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Thriving in a Lower for Longer Environment

Mary Van Domelen, PE, SPEC
November 2019 Tour
Lecture Format

• The challenge
• Market dynamics
• Keys to success
• Impact of technology
• Takeaway points
Unconventional Resources Development
Hydraulically Fractured Horizontal Wells

Image source: Colorado School of Mines
Major US Basins and Shale Plays

Image source: PacWest Consulting Partners (2016)
North American Basins and Shale Plays

Image source: PacWest Consulting Partners (2016)
The Challenge

• In 2014, the price of West Texas Intermediate (WTI) started to drop, reaching a low of $26 per barrel in February 2016.

• Industry analysts predicted that unconventional shale plays would be shut down as they would no longer be economical.

• The shale industry did not just survive: *It thrived...How?*
US Oil Production Growth

West Texas Intermediate (WTI) Price

Data source: macrotrends.net
US Tight Oil Production by Play

Daily Tight Oil Production (million BO/day)

Source: US Energy Information Agency
US Shale Gas Production by Play

Daily Shale Gas Production (bcf/day)

Source: US Energy Information Agency
Wellhead Breakeven Prices

<table>
<thead>
<tr>
<th>Year</th>
<th>Bakken ($29/bbl)</th>
<th>Eagle Ford ($38/bbl)</th>
<th>Niobrara ($34/bbl)</th>
<th>Permian Midland ($33/bbl)</th>
<th>Permian Delaware ($39/bbl)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013</td>
<td>~ $65 - $100/bbl</td>
<td>~ $30 - $40/bbl</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: Rystad Energy NASWellCube
Profitability vs. Breakeven

Dallas Fed Energy Survey—in the top two areas in which your firm is active: What WTI oil price does your firm need to profitably drill a new well?

Data source: Federal Reserve Bank of Dallas (March 2019)
Lloyd Thermals

History Of Successful Project Execution And Capital Discipline

- Modular, scalable designs with standardized engineering and construction
- Not subject to government production quotas
- 10,000 bbls/day Dee Valley now on production
- Rush Lake 2 continues to perform above nameplate
- Project break-evens of $30/bbl WTI

Growth projects update:
- Paced development: Three projects every two years
- Focus on hub centralization and shared infrastructure
- Spruce Lake Central and Spruce Lake North on track for start-up in 2020, adding approximately 20,000 boe/day of capacity
- Expected ‘19 exit rate of +90,000 bbls/day; with 40,000 bbls/day capacity to be added by 2022

Slide Reference: Husky Energy Corporate Presentation, September 2019
Oil and Gas Extraction Workers

US E&P Company Employees (x 1,000)


~80 Bo/day/person

~45 Bo/day/person
Shifting Landscape of Business Drivers

- **Expansion Land Grab (2009-2011)**
- **Production Growth (2012-2014)**
- **Capital Discipline (2015-2017)**

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**Improve ROI**
*Return on Investment*

**Increase Production**
- Decrease Costs
- Reduce Cycle Times
Generating Free Cash Flow

Increase Production
- Longer laterals
- Optimized completions
- Proactive artificial lift designs

Reduce Cost of Supply
- Services and materials pricing
- Decrease cycle time
- Optimize processes
### Composite Well Cost Index

<table>
<thead>
<tr>
<th>Date</th>
<th>Oil Price</th>
<th>Cost Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>2Q-2011</td>
<td>$114</td>
<td>1.07</td>
</tr>
<tr>
<td>2019</td>
<td>~ $55</td>
<td>0.86</td>
</tr>
</tbody>
</table>

- Oil prices dropped ~50%
- Well costs reduced only ~20%

Data source: Spears and Associates, Inc (4Q-2018)
Breakdown of Total Well Costs

Typical horizontal shale well

- Drilling: 30%
- Completion: 50%
- Production and Facilities: 20%
Drilling’s Contributions to Improved ROI

1) Increased lateral lengths
2) Reduced drilling times
3) Pad drilling

Increase Production
Decrease Costs + Improve Cycle Times
Increasing Lateral Lengths by Play
Significantly Reduced Drilling Times

CONTINUALLY IMPROVING DRILLING EFFICIENCY

- 64% Reduction

Drilling Faster
Lateral Ft Drilled per Day

- 14%
- 31%

Drilling Time
- 45% REDUCTION in Spud to Spud Days

Average Drill Days
(Spud to Rig Release)

~33% Improvement

SpringBoard Cycle Time Reduction
New-well Oil Production per Rig

Bakken Play

Source: EIA Drilling Productivity Report (October 2019)
Drilling Efficiency Gains
Technology + Teamwork

Technology Advances
- Formation specific bits
- Improved stator designs
- Better, more reliable, data while drilling lateral
- Geo-steering software
- Auto-drilling software

Teamwork
- Consolidated work force
- Empowerment of the field
- Common goals, improved communication
- Shared data to accelerate learning curve
- Performance analytics
Multi-Well Pad Drilling

Source: ConocoPhillips Eagle Ford Investor Tour  https://www.youtube.com/embed/w5R3FqwJ8oI?rel=0
Multi-Well Pad Drilling Trends

Number of Wells per Pad

- Bakken - Maximum
- Eagle Ford - Maximum
- Bakken - Average
- Eagle Ford - Average

Source: Spears and Associates Insider (June 2019)
Pros and Cons of Multi-Well Pad Drilling

**Advantages**
- Reduced surface footprint
- Fewer rig moves
  - Saves 2-4 days
  - Reduced exposure to personnel
- Batch drill wellbore sections
  - Allows offline cementing operations
  - Reduced mud swaps
  - Less laying down of pipe
- Focus on “hidden” inefficiencies

**Challenges**
- More complex wellbores
  - Anti-collision considerations
  - Longer step-outs
- Concentrated/increased traffic
- Simultaneous operations
  - Multiple rigs on larger pads
  - Drilling and completion simops
- Long lead time bringing wells onto production
Multi-Well Pad Completion

Source: ConocoPhillips Eagle Ford Investor Tour  https://www.youtube.com/embed/w5R3FqwJ8oI?rel=0
Completion Phases

*Horizontal wells with multi-stage hydraulic fractures*

1. Run and cement the lateral liner (or isolate with casing packers)
2. Hydraulically fracture the lateral stage by stage
   a) Fracture first stage
   b) Use wireline to pump down frac plug and perforating guns
      • Set frac plug to isolate prior stage
      • Pull up, perforate, pull out of hole
   c) Fracture next stage – repeat process
3. Drill out frac plugs with coiled tubing (or workover rig)
4. Flowback to recover frac fluids and debris from the wellbore
Completions Impact on Profitability

- Improve ROI
- Decrease Costs
- Reduce Cycle Times

CLR Bakken Performance Improves Year-After-Year
(Source: Drillinginfo)
Enhanced Completions

Drive improved well performance

First year oil decline curves for horizontal wells by production start year

Source: Rystad Energy NASWellCube (February 2018)
Increased Well Productivity

*Expands the economic footprint*

- **Early Bakken Development**
- **New Fairway**
- **Periphery**

Montana  North Dakota
Completion Design Parameters

- Lateral length
- Stage count
- Proppant mass
- Fluid volume
- Injection rate
- Cluster/perforation design
- Well spacing
Evolution of Stage and Cluster Spacing

- **2011 - 2012**
  - 4,500 ft lateral
  - 8-10 stages

- **2016 - 2017**
  - 10,000 ft lateral
  - 60-70 stages

Current trend is to increase stage spacing while reducing cluster spacings:
- 28 to 45 stages with as many as 10-15 clusters (10,000 ft lateral)

This provides significant cost and time savings, without sacrificing production results.
How would you interpret this data?

- Middle Bakken
- Three Forks
Move from Enhanced to Optimized

Bigger is not always better

Upper Bakken Shale
Middle Bakken
Lower Bakken Shale
Three Forks
Middle Bakken to Three Forks Communication

Fracture Driven Interaction Initiates

Offset Well Pressure
Completion Multivariate Analysis

Central Bakken Example

Reference SPE 184851 or SPE 187254 for Analysis Technique
Combine Physical and Statistical Models

Stage spacing transformation \( y = 10.05 \ln(x) + 70.908 \)

Proppant mass transformation \( y = 5.9451 \ln(x) - 15.010 \)

<table>
<thead>
<tr>
<th>Completion Design Parameter</th>
<th>Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transformed ft/stage</td>
<td>0.4440</td>
</tr>
<tr>
<td>Transformed lb/ft</td>
<td>0.5320</td>
</tr>
<tr>
<td>Adjusted 180-day Water Cut</td>
<td>-0.1576</td>
</tr>
<tr>
<td>Hydrocarbon Pore Volume</td>
<td>1.2637</td>
</tr>
<tr>
<td>Completion Technique</td>
<td>1.8173</td>
</tr>
<tr>
<td>Maximum Injection Rate</td>
<td>0.0311</td>
</tr>
<tr>
<td>Gross Interval Thickness</td>
<td>0.0943</td>
</tr>
<tr>
<td>Ave Prop Conc (ppg)</td>
<td>-9.5170</td>
</tr>
</tbody>
</table>

Reference: SPE 184851 or SPE 187254 for Analysis Technique
Optimizing Well Performance

Develop formation specific best practices

• Leverage basin completion & production metrics
• Identify key completion parameters
• Combine statistical analysis with physical models
• Move from *enhanced* to *optimized* completions

Recognize that completion design must be integrally linked to development plans
Completion Cost Breakdown

Bakken 10,000 ft lateral example

- Frac Services: ~65%
- Chemicals
- Proppant: ~20%
- Water (purchase, transfer, dispose)
- Wireline, Perforations, Plugs
- CT Drill-out of Frac Plugs
- Location, Supervision, Rentals, etc.
Game Changer Technologies

1) Cloud technology, data analytics, and machine learning
2) Regional sand and new sand delivery systems
3) Extreme limited entry (XLE) perforating
4) High viscosity friction reducers (HVFR)
5) Produced water recycling
6) Wireline “quick connect” systems
7) Coiled tubing drill-outs
Traditional Frac Stage & Well Files

Printed fracture treatment plot with hand-written annotations about the operations

Paper copies of stage reports

Source: SPE 197105 Leveraging Cloud-Based Analytics to Enhance Near-Real Time Stage Management
Utilizing Cloud-based Technologies

• High frequency (1-sec) fracturing data is collected throughout the entire completion

• As received, the files are poorly structured and difficult to manipulate

• Cloud-based storage makes stage data readily available, allowing rapid visualization and analytics
Machine Learning (ML) Applications

Auto-flagging fracturing events
Combining Frac and Geology Data

Possible with cloud-based technologies

• Each frac stage is an “investigation” into the unique geology along a specific section of the lateral
Driving Down Frac Sand Costs

1) Transport and storage
2) Self-sourcing
3) Regional sand
4) Mine ownership

Source: Rystad Energy
Sand Management Program

Case Study: Chesapeake Energy

Statistics
~ 8 billion pounds per year
~ $100 million savings
~ 92% reduction in sand NPT

Program
• First trials in 2013
• Mid-2018 initiated full program
• Team of 2 to manage
• Hybrid strategy

Reference: Oil and Gas Investor (August 2019)
Facture Initiation Points

Increasing cluster efficiency

Poor Cluster Efficiency

Offset Parent Well

Offset Parent Well
Three Forks to Three Forks

*Diversion Triggering Frac Hit*

Fracture Driven Interaction Initiates
Increasing Cluster Efficiency

Dynamic diversion

1) Ball sealers, perf pac balls
2) Degradable particulates
3) Perf pods
4) Limited entry perforating
5) Extreme limited entry (XLE)

\[ \Delta P_{\text{perf}} = \frac{0.2369 \times Q_{\text{perf}}^2 \times \rho}{N_{\text{perf}}^2 \times D_{\text{perf}}^4 \times C_d^2} \]

- \( Q \) = Total flow rate (bbl/min)
- \( \rho \) = Density of fluid (lb/gal)
- \( N_p \) = Number of perforations
- \( D \) = Diameter of perforations (in)
- \( C_d \) = Coefficient of discharge
# Extreme Limited Entry (XLE)

*Cost effective method to increase cluster efficiency*

---

<table>
<thead>
<tr>
<th>Design Criteria</th>
<th>Limited Entry</th>
<th>Extreme Limited Entry</th>
</tr>
</thead>
<tbody>
<tr>
<td>Perforation Friction</td>
<td>1,000 - 1,500 psi</td>
<td>2,000 – 4,000 psi</td>
</tr>
<tr>
<td>Rate per Perforation</td>
<td>2 – 3 BPM/Perf</td>
<td>4 – 6 BPM/Perf</td>
</tr>
</tbody>
</table>

High Viscosity Friction Reducers (HVFR)

*Primary application – replace hybrid systems*

Hybrid system requirements

- Guar gelling agent
- Low pH buffer
- High pH buffer
- Crosslinker
- Rapid kill biocide
- Fresh (or relatively fresh) water
- Hydration unit on location

Hydration Unit

- Blender Side
- Water Side

~30% reduction in fluid system costs
High Viscosity Friction Reducers (HVFR)

Reduced costs with higher performance

- Higher proppant concentrations
- Reduced water volumes
- Lower friction pressures
- Better proppant transport
- >90% regained permeability

<table>
<thead>
<tr>
<th>Completion Design (10,000 ft lateral)</th>
<th>Proppant Intensity (lb/ft)</th>
<th>Fluid Intensity (bbl/ft)</th>
<th>Average Proppant Concentration (ppg)</th>
<th>Total Fluid (bbl)</th>
<th>Slurry Volume (bbls)</th>
<th>Pump Time @ 80 BPM (hrs)</th>
<th>Savings @ $3/bbl water cost</th>
<th>Pump Time Reduction @ 80 BPM (days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slickwater</td>
<td>1,000</td>
<td>48</td>
<td>0.50</td>
<td>480,000</td>
<td>490,857</td>
<td>102.3</td>
<td>$720,000</td>
<td>2.1</td>
</tr>
<tr>
<td>HVFR</td>
<td>1,000</td>
<td>24</td>
<td>0.99</td>
<td>240,000</td>
<td>250,857</td>
<td>52.3</td>
<td>$720,000</td>
<td>2.1</td>
</tr>
</tbody>
</table>
Considerations

• Availability of fresh water
• Quality of produced water
• Water transfer options
• Central storage

Source: Texas Water Development Board, December 2018
Produced Water Recycling Facilities

Components
• Produced water storage
• Skim or flocculation
• Treatment to remove organics
• Underground water transfer pipelines

Economic Benefits (Oklahoma Example)
• Low OPEX ~ $0.30-$0.50/bbl
• Facilities generate revenue
• Minimizes saltwater disposal
• 30% reduction in freshwater consumption

Temporary Recycling Facilities
• No CAPEX required
• OPEX $2.50-$4.00/bbl depending upon water quality
Data Mining Water Management

Combined intelligence
- Satellite imagery analytics
- Government databases
- Market research
- Internet of things (IoT) sensors

Provides insight into available water for purchase, transportation infrastructure, and disposal options

Source: North America Shale Magazine (September 2019)
Wireline Operations

Multi-well zipper completions

Source: ConocoPhillips Eagle Ford Investor Tour  https://www.youtube.com/embed/w5R3FqwJ8ol?rel=0
Wireline Operations

Reduce interstage time with quick connect systems

Standard operations

• 20 to 30-minute well swaps

Quick connect systems

• 10 to 12-minute well swaps
Coiled Tubing Operations

Significant efficiency gains

• Move toward large diameter coiled tubing (CT) units
  – Reach extended to ~23,000 ft
• Better understanding of debris transport
  – HVFR technology replacing gel pills
  – Elimination of short trips
• Typical performance
  – Drill out entire lateral in a single day (30-50 frac plugs)
  – Wells on production 2-3 days faster
Evolution of Composite Frac Plugs

Supplier competition = innovative designs

• Better composite materials
• Ceramic buttons and powdered metal for slips (previously cast iron)
• Ability to run balls on seats, caged balls, or flappers to isolate the plug
• Smaller OD
  => faster run in speed and less likely to get hung up
• Shorter
  => less material to mill and circulate out of the well
Artificial Lift and Production Facilities

*Production enhancement and cost reduction*

- **Expansion Land Grab** (2009-2011)
  - Flow well until it dies, install rod pumps
- **Production Growth** (2012-2014)
  - Two stage lift program to accelerate production
- **Capital Discipline** (2015-2017)
  - Modular flow back facilities to reduce CAPEX
- **Return on Investment** (2018-2020)
  - Centralized facilities reduce LOE
Takeways

• Collapse of oil price did not stall the growth of shale oil production
• We are a lean industry – capable of producing more with less
• Drilling efficiencies are an all time high
• Optimized completion designs deliver economic well productivity
• Game changer technologies have reduced completion costs and increased operational efficiencies
Your Feedback is Important

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