



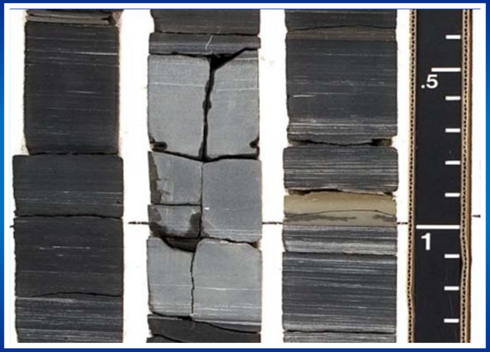
Shale Resources Development and Optimization

Foundational Practices and Technology Opportunities

P.K. Pande – May 4, 2016

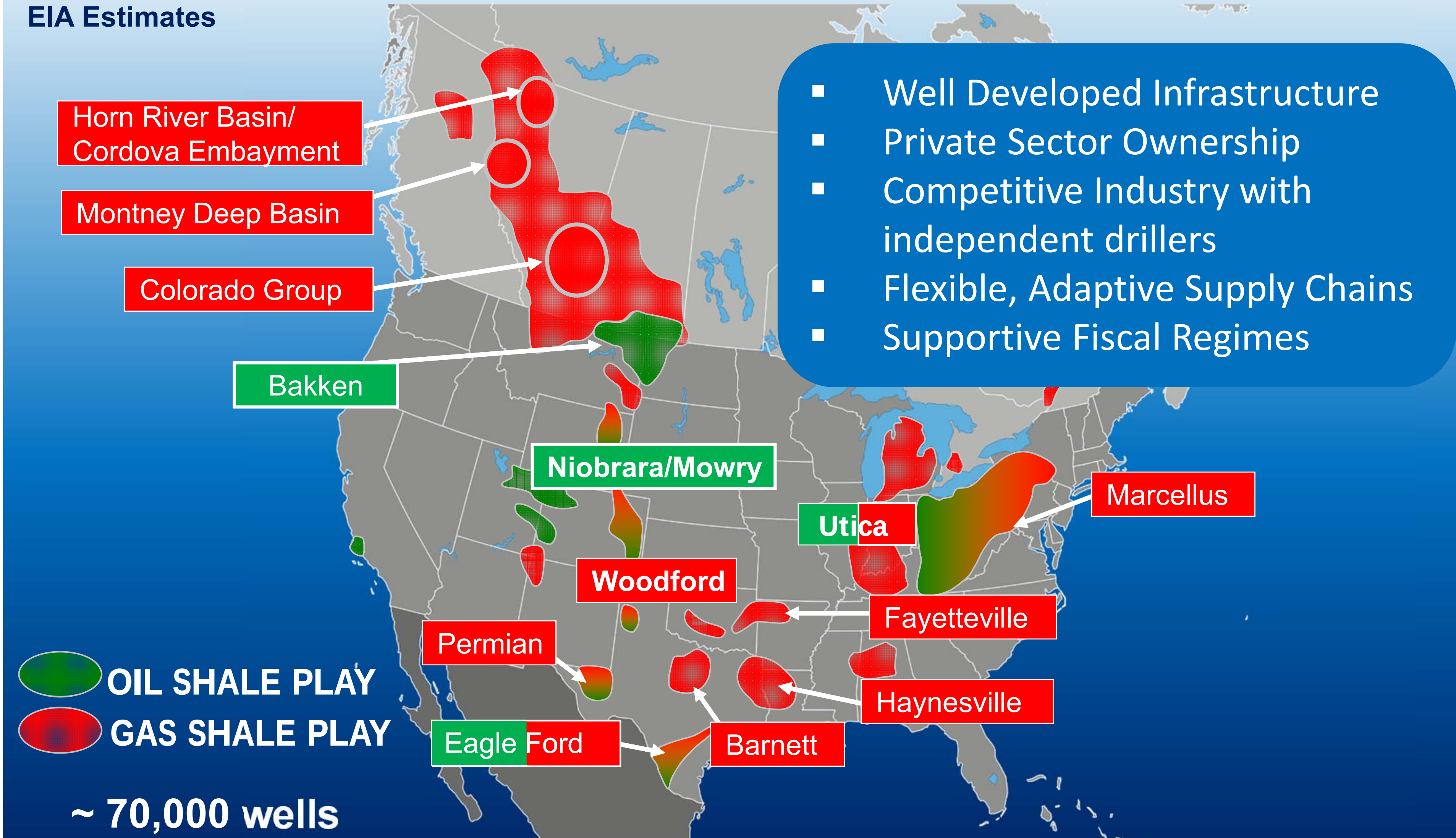
Outline, Full Life Cycle Integrated Approach

- Context & Challenges, North America
- Development Value Drivers
- Core Elements, Integrated Practices
- Key Learnings
- Technology Advancement Opportunities



North America: ~1,750 TCF; ~ 100 BSTB
Global: ~6,000 TCF; ~ 320 BSTB

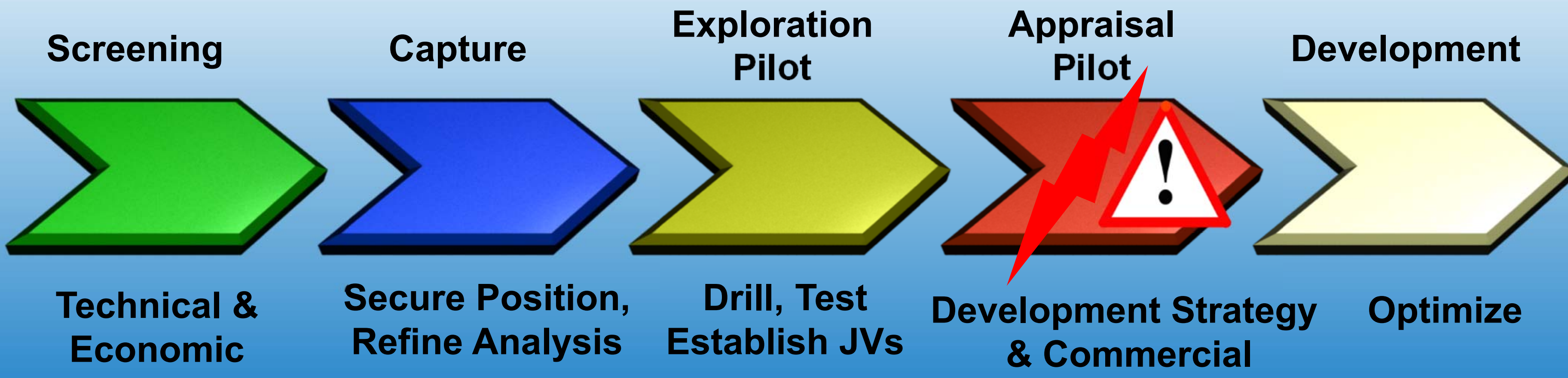
EIA Estimates



- Well Developed Infrastructure
- Private Sector Ownership
- Competitive Industry with independent drillers
- Flexible, Adaptive Supply Chains
- Supportive Fiscal Regimes

~ 70,000 wells

Assessment Challenges



- **Technical**
  - New Play Types, Low Reservoir Producibility
  - Multi-discipline Integration, Subsurface and “Factory Mode Operations”
- **Commercial**
  - Highly Competitive, Large Leaseholds
  - Costs & Optimization

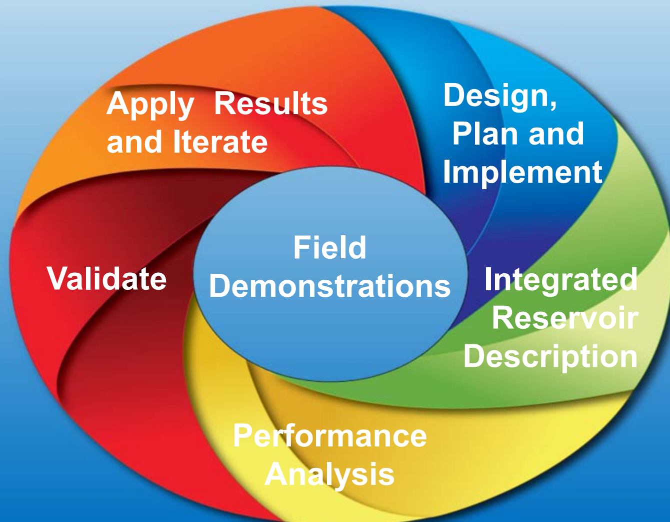
Performance Analysis Tools and Technologies

Performance Prediction Limitations

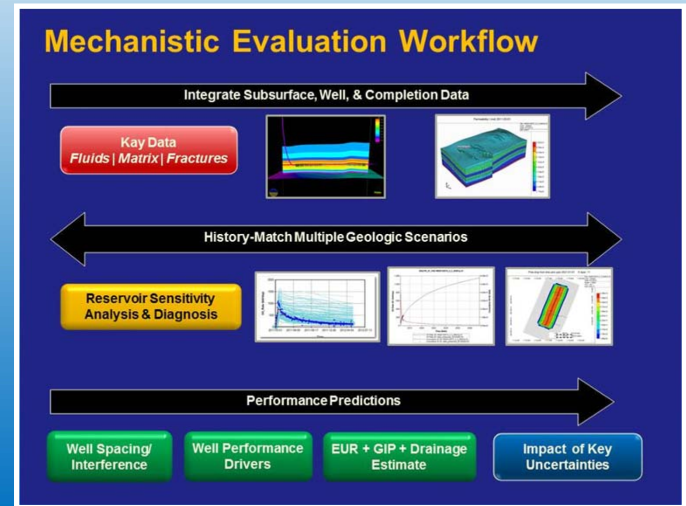
- Shale Performance Forecasting
- Very Low Permeability
- Stress Dependence
- Mechanisms
  - *Fractured Horizontal*
  - *Diffusion*
  - *Phase Behavior*

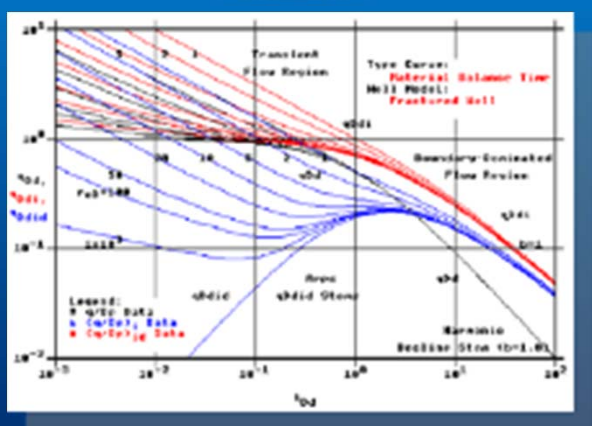
Powerful Workflows for Life Cycle Solutions

Field Demonstrations

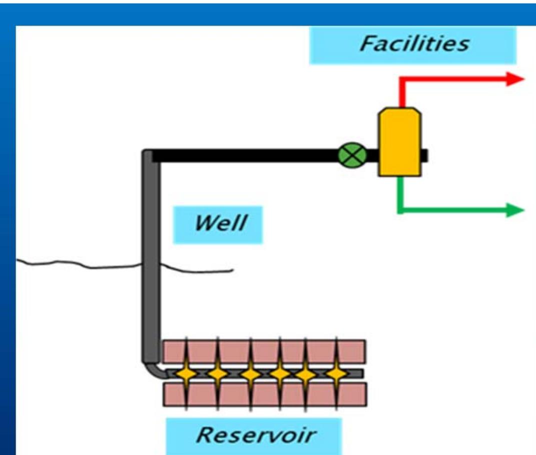


Mechanistic Modelling





Performance Analysis



Integrated Asset Model

Full Life Cycle Integrated Approach - Context & Evolution

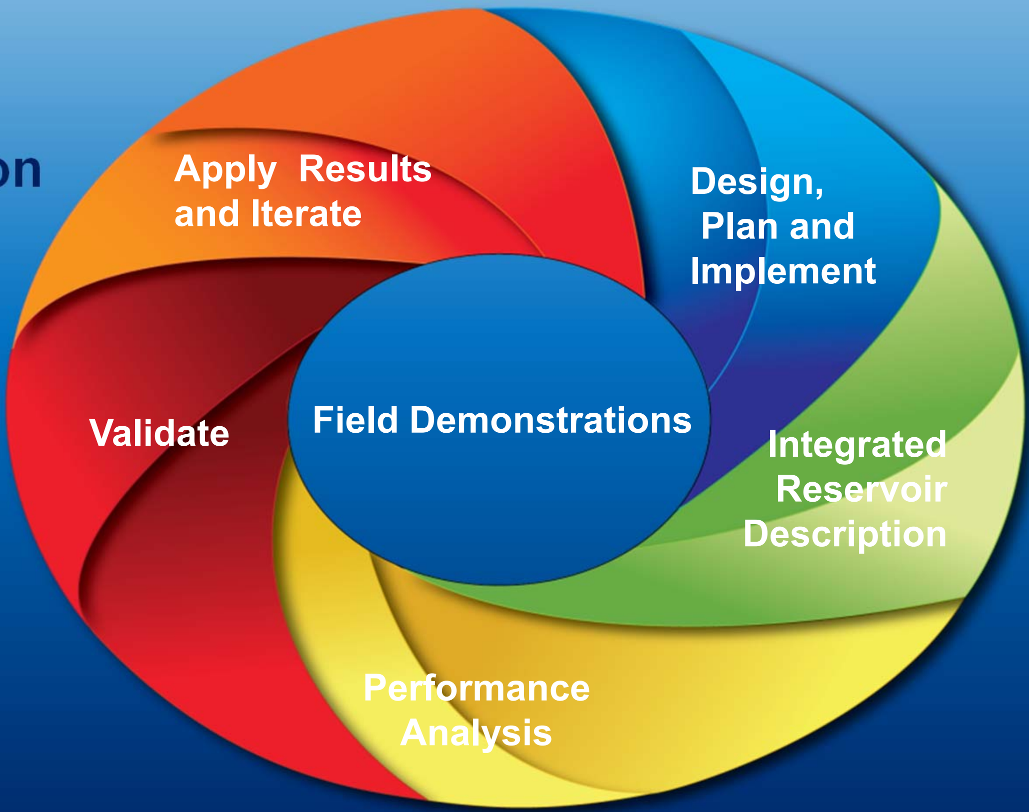
2009 | 2010 | 2011 | 2012 | 2013 | 2014-2016+

Issues	Well Spacing
	Completion Design
	EUR
Solutions	Field Demonstrations
	Mechanistic Modeling
	Performance Analysis
	Micro-Field Demonstrations Seismic
	Permeability Modeling
	Data Acquisition

Field Demonstrations, Controlled Pilots

Multiple Field Pilots to Address Key Issues and Uncertainties

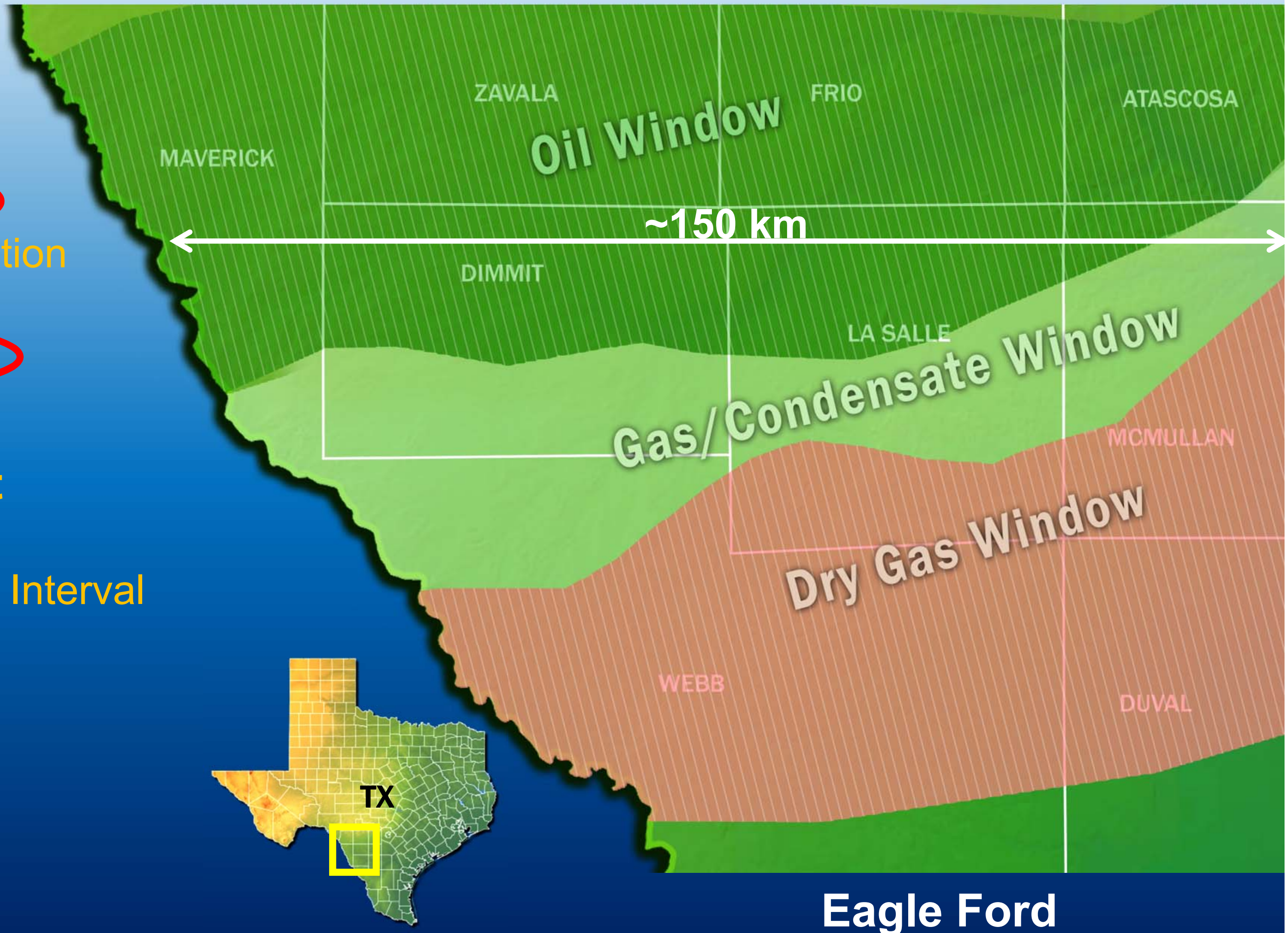
- **To Have Value Must Be:**
  - Systematic
  - Statistically Valid
  - Scalable
- **General Shale Play Application**
  - Build Database of Analogs
- **Goal**
  - Capital Investment Efficiency



"Learning While Drilling"

Field Demonstration Types

- **Strategic**
  - Spacing
  - Characterization
  - PVT/Liquids
  - Completion
- **Development**
  - Azimuth
  - Stratigraphic Interval
  - Target Line

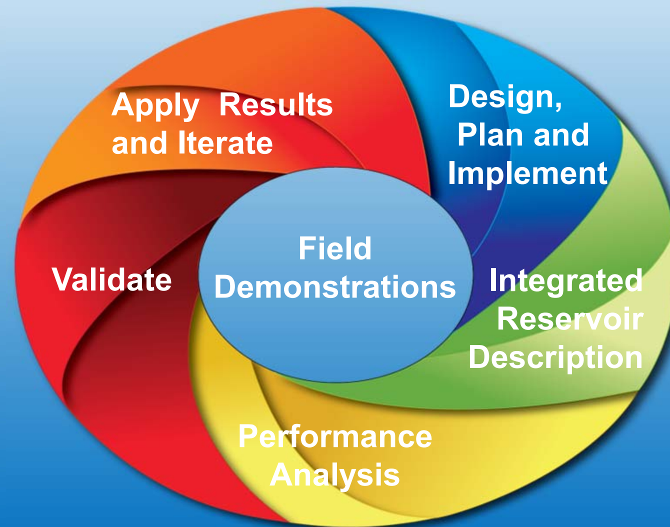


Eagle Ford

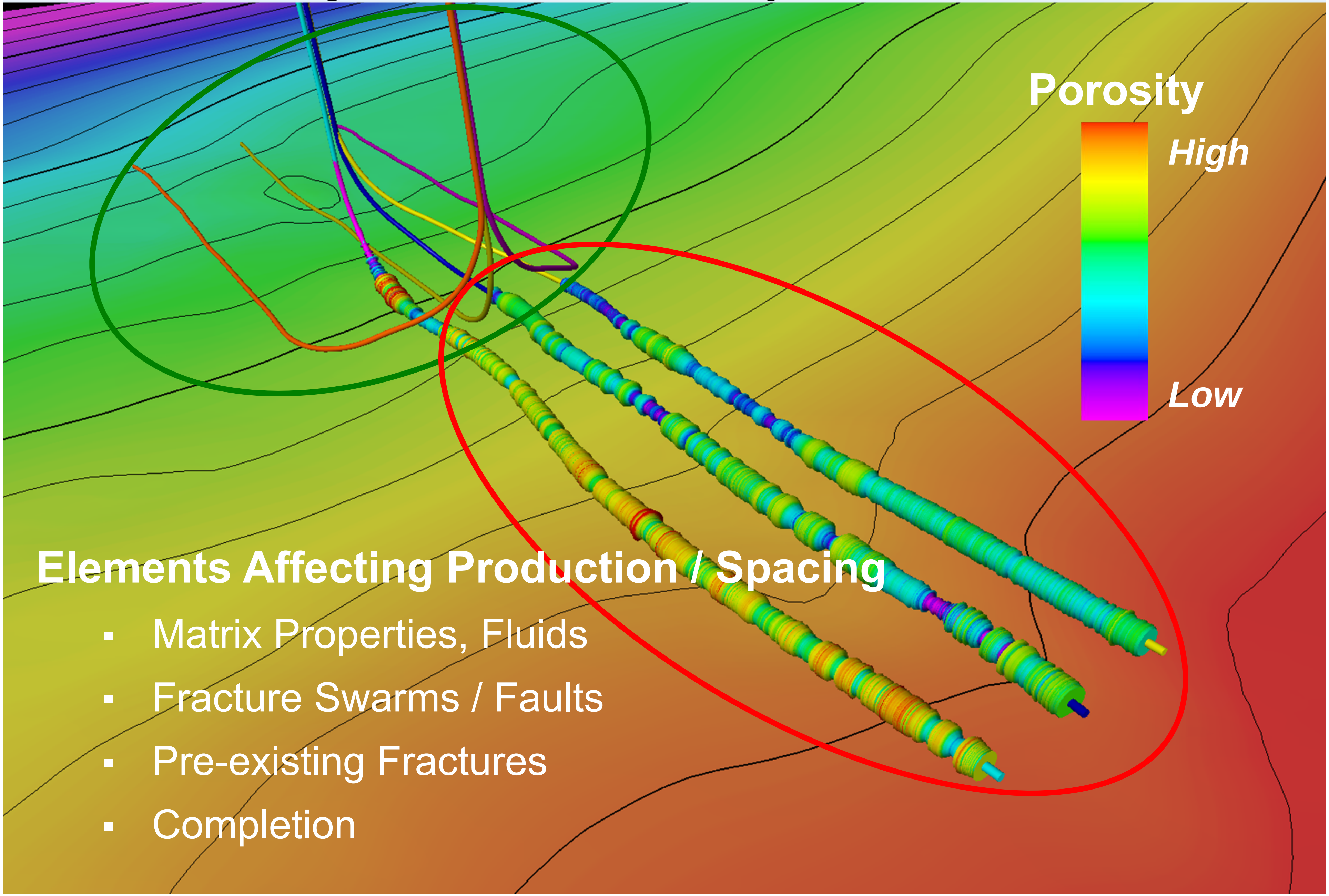
Eagle Ford Well Spacing Field Demonstrations

"Learning While Drilling"

- **12 Million Acres**
- **Production**
  - > ~5+ BCFD
  - > ~940 MBOPD
- **~ 20,000+ Wells**



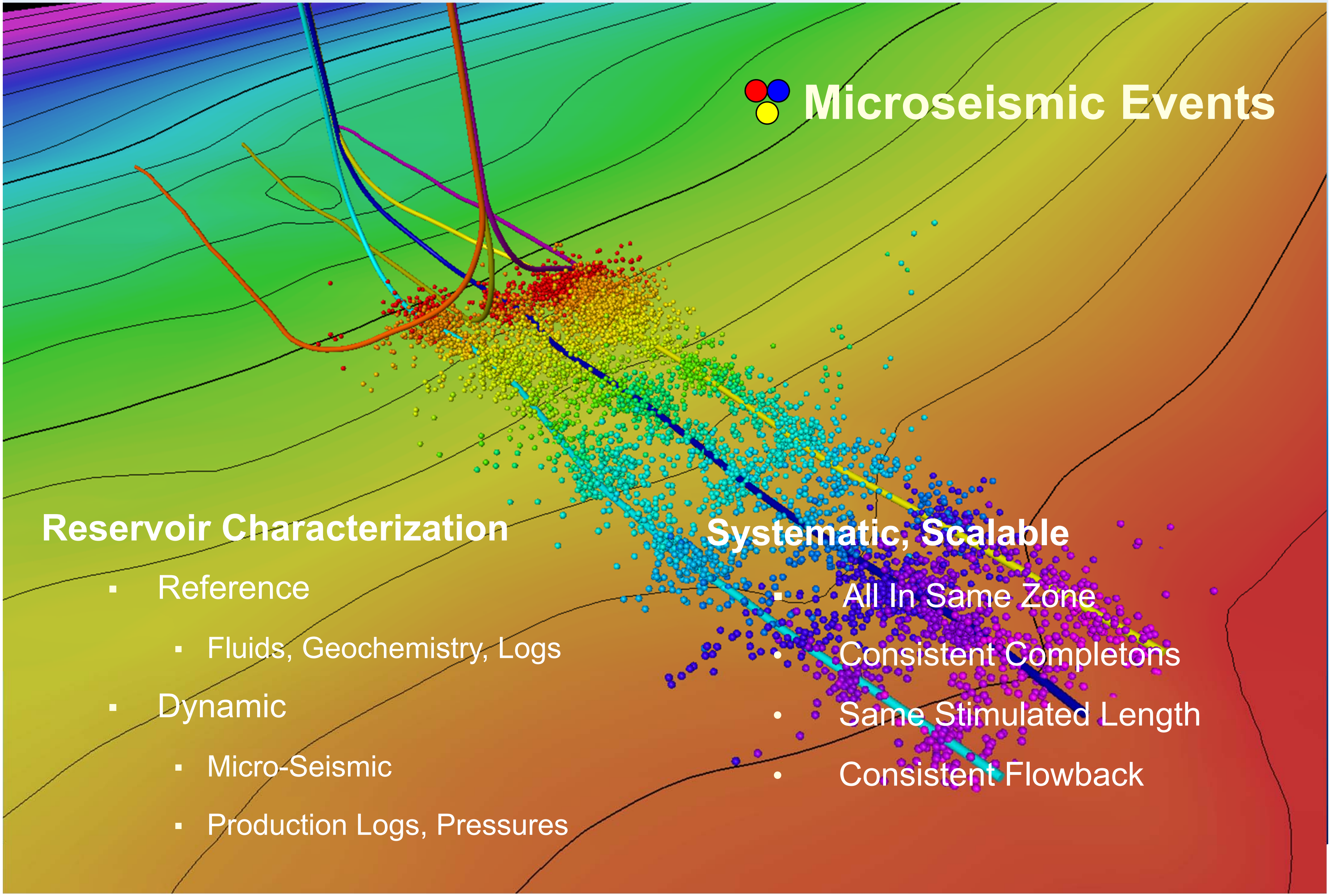
Well Spacing Field Demo - Early vs. New Practices



Elements Affecting Production / Spacing

- Matrix Properties, Fluids
- Fracture Swarms / Faults
- Pre-existing Fractures
- Completion

Field Demo – Data Acquisition Design & Planning



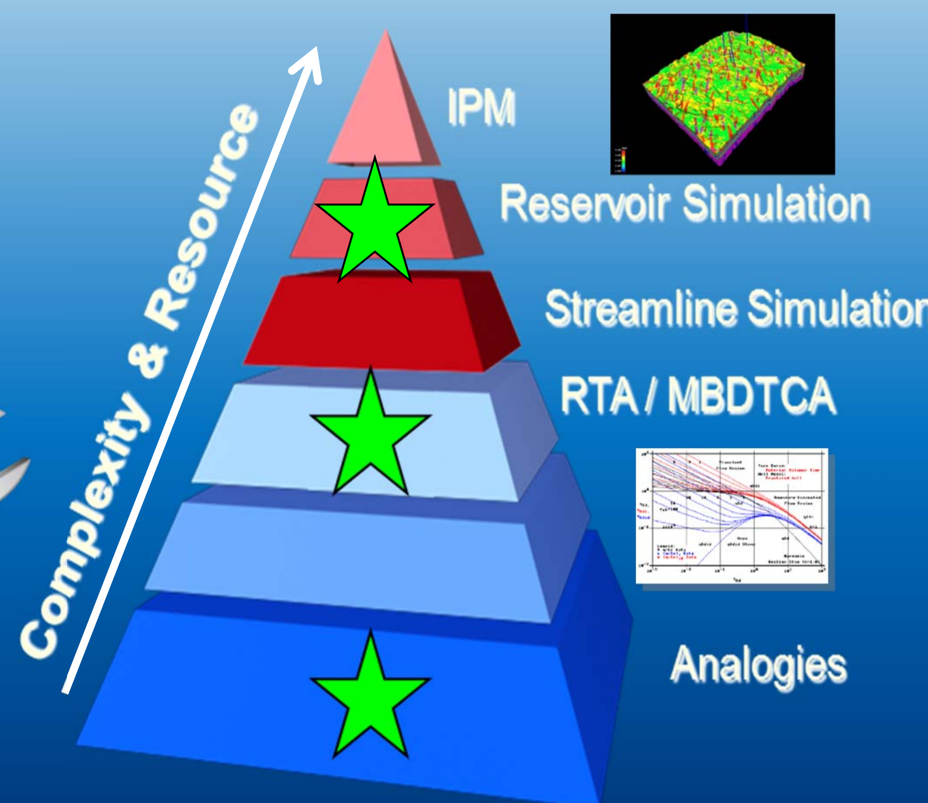
Reservoir Characterization

- Reference
  - Fluids, Geochemistry, Logs
- Dynamic
  - Micro-Seismic
  - Production Logs, Pressures

Systematic, Scalable

- All In Same Zone
- Consistent Completons
- Same Stimulated Length
- Consistent Flowback

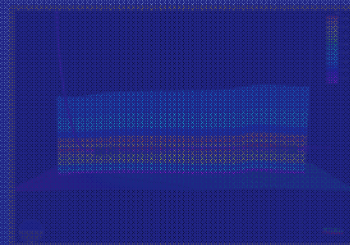
Performance Analysis Tools and Technologies

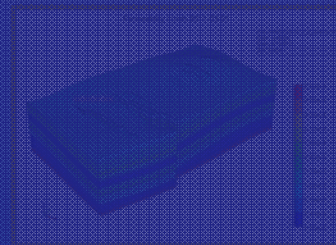


Mechanistic Evaluation Workflow

Integrate Subsurface, Well, & Completion Data

Key Data
Fluids | Matrix | Fractures

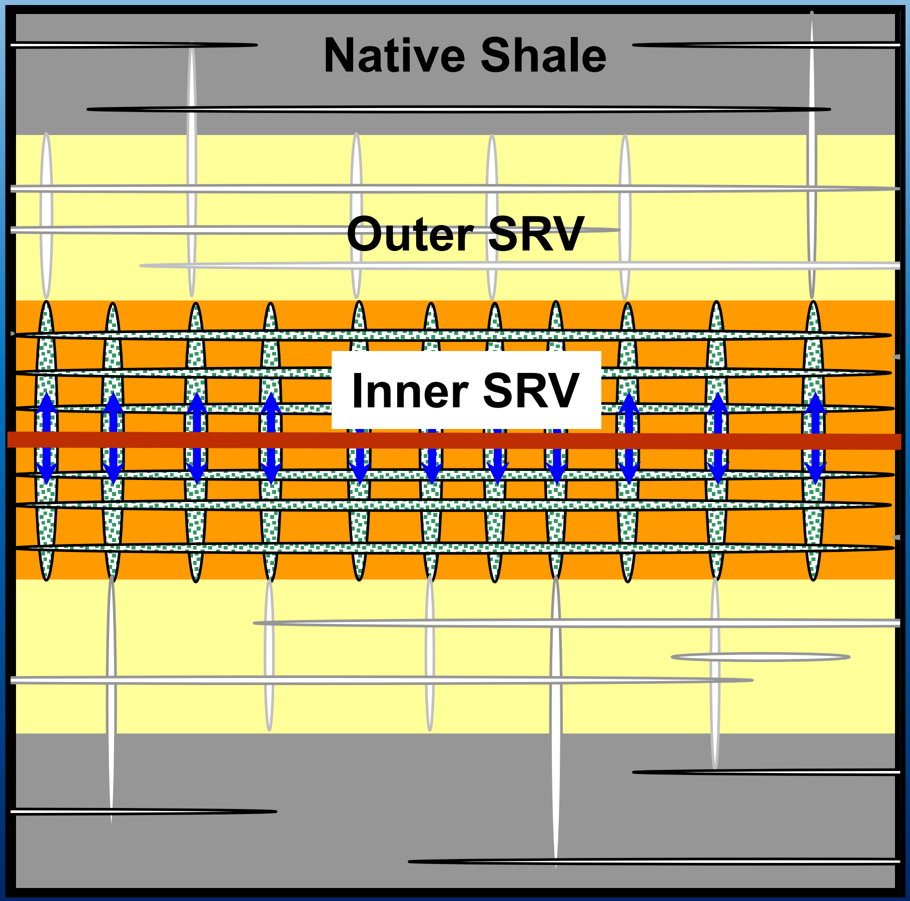




Mechanistic Studies – What Can be Inferred?

- **Completion**
  - Stimulated Rock Volume (SRV) and Fracture Conductivity
- **Phase Behavior**
  - Dry Gas, Liquid Rich Systems
- **Reservoir Characterization**
  - Open Natural Fractures Impact
- **Development Planning**
  - Well Spacing

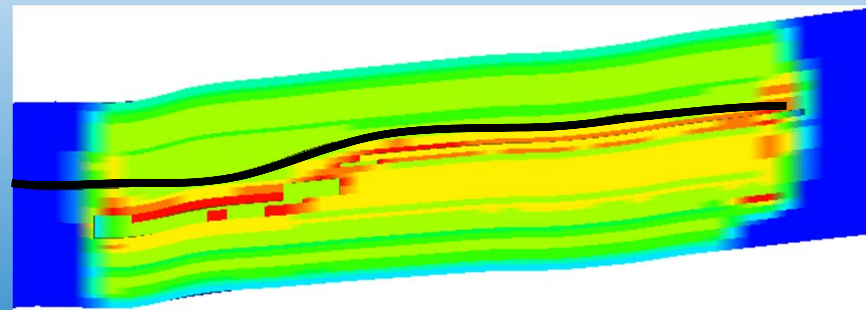
Stimulated Rock Volume (SRV)



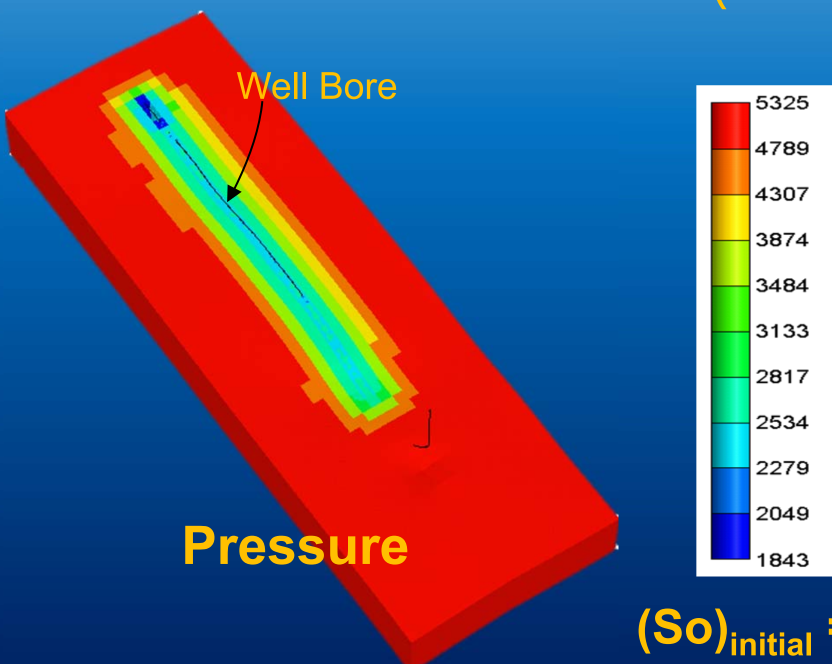
Eagle Ford Rich Gas Condensate Performance (30 yrs)

Pressure Distribution

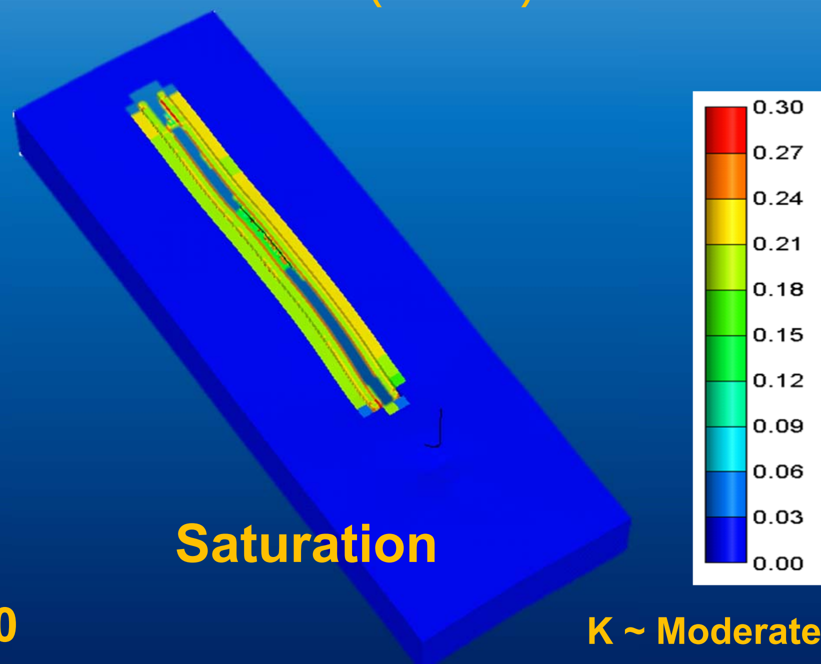
Condensate Distribution



Oil RF = 19% (in SRV) / Gas RF = 30% (in SRV)

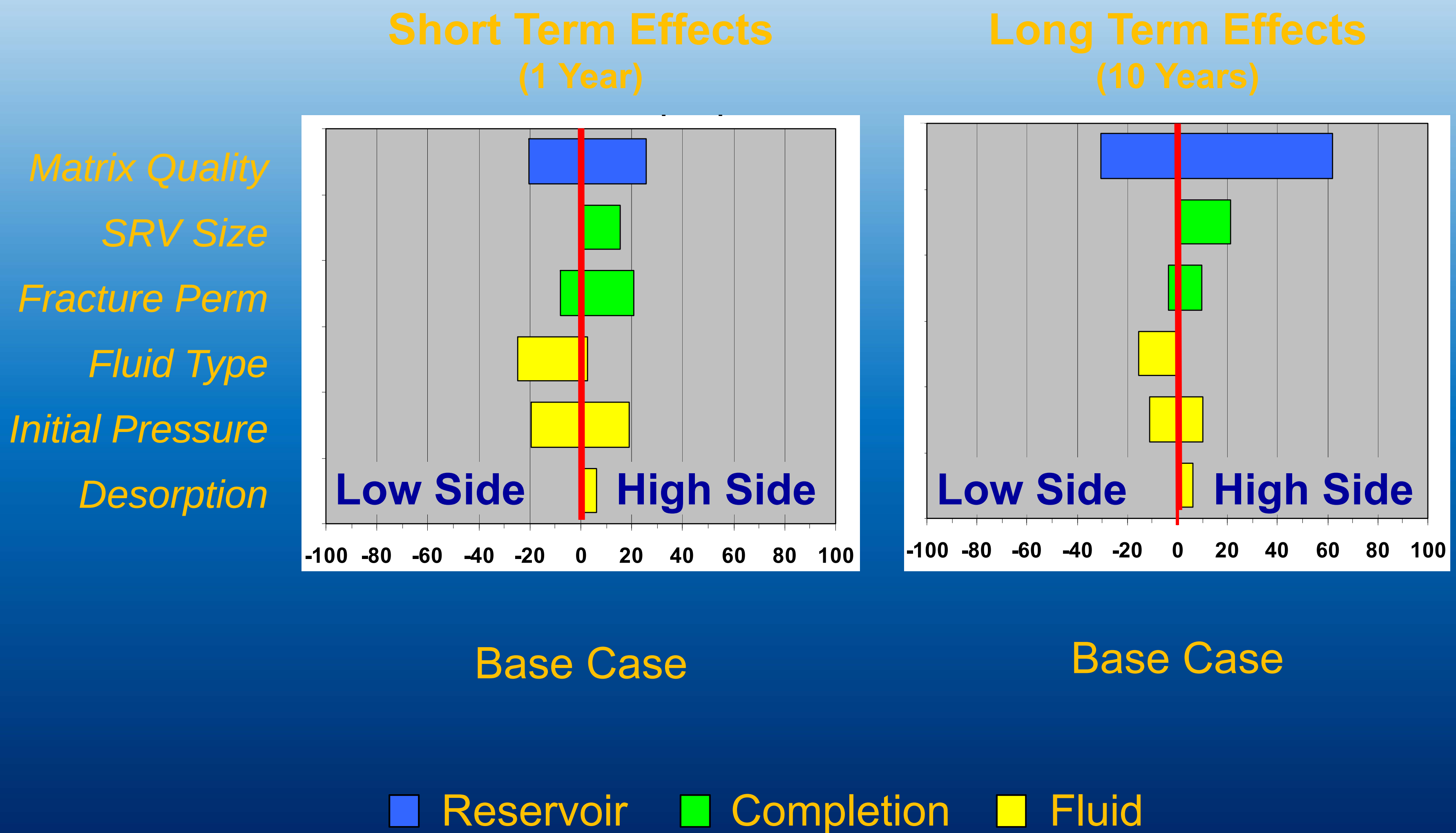


$(So)_{initial} = 0$

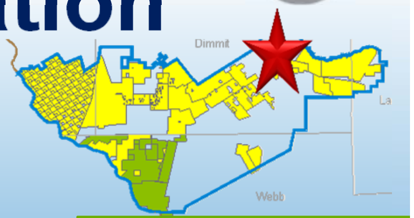


K ~ Moderate - High

Eagle Ford Rich Gas Condensate Shale Sensitivity Analysis
(Production Change (%)

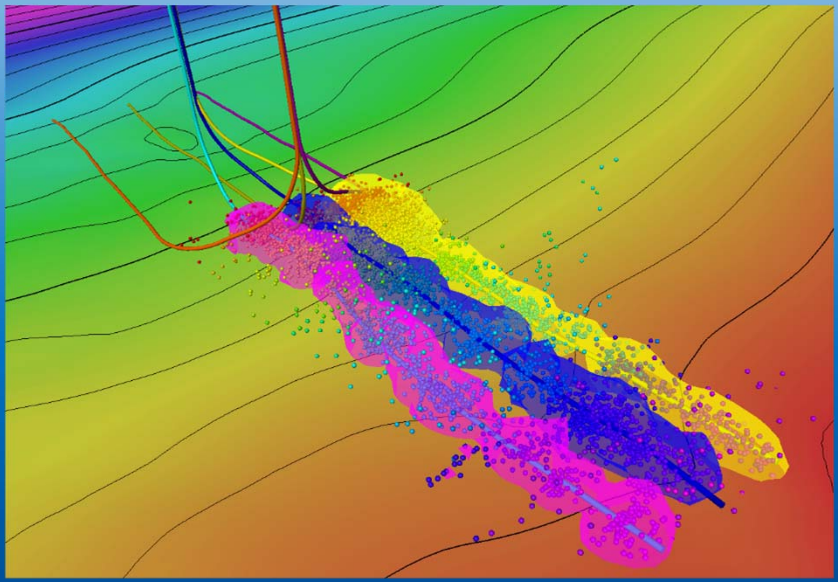


Eagle Ford Well Spacing Demonstration



Near-Critical Oil

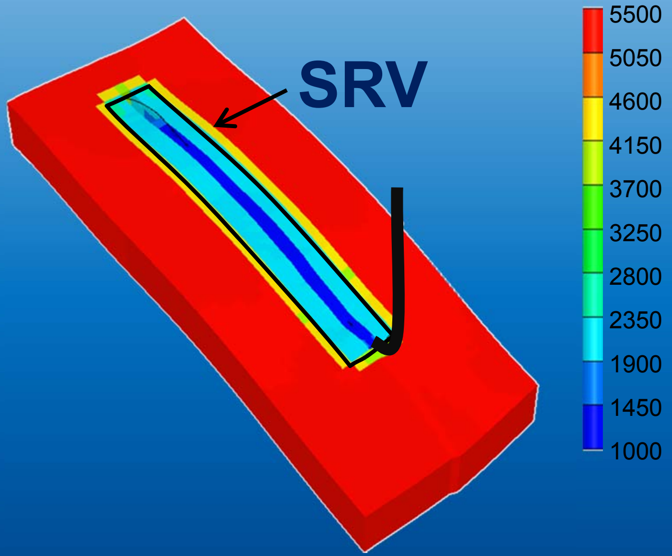
Stimulated Volume from Microseismic



Estimate of ½ Length = 250'

Mechanistic Modeling

Pressure Distribution at 30 Years



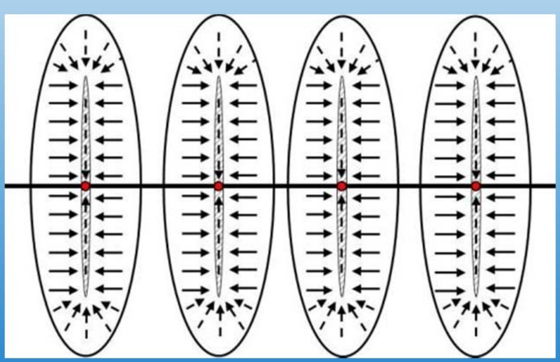
No contribution outside SRV

Combine Both Technologies With Economics…

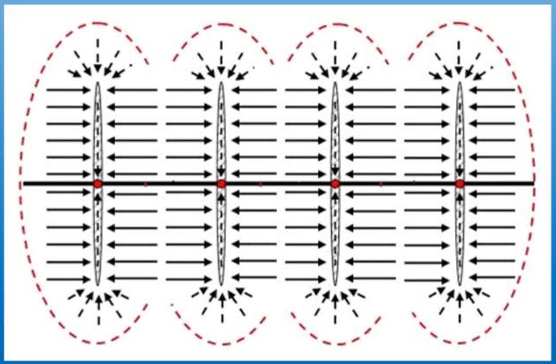
➡ BEST SPACING ESTIMATE

Performance Analysis: Flow Regimes in Unconventional Reservoirs

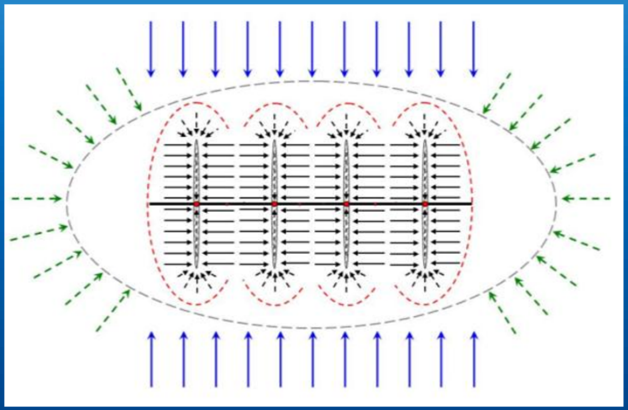
<u>Very Early Time</u>: Linear Flow
(fracture flow <u>does not</u> interfere)



<u>Middle Time "SRV" Flow</u>: ("depletion")
(fracture flow <u>does</u> interfere)

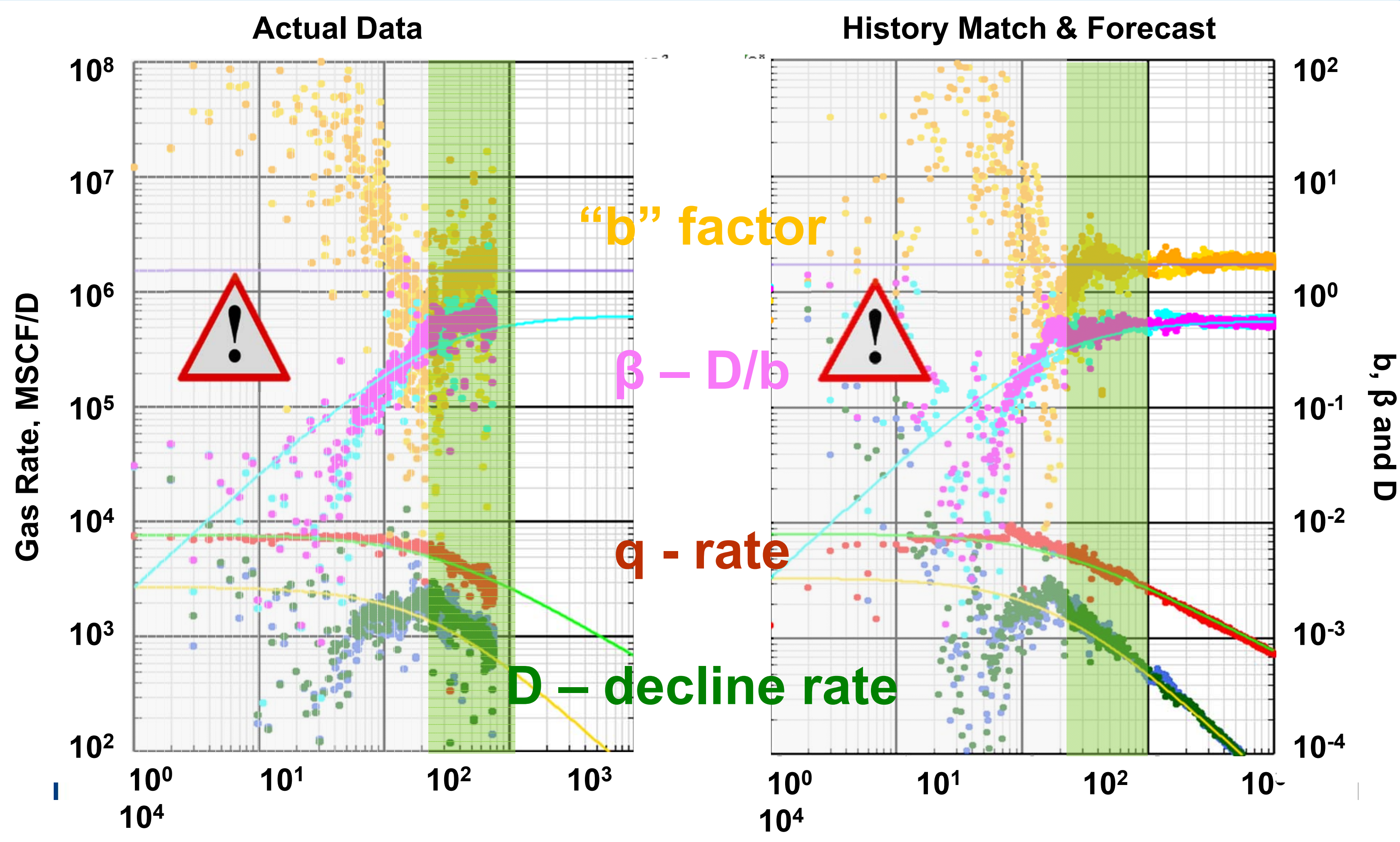


<u>Late Time</u>: "Post-SRV" Flow
("Compound Linear Flow")



Increasing Time →

Marcellus Dry Gas Fractured Shale Production Analysis



Modified Hyperbolic Time Rate Performance Model

Shale Technology Subsurface Integration

- **Field Demonstrations and Mechanistic Studies**
  - Capture Static / Dynamic Data
  - Validate Results

Petrophysics — **Cores, Logs, (f, *k*)**

+

Geochemistry — **Fluid Properties, *PVT***

+

Fracture Analysis — **Rock Mechanics, Fluid Flow**

+

G&G Integration — **Seismic Integration, Horizontal Targeting**

+

Reservoir Modeling

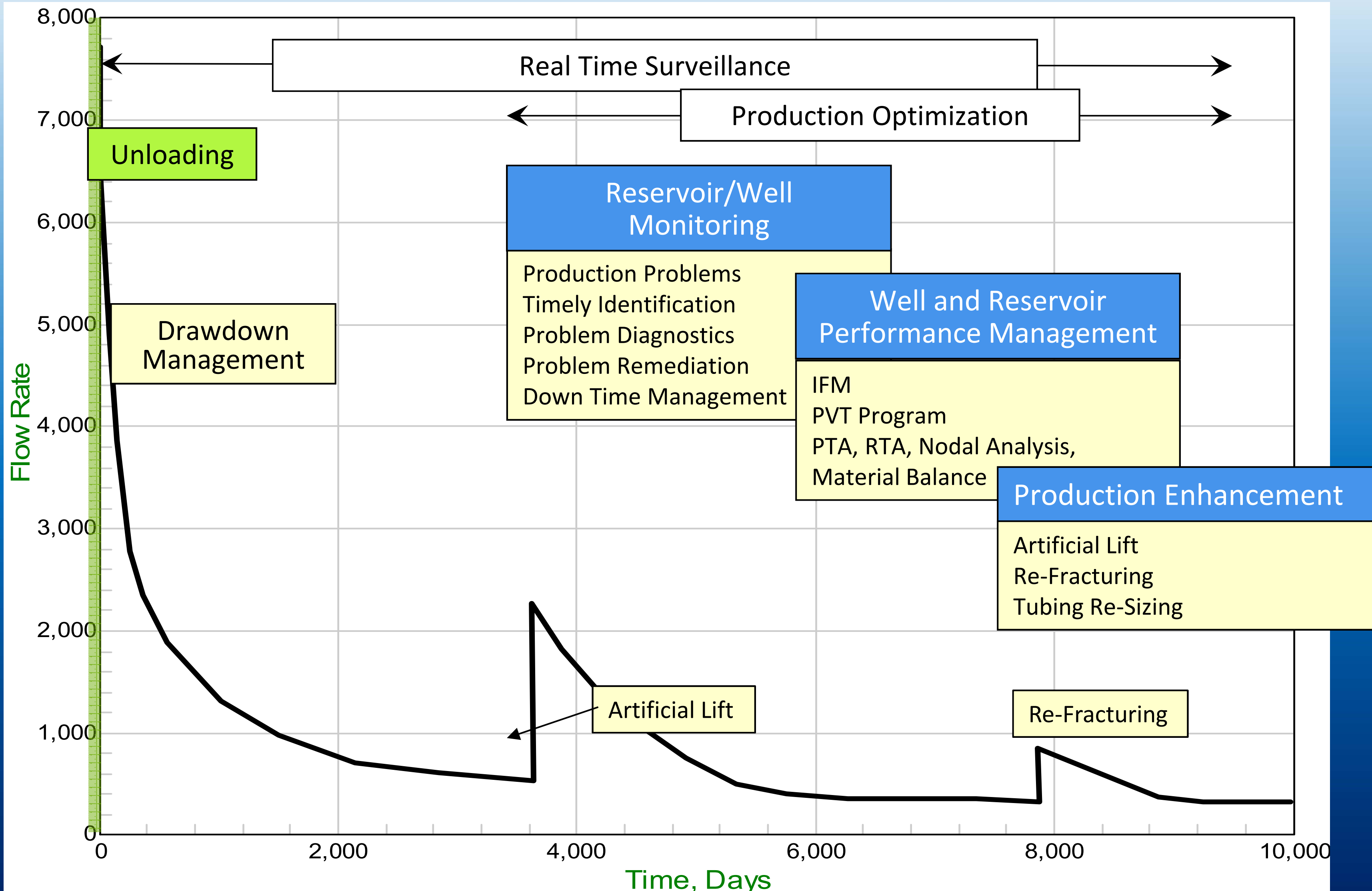
Performance Analysis

EUR Determination

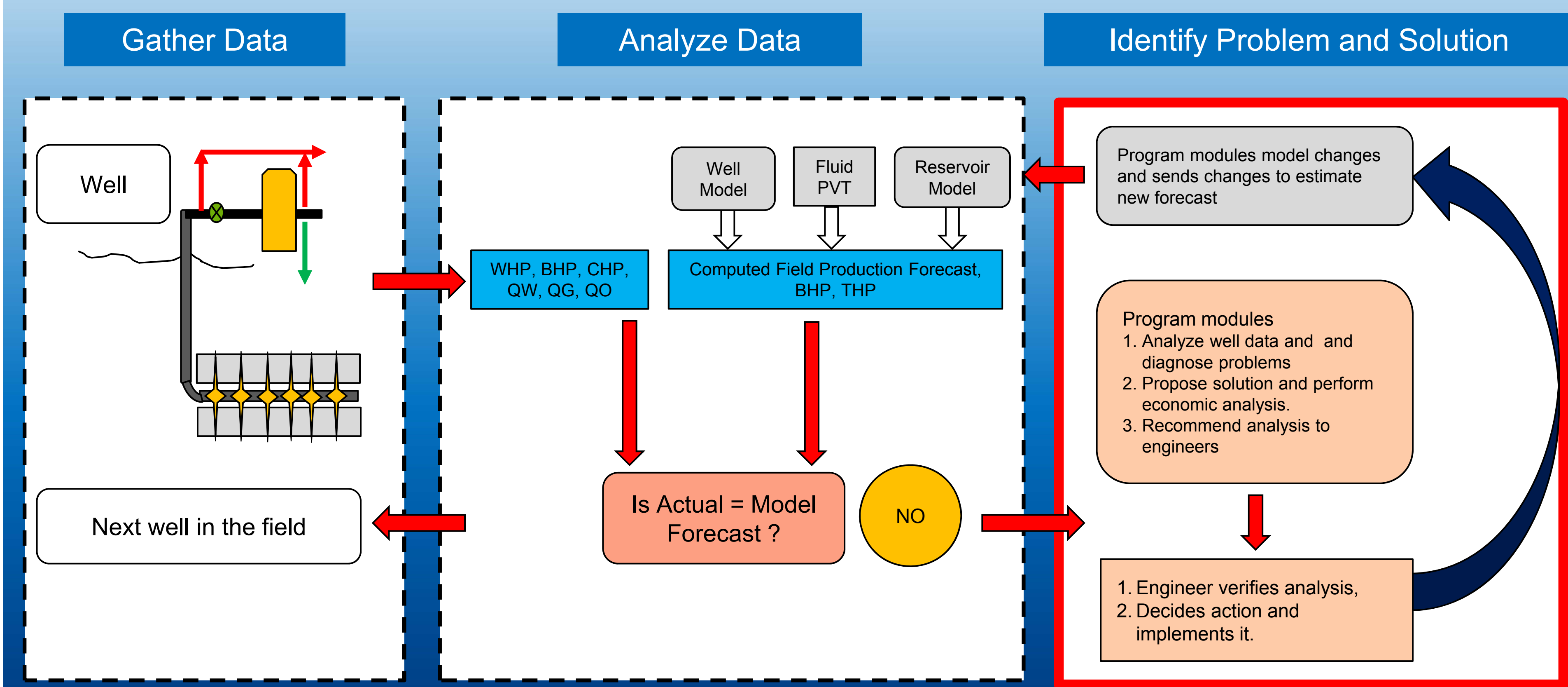
Production Forecasting

Commercial / Technical Success

Integrated Asset Management - Support Well Life Cycle



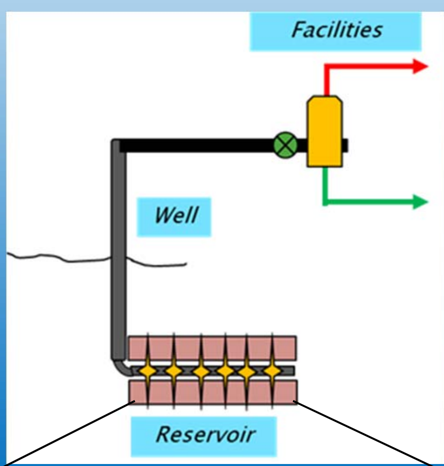
Reservoir Management & Surveillance Systems …Add Production & Create Value Every Day

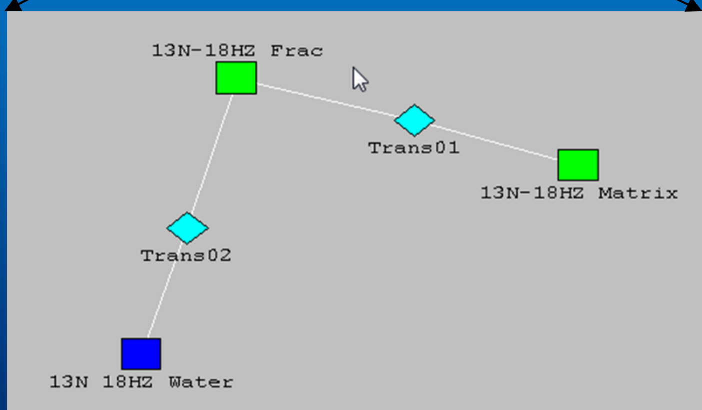


And Repeat this process <u>Every Day for All Wells</u>!

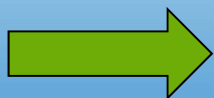
Innovative Tools and Methods to Model Shale Reservoirs

Inegrated Asset Model

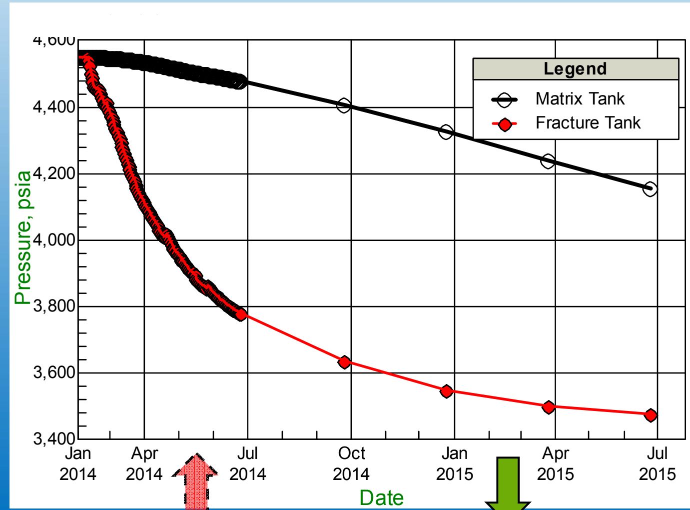


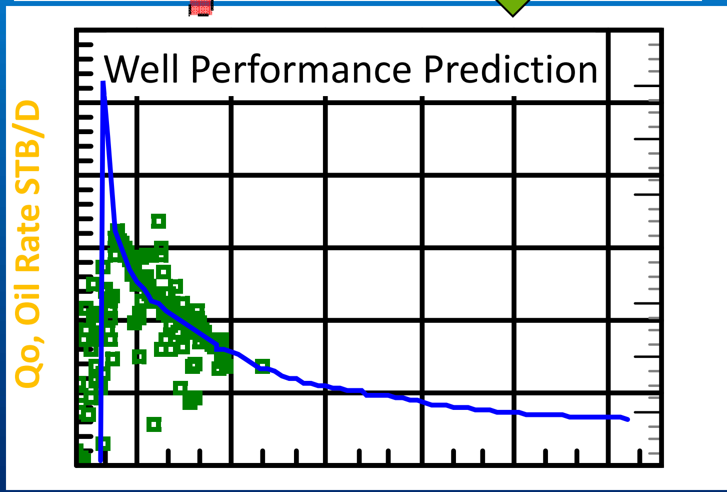


MBAL Shale Model Tanks



Tank Pressure Prediction

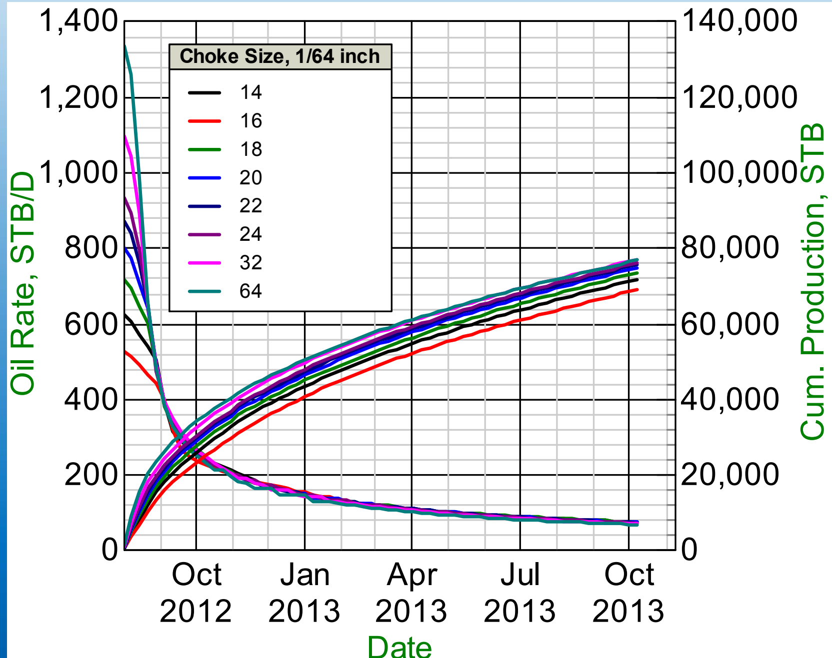




Time

IAM Application For Improved Drawdown Management

Wattenberg Application



Production decline mechanisms:

- **Fracture pressure decline.**
- **Relative permeability effects.**
- **Fracture/proppant compaction.**

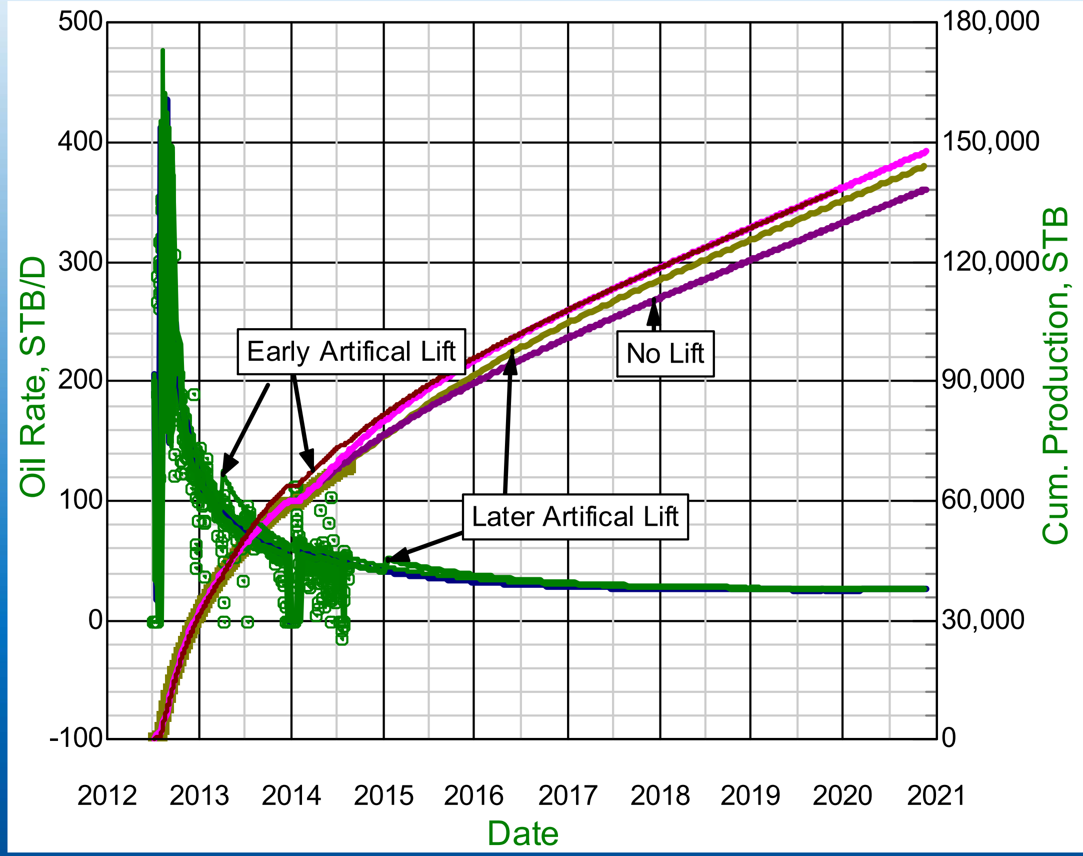
Learnings:

- **Choke (drawdown) changes significant.**

Important:

- ***Early in well life when minimal pressure margins to two-phase PVT region.***

IAM Application For Artificial Lift Design/Impact



Increase Rates and EUR:

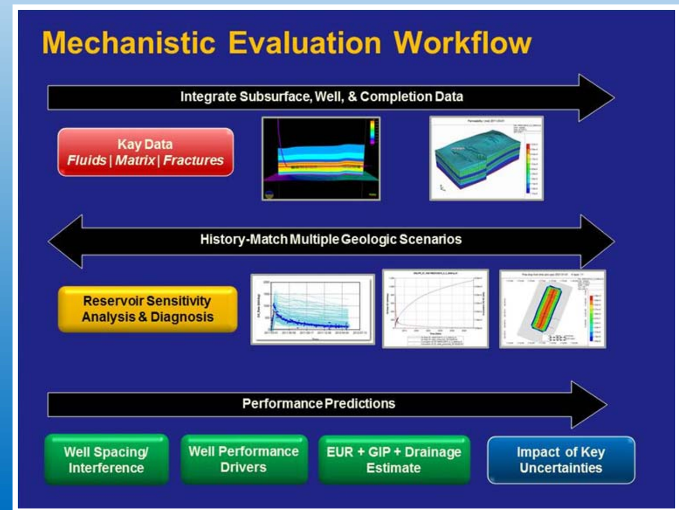
- Timing of artificial lift is important.
- Early artificial lift impacts EUR.

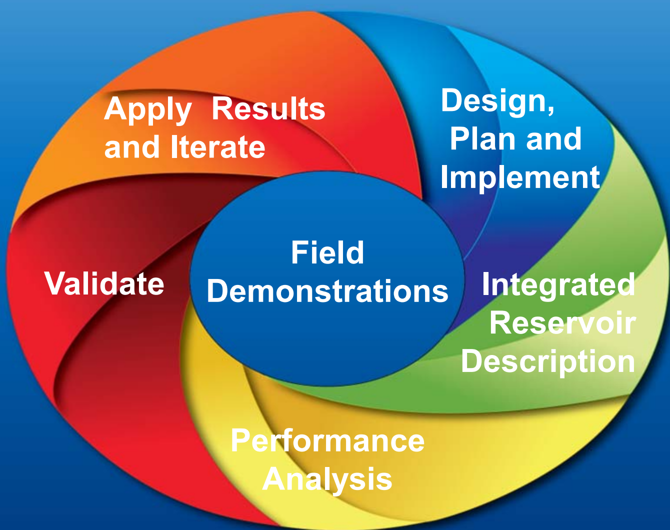
Applicable Types of Artificial Lift:

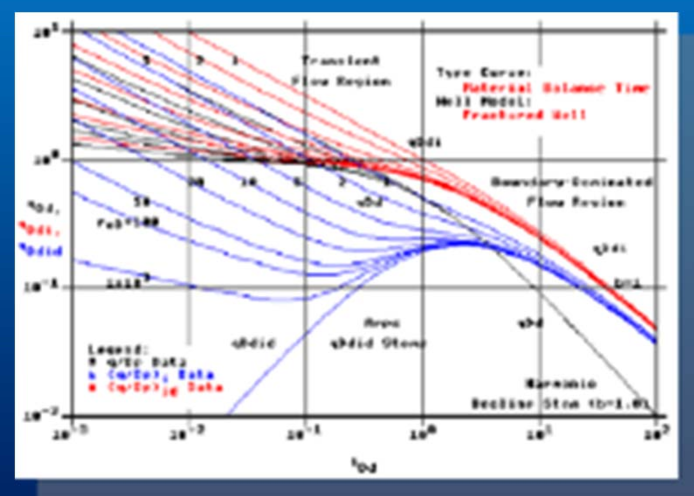
- Sucker rod pumps.
- Continuous gas lift.
- Intermittent gas lift.
- Plunger lift.

Conclusions & Key Learnings – Development Planning

- **Field Demonstrations, Mechanistic Models, Performance Analysis Key to Development and Optimization**
  - Target interval
  - Thermal Maturity Window
  - Well Spacing, Completions







Key Learnings - Full Life Cycle Value Drivers

Value Driver	- - - Value and Resources + + +
Development Approach	
Performance Analysis	
Data Acquisition	
Scale of Measurement	
Subsurface Analysis	
Integrated Asset Management	

Technology Advancement Opportunities Near to Mid-Term Focus

"Fast Adoption" to Operations

Critical:

- **Core Development**
  - ***Robust, early-engineered completions design***
  - ***Focus on well spacing as a development variable***
- **Newest Development Challenges**
  - ***Development of multiple stratigraphic targets***
  - ***Water production mechanisms; handling multi-phase production***

Enabling:

- **Production diagnostics — understand flow regimes earlier in well life**

Production Enhancement

- **Robust technical and performance screening criteria for well completions and re-fracturing**
- **Utilization/timing of artificial lift**

Thank You