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
Field Demonstrations

- Apply Results and Iterate
- Design, Plan and Implement
- Validate Field Demonstrations
- Integrated Reservoir Description
- Performance Analysis

Mechanistic Modelling

Mechanistic Evaluation Workflow

- Integrate Subsurface, Well, & Completion Data
- Key Data: Fluids, Matrix, Fractures
- History-Match Multiple Geologic Scenarios
- Reservoir Sensitivity Analysis & Diagnosis
- Performance Predictions
- Well Spacing; Interference
- Well Performance Drivers
- EUR & GIP + Drainage Estimation
- Impact of Key Uncertainties

Performance Analysis

Integrated Asset Model
Full Life Cycle Integrated Approach - Context & Evolution

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

~150 km
Eagle Ford Well Spacing Field Demonstrations

“Learning While Drilling”

- 12 Million Acres
- Production
  - > ~5+ BCFD
  - > ~940 MBOPD
- ~ 20,000+ Wells
Elements Affecting Production / Spacing

- Matrix Properties, Fluids
- Fracture Swarms / Faults
- Pre-existing Fractures
- Completion
Field Demo – Data Acquisition Design & Planning

Microseismic Events

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

Conventional Tools

Complexity & Resource

IPM
Reservoir Simulation
Streamline Simulation
RTA / MBDTCA
Analogies
Mechanistic Evaluation Workflow

Integrate Subsurface, Well, & Completion Data

Key Data
- Fluids
- Matrix
- Fractures

Reservoir Sensitivity Analysis & Diagnosis

History-Match Multiple Geologic Scenarios
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
Eagle Ford Rich Gas Condensate Performance (30 yrs)

Pressure Distribution

Condensate Distribution

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

Well Bore

Pressure

(So)_{initial} = 0

Saturation

K ~ Moderate - High
Eagle Ford Rich Gas Condensate Shale Sensitivity Analysis
(Production Change (%))

<table>
<thead>
<tr>
<th>Matrix Quality</th>
<th>SRV Size</th>
<th>Fracture Perm</th>
<th>Fluid Type</th>
<th>Initial Pressure</th>
<th>Desorption</th>
</tr>
</thead>
</table>

**Short Term Effects**
(1 Year)

**Long Term Effects**
(10 Years)

Base Case

- Reservoir
- Completion
- Fluid
Eagle Ford Well Spacing Demonstration

Stimulated Volume from Microseismic

Mechanistic Modeling
Pressure Distribution at 30 Years

Estimate of $\frac{1}{2}$ Length = 250’

No contribution outside SRV

Combine Both Technologies With Economics…

BEST SPACING ESTIMATE
Performance Analysis: Flow Regimes in Unconventional Reservoirs

**Very Early Time: Linear Flow**
(fracture flow does not interfere)

**Middle Time "SRV" Flow:** ("depletion")
(fracture flow does interfere)

**Late Time: "Post-SRV" Flow**
("Compound Linear Flow")

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**Increasing Time →**
Marcellus Dry Gas Fractured Shale Production Analysis

Modified Hyperbolic Time Rate Performance Model

- Gas Rate, MSCF/D
- Production Time, Days
- History Match & Forecast
- Actual Data

"b" factor
β – D/b
q - rate
D – decline rate
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

- Reservoir Modeling
  - Targeting

- Performance Analysis
  - EUR Determination
  - Production Forecasting

Commercial / Technical Success
Integrated Asset Management - Support Well Life Cycle

- Real Time Surveillance
- Production Optimization
- Unloading
- Drawdown Management
- Reservoir/Well Monitoring
  - Production Problems
  - Timely Identification
  - Problem Diagnostics
  - Problem Remediation
  - Down Time Management
- Well and Reservoir Performance Management
  - IFM
  - PVT Program
  - PTA, RTA, Nodal Analysis, Material Balance
- Production Enhancement
  - Artificial Lift
  - Re-Fracturing
  - Tubing Re-Sizing
- Artificial Lift
- Re-Fracturing
Reservoir Management & Surveillance Systems

...Add Production & Create Value Every Day

And Repeat this process Every Day for All Wells!
Innovative Tools and Methods to Model Shale Reservoirs

MBAL Shale Model Tanks

Well Performance Prediction

<table>
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<tr>
<th>Qo, Oil Rate STB/D</th>
<th>Time</th>
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<th>Pressure, psia</th>
<th>Date</th>
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<td>Jan 2014</td>
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<td>Apr 2014</td>
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<td>Jul 2014</td>
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Legend
- Matrix Tank
- Fracture Tank

Integrated Asset Model
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.
**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

Mechanistic Evaluation Workflow

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- Well Performance Drivers
- EUR + QIP + Drainage Estimate
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Key Learnings - Full Life Cycle Value Drivers

<table>
<thead>
<tr>
<th>Value Driver</th>
<th>Value and Resources</th>
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<tr>
<td>Development Approach</td>
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<td>Performance Analysis</td>
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<td>Data Acquisition</td>
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<td>Scale of Measurement</td>
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<td>Subsurface Analysis</td>
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<td>Integrated Asset Management</td>
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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