Re-Fracturing the Appalachian Basin:

An Economic Analysis
Our Backgrounds

• Kade Kiselica
• Marathon Oil Company
  • Eagle Ford – Drilling
  • STACK/SCOOPE – Reservoir
  • Bakken – Production

• Taylor Jennings
• Southwestern Energy
  • Marcellus – Production
  • Fayetteville – Facilities/Midstream
  • Marcellus – Facilities
Objectives

Discuss Re-Fracturing Methodology:
- Unconventional Assets
- Conventional Assets

Identify Specific Screening Criteria for Re-Completion Candidates

Develop Economic Model to Quantify Impact

Perform Probabilistic Modelling to Further Economic Conclusions
Introduction to Re-Fracturing

- 45-55% Rate Decrease
  - Within 5-6 months
- 77-89% Rate Decrease
  - 3 Years After Completion
- Significant Delay of Ultimate Recovery
- Re-Fracturing Provides a Quantifiable Production Uplift
Re-Fracturing Impact

- Production Decline is a Function of Fracture Closure and Damage
- Re-Fracturing in Dual Porosity Systems:
  - By-Passes Formation Damage
  - Restores Crushed/Displaced Proppant
  - Re-Opens Natural Fractures
  - Increases Stimulated Reservoir Volume (SRV)
Stress Re-Orientation

- Maximum Horizontal Stress Rapidly Decreases with Production
  - Due to Depletion in the Direction of Fractures
- Minimum Horizontal Stress Slowly Decreases
  - Results in Stress Reversal Near Fractures
- New Fractures Propagate Obliquely
- Additional Thermally Induced Fractures
Re-Fracture Design Comparison

**Unconventional**
- Increase Fracture Length
- Remedy Fracture Closure
- Create New Fracture Networks

**Conventional**
- Increase Fracture Conductivity
  - Larger Proppant Size
  - Greater Proppant Concentration
  - Higher Quality Proppants
- By-Pass Formation Damage
- Improve Sand Control
Re-Fracture Candidacy Metrics

- Well Performance
- Well Depletion
- Proximity to Other Wells
- Original Completion Design
- Performance of Newer Offset Wells
- Wellbore Integrity
- Expected Re-Completion Costs
Performance Evaluation

- Four Possible Outcomes:
  - Additional Volume of Reserves
  - Accelerated Production of Reserves Previously Contacted
  - Loss of Reserves Previously Contacted
  - No Change in Production or Reserves
Developing a Model

- Utilized Modified Hyperbolic Decline
  - Prevents Overestimation of Reserves
  - Switch When $D_e = 8\%$
- Allows for Modeling of Base Production
Predicting Re-Frac Performance

- Incremental Performance Evaluated
  - Allows for Economic Modeling
- Re-fractured Modified Hyperbolic Decline
  - Utilizes Different Decline Parameters
- Re-Fracture Performance Data Derives from SPE 173340
  - Bakken & Eagle Ford
    - Oil Wells
Utilized Public Data to Fit an Average Type Curve (Marcellus/Utica)

Developed Performance Uplift Parameters from Oil Well Data

Applied Parameters to Gas Well Production Forecasts
Transitioning to Probabilistic Modeling

- Developing Monte Carlo Simulation
  - Define Distributions
    - Provides a Range of Values
    - Presents a Wide Array of Possible Outcomes
    - Outcomes Presented in a Confidence Interval
  - Correlation Correction
    - Enhance Accuracy by Modeling Parameter Dependency
    - Created by Ranking Input Parameters
    - Correlation Coefficient ($\sqrt{r^2}$) Measures Correlation Strength
Gas Well Analysis: Undiscounted NPV
Gas Well Analysis: Discounted NPV
Gas Well Analysis: Discounted PIR

![Graphs showing PIR_10/Incremental Economics analysis with various inputs and outputs.](image-url)
### Gas Well Analysis: Summary

<table>
<thead>
<tr>
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<th>Mean NPV</th>
<th>Mean PIR</th>
<th>Chance of Success</th>
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<tr>
<td>Undiscounted</td>
<td>$1.8MM</td>
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<td>62%</td>
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<tr>
<td>Discounted</td>
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Oil Well Analysis: Undiscounted NPV

NPV_00 / Incremental Economics

Values in Millions ($)

Inputs Ranked By Effect on Output Mean

- QLr
- QL
- Pricing
- DDr
- Time to Re-Frac
- DI
- br
- bl
- CAPEX

Baseline = $2,013,391.97

Input High
Input Low

Minimum - $2,013,391.97
Maximum $5,059,689.19
Mean $3,057,499.19
Std Dev $5,008,368.27
Values $488 / 1600
Errors 92
Oil Well Analysis: Discounted NPV
Oil Well Analysis: Discounted PIR
## Oil Well Analysis: Summary

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<tr>
<td><strong>Undiscounted</strong></td>
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<td><strong>Discounted</strong></td>
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Economic Model Limitations

- Developed Using Public Data
  - Horizontal Unconventional Wells
  - Economic Performance Can be Scaled Down for Vertical Shale Wells
- Models Only Consider Two Cases:
  - Dry Gas
  - Oil
    - Interpolate Performance in Liquids-Rich Gas Wells
- Model is Not Analogous for Conventional Reservoirs
  - Would Require Testing and Data Sharing
  - Could be Modeled With Outlined Methodology
Conclusions

• Viable Method to Gain Production from Existing Wells
• Probabilistic Modeling Provides a Range of Potential Outcomes
  • Oil Wells Show Better Economic Metrics
    • $\text{NPV}_{10}$ Range: $-1.1\text{MM}$ to $4.9\text{MM}$
    • Discounted Chance of Success: 63%
  • Dry Gas Wells Still See Economic Uplift
    • $\text{NPV}_{10}$ Range: $-2.0\text{MM}$ to $3.3\text{MM}$
    • Discounted Chance of Success: 59%
Questions


**Appendix: Correlation Coefficient Matrix**

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<th>Qi</th>
<th>Qlr</th>
<th>bi</th>
<th>br</th>
<th>Di</th>
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The table contains correlation coefficient values and visual scatter plots for each pair of variables: Q, Qlr, bi, br, Di, and Dlr.