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Thriving in a Lower for Longer Environment

Mary Van Domelen, PE, SPEC

November 2019 Tour

Society of Petroleum Engineers
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Lecture Format

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- The challenge
- Market dynamics
- Keys to success
- Impact of technology
- Takeaway points

Unconventional Resources Development

Hydraulically Fractured Horizontal Wells

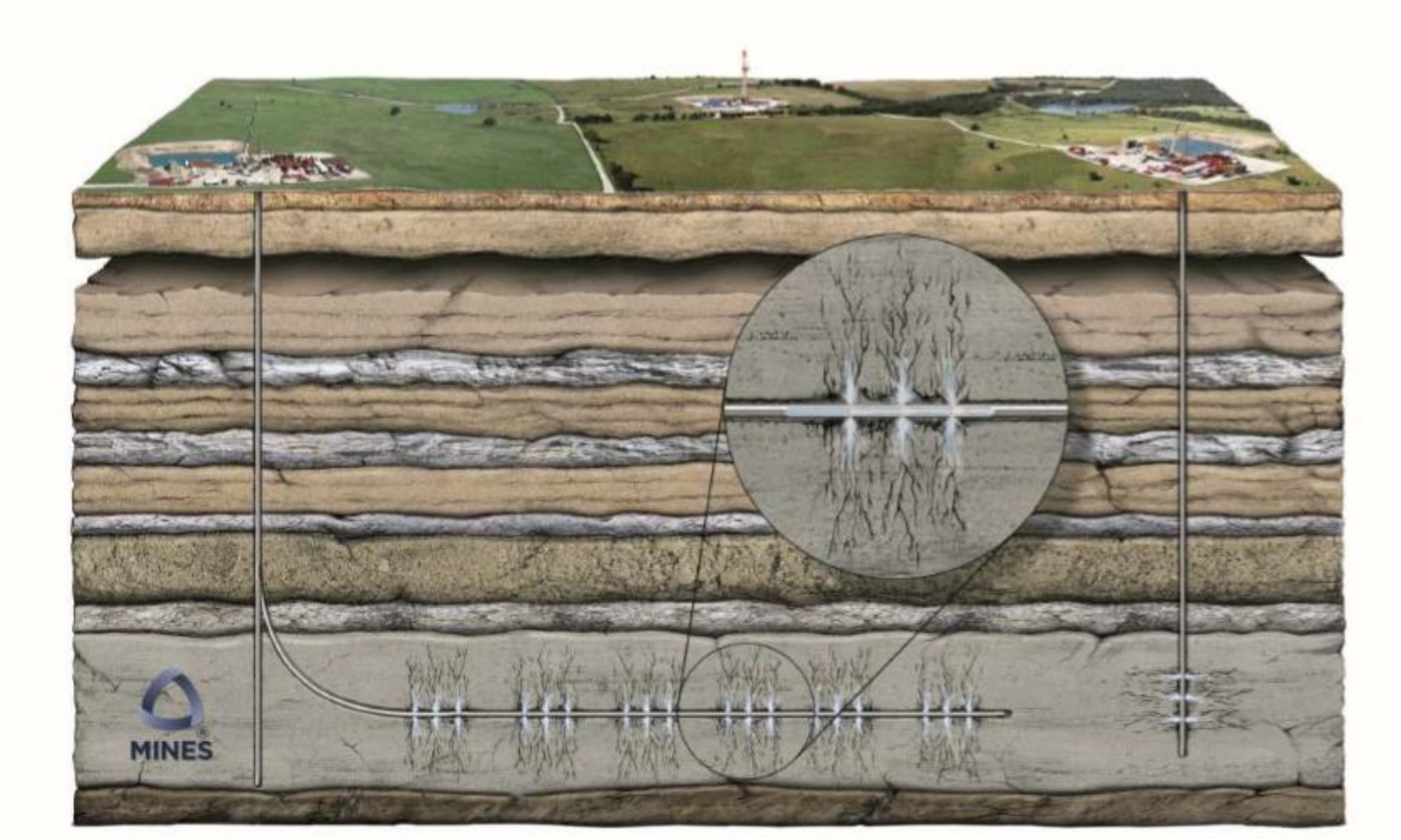
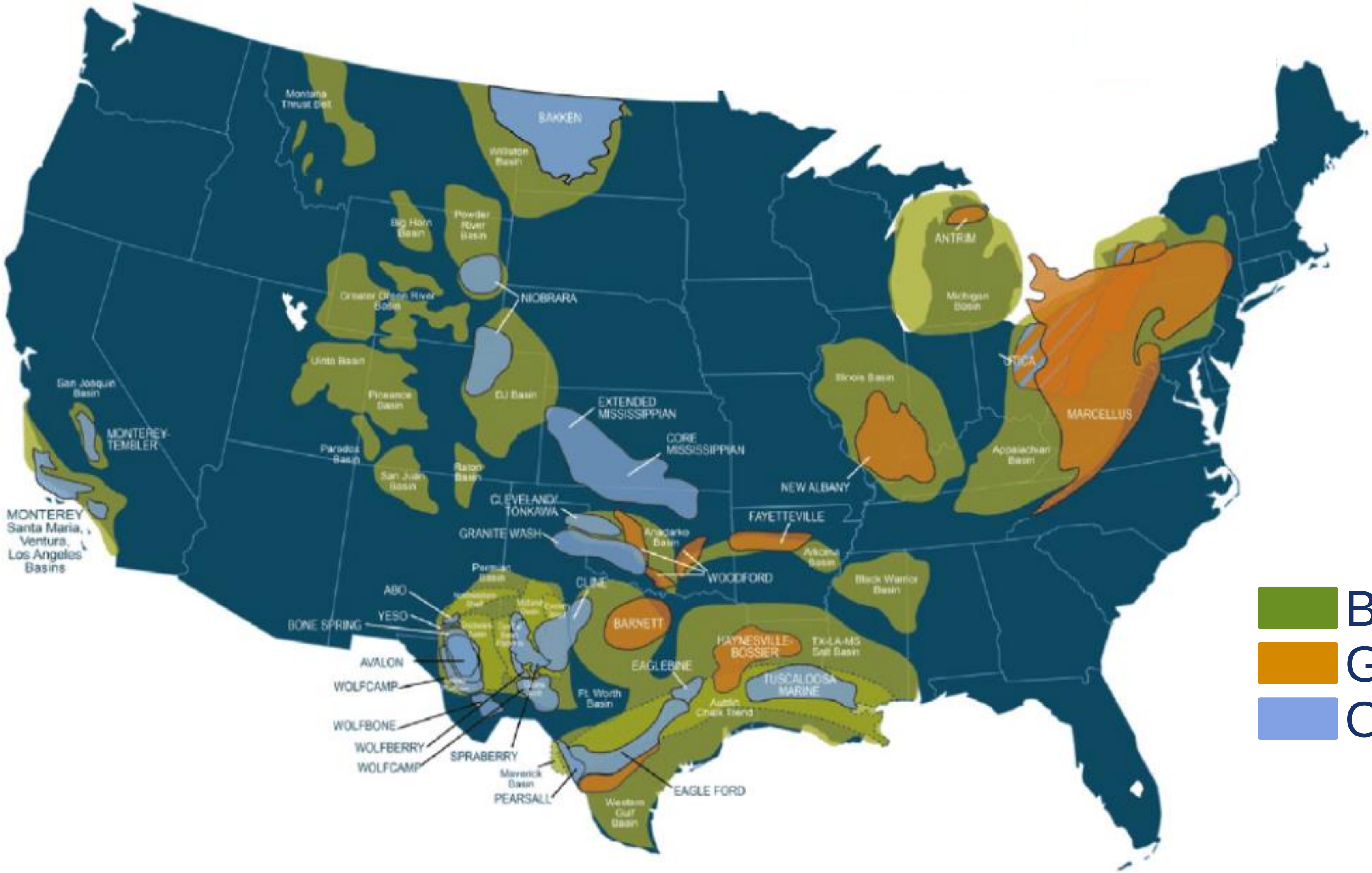


Image source: Colorado School of Mines

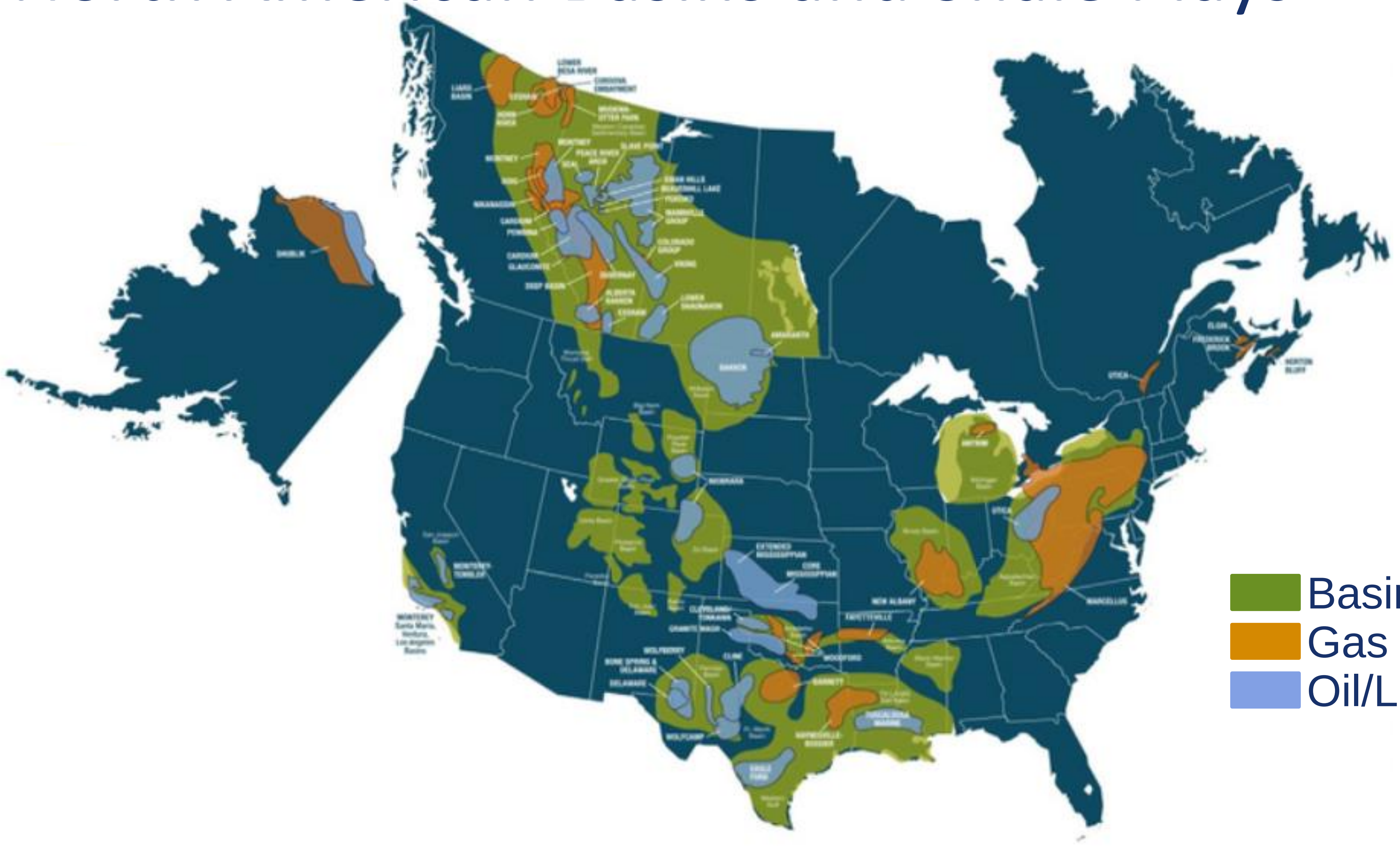
Major US Basins and Shale Plays



Basins
Gas Plays
Oil/Liquid Plays

Image source: PacWest Consulting Partners (2016)

North American Basins and Shale Plays



Basins
Gas Plays
Oil/Liquid 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

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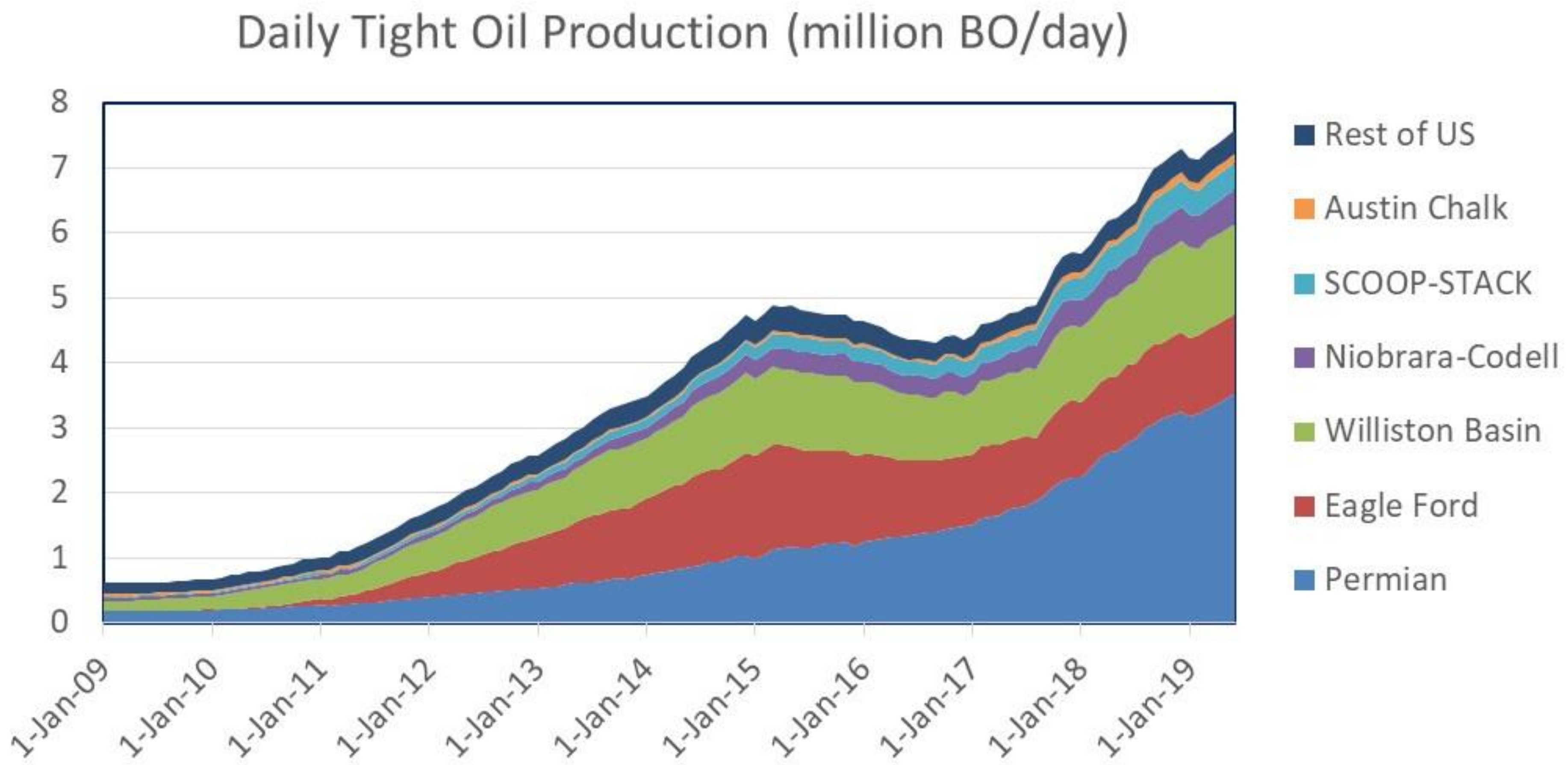
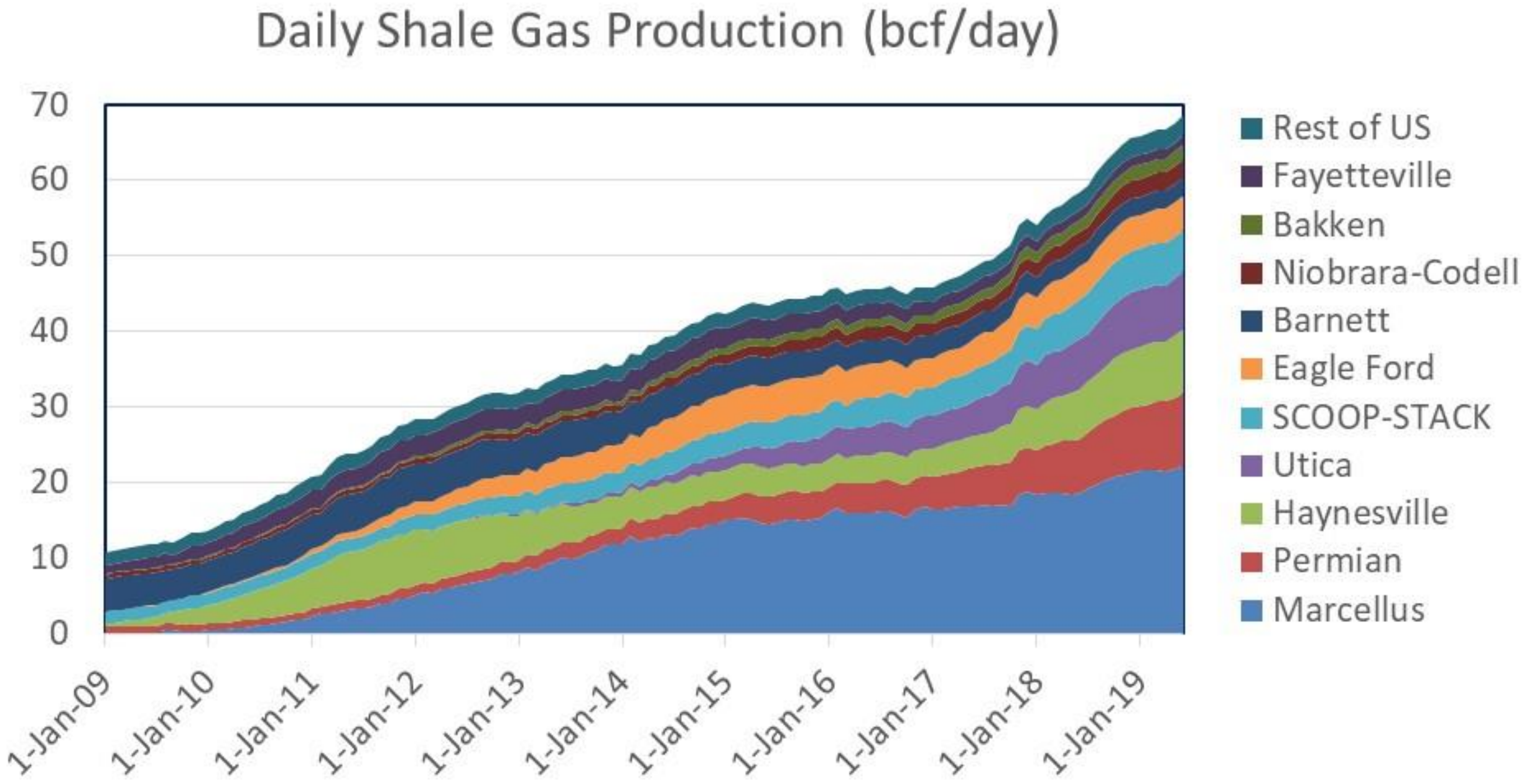
Data source: macrotrends.net

US Tight Oil Production by Play



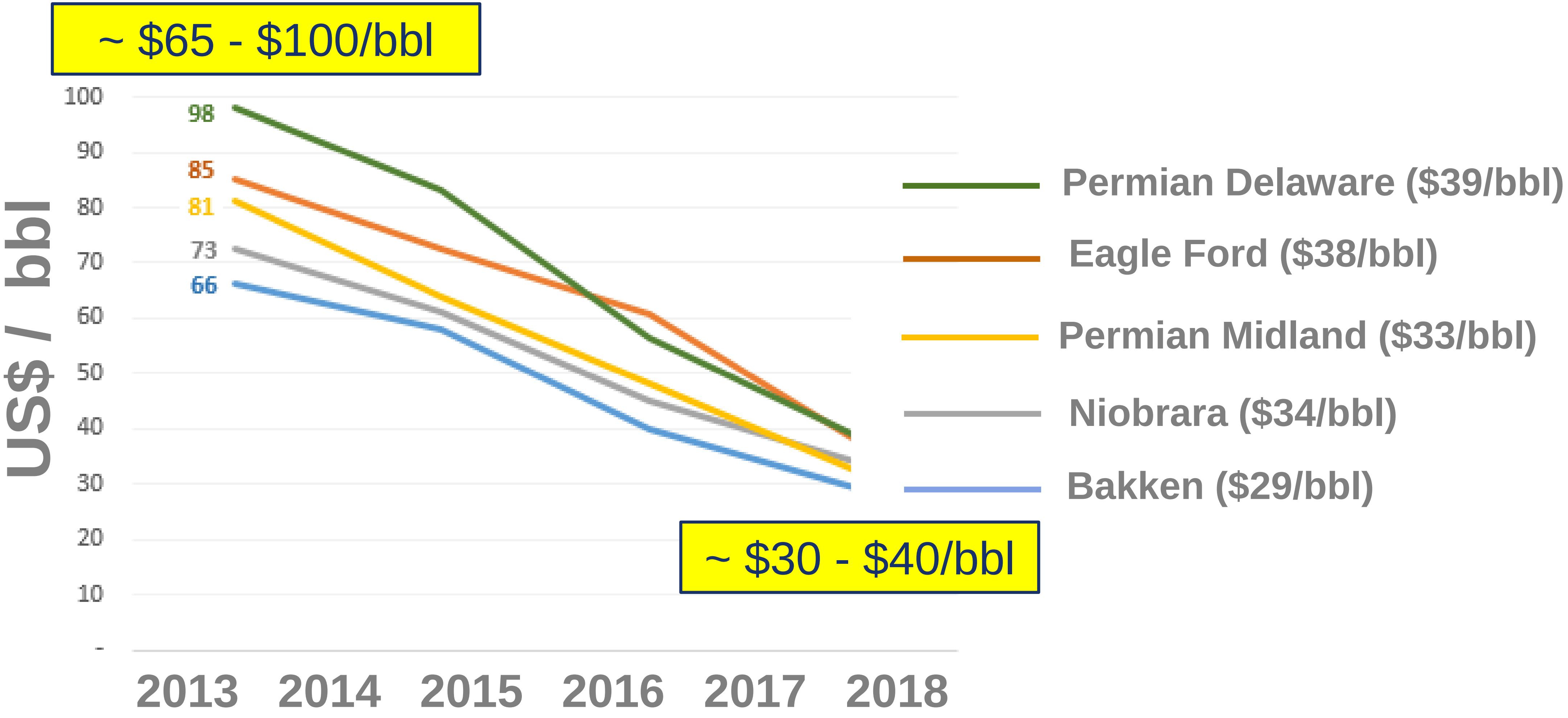
Source: US Energy Information Agency

US Shale Gas Production by Play



Source: US Energy Information Agency

Wellhead Breakeven Prices



Source: Rystad Energy NASWellCube

Profitability vs. Breakeven

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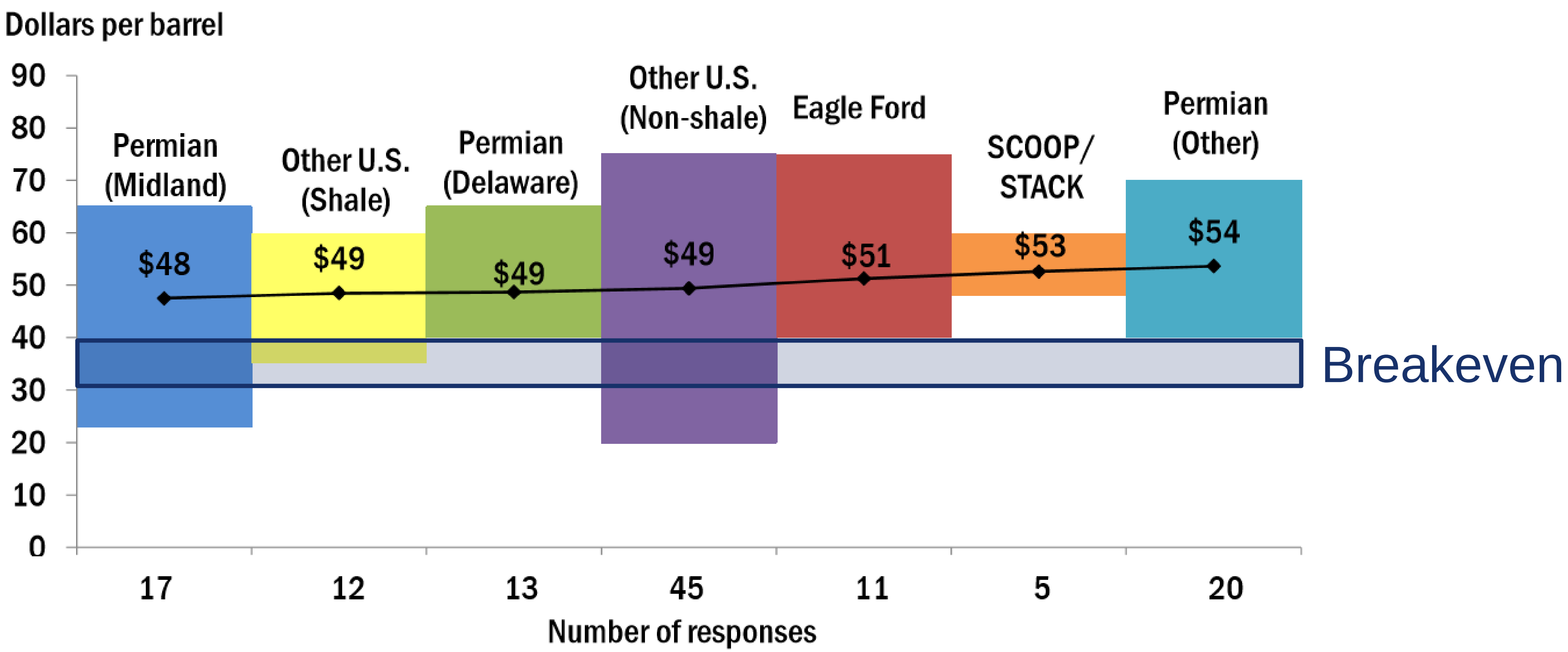
Dallas Fed Energy Survey—In the top two areas in which your firm is active: What WTI oil price does your firm need to profitably drill a new well?



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

Lloydminster DL Presentation

November 18, 2019

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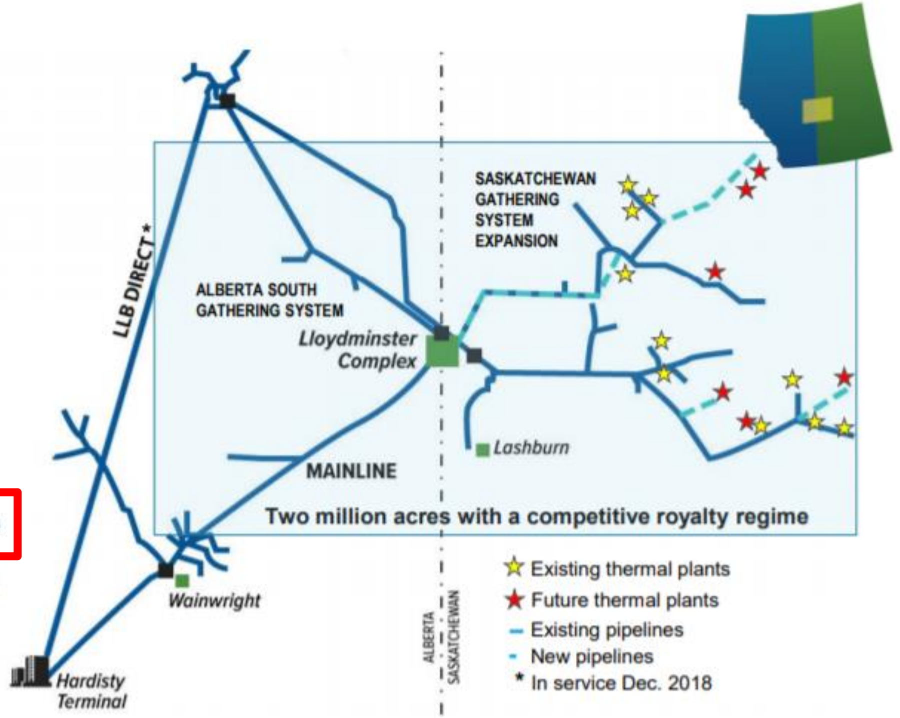
Lloyd Thermals

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

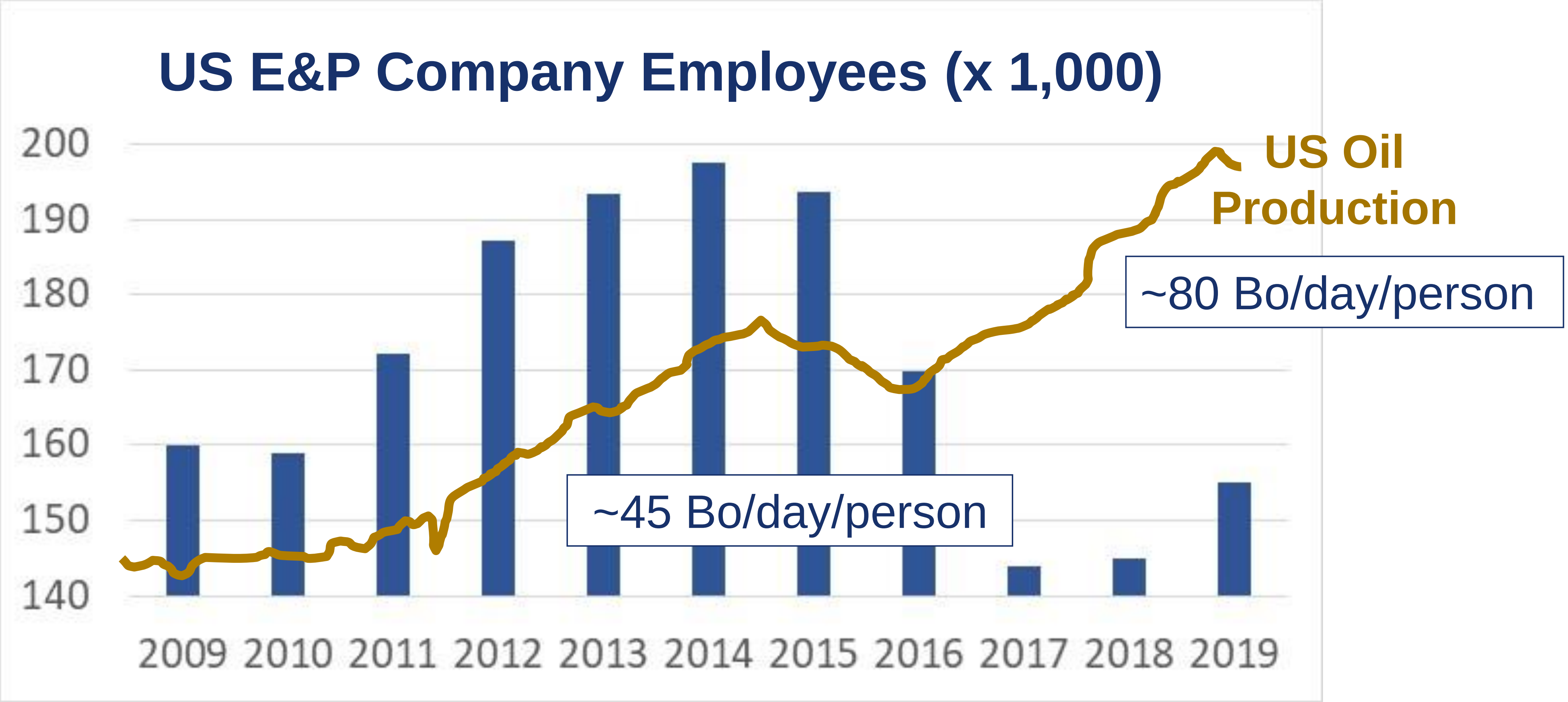
Growth projects update:

- 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



Data source: US Bureau of Labor Statistics (August 2019)

Shifting Landscape of Business Drivers

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Expansion Land Grab (2009-2011) → **Production Growth (2012-2014)** → **Capital Discipline (2015-2017)** → **Return on Investment (2018-2020)**

$$\text{Improve ROI } \textit{(Return on Investment)} \propto \frac{\text{Increase Production}}{\text{Decrease Costs} + \text{Reduce Cycle Times}}$$

Generating Free Cash Flow

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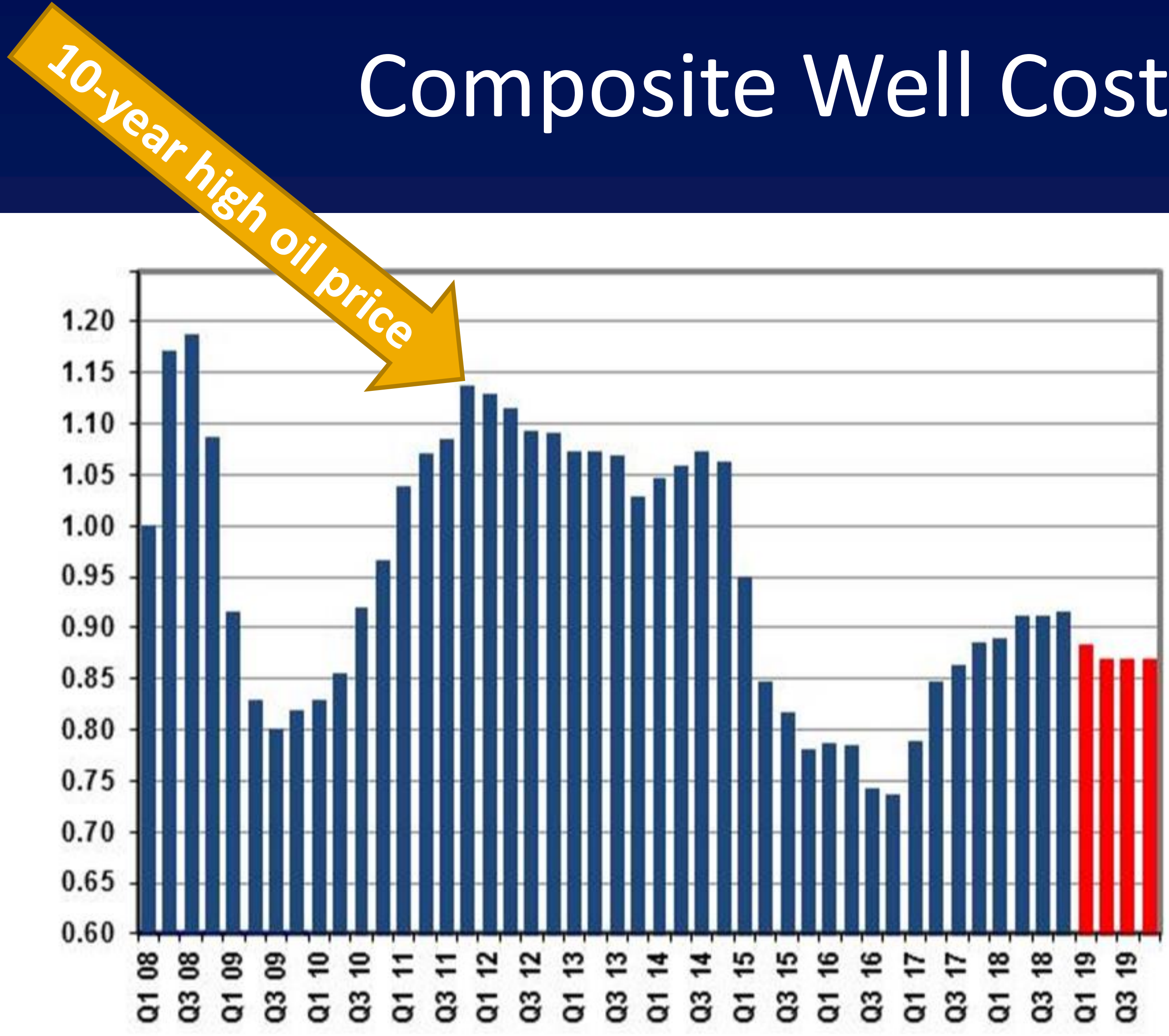
Increase Production

- 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



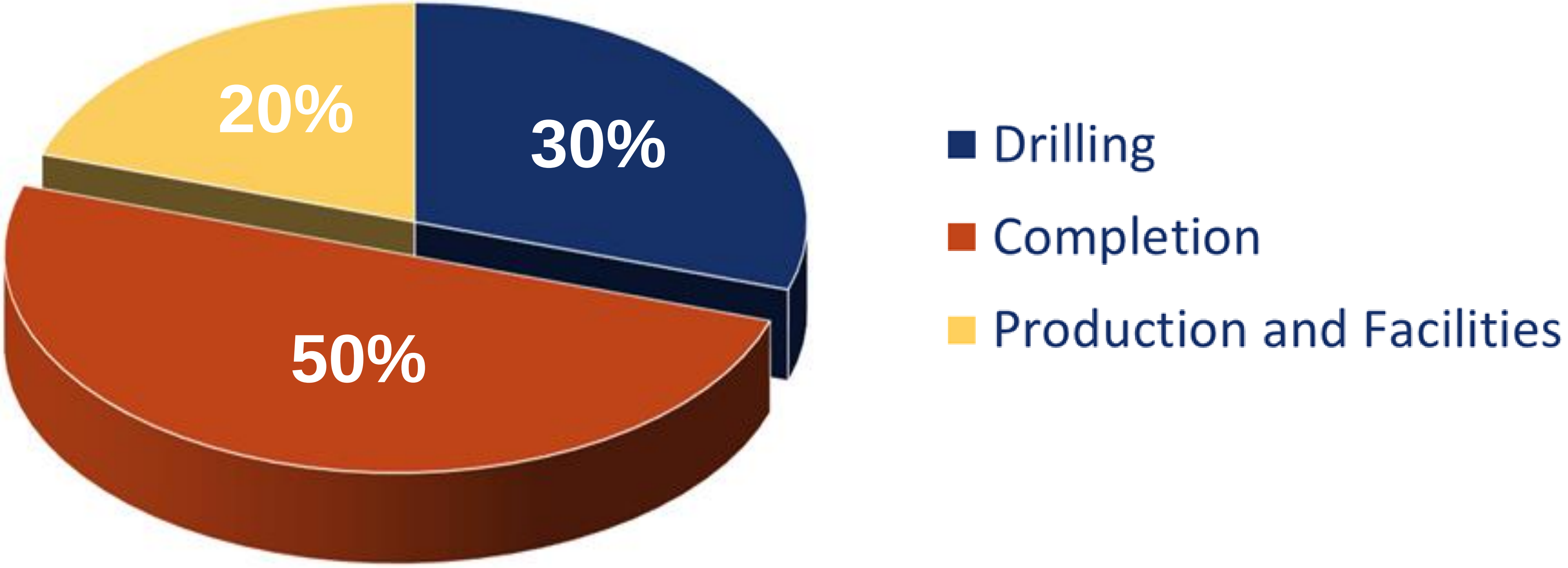
Data source: Spears and Associates, Inc (4Q-2018)

Date	Oil Price	Cost Index
2Q-2011	$114	1.07
2019	~ $55	0.86

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

Breakdown of Total Well Costs

Typical horizontal shale well

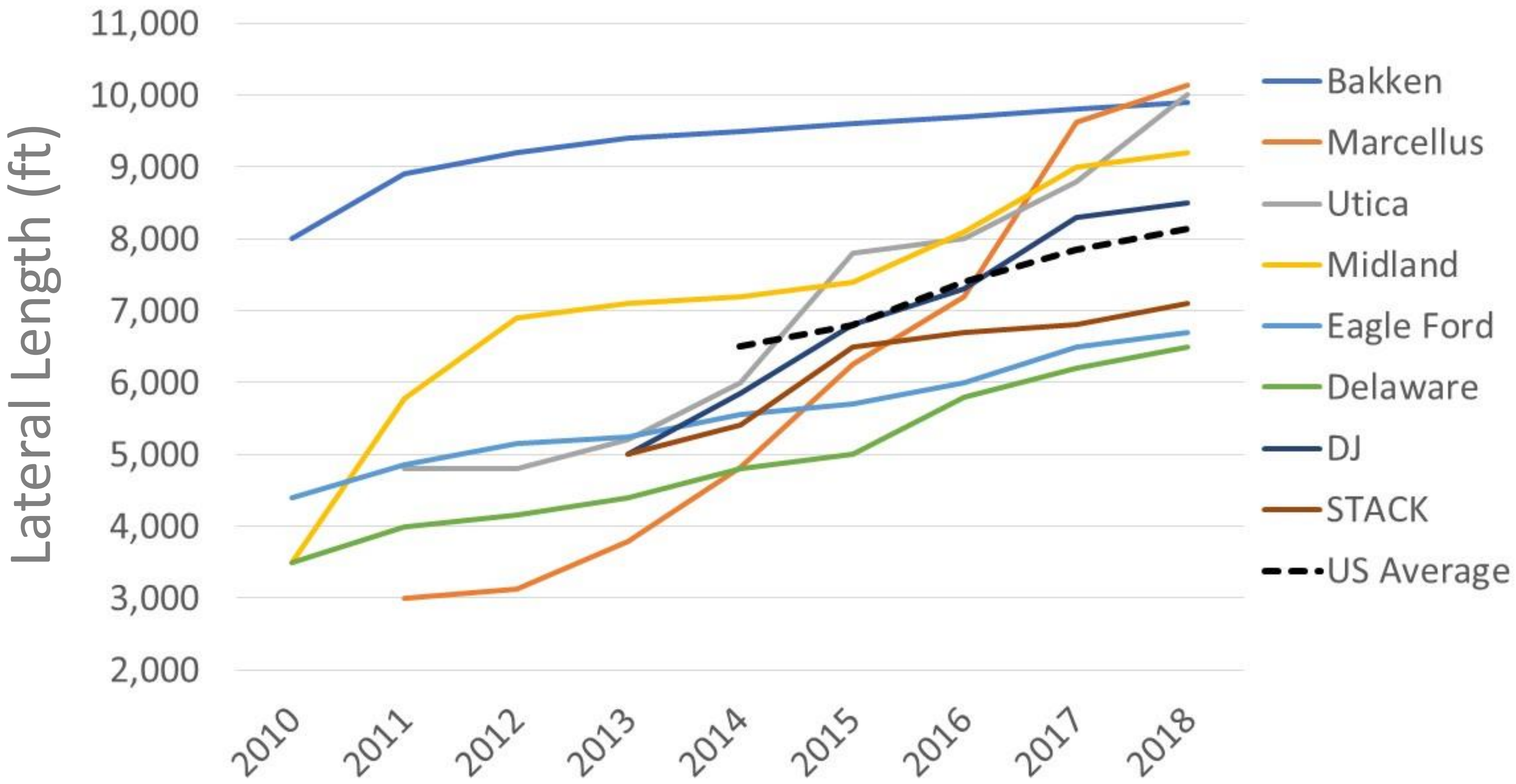


Drilling's Contributions to Improved ROI

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

$$\propto \frac{\text{Increase Production}}{\text{Decrease Costs} + \text{Improve Cycle Times}}$$

Increasing Lateral Lengths by Play



Significantly Reduced Drilling Times

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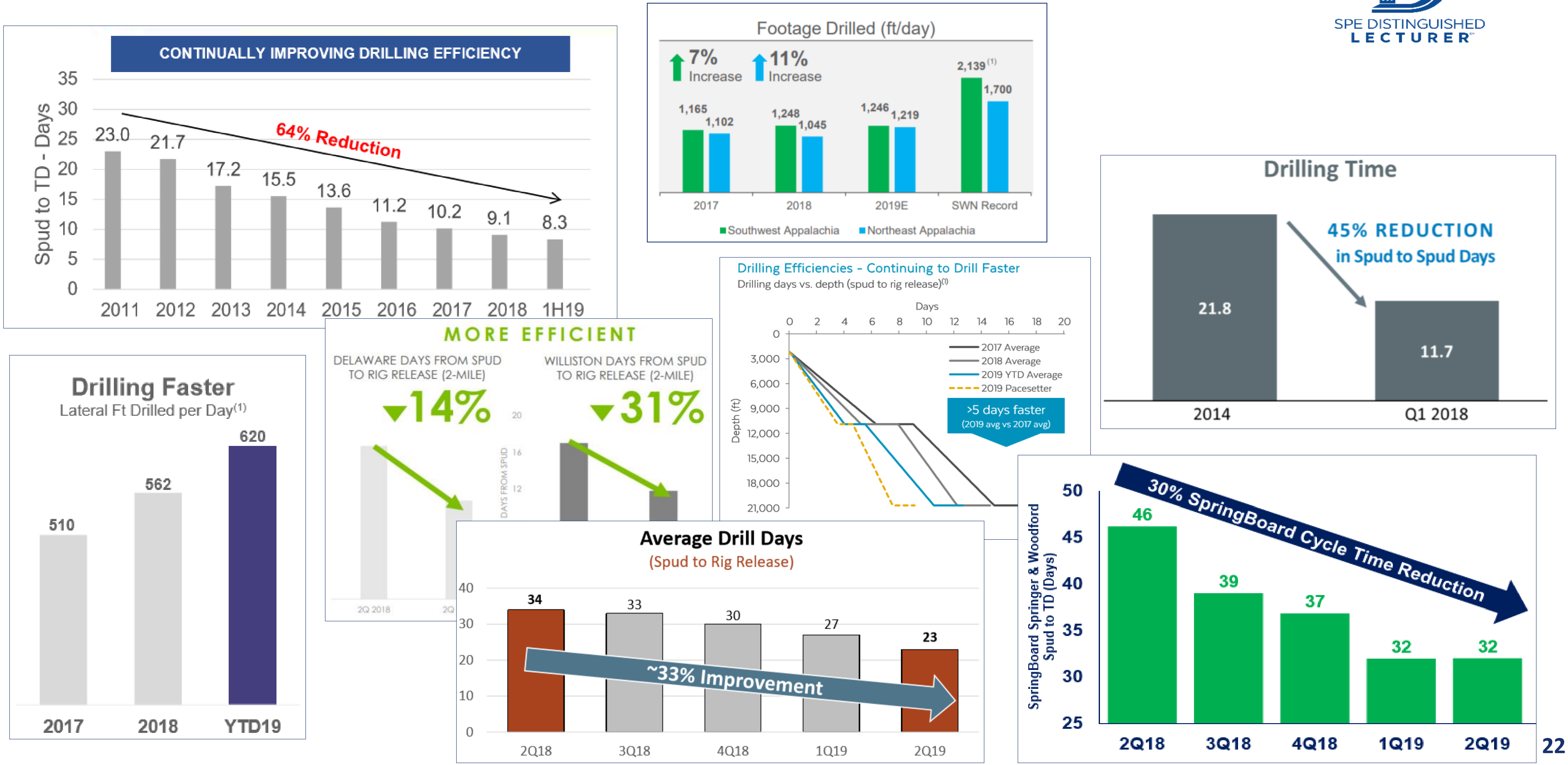
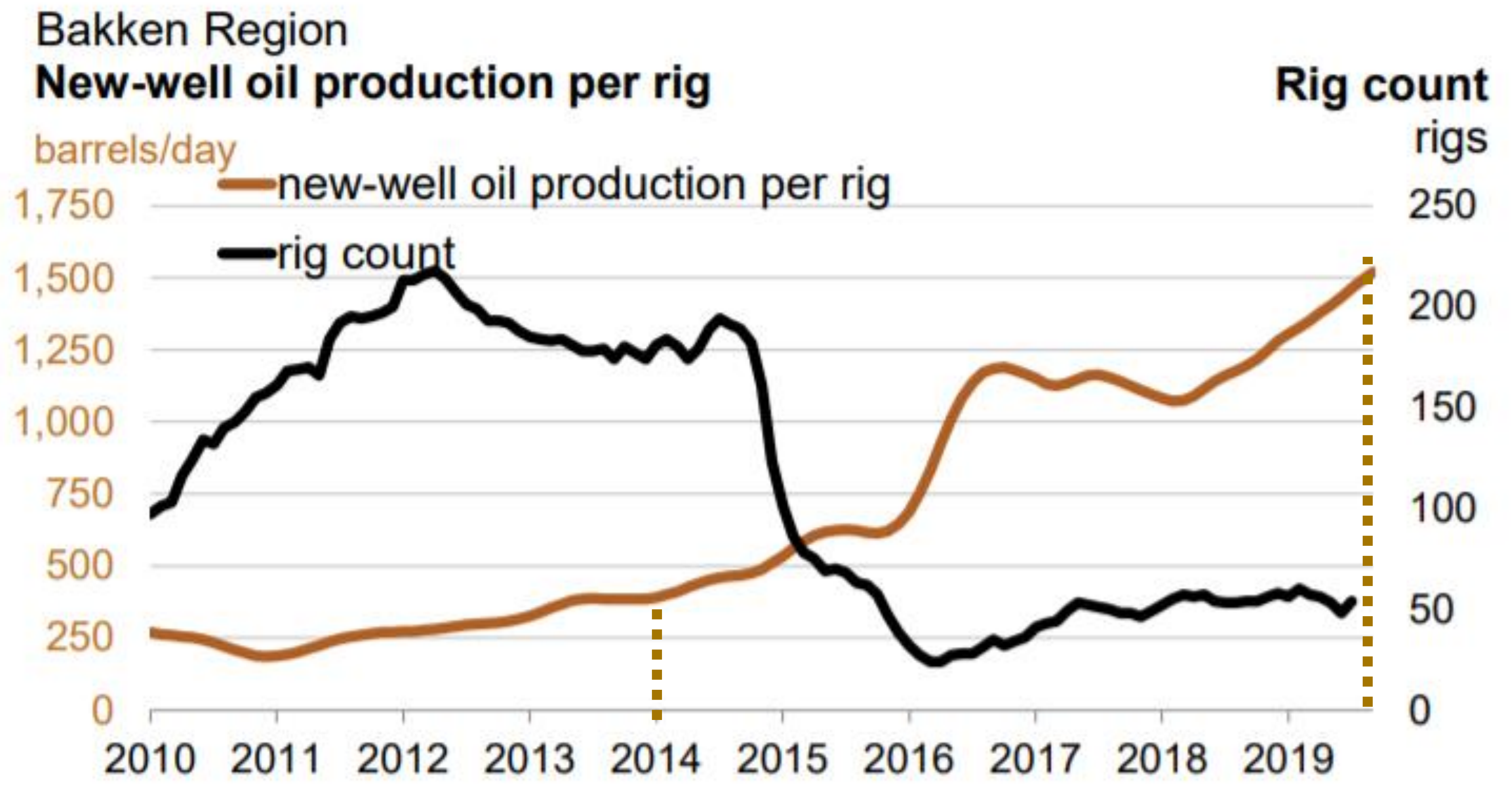


New-well Oil Production per Rig

Bakken Play



Source: EIA Drilling Productivity Report (October 2019)

Drilling Efficiency Gains

Technology + Teamwork

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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

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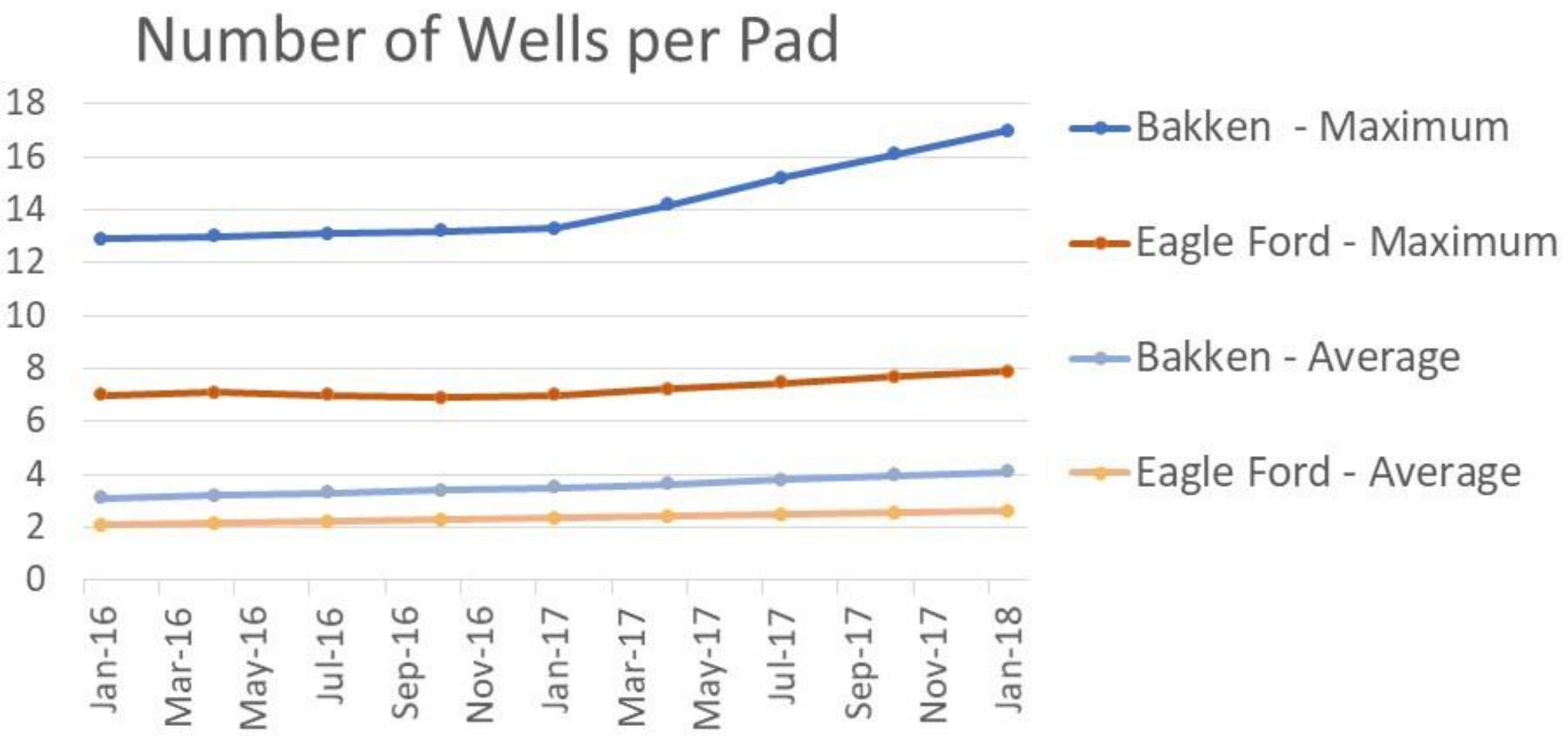

Source: Spears and Associates Insider (June 2019)

Pros and Cons of Multi-Well Pad Drilling

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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

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

Completion Phases

Horizontal wells with multi-stage hydraulic fractures

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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

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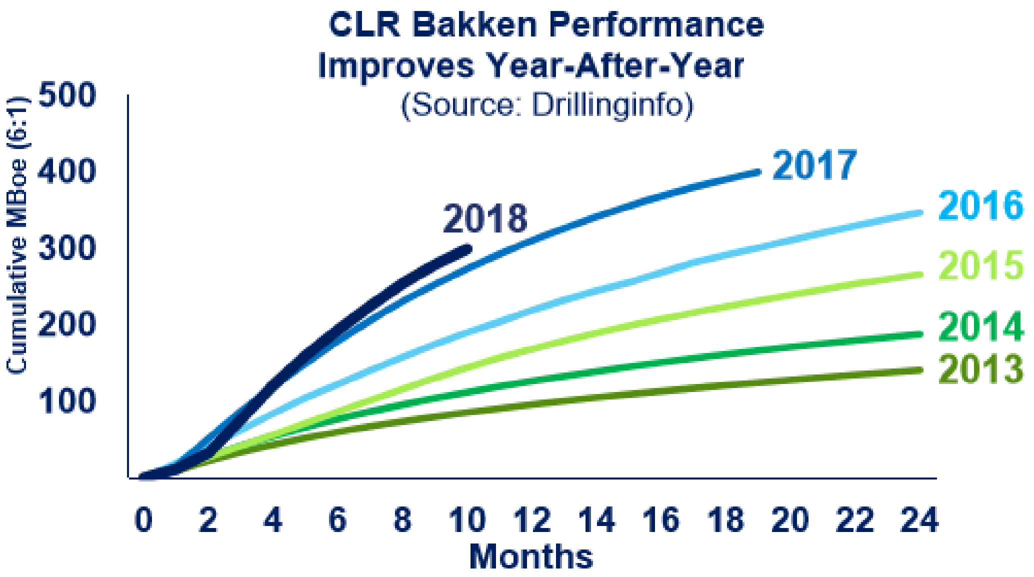


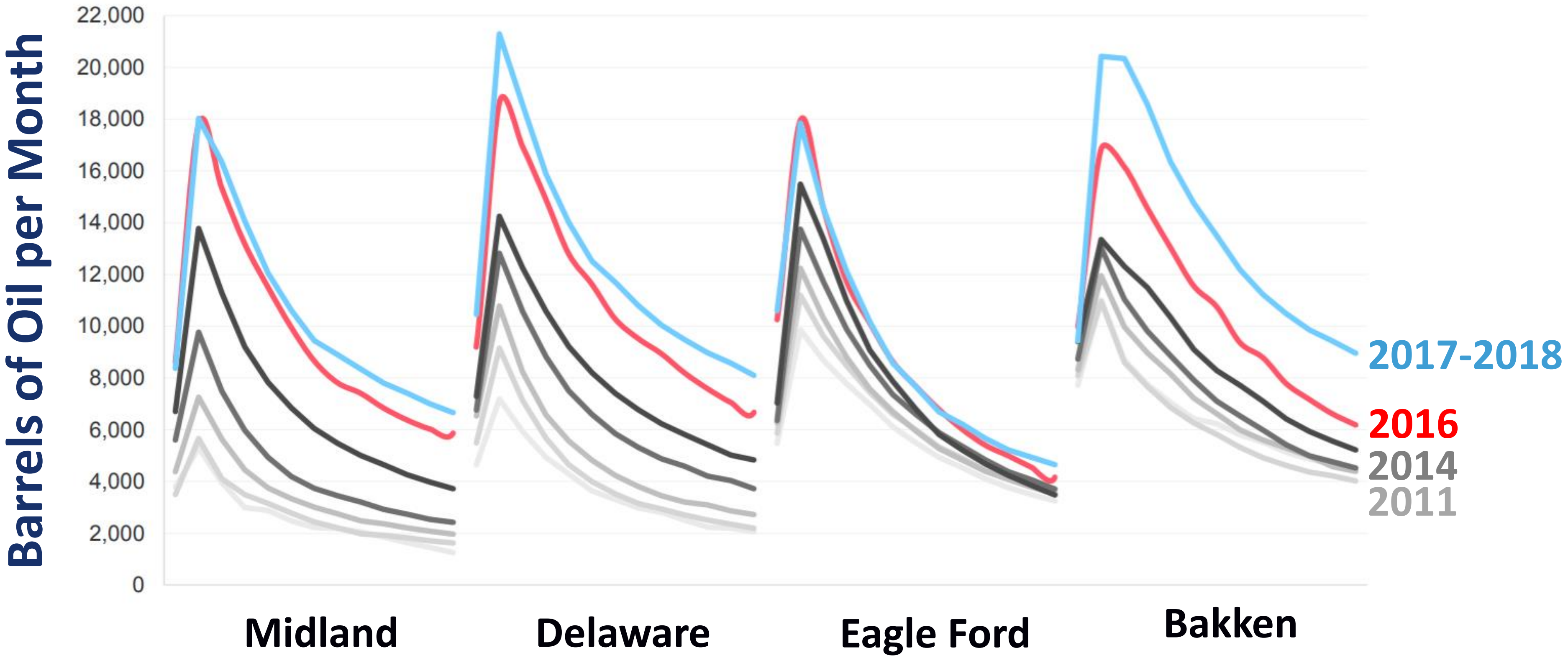
Improve ROI ∝ $\dfrac{\quad}{\text{Decrease Costs} + \text{Reduce Cycle Times}}$

Decrease Costs + Reduce Cycle Times

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

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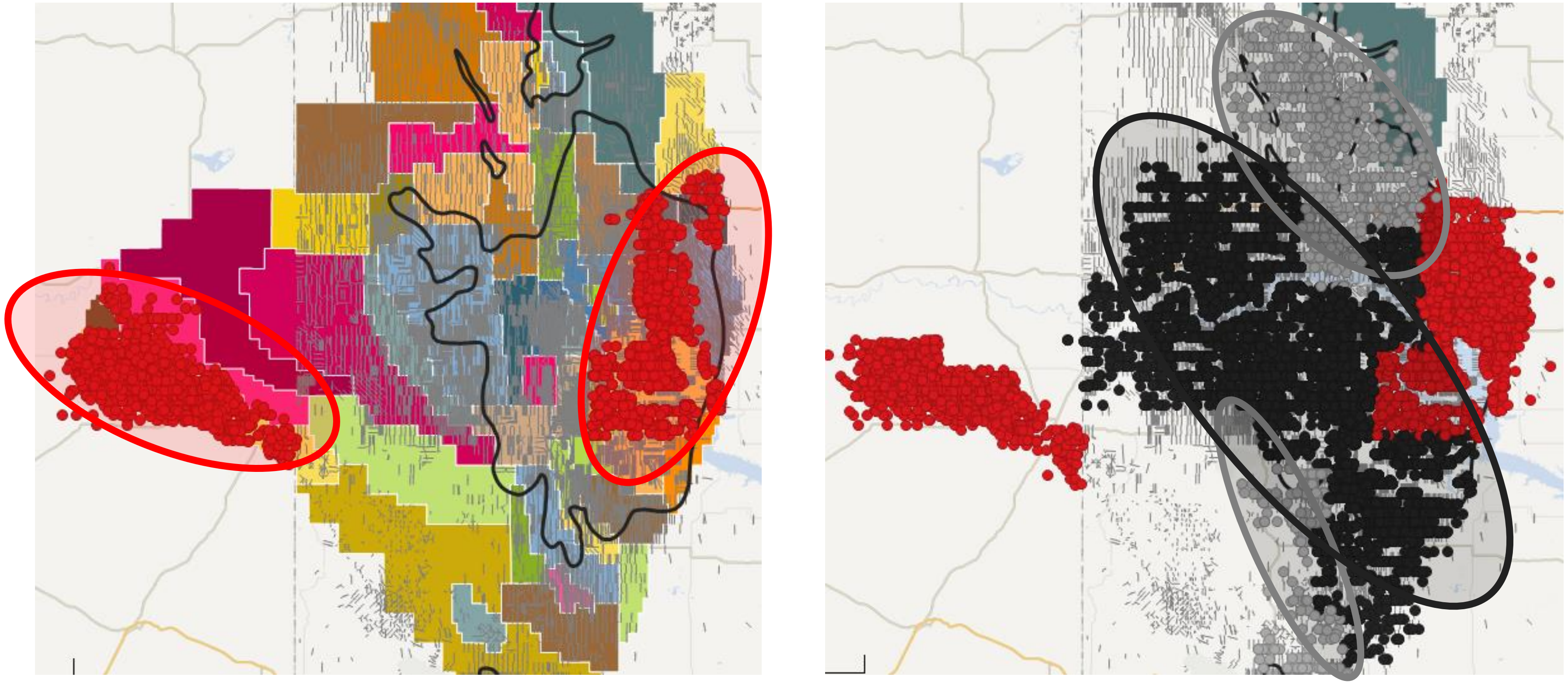

Trends in Completion Design Parameters

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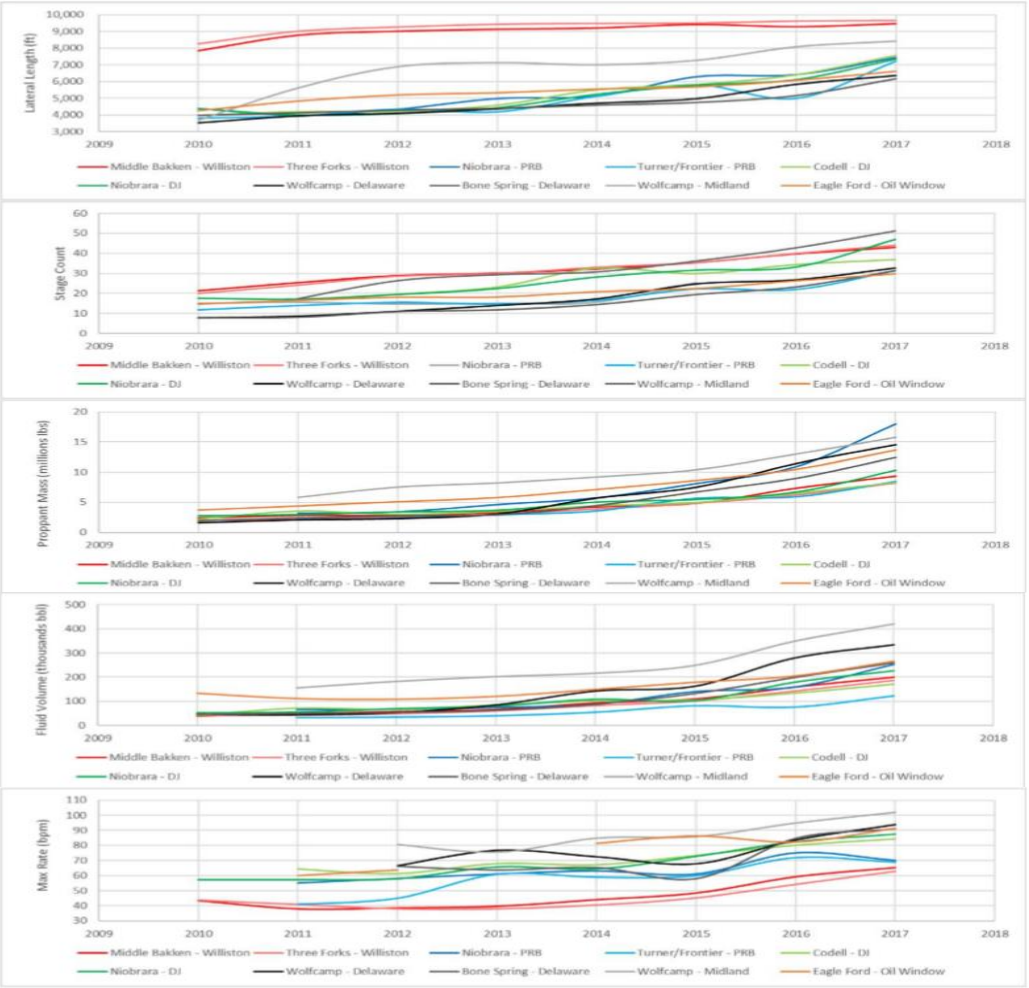
Completion Design Parameters

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



SPE 194345 “Trends in the North American Frac Industry: Invention through the Shale Revolution”

Evolution of Stage and Cluster Spacing

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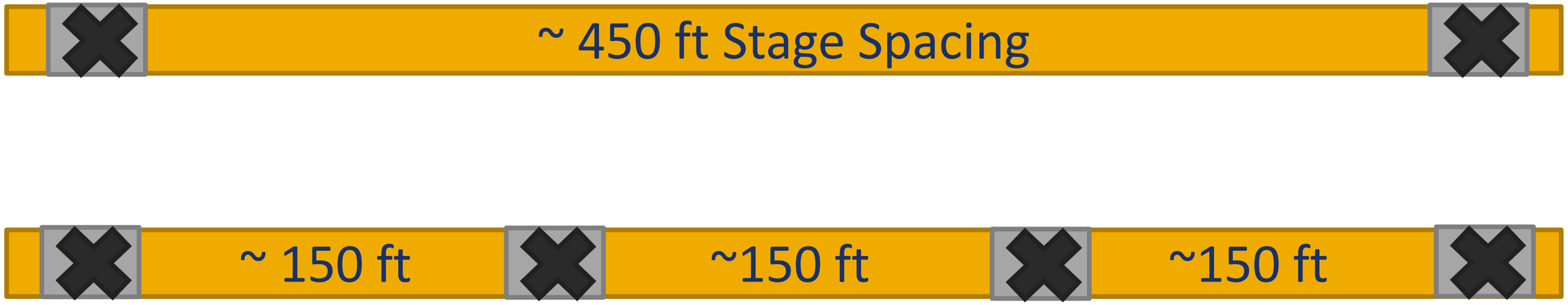
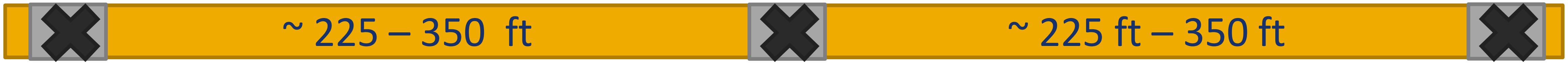


2011 - 2012
4,500 ft lateral
8-10 stages

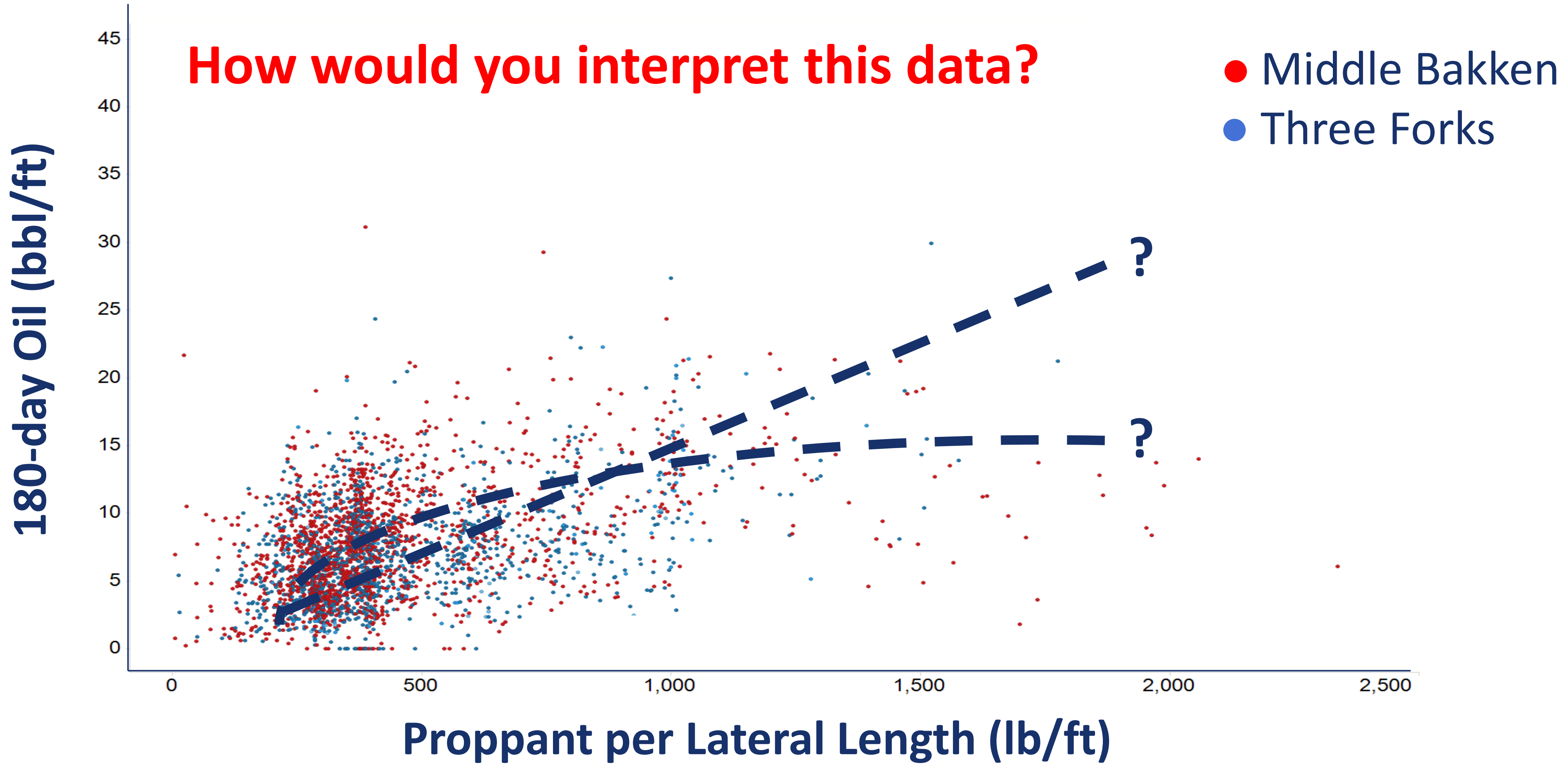
2016 - 2017
10,000 ft lateral
60-70 stages



- 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

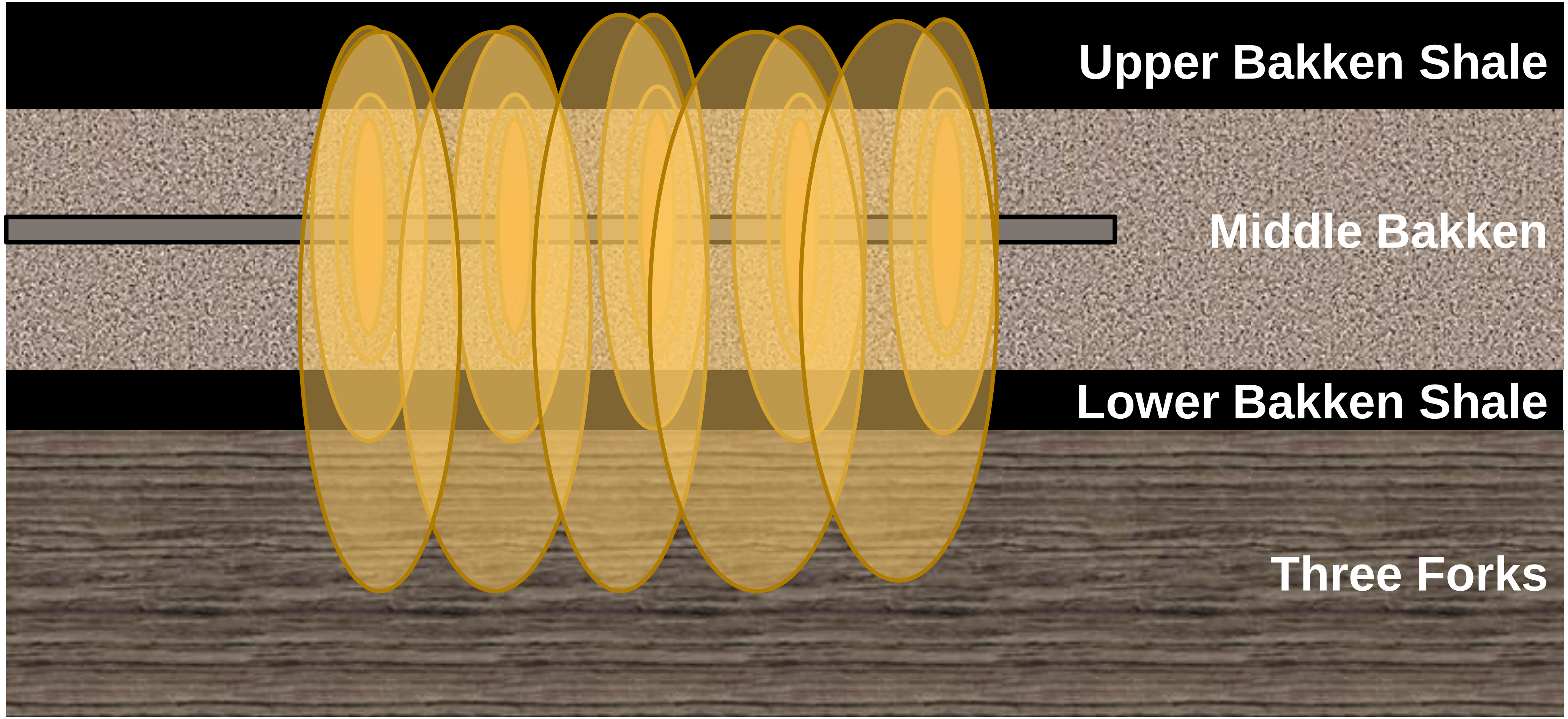
Optimizing Frac Designs

Utilizing completion metrics

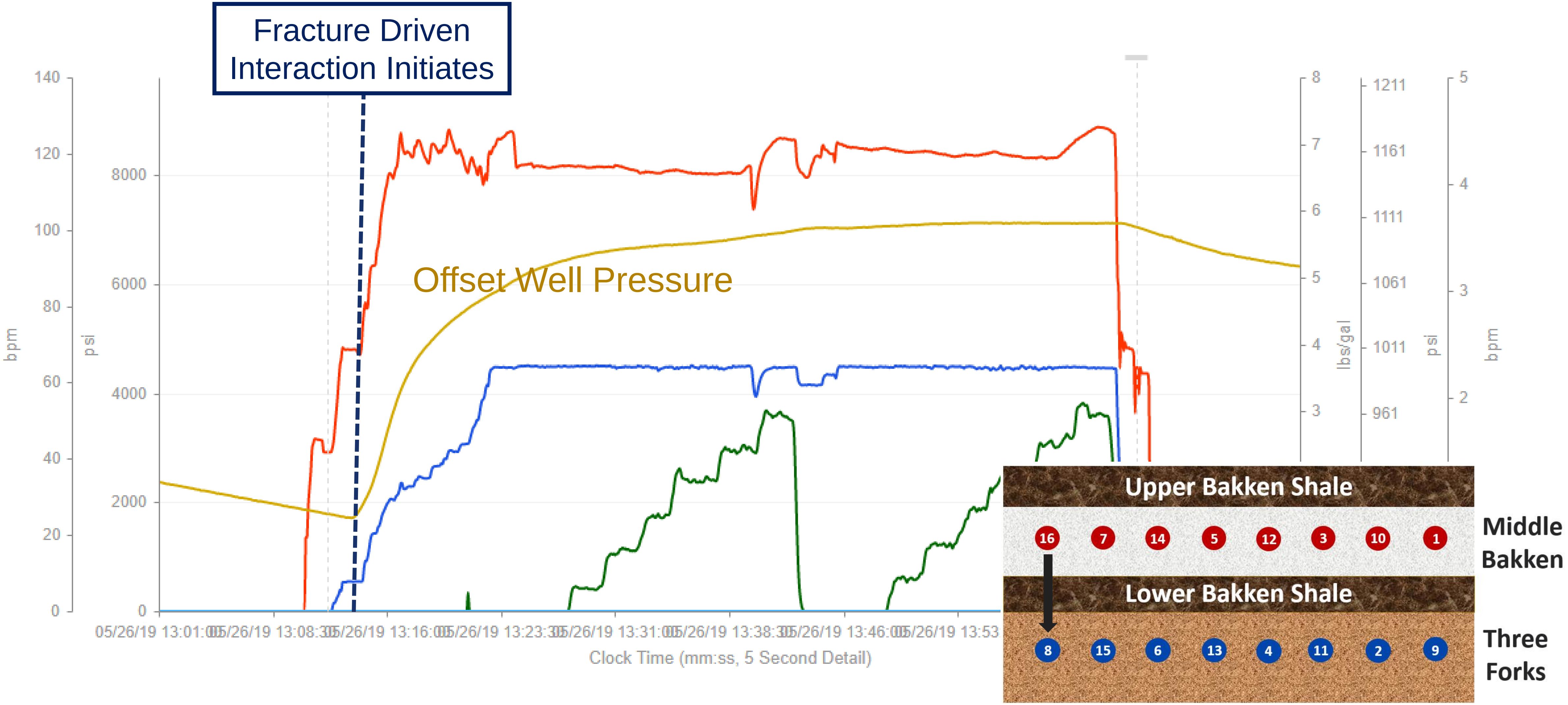


Move from Enhanced to Optimized

Bigger is not always better

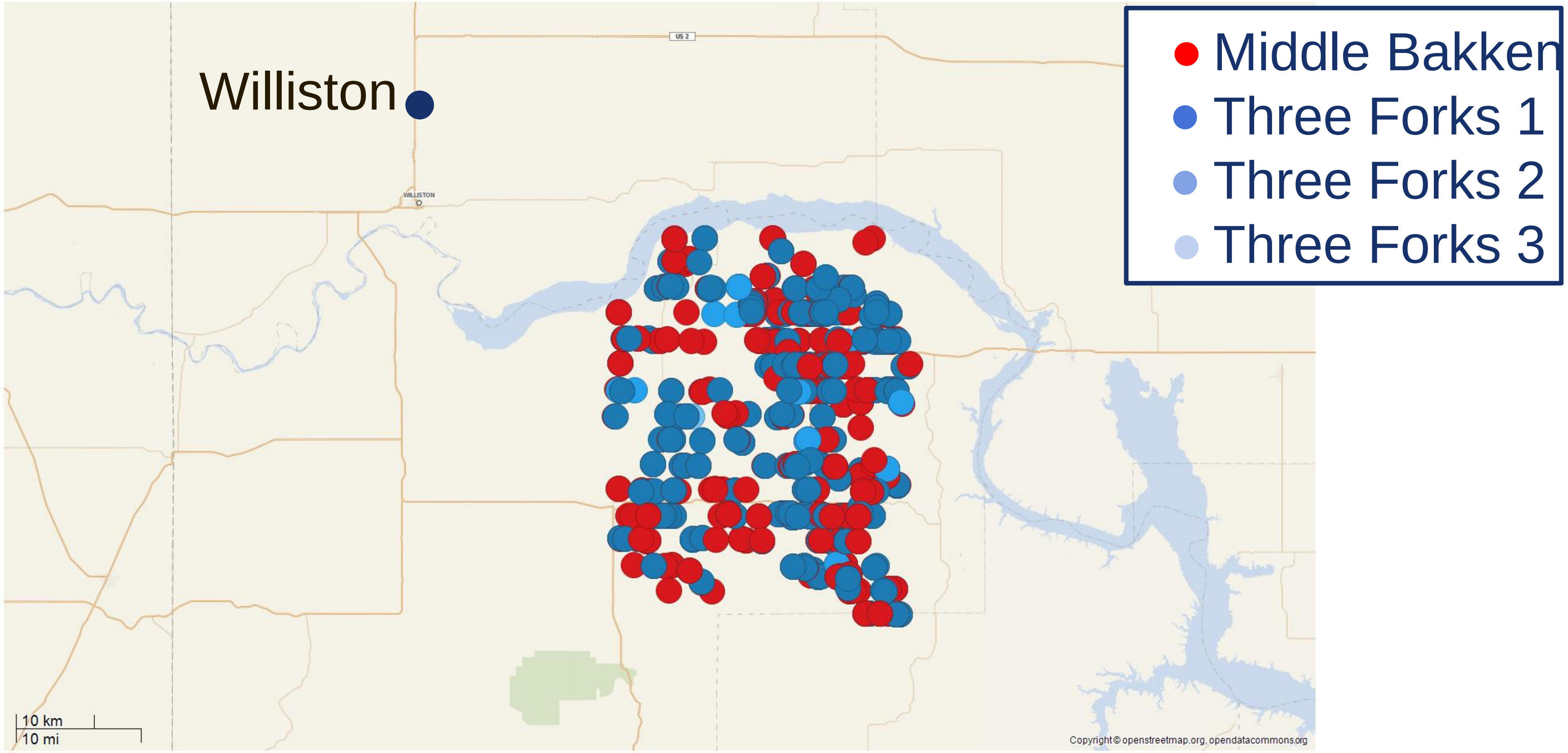


Middle Bakken to Three Forks Communication



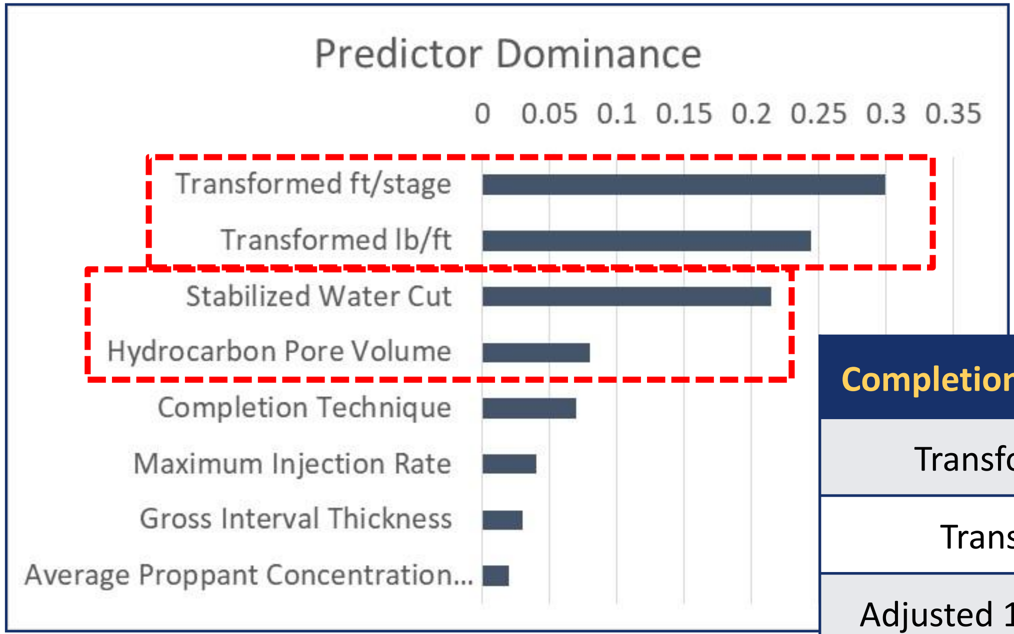
Completion Multivariate Analysis

Central Bakken Example



Reference SPE 184851 or SPE 187254 for Analysis Technique

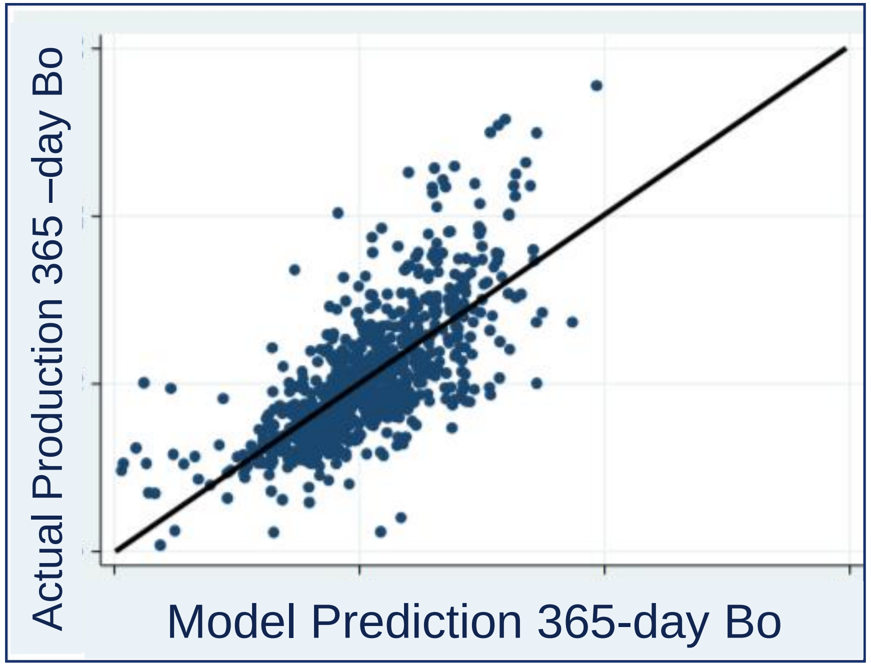
Combine Physical and Statistical Models



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

Proppant mass transformation y = 5.9451*ln(x) – 15.010

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



Reference:
SPE 184851 or SPE 187254
for Analysis Technique

Optimizing Well Performance

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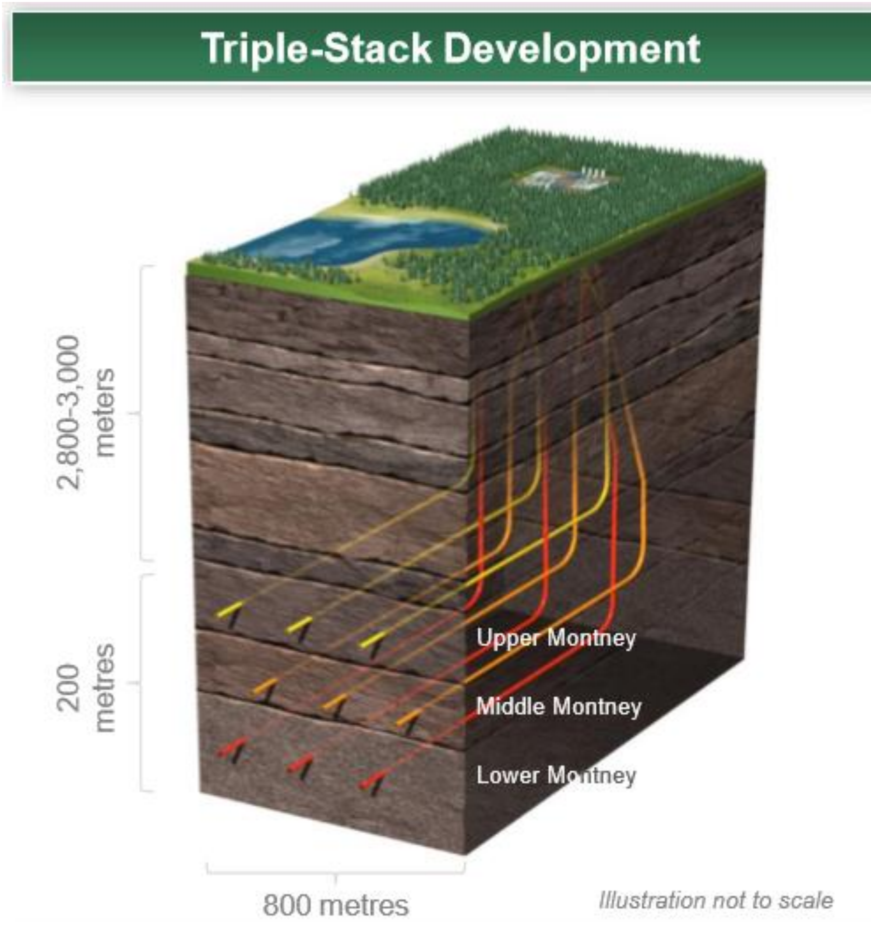
Develop formation specific best practices

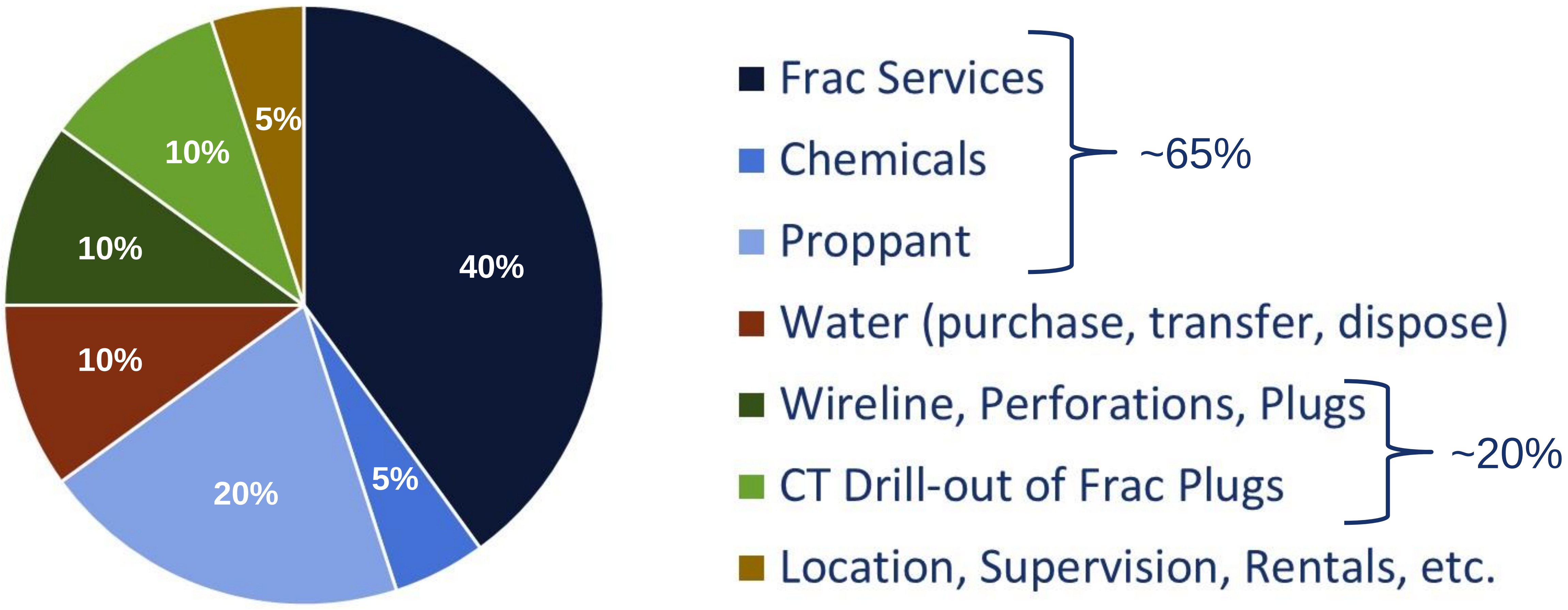
- Leverage basin completion & production metrics
- Identify key completion parameters
- Combine statistical analysis with physical models
- Move from *enhanced* to *optimized* completions

Recognize that completion design must be integrally linked to development plans



Completion Cost Breakdown

Bakken 10,000 ft lateral example



Game Changer Technologies

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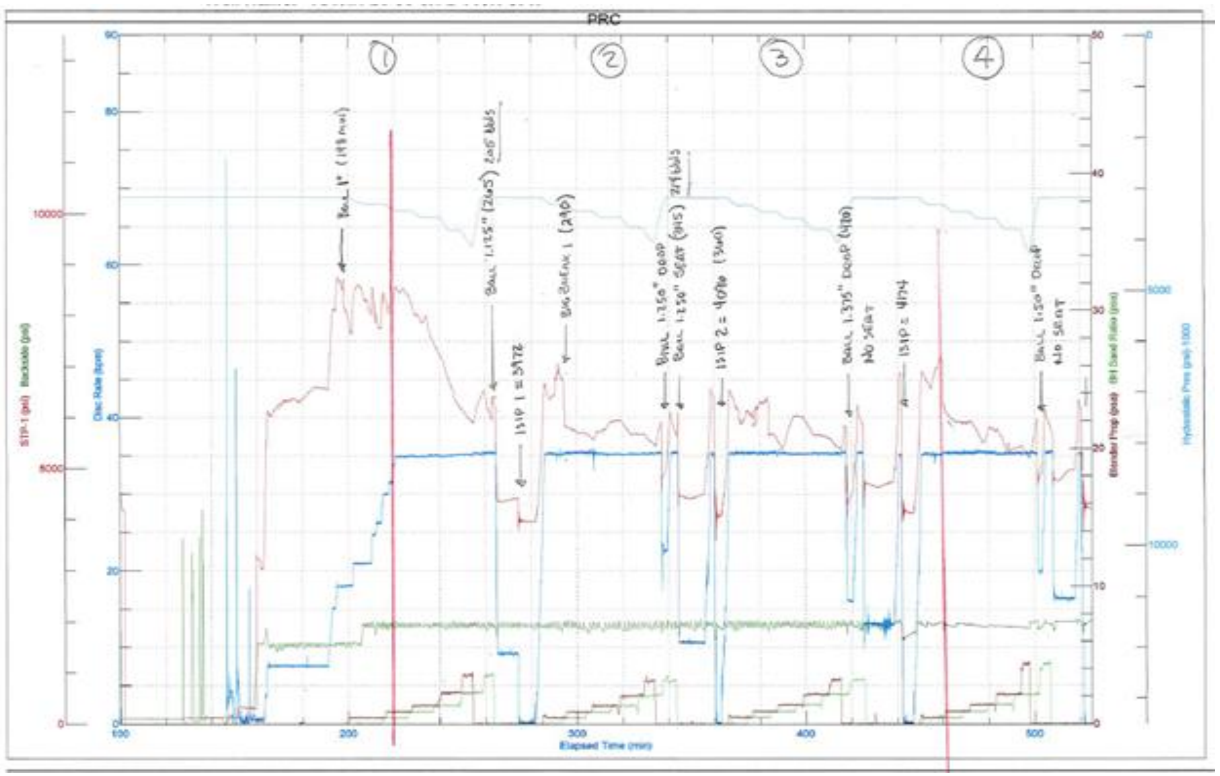
1) Cloud technology, data analytics, and machine learning
2) Regional sand and new sand delivery systems
3) Extreme limited entry (XLE) perforating
4) High viscosity friction reducers (HVFR)
5) Produced water recycling
6) Wireline "quick connect" systems
7) Coiled tubing drill-outs

Traditional Frac Stage & Well Files



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

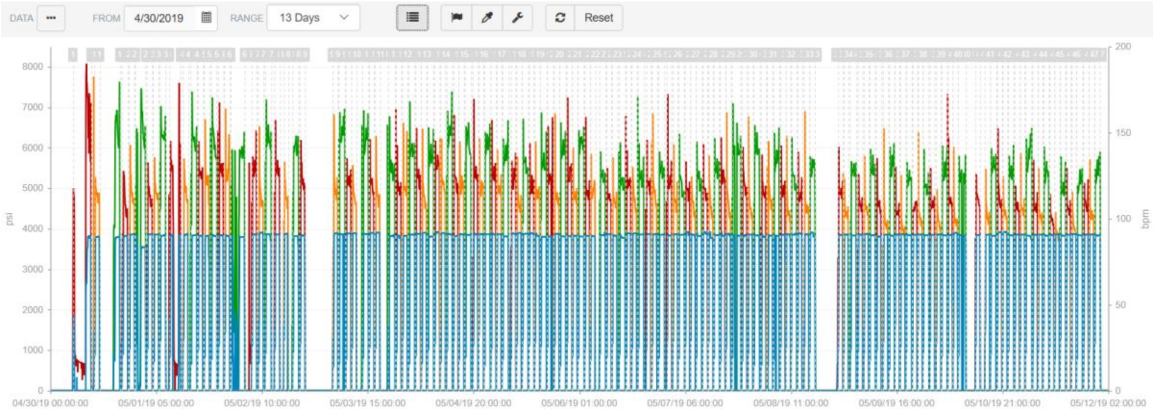
Paper copies of stage reports

Multiple USBs

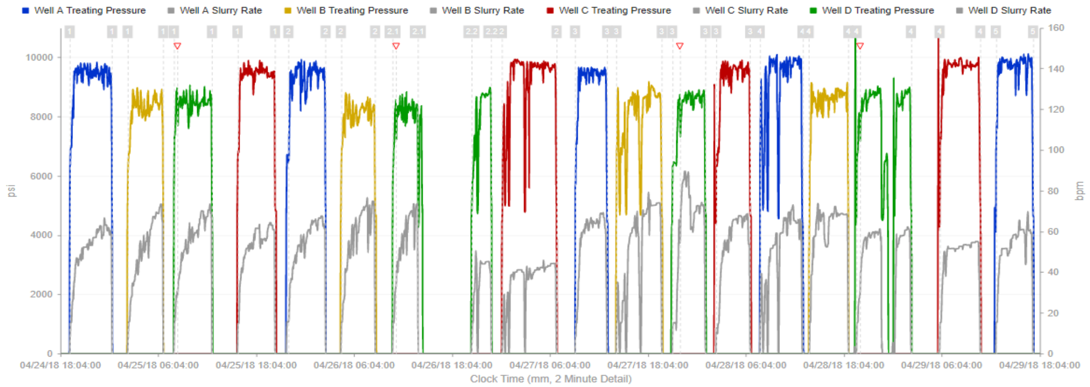
Source: SPE 197105 Leveraging Cloud-Based Analytics to Enhance Near-Real Time Stage Management

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



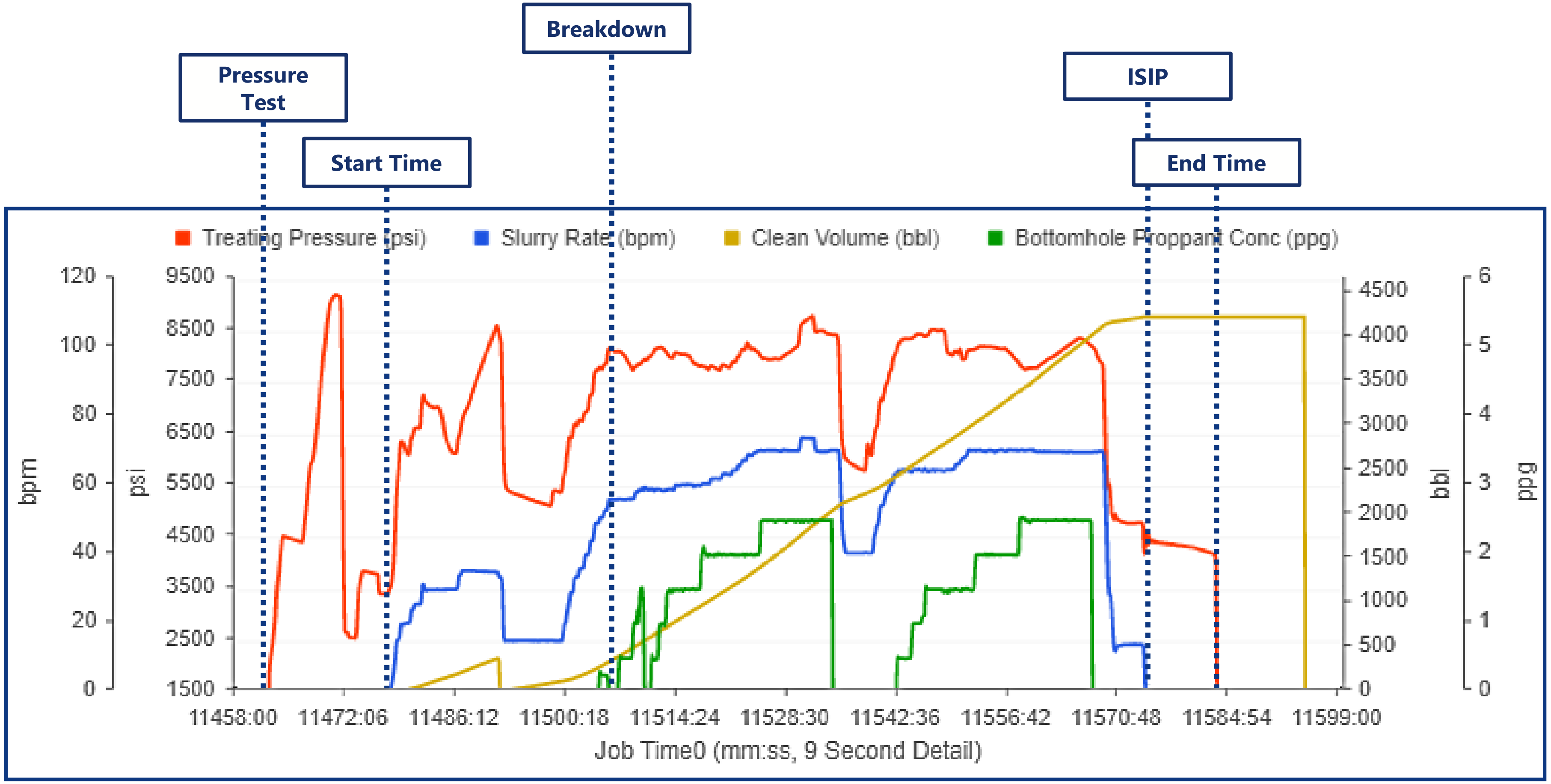
4-way zipper, entire operation, 13 days



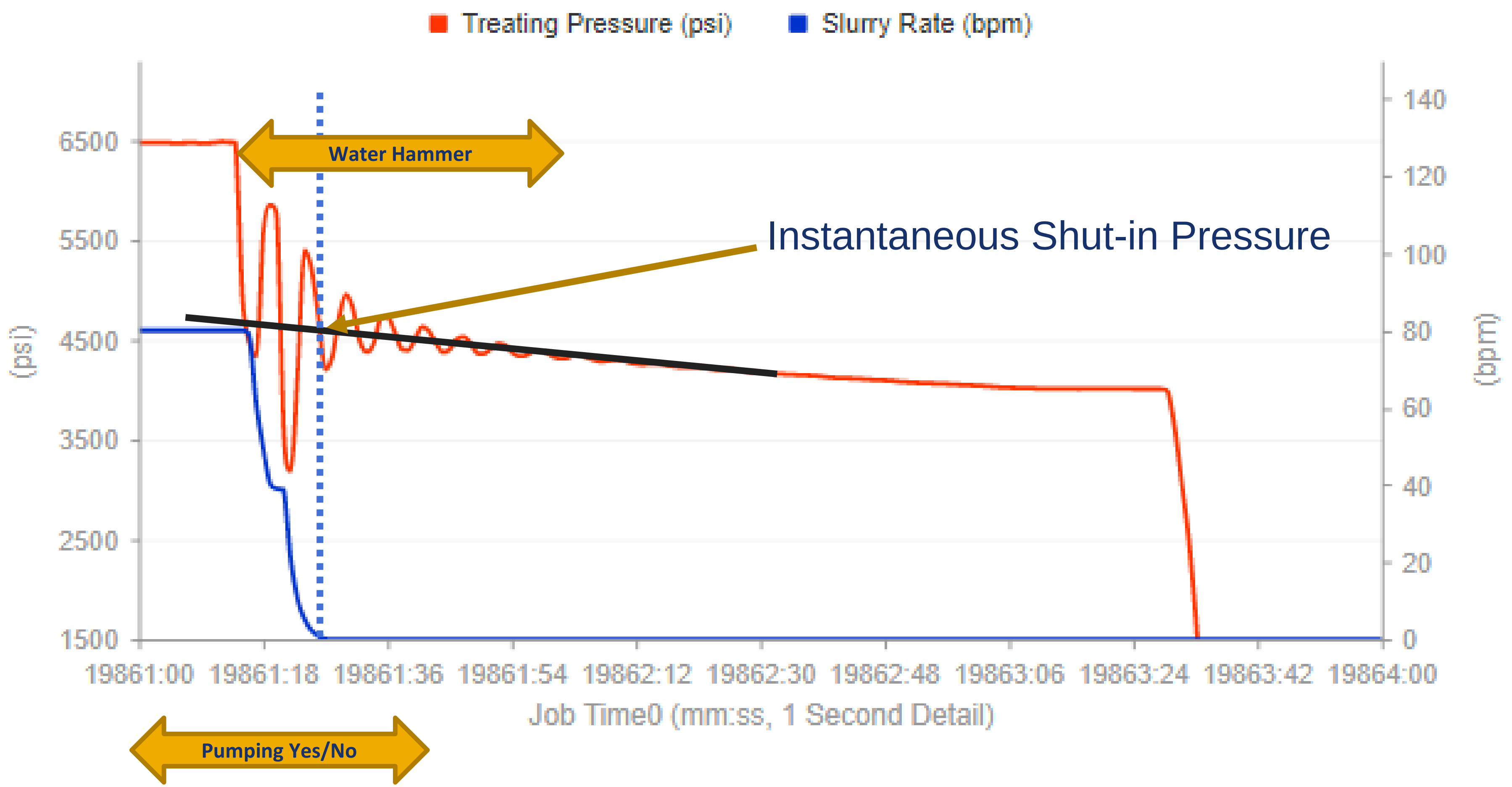
Closer evaluation, 5-day timespan

Machine Learning (ML) Applications

Auto-flagging fracturing events



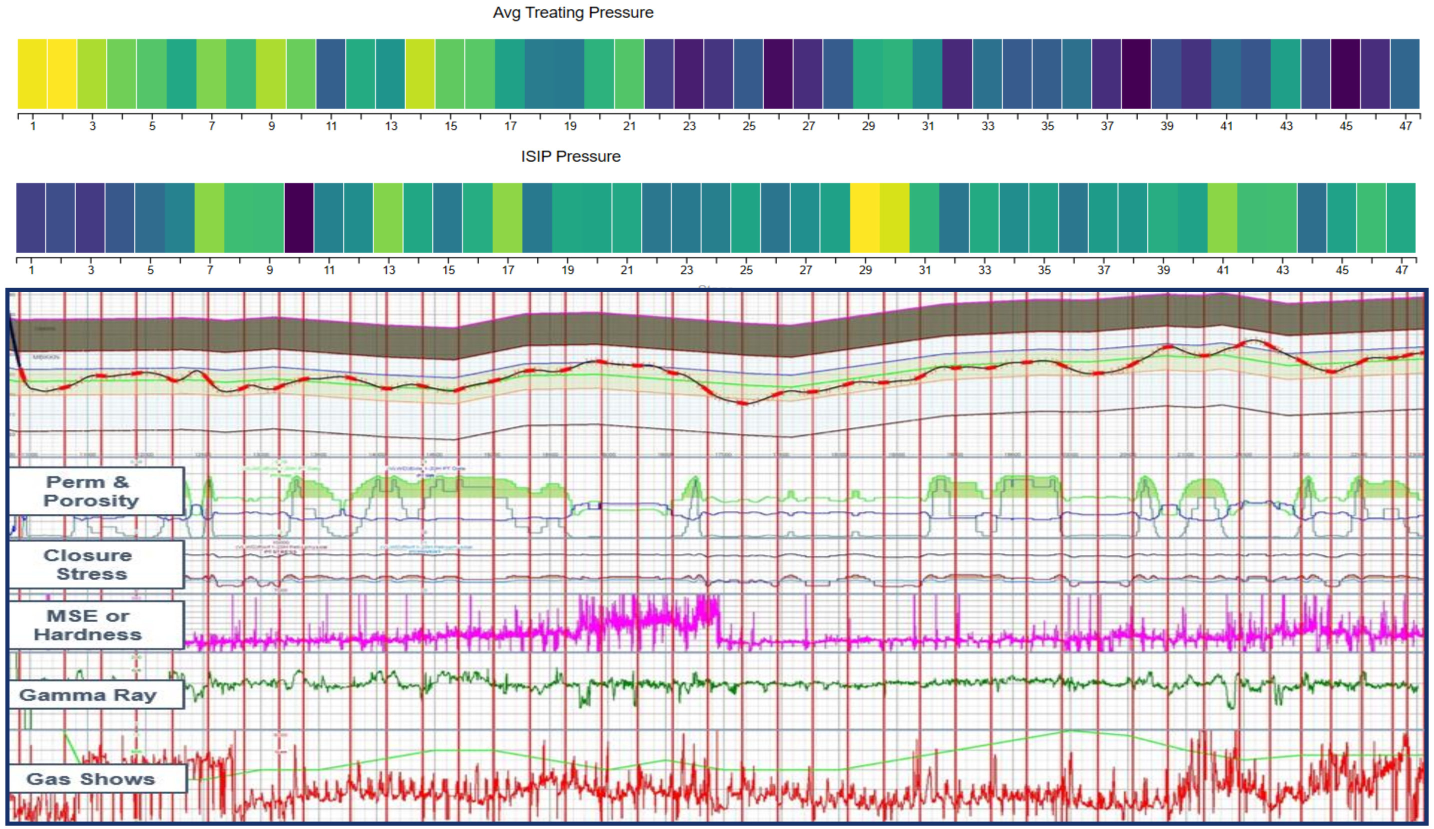
ML Illustration: Auto-picking ISIP



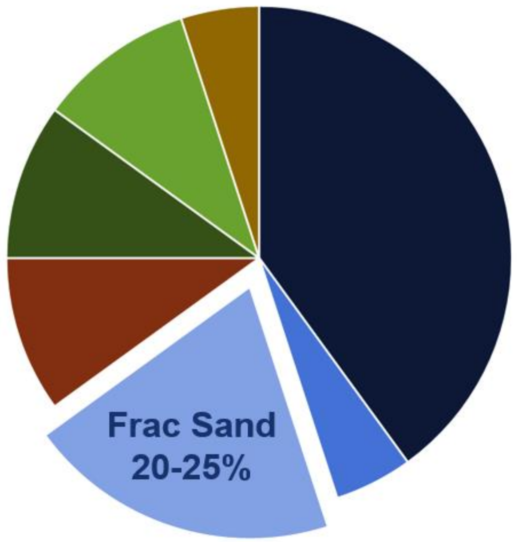
Combining Frac and Geology Data

Possible with cloud-based technologies

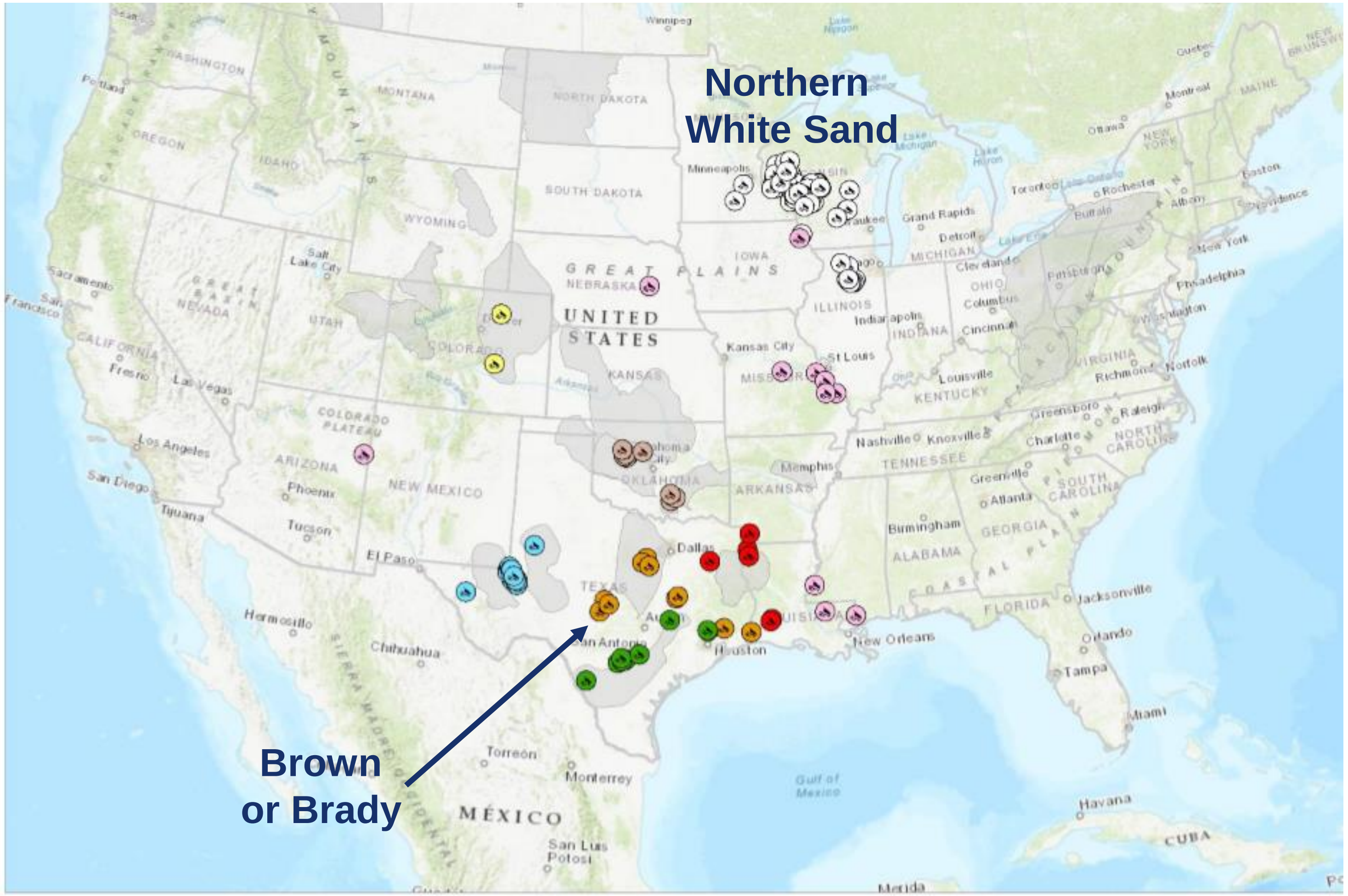
- Each frac stage is an "investigation" into the unique geology along a specific section of the lateral



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

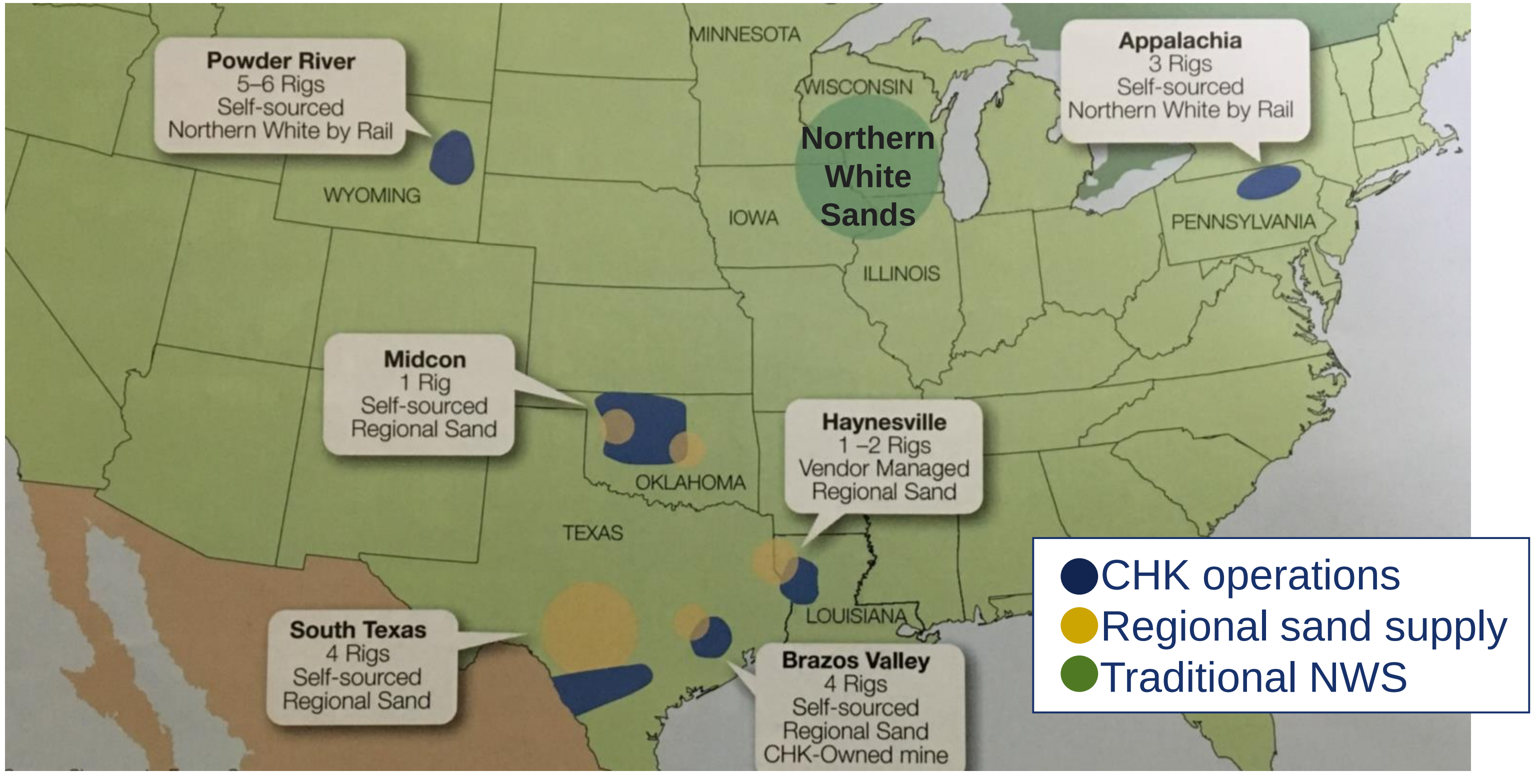
~ 8 billion pounds per year

~ $100 million savings

~ 92% reduction in sand NPT

Program

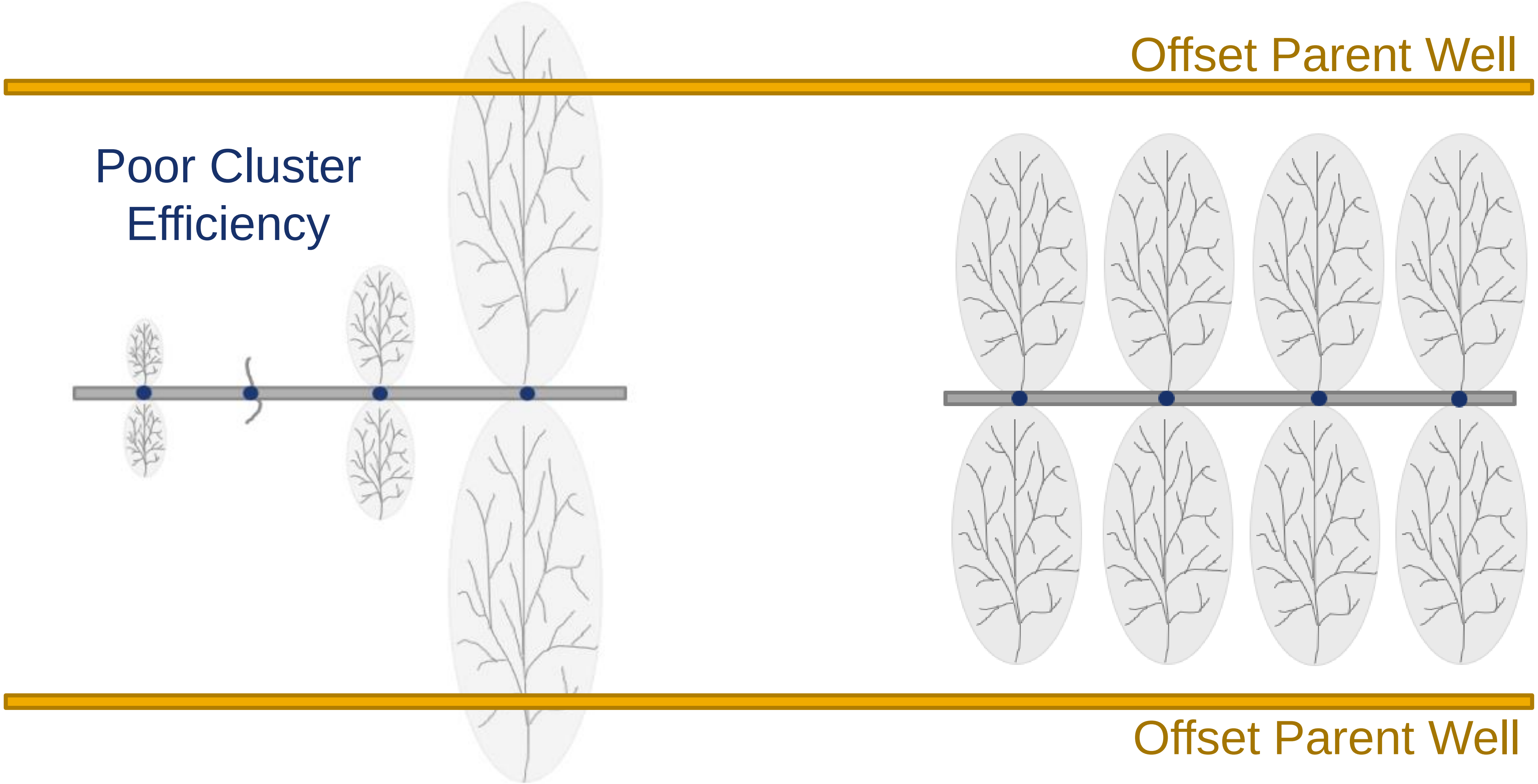
- First trials in 2013
- Mid-2018 initiated full program
- Team of 2 to manage
- Hybrid strategy



Reference: Oil and Gas Investor (August 2019)

Facture Initiation Points

Increasing cluster efficiency



Three Forks to Three Forks

Diversion Triggering Frac Hit

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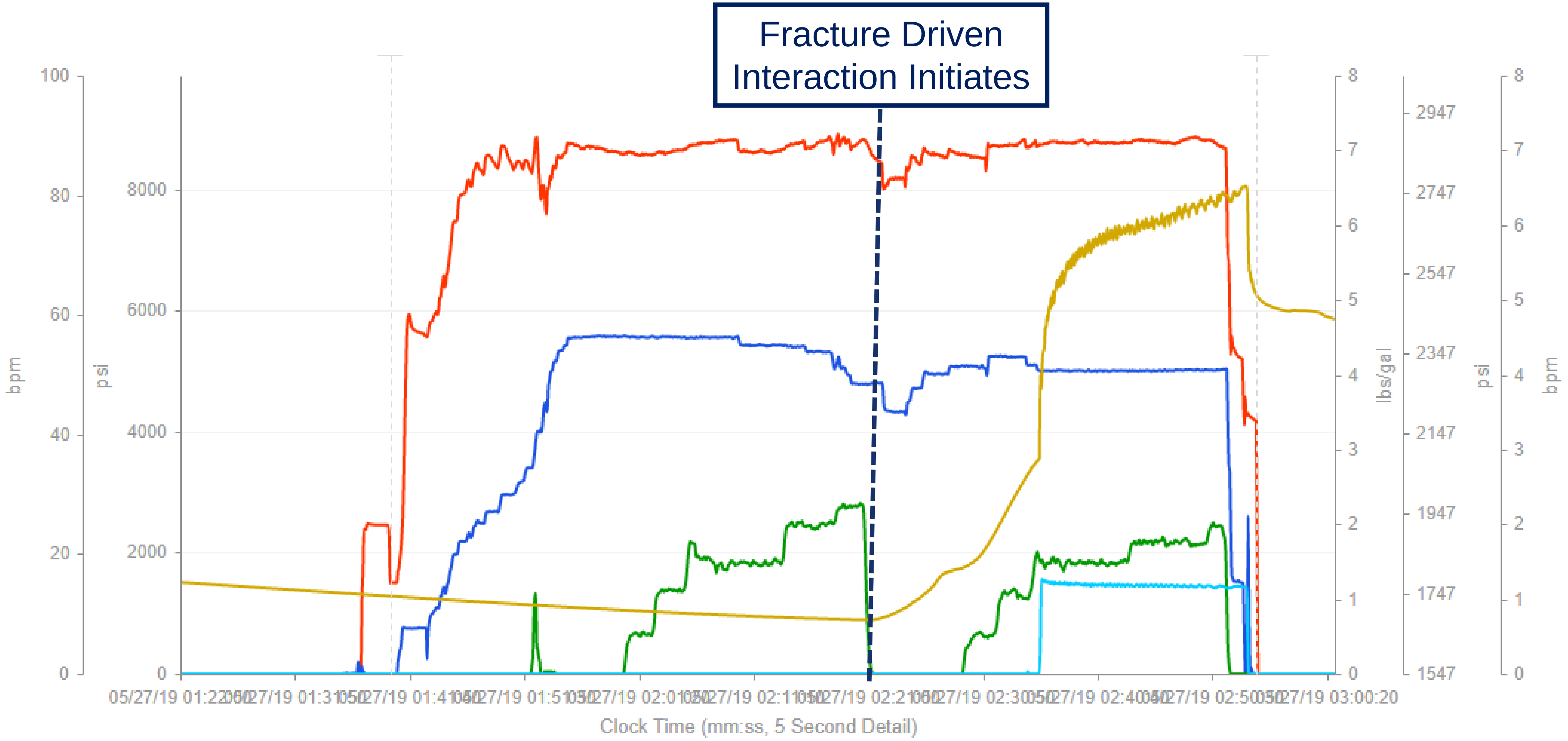


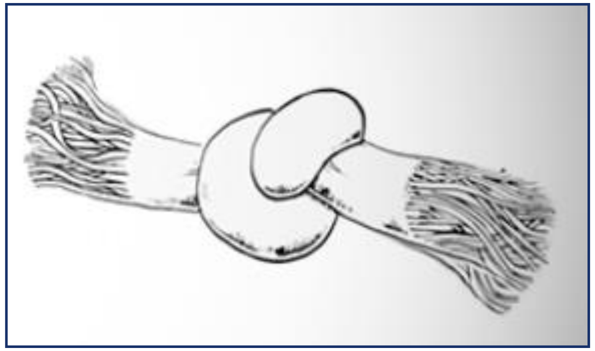
Increasing Cluster Efficiency

Dynamic diversion

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

$$\Delta P_{perf} = \frac{0.2369 \times Q_{perf}^2 \times \rho}{N_{Perf}^2 \times D_{perf}^4 \times C_d^2}$$

Q = *Total flow rate(bbl/min)*
ρ = *Density of fluid (lb/gal)*
N_p = *Number of perforations*
D = *Diamater of perforations (in)*
C_d = *Coefficeit of discharge*



Extreme Limited Entry (XLE)

Cost effective method to increase cluster efficiency

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Design Criteria	Limited Entry	Extreme Limited Entry
Perforation Friction	1,000 - 1,500 psi	2,000 – 4,000 psi
Rate per Perforation	2 – 3 BPM/Perf	4 – 6 BPM/Perf

Recommended references: SPE 179124 (2016), SPE 184834 (2017), SPE 189880 (2018) and SPE 194334 (2019)

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

High Viscosity Friction Reducers (HVFR)

Reduced costs with higher performance

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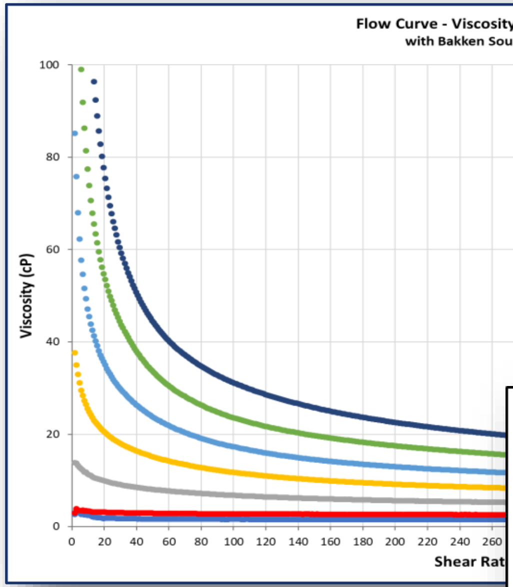
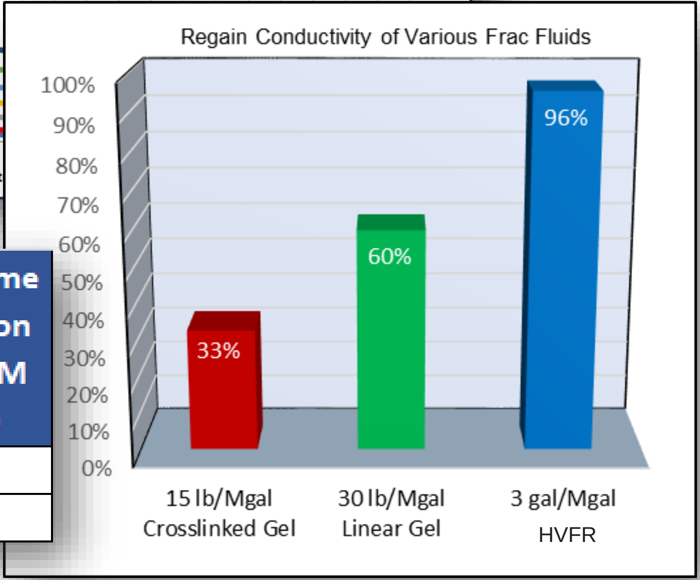
- Higher proppant concentrations
- Reduced water volumes
- Lower friction pressures
- Better proppant transport
- >90% regained permeability





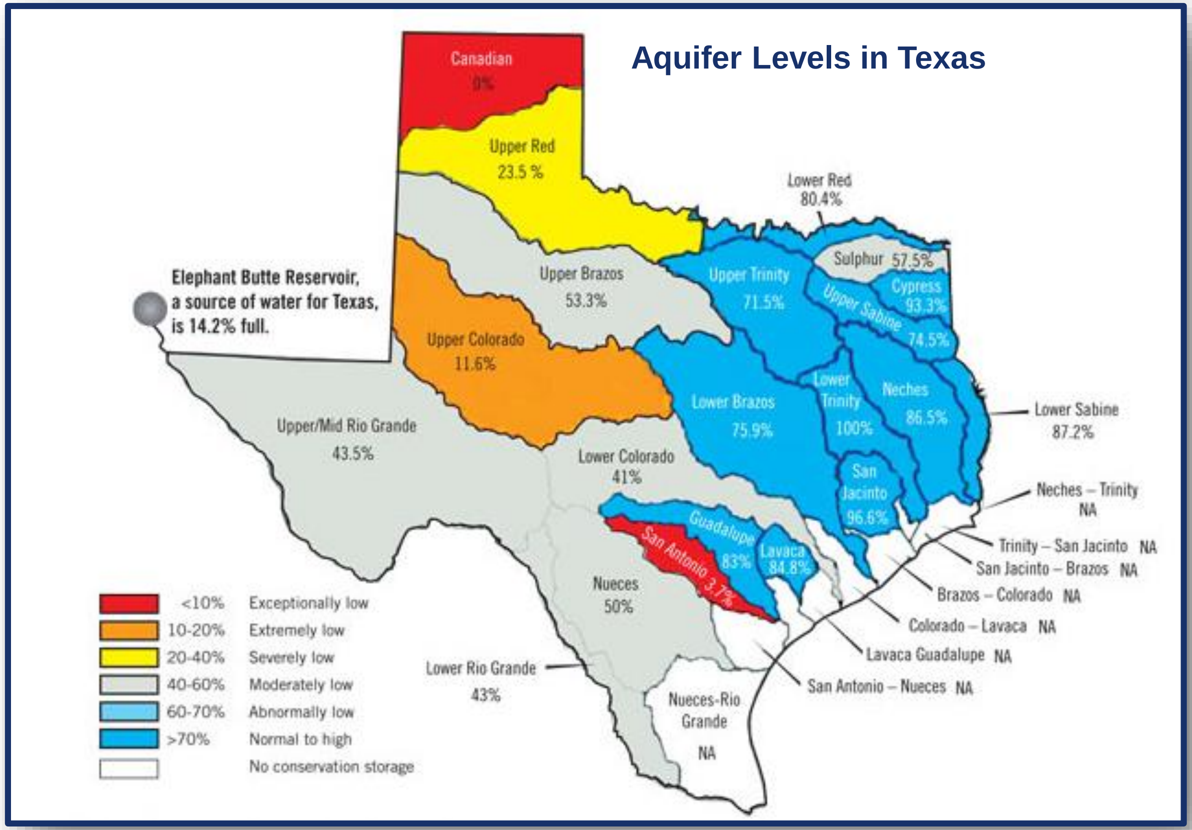
Completion Design (10,000 ft lateral)	Proppant Intensity (lb/ft)	Fluid Intensity (bbl/ft)	Average Proppant Concentration (ppg)	Total Fluid (bbl)	Slurry Volume (bbls)	Pump Time @ 80 BPM (hrs)	Savings @$3/bbl water cost	Pump Time Reduction @80 BPM (days)
Slickwater	1,000	48	0.50	480,000	490,857	102.3	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

Produced Water Recycling

Considerations

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


Remediating for entrained oil and for solids



Source: Texas Water Development Board, December 2018

Produced Water Recycling Facilities

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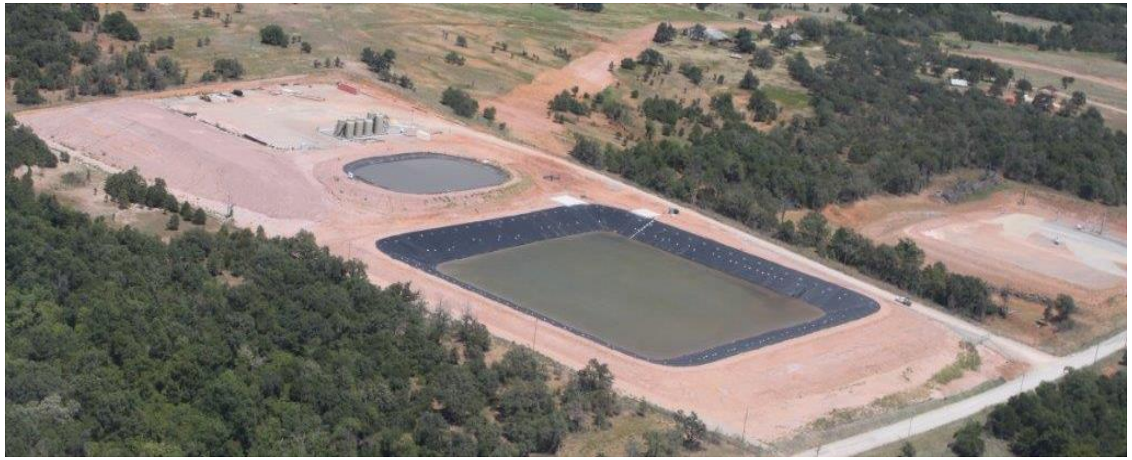
Components

- 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

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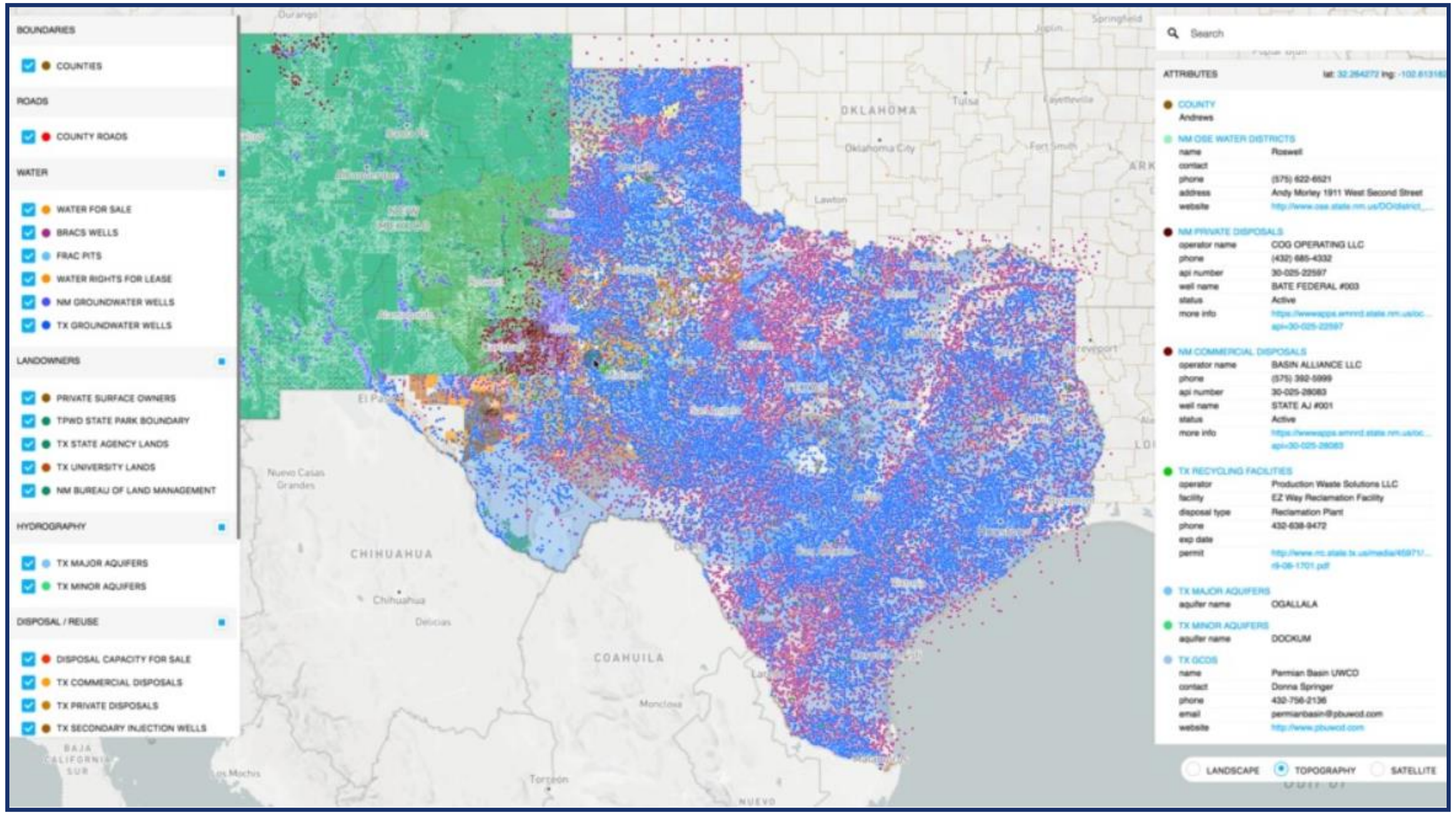
Combined intelligence

- 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

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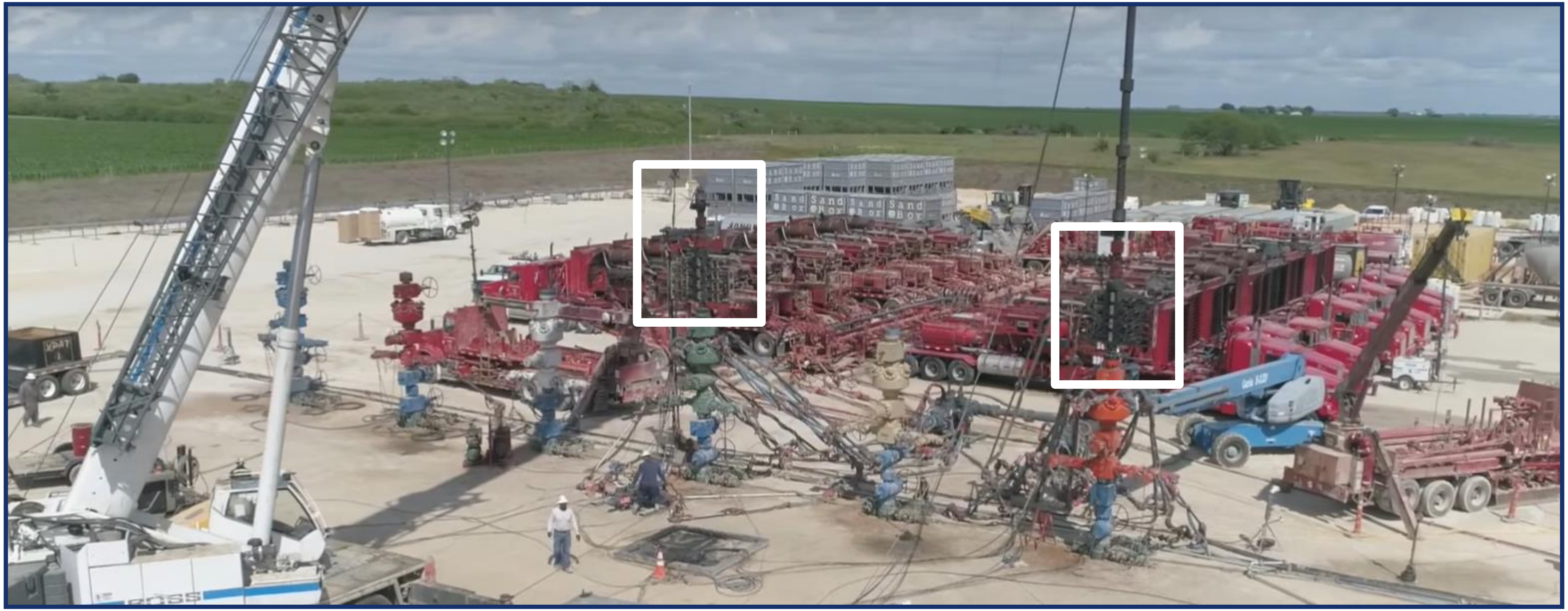

Source: ConocoPhillips Eagle Ford Investor Tour https://www.youtube.com/embed/w5R3FqwJ8oI?rel=0

Wireline Operations

Reduce interstage time with quick connect systems

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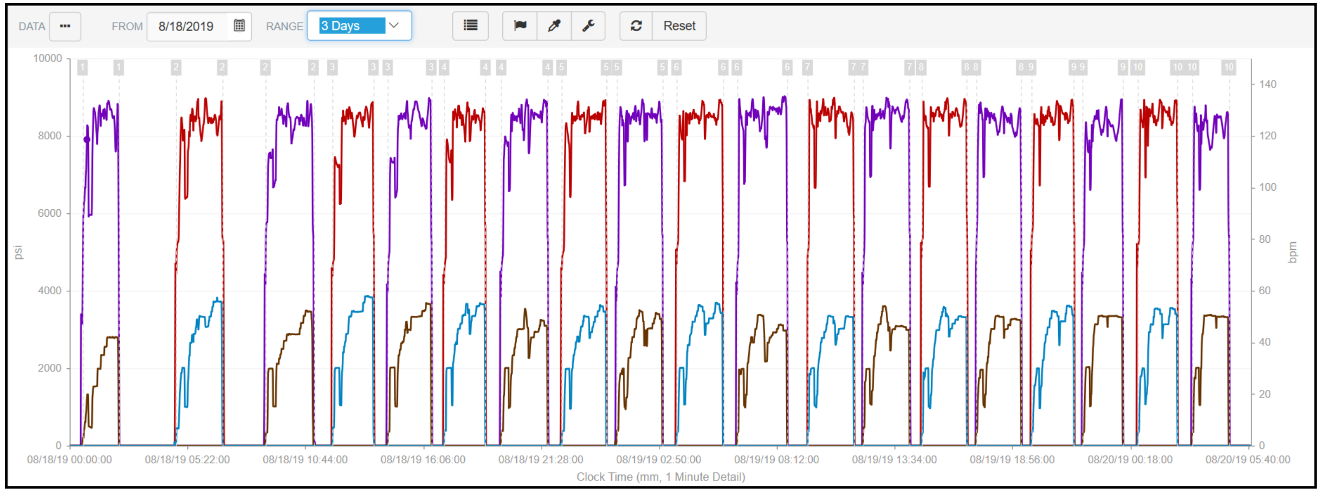
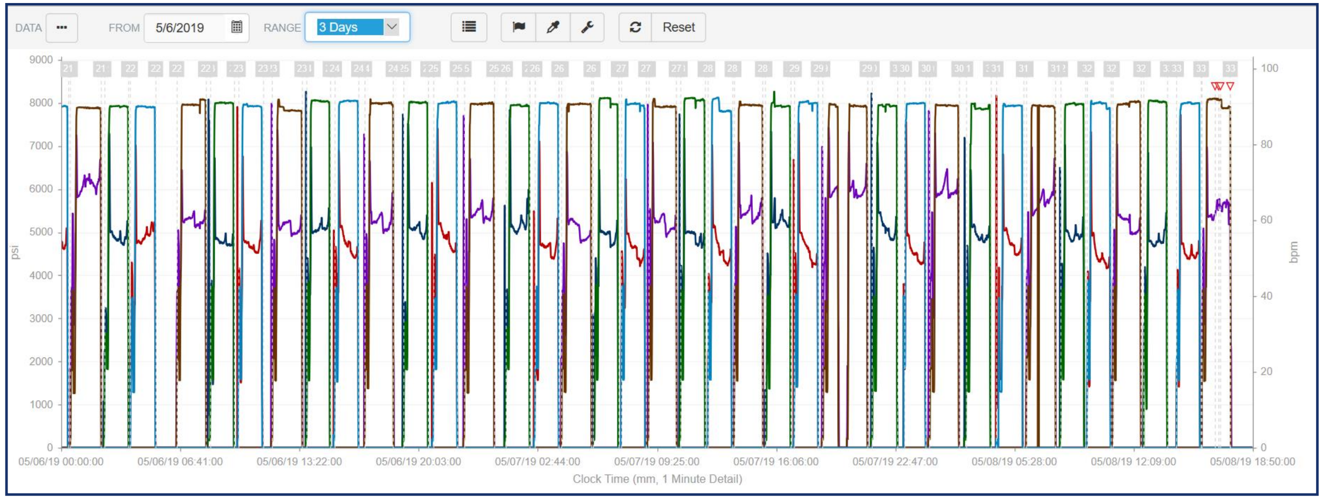
Standard operations

- 20 to 30-minute well swaps



Quick connect systems

- 10 to 12-minute well swaps



Coiled Tubing Operations

Significant efficiency gains

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- 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

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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

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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

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