Farnsworth Unit - Ochiltree Field Project

Southwest Regional Partnership on Carbon Sequestration (SWP)

DE-FC26-05NT42591

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New Mexico Institute of Mining and Technology

U.S. Department of Energy

National Energy Technology Laboratory
Carbon Storage R&D Project Review Meeting
Developing the Technologies and
Infrastructure for CCS

August 12-14, 2014

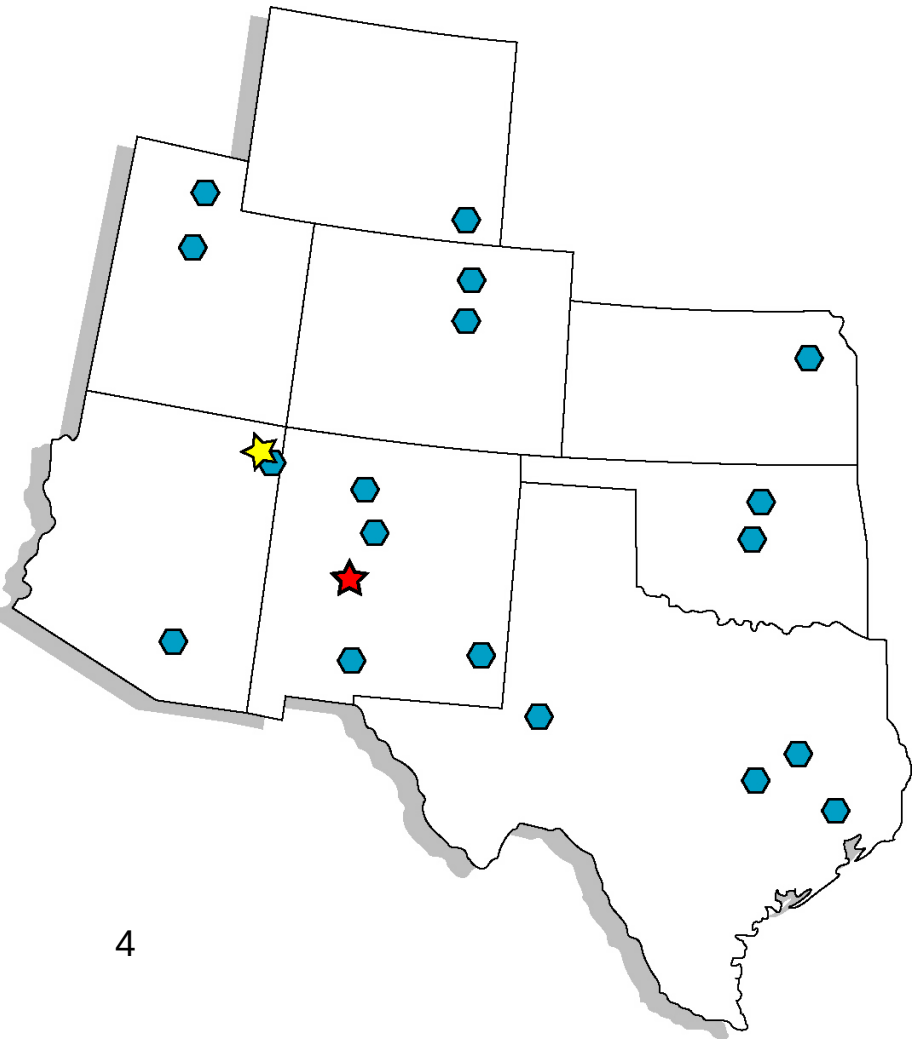
Acknowledgements

- Many thanks to NETL and the U.S. Dept of Energy for supporting this project!
- Thank you to all the SWP partners, technical and otherwise, especially some stellar FFRDC collaborators.
- Special thanks to Schlumberger Carbon Services for their outstanding collaborative efforts.

Presentation Outline

- **Introduction and Summary of Partners**
- Project Overview: Goals and Objectives
- Technical Status
- Accomplishments to Date
- Summary

Introduction: Partners of the SWP



In all partner states:

- major universities
- geologic survey
- other state agencies
- National Laboratories
- over 50 partners

as well as

- Western Governors Association
- five major utilities
- seven energy companies
- three federal agencies
- the Navajo Nation
- many other critical partners

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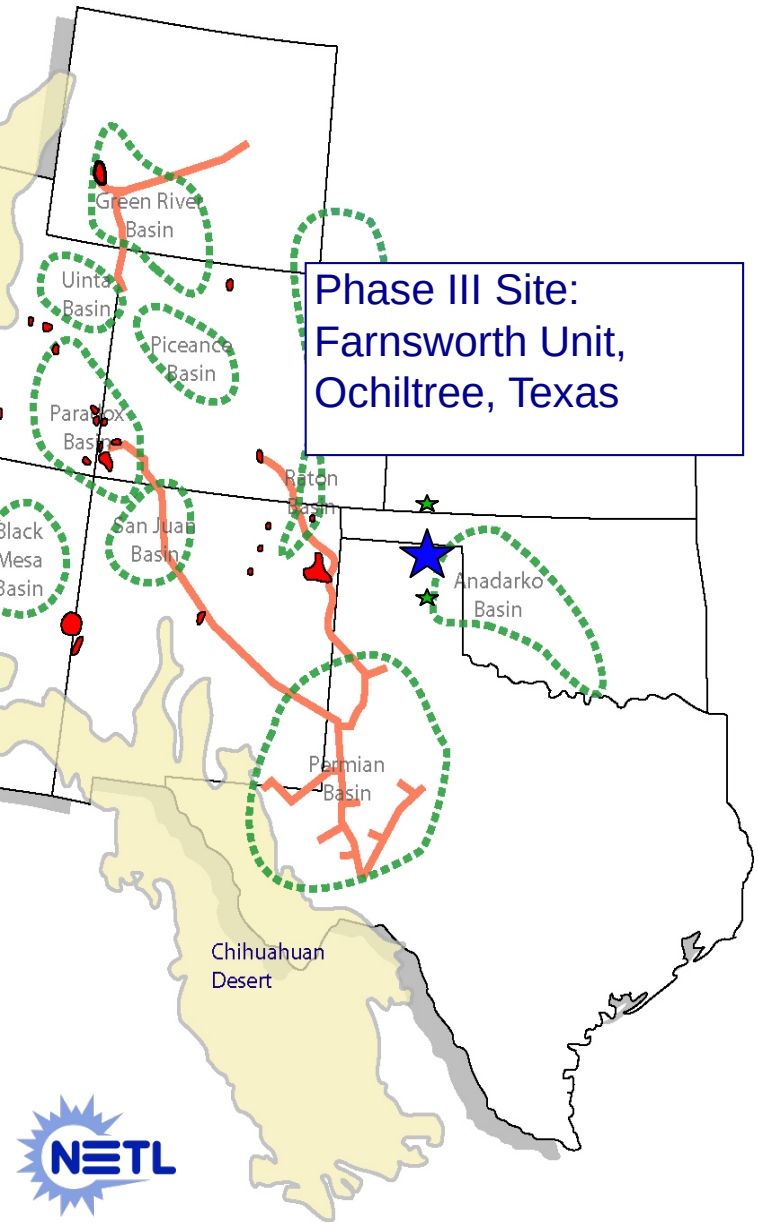
Project Overview: Goals and Objectives



The SWP's Phase III will be a Large-Scale EOR-CCUS Sequestration Test

General Goals:

- One million tons CO_2 injection
- Optimization of storage engineering
- Optimization of monitoring design
- Optimization of risk assessment
- "Blueprint" for CCUS in southwestern U.S.

A key aspect of this project:
NEW FIVE SPOT PATTERNS WILL BE DRILLED EVERY SIX MONTHS. THE SWP WILL "LEARN" FROM RESULTS, RE-ADJUST AND RE-DESIGN MONITORING/ANALYSIS FOR EACH NEW SET OF INJECTION WELLS, BASED ON ANALYSIS OF RESULTS OF THE PREVIOUS SETS OF WELLS.

Presentation Outline

- Introduction and Summary of Partners
- Project Overview: Goals and Objectives
- **Technical Status**
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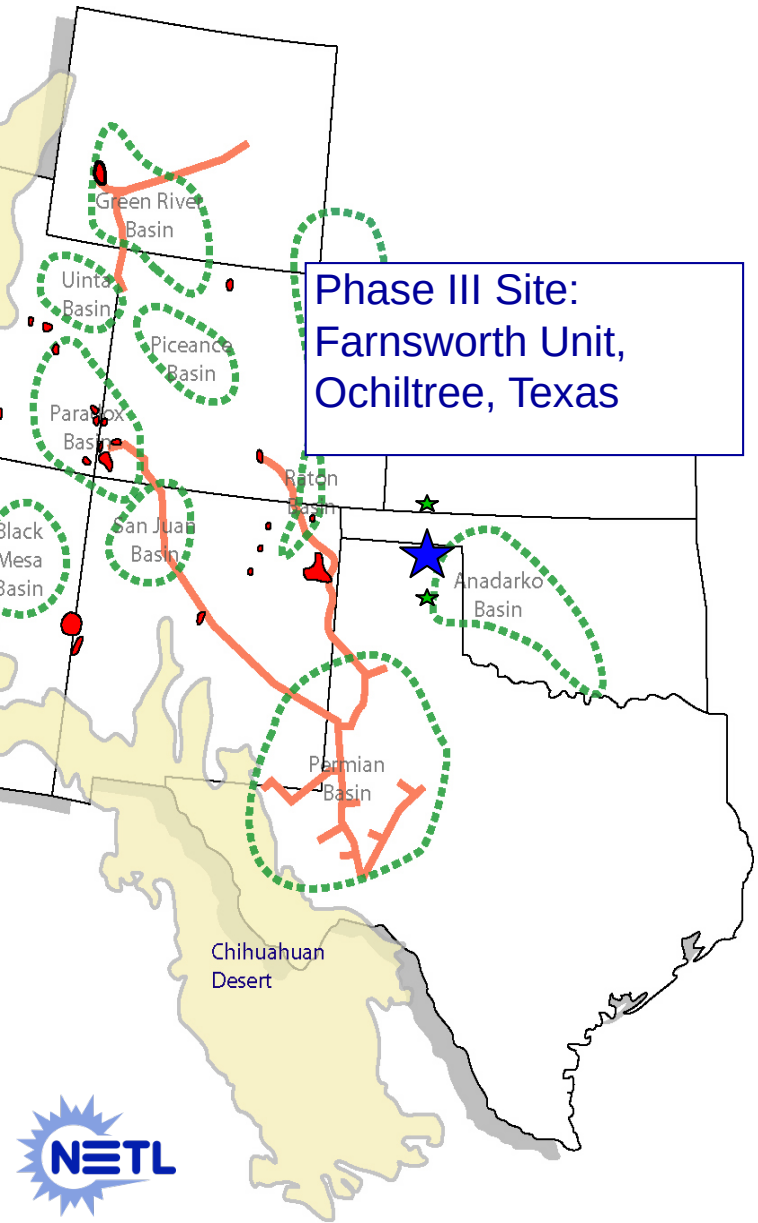
Technical Status



Phase III Site:
Farnsworth Unit,
Ochiltree, Texas

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Presentation Outline

- Introduction and Summary of Partners
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- Project Overview: Goals and Objectives
- Technical Status
- **Accomplishments to Date**
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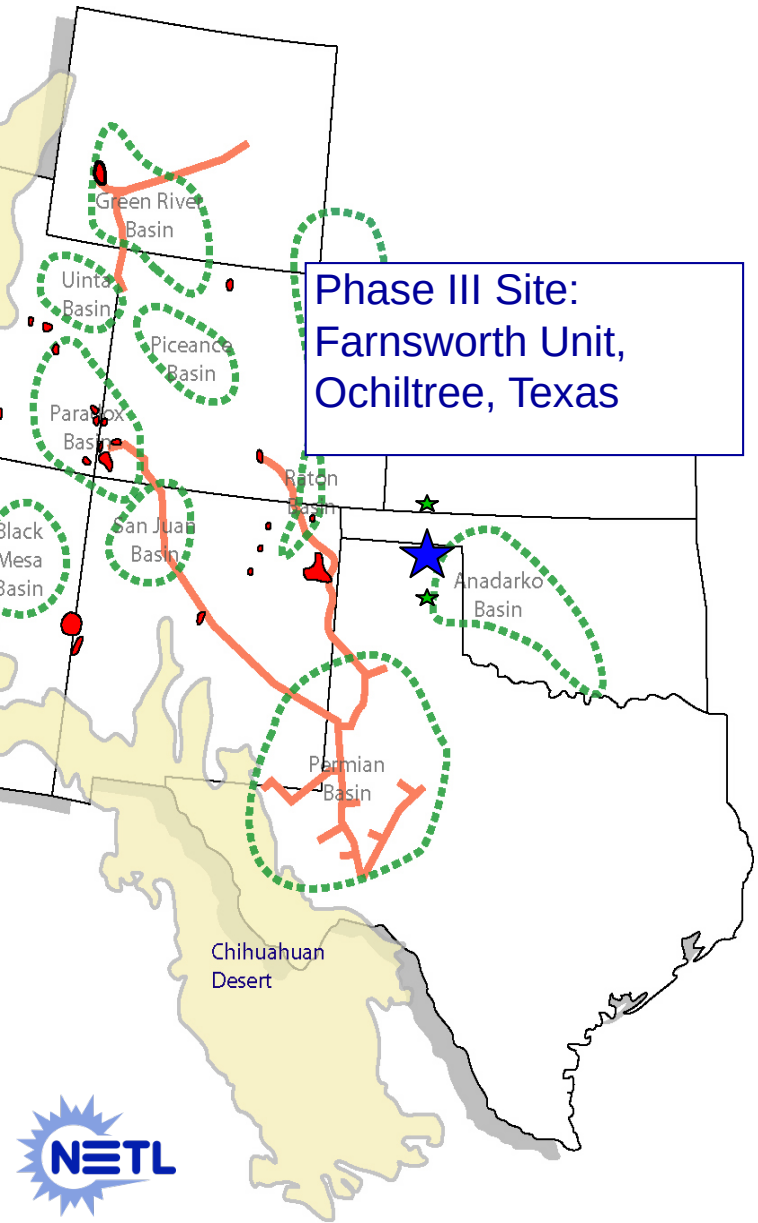
Brief Summary of Accomplishments



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- **One million tons CO_2 injection**
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Major accomplishments thus far:

- site suitability evaluation completed;
- geologic characterization ongoing;
- baseline simulation models developed;
- initial history match simulation completed
- baseline monitoring completed,
- 3D surface seismic survey of full FWU completed
- 3D VSP and crosswell baselines
- 233,000 tonnes CO_2 injected
- 127,000 tonnes CO_2 stored

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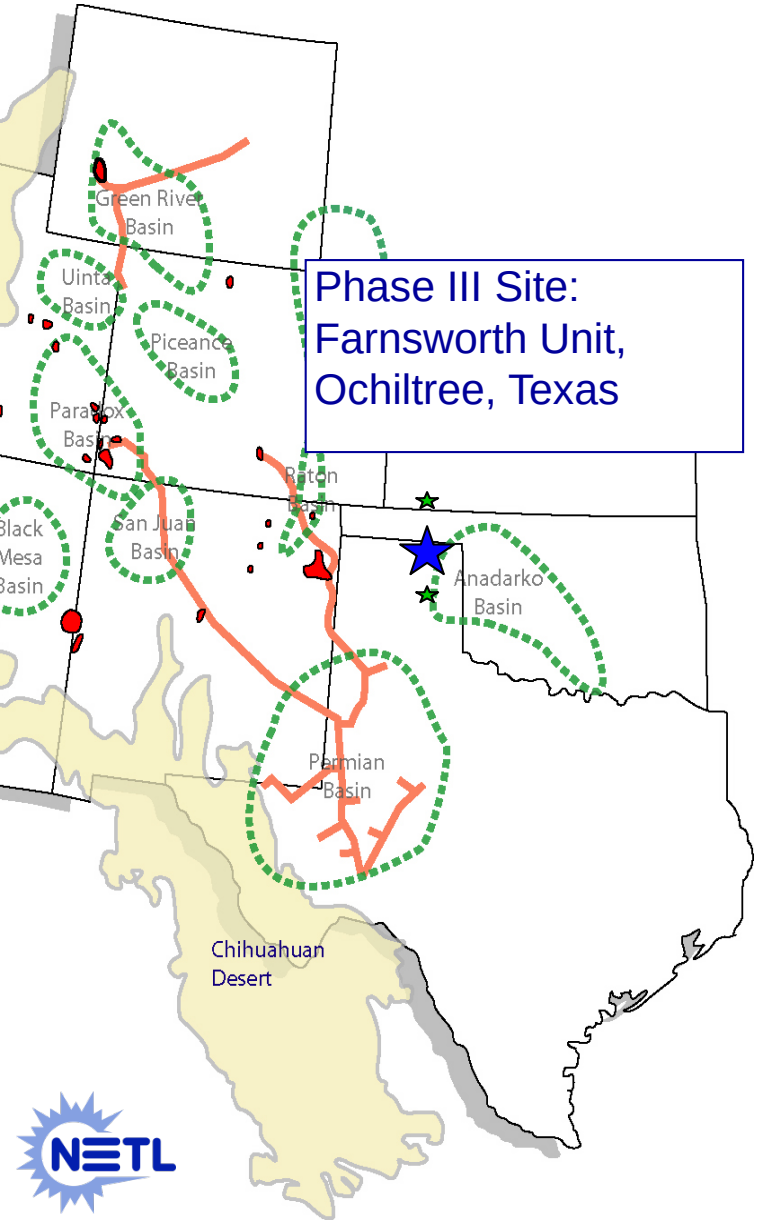

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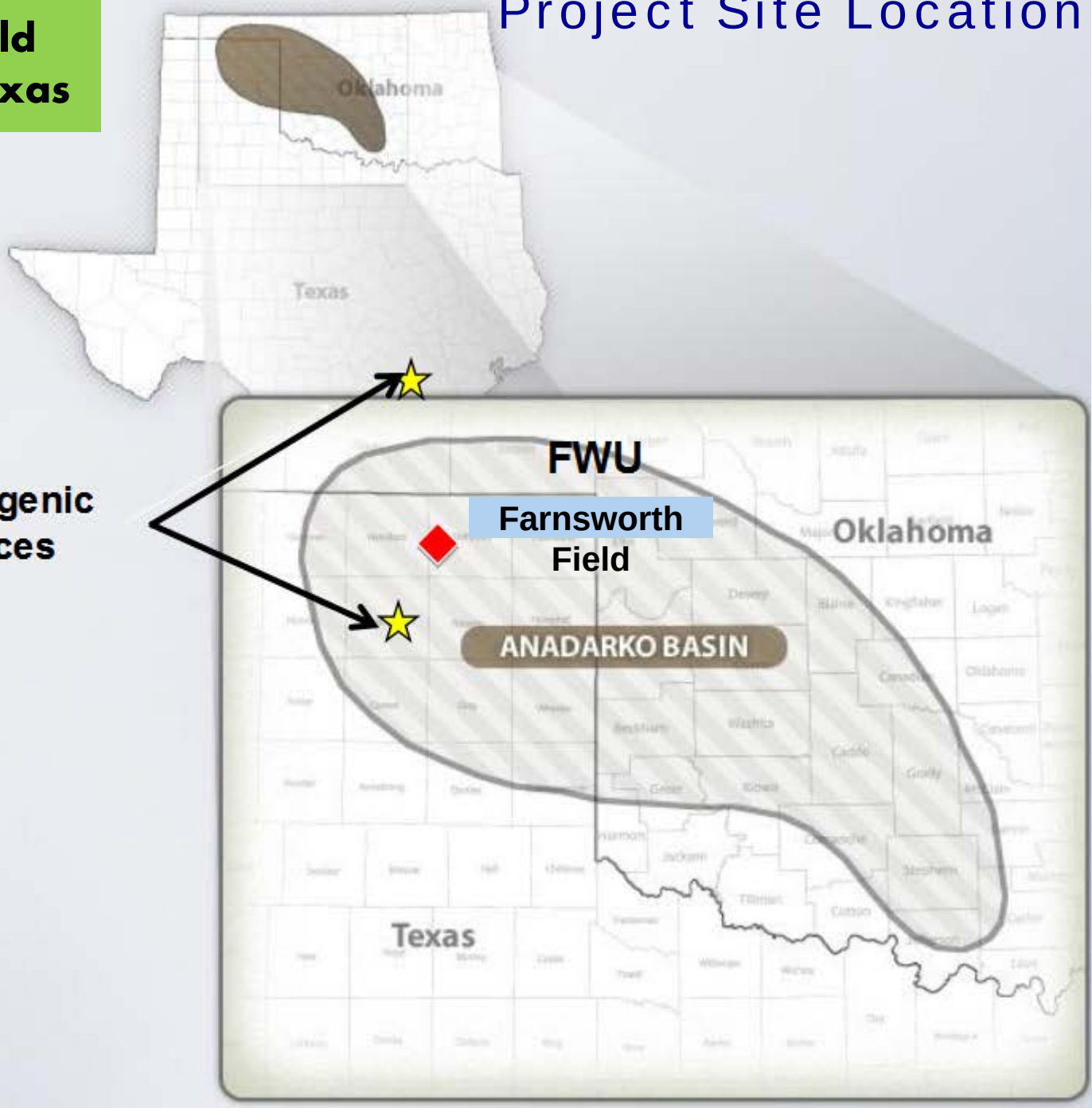
Technical Status: Project Details and Major Accomplishments to Date

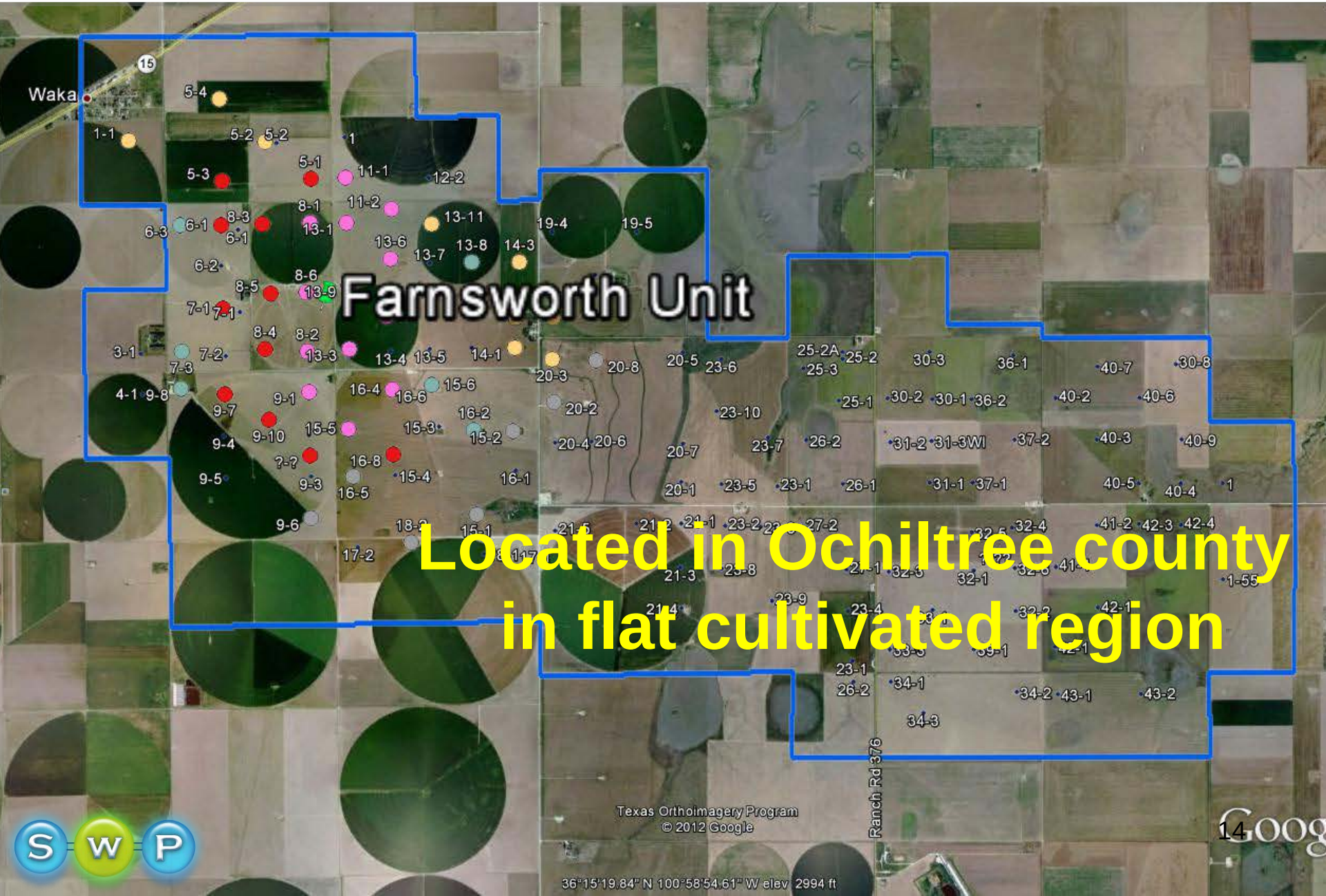
- **Project Location and Site Operator**
- CO_2 Sources
- Major Accomplishments

Project Site Location

Farnsworth Oil Field
Ochiltree County, Texas



Project Site Location



Site Operator: Chaparral Energy, LLC

Technical Status: Project Details and Major Accomplishments to Date

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- **CO_2 Sources**
- Major Accomplishments

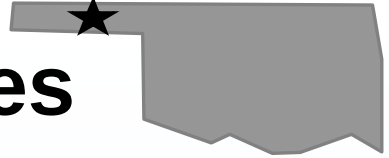
CO_2 Sources 100% Anthropogenic

CO_2 Supply

Arkalon Ethanol Plant Liberal KS

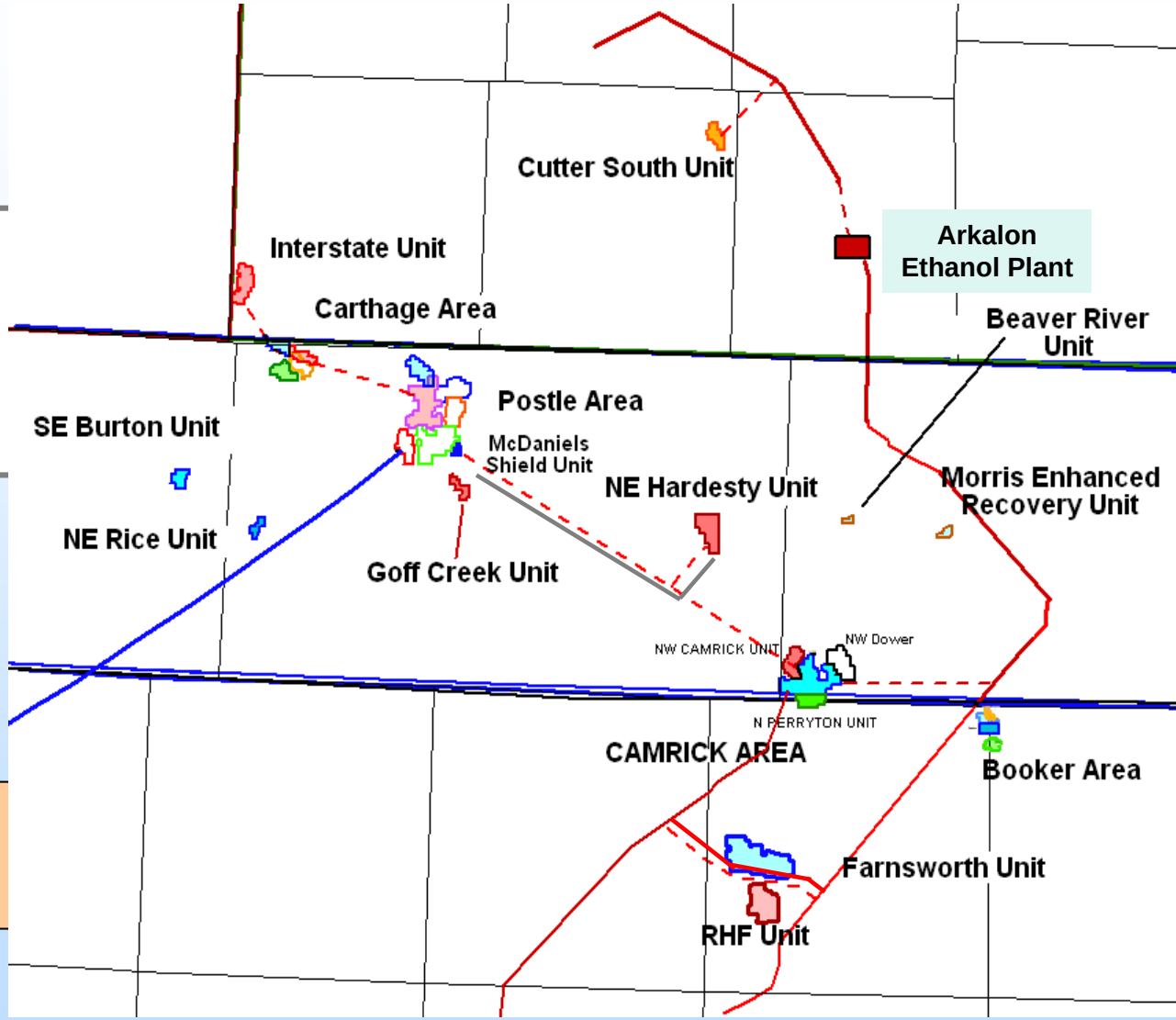
Agrium Fertilizer Plant Borger TX

Panhandle Area CO_2 Opportunities



Panhandle Area: 24 Projects
Net Potential: 35 MMBoe, 18% of total

Total OOIP	713 MMBO
Primary Production	74 MMBO
Secondary Recovery	116 MMBO
Tertiary Potential	74 MMBO
Net Tertiary Potential	35 MMBO



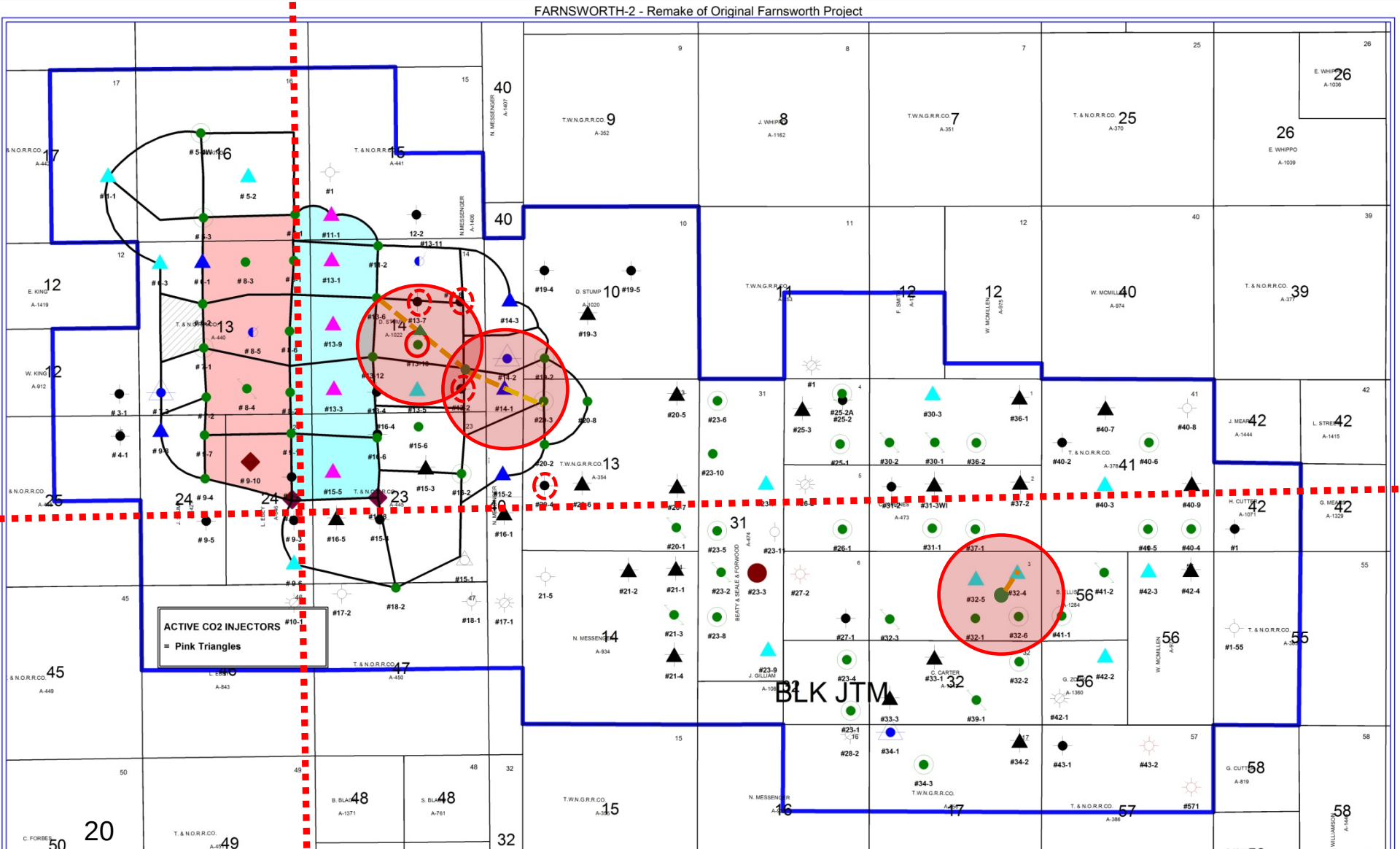
- Existing CELLC CO_2 Pipelines
- Proposed CELLC CO_2 Pipelines
- CO_2 Pipelines of Others

Technical Status: Project Details and Major Accomplishments to Date

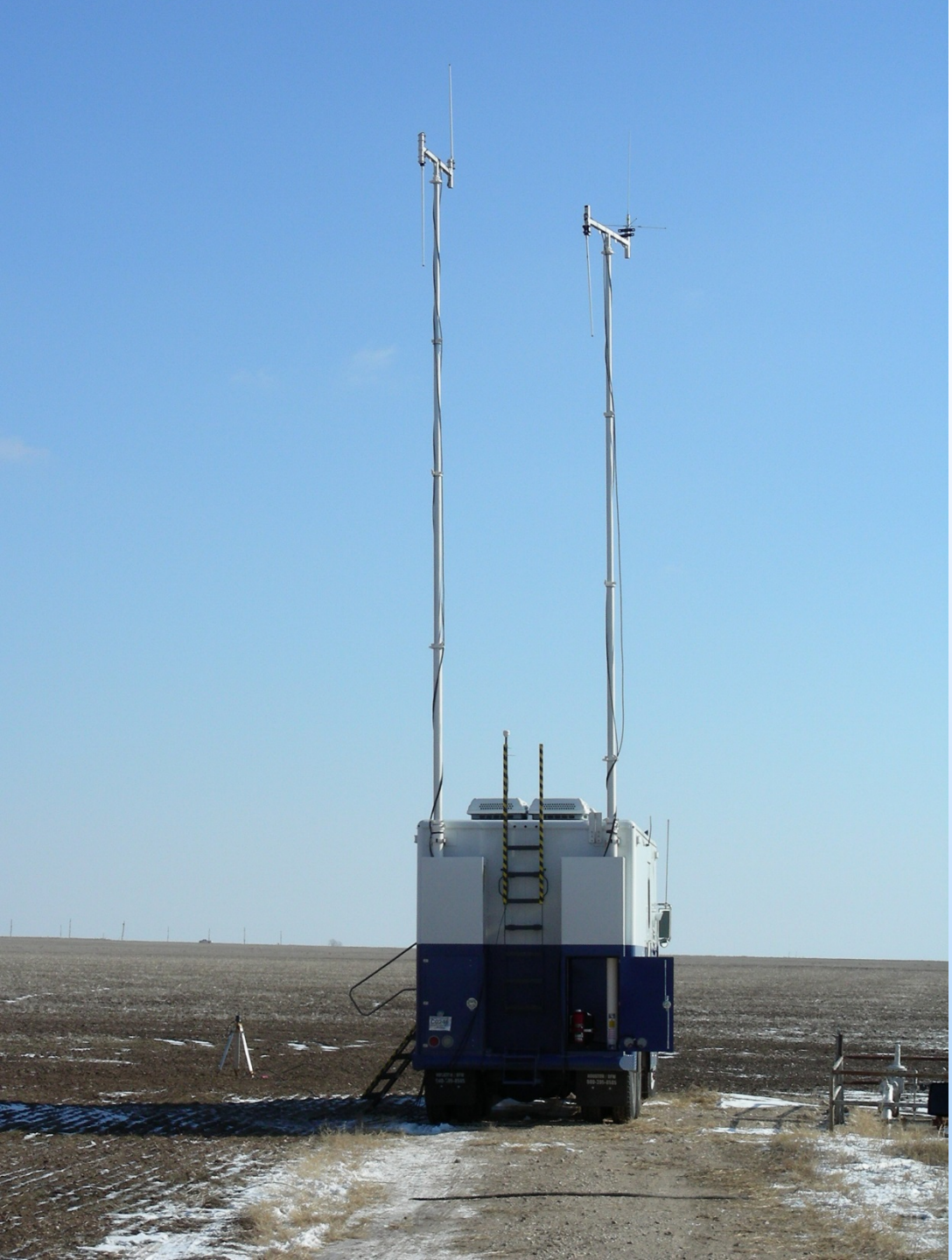
- Project Location and Site Operator
- CO_2 Sources
- **Major Accomplishments:**
  - **3-D Surface, baseline VSP and crosswell surveys**
  - 3 Characterization Wells drilled, logged, and cored
  - CO_2 injection and production; oil production
  - Effective Simulation Model based on Seismic and other Data
  - Initial History Match Simulation Completed

Existing and Planned Seismic Acquisitions

3D VSP **Passive** **Cross-well** **Legacy 2D** **FWU Border**



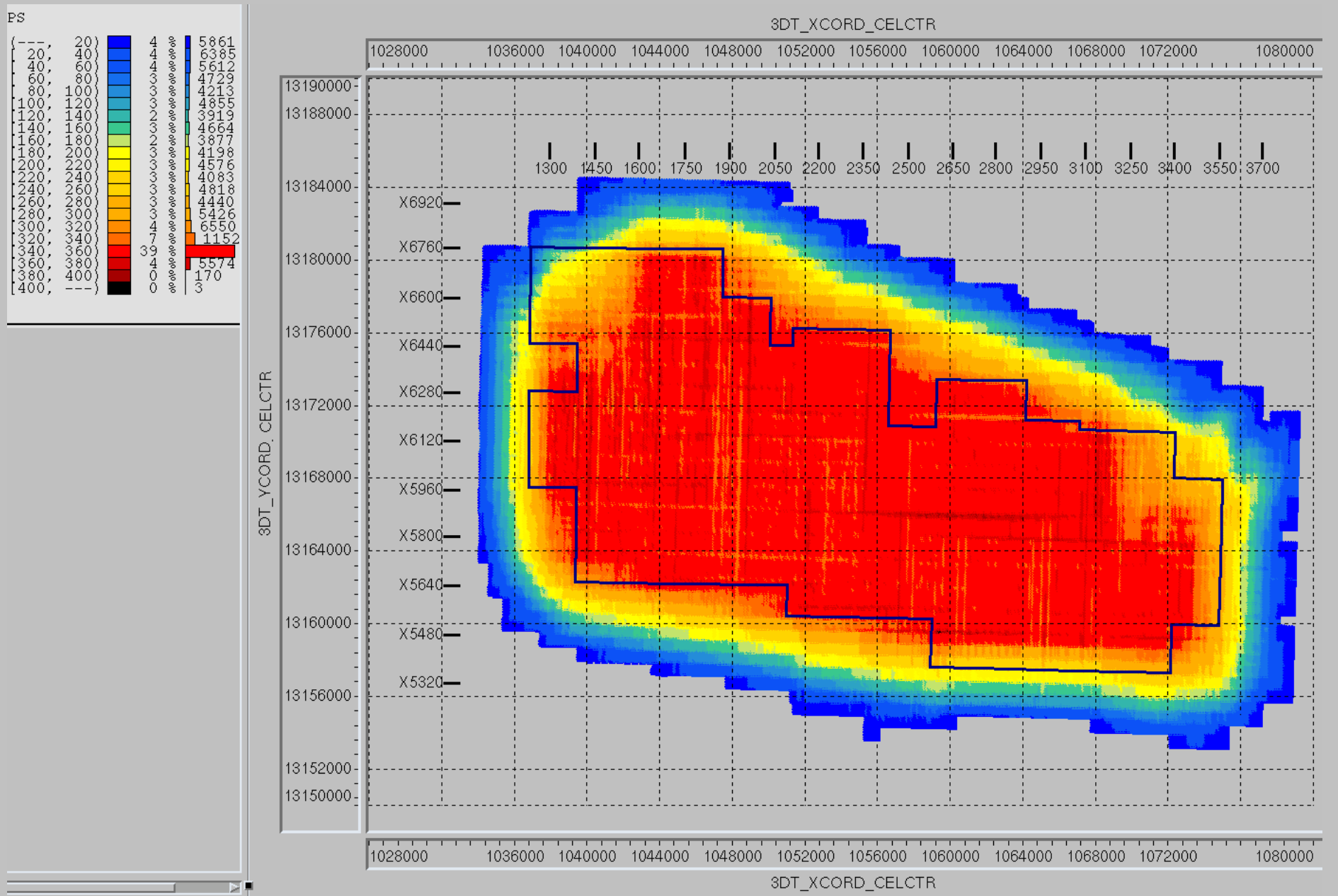

AHV-IV
COMMANDER

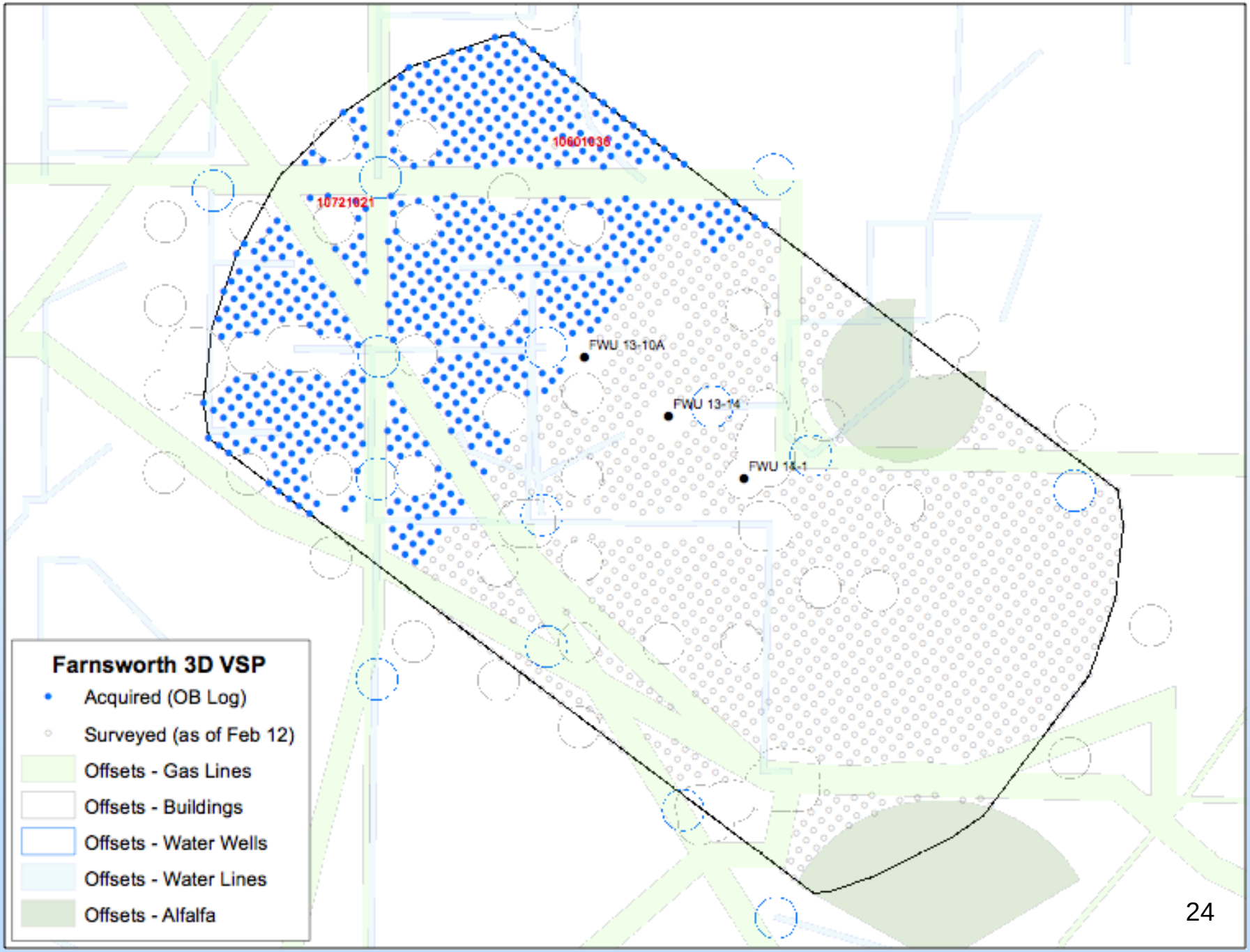


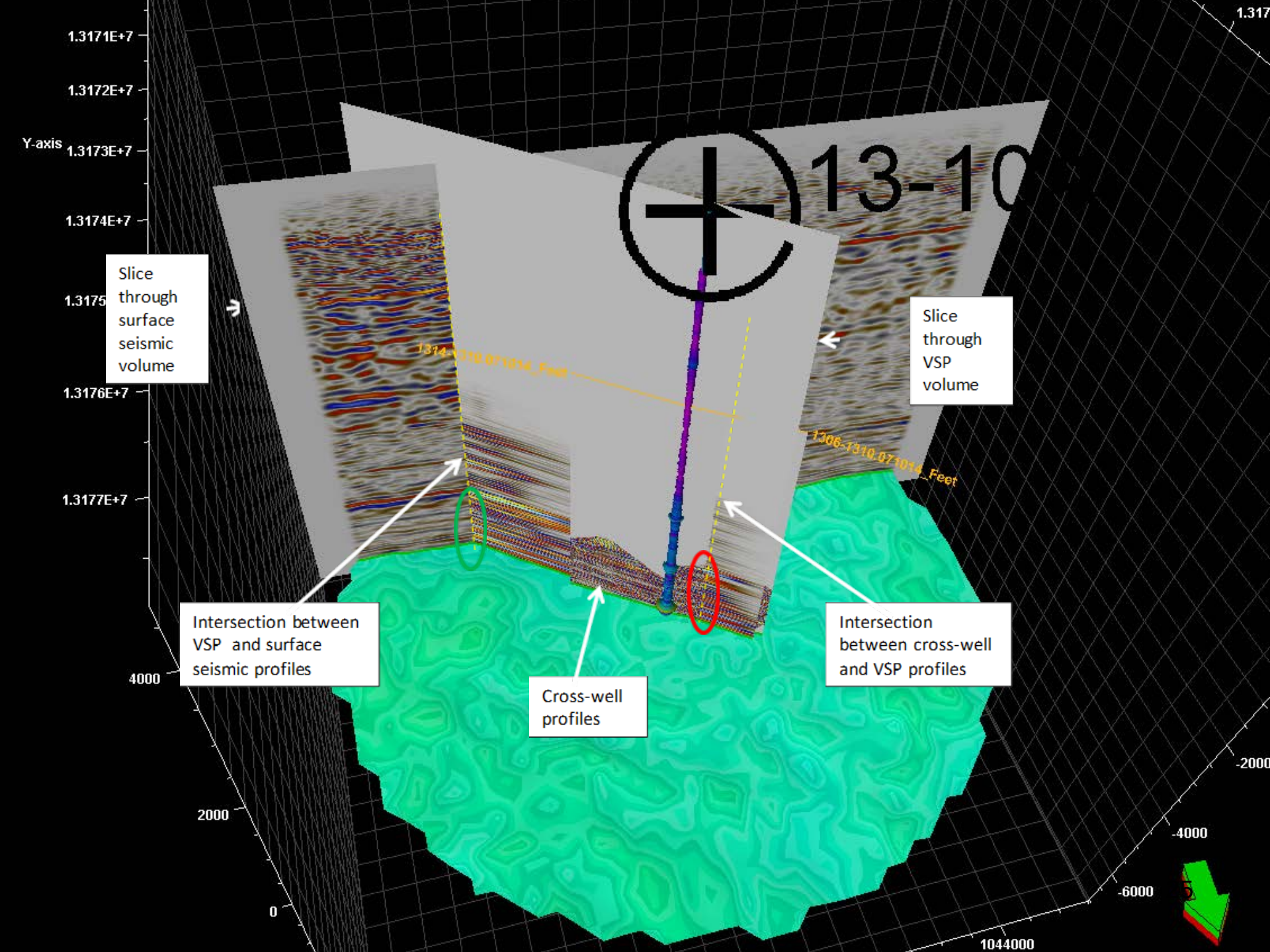
Seismic Acquisition

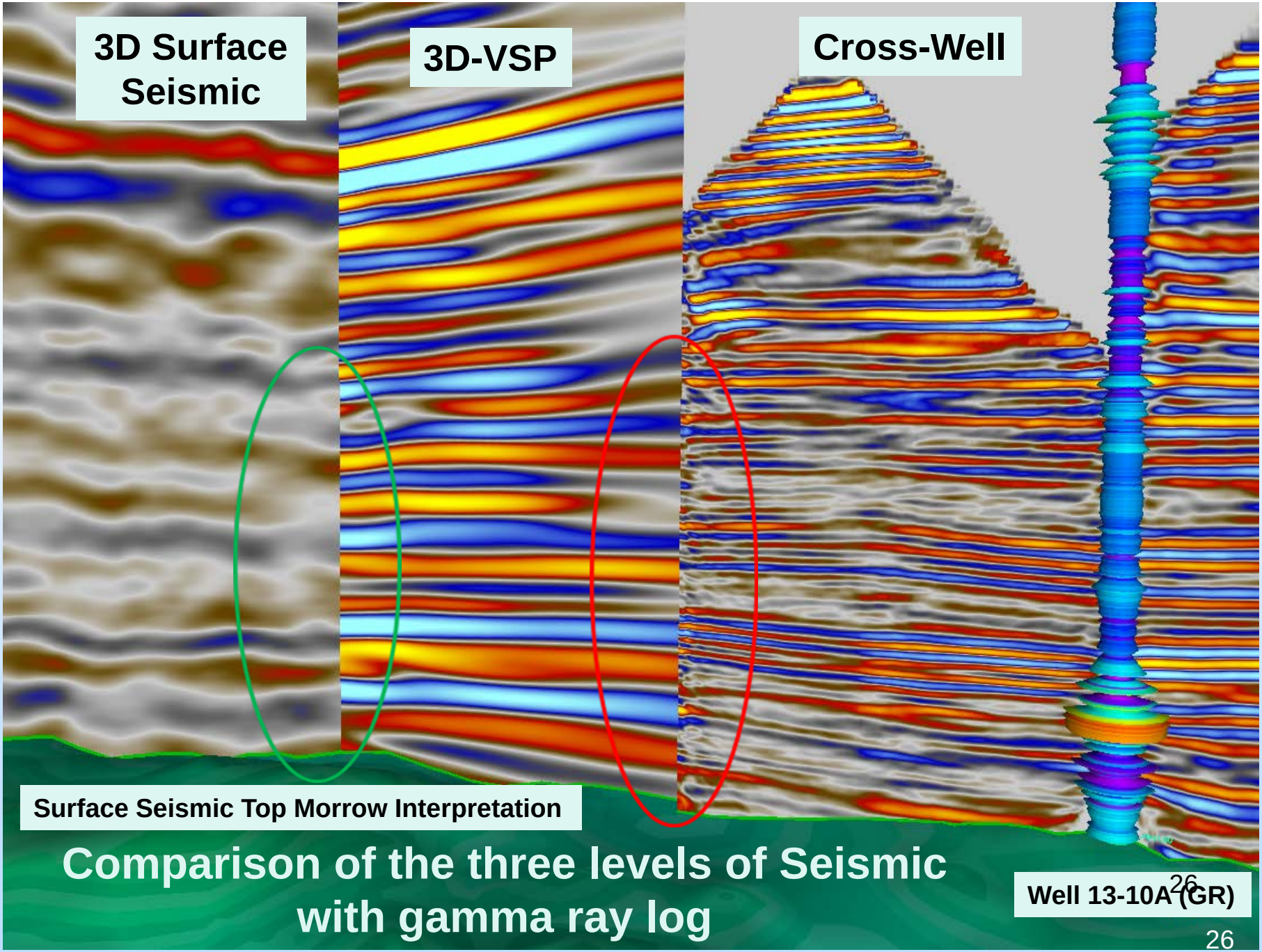
- **Data gathered at a mobile site which moved as portions of the field were shot**
- **Coordinated vibroseis trucks**
- **Initial QC on data**
- **Stored field data for each day before overnight review and pre-processing**

Fold Map with Unit Boundary




10601036
10721021
FWU 13-10A
FWU 13-14
FWU 14-1
Farnsworth 3D VSP
Acquired (OB Log)
Surveyed (as of Feb 12)
Offsets - Gas Lines
Offsets - Buildings
Offsets - Water Wells
Offsets - Water Lines
Offsets - Alfalfa


1.3171E+7
1.3172E+7
Y-axis
1.3173E+7
1.3174E+7
1.3175
1.3176E+7
1.3177E+7
4000
2000
0
-2000
-4000
-6000
1044000
13-10
Slice through surface seismic volume
Slice through VSP volume
Intersection between VSP and surface seismic profiles
Cross-well profiles
Intersection between cross-well and VSP profiles



Comparison of the three levels of Seismic with gamma ray log

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Technical Status: Project Details and Major Accomplishments to Date

- Project Location and Site Operator
- CO_2 Sources
- **Major Accomplishments:**
  - 3-D Surface, baseline VSP and crosswell surveys
  - **Three Characterization Wells drilled, logged, and cored**
  - CO_2 injection and production; oil production
  - Effective Simulation Model based on Seismic and other Data
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Three Characterization Well drilled

1310A: Nov ’13 – Jan ‘14
1314: Jan ‘14 – Feb ‘14
3208: Jun ‘14 – Jul ‘14

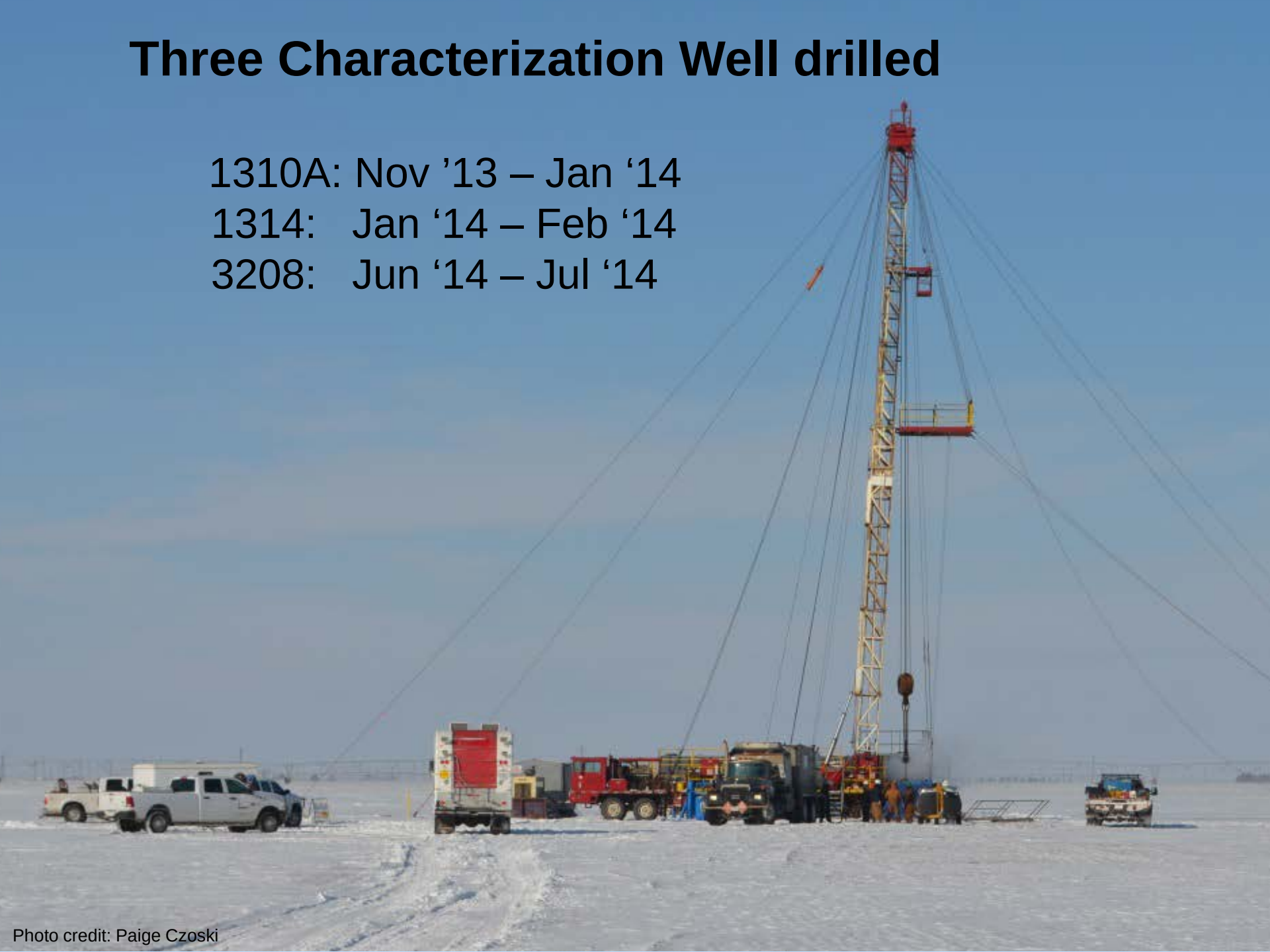
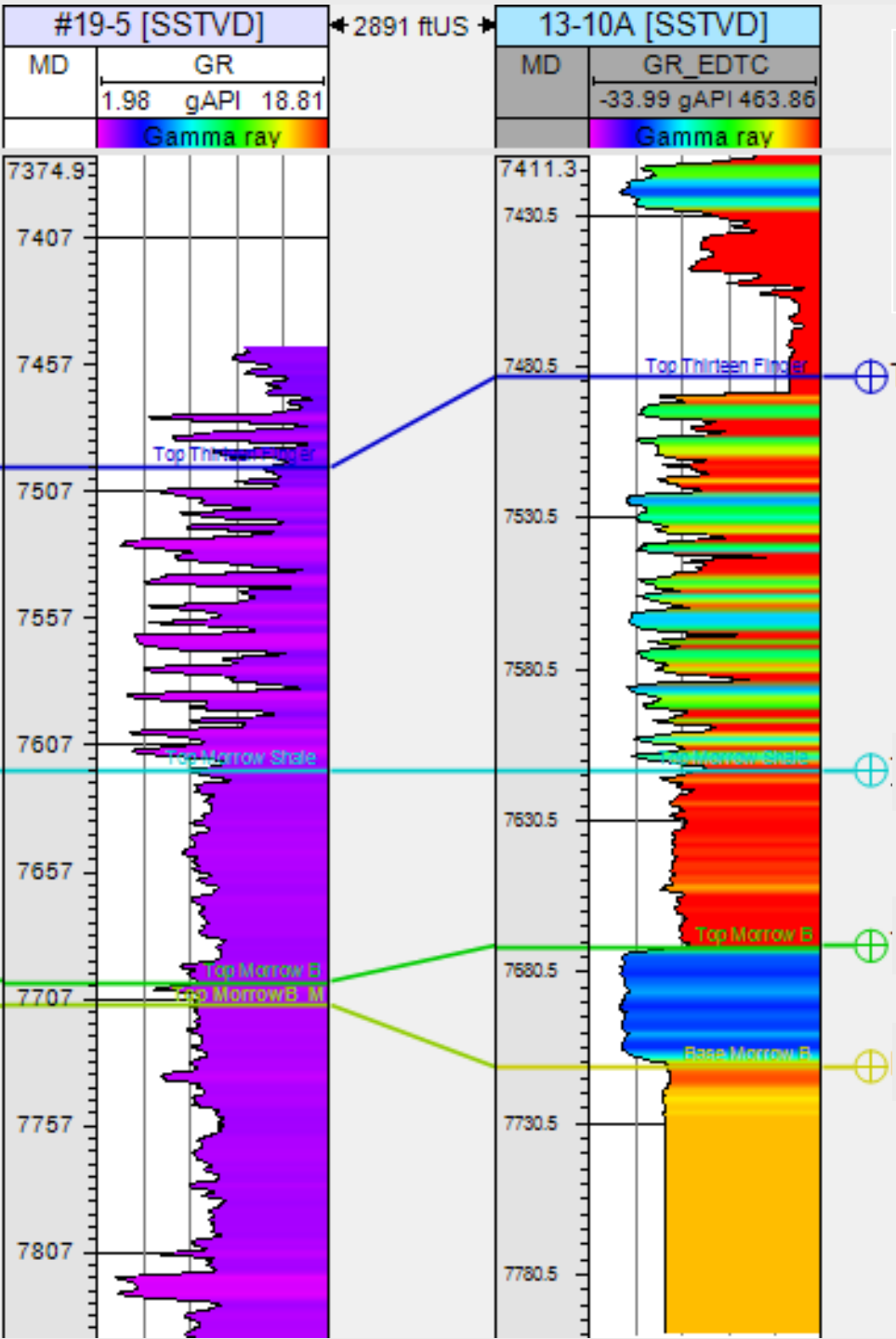


Photo credit: Paige Czoski



Left: GR log of well #19-5, without channel fill accumulation.

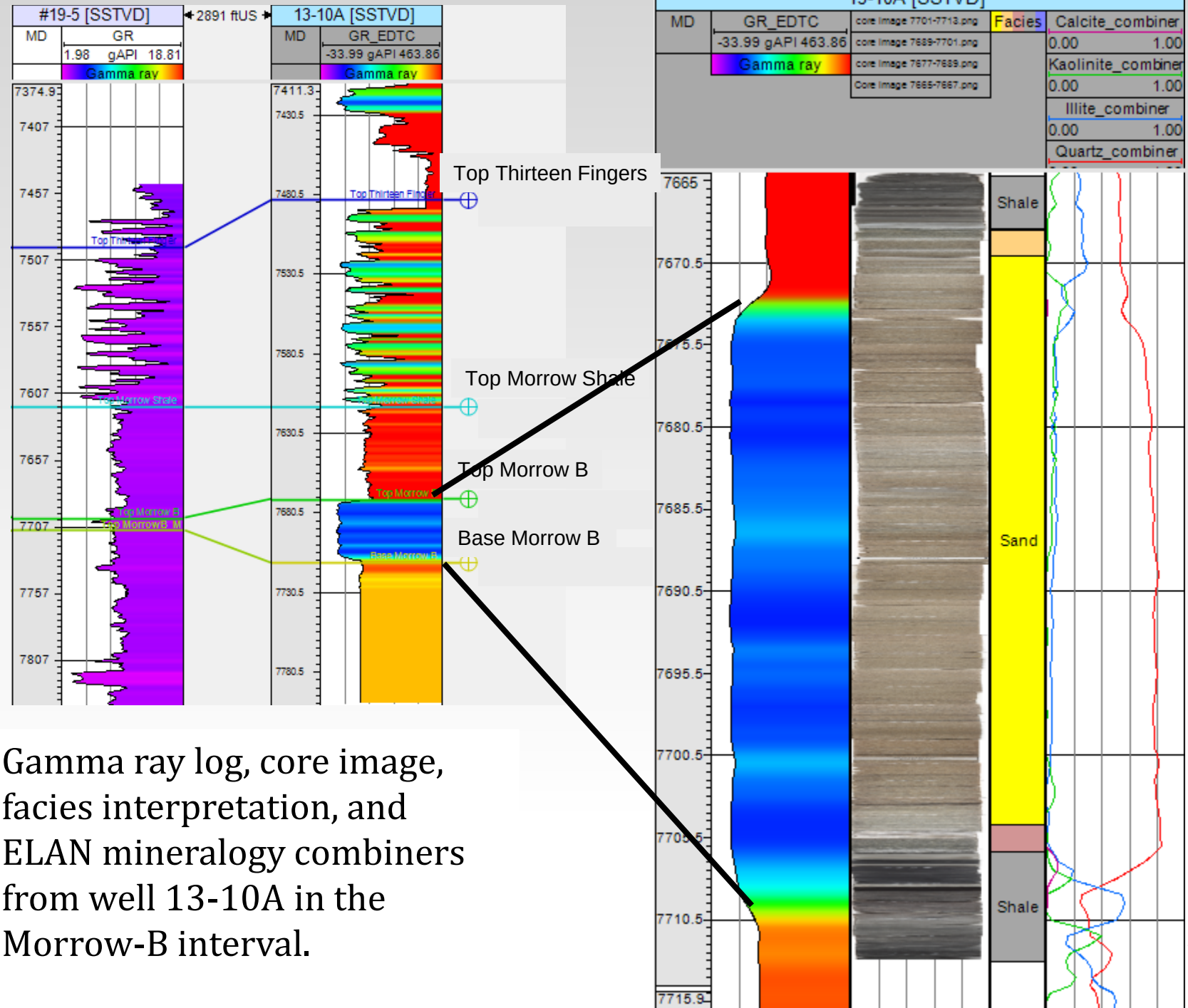
Right: GR log of well 13-10A with channel fill section.

Top Thirteen Fingers

Top Morrow Shale

Top Morrow B

Base Morrow B



Gamma ray log, core image, facies interpretation, and ELAN mineralogy combiners from well 13-10A in the Morrow-B interval.

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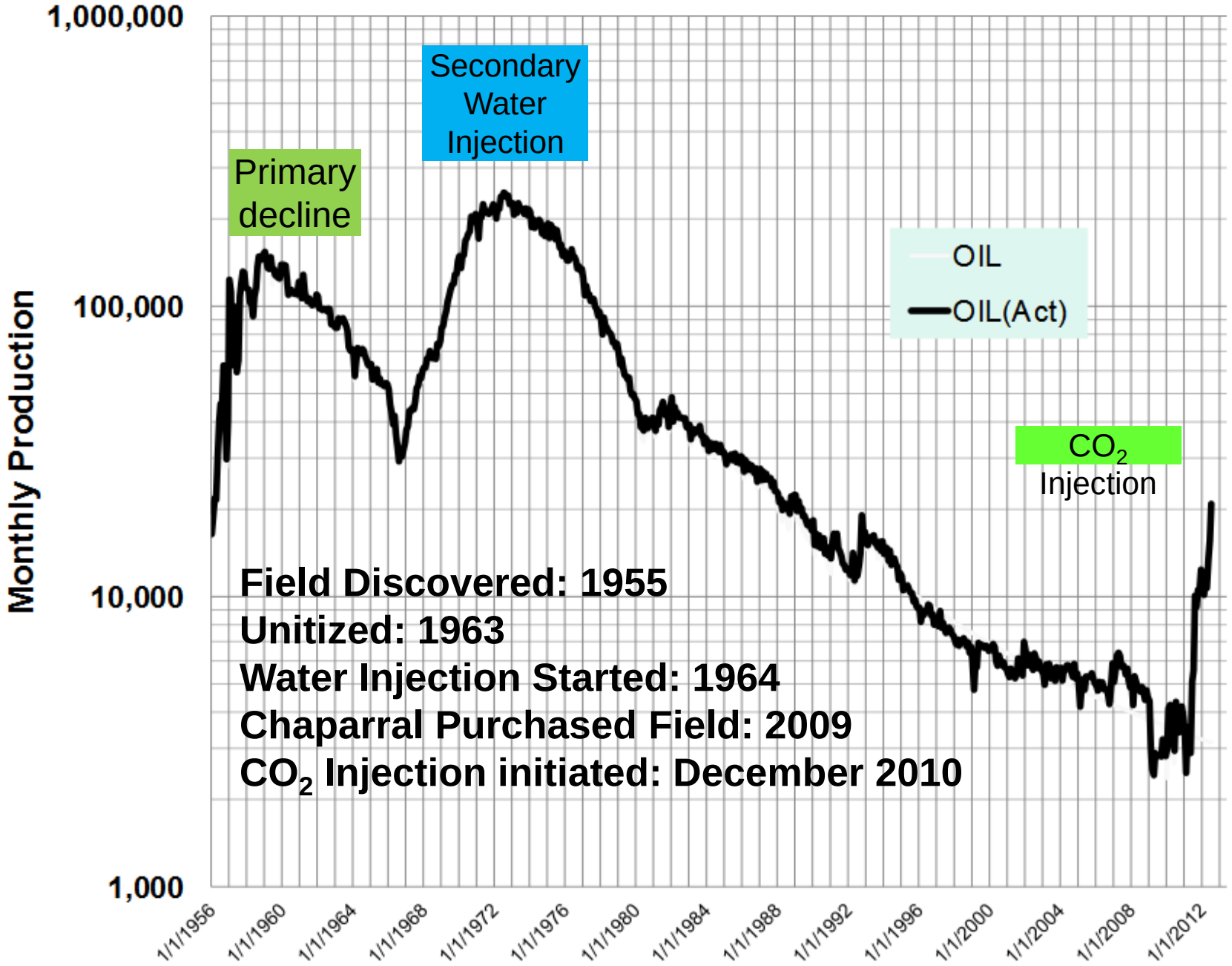
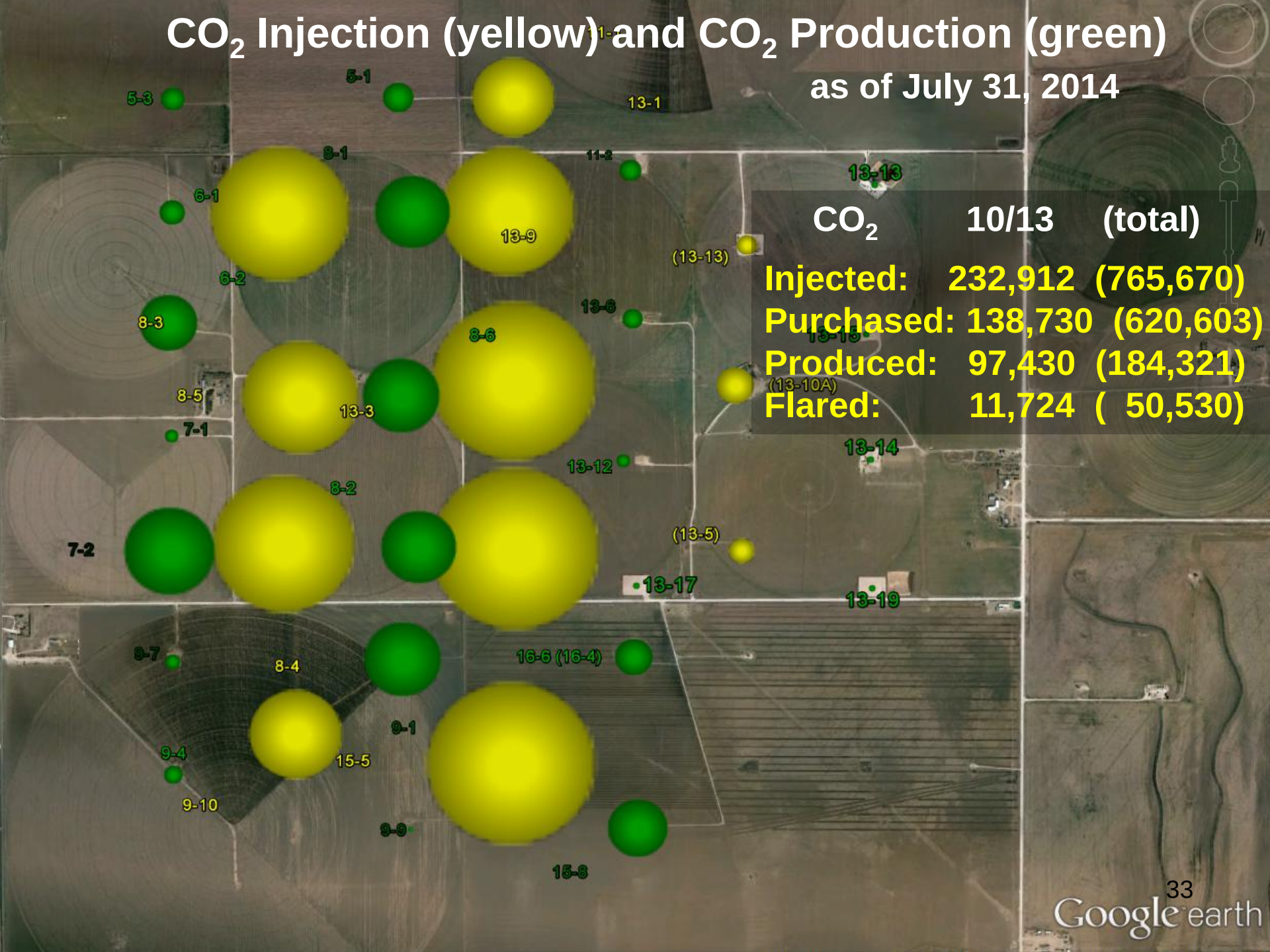
FWU Production 1956 - 2012



CO_2 Injection (yellow) and CO_2 Production (green)

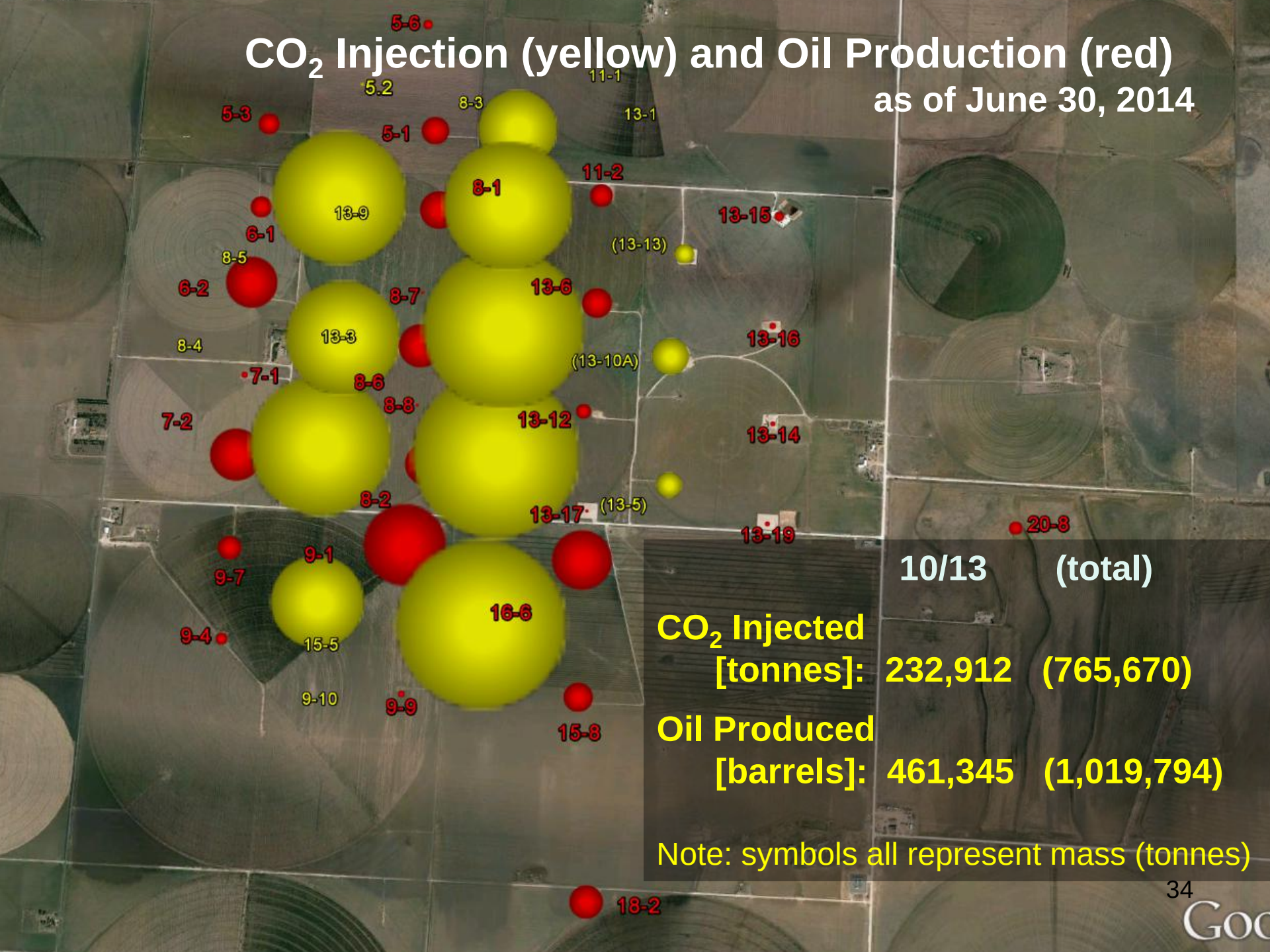
as of July 31, 2014



CO_2	10/13	(total)
Injected:	232,912	(765,670)
Purchased:	138,730	(620,603)
Produced:	97,430	(184,321)
Flared:	11,724	(50,530)

CO_2 Injection (yellow) and Oil Production (red)

as of June 30, 2014



	10/13	(total)
CO_2 Injected [tonnes]:	232,912	(765,670)
Oil Produced [barrels]:	461,345	(1,019,794)

Note: symbols all represent mass (tonnes)

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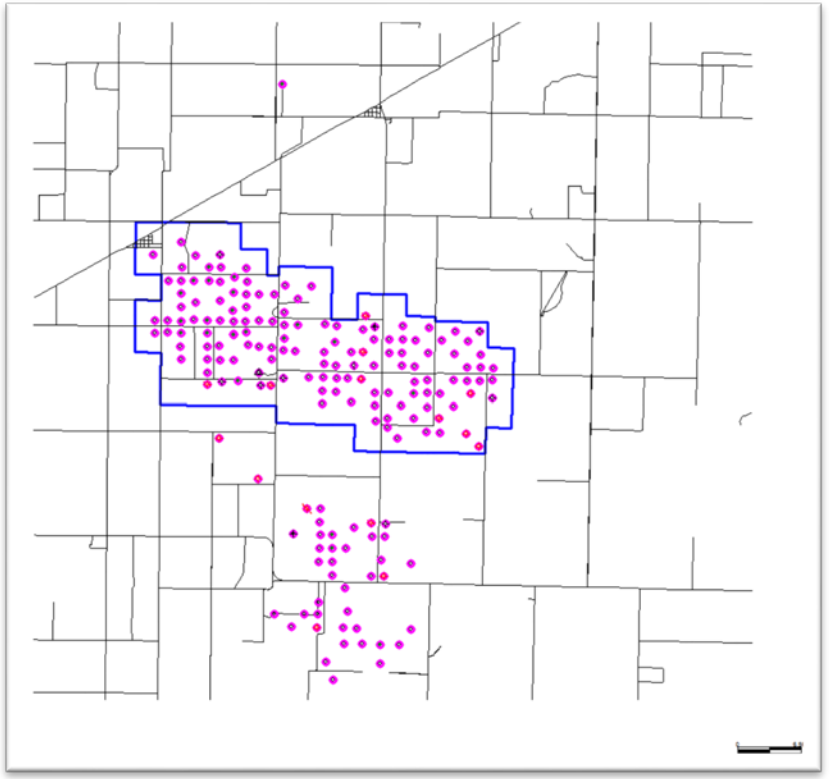
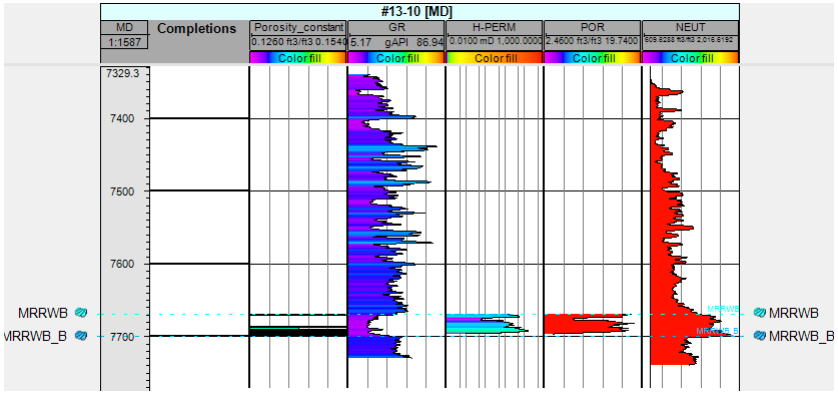
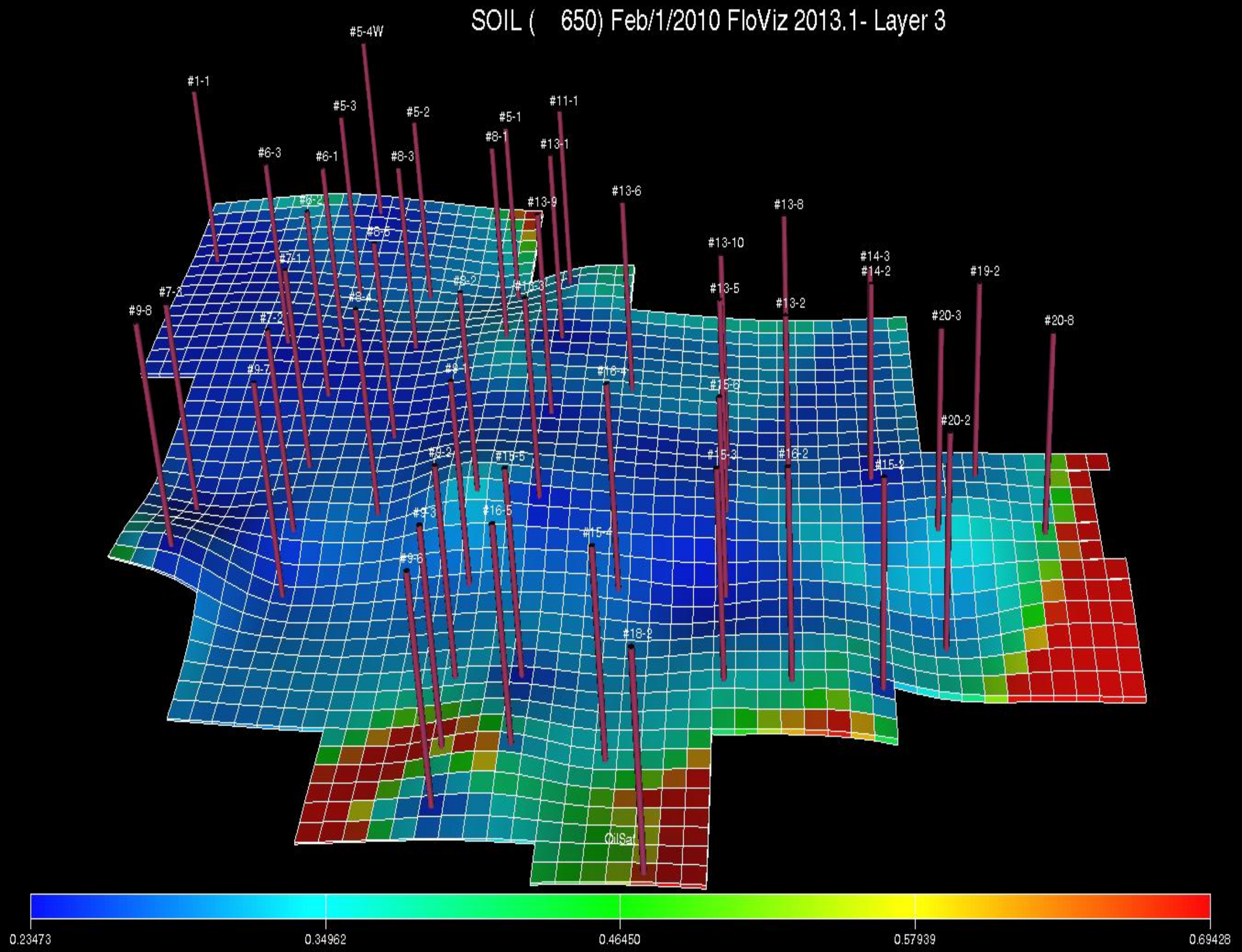
Well logs

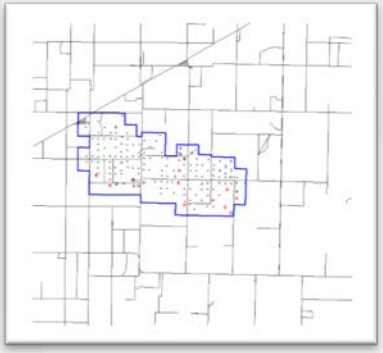
- *1,009 well log curves from 181 wells*
- *Spontaneous potential logs*
- *Gamma ray*
- *Resistivity logs, micrologs, short normal*
- *Sonic logs*
- *Neutron porosity*
- *Bulk density*
- *Core plug porosity*
- *Horizontal core perm*

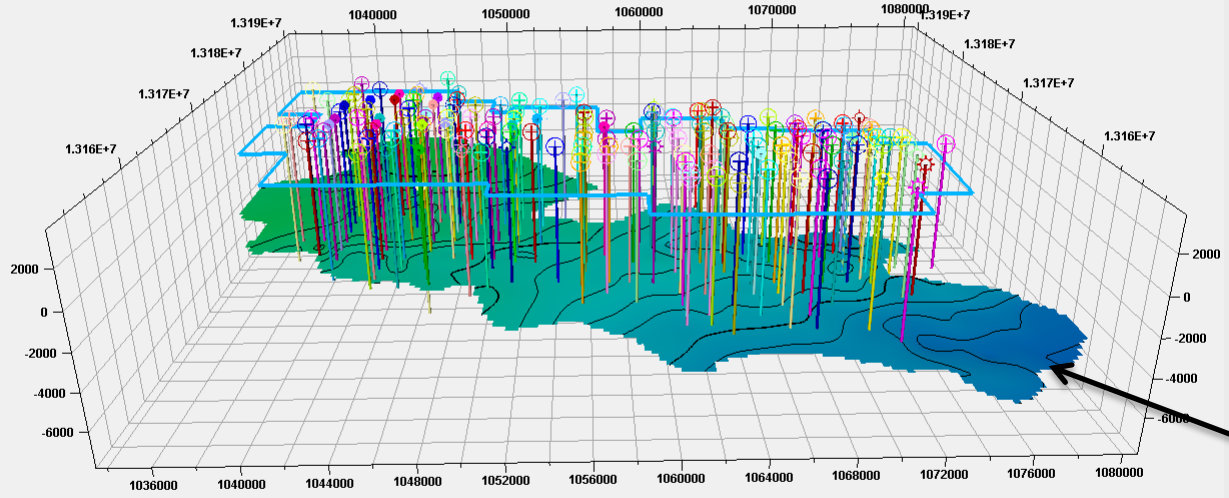





SOIL (650) Feb/1/2010 FloViz 2013.1- Layer 3
#5-4W
#1-1
#5-3
#5-2
#5-1
#11-1
#6-3
#6-1
#8-3
#8-1
#13-1
#13-9
#13-6
#13-8
#13-10
#14-3
#14-2
#19-2
#7-3
#9-8
#13-5
#13-2
#20-3
#20-8
#20-2
#15-3
#16-2
#15-2
#16-5
#18-2
0.23473
0.34962
0.46450
0.57939
0.69428

Model Development

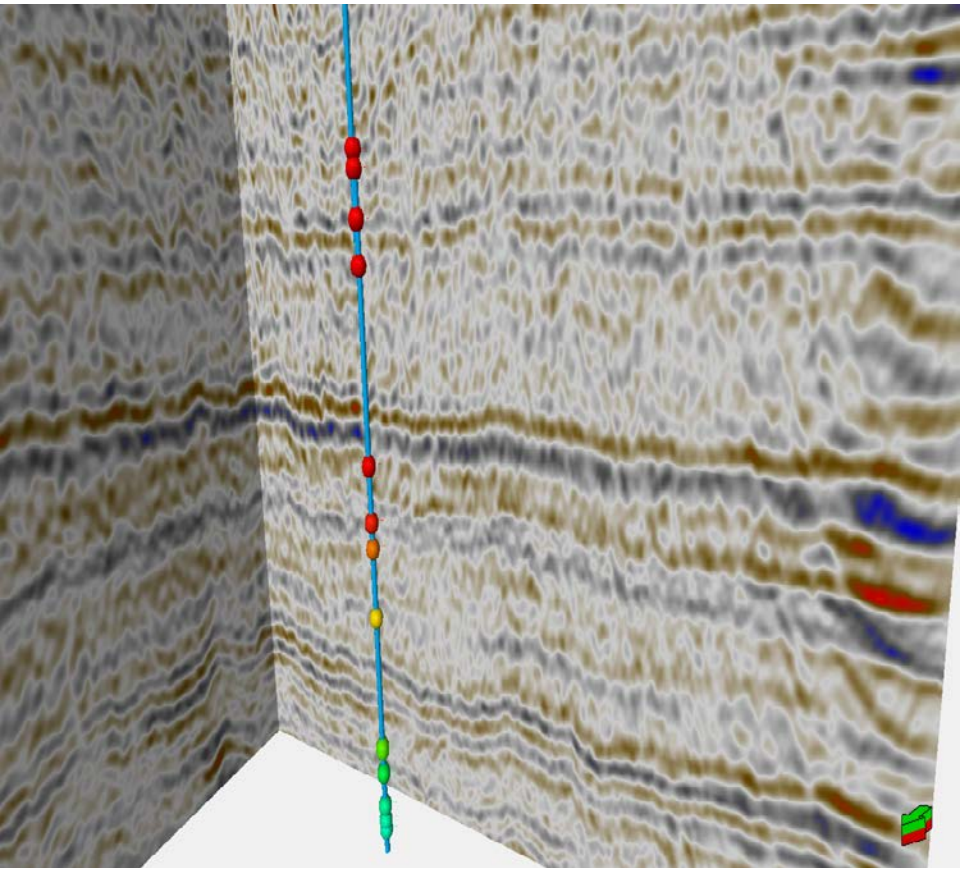


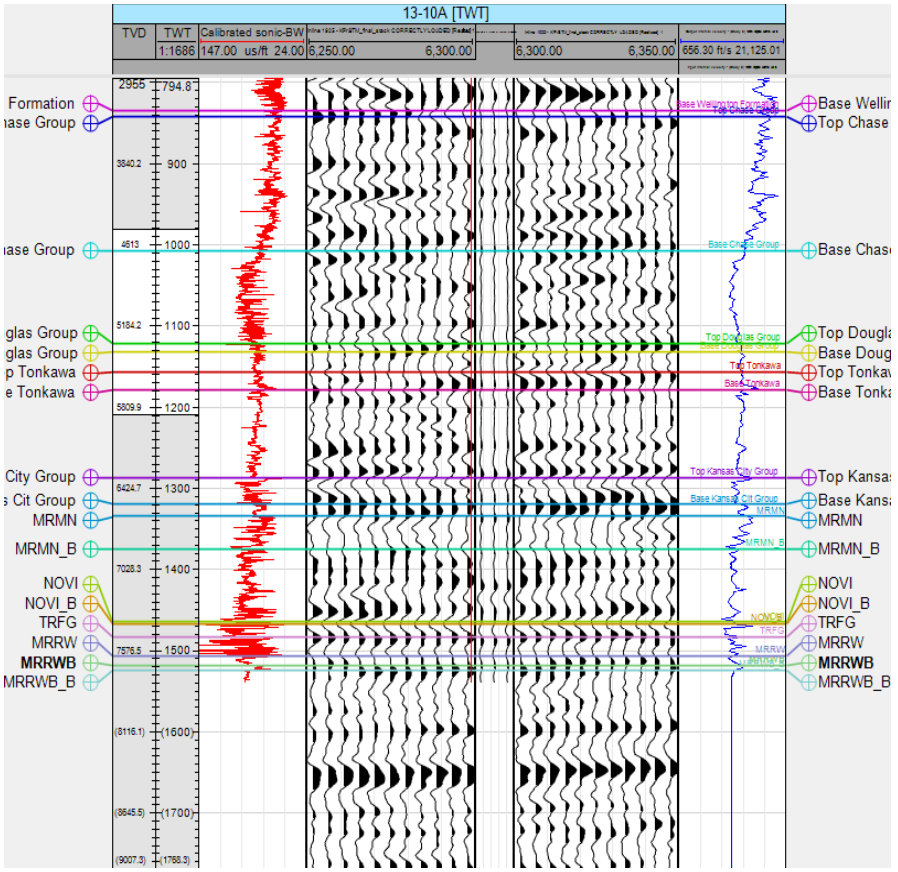


- *181wells with logs within the FWU boundary*

Top of Morrow B

Reservoir Model Also Calibrated to Seismic Model





Ashley Hutton, 2014

Petrophysical Modeling of Seismic and other Geological and Geophysical Data (logs)

Deterministic Techniques

- Kriging
- Moving Average

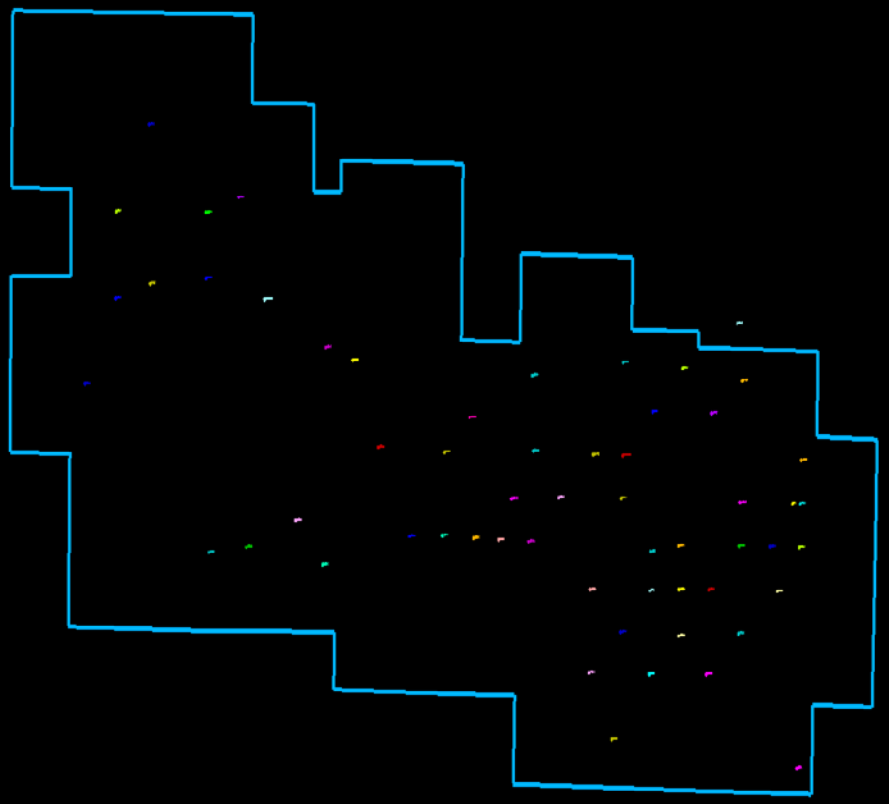
Stochastic Techniques

- Sequential Gaussian Simulation
- Gaussian Random function Simulation

Just Over 1000 Realizations for the Initial Analysis

Porosity Logs

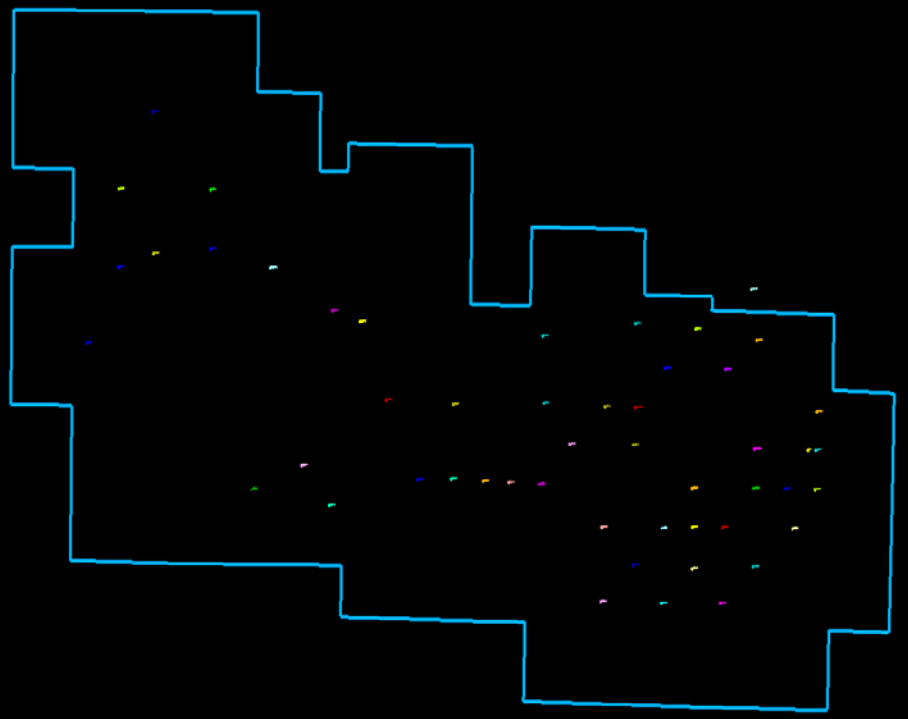
- 55 Wells Included Porosity logs
- 14 wells on West Side
- 41 Wells on East Side
- based on combined core and log data used for interpretation
- extrapolation/interpolation using deterministic/stochastic techniques



Wells with Porosity data distributed throughout the field used in the initial modeling

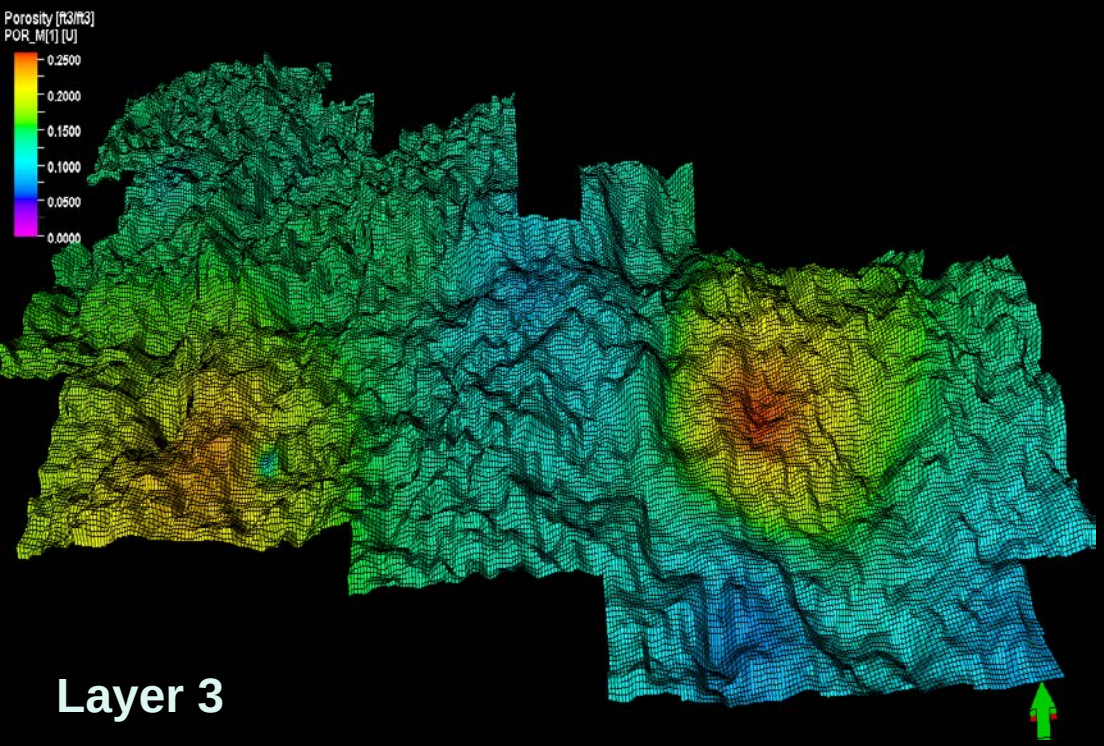
Permeability Logs

- 48 Permeability Logs
- based on direct core measurements
- About 12 on West side
- 36 on East Side
- geometric averaging used where appropriate
- extrapolation/interpolation using deterministic/stochastic

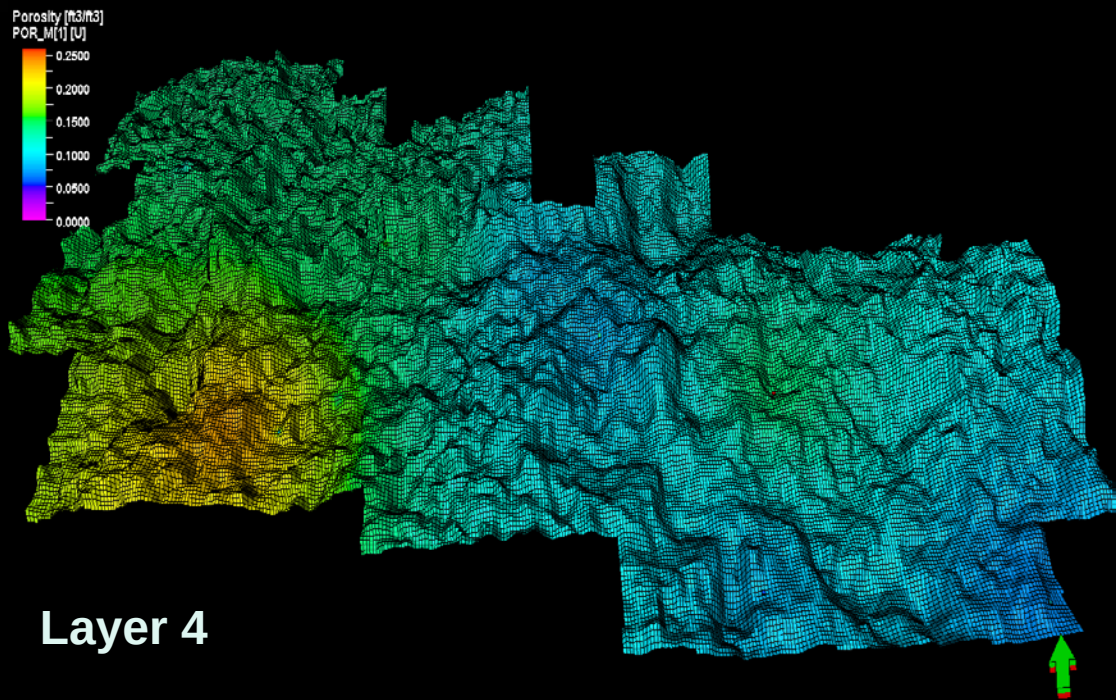


Wells with permeability data distributed throughout the field are used in the initial modeling. Majority of the core data are concentrated on the eastern side of the field.

Interpreted Porosity Distribution

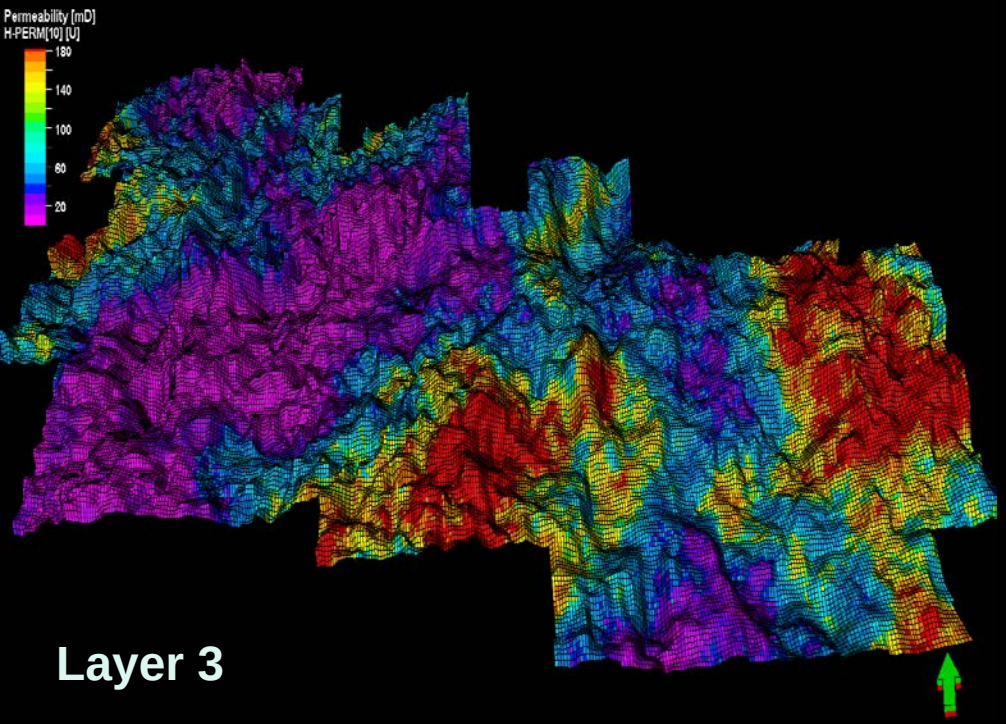


Layer 3

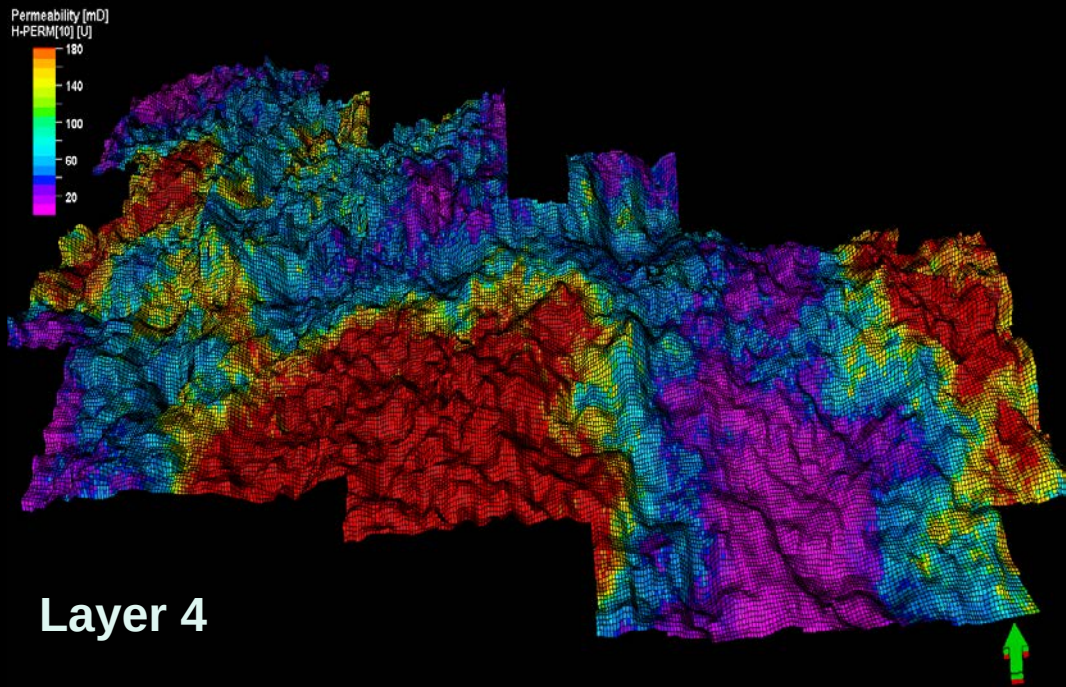


Layer 4

Interpreted Permeability Distribution



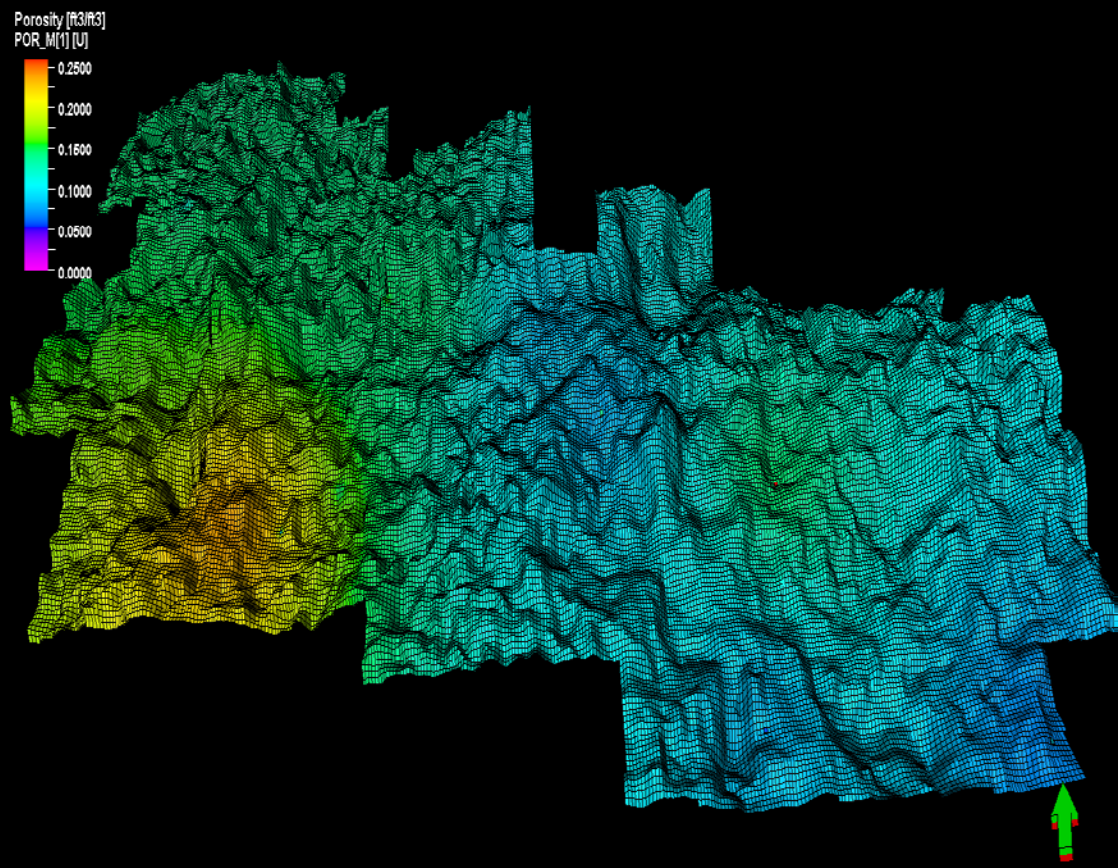
Layer 3



Layer 4

Some Details of the Initial Model

- Grid Cells
  381 x 233 x 8
- Grid Cell Dimensions
  100ft x 100ft
- Total # cells
  710184



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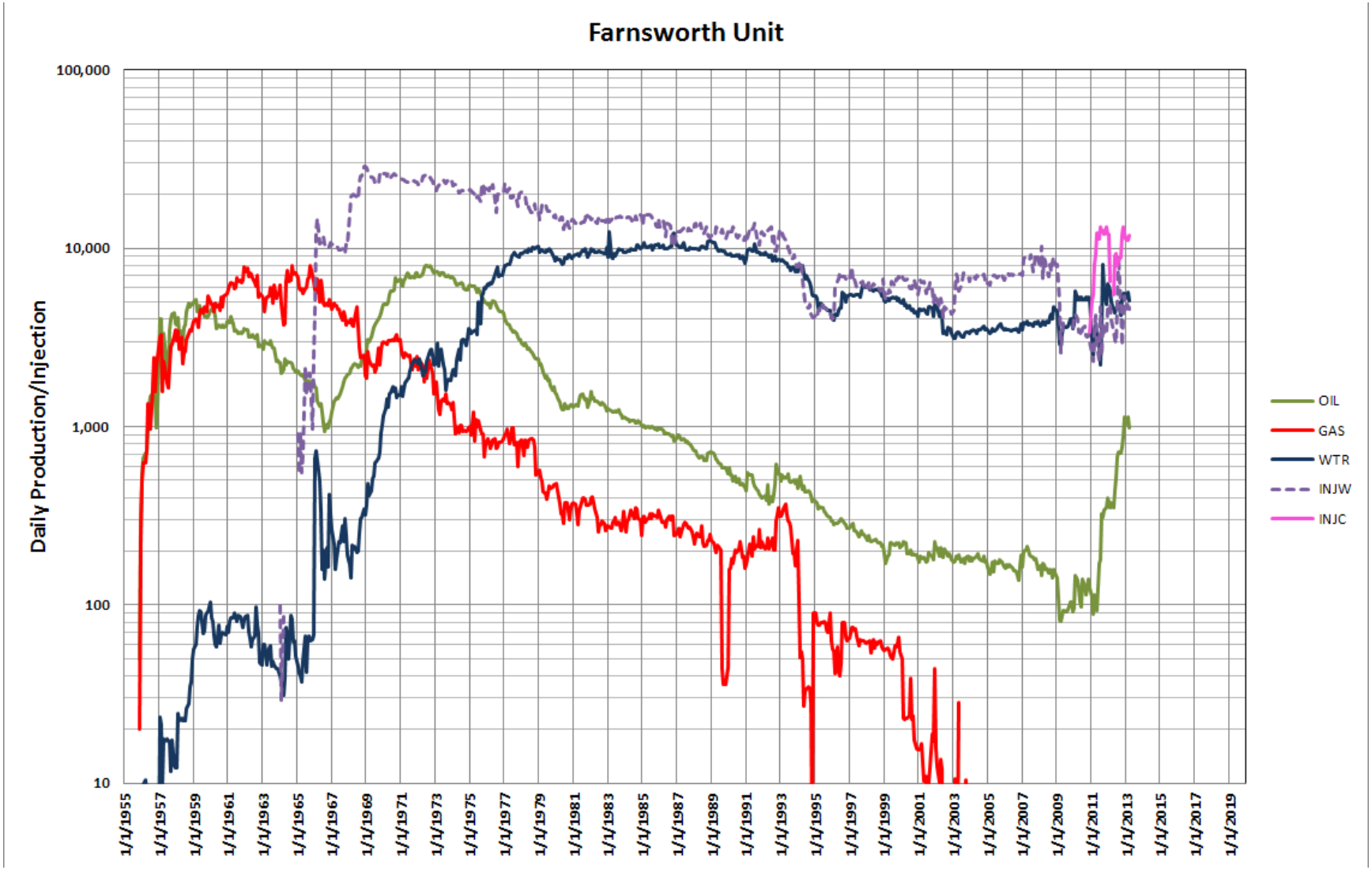
History Match Effort: Actual Data



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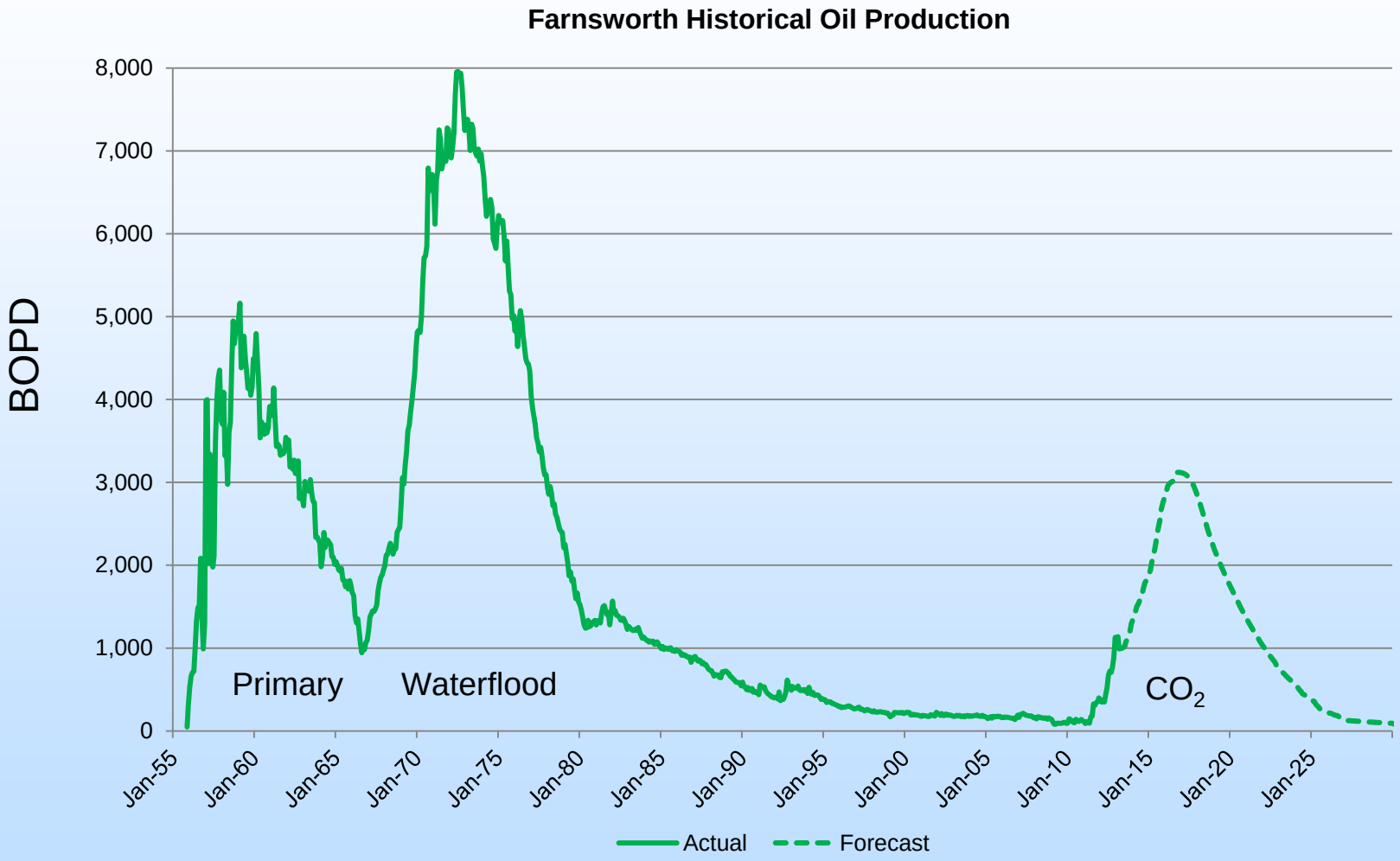
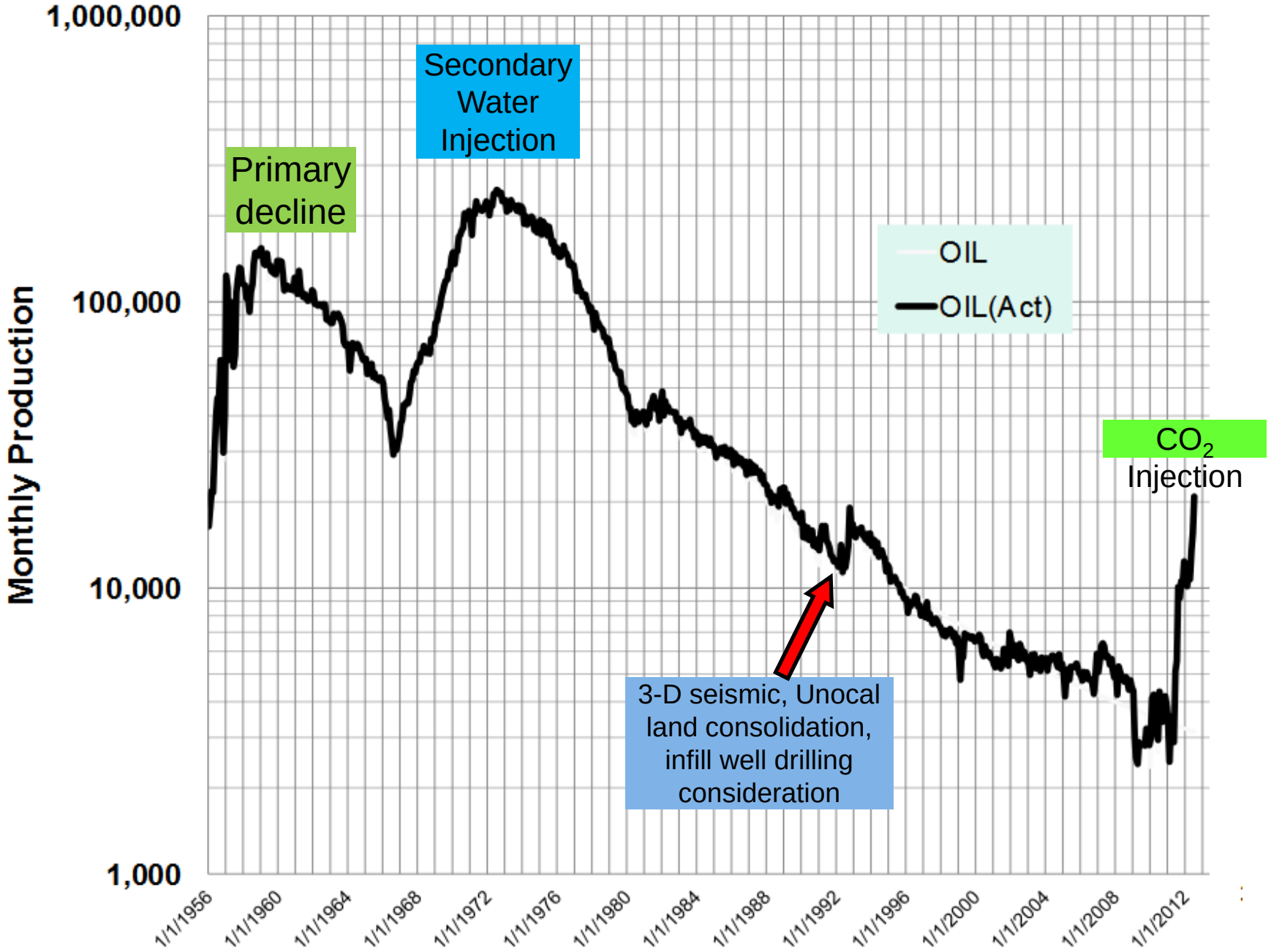
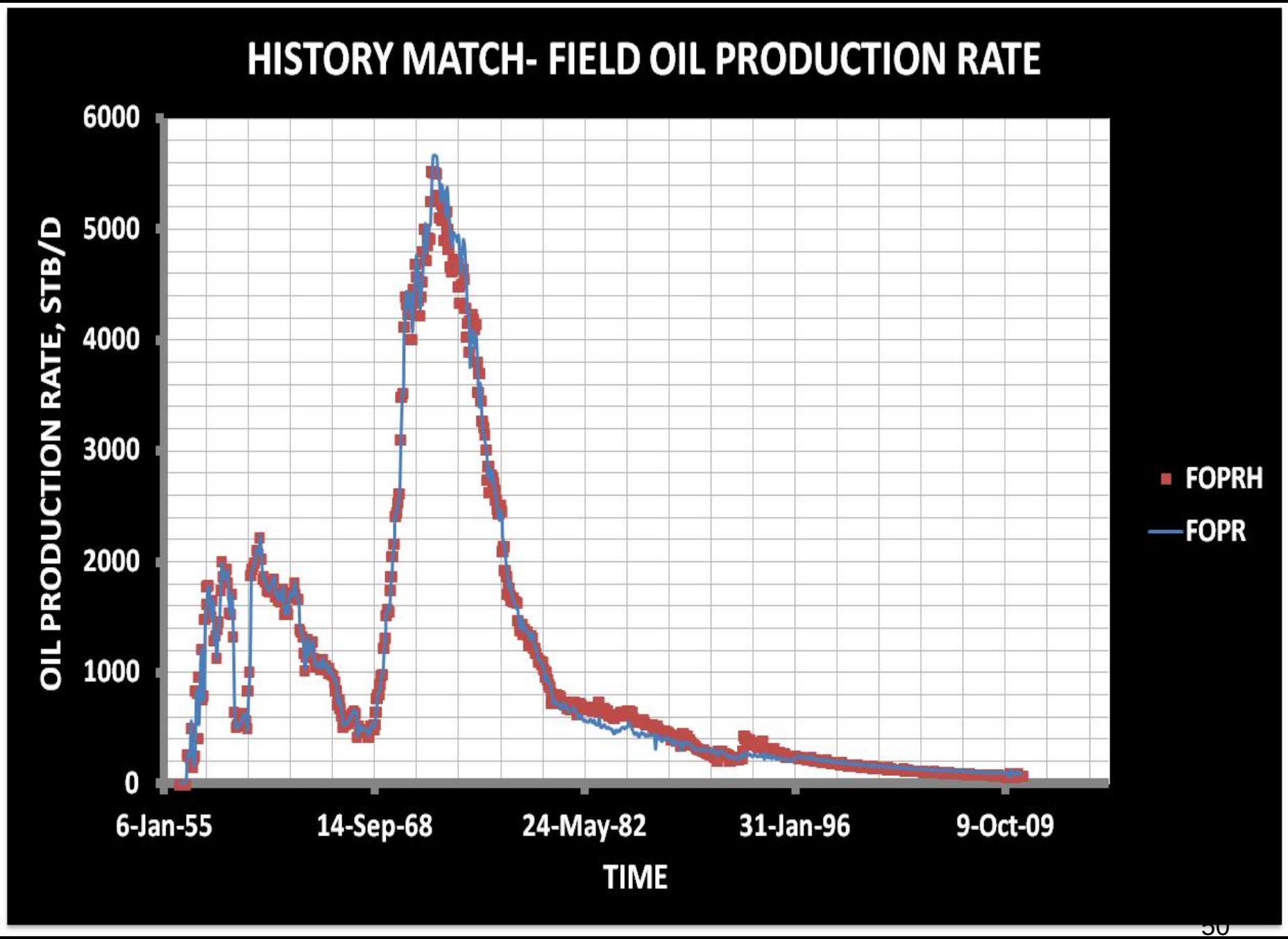
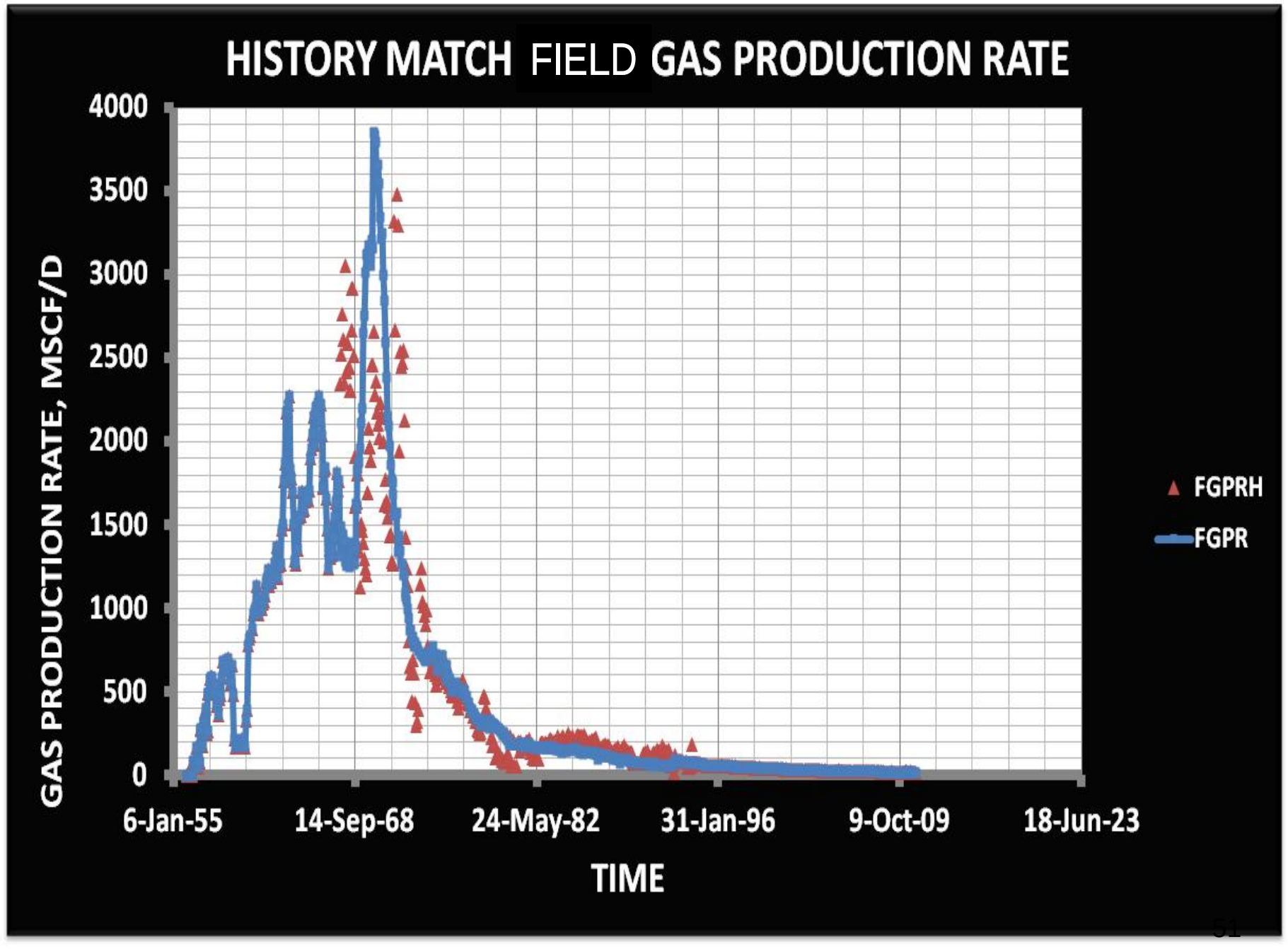
History Match Effort: Actual Data with Forecast



FWU Production 1956 - 2012




HISTORY MATCH- FIELD OIL PRODUCTION RATE
OIL PRODUCTION RATE, STB/D
6000
5000
4000
3000
2000
1000
0
6-Jan-55
14-Sep-68
24-May-82
31-Jan-96
9-Oct-09
TIME
FOPRH
FOPR


HISTORY MATCH FIELD GAS PRODUCTION RATE
GAS PRODUCTION RATE, MSCF/D
4000
3500
3000
2500
2000
1500
1000
500
0
6-Jan-55
14-Sep-68
24-May-82
31-Jan-96
9-Oct-09
18-Jun-23
TIME
FGPRH
FGPR

Presentation Outline

- Introduction and Summary of Partners
- Project Overview: Goals and Objectives
- Technical Status
- Accomplishments to Date
- **Summary**

Summary

Key Findings and Lessons Learned:

- Production objectives, oil prices influence CO_2 availability;
- Reservoir responding at or above expectations;
- Injectivity is excellent, but the field could accommodate much more CO_2 injection;
- Anthropogenic CO_2 sources not as stable as anticipated; source uncertainty must be factored into project economics, including carbon credits sought;
- A major key to success is cooperation of operator;
- VSP more effective than reflection; passive seismic monitoring is **extremely** useful for characterization;
- Fluid pressure monitoring and associated hydraulic diffusivity maps (with modeling) are very effective tools;
- Regulatory policies are still not clear.

Summary

- Future Plans
  - Field:
    - Complete core analysis on three characterization wells
    - Repeat seismic (3D-VSP and crosswells)
    - Continue surface monitoring
    - Tracer tests
  - Reservoir modeling:
    - Incorporate seismic, new logs, and core findings into geomodel
    - Integrate reservoir models and seismic models.
  - Risk assessment: Initial quantitative risk analysis results coming online now;
  - Laboratory: With initial core characterization near completion, lab testing just beginning.

Appendix

– These slides will not be discussed during the presentation, but are mandatory

Organization Chart

- Describe project team, organization, and participants.
  - Link organizations, if more than one, to general project efforts (i.e. materials development, pilot unit operation, management, cost analysis, etc.).
- Please limit company specific information to that relevant to achieving project goals and objectives.

Gantt Chart

- Provide a simple Gantt chart showing project lifetime in years on the horizontal axis and major tasks along the vertical axis. Use symbols to indicate major and minor milestones. Use shaded lines or the like to indicate duration of each task and the amount of that work completed to date.

Bibliography

List peer reviewed publications generated from project per the format of the examples below

- Journal, one author:
  - Gaus, I., 2010, Role and impact of CO2-rock interactions during CO2 storage in sedimentary rocks: International Journal of Greenhouse Gas Control, v. 4, p. 73-89, available at: XXXXXXX.com.
- Journal, multiple authors:
  - MacQuarrie, K., and Mayer, K.U., 2005, Reactive transport modeling in fractured rock: A state-of-the-science review. Earth Science Reviews, v. 72, p. 189-227, available at: XXXXXXX.com.
- Publication:
  - Bethke, C.M., 1996, Geochemical reaction modeling, concepts and applications: New York, Oxford University Press, 397 p.

Presentation Outline

- Introduction and Summary of Partners
- **Benefit to the Program**
- Project Overview: Goals and Objectives
- Technical Status
- Accomplishments to Date
- Summary

Benefit to the Program: Program Goals Addressed

- Support industry's ability to predict CO_2 storage capacity in geologic formations to within ±30 percent.
- Develop and validate technologies to ensure 99 percent storage permanence.
- Develop technologies to improve reservoir storage efficiency while ensuring containment effectiveness.
- Develop Best Practice Manuals for monitoring, verification, accounting, and assessment; site screening, selection and initial characterization; public outreach; well management activities; and

Benefit to the Program: Specific Benefits

- This project will demonstrate carbon storage concomitant with EOR, and elucidate aspects that maximize storage capacity without compromising EOR recovery efficacy. Although this project contributes to several program goals (previous slide), perhaps the most significant is development of technologies to improve reservoir storage efficiency while ensuring containment effectiveness

Project Overview: Goals and Objectives

- Storage Capacity Verification
  - The SWP is developing technologies that will support our industry partner's ability to predict and confirm CO2 storage capacity in geologic formations
  - The uncertainty or tolerance planned is ±30 % (target is ±10 %)
  - Injectivity determined from wellbore simulation models calibrated with CO2 injection from existing patterns, laboratory analysis of core, and well-testing of characterization wells.
  - Capacity verification via 3-D simulation models and direct data, 3D-VSP, crosswell tomography, tracers, pressure and temperature, and production data.
  - **Success Criteria: consistency between gross totals from simulated forecasts to gross mass balance data provided by operator**
- Verification of Containment
  - The SWP will confirm that 99 % of injected CO2 remains in the injection zones
  - **Success Criteria: From Phase II project results, we find that the most effective criteria are results of indirect monitoring including geophysical (VSP) surveys, and results of direct monitoring including tracer measurements, pressure and geochemical monitoring**

NETL

Project Overview: Goals and Objectives

- Storage Permanence
  - Storage permanence will be inferred by evaluating time-scales of CO2 migration, with results assessed by geophysical (VSP) surveys, tracer monitoring, pressure and geochemical monitoring, and detailed numerical modeling calibrated by these data.
  - **Success criteria: for permanent storage, no criteria possible, but confirmation for the duration of the project will be continuous**
- Plume Extent and Potential Leakage Pathways
  - The SWP will characterize and forecast potential plume extent and potential leakage pathways via geophysical surveys, tracer monitoring, pressure and geochemical monitoring, and detailed numerical modeling.
  - **Success criteria: confirm forecasts through continuous direct monitoring (especially tracers in the production stream) during and after injection**

Project Overview: Goals and Objectives

- Risk Assessment
  - The SWP has developed a comprehensive risk assessment strategy which is "Adaptive"— iterative modeling-monitoring approach for assessment of uncertainty and performance assessment: healthy/safety risks, economic and programmatic risks, and otherwise
  - **Success criteria: review of risk assessment results by NETL and external panel of risk experts**

As indicated previously: NEW FIVE SPOT PATTERNS WILL BE DRILLED EVERY SIX MONTHS. THE SWP WILL "LEARN" FROM RESULTS, RE-ADJUST AND RE-DESIGN DEPLOYMENT FOR EACH NEW SET OF INJECTION WELLS, BASED ON ANALYSIS OF RESULTS OF THE PREVIOUS SETS OF WELLS.