Improving Well Performance through Multi-Variate Completion Analyses in the US Bakken Shale

C. Mark Pearson
• An independent, private-equity backed E&P company with industry leading expertise in developing tight-oil plays using advanced completion designs and fracs.

• Operates in the Williston Basin (ND) and Powder River Basin (WY) with gross operated production over 10,000 boepd.

• Team has been working in the Williston Basin (Bakken) since 2009 and has already sold its assets once – in mid-2013 – and then re-entered the basin in 1Q 2014 as Liberty Resources II LLC.

• The company is operating a one-rig program in the Williston Basin and will be starting a drilling program in the Powder River Basin in November 2016.
OUTLINE

• Public E&P databases in the US:
  - Frac Focus (US Frac reporting database)
  - North Dakota Industrial Commission (NDIC) public database

• Bakken Introduction
  - Location, Geology, Development History

• Multi-variate Analysis of Completion and Production Data

• Latest Completion Trends in the Bakken

• The end result – Well Performance
FracFocus is the national hydraulic fracturing chemical registry. FracFocus is managed by the Ground Water Protection Council and Interstate Oil and Gas Compact Commission, two organizations whose missions both revolve around conservation and environmental protection.

The primary purpose of this site is to provide factual information concerning hydraulic fracturing and groundwater protection. To help users put this information into perspective, the site also provides objective information on hydraulic fracturing, the chemicals used, the purposes they serve and the means by which groundwater is protected.

The site was created to provide the public access to reported chemicals used for hydraulic fracturing within their area.

Currently, twenty-three states use FracFocus in this manner as shown in the map.
Start at the main FracFocus page [www.fracfocus.org](http://www.fracfocus.org) and click on Find a Well (on the green map).

**Looking for information about a well site near you?**

Search for nearby well sites that have been hydraulically fractured to see what chemicals were used in the process.

**FracFocus contains many ways to search the public database for specific disclosures by:**

- State
- County
- Operator Name
- Date range (on, on or before, on or after, between)
- API well number
- CAS number
- On Federal or Indian lands
- Well name
- Specific ingredients.
FracFocus- Search for a Well

You can search using either a Standard Search or a Map Search:

Find a Well

Search Options

- **State:** Choose a State
- **County:** Choose a State First
- **Wells in County:** Choose a County First
- **Operator:** Choose One
- **Job/Submitted Date:** Job Start Date
- **Date Range:** Between
- **Range Start Date:**
- **Range End Date:**
- **Federal Well:**
- **Indian Well:**
- **API Well Number:**
- **Well Name:**
- **CAS Number:**

**Ingredient List:**

**Search**

Displaying **90** of Records
FracFocus Completed Entry Form Example

You can click on the .pdf icon to the left of any record. This opens up a .pdf file that shows the public disclosure:

<table>
<thead>
<tr>
<th>Trade Name</th>
<th>Supplier</th>
<th>Purpose</th>
<th>Ingredients</th>
<th>Chemical Abstract Service Number (CAS #)</th>
<th>Maximum Ingredient Concentration in Additive (% by mass)**</th>
<th>Mass per Component (LBS)</th>
<th>Maximum Ingredient Concentration in HF Fluid (% by mass)**</th>
<th>Comments</th>
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<tbody>
<tr>
<td>Water</td>
<td>Operator</td>
<td>Carrier</td>
<td>Water</td>
<td>7732-18-5</td>
<td>100%</td>
<td>27,660,000</td>
<td>82,072,574</td>
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<tr>
<td>CTPE-20 (THA)</td>
<td>Liberty Oilfield</td>
<td>Friction reduction</td>
<td>Petroleum diacetate, hydrogel, light</td>
<td>03742-47-9</td>
<td>30%</td>
<td>17,349</td>
<td>0.002559</td>
<td>Surfactant 13</td>
</tr>
<tr>
<td>SFT-72 (Emulsion)</td>
<td>Liberty Oilfield</td>
<td>Non Emulsifier</td>
<td>Proprietary Surfacants</td>
<td>03629-46-3</td>
<td>51%</td>
<td>2,575</td>
<td>0.002574</td>
<td>Surfactant 13</td>
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<tr>
<td>Light Alcan Amylamine</td>
<td>Liberty Oilfield</td>
<td>Methanol</td>
<td>Methanol</td>
<td>07661-96-7</td>
<td>15%</td>
<td>2,562</td>
<td>0.001574</td>
<td>Surfactant 13</td>
</tr>
<tr>
<td>1-2-4-Tetrahydrobenzene</td>
<td>Liberty Oilfield</td>
<td>Guip Screen</td>
<td>Mixture containing 5-Chloro-2-methyl-2H</td>
<td>44742-55-8</td>
<td>5%</td>
<td>1,294</td>
<td>0.001574</td>
<td>Guip 1</td>
</tr>
<tr>
<td>BFN-68 (Buffer)</td>
<td>Liberty Oilfield</td>
<td>High pH Buffer</td>
<td>Potassium Hydroxide Solution</td>
<td>1510-85-3</td>
<td>30%</td>
<td>12</td>
<td>0.000217</td>
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<tr>
<td>Sodium Chloride Solution</td>
<td>Liberty Oilfield</td>
<td>Crosslinker</td>
<td>Sodium Chloride</td>
<td>1112-73-2</td>
<td>30%</td>
<td>12</td>
<td>0.000217</td>
<td></td>
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<tr>
<td>aste</td>
<td>Liberty Oilfield</td>
<td>Crosslinker</td>
<td>Borate Salt</td>
<td>1303-36-6</td>
<td>30%</td>
<td>15</td>
<td>0.000002</td>
<td>Crosslinker 1</td>
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<td>BHN-42 (Breaker)</td>
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<td>Liquid Breaker</td>
<td>Decyl sulfate, Sodium Salt</td>
<td>7758-19-2</td>
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<td>1,972</td>
<td>0.000217</td>
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<td>SFT-72W (Emulsion)</td>
<td>Liberty Oilfield</td>
<td>Non Emulsifier</td>
<td>Proprietary Surfacants</td>
<td>7667-14-5</td>
<td>5%</td>
<td>2,575</td>
<td>0.002574</td>
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<tr>
<td>Nitrogen</td>
<td>Liberty Oilfield</td>
<td>Ethanol Alcohol</td>
<td>Ethanol Alcohol</td>
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<td>10%</td>
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<td>Surfactant 13 Wettered</td>
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<tr>
<td>Methanol</td>
<td>Liberty Oilfield</td>
<td>Methanol</td>
<td>Methanol</td>
<td>07661-96-7</td>
<td>15%</td>
<td>2,562</td>
<td>0.001574</td>
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<td>Guip Screen</td>
<td>Mixture containing 5-Chloro-2-methyl-2H</td>
<td>44742-55-8</td>
<td>5%</td>
<td>1,294</td>
<td>0.001574</td>
<td>Guip 1</td>
</tr>
<tr>
<td>Clean Out Fluid</td>
<td>Liberty Oilfield</td>
<td>Cleanup Solution</td>
<td>Alkaline</td>
<td>729-00-2</td>
<td>100%</td>
<td>729</td>
<td>0.000030</td>
<td>Liberty Clean Out Fluid</td>
</tr>
<tr>
<td>TLR-1207 (FR)</td>
<td>Cemtech Frac</td>
<td>Friction Reducer</td>
<td>Hydrogelized Light Distillate</td>
<td>03742-47-9</td>
<td>20%</td>
<td>144</td>
<td>0.000030</td>
<td>EOG FR</td>
</tr>
<tr>
<td>Ceramic Proppant-45/50</td>
<td>Liberty Oilfield</td>
<td>Proppant</td>
<td>Ceramic</td>
<td>1508-23-1</td>
<td>65%</td>
<td>1,370,000</td>
<td>Liberty IS-Ceramic/US</td>
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<tr>
<td>Ceramic Proppant-20/45</td>
<td>Liberty Oilfield</td>
<td>Proppant</td>
<td>Ceramic</td>
<td>1508-23-1</td>
<td>65%</td>
<td>1,370,000</td>
<td>Liberty IS-Ceramic/US</td>
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<tr>
<td>Ceramic Proppant-20/45</td>
<td>Liberty Oilfield</td>
<td>Proppant</td>
<td>Ceramic</td>
<td>1508-23-1</td>
<td>65%</td>
<td>1,370,000</td>
<td>Liberty IS-Ceramic/US</td>
<td></td>
</tr>
</tbody>
</table>

SPE Asia Pacific
Hydraulic Fracturing Conference

Multi-Variate Bakken Completion Analyses • C. Mark Pearson
NDIC Typical Well File
https://www.dmr.nd.gov/oilgas/

• 100+ pages
• Form 6 – Completion Report
• Form 4 – Sundries
• Form 1 – Application for Permit to Drill (APD)
### NDIC Well File – Form 6 (Frac Data)

#### CASING & TUBULARS RECORD (Report all strings set in well)

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<thead>
<tr>
<th>Well Bore</th>
<th>Type</th>
<th>String</th>
<th>Size (Inch)</th>
<th>Top Set (MD Ft)</th>
<th>Depth Set (MD Ft)</th>
<th>Hole Size (Inch)</th>
<th>Weight (Lbs/Ft)</th>
<th>Anchor Set (MD Ft)</th>
<th>Packer Set (MD Ft)</th>
<th>Sacks Cement</th>
<th>Top of Cement</th>
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<tbody>
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<td>Lateral1</td>
<td>Conductor</td>
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<td></td>
<td>105</td>
<td>16</td>
<td>K-65</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surface</td>
<td>9 5/8</td>
<td></td>
<td></td>
<td>2023</td>
<td>13 1/2</td>
<td>36. J55</td>
<td></td>
<td></td>
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<tr>
<td>Intermediate</td>
<td>7</td>
<td>9223</td>
<td>8 3/4</td>
<td>32</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Liner</td>
<td>4 1/2</td>
<td>19555</td>
<td>6</td>
<td>11.6</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Tubing</td>
<td>2 7/8</td>
<td>9018</td>
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</tr>
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#### PERFORATION & OPEN HOLE INTERVALS

<table>
<thead>
<tr>
<th>Well Bore</th>
<th>Well Bore TD Drillers Depth (MD Ft)</th>
<th>Completion Type</th>
<th>Open Hole/Perforated Interval (MD Ft)</th>
<th>Kick-off Point (MD Ft)</th>
<th>Top of Casing Window (MD Ft)</th>
<th>Date Perf’d or Drilled</th>
<th>Date Isolated</th>
<th>Isolation Method</th>
<th>Sacks Cement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lateral1</td>
<td>19870</td>
<td></td>
<td>9938 19655 9128</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Frac Data

- # Stages, Total Fluid Volume, Total Lbs Proppant, Max Treating Pressure and Rate

**Specific Stimulation Details**

- **Date Stimulated:** 12/13/2014
- **Stimulated Formation Bakken:** 939
- **Top (Ft):** 9938
- **Bottom (Ft):** 19555
- **Stimulation Stages:** 50
- **Volume:** 193731
- **Volume Units Barrels:**
- **Type Treatment:** Sand Frac
- **Acid %:** 0%
- **Lbs Proppant:** 4218773
- **Maximum Treatment Pressure (PSI):** 9528
- **Maximum Treatment Rate (BBLS/Min):** 84.0
- **Details:** 4,216,773 of 40/70 & 30/50 proppant

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**Cemented vs Uncemented**

**Perforated Interval**
Bakken Shale – Williston Basin

Central Basin
Bakken Structure and Development History

1. Antelope Arch
2. Nesson & Billings Anticlines
3. Elm Coulee Field
4. Sanish / Parshall / Ross Fields
5. Central Basin

1953 to 1970
Well Count +58
Bakken Structure and Development History

1. Antelope Arch
2. Nesson & Billings Anticlines
3. Elm Coulee Field
4. Sanish / Parshall / Ross Fields
5. Central Basin

1971 to 1985
Well Count
+190
Bakken Structure and Development History

1. Antelope Arch
2. Nesson & Billings Anticlines
3. Elm Coulee Field
4. Sanish / Parshall / Ross Fields
5. Central Basin

1986 to 2000 Well Count
+273
Bakken Structure and Development History

1. Antelope Arch
2. Nesson & Billings Anticlines
3. Elm Coulee Field
4. Sanish / Parshall / Ross Fields
5. Central Basin

2001 to 2005
Well Count +383
Bakken Structure and Development History

1. Antelope Arch
2. Nesson & Billings Anticlines
3. Elm Coulee Field
4. Sanish / Parshall / Ross Fields
5. Central Basin

2006 to 2009
Well Count +1622
Bakken Structure and Development History

1. Antelope Arch
2. Nesson & Billings Anticlines
3. Elm Coulee Field
4. Sanish / Parshall / Ross Fields
5. Central Basin

2010 to Present
Well Count +9952
Central Basin Initial Development (2009-2012)

- T148-159, R97-105
- 97 townships
- 72 miles by 48 miles
- 1185 completions from 2009 to 2012
- Over 28 operators
- 17 operators >20 completions
- ~½ ND Rigs
- Large area (~3500 mi²)
Williston Central Basin
Cumulative Oil Production – Middle Bakken Wells Completed 2009-2012

- 1000 MBOE Type Curve
- 700 MBOE Type Curve
- 400 MBOE Type Curve
Options in defining a relevant production metric

Using monthly production records:
- First Month’s production
- Highest Month’s production
- First 6 months production

Using monthly production records AND producing days:
- 30-day cum production
- 90-day cum production
- 180-day cum production
- 365-day cum production
Use of 180-Day Cum Oil as Predictor
3-Year Cum Oil vs 180-Day Cum Oil

$R^2 = 0.87$
Multi-Variate Analysis

- Allows looking at multiple variables over large areas
- Includes geological variables (reservoir quality) and completion (frac) parameters
- User specified variables summed in “transformations” versus a “response” variable (180-day cum production)
- High level of correlation, no need to use a small area as is the case for bi-variate analysis
- Able to compare completions across a larger study area
Multi-Variate Analysis

Model Input Parameters (SPE 166479)

• **Reservoir / Geological / Production**
  - Cumulative Water Cut (co-linear with pore pressure and depth); no/minimal dependence on calculated OOIP/$S_o \Phi_H$ or net pay

• **Completion / Frac Design**
  - Lateral Length, ft
  - Stage Length, ft/stage - (number stages)
  - Proppant Amount, lbs/ft
  - Fluid Volume, bbls/ft
  - Proppant Type, % sand (proxy for the amount of “premium proppant”)
Multivariate Model Predicted vs. Actual

180-Day Cum Oil Analysis

180-Day Analysis

$R^2 = 0.77$
Different Completion Methods
Operator 180 Day Production vs. Water Cut

Wells consistently group by operator in linear trends above and below the "average" completion.
General Completion Type and Cost By Operator

Six different completion types run between 8 operators

<table>
<thead>
<tr>
<th>Operator</th>
<th>Color Code</th>
<th>Number Wells</th>
<th>Liner</th>
<th>Av. No. Stgs</th>
<th>Comp. Type</th>
<th>Frac Type</th>
<th>Av. lbs/ft</th>
<th>Av. bbls/ft</th>
<th>Av. % Sand</th>
<th>Av. % Ceramic</th>
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</thead>
<tbody>
<tr>
<td>A&amp;C</td>
<td></td>
<td>45</td>
<td>SP</td>
<td>35</td>
<td>PNP</td>
<td>SW</td>
<td>396</td>
<td>25.1</td>
<td>0%</td>
<td>100%</td>
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<tr>
<td>B</td>
<td></td>
<td>144</td>
<td>SP</td>
<td>34</td>
<td>PNP</td>
<td>Hybrid</td>
<td>395</td>
<td>7.9</td>
<td>38%</td>
<td>62%</td>
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<tr>
<td>E</td>
<td></td>
<td>56</td>
<td>Cmt</td>
<td>25</td>
<td>PNP</td>
<td>Gel</td>
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<td>157</td>
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<td>68</td>
<td>SP</td>
<td>28</td>
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<td>76</td>
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<td>25</td>
<td>PNP</td>
<td>Gel</td>
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<td>6.5</td>
<td>100%</td>
<td>0%</td>
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- Swell Packer: SP
- Cemented Liner: Cmt
- Plug and Perf: PNP
- Ball and Sleeve: BS
- Slickwater: SW
- XL Gel
- Hybrid Slickwater/Gel: Hybrid
Different Completion Methods
Operator 180 Day Production vs. Water Cut

<table>
<thead>
<tr>
<th>Operator</th>
<th>Color Code</th>
<th>Comp. Type</th>
<th>Frac Type</th>
<th>Av. % Ceramic</th>
</tr>
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<tbody>
<tr>
<td>A&amp;C</td>
<td>PNP</td>
<td>SW</td>
<td>100%</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>PNP</td>
<td>Hybrid</td>
<td>62%</td>
<td></td>
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<tr>
<td>E</td>
<td>PNP</td>
<td>Gel</td>
<td>100%</td>
<td></td>
</tr>
<tr>
<td>L</td>
<td>PNP</td>
<td>Gel</td>
<td>31%</td>
<td></td>
</tr>
<tr>
<td>Y&amp;T</td>
<td>BS</td>
<td>Gel</td>
<td>15%</td>
<td></td>
</tr>
<tr>
<td>R</td>
<td>PNP</td>
<td>Gel</td>
<td>0%</td>
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<table>
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<tr>
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<td>110,000</td>
<td>10,000</td>
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<tr>
<td>120,000</td>
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Water Cut: 20% 30% 45% 60%
### EUR by Completion Technique

**(2009-2012 Central Basin Wells; 30% Water Cut Areas)**

#### Table:

<table>
<thead>
<tr>
<th>Operator</th>
<th>Color Code</th>
<th>Comp. Type</th>
<th>Frac Type</th>
<th>Av. % Ceramic</th>
</tr>
</thead>
<tbody>
<tr>
<td>A&amp;C</td>
<td></td>
<td>PNP</td>
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<td>100%</td>
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<td>15%</td>
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<tr>
<td>R</td>
<td></td>
<td>PNP</td>
<td>Gel</td>
<td>0%</td>
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</table>

#### Graph:

- **1100 MBOE**
- **800 MBOE**
- **600 MBOE**

---

*SPE Asia Pe Hydraulic Fracturing Conference*
EUR by Completion Technique
(2009-2012 Central Basin Wells; 45% Water Cut Areas)

<table>
<thead>
<tr>
<th>Operator</th>
<th>Color Code</th>
<th>Comp. Type</th>
<th>Frac Type</th>
<th>Av. % Ceramic</th>
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<tbody>
<tr>
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</tr>
<tr>
<td>E</td>
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<td>100%</td>
<td></td>
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<tr>
<td>L</td>
<td>PNP</td>
<td>Gel</td>
<td>31%</td>
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<tr>
<td>Y&amp;T</td>
<td>BS</td>
<td>Gel</td>
<td>15%</td>
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</tr>
<tr>
<td>R</td>
<td>PNP</td>
<td>Gel</td>
<td>0%</td>
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</tr>
</tbody>
</table>

Multi-Variate Bakken Completion Analyses • C. Mark Pearson
EUR by Completion Technique
(2009-2012 Central Basin Wells; 60% Water Cut Areas)

### Table: EUR by Completion Technique

<table>
<thead>
<tr>
<th>Operator</th>
<th>Color Code</th>
<th>Comp. Type</th>
<th>Frac Type</th>
<th>Av. % Ceramic</th>
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<tr>
<td>A&amp;C</td>
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<td>PNP</td>
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<tr>
<td>E</td>
<td>E</td>
<td>PNP</td>
<td>Gel</td>
<td>100%</td>
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<tr>
<td>L</td>
<td>L</td>
<td>PNP</td>
<td>Gel</td>
<td>31%</td>
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<tr>
<td>Y&amp;T</td>
<td>Y</td>
<td>BS</td>
<td>Gel</td>
<td>15%</td>
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<tr>
<td>R</td>
<td>R</td>
<td>PNP</td>
<td>Gel</td>
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</tr>
</tbody>
</table>

**Color Code Legend:**
- A&C: Green
- B: Blue
- E: Pink
- L: Orange
- Y&T: Light Blue
- R: Yellow
Central Basin (T148-159, R97-105) - 2421 Wells
(completions since 1/15/2009, production through May '16)
• How has Industry put these learnings to work?
ND Average Stage Count (2-mile laterals) by Year
North Dakota Proppant Pumped by Year

- 2006: 0.03 Billion Lbs Proppant
- 2007: 0.11 Billion Lbs Proppant
- 2008: 0.50 Billion Lbs Proppant
- 2009: 0.67 Billion Lbs Proppant
- 2010: 1.76 Billion Lbs Proppant
- 2011: 3.29 Billion Lbs Proppant
- 2012: 5.04 Billion Lbs Proppant
- 2013: 6.45 Billion Lbs Proppant
- 2014: 8.93 Billion Lbs Proppant
- 2015: 7.21 Billion Lbs Proppant
Middle Bakken Proppant, Lbs/Ft, by Year
Increased Use of Slickwater Completions
(Central Basin Middle Bakken Wells)
Average Middle Bakken 180-Day Cum Oil by Year

- More stages
- More proppant
Current Multivariate Input Parameters

- Reservoir / Geological / Production
  - Township and Range
  - Cumulative *Shifted* Water Cut
  - Cumulative GOR

- Completion / Frac Design
  - Lateral Length, ft
  - Cemented Liner
  - Well Order
  - Stage Length, ft/stage - (number stages)
  - Proppant Amount, lbs/ft
  - Average Proppant Concentration, ppg
  - Fluid Volume, bbls/ft
  - Proppant Type, % sand
Current Multi-Variate Example Modeling Results

- Bivariate Statistics
  - Regression Fit: $y = 1.000x + (-0.00112)$
  - R Squared: 0.820
  - Correlation Coeff.: 0.905
  - Rank Corr. Coeff.: 0.899

- Bivariate Statistics
  - Regression Fit: $y = 1.000x + (-0.0002115)$
  - R Squared: 0.838
  - Correlation Coeff.: 0.915
  - Rank Corr. Coeff.: 0.910
North Dakota Oil Production

BOPD

source: https://www.dmr.nd.gov/oilgas/stats/historicaloilprodstats.pdf

June '16
1,026,584 BOPD
Middle Bakken – Entire Williston Basin - 6341 Wells
(completions since 1/15/2009, all operators >10 wells; NDIC production through May '16)
Acknowledgements

Co-workers at Liberty Resources
especially Stacy Strickland, Paul Weddle, Larry Griffin
and Juliana Chikaloff
Thank You / Questions