HFTS I

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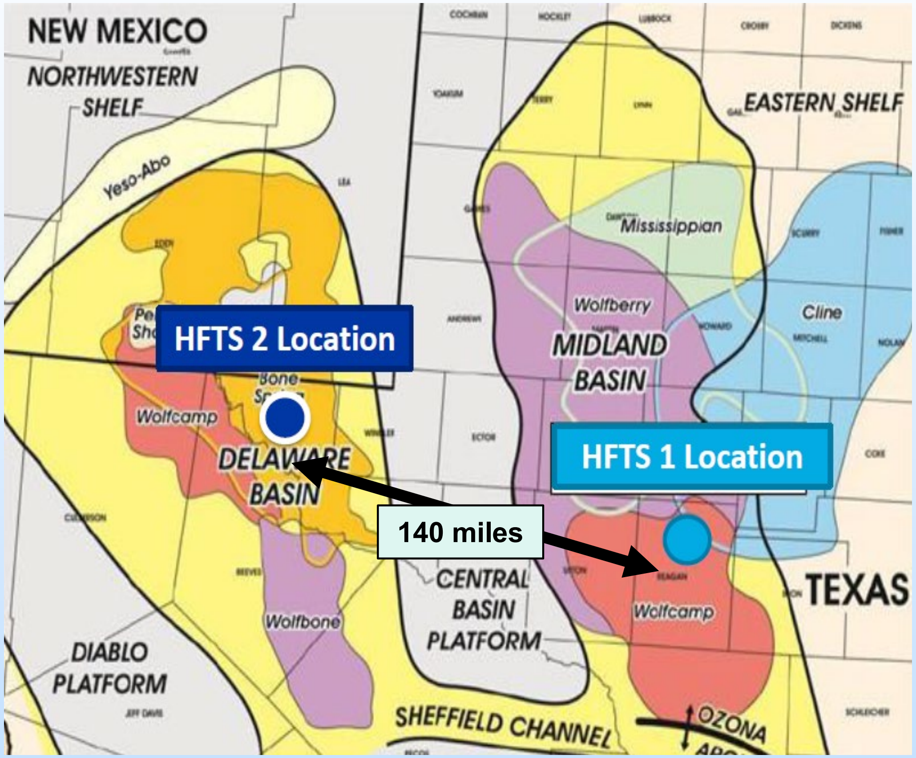
U.S. Department of Energy
National Energy Technology Laboratory
Resource Sustainability Project Review Meeting
October 25 - 27, 2022

Presentation Outline

- Project Summary
- Overview of Test Sites
- Phase 1
- Phase 2
- Phase 3
- Lessons Learned
- Appendix

HFTS 1 Project Overview



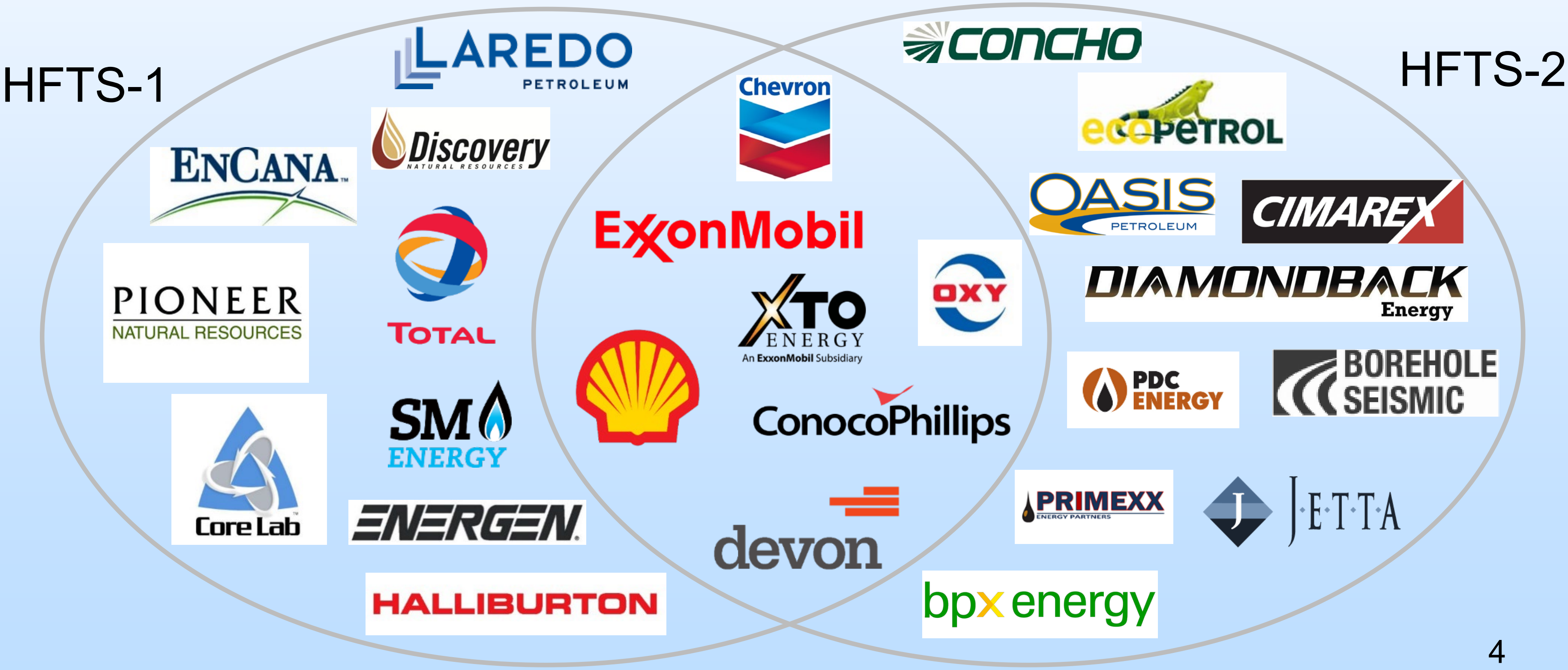
- Field-based integrated data rich diagnostic pilots utilizing dedicated science wells
- Ground truth SRV core; indisputable evidence of fracs and proppant
- Advanced diagnostics; reservoir pressure monitoring, OH logs, FO measurements, tracers, etc.
- Public-private partnership, comprised of 20+ participating companies
- Potential to reduce the number of wells required to develop west Texas resources by thousands

POP	DOE	GTI	Total
10/1/14-6/30/23	$21,464,101	$22,738,430	$44,202,531

Project Participants

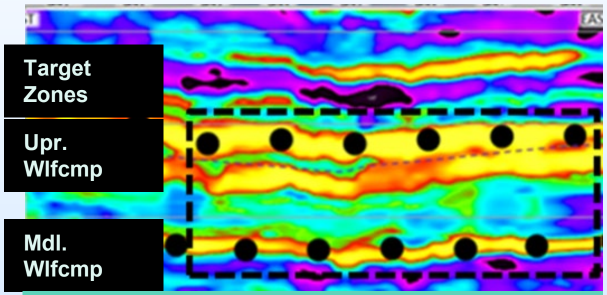
U.S. DEPARTMENT OF ENERGY | Fossil Energy
OFFICE OF OIL & NATURAL GAS

NATIONAL ENERGY TECHNOLOGY LABORATORY



Overview of HFTS-1Test Sites

- Phase 1 (completed)



Earth Model showing zones of highest potential (yellow)

Image Courtesy: Laredo Petroleum

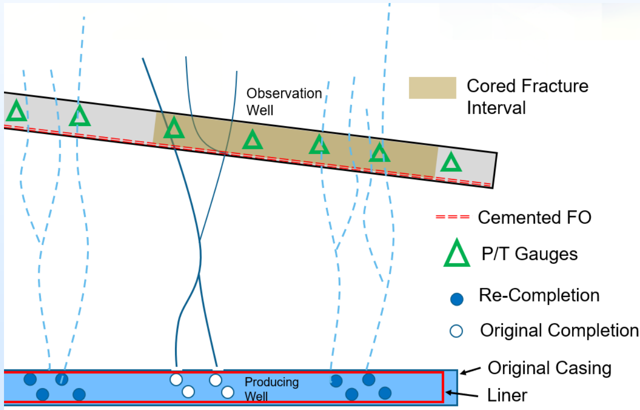
- Reagan Co. TX
- 11 tightly spaced test wells in MW & UW
- 1st core-through well providing insight into frac geometry and proppant distribution
- Air & water monitoring

- Phase 2 EOR (completed)

Image Courtesy: Laredo Petroleum

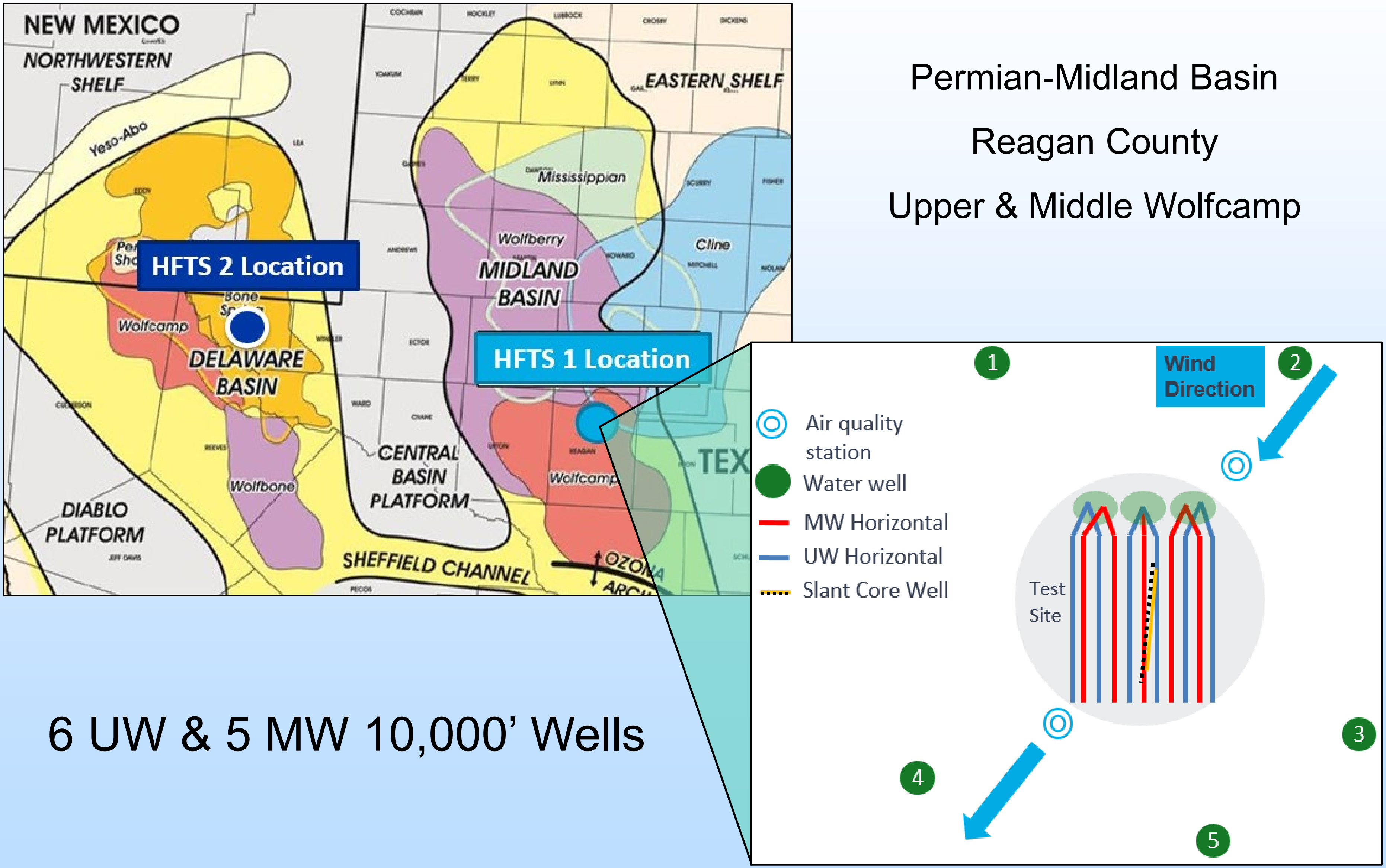
- Huff-n-Puff EOR field pilot
- Injected ~1/4 Bcf field gas
- 2nd fracture core-through
- Proppant analysis
- Field tested membrane distillation water treatment technology

- Phase 3 EOR2 Liner Refrac



- DeWitt Co. TX EagleFord
- Cemented liner recompletion/re-stimulation
- 3rd core through well
- Advanced FO diagnostics and P/T gauges
- Proppant Log

HFTS 1 Location



Permian-Midland Basin

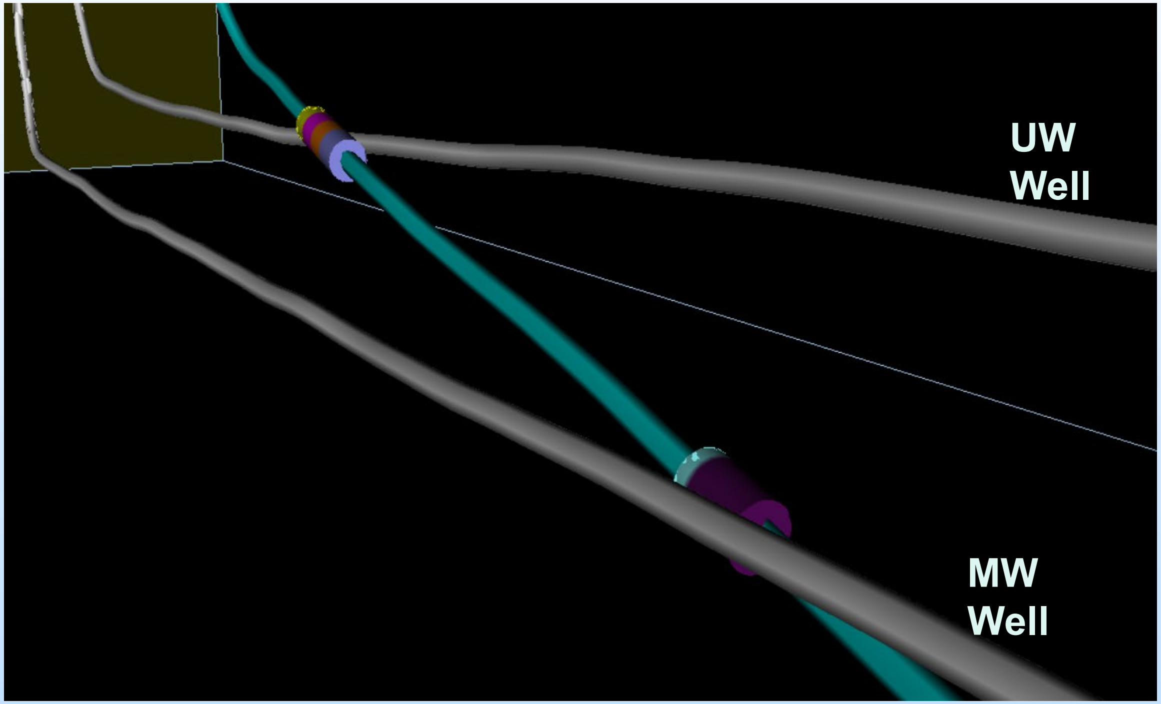
Reagan County

Upper & Middle Wolfcamp

6 UW & 5 MW 10,000’ Wells

HFTS-1 Phase 1 Core Through Well (all are slanted in some fashion)

- Nearly 600 feet of SRV core
  - Upper & Middle Wolfcamp
  - Core proppant analysis
- Open hole logs
  - Quad Combo, including spectral gamma and image log (OBMI)
- Pressure gages



Core Summary – Upper Wolfcamp

Recovered ~436 feet of core in Upper Wolfcamp in 4 coring trips

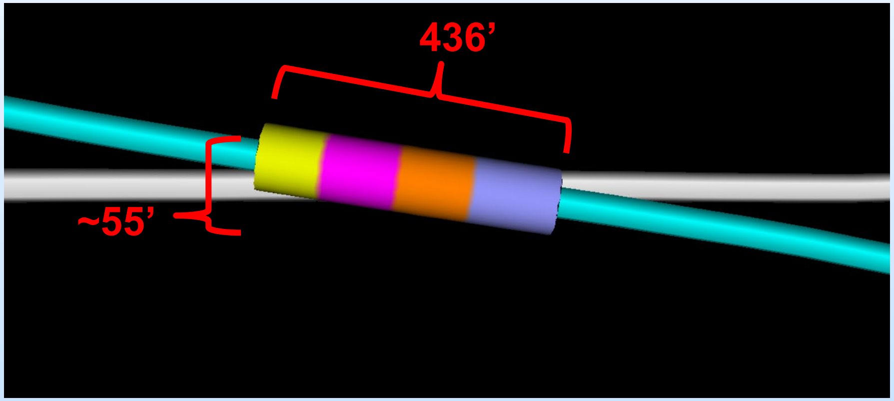
-Core 1 – 86’

-Core 2 – 115’

-Core 3 – 108’

-Core 4 – 127’

Side View

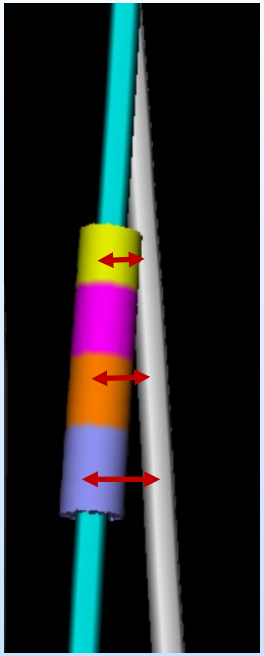


Z-Distances

40’ above 6SU

15’ below 6SU

Plan View



X-Distances

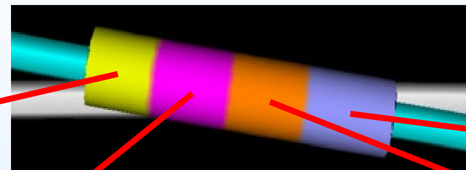
40’ highest depth

85’ same depth

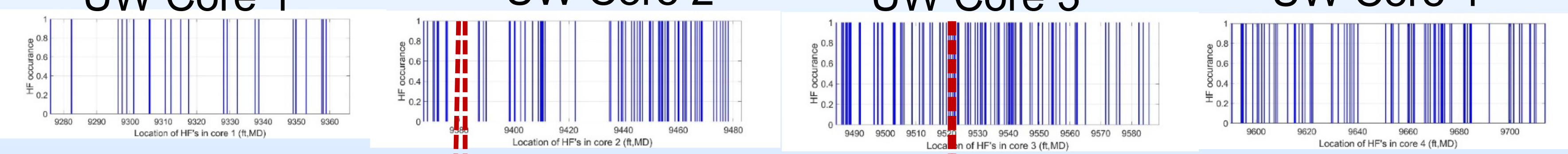
105’ lowest depth

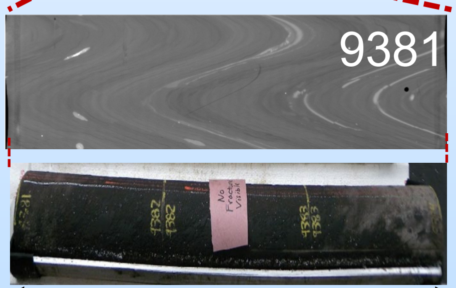
*Note this distance as it will be important later

Upper Wolfcamp Core – Fracture Clustering and Voids

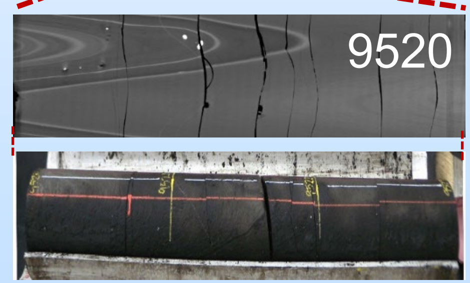


UW Core 1* UW Core 2* UW Core 3* UW Core 4*





No HF in 3' Section



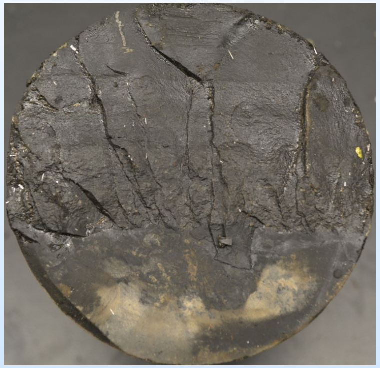
8 HF in 3' section

-Over 600 fractures in 436 feet of core
-323 fractures identified as HF
-1 HF every 1.3' of core on average
-Swarming behavior

*Fracture description data: Dr. J. Gale, BEG

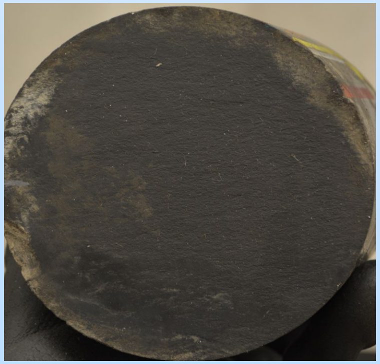
Hydraulic Fractures in Core – Variable Morphology

Complex breaks, irregular patterns, stepping planes



Smooth planar surfaces

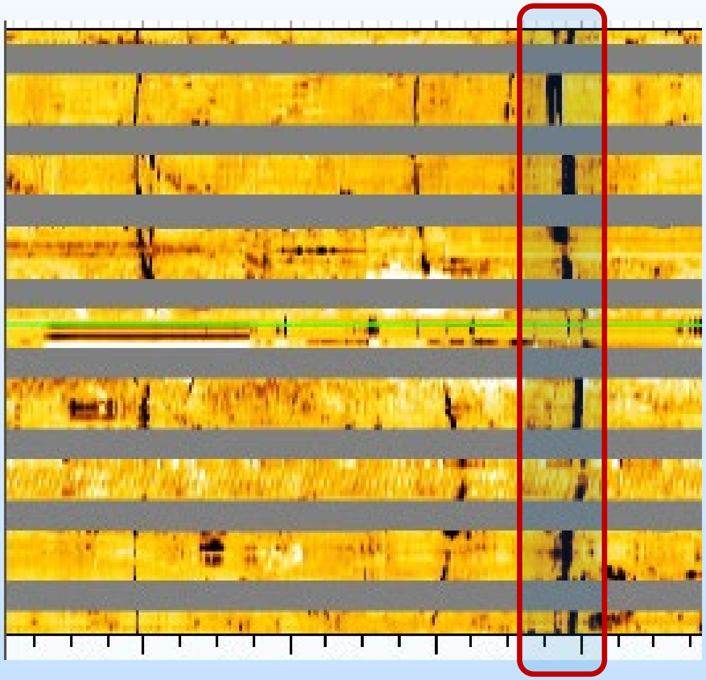
Images by J. Gale BEG

Proppant in “Rough” Fracture

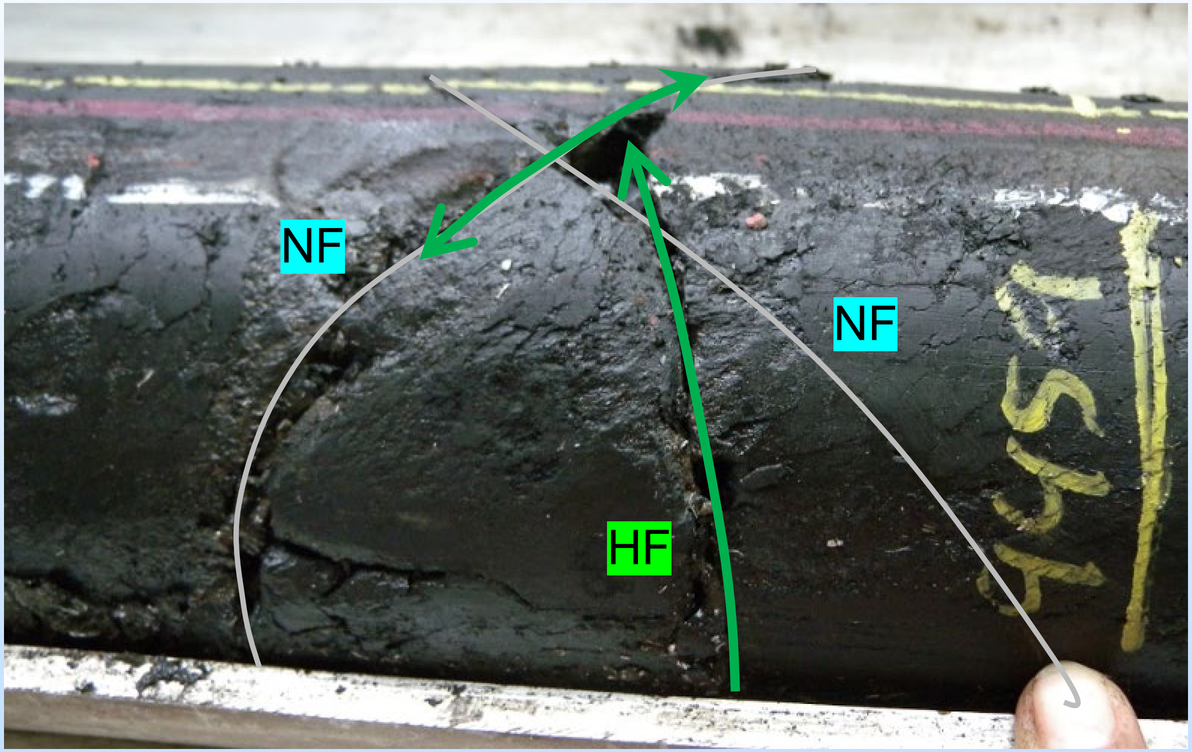
Tortuous path for proppant

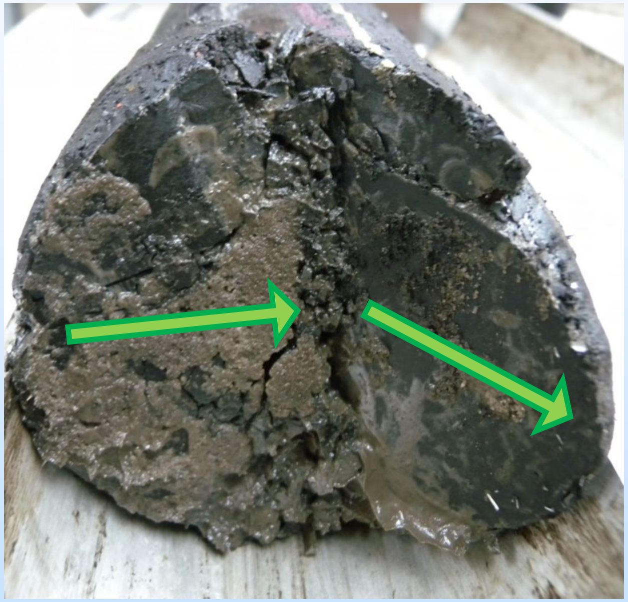
Images by J. Gale BEG

Proppant Pack in Image Log (~85 feet away)

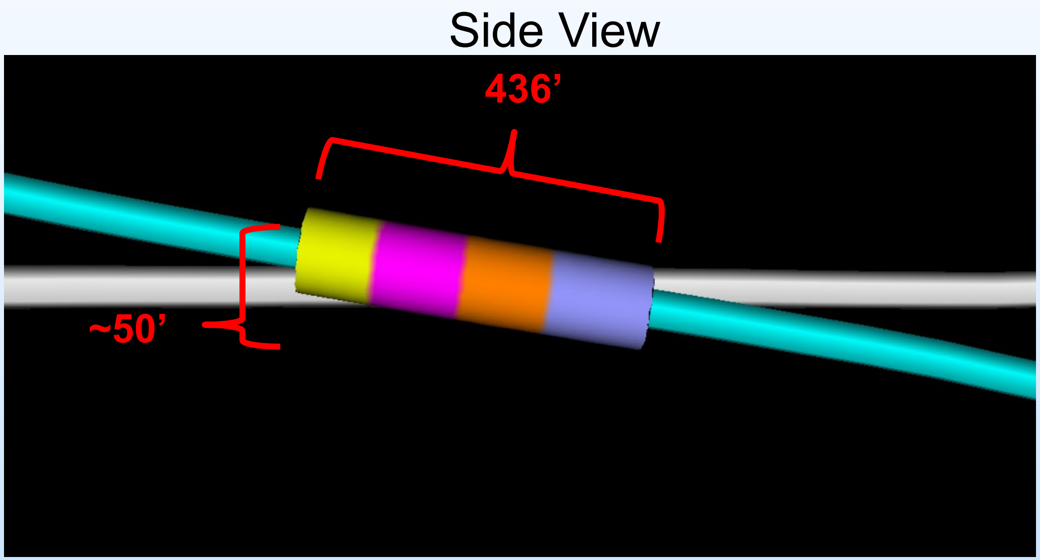


Proppant in HF/NF Complex

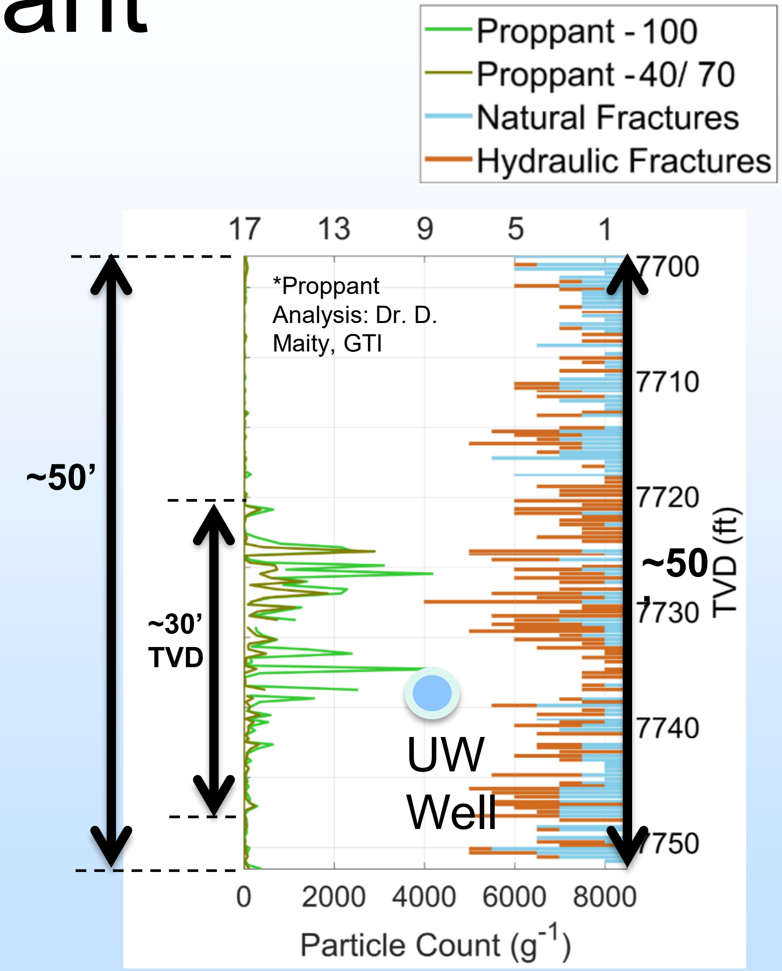




ProppantLog Provides Insights into Vertical Proppant Distribution



*Limited vertical proppant distribution



Phase 2 – EOR

Huff-and-Puff Field Pilot in the M. Wolfcamp

2nd Slant Core Well

HFTS Phase 2: EOR Field Pilot

Goal of the EOR experiment is to determine the effectiveness of cycling gas injection (huff-and-puff) in increasing oil recovery from the Wolfcamp shale.

Characterize existing fracture system from new slant core well

Perform HP cyclic gas injections in existing wells and monitor gas movement

EOR Wells ~1.5miles from Phase 1

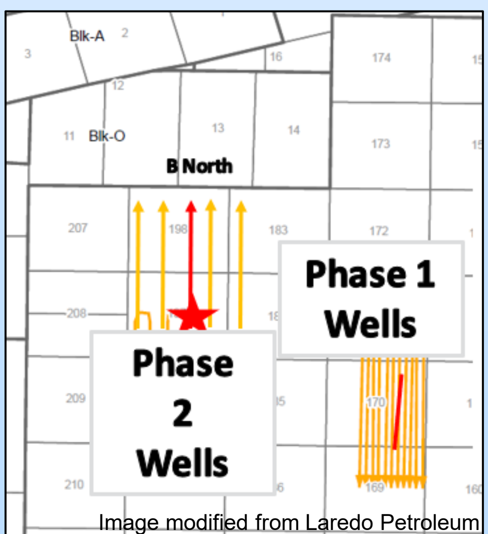
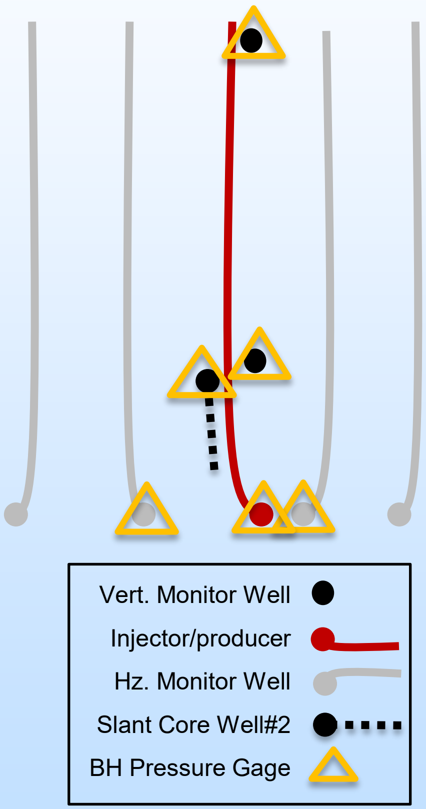


Image modified from Laredo Petroleum


HP Compressor, Image Courtesy Laredo

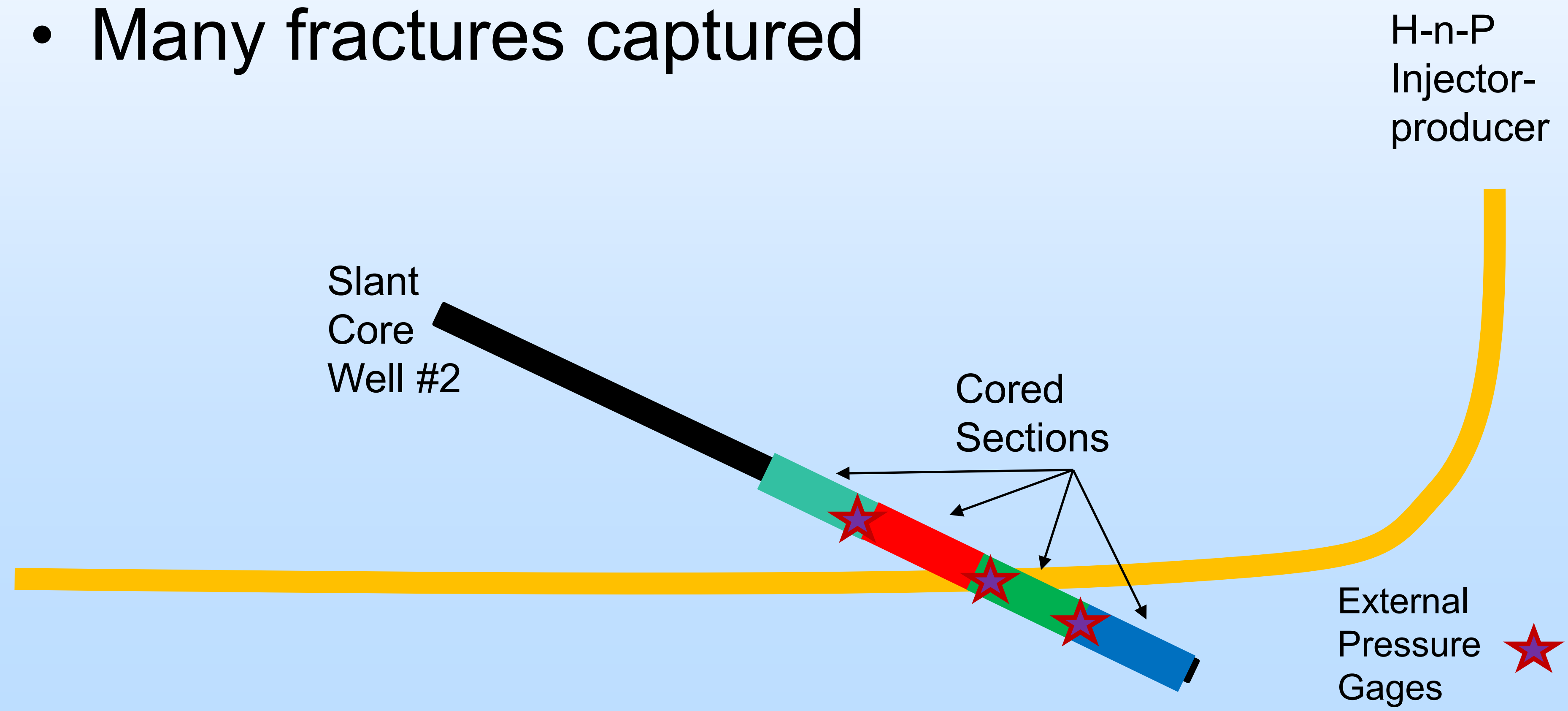
H-n-P Pilot Details

- Lean field gas as injectant
- Bottom hole pressure gages in offset horizontal and vertical wells
- FO Injection/production logs
- Surface passive seismic monitoring
- New slant core well adjacent to injector well
  - Capture fractures in SRV from core description and image log, proppant distribution.



Slant Core Well #2

- Recovered 260’ of core
- Installed 3 pressure gages
- Many fractures captured



HFTS-1 Phase 2 Huff-and-Puff EOR Results

Injection Rate

Image modified from Laredo Petroleum

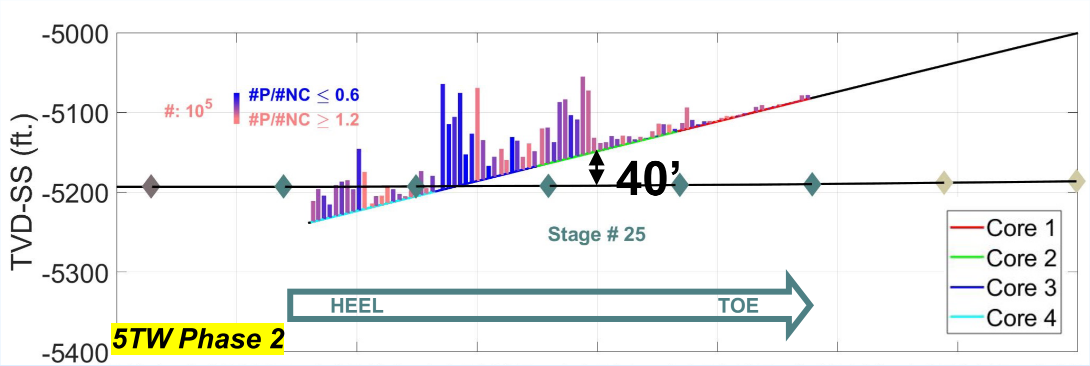
Injected over 0.25Bcf of field gas over 2 months time, pressure stabilized, not able to reach miscibility pressure (4,425psi), no discernable improvement in production

Injected gas quickly spread through field, evidenced by elevated gas production in offset wells, 7 hz wells shut in due to gas breakthrough, increased gas production noted more than mile away from injector

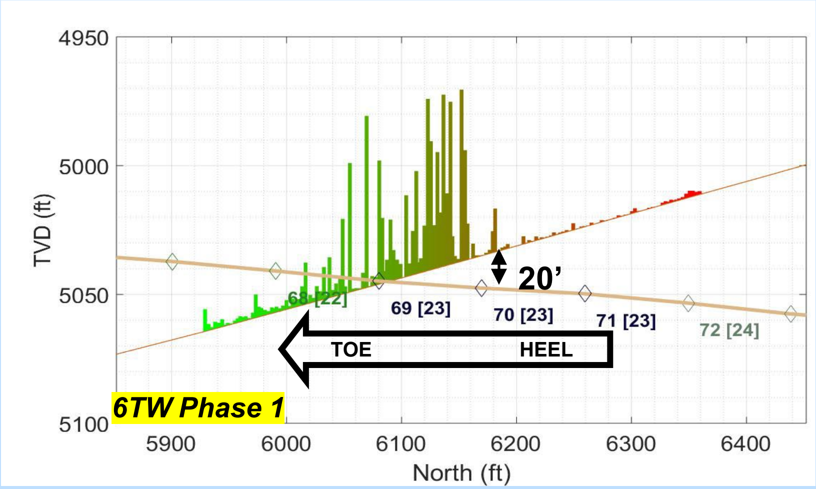
Evidence of extensive fracture network in core, including swarming, supports rapid gas movement, inability to build pressure

“Leaky Bucket”

Proppant height observations from Phase 1 & 2



Both cores show that proppant peaks can be observed below the lateral at significant depths. For 6TW, this was ~ 25' & for 5TW, this is ~ 50' [limited by coring depth].



There is limited proppant distribution above the laterals. For 6TW core, this was ~ 20 ft & for 5TW core, this is ~ 40 ft [barring errors in directional surveys].

Lessons Learned P1&P2

- Fracture quantity and complexity far beyond what current simulators/models can predict.
- Vertical proppant distribution measured in core is limited
- Multiple proppant packs found, others likely washed-out during coring, indicating inefficient proppant placement.
- Far-field created fractures (100+ ft away) are multiple in number, non-uniform in distribution with fracture clusters and voids
- Injected gas tends to quickly spread across field, limiting pressure buildup and miscibility
- Fracture voids indicate many areas of reservoir not stimulated which have potential for future stimulation and recovery improvement

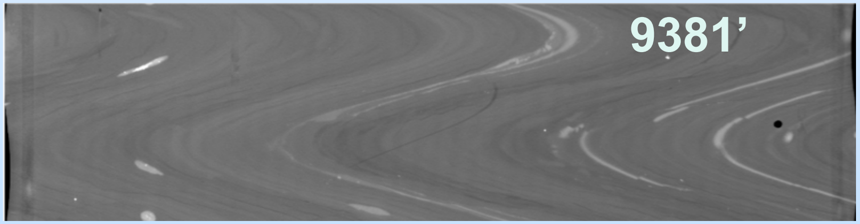
Image courtesy: Laredo Petroleum

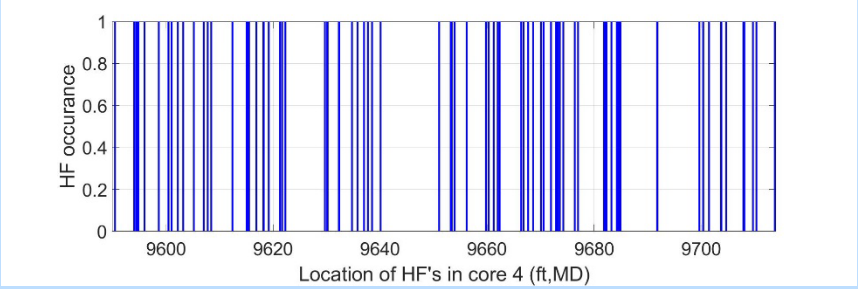
Phase 3 – EOR v.2

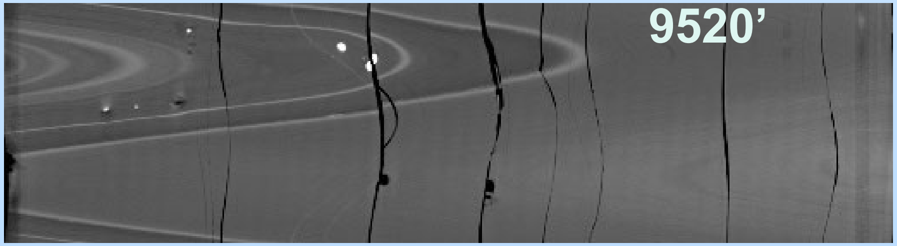
Liner Recompletion In-fill Stimulation (Refracturing) in the Eagle Ford

HFTS-1 Phase 3 EORv2 Liner Recompletion "Infill-stimulation"

- Answer the key question – Can new, previously undrained reservoir be identified within a wellbore, and successfully stimulated utilizing liner technology?
- Understand how new fractures grow in presence of existing depleted fractures, and changes in drainage
- Utilize latest FO diagnostic, perforation imaging and proppant logging technologies
- Quantify the economic viability of infill stimulation and potential added resource, and environmental benefits by reducing the need for new wells



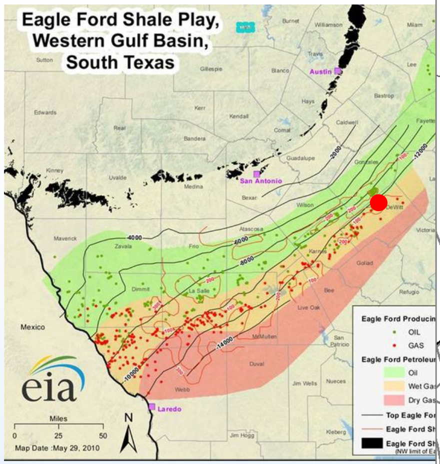


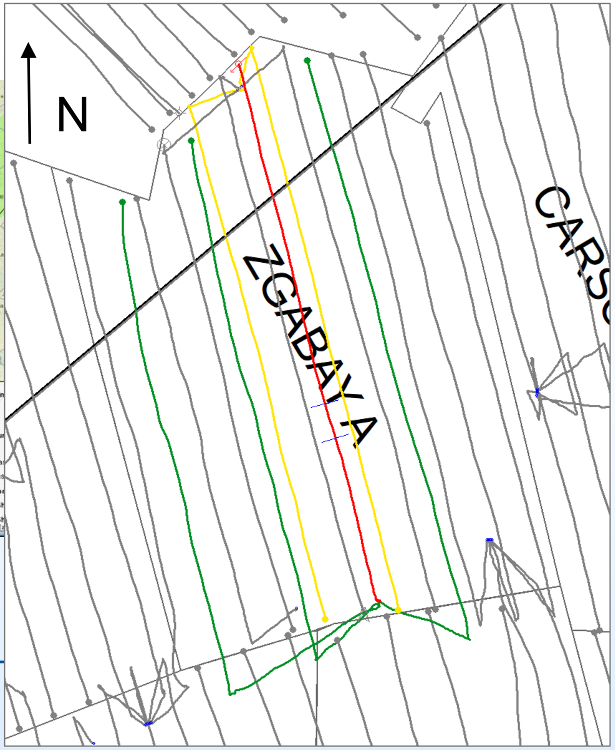


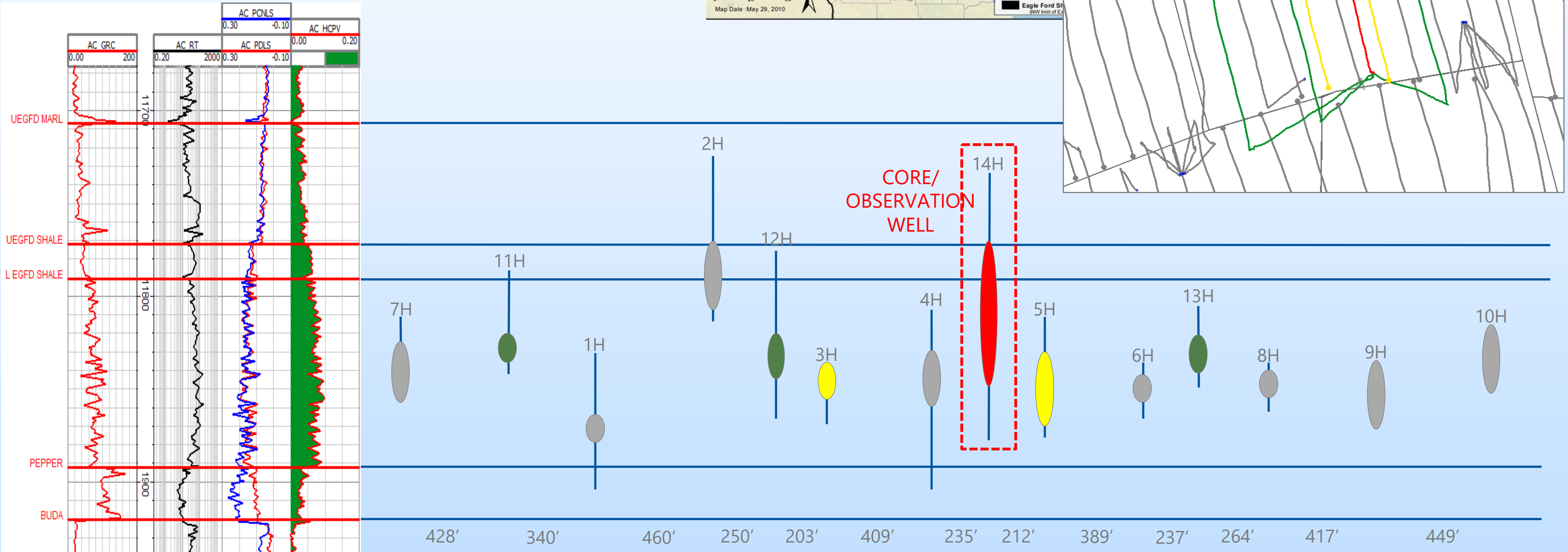
Current Status

- Installed and cemented liner in 2 wells
- Drilled observation well, recovered 420’ of SRV core, installed FO and 9 P/T gauges
- Fracture stimulated liner re-completed wells, monitored with FO and pressure gauges
- Placed wells on production and completed 2 interference tests
- Data analysis and integration ongoing

Phase 3 Test Site Wells







Legend

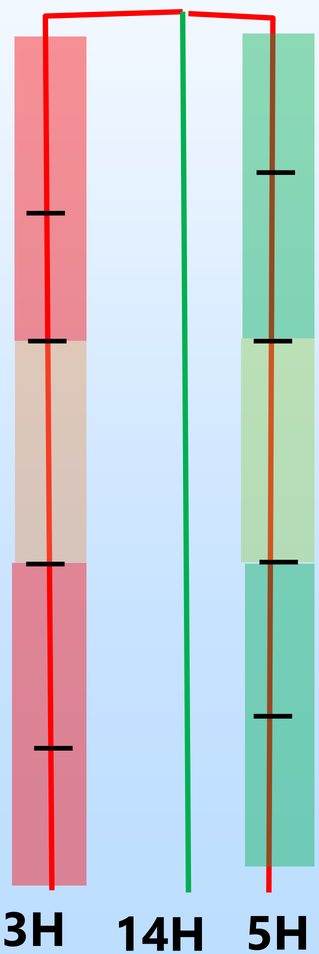
- Existing Wells
- Production Infill Wells
- Observation Well
- Re-Frac Wells

Completion Comparison

Original completion ~8-years ago: geometric 6-50' 36spf

Zgabay 3H Refrac

Stages	Clusters Per Stage	Cluster Spacing	Perf Friction
1-6	7	15'	low
8-13	12		
15-17	22	10'	
18-20	22		high
22-28	7	15'	
30-36	12		
7, 14, 21, & 29	1	—	low



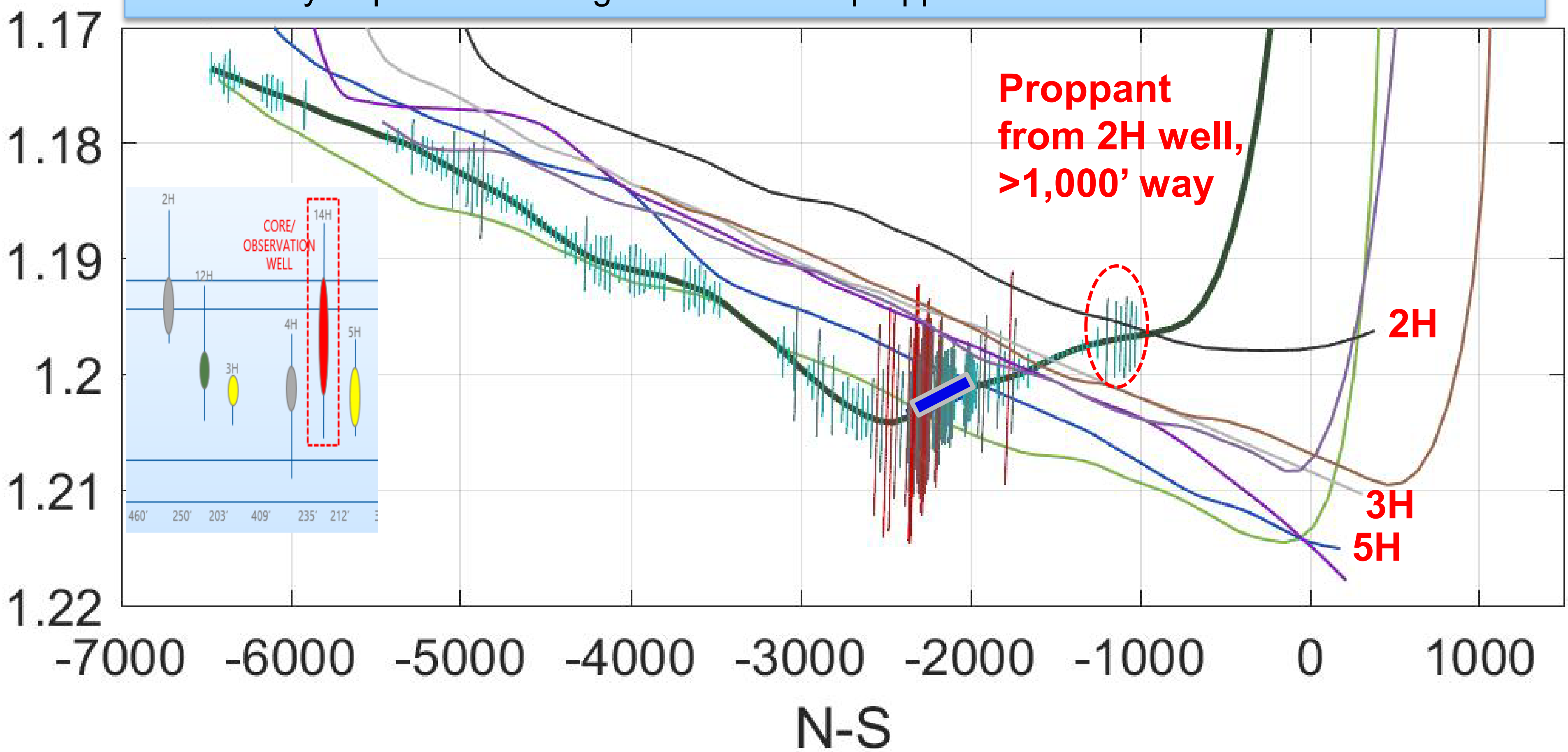
Zgabay 5H

Stages	Clusters Per Stage	Cluster Spacing	Perf Friction
1-6	7	20'	low
8-13	12		
15-17	22	12'	
18-20	22		high
22-26	7	20'	
28-32	12		
7, 14, 21, & 27	1		low

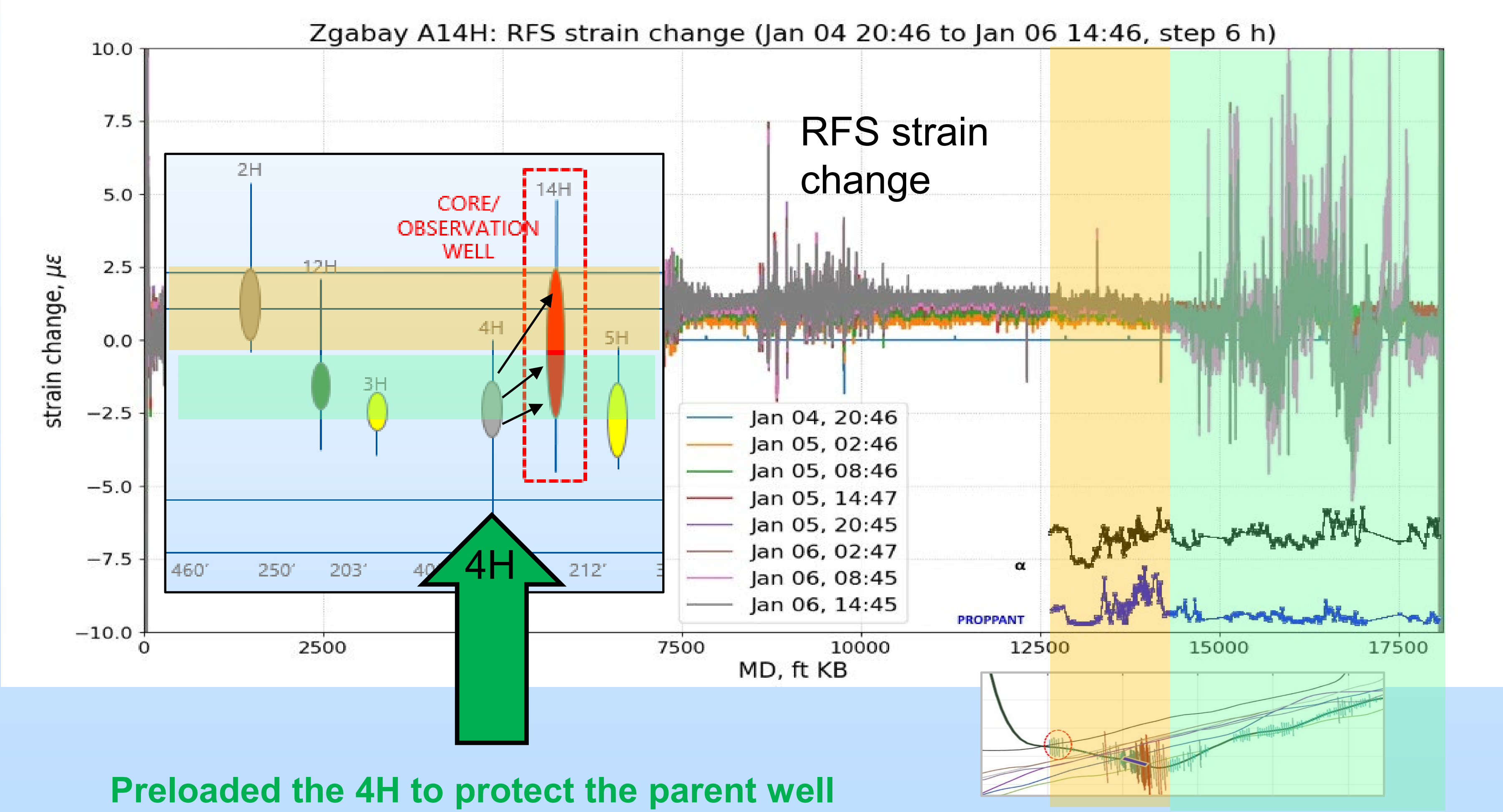
Proppant Log from Mud Returns

Complex well scenario with many adjacent wells on both sides, at various landing points. Proppant seems to be either at or below adjacent well depth.

Proppant found at same depth as well over 1,000' away. Pressure gauge and FO x-well strain analysis provides strong evidence that proppant came from the 2H well.

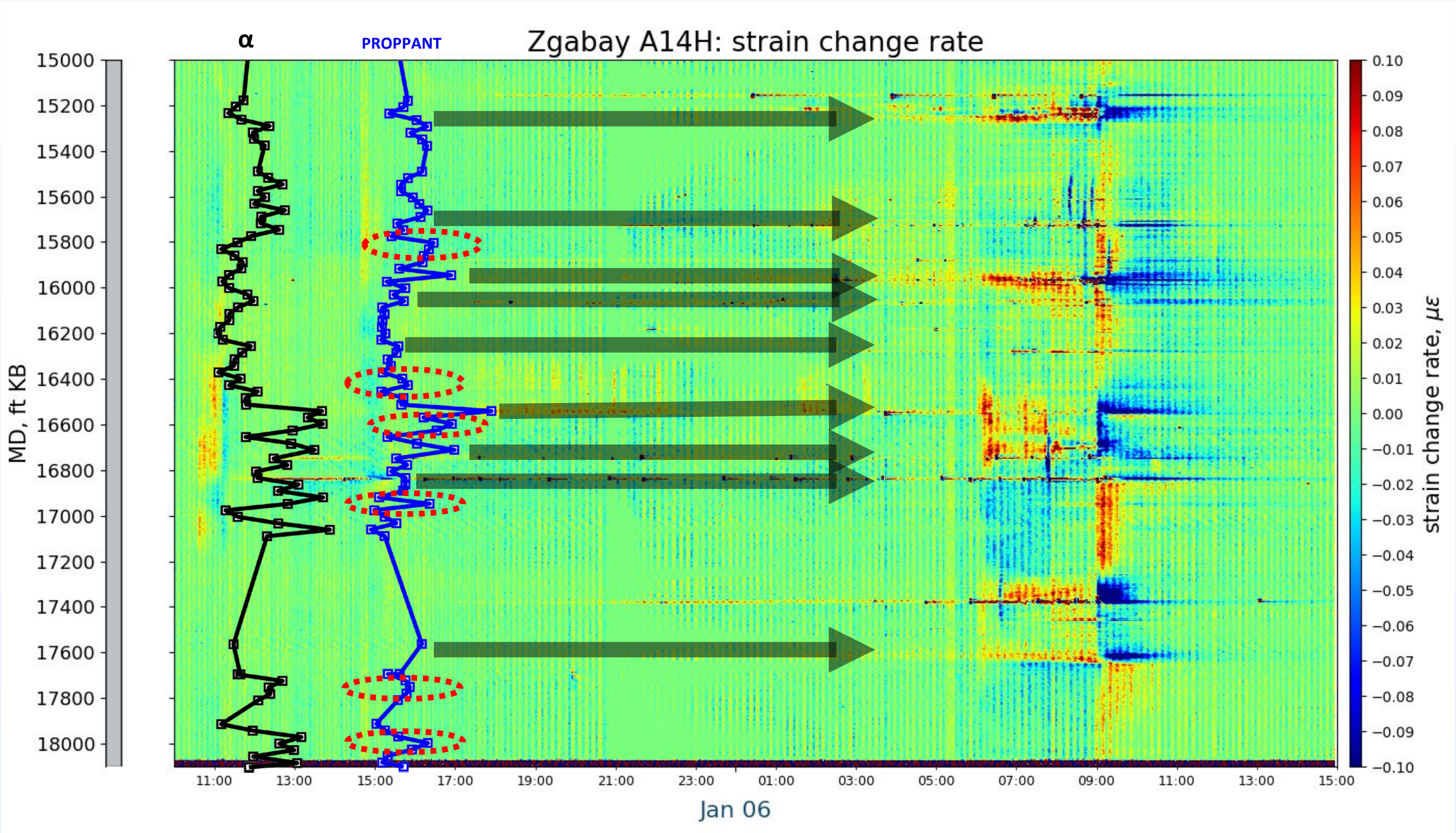


Where did Proppant Originate?
4H Preload X-Well Strain Data



Preloaded the 4H to protect the parent well and reduce asymmetric frac growth

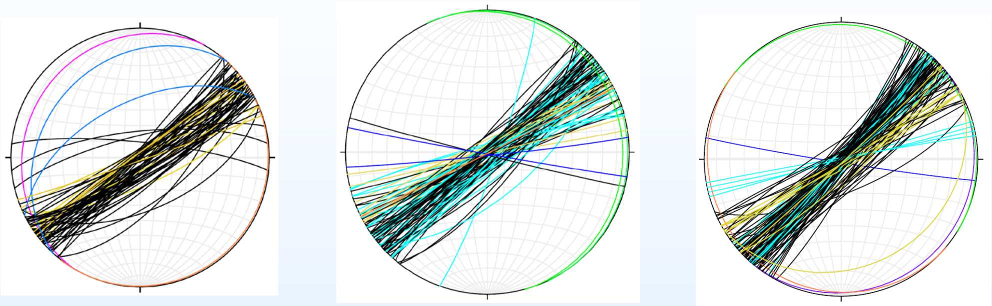
Communication – strain change – 4H preload



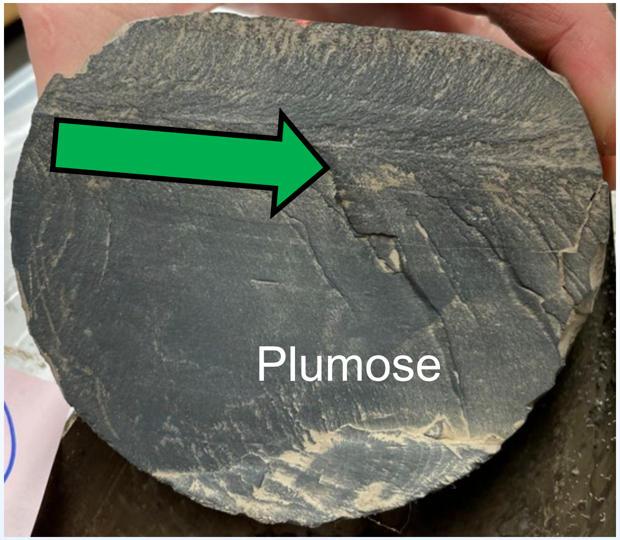
Most definable zones from strain change rate maps tie with local peaks from the log data.

Other peaks not showing strain change response does not mean they are not propped. Likely associated with other wells.

Core Fractures



Very consistent HF orientation



Production Results

- 3H Refrac Well
  - Original completion IP ~900 bopd
  - Production before refrac: ~20 bopd
  - Production after refrac: max ~1200 bopd
- 5H Refrac Well
  - Original completion IP ~900 bopd
  - Production before refrac: ~20 bopd
  - Production after refrac: max ~1000 bopd

Lessons Learned

- Multiple diagnostics confirm fractures from initial completions and fracture corridors from liner recompletions
- High perf friction low cluster designs show best efficiency in both nearfield (perf imaging) and far field (cross-well strain)
- Mud-return proppant-log can quantify proppant and identify stimulated areas of the reservoir
- Significant EUR uplift from liner recompletions
  - Able to capture stranded reserves from less effective early completions which leave significant fracture voids
  - Much smaller environmental footprint than new-drills, and in some cases more economic

Acknowledgements

Thanks to Department of Energy (DOE), National Energy Technology Laboratory (NETL), Laredo Petroleum, Devon, and HFTS Sponsors.

Images Courtesy: DOE/NETL, Laredo, GTI

Appendix

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

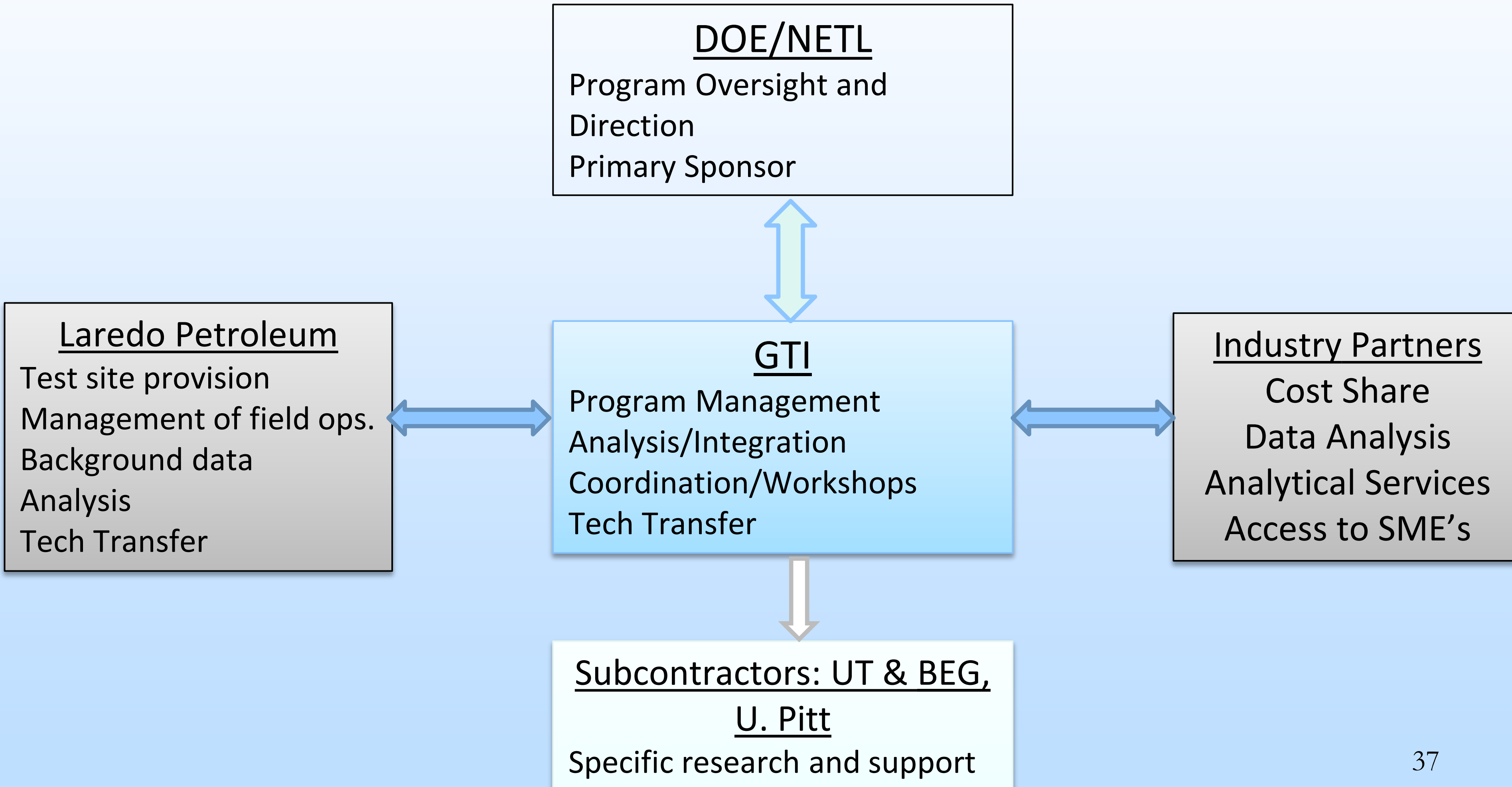
Benefit to the Program

- 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.

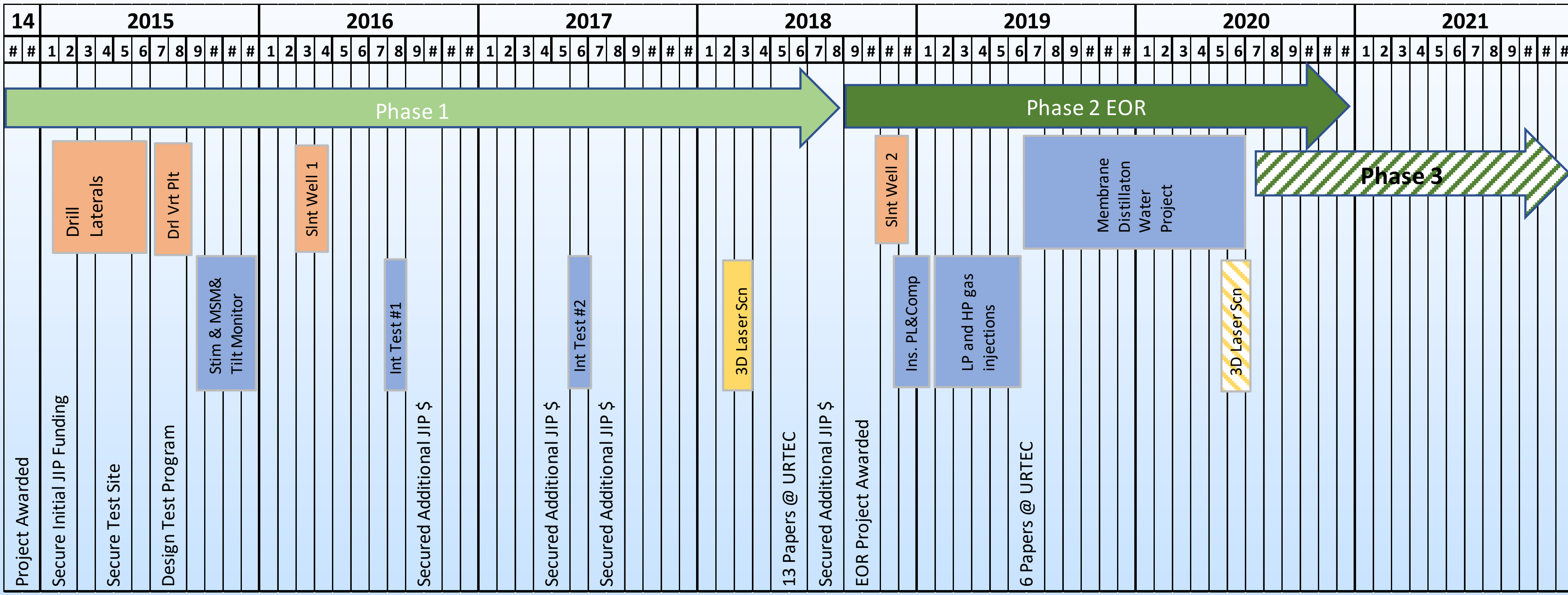
Project Overview
Goals and Objectives

- 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



Gantt Chart


14
2015
2016
2017
2018
2019
2020
2021
Phase 1
Phase 2 EOR
Phase 3
Drill Laterals
Drl Vrt Plt
Stim & MSM& Tilt Monitor
Slnt Well 1
Int Test #1
Int Test #2
3D Laser Scn
Slnt Well 2
Ins. PL&Comp
LP and HP gas injections
Membrane Distillaton Water Project
3D Laser Scn
Project Awarded
Secure Initial JIP Funding
Secure Test Site
Design Test Program
Secured Additional JIP $
Secured Additional JIP $
Secured Additional JIP $
13 Papers @ URTEC
Secured Additional JIP $
EOR Project Awarded
6 Papers @ URTEC

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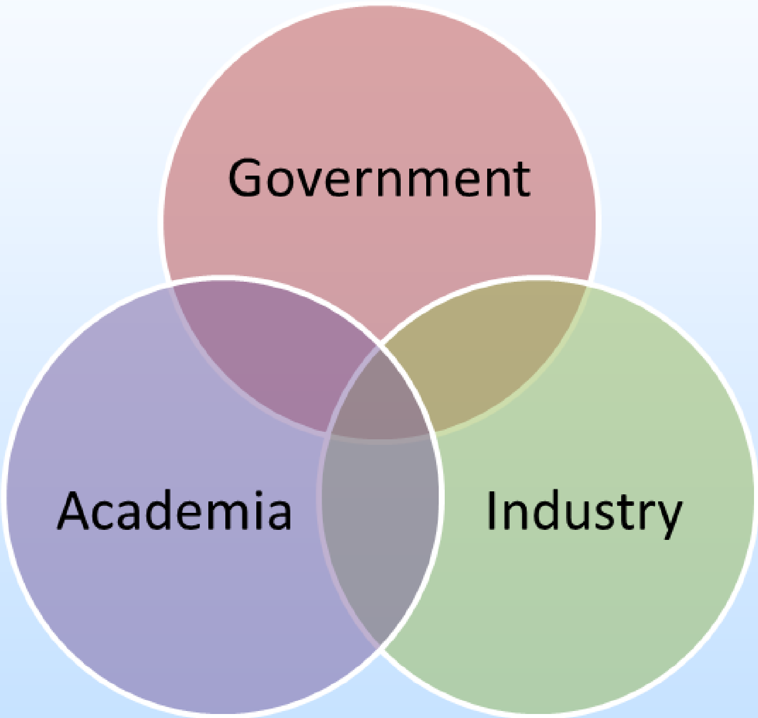
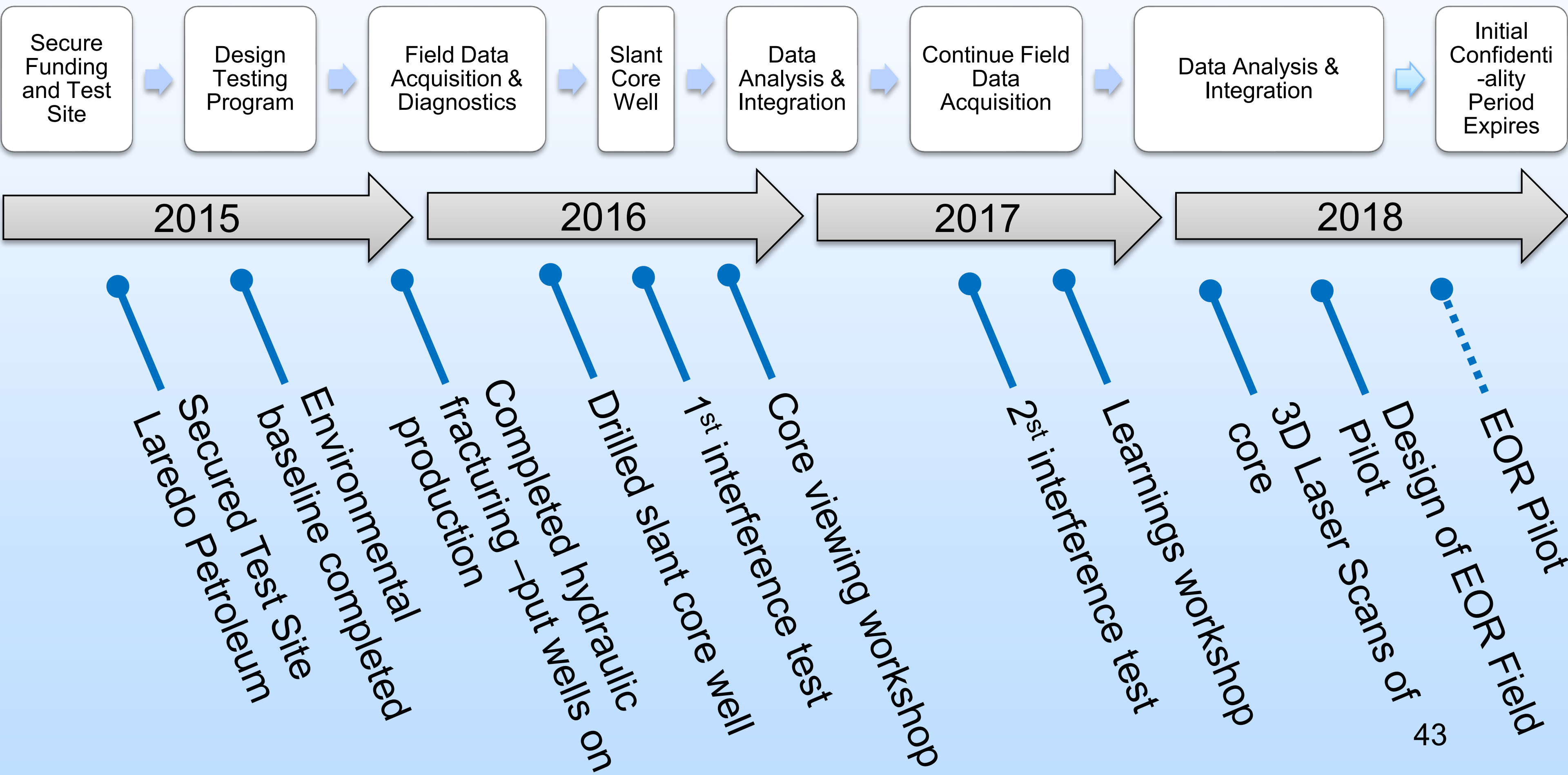
Public Private Partnership



- 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
  - 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

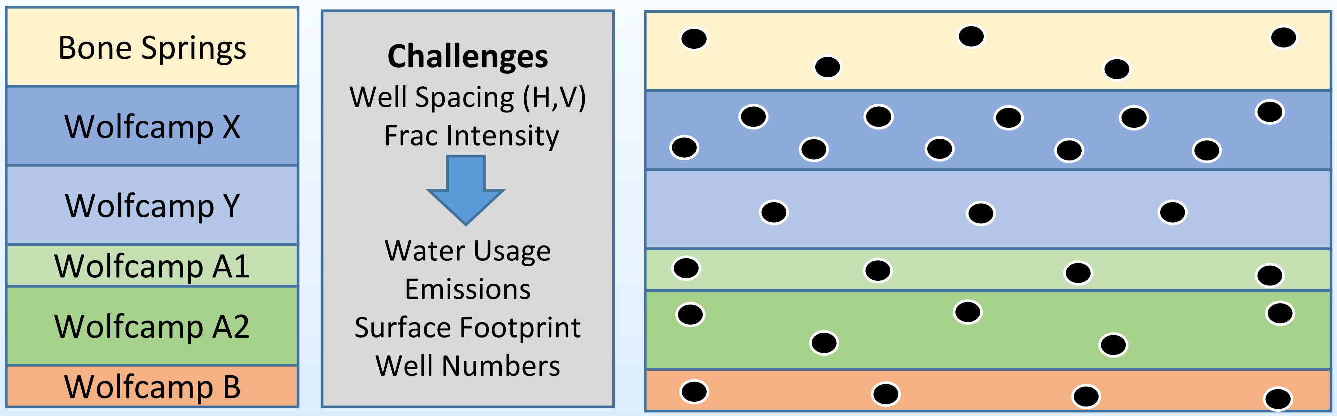
Project Progress and Major Milestones



Stacked Pay Resource Development a “Rubik's Cube”

Permian “Stacked Pay”

Example of Potential Wells Required



Public-private research programs such as HFTS leverage public and private funding and expertise to address the complexities of sustainably developing stacked pay resources

POP	DOE	GTI	Total
10/1/14-6/30/23	$21,464,101	$22,738,430	$44,202,531