Hydraulic Fracturing Test Site (HFTS)

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

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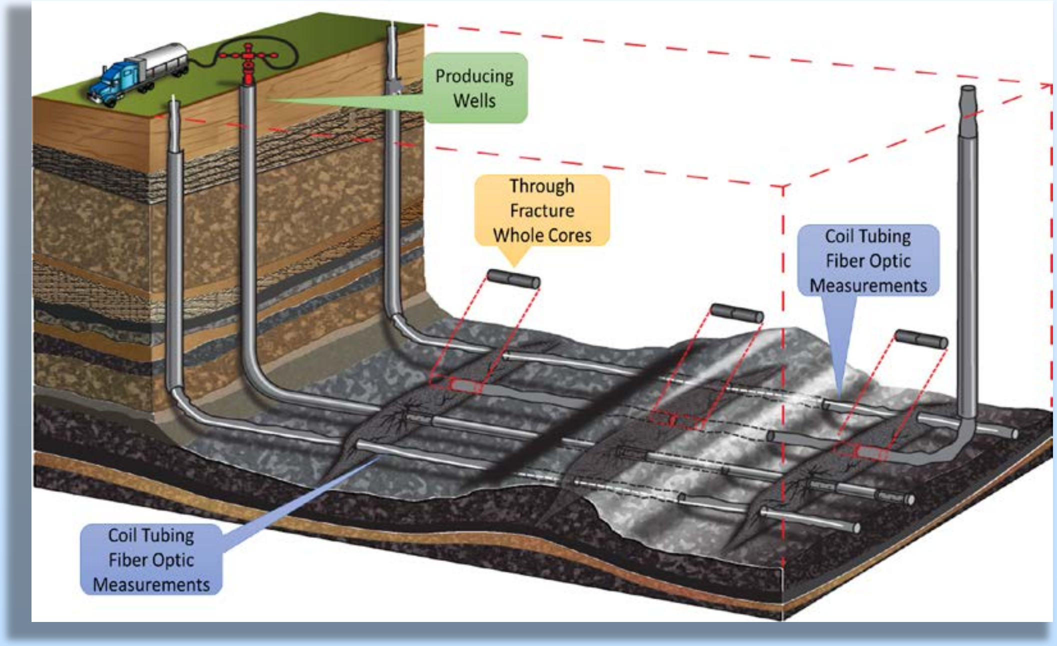
Presentation Outline

- HFTS Overview
- Review of Test Site Location and Details
- Project Progress
- Technical Status: Diagnostics Used to Refine Fracture Dimensions
- Accomplishments to Date
- Lessons Learned
- Synergy Opportunities
- Summary
- Appendix

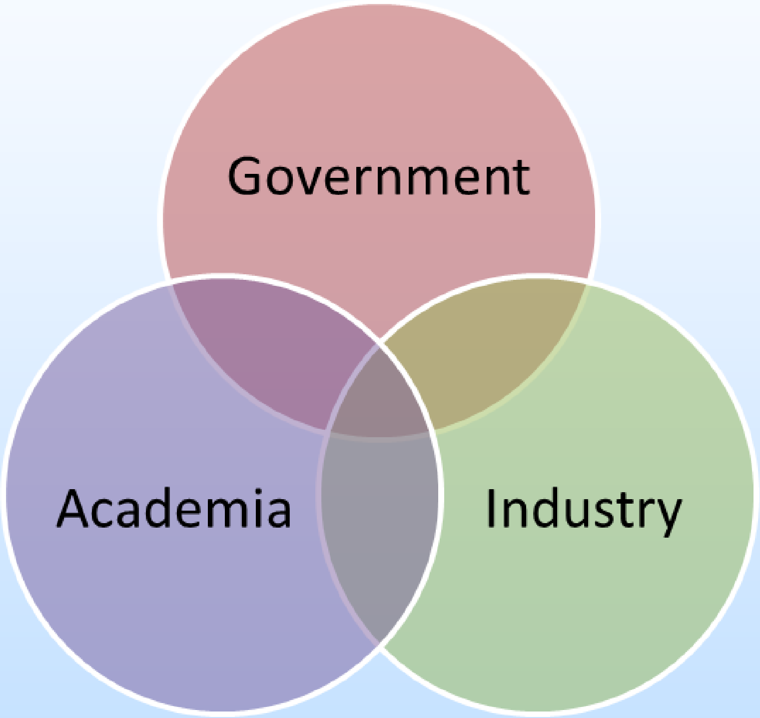
Hydraulic Fracturing Test Site: Project Overview

Comprehensive $25-million JIP research program



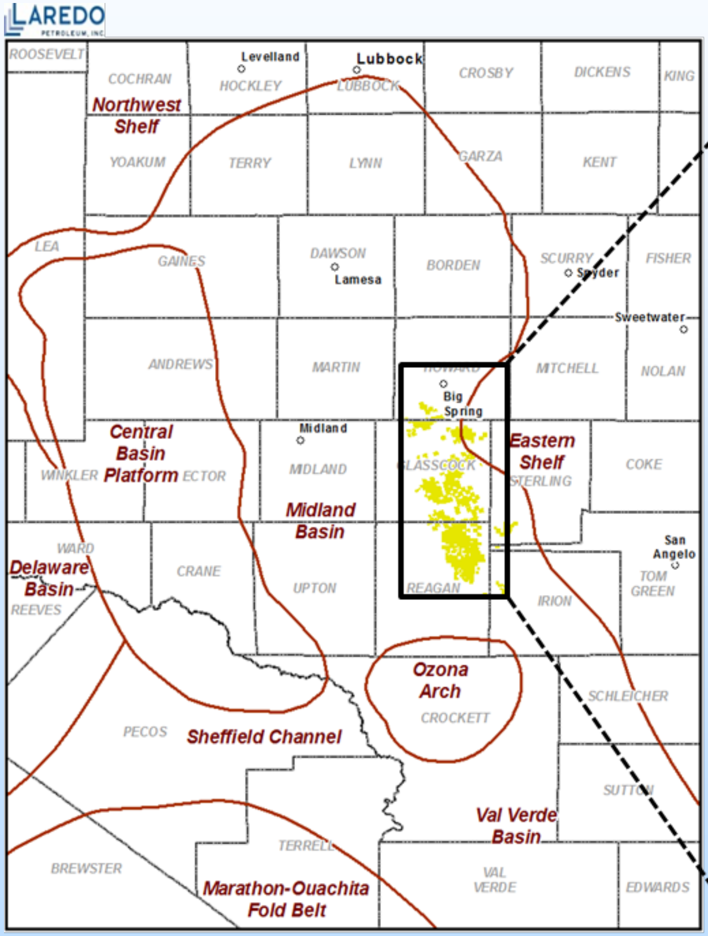
- Capture fundamental insights of fracturing process
- Acquisition of nearly 600 feet of through-fracture whole core
- Physical observation of created fractures and proppant distribution

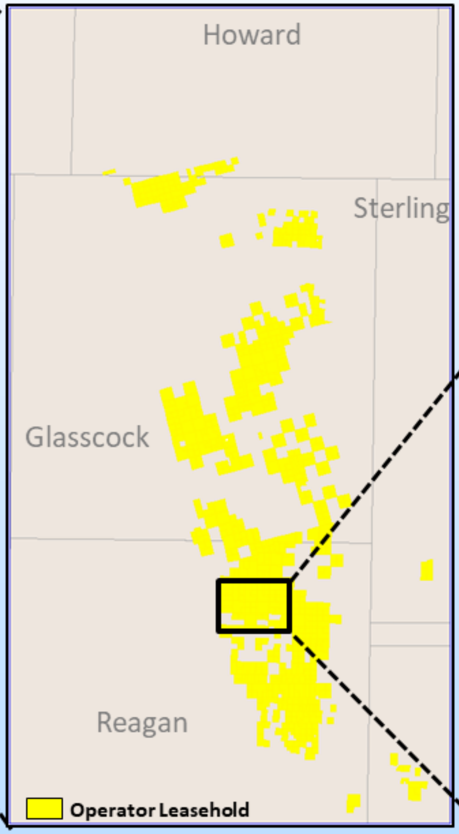
Public Private Partnership

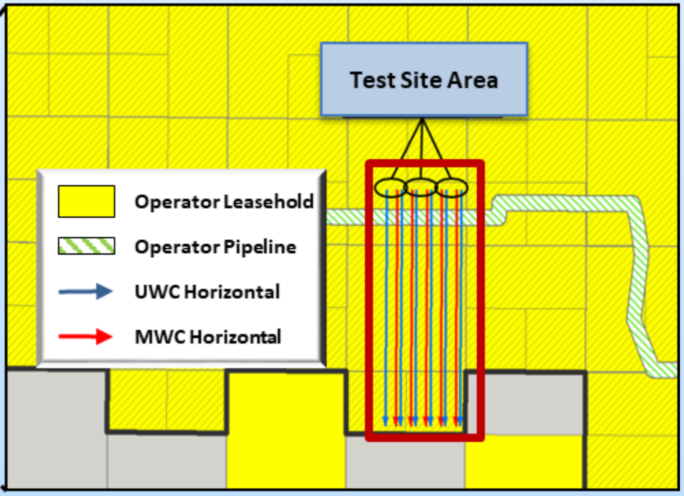


- Leveraged investment in a dedicated, controlled field experiment
  - Access to producing and science wells explicitly designed for hydraulic fracturing diagnostics, environmental monitoring, data collection and technology testing
  - Use of multiple near-well and far-field diagnostics and verification with through fracture cores
  - Careful planning - staged approach to experiments
  - Access to many subject matter experts
  - Early adoption of learnings by industry participants – technology transfer
  - Balanced science and practical issues
- Data available to public upon of expiration of confidentiality period

Test Site Location







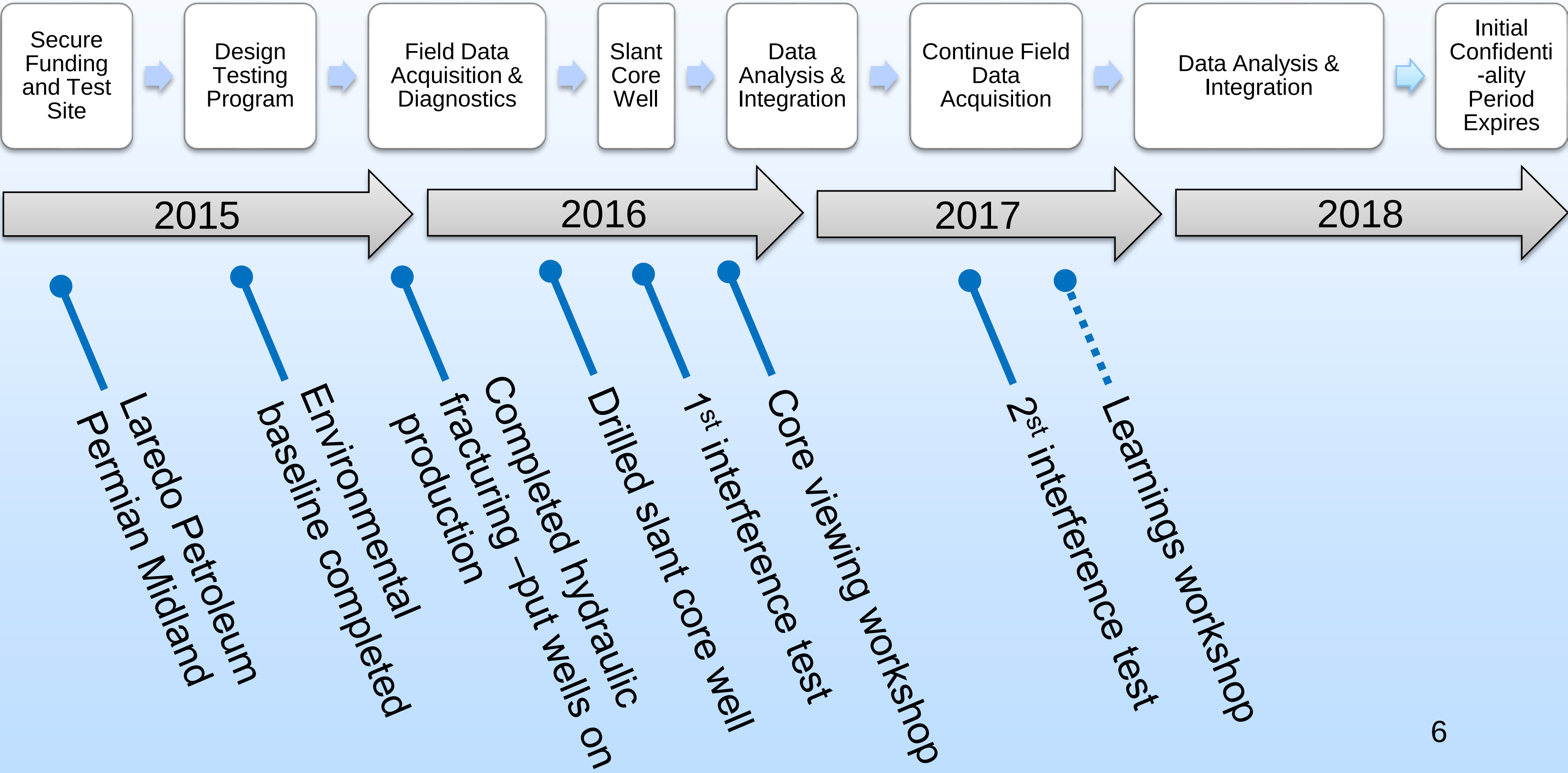
Study Area

Permian-Midland Basin

Reagan County

Upper & Middle Wolfcamp

Project Progress and Major Milestones



- Secure Funding and Test Site
- Design Testing Program
- Field Data Acquisition & Diagnostics
- Slant Core Well
- Data Analysis & Integration
- Continue Field Data Acquisition
- Data Analysis & Integration
- Initial Confidenti-ality Period Expires

2015

2016

2017

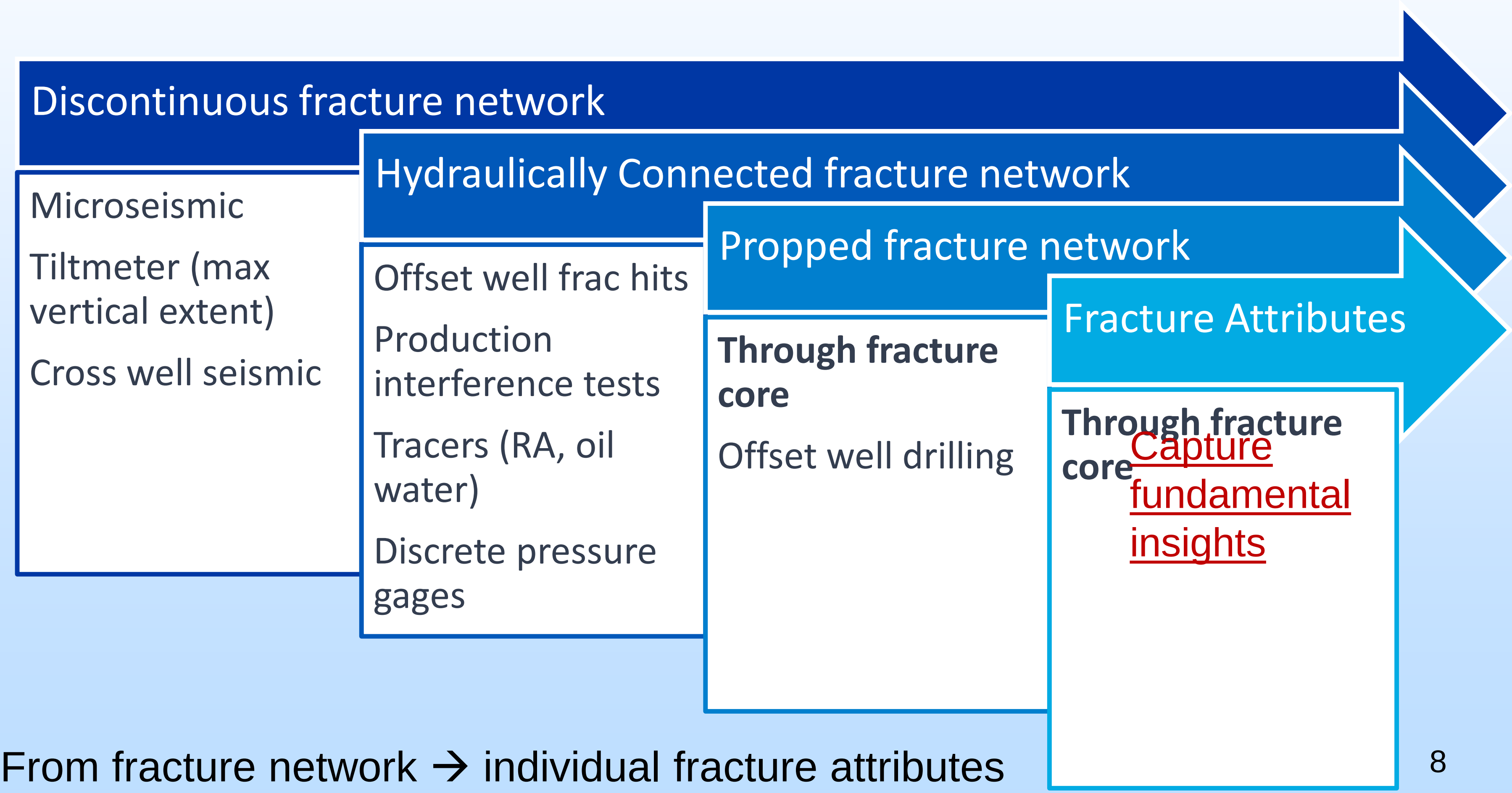
2018

- Laredo Petroleum Permian Midland
- Environmental baseline completed
- Completed hydraulic fracturing –put wells on production
- Drilled slant core well
- 1st interference test
- Core viewing workshop
- 2st interference test
- Learnings workshop

Technical Status

- **Diagnostics at HFTS used to refine fracture dimensions**
- Core: Capture fundamental insights of fracturing process
- Due to confidentiality limitations, will focus on what was done with examples and general conclusions

Diagnostics at HFTS used to refine fracture dimensions



Discontinuous fracture network

- Microseismic
- Tiltmeter (max vertical extent)
- Cross well seismic

Hydraulically Connected fracture network

- Offset well frac hits
- Production interference tests
- Tracers (RA, oil water)
- Discrete pressure gages

Propped fracture network

- **Through fracture core**
- Offset well drilling

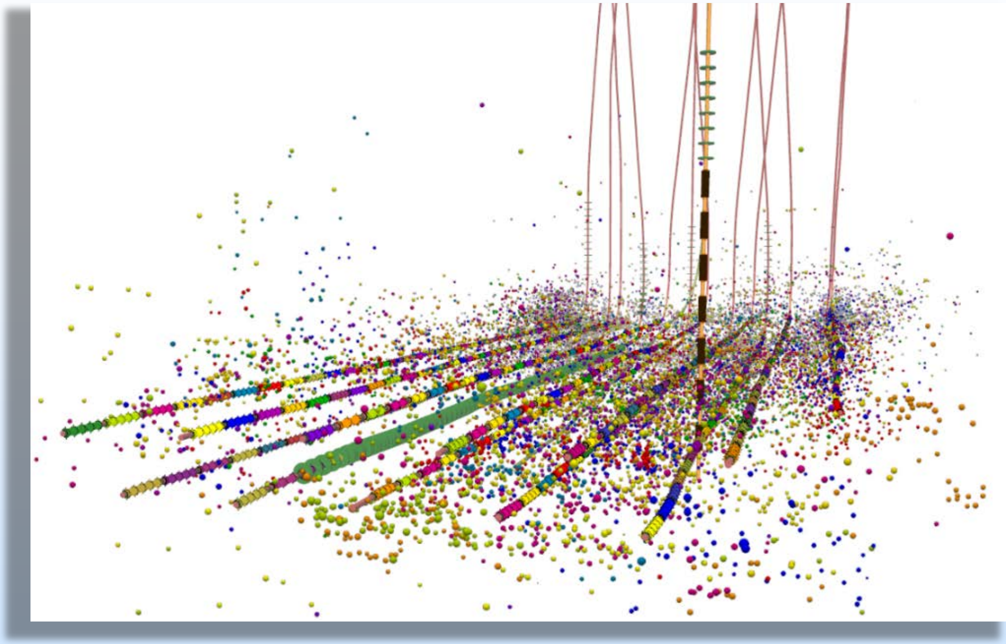
Fracture Attributes

- **Through fracture core**

Capture fundamental insights

From fracture network → individual fracture attributes

Discontinuous fracture network



- Microseismic survey
  - Almost 400 stages monitored with dual-array (vertical and horizontal) borehole tools
  - Tools moved to reduce distance bias

- Tiltmeter
  - 7 level vertical array
  - Only 3 times the lower most tiltmeter registered any response, below 5000’ TVD

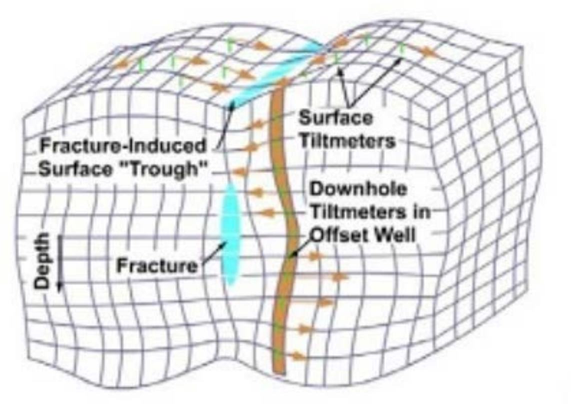
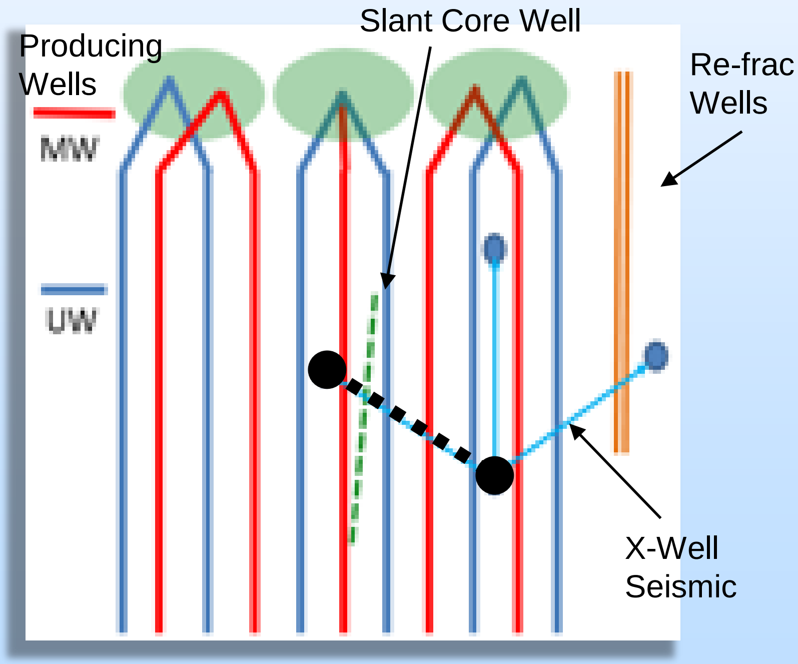


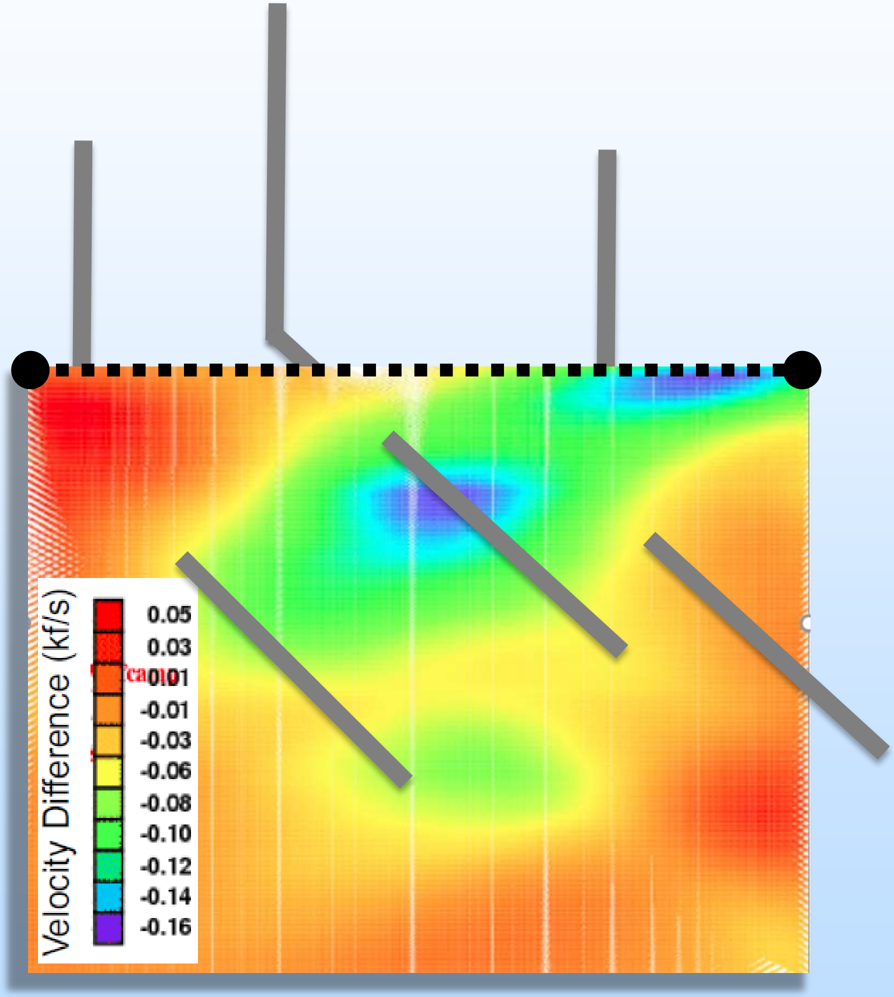
Image courtesy: Petroskills

Discontinuous fracture network

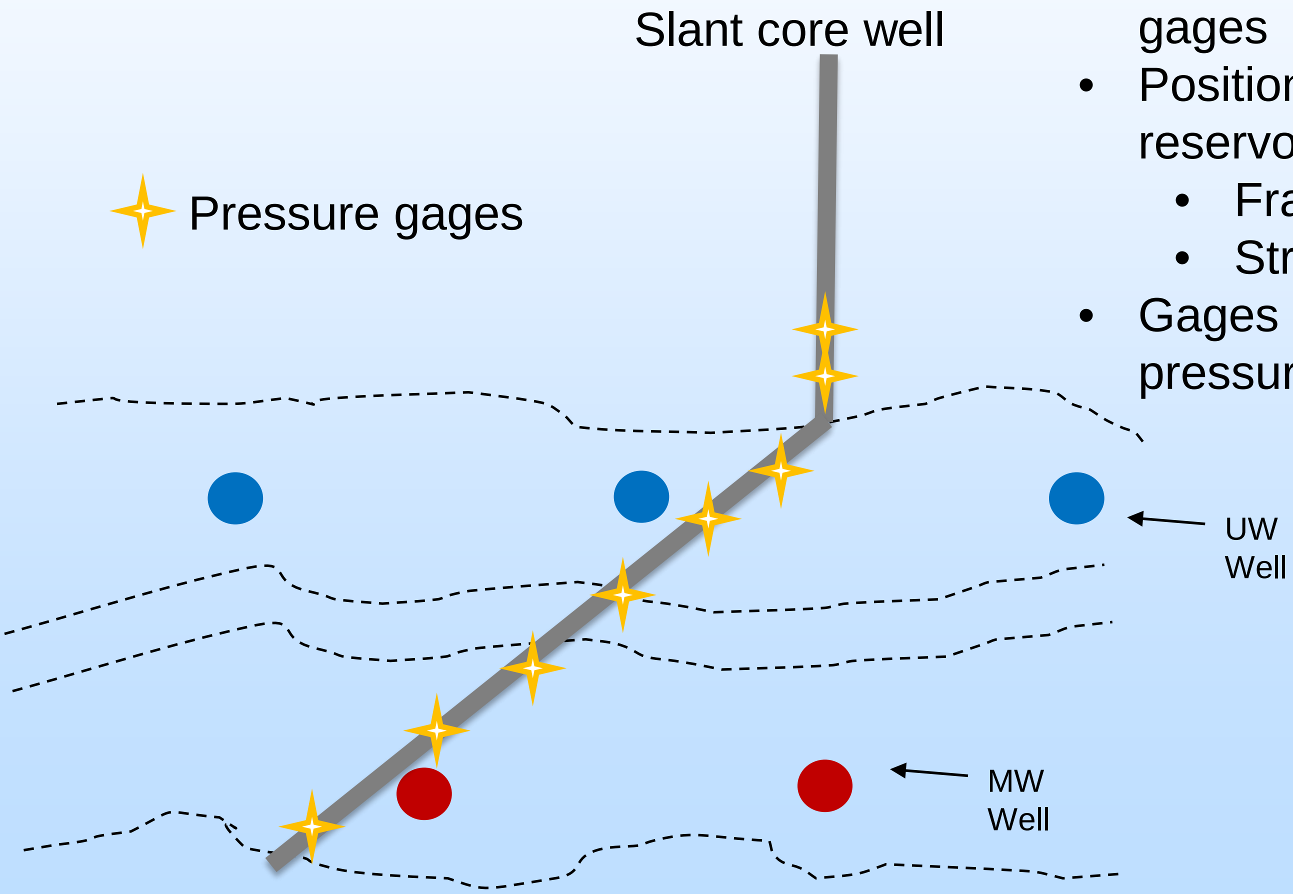
Initial and repeat X-Well seismic surveys

- 3 images: across core well, normal to fracture plane, refrac wells
- Velocity difference





Hydraulically connected fracture network



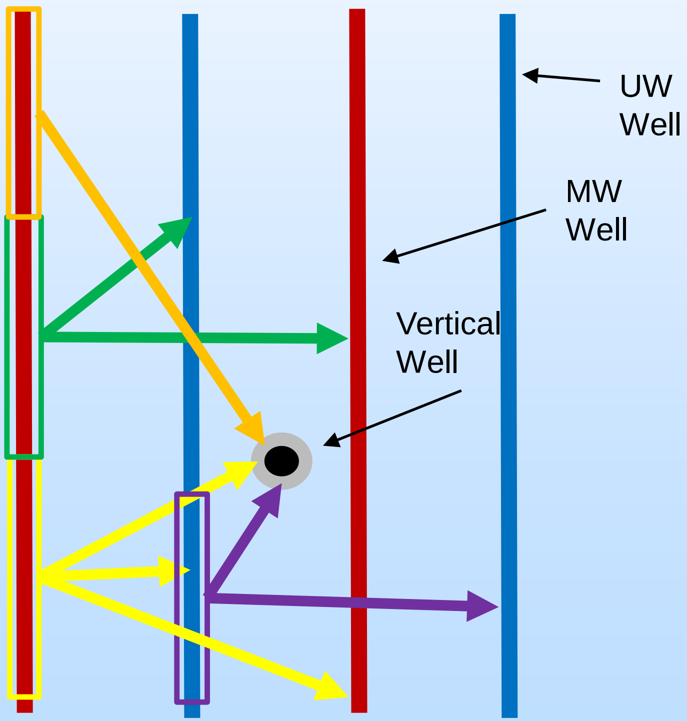
Discrete reservoir pressure gages

- 8 isolated bottom hole pressure gages
- Positioned across sections of reservoir with various attributes
    - Fracture count, type, etc.
    - Stress, etc
- Gages provide vertical and lateral pressure discrimination

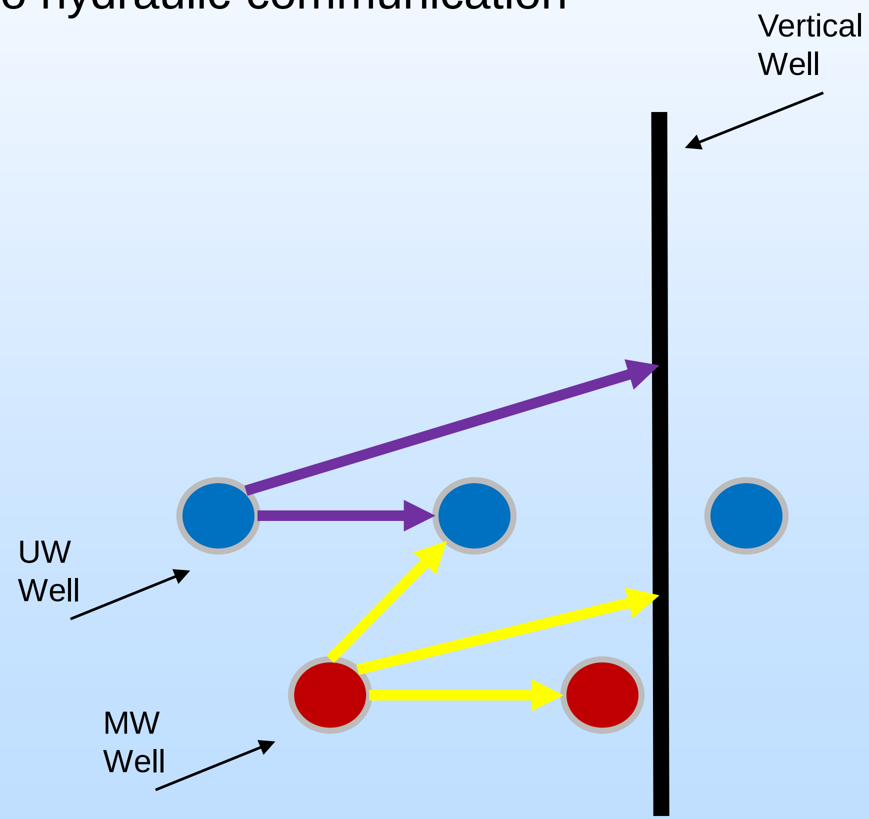
Hydraulically connected fracture network

Tracers

- Oil and water tracers, RA tracers
- Communication of fracturing and reservoir fluids across wells
- Long term sampling provides insight into hydraulic communication changes over time

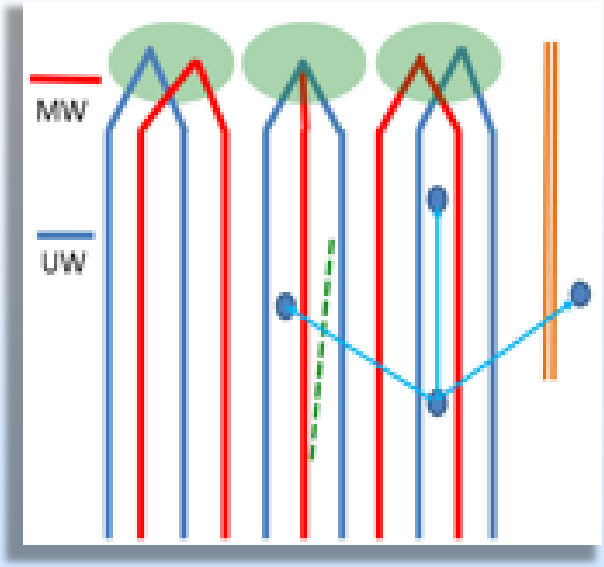


Plan View



Gunbarrel View

Hydraulically connected fracture network



Pressure/production interference testing

- BH gages in producing wells used to detect change in pressure as offset wells are shut in/opened
- Sequence designed to determine vertical and horizontal pressure interference
- Initial and repeat tests provide insight in hydraulic communication change over time
- 1st test after 6 months, second after 18 months

	Well 1	Well 2	Well 3	Well 4	Well 5	Well 6	Well 7
Day 1	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Day 2	🟨	🟩	🟩	🟩	🟩	🟩	🟩
Day 3	🟨	🟨	🟩	🟩	🟩	🟩	🟩
Day 4	🟨	🟨	🟨	🟩	🟩	🟩	🟩
Day 5	🟩	🟨	🟨	🟨	🟩	🟩	🟩
Day 6	🟩	🟩	🟨	🟨	🟨	🟩	🟩
Day 7	🟩	🟩	🟩	🟨	🟨	🟨	🟩
Day 8	🟩	🟩	🟩	🟩	🟨	🟨	🟨
Day 9	🟩	🟩	🟩	🟩	🟩	🟨	🟨
Day 10	🟩	🟩	🟩	🟩	🟩	🟩	🟨
Day 11	🟩	🟩	🟩	🟩	🟩	🟩	🟩

🟩	Producing
🟨	Shut In

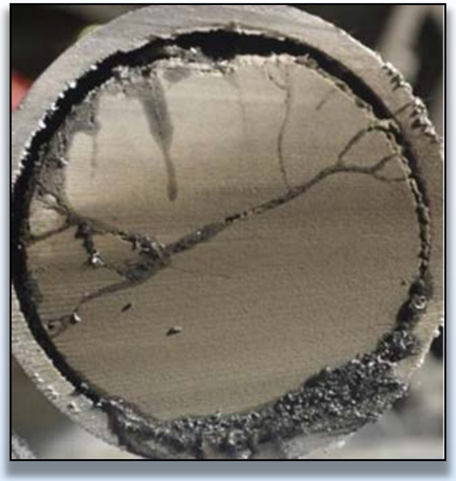
Propped fracture network

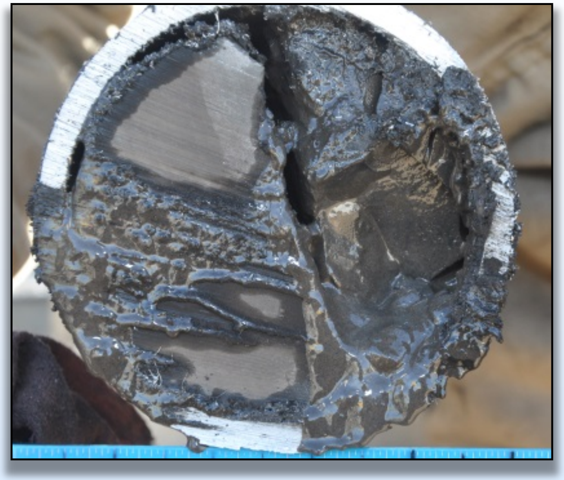
- Developed methods for detection and quantification of subsurface proppant distribution
- Resolved spatial distribution of proppant in the created SRV along the cored interval
- Results provided insights into propped fracture dimensions, concentration, perforation cluster efficiency, impact of natural fractures on proppant transport

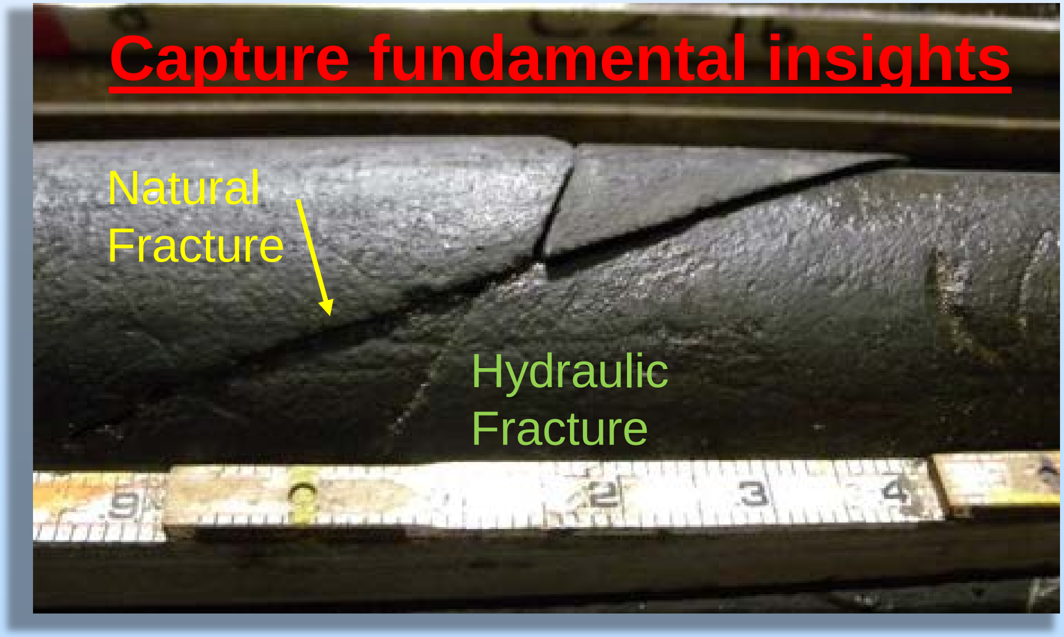
Sludge collected from core.

After washing and sieving, proppant and other particles can be identified and quantified

Fracture Attributes from Core







Capture fundamental insights

- Type
- Occurrence
- Orientation
- Morphology
- Mineral fill
- Interactions
  - HF/NF
  - Bedding
  - Frac fluid

Accomplishments to Date

- Formed a successful public-private partnership
- Drilled 11 new long-reach test wells, 6UW & 5MW
  - Vertical pilot below lower WC
  - Advanced OH logs and cores, 14 uDFIT's
  - Complete core analysis, petrophysics, geochem, petrography, imaging, etc.
- Completed 13 wells (2 refrac) with over 450 frac stages
  - Tracer, microseismic, and tilt-meter surveys
  - 4 toe DFIT's in cased horizontals
- Advanced open hole horizontal logs in 2 wells adjacent to core well

Accomplishments to Date

- Collected ~600 feet of through fracture whole core
  - CT scanned entire Core
  - Ran advanced OH – QC, Image, SG
- Ran multiple isolated pressure gages in core well to monitor reservoir pressure in multiple formations exhibiting various levels of fracturing as identified in whole through-fracture cores
- Completed detailed fracture description
- FIB-SEM
- Completed initial and repeat multi well sequential production interference test with high resolution BH pressure and temperature data

Accomplishments to Date

- Air and water sampling, before, during, and after completions
- 2 Fiber Optic coil tubing production logs
- BH pressure gages in all producing wells, including refracs
- Collected a before and after fracturing cross-well seismic survey
  - 3 profiles across various fracture orientations, including refrac wells
- Industry and Government involvement
  - 23 subject matter specific workshops with hundreds of attendees
  - 57 project update net-meetings/phone conferences

Lessons Learned

- Careful planning and operational de-risking helps ensure project tracks on budget and on time
- Multi-disciplinary teamwork critical for successful execution
- Multi agency involvement provides access to SME's and allows early adoption of learnings, leading to efficient technology transfer
- A balance between science and practical issues is key to success when collaborating with various stakeholders

Synergy Opportunities

- Collaborate with other NETL field test sites; in the Marcellus and Utica shale
- Access to field samples in the near future
- Continue to grow the public-private partnership to extend field data acquisition, analysis, and data integration

Project Summary

- We have captured fundamental insights of fracturing
- Hydraulic fractures do not grow into fresh water zones
    - No evidence of fracturing or reservoir fluids migrating into aquifer
    - Substantiated with fracture diagnostics and aquifer fluid sampling
- Propped fracture dimensions are very different from hydraulic fracture dimensions
- No impact on local air quality during hydraulic fracturing
    - Potential for elevated emissions during flowback if using open systems
- We will continue to analyze and integrate various datasets to get a deeper understanding of the fracturing process

Appendix

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

Benefit to the Program

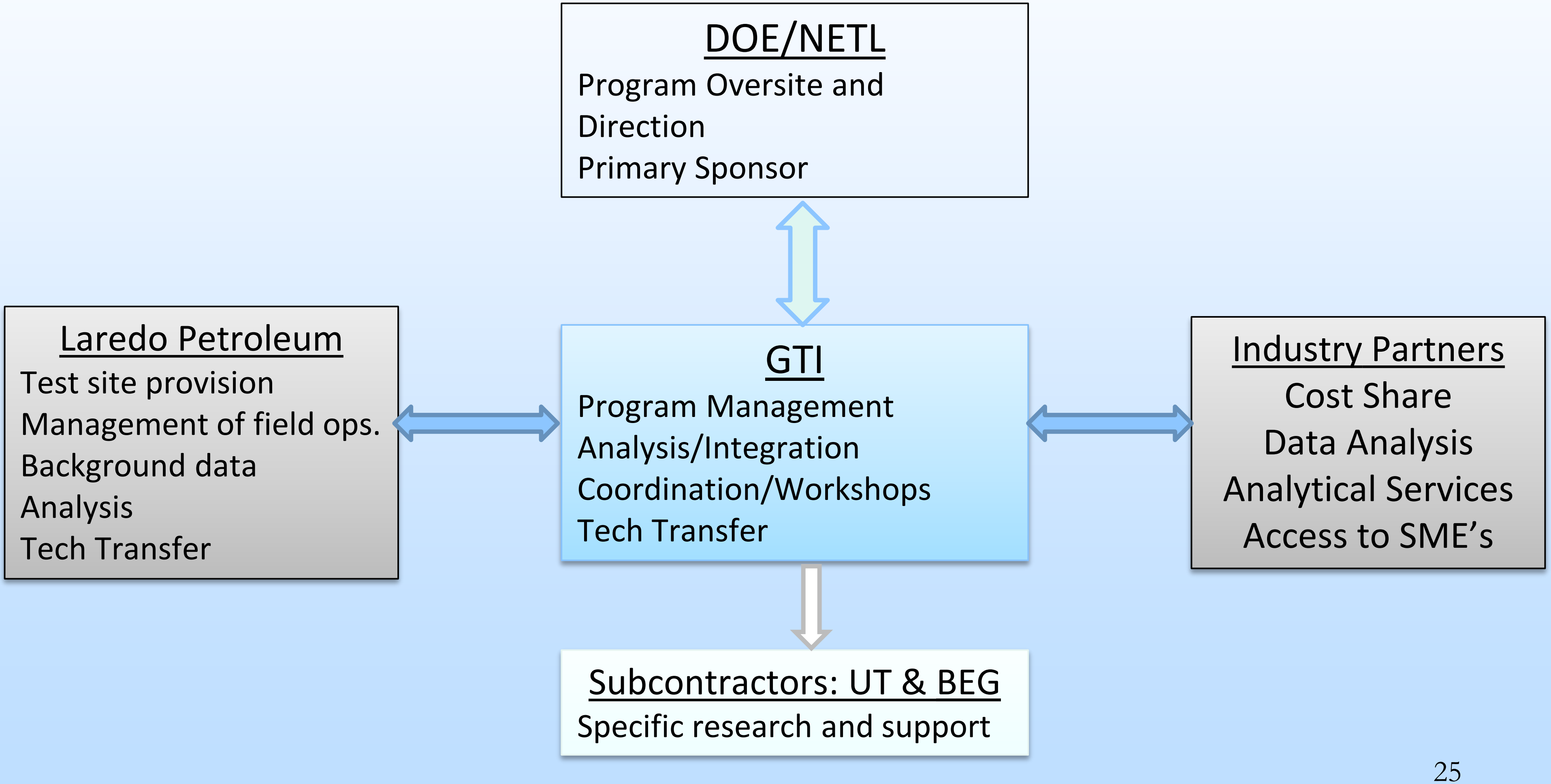
- The research project is focused on **environmentally prudent development of unconventional resources & enhanced resource recovery.**
- The HFTS is a collaborative, comprehensive hydraulic fracturing diagnostics and testing program in horizontal wells at a dedicated, controlled field-based site. The program emulates the field experiments DOE/NETL and GRI performed in vertical wells in the 1990s (Mounds, M-Site, SFEs). Technology has since advanced into long horizontal, multi-stage shale wells creating a new set of challenges and unanswered questions. HFTS will conduct conclusive tests designed and implemented using advanced technologies to adequately characterize, evaluate, and improve the effectiveness of individual hydraulic fracture stages. Through-fracture cores will be utilized to assess fracture attributes, validate fracture models, and optimize well spacing. When successful, this will lead to fewer wells drilled while increasing resource recovery.

Project Overview

Goals and Objectives

- The primary goal of the HFTS is to minimize current and future environmental impacts by reducing number of wells drilled while maximizing resource recovery.
- Objectives
  - Assess and reduce air and water environmental impacts
  - Optimize hydraulic fracture and well spacing
  - Improve fracture models
  - Conclusively determine maximum fracture height

Organization Chart



DOE/NETL
Program Oversite and Direction
Primary Sponsor

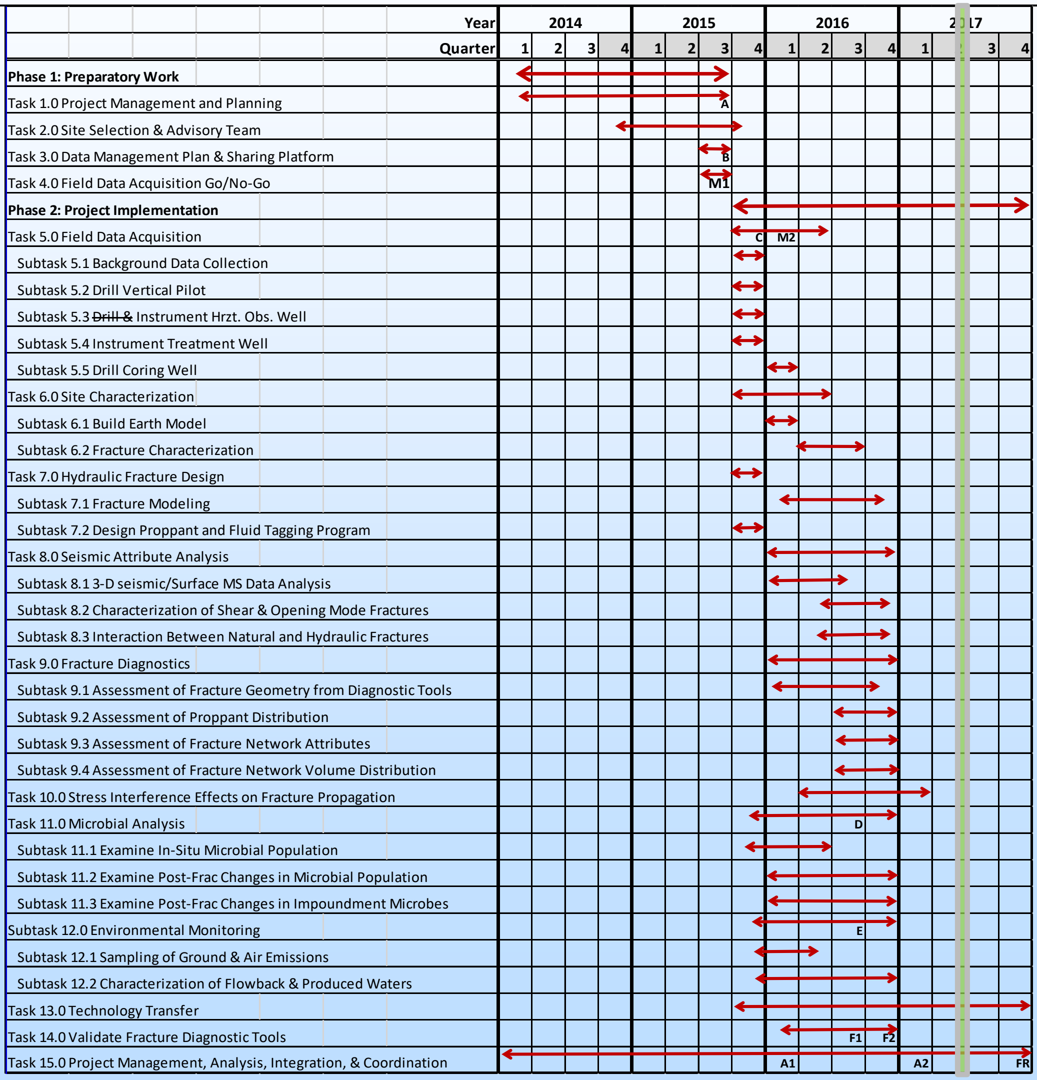
Laredo Petroleum
Test site provision
Management of field ops.
Background data
Analysis
Tech Transfer

GTI
Program Management
Analysis/Integration
Coordination/Workshops
Tech Transfer

Industry Partners
Cost Share
Data Analysis
Analytical Services
Access to SME's

Subcontractors: UT & BEG
Specific research and support

Gantt Chart



Phase 1: Preparatory Work
Task 1.0 Project Management and Planning
Task 2.0 Site Selection & Advisory Team
Task 3.0 Data Management Plan & Sharing Platform
Task 4.0 Field Data Acquisition Go/No-Go
Phase 2: Project Implementation
Task 5.0 Field Data Acquisition
- Subtask 5.1 Background Data Collection
- Subtask 5.2 Drill Vertical Pilot
- Subtask 5.3 ~~Drill &~~ Instrument Hrzt. Obs. Well
- Subtask 5.4 Instrument Treatment Well
- Subtask 5.5 Drill Coring Well

Task 6.0 Site Characterization
- Subtask 6.1 Build Earth Model
- Subtask 6.2 Fracture Characterization

Task 7.0 Hydraulic Fracture Design
- Subtask 7.1 Fracture Modeling
- Subtask 7.2 Design Proppant and Fluid Tagging Program

Task 8.0 Seismic Attribute Analysis
- Subtask 8.1 3-D seismic/Surface MS Data Analysis
- Subtask 8.2 Characterization of Shear & Opening Mode Fractures
- Subtask 8.3 Interaction Between Natural and Hydraulic Fractures

Task 9.0 Fracture Diagnostics
- Subtask 9.1 Assessment of Fracture Geometry from Diagnostic Tools
- Subtask 9.2 Assessment of Proppant Distribution
- Subtask 9.3 Assessment of Fracture Network Attributes
- Subtask 9.4 Assessment of Fracture Network Volume Distribution

Task 10.0 Stress Interference Effects on Fracture Propagation
Task 11.0 Microbial Analysis
- Subtask 11.1 Examine In-Situ Microbial Population
- Subtask 11.2 Examine Post-Frac Changes in Microbial Population
- Subtask 11.3 Examine Post-Frac Changes in Impoundment Microbes

Subtask 12.0 Environmental Monitoring
- Subtask 12.1 Sampling of Ground & Air Emissions
- Subtask 12.2 Characterization of Flowback & Produced Waters

Task 13.0 Technology Transfer
Task 14.0 Validate Fracture Diagnostic Tools
Task 15.0 Project Management, Analysis, Integration, & Coordination

	Milestones & Deliverables
A	Project Management Plan
B	Data Management Plan & Data Sharing Platform
M1	Go/No-Go Decision Point
M2	Complete Hydraulic Fracturing Field Data Acquisition and Put Wells on Production
C	Technology Test & Verification Plan
D	Topical Report on Microbial Population Changes
E	Topical Report on Environmental Monitoring
F1, F2	Technical Reports on Fracture Design, Implementation, Monitoring and Analysis
A1, A2	Annual Report
FR	Final Report

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