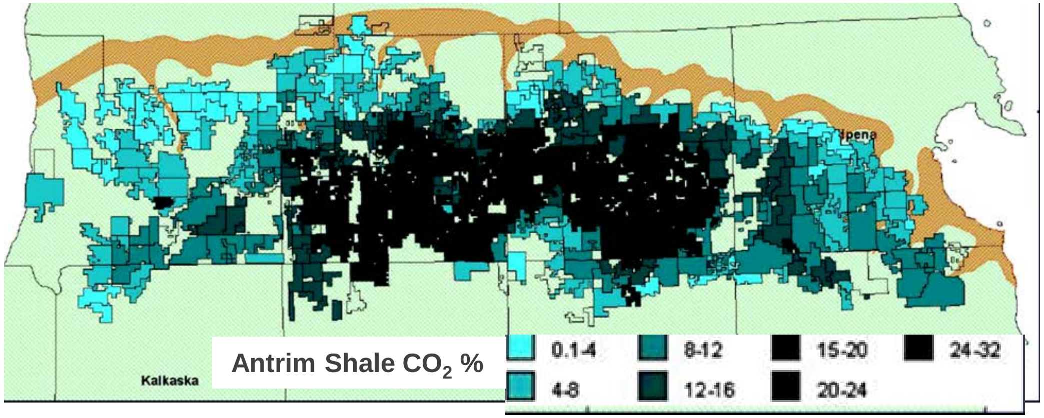


Technical Status

- **Michigan Basin site**
- 100's existing wells circa 1960-2016.
- 20-30 wells in CO_2 EOR fields.
- 5-30% CO_2 in Antrim Shale, 300-500 m.
- 95-99% CO_2 in EOR zone at 1,500-2000 m.



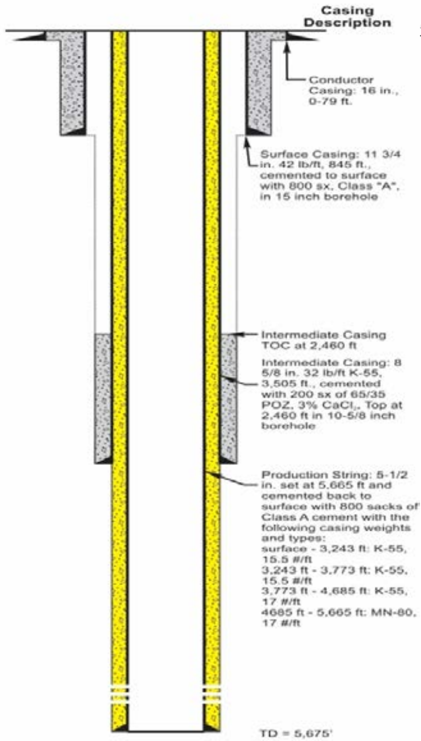
Antrim Shale CO_2 % in Produced Gas Volume

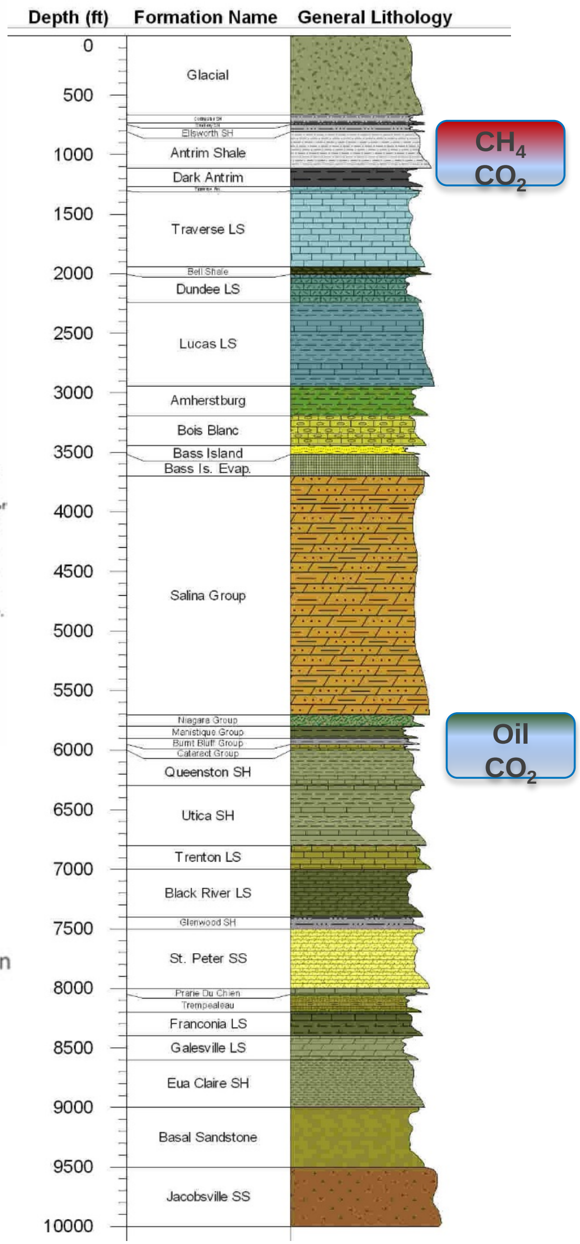


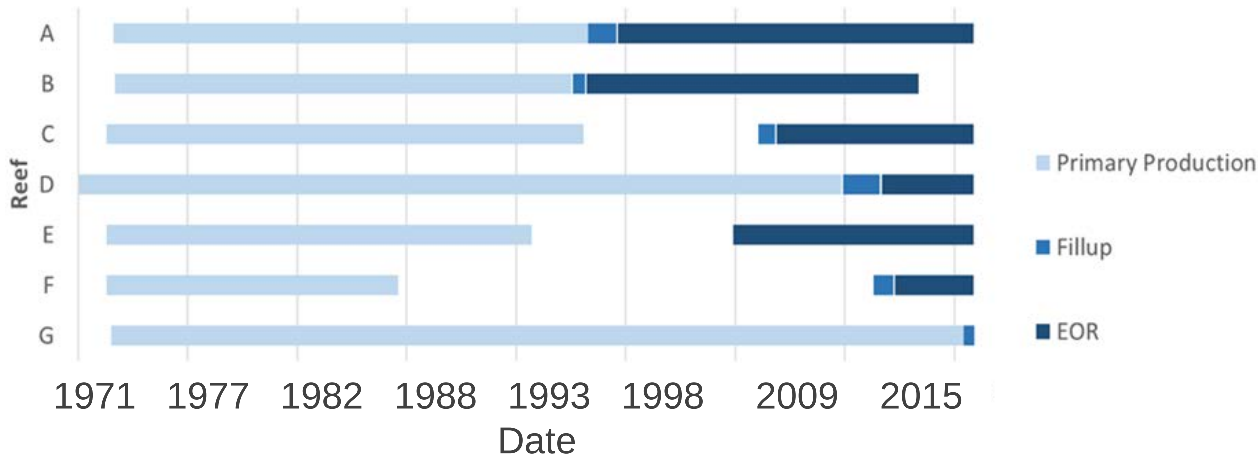
(Source: Goodman et al, 2014)

Technical Status

- **Michigan Basin site** has wells with high natural CO_2 levels in a relatively shallow (350 m) shale gas play, and a deeper (1850 m) carbonate reef CO_2 enhanced oil recovery field.







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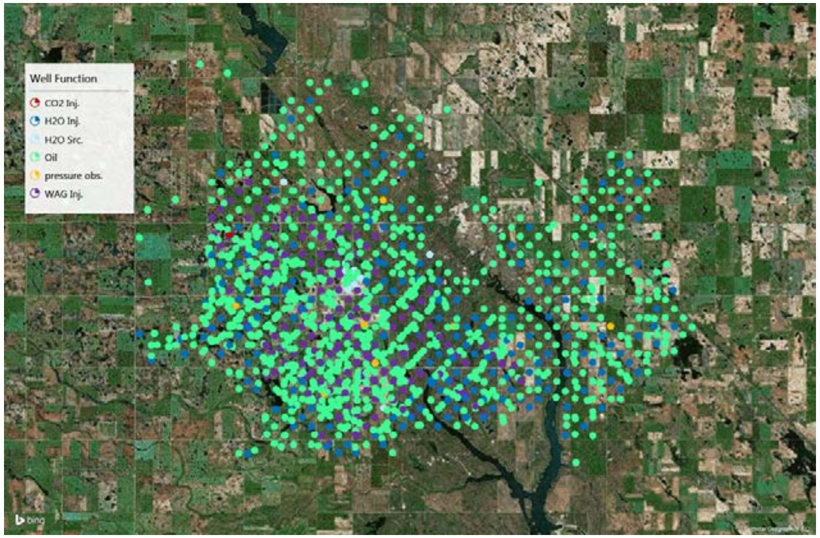
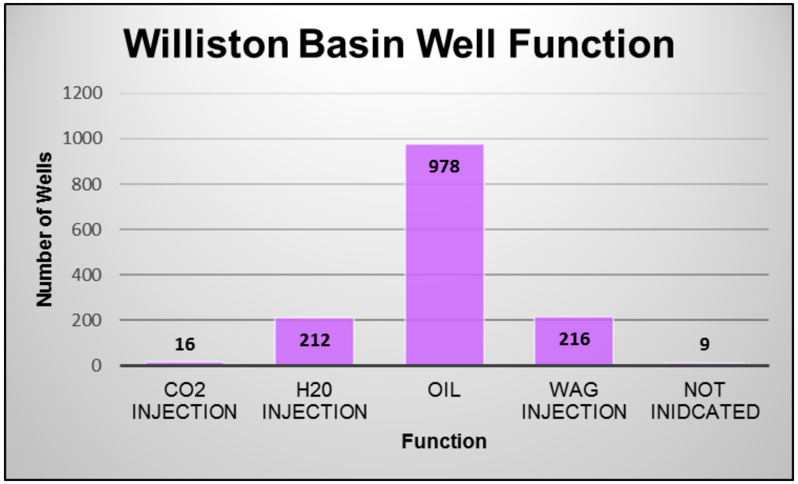
Technical Status

- **Williston Basin site** has ~3000 wells, and 1425 were examined in this study.
- The wells were primarily oil producers with select wells used for H_2O or CO_2 injection.
- Wells used for CO_2 & H_2O injection. Some H_2S gas present.
- Well age ranges from 1950s to 2000s.
- EOR zone at 1500 m.





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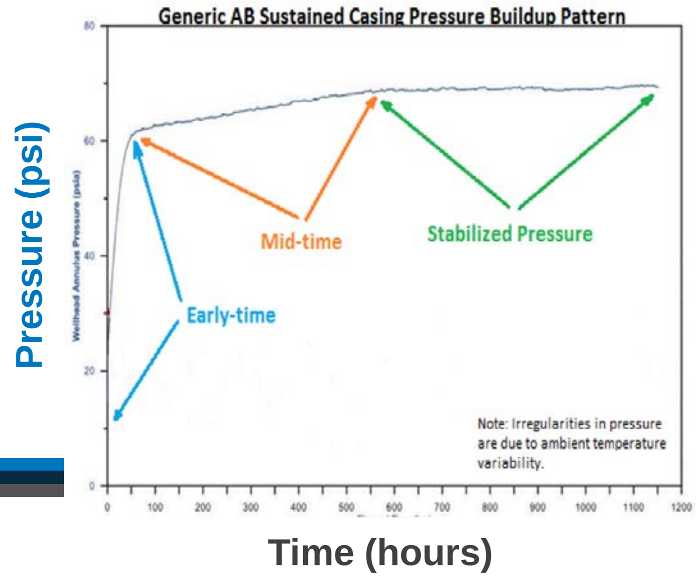
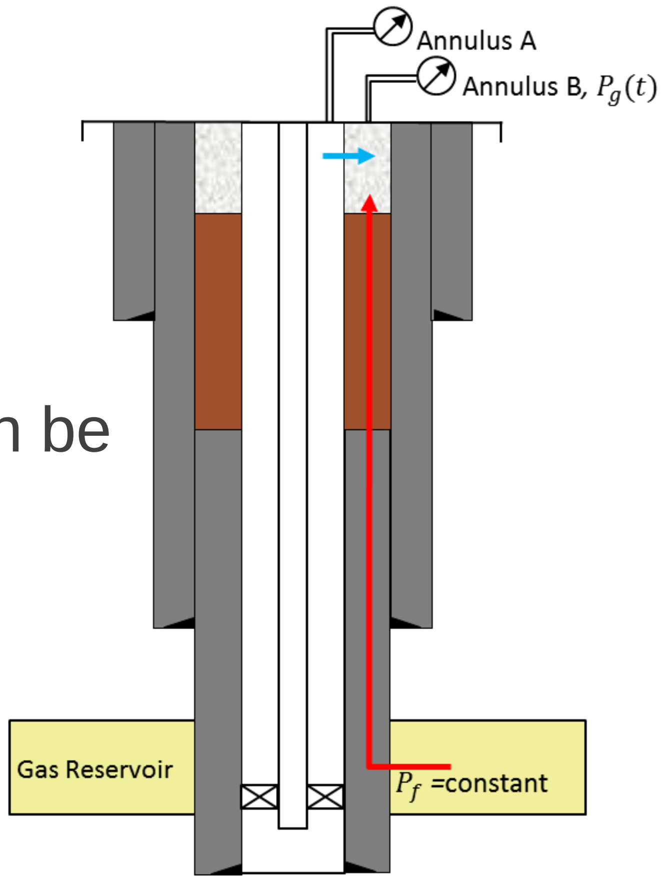
Technical Status- SCP testing

- Well defects may result in “sustained casing pressure” or vent flow gas.
- Gas migrates through casing/cement into ‘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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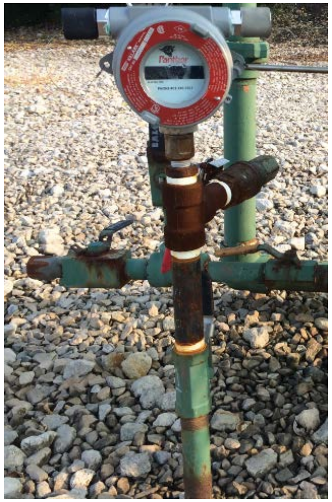
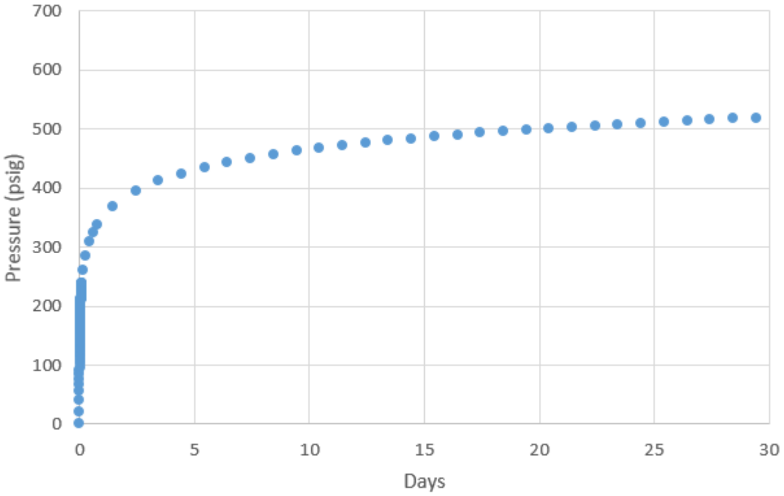
Technical Status- SCP testing



- 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!

Pressure Build-Up Monitoring



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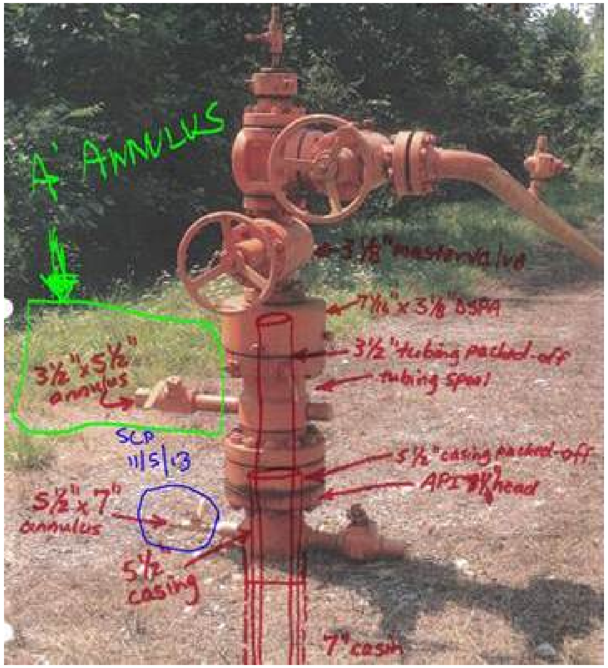
Technical Status- SCP testing

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



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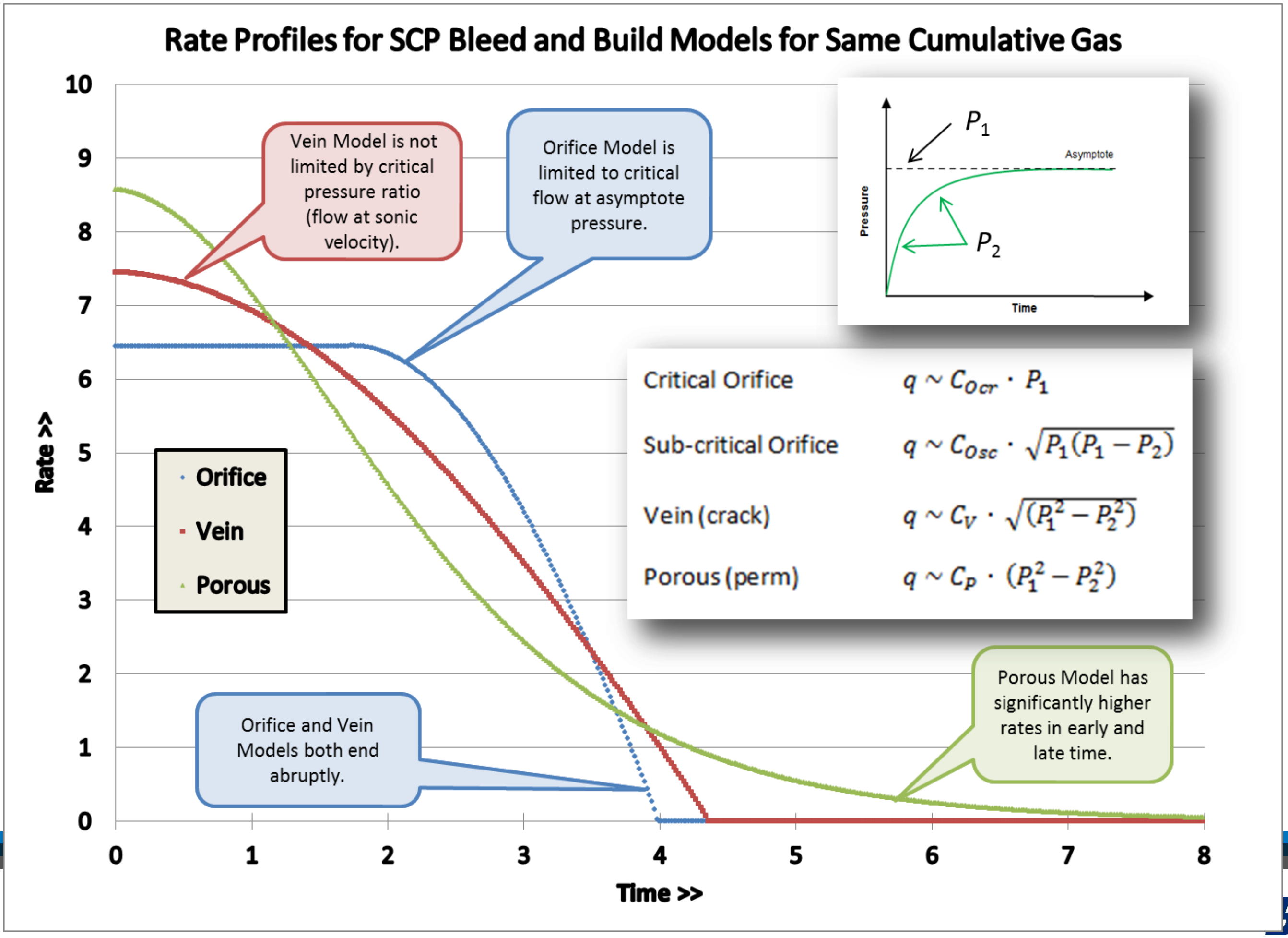
Technical Status

- SCP testing analysis method developed to analyze legacy well because they often have various well defects (Dotson et al., 2015).



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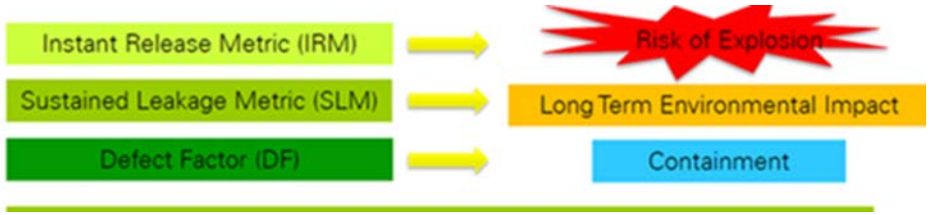
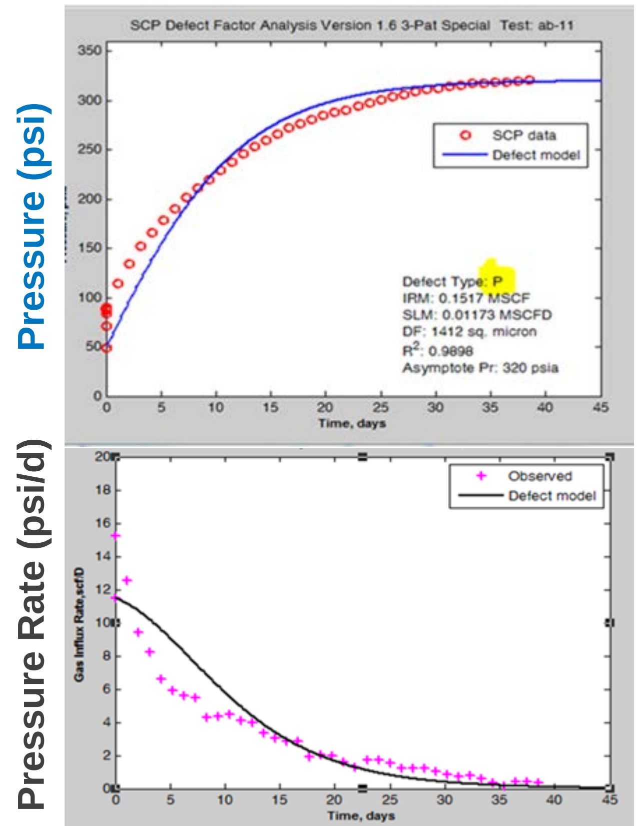
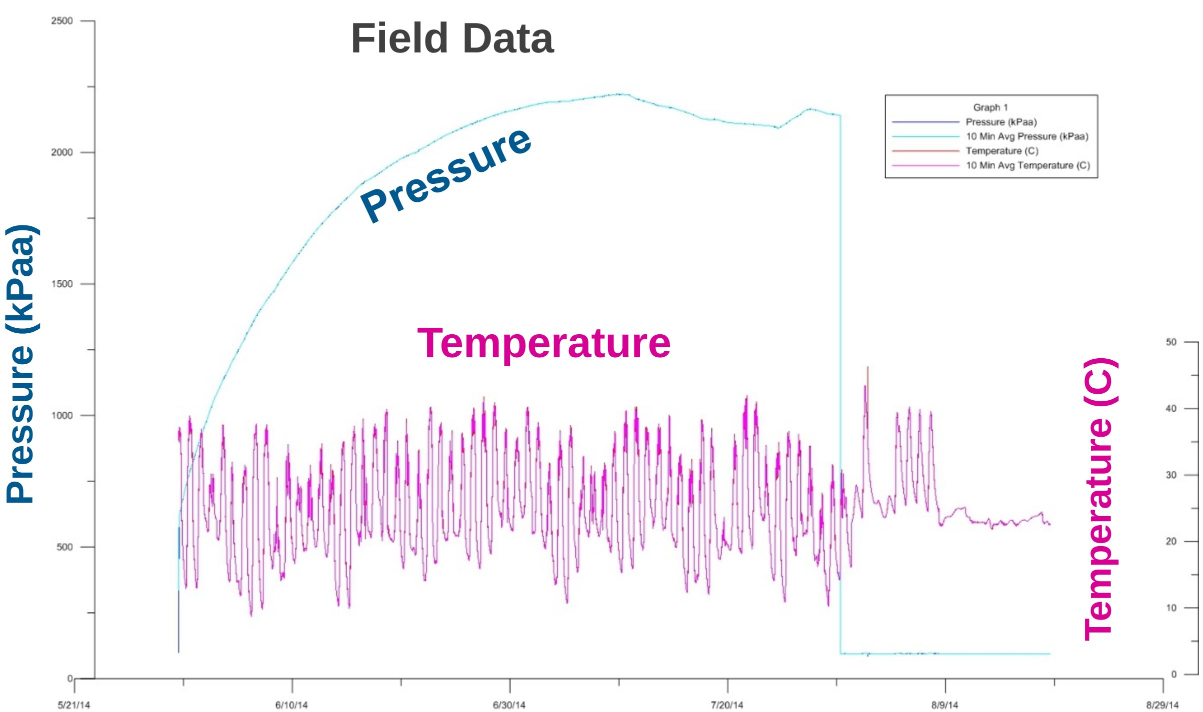


Rate Change Model



Time (days)



Time (days)

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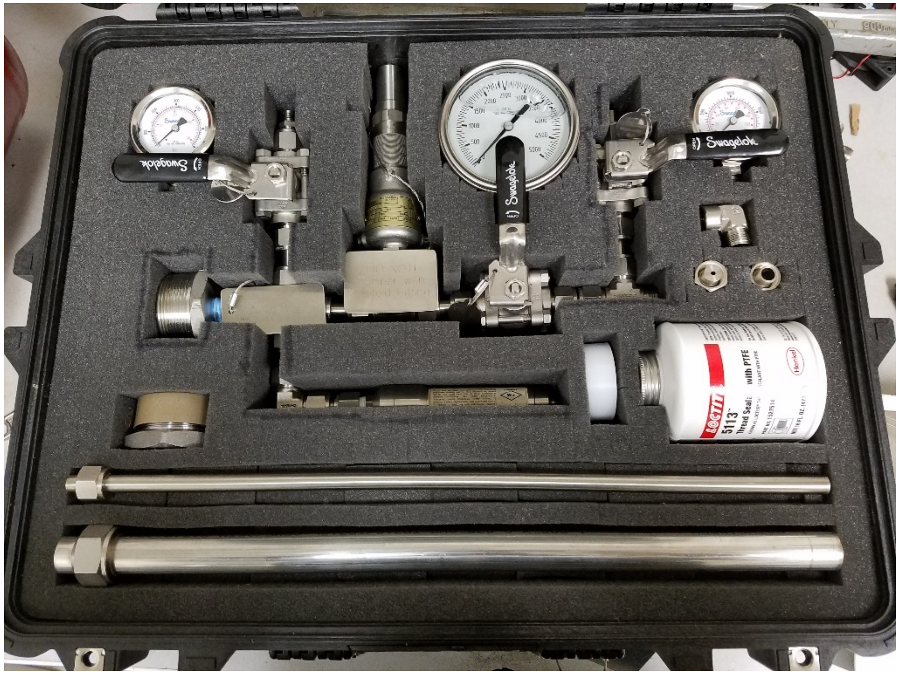
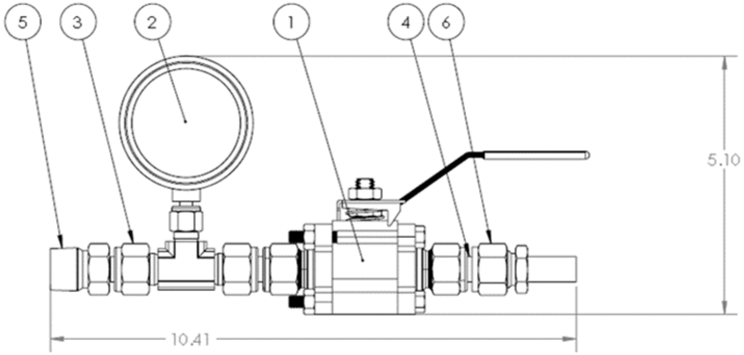
Technical Status

- 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

- **MI Basins Site**- 23 CO_2 EOR wells circa 1960-2003 were surveyed.
- 6 wells identified with some indicators of potential SCP.

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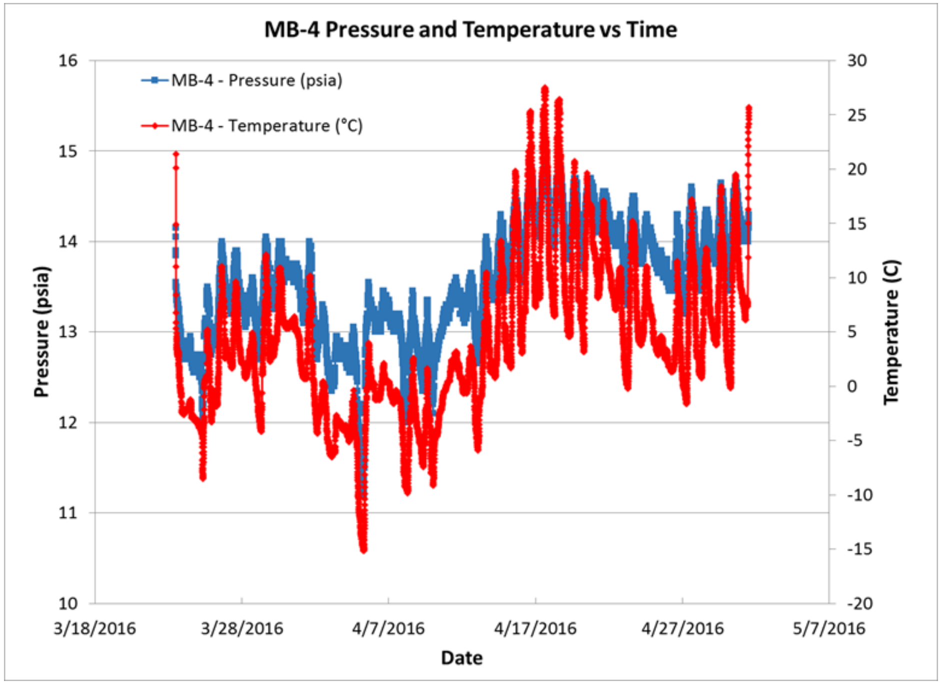
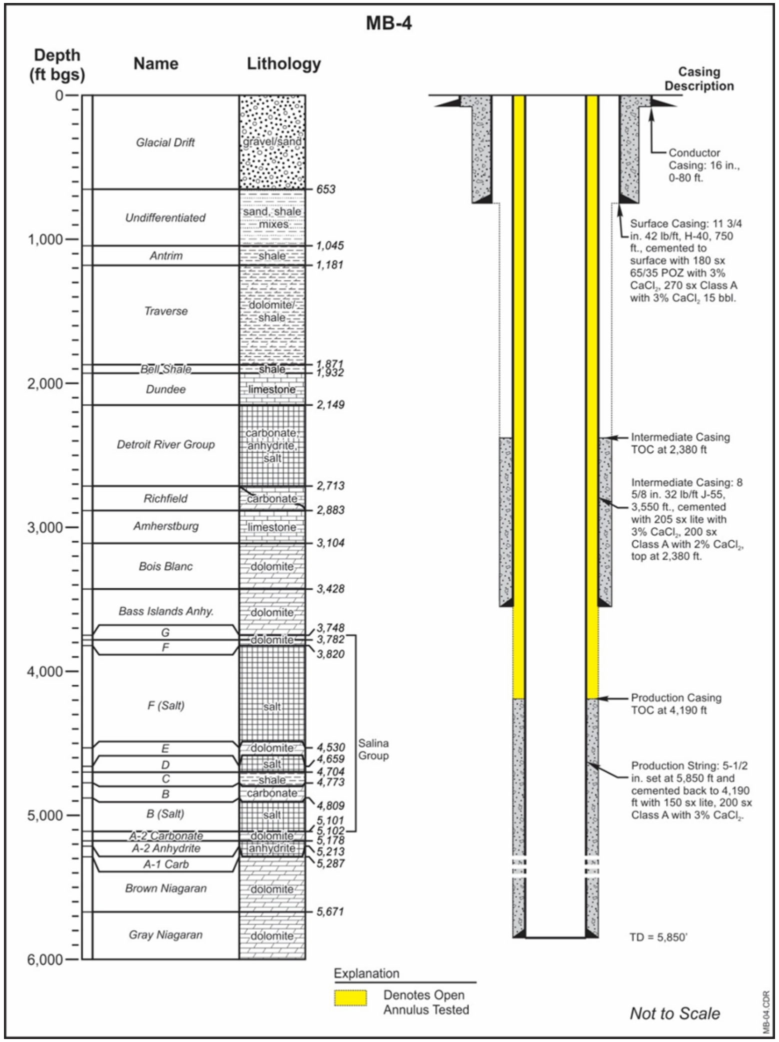
Technical Status- SCP Testing

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





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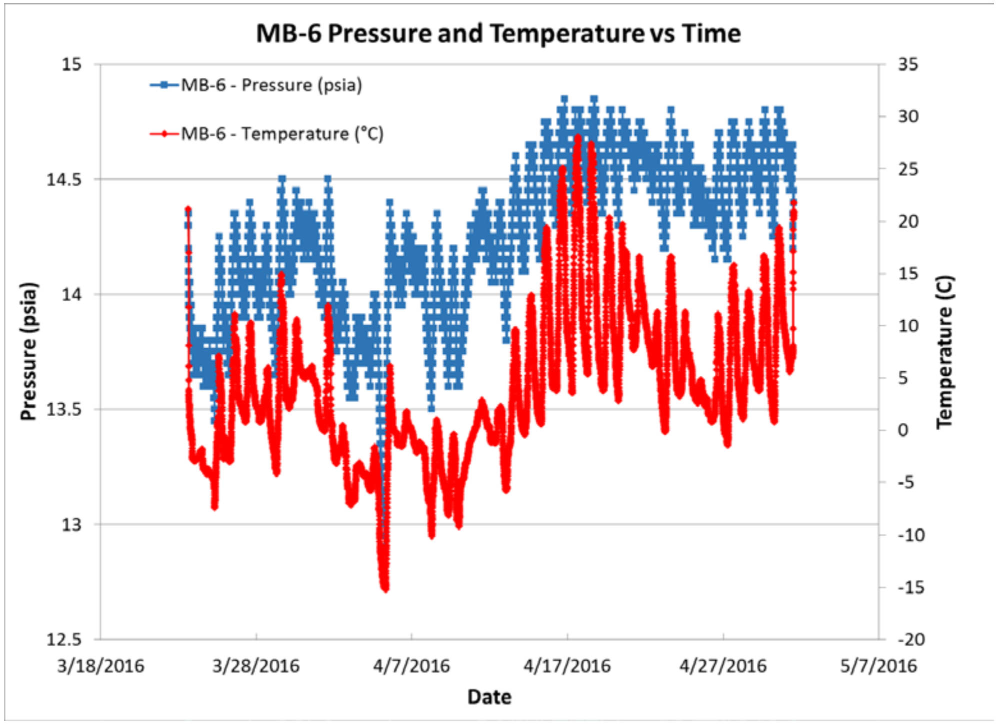
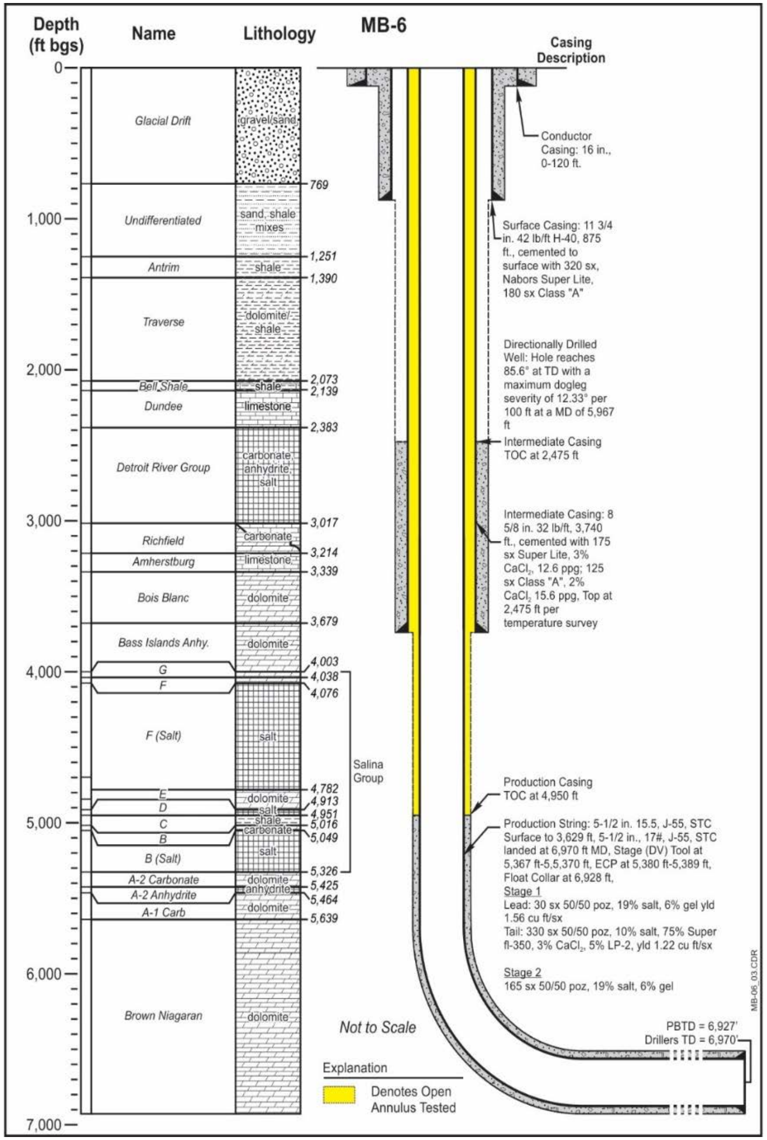
Technical Status- SCP Testing

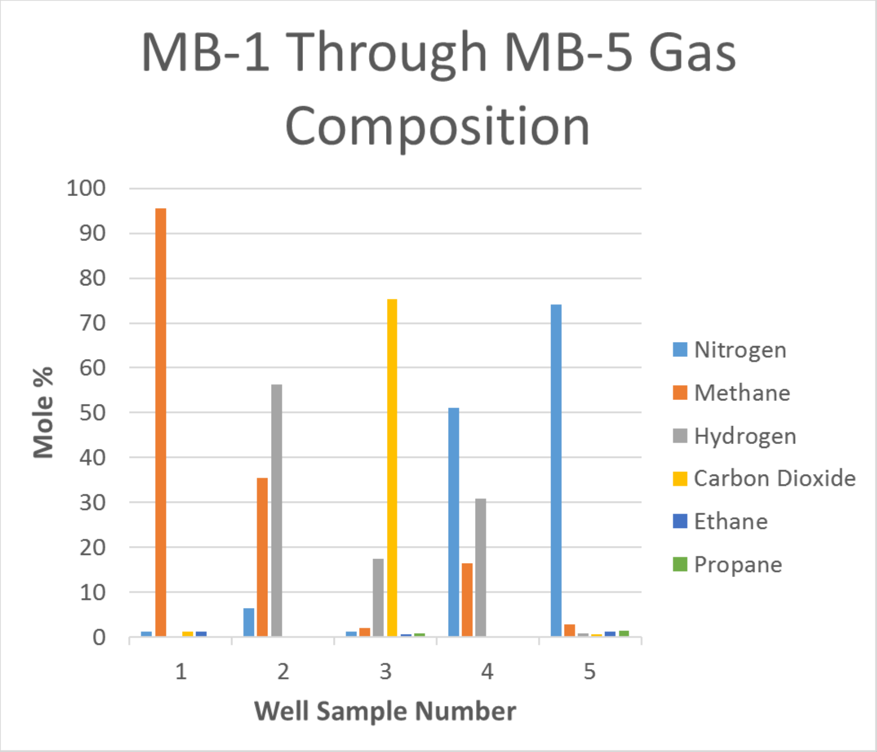
- All pressures were <50 psi.
- Pressure did not rebound to initial levels in many wells.





Technical Status- SCP Testing

- Gas sample analysis showed mostly methane, nitrogen, and hydrogen. Most likely from intermediate zones, atmosphere or cathodic protection.
- One well had higher CO_2 levels.



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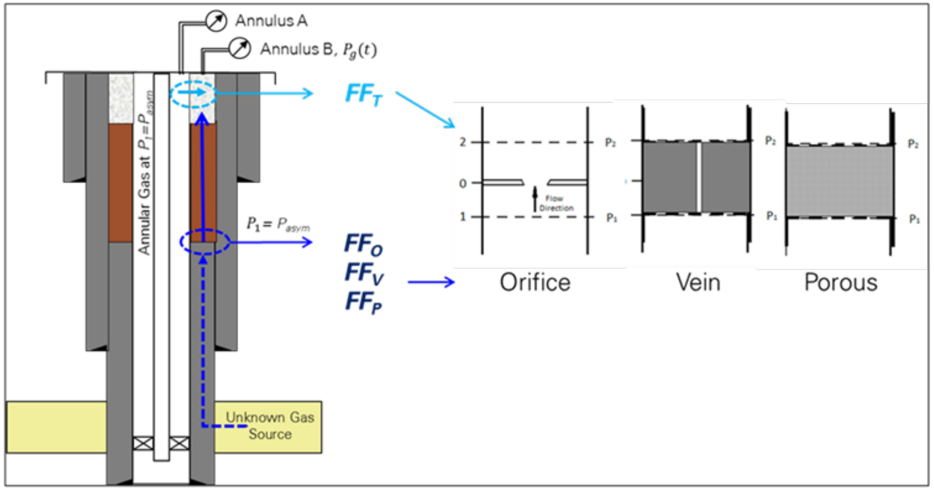
Technical Status- SCP Testing

- **Williston Basin site** SCP testing is planned in 30 CO_2 EOR wells for Summer-Fall 2017.
- Initial screening completed to identify wells for testing.
- Most wells appear to have lower SCP pressures (<60 psi).



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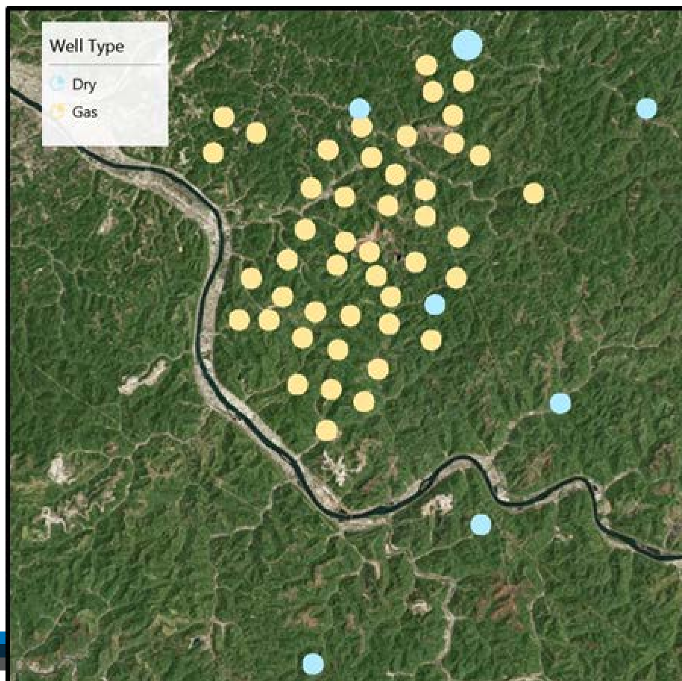
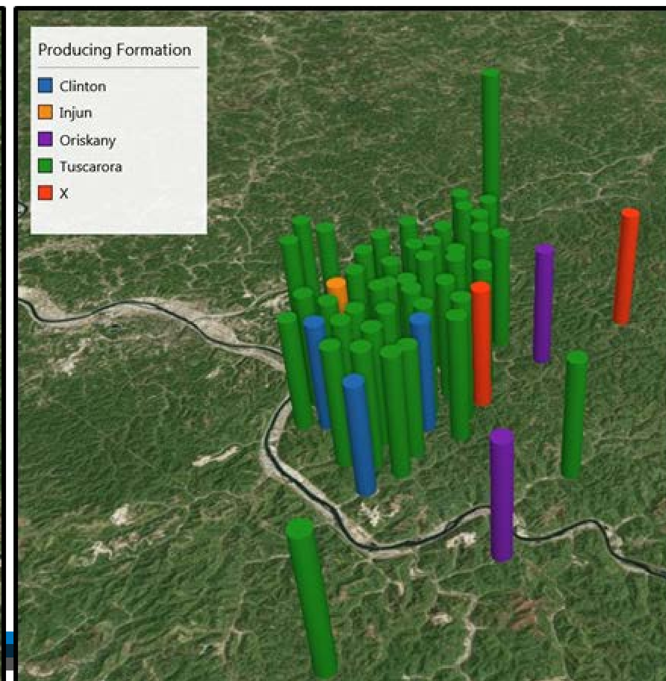
Technical Status- SCP Testing

- **Appalachian Basin site** sold to new operator, and the site was not available for SCP testing...but we continue discussions with the operator.
- Well history/record review indicates these wells did not have any more problems than typical oil & gas wells.





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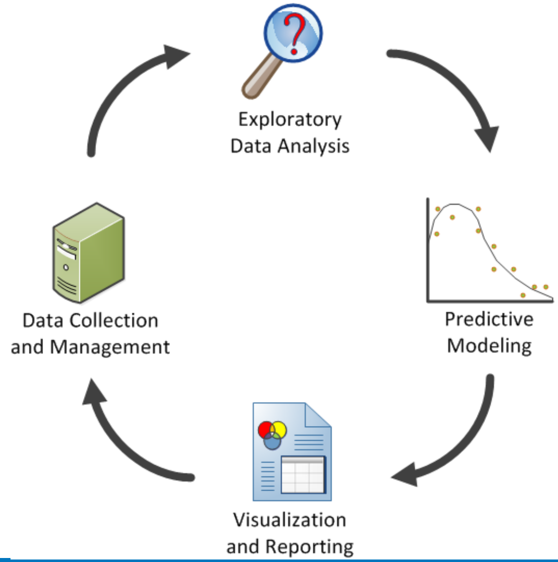
Technical Status

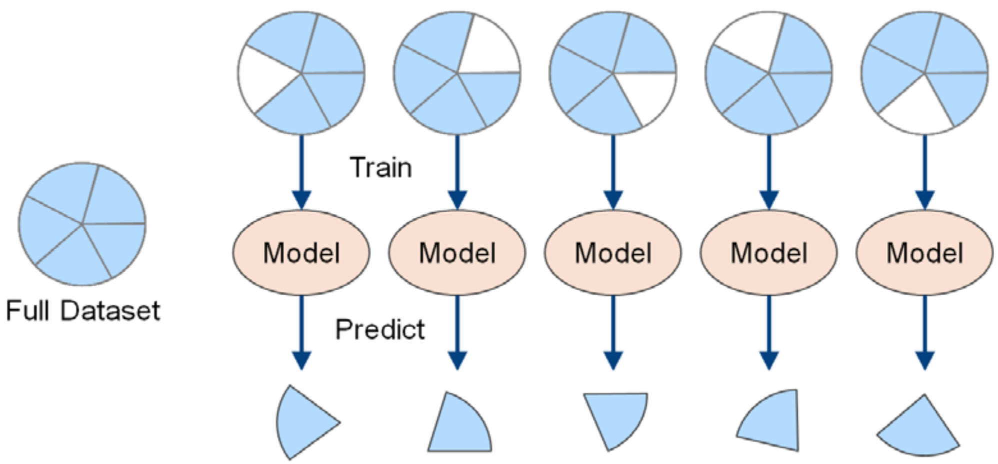
- Additional tasks on statistical machine based learning and uncertainty analysis of wellbore integrity metrics are planned in FY2019.
- Analytics with Machine Learning
  - Transform raw data into information for decision-making
  - Includes all of the infrastructure required to do that transformation:
    - Data collection & management
    - Exploratory data analysis
    - Predictive modeling
    - Visualization & reporting



Technical Status

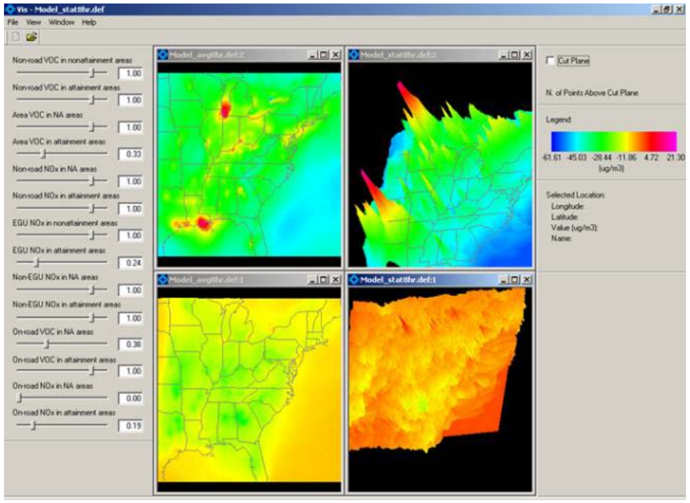
- Task 6.1 Well Integrity Regression Analysis
- Task 6.2 Data Analysis Algorithm Development
- Task 6.3 Meta-modeling on test fields

Data “Training”



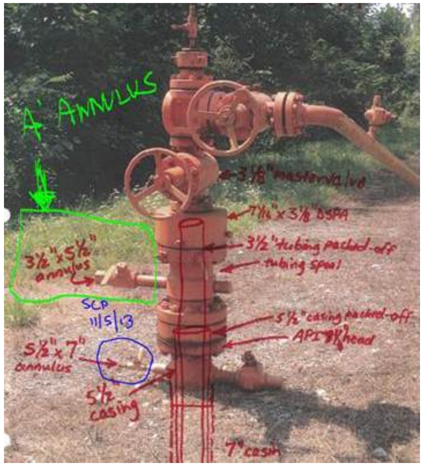
Source: Schuetter et al., 2105 SPE URTeC 2167005

Meta-Modeling “Sliders”



Accomplishments to Date

- 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, w-central U.S.) 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,
  - Advanced analytical processing of well construction parameters based on historical and spatial trends and machine learning to sustained casing pressure results.



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Accomplishments to Date

- Completed well integrity registry to identify processes that may affect wellbore (Task 2).
- Completed site characterization of geology, well construction, field history, well status, for test study areas in Appalachian Basin, Michigan Basin, and Williston Basin (Task 3).
- Completed sustained casing pressure testing in Michigan Basin site. Testing in-progress at Williston Basin Site. Appalachian Basin field sold to new operator so this study was more based on records/well history (Task 5).

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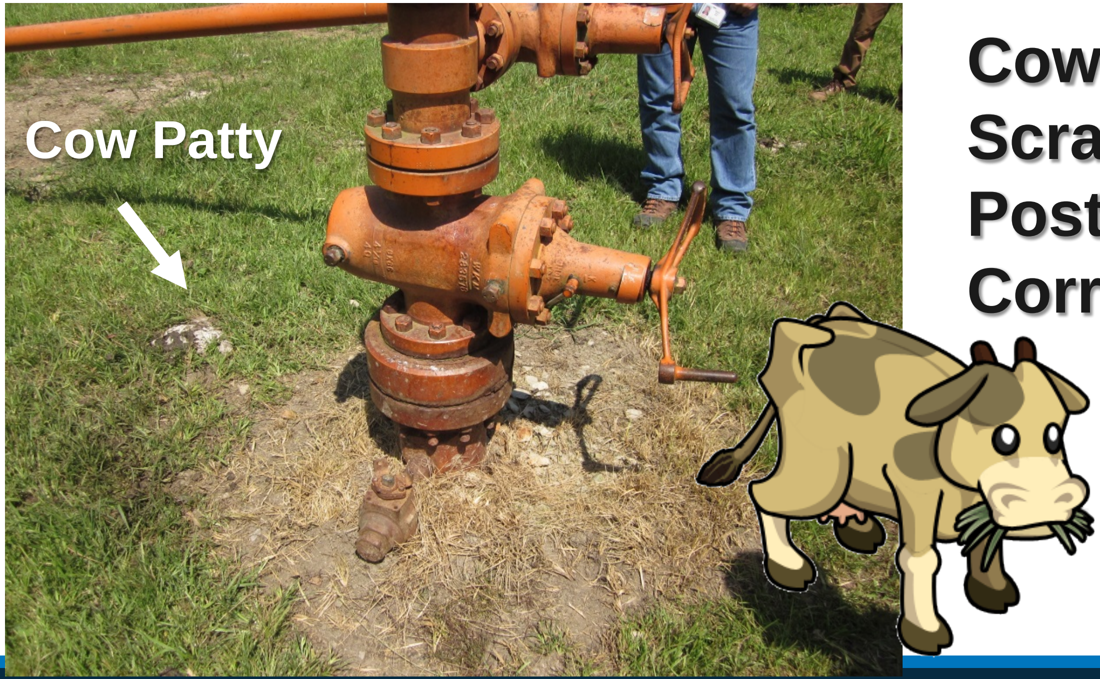
Lessons Learned

- SCP testing/monitoring method is effective, direct, low-cost method to test/monitor wells for variety of defects.
- Method doesn't require well to be offline or service rig.
- Data may show defect nature, severity, and location.



Cow Scratching Post Well Corrosion

Lessons Learned

- 23 CO_2 wells were surveyed for casing pressure at Michigan Basin. 6 wells had indications of casing pressure and were tested for casing pressure buildup.
- These wells showed only minor casing pressure related to thermal effects.
- Overall, sustained casing pressure was not a common problem for the tested wells at the Michigan Basin site.
- Well construction practices were sufficient to isolate the injection zone and prevent any significant migration of CO_2 into the wellbore.

Lessons Learned

- Well construction methods that appear to have helped maintain wellbore integrity at the site include:
  - Multiple strings of casing (conductor, surface, intermediate, and deep) are present in the wells which reduces potential for gas migration from intermediate zones.
  - 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 are cemented in with several hundred feet of cement, and in many cases over 1000 ft of cement.
  - Cement was allowed to set and the top of cement was tagged to confirm the top of cement, which was especially pertinent to this site because there was potential to lose cement in washout zones.

Lessons Learned

- Well records at an Appalachian Basin site did not show unusual well history related that would suggest substantial issues with these well exposed to a natural CO_2 field in the subsurface.
- Future work will expand sustained casing pressure testing to Williston Basin field to provide additional data on well integrity.
- Results will be analyzed with machine based learning methods to determine if certain well construction factors may be related to CO_2 corrosion.

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

- The project is designed to develop a comprehensive approach to analyzing wellbore integrity for CO_2 storage applications from start to finish.
- Results of the project will benefit CO_2 storage applications throughout the U.S. and advance technologies aimed at surveying, identifying, and characterizing well integrity factors.
- The project methods will be validated with actual well data from CO_2 environments, providing realistic results.

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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.

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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 automated machine based learning analytics can identify wells with poor integrity
- 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

Sponsors

U.S. DEPARTMENT OF ENERGY | NATIONAL ENERGY TECHNOLOGY LABORATORY

Project Lead

Battelle
The Business of Innovation

Technical Advisory Committee

Rick Pardini (Core Energy)
Neeraj Gupta (Battelle)

Project Management (Task1)

Principal Investigator: Mark Moody

Project Manager: J.R. Sminchak

Task 8

Reporting & Tech Transfer

J.R. Sminchak (Battelle)

Task 2

Well Integrity Registry

Andrew Duguid

Task 3

Well Record Data Collection & Review

Autumn Haagsma

P. Dinterman

WVGES
GEOLOGY UNDERLIES IT ALL

Task 4

Log & Testing Based Well Integrity Assessment

Andrew Duguid

Task 5

Sustained Casing Pressure Analysis

Mark Moody

Task 6

Well Integrity Analysis Machine Based Learning

Cheryl Triplett

Task 7

Wellbore Integrity Factor Uncertainty Analysis

Andrew Duguid

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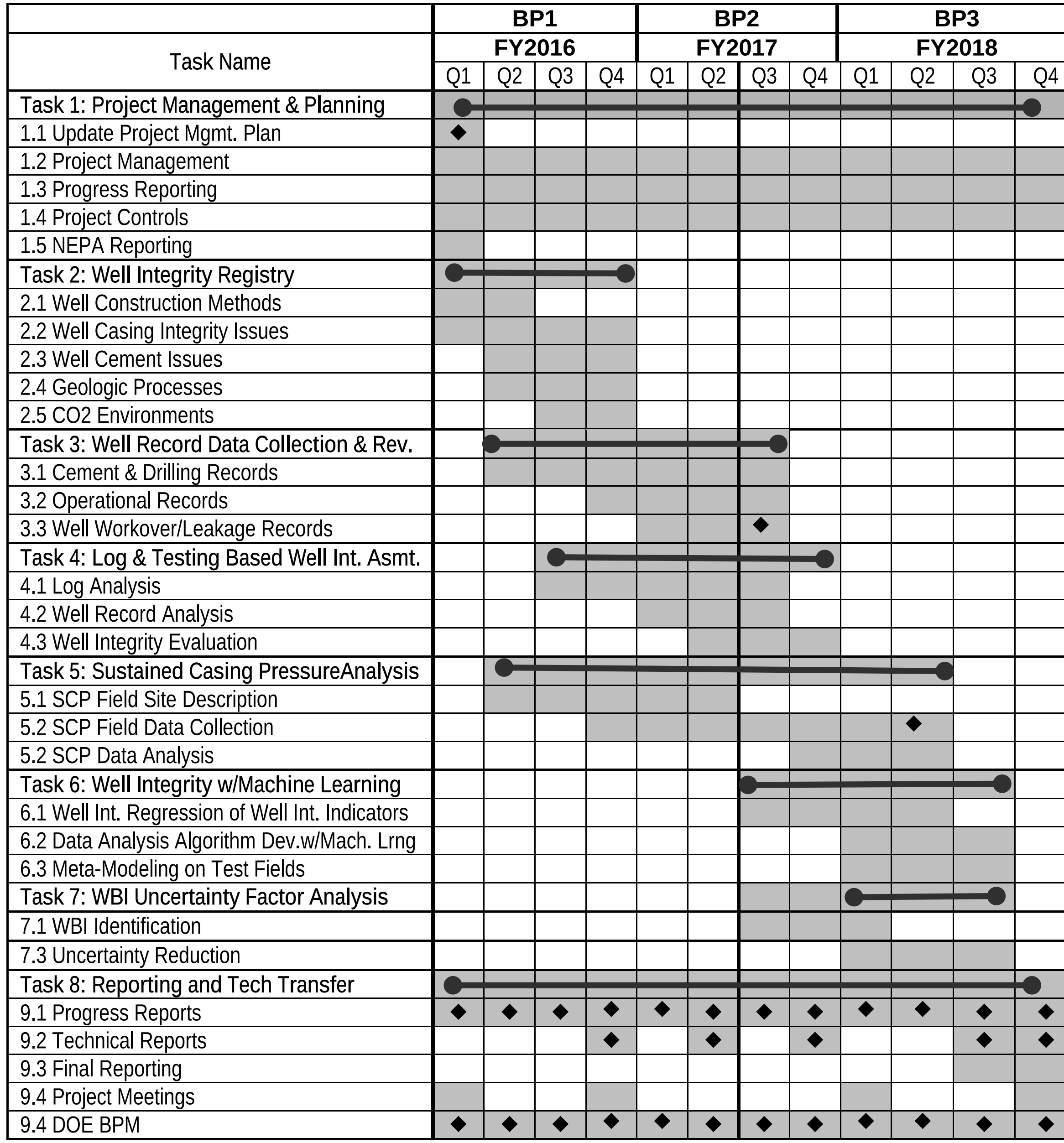
Gantt Chart

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



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