Status of Unconventional IOR

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PetroEconomic Solutions, LLC

Environmentally Friendly Technologies for Subsurface Development

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Tertiary Oil Recovery Program (TORP)
Kansas Interdisciplinary Carbonate Consortium (KICC)

- Characterization of reservoirs at multiple scales: nano-, laboratory and field scale.
- Core floods at temperatures up to 200 degrees C
- Development of innovative, environmentally friendly technology for subsurface development (enhanced geothermal, carbon storage, carbon utilization, improved completions.

What does the future look like?

> "The world is hungry for energy."
>
> Professor Tom Blasingame, TAMU & President of SPE

1. Is there a need for IOR in Unconventional Oil Wells?
2. Overview of IOR methods
3. Early results and opportunities to improve IOR
4. HnP conformance improvement
5. Expanding CO_2 supply in the U.S.

The Real Reasons Behind China's Energy Crisis

FP

Cheap pricing and too much coal are leaving Chinese in the dark. OCTOBER 7, 2021, 11:52 AM

Energy crisis could force more UK factories to close

By Walé Azeez, CNN Business

Updated 2:52 PM ET, Mon October 11, 2021

CNN BUSINESS

Energy

October 21, 2021

Putin warns of possible oil shortage due to lack of investment

REUTERS®

Biden: 'We're not getting rid of fossil fuels for a long time'

October 23, 2020

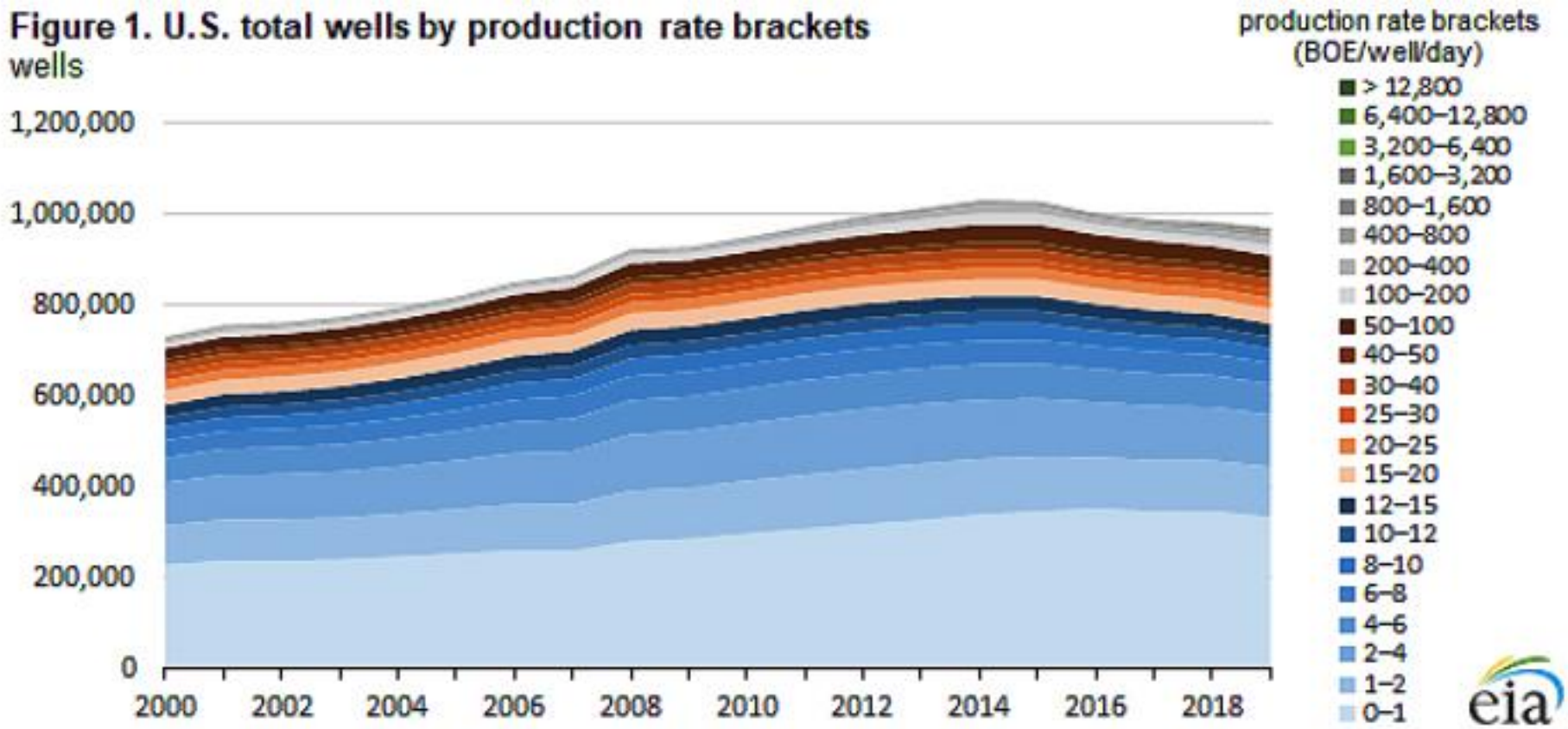
THE HILL

Lithium Shortage May Stall Electric Car Revolution And Embed China's Lead: Report

November 14, 2020

Forbes

U.S. Wells Are Aging



Horizontal Oil Wells Producing < 10 BOPD

Basin	Total No. Producing Wells	No. Wells Now Producing < 10 BOPD	% Wells Now Producing < 10 BOPD	# Operators with > 20 Marginal Wells
Permian	29,139	8258	28%	50
Eagle Ford	23,776	10243	43%	50
Williston	15,846	4326	27%	30
DJ Basin	8,479	4102	48%	16
STACK	3,727	1496	40%	16
SCOOP	1,722	711	41%	7
Powder River Basin	1,647	660	40%	7
Totals	84,336	29,796	35%	

Economic limit level of production is ~ 6 BOPD, assuming $74/bbl oil and $3/MCF gas prices, $10,000/month total operating expense

Shale Ingenuity LLC – November 2021

Overview of Enhanced Oil Recovery

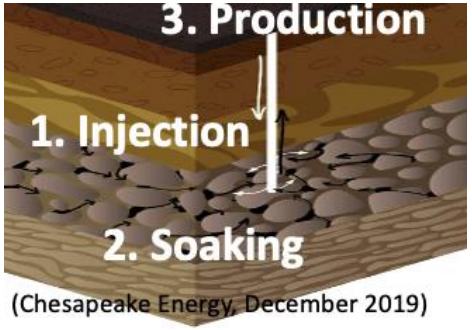
Enhanced oil recovery (EOR) is oil recovery by injection of materials not originally present in petroleum reservoirs.

Professor Larry Lake, University of Texas

Categories of EOR

- Chemical – surfactant, polymer, alkaline
- Miscible gas – enriched natural gas, carbon dioxide
- Thermal – steam, in situ combustion
- Microbial – proliferation of natural bugs, introduction of foreign bugs

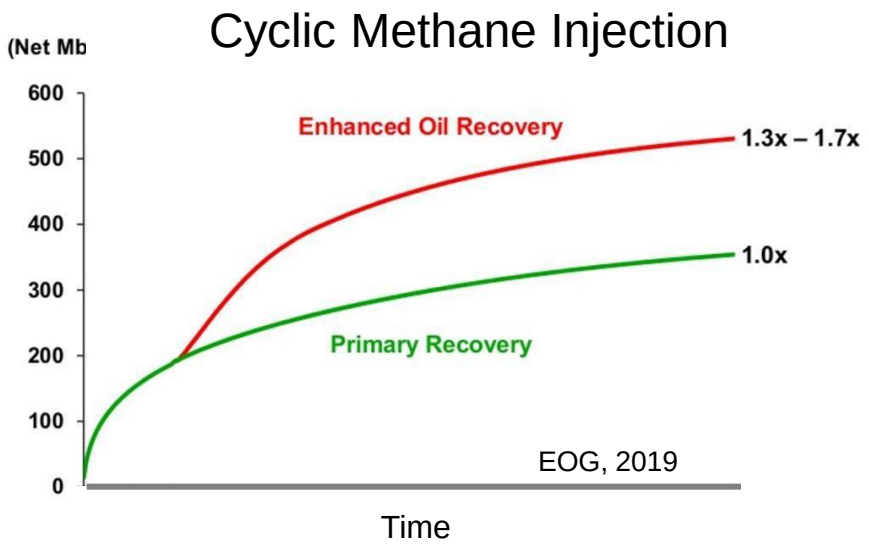
Miscible Gas Injection in Nano-darcy Rock



(Chesapeake Energy, December 2019)

Why EOR/IOR?

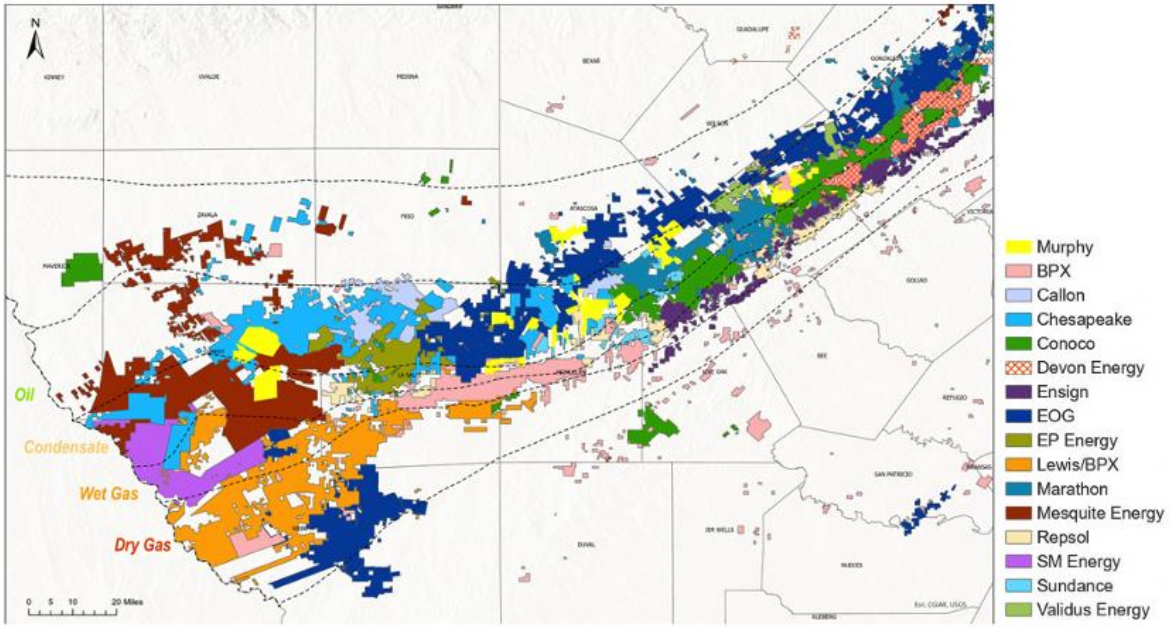
- Used or evaluated in the Eagle Ford
  - Gas HnP
  - Surfactants
  - Thermal
- Injection fluid
  - Methane
  - CO2
  - NGLs
- Challenges
- Risks
- Looking to the future



- Optimal time to initiate HnP
- Economic life of IOR – 3 to 5 years

Petroleum System Windows in the Eagle Ford

- Petroleum Systems
  - Black oil
  - Volatile oil
  - Wet gas
  - Dry gas
- Operators
- Geology
  - Thickness
  - Lithology
  - Natural fracturing
  - Other



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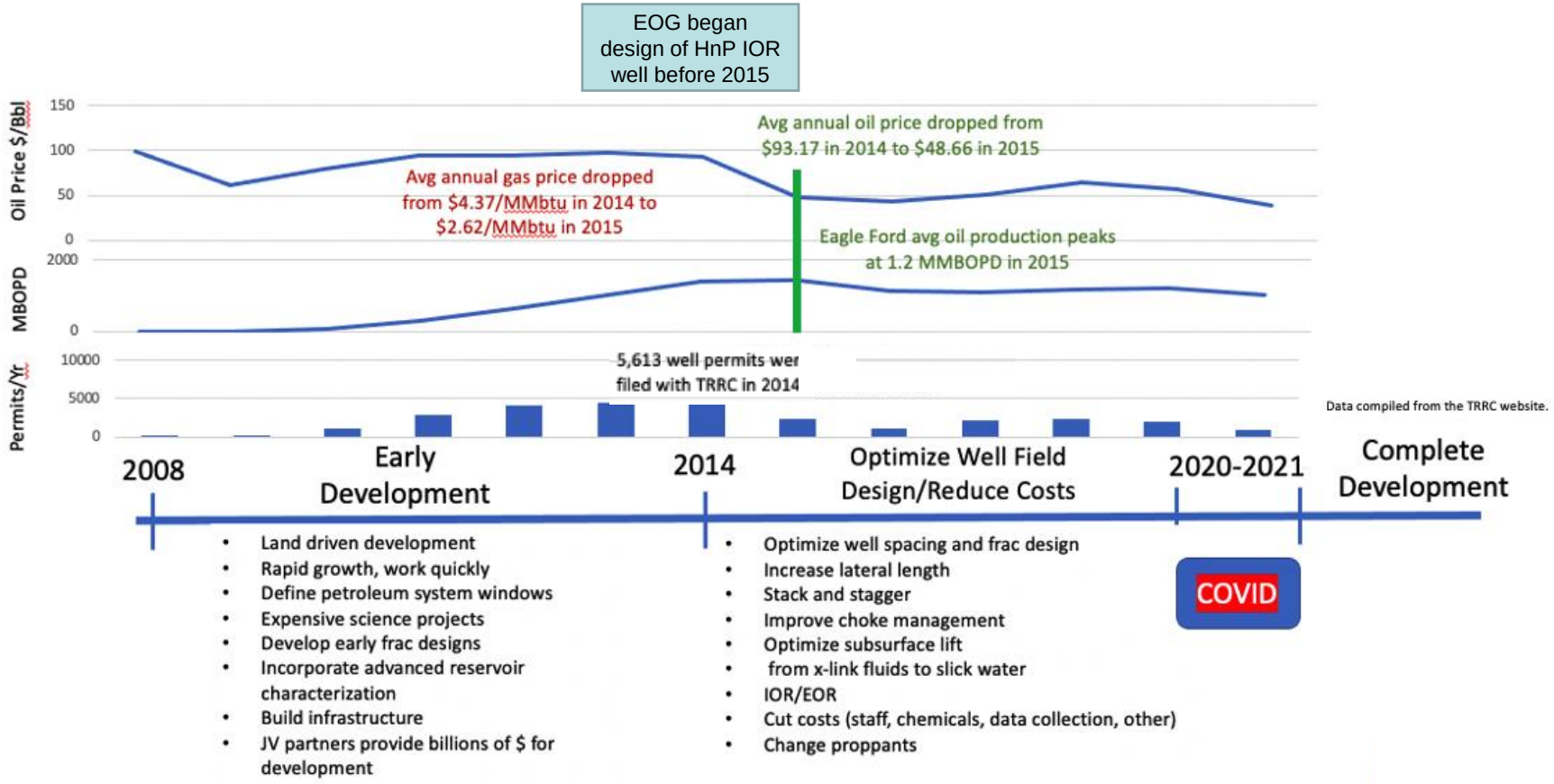
SPE Eagle Ford Forum, July 2021

Eagle Ford Timeline



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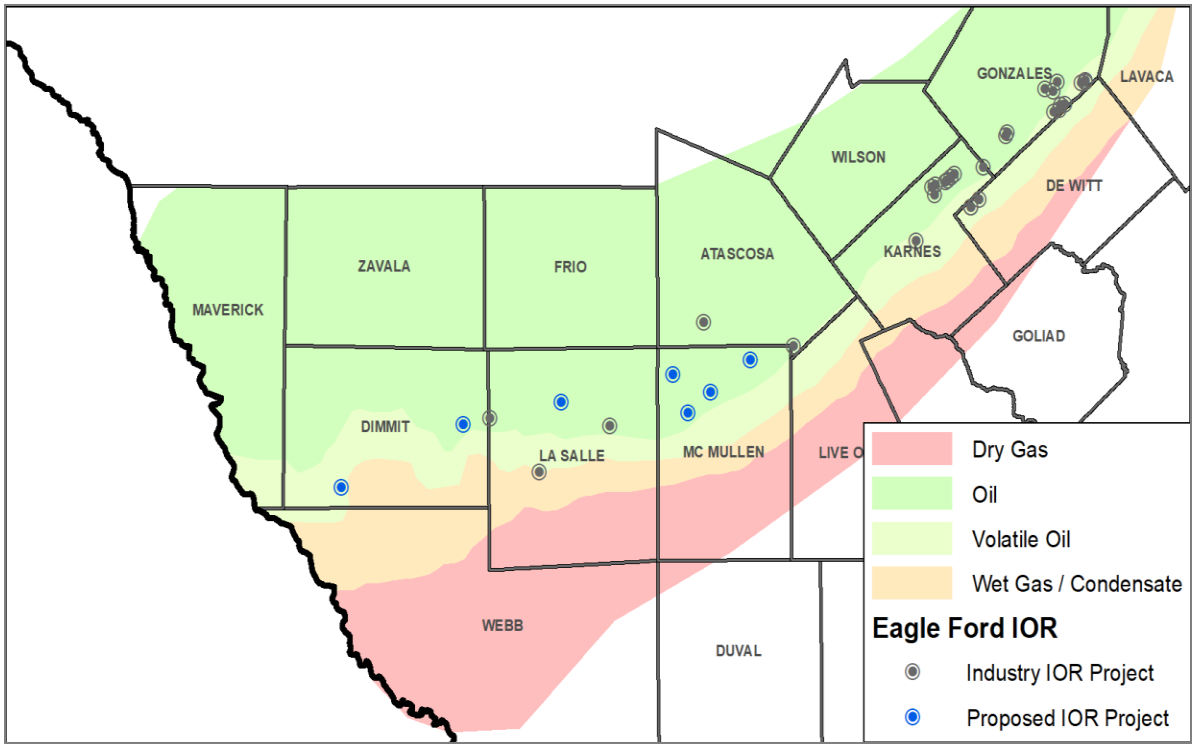
Existing and Proposed HnP Projects



Industry locations (Malo, McNamara, Volkmer & Amirian, 2019; Texas Railroad Commission & Industry Operators)
SPE 200415-MS URTeC, Houston, TX August 2021

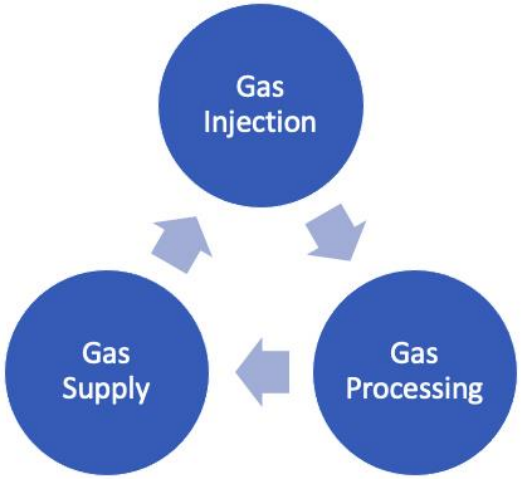
EOG
Marathon
ConocoPhillips
EP Energy
Murphy

Chesapeake

Methane HnP

Define Success

- Technical
- Economic



At What Price?

HnP Methane Injection - $70 to $80/bbl

Depends on prices of natural gas and NGLs

Surfactant Injection – At what price?

Other Technologies?

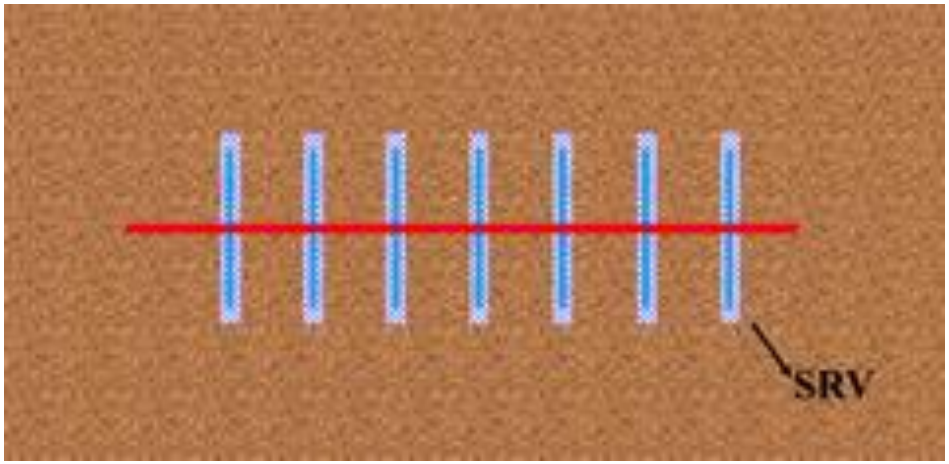
Challenges

- Technical issues
  - Design for safety (pipe spec, controls, pressure relief)
  - Timing (life cycle design including IOR)
  - Cost to retrofit facilities (wellheads, separators, tubing, piping)
  - Evaluation of gas containment
- Lease Agreements
  - Unitization
  - Royalties for produced and working gas
- Gas availability/contracting
- Gas management
  - Gas processing
  - Operational flexibility
  - Contingency planning

What is an SRV?

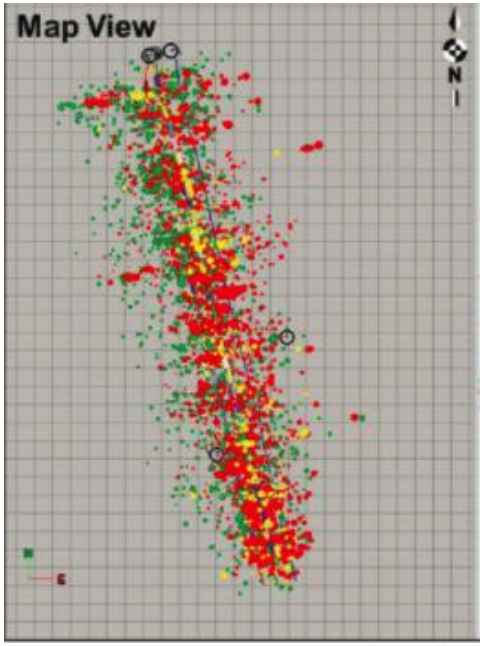
Stevie Ray Vaughan

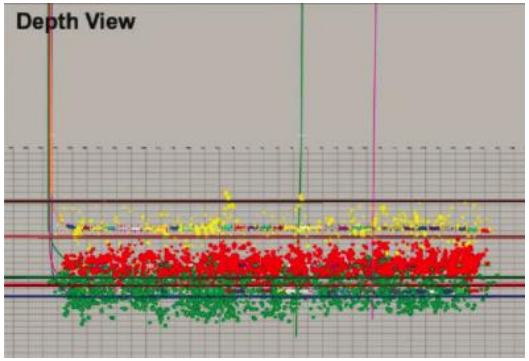
Stimulated Rock Volume – a network of induced hydraulic fractures, combined with conductive natural fractures



Characterization of the SRV

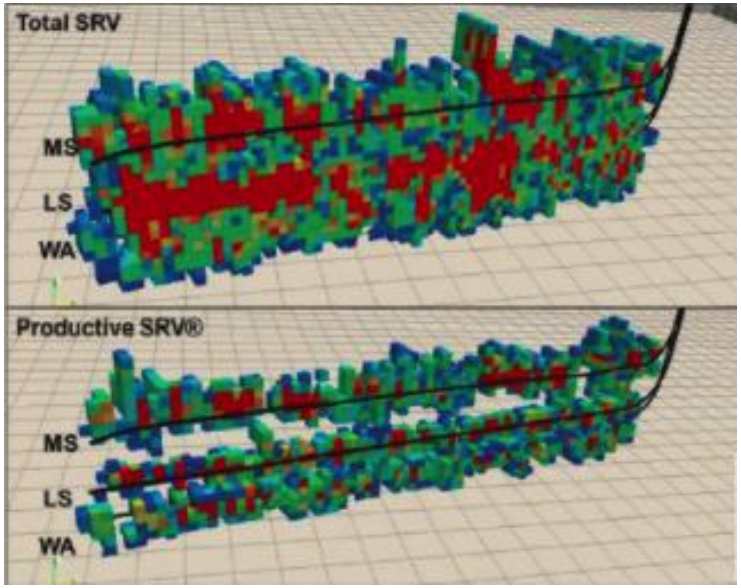
Microsiesmic events that describe the dimensions of multistage hydraulic fracturing along three stacked lateral wellbores.





MicroSeismic Inc, July 2017

Total stimulated reservoir volume (SRV) versus productive SRV

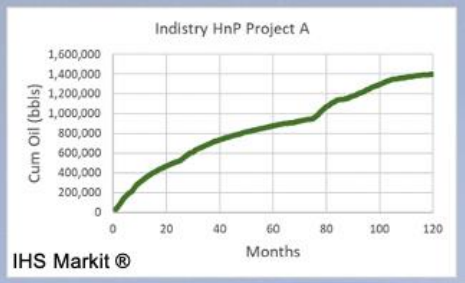


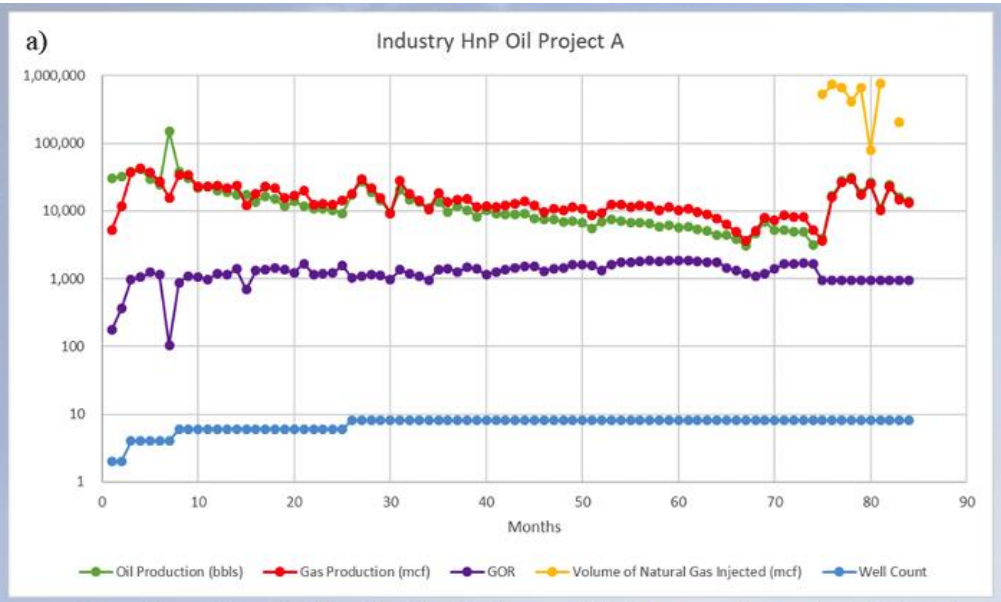
Characterization of the SRV

- Methods used to characterize geometry and conductivity
  - Evaluate production and pressure data
  - Fiber optic measurements near wellbore
  - Microseimic surveys
  - Resistivity at depth (measured from the surface)
  - Tracers
  - Computer simulation/material balance
  - Sealed wellbore pressure monitoring*
  - Child pressure group*
- Lessons learned

Anolog Evaluation

- Number of Wells
- Well Orientation
- Lateral Length
- Spacing
- Initial GOR
- Fluid Type
- Injection volumes from regulatory filings





8-well project in black oil window with 10 months of gas injection

Texas Railroad Commission & Industry Operators

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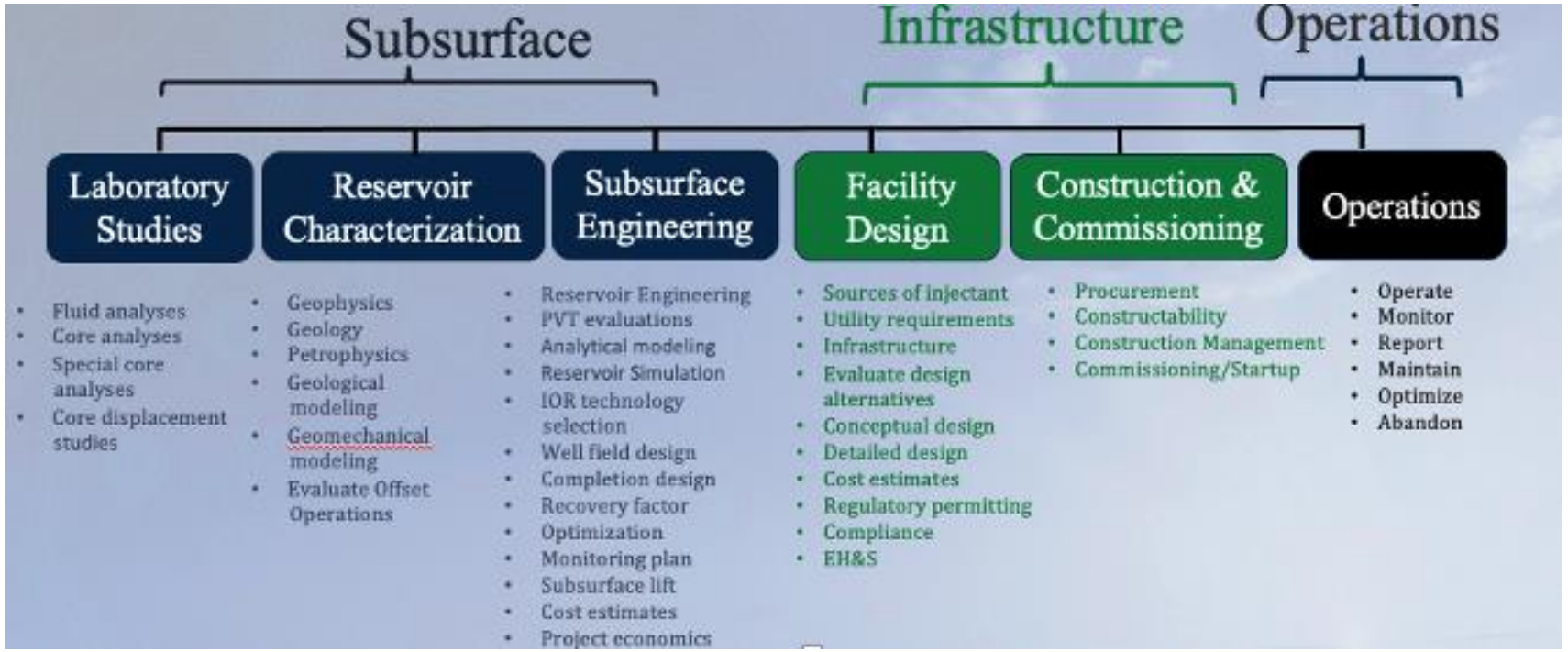
What Does a Project Team Look Like?



Experience designing and operating gas floods and understanding material balances in the subsurface is essential to project success.

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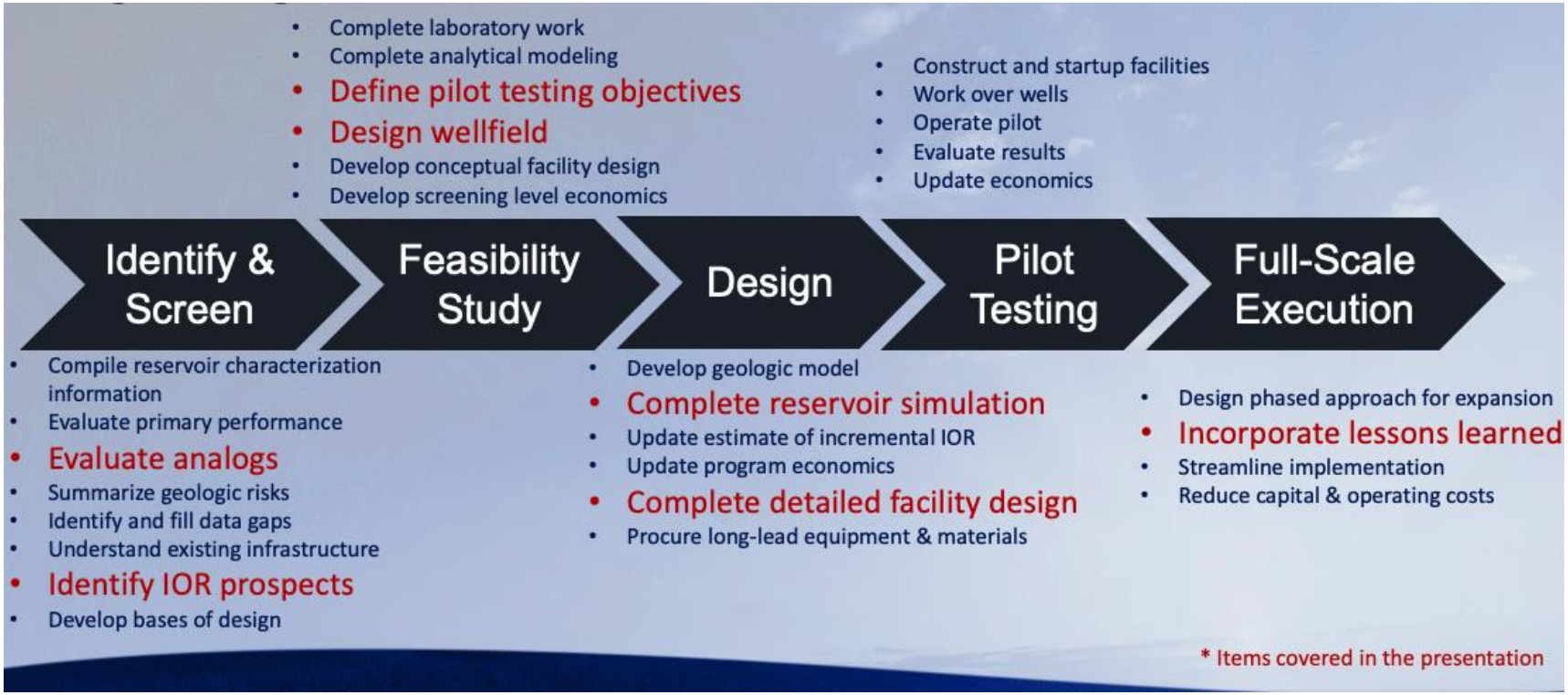
Workflow



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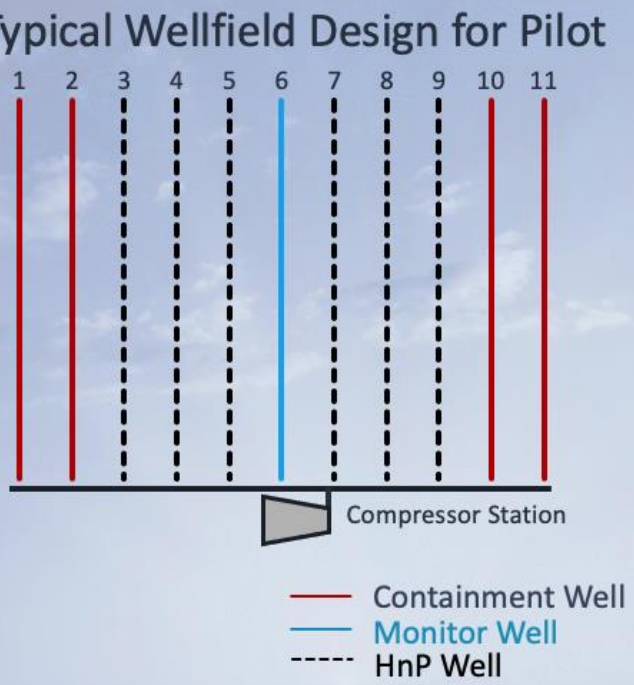
Risks

- Commodity prices
- Safe and reliable operation
- Reliable source of injectant/gas
- Approval by stakeholders
- Schedule slip and cost management
  - Staff changes
  - Streamlined decision making
  - Dedicate a small vital, team to implement
- Loss of valuable injectant

Well Field Design

Well Field Design

- Wellfield design dependent on objectives of pilot testing
- Eagle Ford HnP pilots have varied size - a few wells to more than ten wells.
- IOR typically utilizes existing wells
- Three types of wells are used for HnP:
  - **Containment – keep gas within injection area, always producing**
  - **Monitor – help isolate injection side from production side of pattern**
  - **Huff n' Puff (HnP) – injection & production well**



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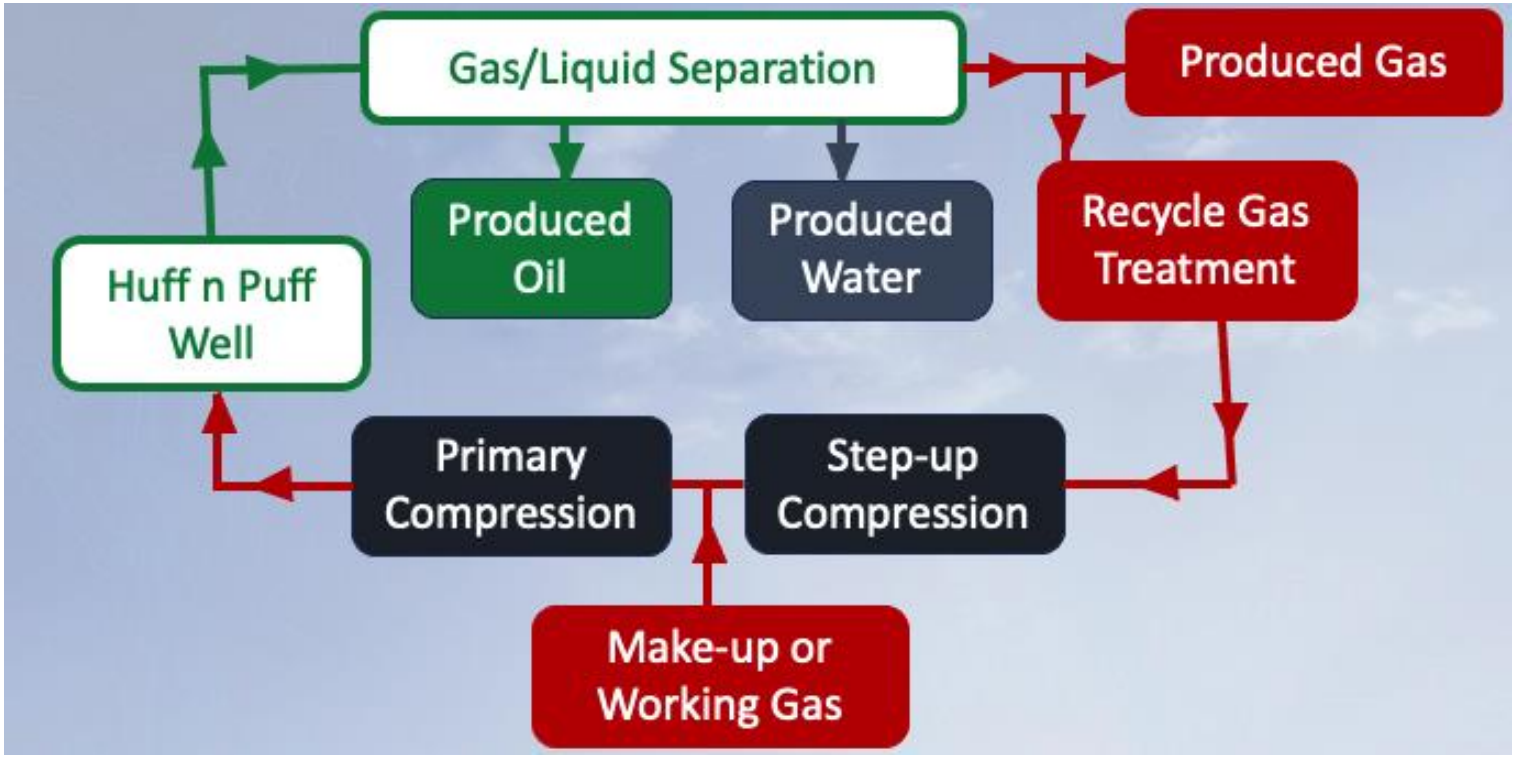
Expanded Process Description



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Reservoir Characterization

- Develop a geological model
- Identify geological hazards
- Estimate natural fracturing intensity and orientation
- Identify possible preferential flow pathways between wells
- Evaluate containment of injected fluids
- Develop a material balance for reservoir fluids

Pilot Testing Objectives

- Quantify fluid injectivity
- Improve operational understanding of HnP
- Demonstrate secondary oil production and estimate incremental reserves resulting from IOR
- Determine optimal injection rates and pressures
- Evaluate fluid containment
- Demonstrate economic feasibility
- Provide a basis to accelerate scale-up

Lessons Learned

- Begin with the end in mind – the initial design must incorporate IOR operations
- Incorporate operations/field staff in the project from the beginning
- Project manager must have substantial experience designing and operating floods
- Define project objectives and accountability within all disciplines
  - Legal
  - Gas marketing
  - Land
  - Engineering
  - Geology/geophysics/petrophysics
- Understand landowner/community concerns and address them as early in the project as possible

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Cyclic Gas Injection Publications

Baldwin A., Mohrbacher J., Chesapeake Energy, et. al. A Methodological Workflow for Assessment and Design of Huff-N-Puff Hydrocarbon Gas Injection Pilot Test as an EOR Technique for Eagle Ford Shell Oil Reservoirs, Society of Petroleum Engineers, Conference Paper 200415-MS, 2020.

Cudjoe, Sherifa, University of Kansas, et. al. Pore-Scale Characterization of Eagle Ford Outcrop and Reservoir Cores with SEM/BSE, EDS, FIB-SEM and Lattice Boltzmann Simulation, Society of Petroleum Engineers, Conference Paper 195805-MS, 2019.

Cudjoe, Sherifa, University of Kansas, et. al. Nuclear Magnetic Resonance Estimation of Petrophysical Properties and Evaluation of Hydrocarbon Huff-N-Puff Gas Injection in Lower Eagle Ford Shale Oil Samples, Unconventional Resources Technology Conference, July 31, 2019, Conference Paper 2019-496-MS.

Cudjoe S., Barati R. University of Kansas et. al. An Integrated Pore-Scale Characterization Workflow for Hydrocarbon Gas Huff-N-Puff Injection into the Lower Eagle Ford Shale, Unconventional Resources Technology Conference, July 31, 2019, Conference Paper 2019-442-MS.

Cudjoe S., Barati R. University of Kansas et. al. Application of Raman Spectroscopy in Investigating the Effect of Source and Temperature on the Maturity of the Organic Matter Exposed to Hydrocarbon Gas Injection, Unconventional Resources Technology Conference, July 31, 2019, Conference Paper 2019-501-MS.