Developments in Unconventional Resource Technology

Andy Finley
Leo Giangiacomo

Wyoming Oil and Gas Fair
Enhanced Oil Recovery Institute
September 13, 2018
Amara’s Law

We tend to overestimate the effect of a technology in the short run and underestimate the effect in the long run.
Gartner Hype Curve
Developments in Unconventional Resource Technology

- Conventional versus unconventional
- What it takes to complete an unconventional well
- Play activity
Unconventional Shale Oil

• It’s not really unconventional
  • Requires combination of conventional horizontal and/or stage frac technology

• It’s not really shale
  • It’s smaller grained clastics more like silts with high clay contents

• It may have an unconventional component
  • Organic content
  • Non-Darcy Flow
Unconventional Vs Conventional Tight Reservoirs

Modified from Pollastro, 2001
Hydrocarbons Migrate from Unconventional Traps to Conventional Traps

Unconventional

- Generative Source Rock
- OM Heat Time
- Clays & OM Layers (*poor, ductile reservoir*)
- Clay, Coarser Grains, OM Layers (*good, brittle reservoir*)
- Migration Route
- Fractures & Faults
- Top Sealed – Potential Trap (*if source is generating*)
- Contact with Low Perm Carrier Beds – Potential Trap (*if source is generating*)

Conventional

- Traditional Traps
- Hydro- & Geopressured Anticlinal, Fault, Stratigraphic Traps
- Carrier Formations
- Low Perm – potential geopressured trap
- High Perm – no potential trap
- Carbonate Zone with no Geopressure – potential trap

Migration Route
Unconventional Vs Conventional

Conventional

Unconventional

Green dots are 10 nm diameter

Mowry Porosity
Unconventional Vs Conventional
Ken Williams, HGS 2014

- Capillary topseals, weak seals
- Overpressure seals, No HC Migration

- Coal pore throats ~1 nm
- Clay mineral spacings

- Mesh size

- Darcy Flow
- Slippage Flow

- Conventional Reservoirs
- Tight Gas
- Gas Source Rock Res

- Tight Oil

- Permeability in Darcys
- 1 Darcy permits a flow of 1 cm³/s of a fluid with 1 cP viscosity under a pressure of 1 atm

- Res Logs
- Por Logs
- FMI Logs

- Conventional Pore Throats
- Tight Gas Pore Throats
- Gas Source Rock Res Pore Throats

- Tight Oil Pore Throats

- Oil Source Rock Res

- Tight Gas

- Gas Source Rock Res

- Coal pore throats ~1 nm
- Clay mineral spacings
- Asphaltene ring structures
- Paraffins

- ng
- µg
- mg
- cg

- mm:
- µm:
- nm:

- angstrom

- pencil lead
- human hair
- soap film

- 10⁻³ m
- 10⁻⁶ m
- 10⁻⁹ m


© 2013 Halliburton All Rights Reserved
Unconventional Vs Conventional

- 200 ft³ rock contacted

<table>
<thead>
<tr>
<th>Year</th>
<th>Vertical Perfs</th>
<th>Vertical Fracs</th>
<th>Horizontal Big Fracs</th>
<th>Horizontal Complex Fracs Multi-Stage Fracs</th>
</tr>
</thead>
<tbody>
<tr>
<td>1860</td>
<td></td>
<td>500</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1900</td>
<td></td>
<td>3,200</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1950</td>
<td></td>
<td></td>
<td>240,000</td>
<td></td>
</tr>
<tr>
<td>2000</td>
<td></td>
<td></td>
<td></td>
<td>EOG et. al.</td>
</tr>
</tbody>
</table>

EOG et. al.
<table>
<thead>
<tr>
<th>Conventional</th>
<th>Unconventional</th>
</tr>
</thead>
<tbody>
<tr>
<td>Localized trap</td>
<td>Continuous type accumulation</td>
</tr>
<tr>
<td>External sourcing</td>
<td>Self-sourcing</td>
</tr>
<tr>
<td>Hydrodynamic influence</td>
<td>Minimal hydrodynamic influence</td>
</tr>
<tr>
<td>Porosity important</td>
<td>Porosity may not be important</td>
</tr>
<tr>
<td>$k &gt; 0.1$ md</td>
<td>$k &lt; 0.1$ md</td>
</tr>
<tr>
<td>Traditional phase behavior</td>
<td>Complex phase behavior</td>
</tr>
<tr>
<td>Minimum extraction effort</td>
<td>Significant extraction effort</td>
</tr>
<tr>
<td>Significant production history</td>
<td>Limited production history</td>
</tr>
<tr>
<td>Exponential decline rates</td>
<td>Hyperbolic decline rates</td>
</tr>
<tr>
<td>Few wells for commerciality</td>
<td>Many wells for commerciality</td>
</tr>
<tr>
<td>Reserves based on volumetrics</td>
<td>Reserves based on analogs</td>
</tr>
<tr>
<td>Assess entire project before drilling</td>
<td>Prospect driven by drilling</td>
</tr>
<tr>
<td>Boundary dominated flow</td>
<td>No boundary dominated flow</td>
</tr>
<tr>
<td>Gas on Oil on Water</td>
<td>Water on Oil on Gas</td>
</tr>
</tbody>
</table>
Frontier Sandstone

Unconventional

Conventional
Frontier Sandstone

CONVENTIONAL
This is where well produced from.

UNCONVENTIONAL
This is how a horizontal well with a frac cloud would produce.

lower gamma ray
notice how similar the reservoir looks
higher gamma ray

GR (1-25 highlighted in yellow)
Shale baseline shifted to match wells in 37N 74W
Resistivity
Frac propagation
Geophysics

• Rocks matter
• Improved 3D interpretation/integration
  • “A man’s got to know his limitations” Clint Eastwood
• Pre-stack migration can be used to estimate Poisson’s Ratio and Young’s Modulus
• AVO and azimuthal inversion can be used to estimate principal stresses and the horizontal stress ratio. Nash 2015
• High grading locations
• Optimizing landing zones
• Integrating with petrophysics
Cost Breakdown

• Drilling 40%
• Completion 60%
• Breakdown
  • Sand and water 30-35%
  • Casing 10-12%
  • Pressure pumping 10-12%
  • Drilling rig 9-11%
  • Cement and mud 6-8%
Key to Unconventional Success

• Sufficient Oil-in-Place to support operations
  • Know rock mineralogy, deposition, layering (get core, image logs)
  • Know porosity system (do petrographics, thin section, SEM, CT)
  • Know saturation distribution (mud logs, core/log integration)
  • Know controls on mobility (wettability, relative permeability, capillary pressures)
  • Know oil/gas physical properties (PVT studies)
• Effective Stimulation Program
  • Know rock (layering, facies, mineral compositions)
  • Know stresses (DFIT test for shmin)
  • Know mechanical properties (dipole sonic calibrated to DFIT)
  • Know permeability (DFIT leakoff, G function, facies, correlation to phi for each facies)
  • Understand natural fracture system (outcrop, core, performance)
  • Know frac height, width (three dimensional frac modelling calibrated to DFIT)
  • Know maximum effective frac length (model, match to real data, microseismic, tracer)
  • Know how to optimize completion (element of symmetry simulation)
    • Perforations
    • Cluster spacing
    • Stage spacing
The Unconventional Completion

- Higher rates and EUR’s
- Understand the rock and facies distinctions
- Drill in the right place
- Deploy the optimum completion

### Petrophysics
- Core/log Integration
- Mineral Model
- Porosity Model
- Saturation Model
- Permeability Model

### Geomechanics
- Rock Mechanical Properties
- Insitu Stress Magnitudes
- Vertical Stress Profile

### Reservoir Description
- Oil in Place Model
- Frac Cluster/Stage Model

### Frac Design
- Define Frac Height
- Maximize Length
- Estimate Complexity and Stress Shadow
- Optimize Cluster Design using 3D Model

### Operations
- Zonal Isolation
- Maximize Diversion with Rate/Perf Design Considering Stress Shadow
- Consider offset development
- Tracers
- Frac Hits

### Feedback
- Match predicted performance to actual
- Develop Lessons Learned
Petrophysics
Petrophysics

- Core analysis
  - CT Scanning making routine analysis obsolete
  - Low permeability measurement techniques

- Logs
  - Dipole Sonics
  - Imaging Logs
  - Mineral identification
  - NMR

- Rock Mechanical properties
  - Young’s Modulus
  - Poisson’s Ratio
  - Brittleness Index
  - Static vs Dynamic
  - Stress Field Characterization

- Core-Log Integration
Petrophysics in high \( \phi \) low k reservoirs

- Strong diagenetic effects and clay filling by chlorite and illite need to be studied by means of adhoc petrophysical models and specialized lithology logs
- Low resistivity contrasts affect water saturation evaluation
- Good total porosity determination using density, neutron and sonic
- NMR logging – good porosity estimation and poor k estimation
- Extensive laboratory analysis for Archie parameters (especially n) are required

Gonfalini, 2005
Petrophysics in low φ low k reservoirs

- Very high resistivity contrasts, anisotropy and dipping effects require resistivity modeling
- Lack of accuracy for all porosity logs
- Extensive laboratory analysis for Archie parameters (especially m and Rw)
- Need for image acquisition and interpretation (geology and formation/stress anisotropy)
- Need for acoustic anisotropy acquisition and interpretation (to improve seismic interpretation and better characterize in situ stress anisotropy)
Conventional Petrophysical Model
Conventional Petrophysical Model

Standard vs. Shale Only Density/Neutron Cross Plots
Unconventional Petrophysical Model

*Note: Components not to scale*
Unconventional Petrophysical Model

Four Porosity Component Model

The goal is to calculate the four porosity components from the unconventional reservoir model

- Effective Porosity $\Phi_e$
- Total Organic Carbon TOC
- Clay Porosity $\Phi_{Clay}$
- Free Shale Porosity $\Phi_{FS}$

Phi Components
Unconventional Petrophysical Model

Standard vs. Shale Oil Density/Neutron Cross Plots

Shale Only

Calculate
Clay Porosity = Cross Plot Porosity X VSh
Free Shale Porosity = Total Porosity – (Effective Porosity + TOC Volume + Clay Porosity)
Unconventional Petrophysical Model

Free vs. Adsorbed Hydrocarbons

- Free hydrocarbons are located in the free available porosity element, and are calculated using standard approaches.
- Publications on calculating adsorbed hydrocarbon volumes are sparse. Empirical relations are:

\[
\text{Gas – Published Relation} \\
\text{Adsorbed G.I.P. (SCF) = 1359.7 X Area X Thickness X RhoB X (16 X TOC)}
\]

\[
\text{Oil – Suggested Relation} \\
\text{Adsorbed O.I.P. (Bbl) = S2 X 0.0007 X RhoB X h X Area X 7758}
\]

\text{S2 = Hydrocarbons generated by thermal cracking}
Unconventional Petrophysical Model

Mechanical Properties – Brittle vs. Ductile

- To calculate mechanical properties, the following measurements are required
  - Acoustic compressional
  - Acoustic shear
  - Density

- Often acoustic shear is not available but can be estimated from other logs. The example shows pseudo curves based on the Krief geophysical model (Dipole Sonic not run in the Niobrara example).
Unconventional Petrophysical Model

Iterative Process

Better characterization of component minerals seems to be the most important issue currently for all unconventional petrophysics.
Unconventional Petrophysical Model
Other Points

• Calibrate log data to core data
  • Determine lithology model by calibrating log response to XRD
  • Need to account for sand, clay, calcite, iron

• Rw in Shaly Sandstones (Rw bound water ≠ Rw free water)

• Effective Porosity determination in Shaly Sandstones-Sonic, Density, etc.

• Clay content determination (Spectral GR, NDXP, GR calibration)

• Is a sonic log helpful in an over-pressured, gassy, fractured environment?

• How do you characterize reservoir scale petrophysics (nano to micro scale) using macro petrophysical readings (log scale)?

• How do you reconcile unknown Rw, Saturation, Hydrocarbon in Place and Recovery Factor with 2 equations (Saturation and OOIP)?
Geomechanics
Geomechanics

• Needed to design well orientation, frac

• Rock Mechanical Properties
  • Determined with a shear and compressional sonic log
  • Young’s Modulus related to treating pressure and frac width
  • Poisson’s Ratio related to frac height (JPT Feb 1984, p287-290)

• Stress Field Magnitude and Orientation
  • Vertical stress estimated from density log at nearly 1.0 psi/ft
  • Minimum horizontal stress determines frac gradient
    • Best determined by a set of DFIT tests, then mechanical properties log calibrated
  • Maximum horizontal stress determines frac azimuth
    • Best determined by image logs, borehole enlargement (Powder River Basin)
  • Ratio of horizontal stresses related to fracture complexity
Elastic Modulii

• Bulk Modulus, $K$, is the stiffness of a material in hydrostatic compression
• Young’s Modulus, $E$, is the stiffness of a rock in simple (unconfined) uniaxial compression
• Poisson’s Ratio, $v$, is the ratio of lateral expansion to axial shortening
• Shear modulus, $G$, is the ratio of an applied shear stress to a corresponding shear strain.
• Lame’s constant, $\lambda$, does not have a straightforward physical representation. In a material where Poisson’s ratio is 0.25, $\lambda = G$
• The M modulus was developed to determine rock stiffness directly from seismic wave velocities
Static vs Dynamic

• Static means that the measurements were made in a laboratory experiment
• Dynamic means that the measurements were made with seismic velocity measurements at ultrasonic frequency
Stress

• Stress is defined as force divided by area
• Main stresses to be considered in reservoir
  • Vertical stress
  • Minimum horizontal stress
  • Maximum horizontal stress
  • Pore pressure
Brittleness Index

• Brittleness index describes the brittleness of rocks (high Young’s Modulus and low Poisson’s Ratio) in three ways
  • Elastic properties (E/v)
  • Petrophysical properties (fraction of high E rocks to total matrix volume)
  • Strength properties (compressive strength divided by tensile strength)
Reservoir Description
Reservoir Description

• Need to know the distribution of oil-in-place
• Volumetric map set
  • Facies
  • Effective porosity
    • Permeability from relationship for respective facies
• Clay Volume
• Water Saturation
• Raw Oil-in-Place
• Cutoff Oil-in-Place
  • Filtered for porosity, water saturation, clay volume
  • Also provides net thickness
Reservoir Flow Model

• Use volumetric oil-in-place model to set up element of symmetry flow model with physical fractures to mimic a half frac stage
• Appropriate minimum layering to save computing complexity
• Physically model fractures
• Use buffer blocks along edge to represent well spacing
Leverage Darcy’s Law

- \[ q = \frac{k A \Delta p}{\Delta L} \]
- If \( k \) is too low for an economic \( q \), make \( A \) bigger
- Limit becomes how close can you space clusters to maximize recovery between the fracs and minimize the cost of creating them

<table>
<thead>
<tr>
<th>Frac Surface Area Calculation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frac Wings</td>
</tr>
<tr>
<td>Sand faces per frac</td>
</tr>
<tr>
<td>Half Length</td>
</tr>
<tr>
<td>Frac Heigth</td>
</tr>
<tr>
<td>Lateral Length</td>
</tr>
<tr>
<td>Stage Length</td>
</tr>
<tr>
<td>Stages</td>
</tr>
<tr>
<td>Clusters per stage</td>
</tr>
<tr>
<td>Cluster spacing</td>
</tr>
<tr>
<td>Complexity Index</td>
</tr>
<tr>
<td>Flow Area</td>
</tr>
<tr>
<td>Proppant Concentration</td>
</tr>
<tr>
<td>Proppant Required</td>
</tr>
<tr>
<td>Proppant Distribution</td>
</tr>
</tbody>
</table>
Interference between clusters

- Cluster optimization using element of symmetry
- Cells midpoint between clusters must be drained in economic time
- Function of permeability, time, and drawdown pressure (Darcy’s Law)
Hydraulic Fracture Design
Basic Elements

• Goal is to maximize surface flow area (Darcy’s Law)
  • Complexity
  • Shear dilation

• Differential Stress
  • Low promotes complexity
  • High promotes planarity

• Fluids
  • Thinner fluids promote complexity
  • Thicker fluids tend to more planar shapes

• Proppants
  • Use to maximize surface area, not conductivity

• Rates
  • High rates promote complexity, but need to stay within height growth boundaries

• Additives
  • Viscosity
  • Clay protection
  • Surfactants
Hydraulic Fracture Operations
Casing and Cementing

• Difficult to get cement placed all the way around casing
  • Top rubber plugs may need to be doubled up
  • Centralizers needed
  • CBL to make sure zonal isolation is possible
    • Maybe *you can’t handle the truth* (Jack Nicholson A Few Good Men)
    • Channel is common at top along longitude of string due to water separation
      • Can help to steer frac longitudinally in right stress position

• Marker joints helpful to get on depth
• Minimize doglegs to avoid stress on casing couplings
Perforations

• Hole Size Consistency
  • Casing size needs to be same as you are using due to standoff variation
  • Horizontal wells do not give good centralization
  • Statistics for holes should be tight
  • Erosion will take advantage of aberrations

• Reliability
  • Pre wired guns
  • Select fire
  • Sticking
Effective Diversion

- Frac treatment must treat each cluster in a stage with an equivalent volume of fluid and sand
- Diversion can be accomplished by
  - Rate
    - Perforation size
    - Perforation number/density
    - 2 BPM per perf rule of thumb
    - Should be calculated
  - Mechanical
    - Soluble solids
    - BioBalls

<table>
<thead>
<tr>
<th>Stage</th>
<th>Length</th>
<th>Cluster</th>
<th>Spacing</th>
<th>TVD</th>
<th>SPF</th>
<th>Perf Size</th>
<th>Flow Area</th>
<th>Θ_Pf</th>
<th>Θ_Cluster</th>
<th>Frac Gradient</th>
<th>Stress Gradient</th>
<th>Net Extension</th>
<th>Frac Friction</th>
<th>Pressure Between Clusters</th>
<th>Req'd Formation Side Pressure</th>
<th>Req'd Casing Side Pressure</th>
<th>Required Rate per Cluster</th>
</tr>
</thead>
<tbody>
<tr>
<td>17</td>
<td>128.5</td>
<td>1</td>
<td>25.0</td>
<td>6655</td>
<td>4</td>
<td>0.45</td>
<td>0.159</td>
<td>0.636</td>
<td>0.222</td>
<td>119.7</td>
<td>119.7</td>
<td>0.660</td>
<td>0.340</td>
<td>6655.0</td>
<td>207.0</td>
<td>1.1</td>
<td>1097.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>25.0</td>
<td>6632</td>
<td>4</td>
<td>0.45</td>
<td>0.159</td>
<td>0.636</td>
<td>0.222</td>
<td>119.7</td>
<td>119.7</td>
<td>0.660</td>
<td>0.302</td>
<td>6381.6</td>
<td>207.0</td>
<td>1.1</td>
<td>1093.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>25.0</td>
<td>6599</td>
<td>4</td>
<td>0.45</td>
<td>0.159</td>
<td>0.636</td>
<td>0.222</td>
<td>119.7</td>
<td>119.7</td>
<td>0.660</td>
<td>0.264</td>
<td>6109.6</td>
<td>207.0</td>
<td>1.1</td>
<td>1089.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4</td>
<td>25.0</td>
<td>6586</td>
<td>3</td>
<td>0.45</td>
<td>0.159</td>
<td>0.477</td>
<td>0.167</td>
<td>119.7</td>
<td>119.7</td>
<td>0.660</td>
<td>0.227</td>
<td>5839.9</td>
<td>207.0</td>
<td>1.1</td>
<td>1086.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5</td>
<td>25.0</td>
<td>6563</td>
<td>3</td>
<td>0.45</td>
<td>0.159</td>
<td>0.477</td>
<td>0.167</td>
<td>119.7</td>
<td>119.7</td>
<td>0.660</td>
<td>0.189</td>
<td>5571.6</td>
<td>207.0</td>
<td>1.1</td>
<td>1082.3</td>
</tr>
</tbody>
</table>

Total Perforations: 18
Estimated Rate per Perf: 2.10
Estimated Total: 38

Design Rate: 85.0
Formation Damage

- Unconventional rocks have more clays
- Damage due to drilling fluids, frac fluids, completion fluids
- Control is to create enough surface area that damage can be overlooked
- Identify clays with logs, XRD, cuttings analysis
- Identify damage mechanism
  - Surface hydration
  - Ionic hydration
  - Osmotic hydration
  - Solids
  - Wettability alteration
- Develop effective controls to minimize damage
  - Don’t forget pump-down fluids
- Reducing $\Delta p_{\text{damage zone}}$ will increase EUR, timely return on capital
Plugs

• Setting reliability
  • Wireline pump down
  • Release from plug

• Holding reliability
  • Frac differential pressure

• Drilling reliability
  • Jointed tubing
  • Coiled tubing

• Dissolvable
  • Fluid composition
  • Temperature
  • Debris
Tracers

• Radioactive
  • Evaluate distribution of sand in each cluster and stage
  • May find longitudinal channeling along cement weak zones
  • Requires post frac log run to evaluate

• Chemical
  • Oil phase and water phase tracers
  • Tracks contribution of each stage for each phase
  • Can be used for interwell communication
Additives

• Paraffin control
• Clay control
• Nano fluid
• Biocide
Cubes and Zippers

• Stress drives simultaneous fracturing operations
  • Low pore pressures embrittle rock and attract frac
  • Difficult to get virgin rock frac’ed

• Zipper fracs alternate stages between two adjacent wells
  • Able to more effectively utilize pump and wireline equipment
  • Must have zippers aligned in the stress field
  • Must have lengths that just start to interfere
  • Creates stress shadows that increase frac gradients and steer frac extension

• Cube development takes in stacked reservoirs
  • Enhances economy of scale by developing all wells in all reservoirs at the same time
  • Thick reservoirs may be zippered in three dimensions
Boosting Productivity

- Rocks matter
- Deep understanding of petrophysics
- Understand why ideas are successful
- High-density completions
  - Maximize surface area with enhanced complexity (higher GOR’s)
  - Contain events closer to wellbore
- Longer laterals (15000 ft)
- Tighter clusters (20 feet)
- Higher proppant volumes (2,500 lb/ft)

Encana, Pioneer Q2 presentation
Boosting Efficiency

- Large lease block
- Stacked pay
- Multi-well pads
- Simultaneous operations
- Develop the cube
- Minimize trucking
- Control supply chain

Concentration of Resources Drives Efficiencies

3 sections / 64 wells
4 Zones
Reserves: ~44 MMBOE
1 rig program: 5+ years D+C
Hydraulic Fracture Evaluation
**Diagnostics**

- **Stress Field**
  - Dipole sonic (shear and compressional travel time)
  - Imaging logs (or x-y caliper)
    - Resistivity
    - Acoustic

- **Frac treatment**
  - DFIT (Diagnostic Fracture Injection Test)
    - G-function analysis for closure stress
  - Microseismic
    - Stimulated reservoir volume (or is it?)

- **Flowback Analysis**
  - Tracers
  - Rate, pressure
  - Fluids and concentrations

- **Productivity Predictions**
  - Production logging

- **Reservoir/Fracture simulations**
  - Match back to design models
Feedback

• Real production should match predicted
• If it does not, the model is wrong and needs to be updated to understand the mechanisms at work.
• There must be an effective feedback system at work to expect real improvement in future efforts
Production

- Pump depth
  - In curve
  - In horizontal
  - Doglegs
- Pump Type
  - Jet Pump
  - Rod Pump
  - Hydraulic Pump
  - Submersible PC
- Failure Analysis
- Compression optimization

In the event that a beam lift unit is utilized for lifting a horizontal well, there may be as much as 1,000 to 1,500 feet of water in a well that does not have sufficient gas velocity to unload the well by natural flow.

1,000 to 1,500 feet of water left in a horizontal well may hold as much as 450 to 650 psi back pressure.
Big Data

- Over two billion feet of horizontal has been drilled
- Data collection averages 1 megabyte per foot or between 1 and 15 terabytes per well. Total data collected on horizontals is 600 petabytes.
- Storage, data mining, and analytics is becoming hugely important
- EOG using Real-Time Data-Driven Analysis
  - Collection from rigs, frac fleets, production wells
  - Stored and optimized for analysis
  - Algorithms, data science, software puts predictive analytics on desktop, mobile platforms
Water Management

• Source
  • Aquifer depletion
  • Biological contamination

• Transportation
  • Emissions
  • Trucking costs

• Storage
  • Central ponds
  • Temperature control

• Usage
  • Biocide issue

• Treatment
  • Recycling produced and flowback

• Disposal
  • Earthquakes
Remedial Operation

• Cleanout Plugs

• Proppant Flowback Control
  • Resin coated sand tail-in
  • Fiber
  • Thermoplastic film

• Refrac
  • Unstimulated volume
  • Embedment in softer rock
    • Lost communication with upper zones
Play Board

EOG Active in Every Major U.S. Horizontal Oil Play

Total Oil Production (MBopd)

- Bakken/Three Forks 1.165 (23%)
- Powder River Basin 0.5 (2%)
- DJ Basin 410 (7%)
- SCOOP/Stack 255 (5%)
- Permian 2,115 Total (37%)
- Eagle Ford 1,136 (23%)

6 Plays Make up 90%
of U.S. Horizontal Oil Production = 5.7 MMBopd

Source: IHS - Gross Crude and Condensate Production as at December 2017
Bakken

- EOG drilling and completing for $4.6 million
  - Type curve is regressive
- Whiting using 8 MM lbs proppant to get 1000+ MBOE EUR’s in Bakken/Three Forks
  - 40 stages
  - 42 perforations per stage
  - 900 lbs proppant per foot
  - Diverting agents
- Continental making significant improvements
  - 40 stages, testing 60 stages for 10,000 ft lateral
  - 1250 lbs proppant per foot
DJ Basin Niobrara

- Noble Energy
  - 1800 lbs proppant per foot
  - 10,500 ft lateral
  - 1100 BOEPD for more than 100 days
DJ Basin Niobrara

Wattenberg: More Intervals, Tighter Spacing & Improved Rates/EURs

Noble Energy Leading Development

- 9,000 laterals, 750M EUR, 188% BT ROR are being achieved in the main Niobrara B bench
- Play is extending in to northern Colorado’s East Pony area
- Full development for the Codell sandstone and emerging development plans for the Greenhorn lime stone.
- Bonanza Creek and PDC are following Noble’s lead in high density well count, extending the vertical opportunity, and improving well results.

DJ Basin / Niobrara: Noble Energy

DJ Basin / Niobrara: From 4 to 30 wells per DSU

Noble Energy
Powder River Basin

• Chesapeake PRB type curves top all other shale plays
• EOG booked 9.2 billion BOE in Turner, Mowry, Niobrara at $9.29/BOE OPEX
• Wold 4535 BOPD Frontier Turner in 38 74
• Anadarko
• Anschutz
• Navigation

Powder River Basin SE Niobrara Type Curve

<table>
<thead>
<tr>
<th></th>
<th>Oil</th>
<th>Gas</th>
<th>Water</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>STB</td>
<td>MCF</td>
<td>bbls</td>
</tr>
<tr>
<td>IP Adjust</td>
<td>1.7</td>
<td>3.2</td>
<td>1</td>
</tr>
<tr>
<td>Qi</td>
<td>21,890</td>
<td>42,227</td>
<td>26,496</td>
</tr>
<tr>
<td>De</td>
<td>97.5</td>
<td>92</td>
<td>99.99999999</td>
</tr>
<tr>
<td>a</td>
<td>3.689</td>
<td>2.526</td>
<td>23.026</td>
</tr>
<tr>
<td>b</td>
<td>0.8</td>
<td>0.8</td>
<td>0.7</td>
</tr>
<tr>
<td>amin</td>
<td>0.05</td>
<td>0.05</td>
<td></td>
</tr>
<tr>
<td>Type EUR</td>
<td>236,505</td>
<td>636,268</td>
<td>51,857</td>
</tr>
<tr>
<td>Real EUR</td>
<td>241,638</td>
<td>621,410</td>
<td>65,377</td>
</tr>
</tbody>
</table>
Powder River Basin

Powder River Basin – Mowry and Niobrara Shale
Competitive Across EOG Premium Assets

Revenue¹ and Well Cost² per 1,000 Feet Lateral ($M)

<table>
<thead>
<tr>
<th>Asset</th>
<th>Revenue</th>
<th>Well Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>DB Wolfcamp Oil</td>
<td>4,240</td>
<td>1,055</td>
</tr>
<tr>
<td>PRB Niobrara</td>
<td>3,270</td>
<td>620</td>
</tr>
<tr>
<td>PRB Mowry</td>
<td>3,240</td>
<td>640</td>
</tr>
<tr>
<td>Eagle Ford</td>
<td>2,780</td>
<td>310</td>
</tr>
<tr>
<td>Woodford Oil Window</td>
<td>2,735</td>
<td>620</td>
</tr>
</tbody>
</table>

¹ Revenue calculated using $40 WTI, $2.50 NYMEX and $15 HGL. Faced for 10,000 wells.
² Well Costs = Drilling, Completion, Well-site Facilities and Flowback.
Eagle Ford Play, South Texas

- EOG drilling and completing for $4.3 million
Permian Basin, Texas

• Encana is employing cube development to develop multiple stacked pay from a single location (Sprayberry, Wolfcamp, Bone Spring)
  • Maximize production and resource recovery
  • Minimize risk of erosion of value connected with infill and frac hits
  • Improved logistics efficiency

• EOG drilling and completing for $7.6 million and getting 950 to 1175 MBOE per well
Oklahoma STACK play

• Anadarko Basin
  • Mississipian primary target with 10 additional horizontal targets
  • Sweet spot is Meramec area in Kingfisher, Blaine, Canadian counties

• Operators include Devon, Newfield, Marathon, Chesapeake, Continental Resources, Cimarex

• Devon’s Privott 17-H Meramec 6,000 BOEPD, 2 MMBOE EUR
  • Average peak month productivity is 110 BOEPD per 1000 feet.

• Wells are 10,000 ft vertical, 10,000 ft horizontal with 2500 pounds per foot proppant

Acknowledgements

• Wyoming Oil and Gas Fair
• EORI
• Attendees