SPE Asia Pacific
Hydraulic Fracturing Conference

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BEIJING, CHINA

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

C. Mark Pearson

LIBERTY RESOURCES

Society of Petroleum Engineers

Liberty Resources LLC – Denver, CO

- 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 Introduction

FracFocus Chemical Disclosure Registry

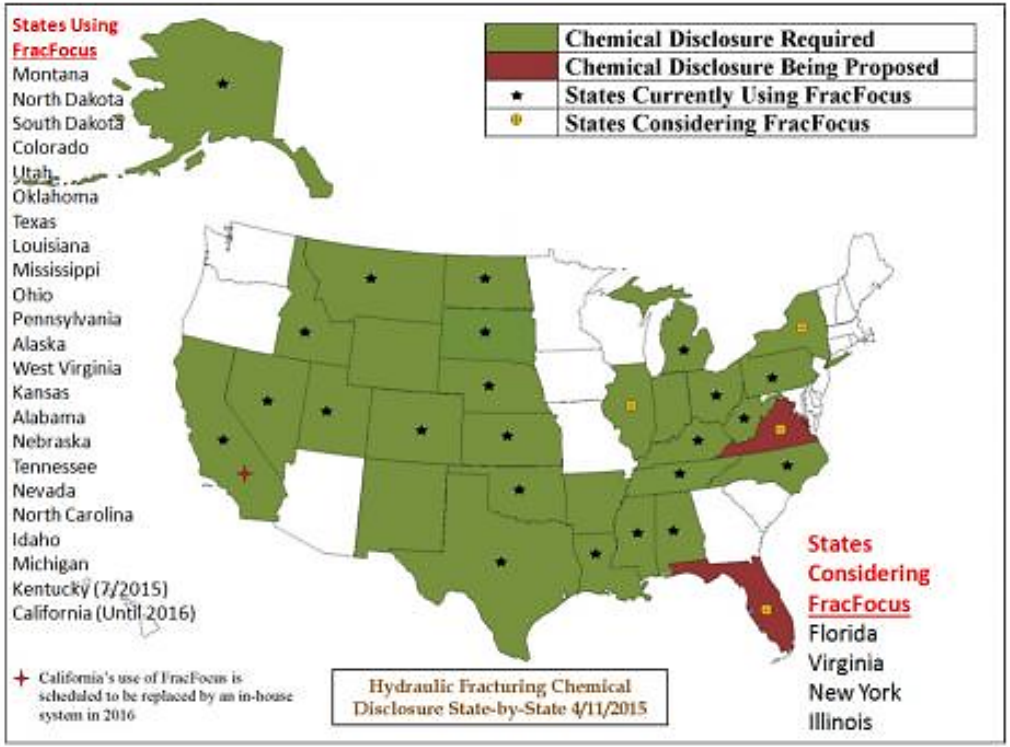
http://fracfocus.org

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.



FracFocus - Search for a Well

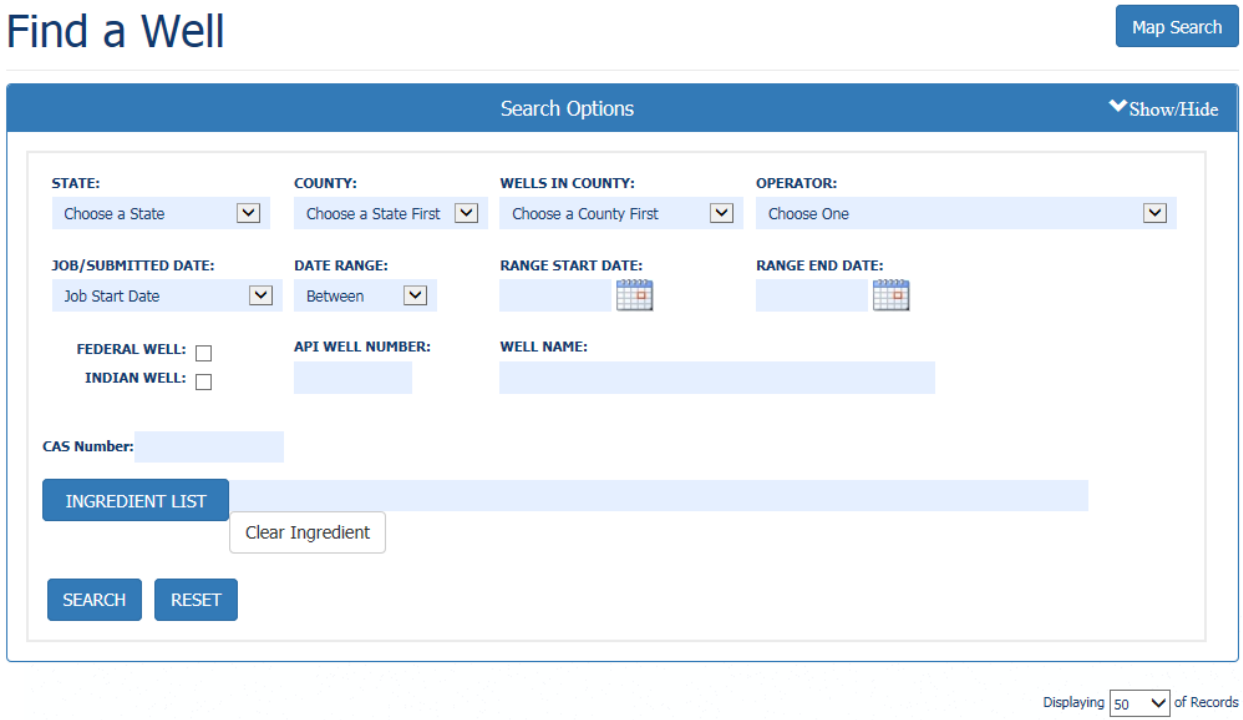
Start at the main FracFocus page **www.fracfocus.org** and click on Find a Well (on the green map).

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:



FracFocus Completed Entry Form Example

Fracture Start Date	11/23/2014
Fracture End Date	12/12/2014
State:	ND
County:	Williams
API Number:	33-105-03538
Operator Name:	Liberty Resources LLC
Well Name and Number:	Gohrick 158-95-17-8-5MBH
Longitude:	-102.976615
Latitude:	48.503657
Long/Lat Projection:	NAD83
Production Type:	Oil
Federal Well:	NO
True Vertical Depth (TVD):	9,612
Total Water Volume (gal)*:	8,136,702

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

Hydraulic Fracturing Fluid Composition:

Trade Name	Supplier	Purpose	Ingredients	Chemical Abstract Service Number (CAS #)	Maximum Ingredient Concentration in Additive (% by mass)**	Mass per Component (LBS)	Maximum Ingredient Concentration in HF Fluid (% by mass)**	Comments
Water	Operator	Carrier	Water	7732-18-5	100%	67,860,095	93.87275%	
FRP-20 (FR)	Liberty Oilfield	Friction reduction	Petroleum distillates, hydrotreated light	64742-47-8	30%	17,339	0.02399%	Stimlube W 3
SFT-72 (Surfactant)	Liberty Oilfield	Non Emulsifier	Proprietary Surfactants	68439-46-3	20%	5,176	0.00716%	Surfactant 13
			Methanol	67-56-1	15%	3,882	0.00537%	
			D-Limonene	5989-27-5	10%	2,588	0.00358%	
			Light Aromatic Naphtha	64742-95-6	5%	1,294	0.00179%	
CSA-23 (Clay Treat)	Liberty Oilfield	Permanent clay stabalizer	Trade Secret	Proprietary	100%	38,898	0.05381%	Liberty Clay Treat 1
CMB-6LF (intermediate)	WST	Biocide	Water	7732-18-5	54%	2,725	0.00377%	
			Ethylene Glycol	107-21-1	40%	2,019	0.00279%	
			Bronopol	52-51-7	5%	272	0.00038%	
			Mixture, contaning 5-Chloro-2-methyl-2H-	55965-84-9	1%	62	0.00009%	
LGA-68 (Guar)	Liberty Oilfield	Guar Slurry	Distillates Petroleum, Hydro Treated	64742-47-8	65%	21,756	0.03010%	Guar 7
BFH-68 (Buffer)	Liberty Oilfield	High pH Buffer	Potassium Hydroxide Solution	1310-58-3	30%	12	0.00002%	
			Sodium Hydroxide Solution	1310-73-2	30%	12	0.00002%	
XLB-88 (Crosslinker)	Liberty Oilfield	Crosslinker	Borate Salt	1303-96-4	30%	15	0.00002%	Crosslinker 1
			Polyol Mixture	NA	65%	33	0.00004%	
BHL-48 (Breaker)	Liberty Oilfield	Liquid Breaker	Chlorous Acid, Sodium Salt	7758-19-2	10%	1,752	0.00242%	Liquid Breaker 3
			Sodium Chloride	7647-14-5	30%	5,255	0.00727%	
SFT-72W	Liberty Oilfield	Non Emulsifier	Ethoxylated Alcohol	Proprietary	10%	1,775	0.00246%	Surfactant 13 Winterized
			d-Limonene	5989-27-5	5%	888	0.00123%	
			Methanol	67-56-1	40%	7,102	0.00982%	
			1,2,4-Trimethylbenzene	95-63-6	0%	36	0.00005%	
Clean Out Fluid	Liberty Oilfield	Cleanup Solution	Alkanes	Proprietary	100%	728	0.00101%	Liberty Clean Out Fluid
FR-1207 (FR)	Chem Rock	Friction Reducer	Hydrotreated Light Distillate	64742-47-8	20%	344	0.00048%	EOG FR
Ceramic Proppant-40/70	Liberty Oilfield	Proppant	Corundum	1305-25-1	65%	1,379,193	1.90788%	Liberty IS-Ceramic / LOS
			Mullite	1305-25-1	35%	742,643	1.02732%	
Ceramic Proppant-30/50	Liberty Oilfield	Proppant	Corundum	1305-25-1	65%	1,370,600	1.89599%	Liberty IS-Ceramic / LOS
			Mullite	1305-25-1	35%	738,016	1.02092%	

North Dakota Industrial Commission (NDIC) Monthly Production by Well

https://www.dmr.nd.gov/oilgas/

North Dakota nd.gov Official Portal for North Dakota State Government

Related Links
- Premium Services
- Scout Ticket Data
- Digital & Image Logs
- Field Production
- Map This Well
- Get Well File

Get Well Production History Data

Enter File Number: [ ]

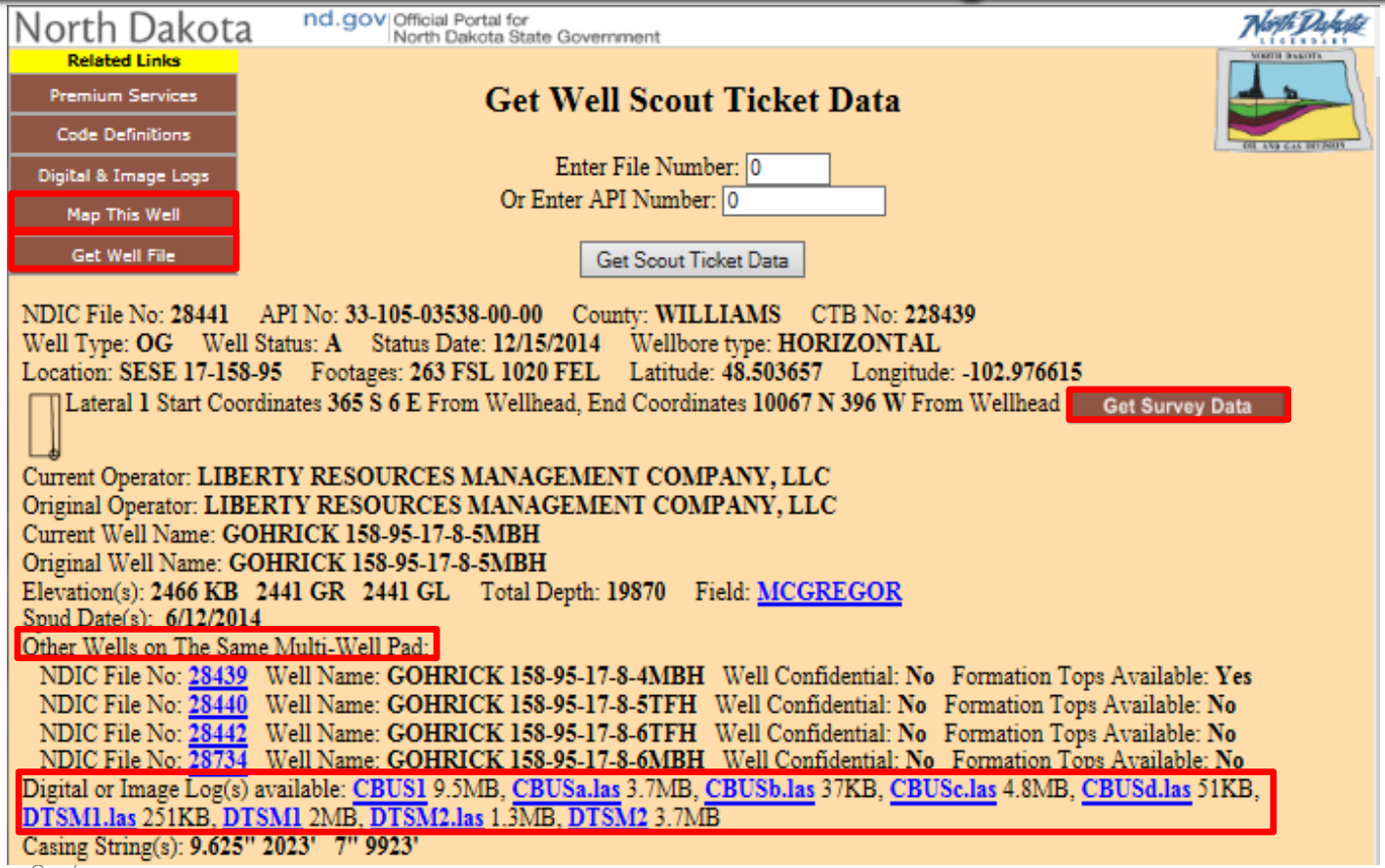
Get Monthly Production Data

NDIC File No: **28441** API No: **33-105-03538-00-00** CTB No: **228439**
Well Type: **OG** Well Status: **A** Status Date: **12/15/2014** Wellbore type: **Horizontal**
Location: **SESE 17-158-95** Footages: **263 FSL 1020 FEL** Latitude: **48.503657** Longitude: **-102.976615**
Current Operator: **LIBERTY RESOURCES MANAGEMENT COMPANY, LLC**
Current Well Name: **GOHRICK 158-95-17-8-5MBH**
Elevation(s): **2466 KB 2441 GR 2441 GL** Total Depth: **19870** Field: **MCGREGOR**
Spud Date(s): **6/12/2014**
Casing String(s): **9.625" 2023' 7" 9923'**
Completion Data
Pool: **BAKKEN** Perfs: **9923-19870** Comp: **12/15/2014** Status: **AL** Date: **6/19/2015** Spacing: **2SEC**
Cumulative Production Data
Pool: **BAKKEN** Cum Oil: **186295** Cum MCF Gas: **304202** Cum Water: **337178** [Interactive Performance Curve] [PDF Curve]
Production Test Data
IP Test Date: **12/29/2014** Pool: **BAKKEN** IP Oil: **1032** IP MCF: **1116** IP Water: **3461**
Monthly Production Data

Pool	Date	Days	BBLS Oil	Runs	BBLS Water	MCF Prod	MCF Sold	Vent/Flare
BAKKEN	6-2016	30	3257	3123	8149	22886	17437	5449
BAKKEN	5-2016	31	4641	4592	8845	24304	13785	10519
BAKKEN	4-2016	30	5139	5202	7997	24130	21637	2493
BAKKEN	3-2016	30	5668	5571	8461	14548	13342	1206
BAKKEN	2-2016	24	5078	5044	7659	12728	10658	2070
BAKKEN	1-2016	28	7107	6811	12307	15020	14063	957

NDIC Scout Ticket Data

https://www.dmr.nd.gov/oilgas/



North Dakota nd.gov Official Portal for North Dakota State Government

Related Links
Premium Services
Code Definitions
Digital & Image Logs
Map This Well
Get Well File

Get Well Scout Ticket Data

Enter File Number: 0
Or Enter API Number: 0

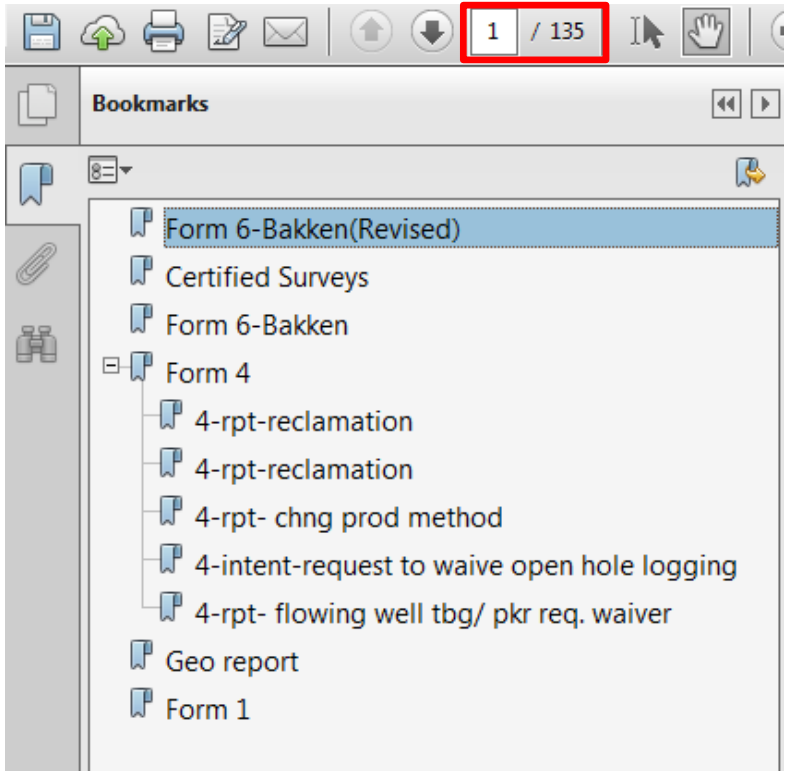
Get Scout Ticket Data

NDIC File No: **28441** API No: **33-105-03538-00-00** County: **WILLIAMS** CTB No: **228439**
Well Type: **OG** Well Status: **A** Status Date: **12/15/2014** Wellbore type: **HORIZONTAL**
Location: **SESE 17-158-95** Footages: **263 FSL 1020 FEL** Latitude: **48.503657** Longitude: **-102.976615**
Lateral **1** Start Coordinates **365 S 6 E** From Wellhead, End Coordinates **10067 N 396 W** From Wellhead Get Survey Data

Current Operator: **LIBERTY RESOURCES MANAGEMENT COMPANY, LLC**
Original Operator: **LIBERTY RESOURCES MANAGEMENT COMPANY, LLC**
Current Well Name: **GOHRICK 158-95-17-8-5MBH**
Original Well Name: **GOHRICK 158-95-17-8-5MBH**
Elevation(s): **2466 KB 2441 GR 2441 GL** Total Depth: **19870** Field: MCGREGOR
Spud Date(s): **6/12/2014**
Other Wells on The Same Multi-Well Pad:
NDIC File No: 28439 Well Name: **GOHRICK 158-95-17-8-4MBH** Well Confidential: **No** Formation Tops Available: **Yes**
NDIC File No: 28440 Well Name: **GOHRICK 158-95-17-8-5TFH** Well Confidential: **No** Formation Tops Available: **No**
NDIC File No: 28442 Well Name: **GOHRICK 158-95-17-8-6TFH** Well Confidential: **No** Formation Tops Available: **No**
NDIC File No: 28734 Well Name: **GOHRICK 158-95-17-8-6MBH** Well Confidential: **No** Formation Tops Available: **No**
Digital or Image Log(s) available: CBUS1 9.5MB, CBUSa.las 3.7MB, CBUSb.las 37KB, CBUSc.las 4.8MB, CBUSd.las 51KB, DTSM1.las 251KB, DTSM1 2MB, DTSM2.las 1.3MB, DTSM2 3.7MB
Casing String(s): **9.625" 2023' 7" 9923'**

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)

Well Bore	String Type	String Size (Inch)	Top Set (MD Ft)	Depth Set (MD Ft)	Hole Size (Inch)	Weight (Lbs/Ft)	Anchor Set (MD Ft)	Packer Set (MD Ft)	Sacks Cement	Top of Cement
Lateral1	Conductor	16		105	16	K-55				
	Surface	9 5/8		2023	13 1/2	36, J55			625	0
	Intermediate	7		9923	8 3/4	32			1145	0
	Liner	4 1/2		19855	6	11.6			633	9046
	Tubing	2 7/8		9018						

Cemented vs Uncemented

PERFORATION & OPEN HOLE INTERVALS

Well Bore	Well Bore TD Drillers Depth (MD Ft)	Completion Type	Open Hole/Perforated Interval (MD,Ft) Top	Open Hole/Perforated Interval (MD,Ft) Bottom	Kick-off Point (MD Ft)	Top of Casing Window (MD Ft)	Date Perf'd or Drilled	Date Isolated	Isolation Method	Sacks Cement
Lateral1	19870		9938	19555	9128					

Perforated Interval

Frac Data

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

Well Specific Stimulations

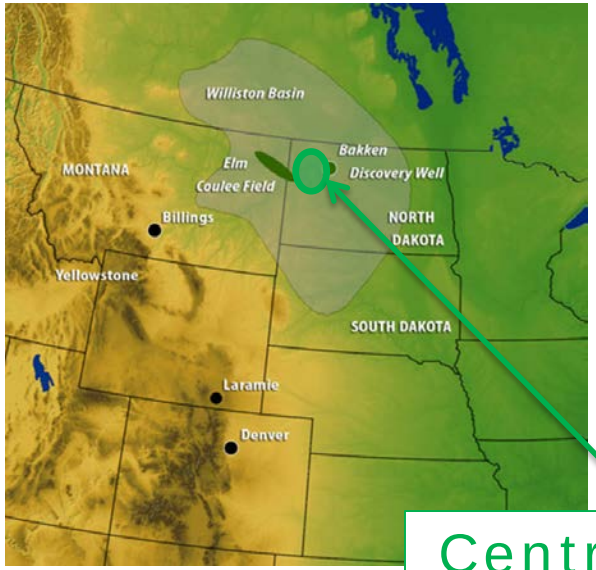
Date Stimulated	Stimulated Formation	Top (Ft)	Bottom (Ft)	Stimulation Stages	Volume	Volume Units
12/13/2014	Bakken	9938	19555	50	193731	Barrels

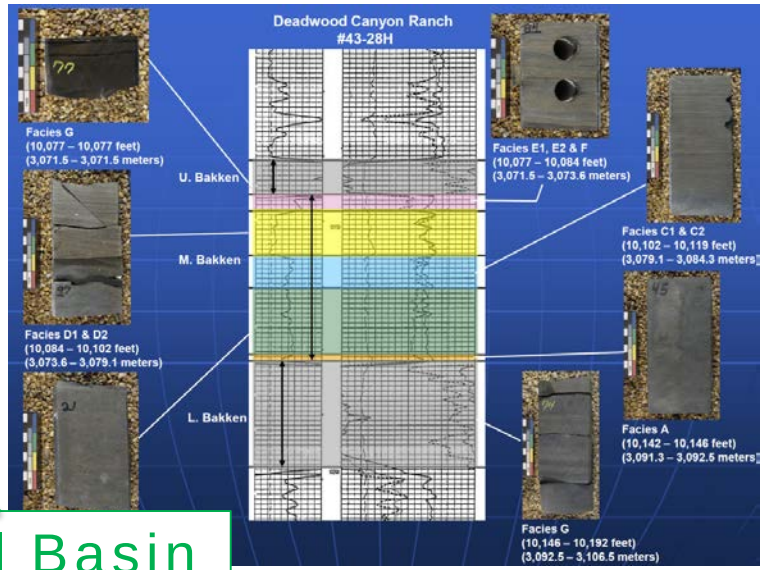
Type Treatment	Acid %	Lbs Proppant	Maximum Treatment Pressure (PSI)	Maximum Treatment Rate (BBLS/Min)
Sand Frac	0%	4218773	9528	84.0

Details

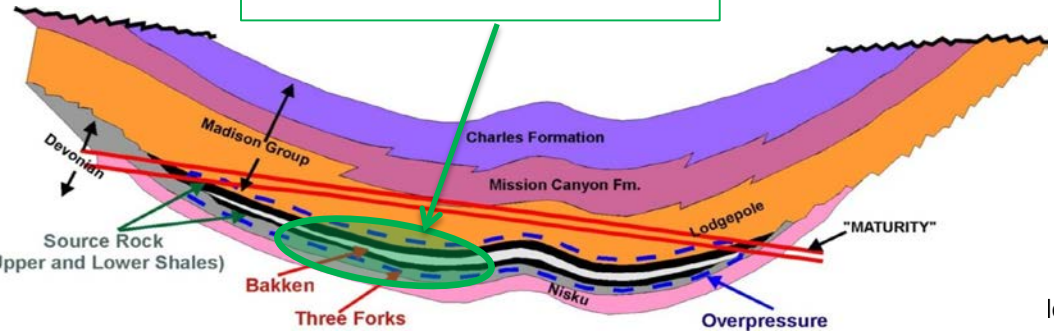
4,218,773 of 40/70 & 30/50 proppant

Bakken Shale – Williston Basin

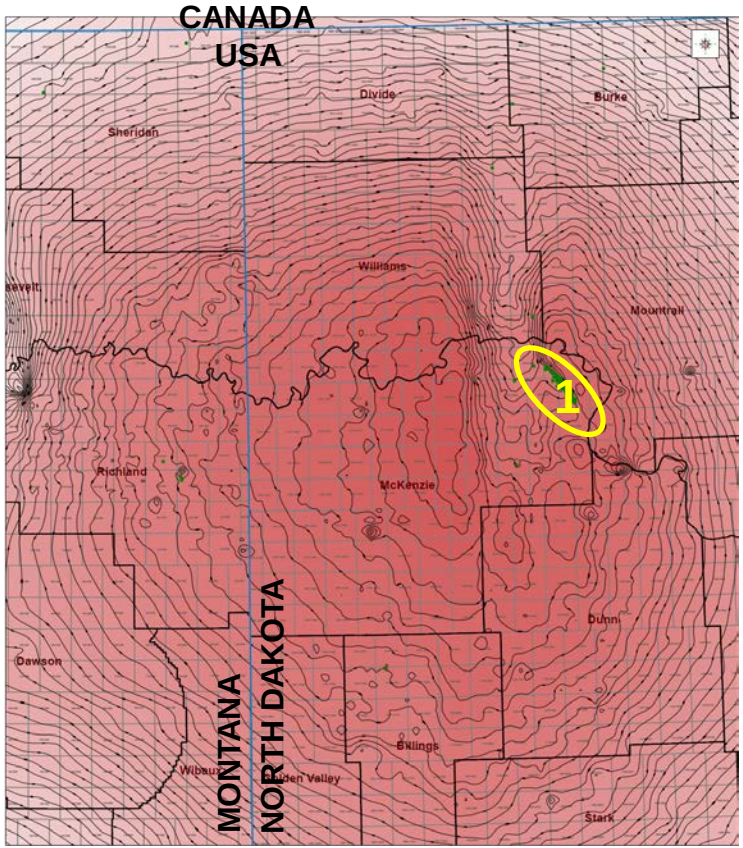




Central Basin



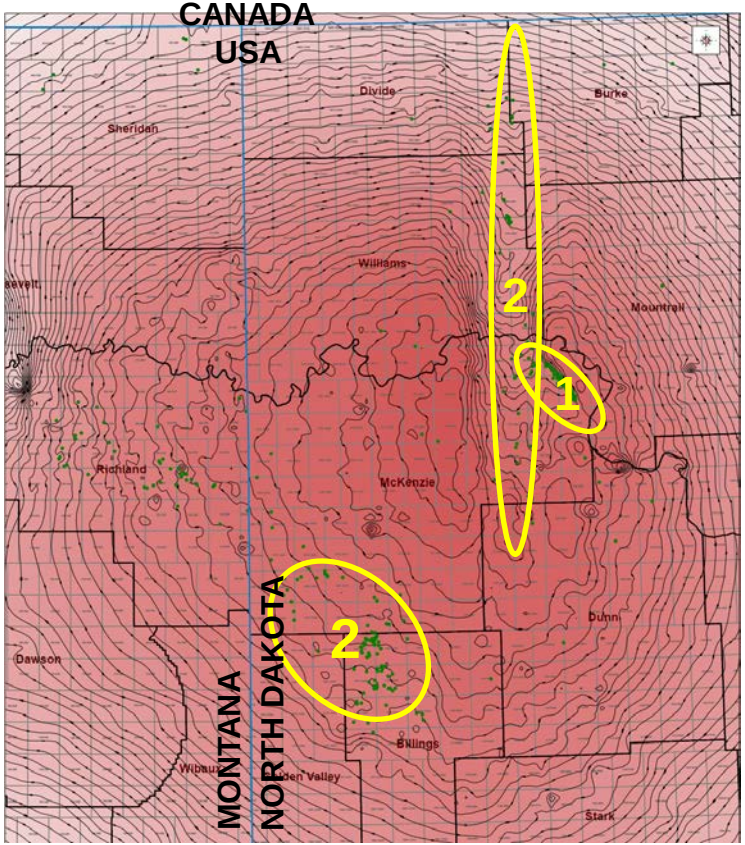
Bakken Structure and Development History



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**
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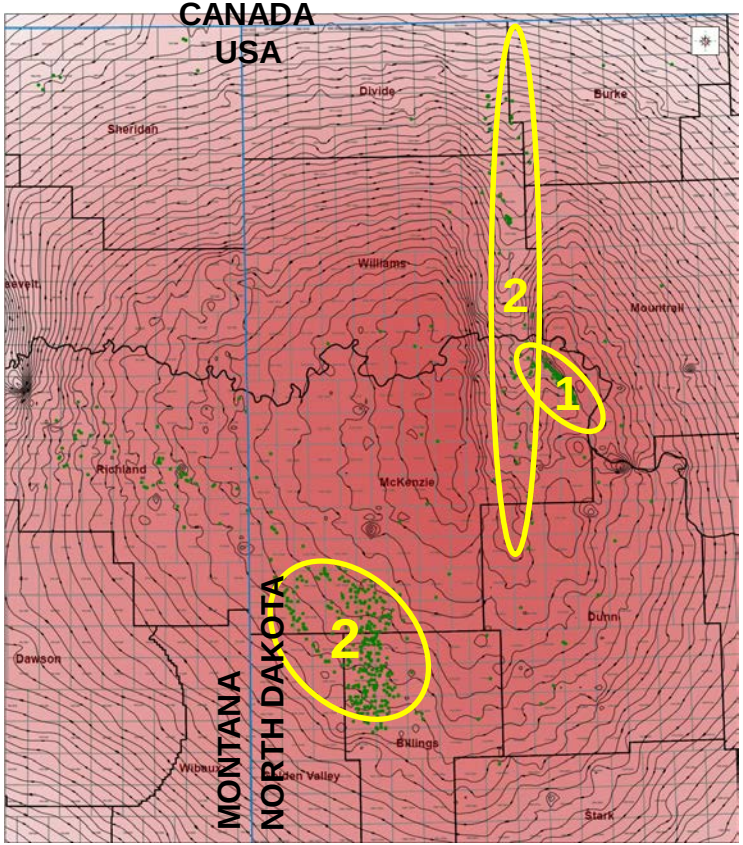
5. Central Basin

1971 to 1985
Well Count
+190

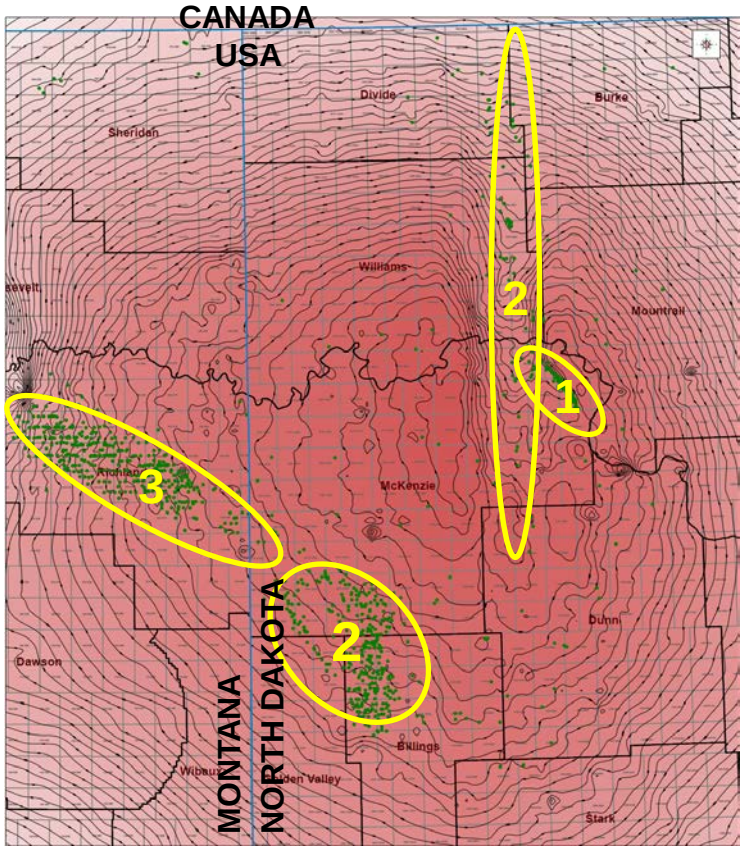
Bakken Structure and Development History



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

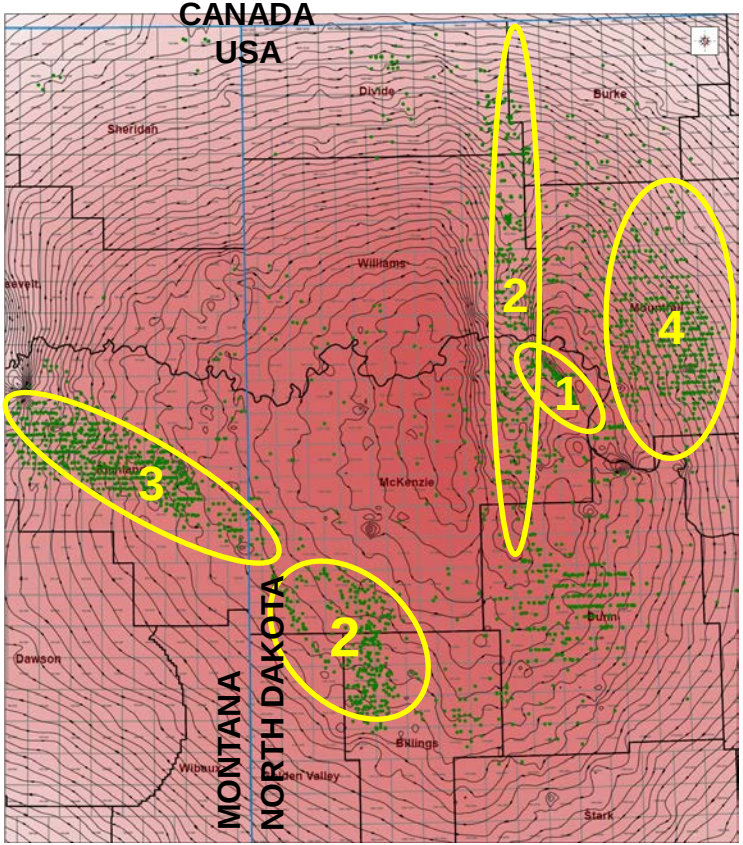
Bakken Structure and Development History



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

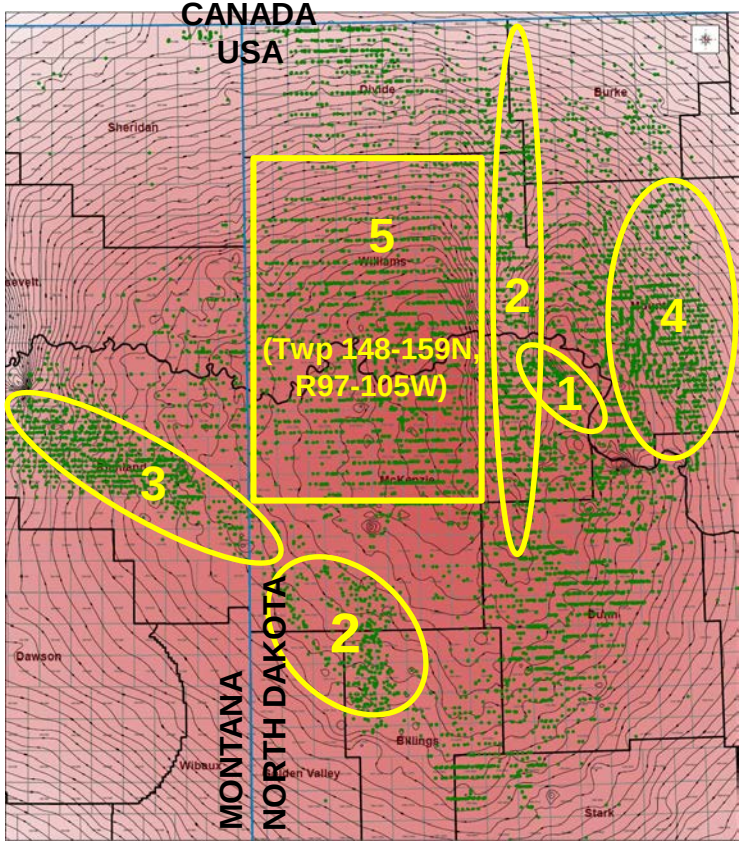
Bakken Structure and Development History



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

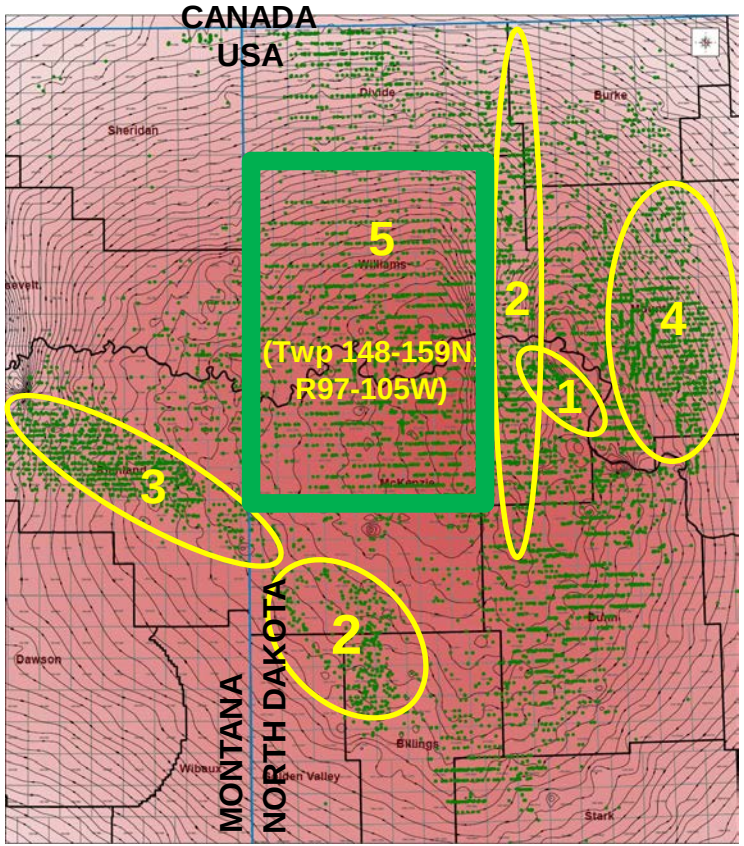
Bakken Structure and Development History



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

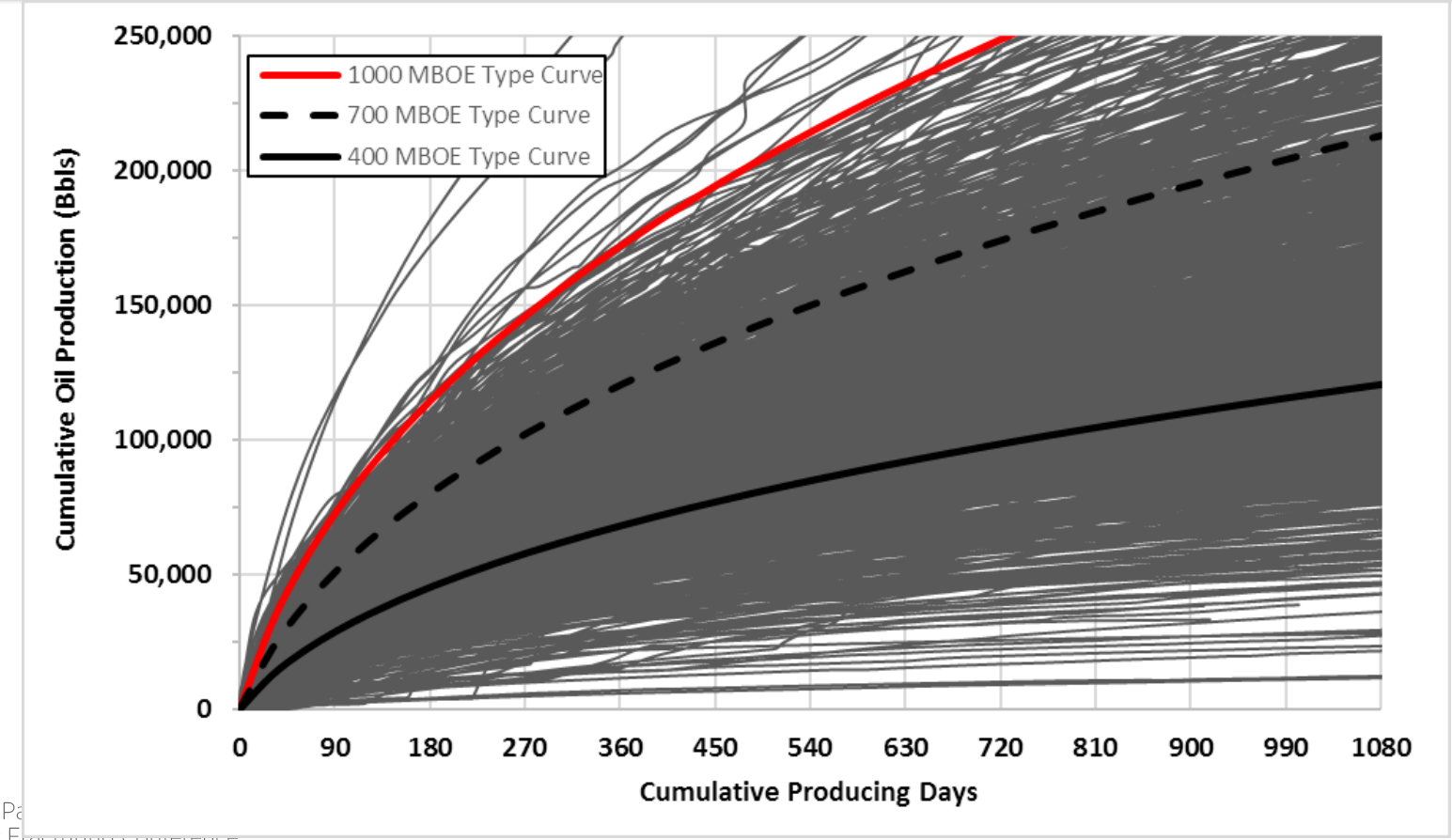
Central Basin Initial Development (2009-2012)



- 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 mi^2)

Williston Central Basin

Cumulative Oil Production – Middle Bakken Wells Completed 2009-2012

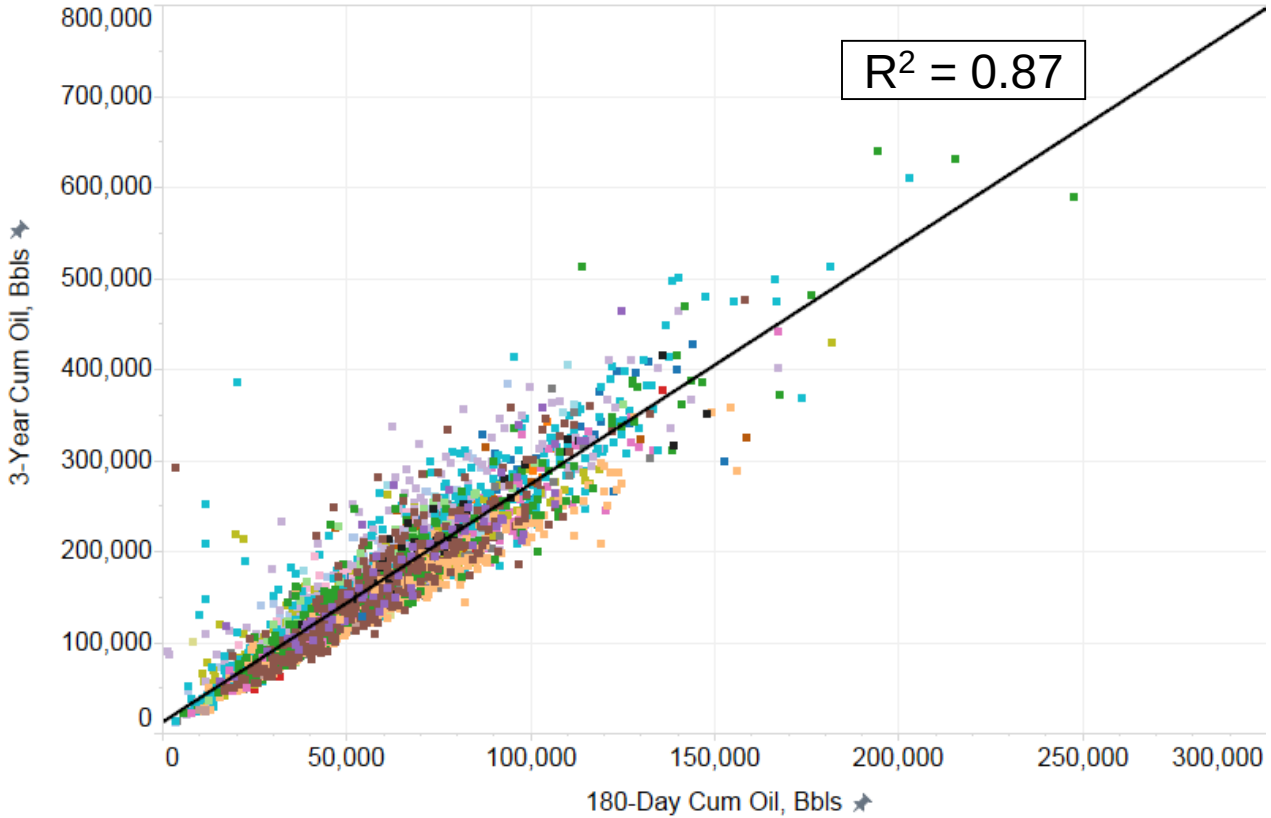


Options in defining a relevant production metric

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



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

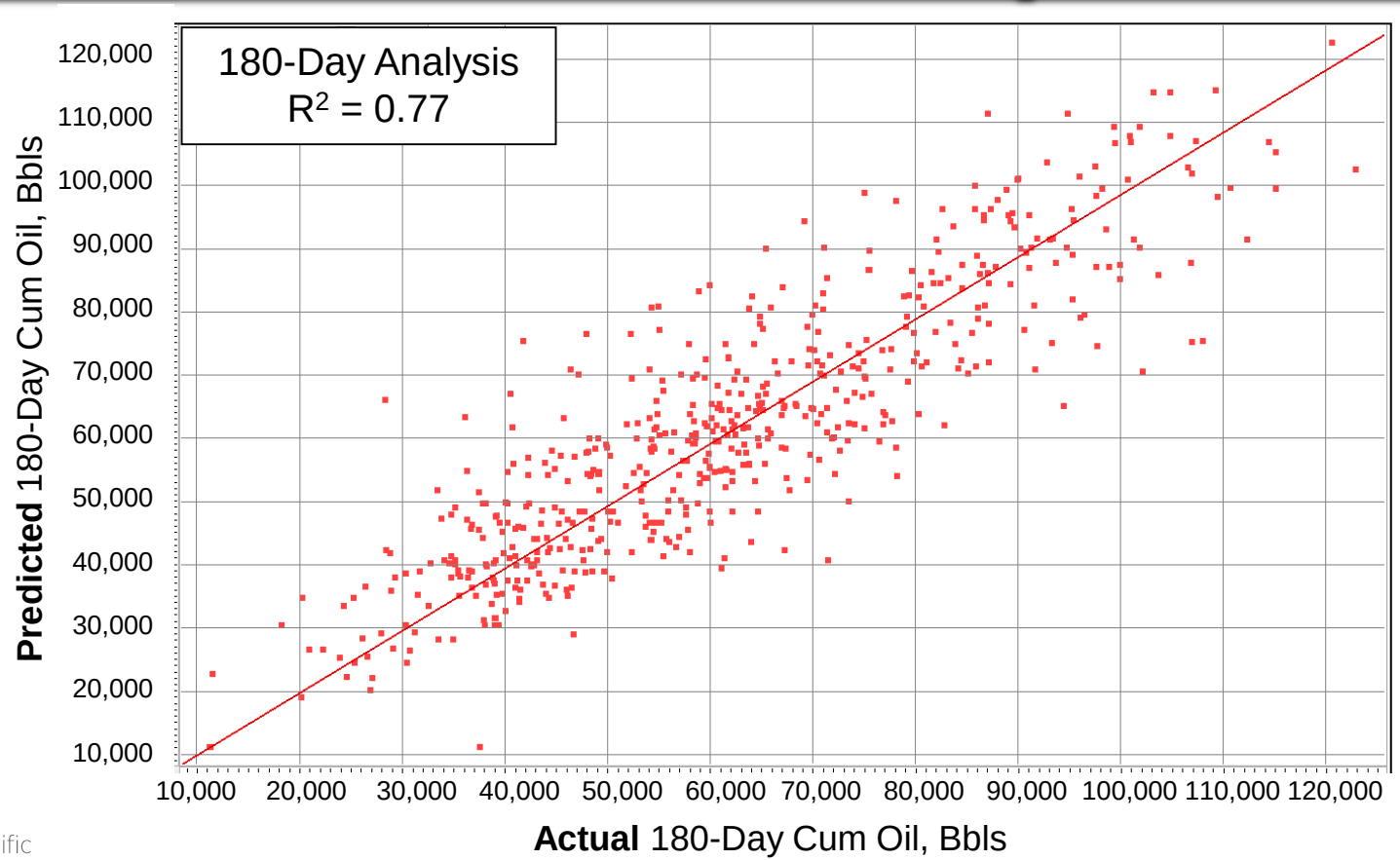
Multi-Variate Analysis

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”)

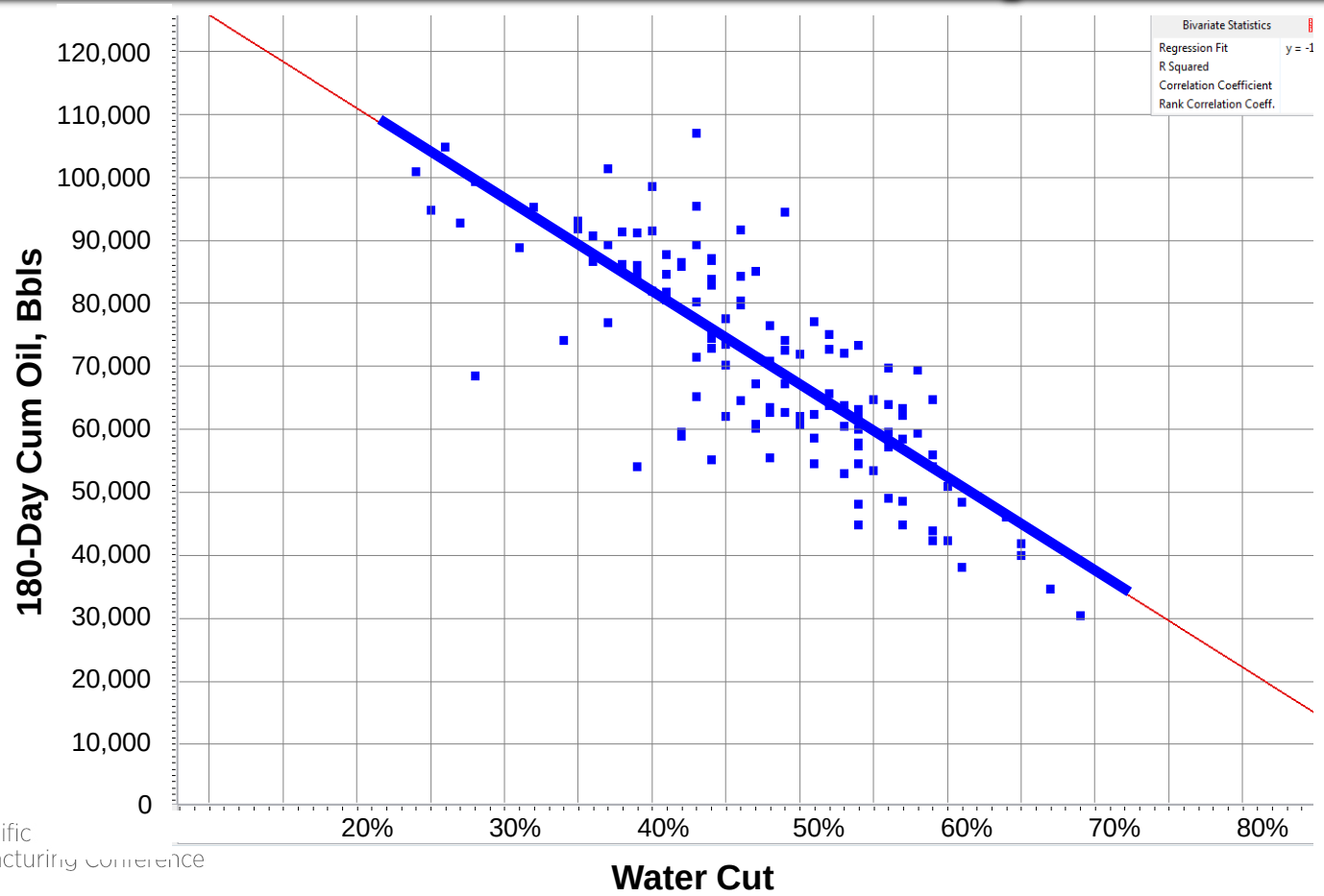
Multivariate Model Predicted vs. Actual

180-Day Cum Oil Analysis



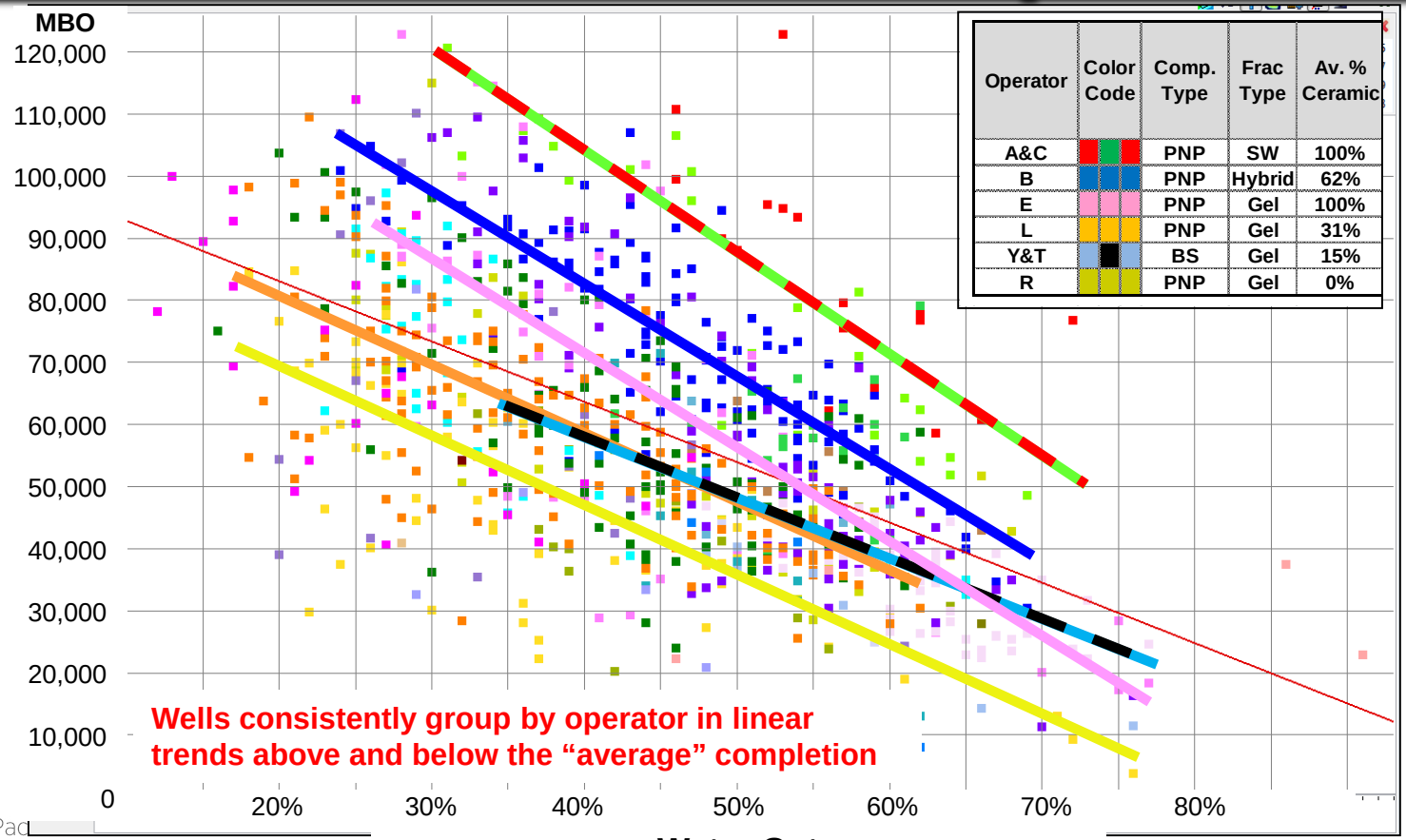
180 Day Production vs. Cum Water Cut

Single Operator



Different Completion Methods

Operator 180 Day Production vs. Water Cut



Operator	Color Code	Comp. Type	Frac Type	Av. % Ceramic
A&C		PNP	SW	100%
B		PNP	Hybrid	62%
E		PNP	Gel	100%
L		PNP	Gel	31%
Y&T		BS	Gel	15%
R		PNP	Gel	0%

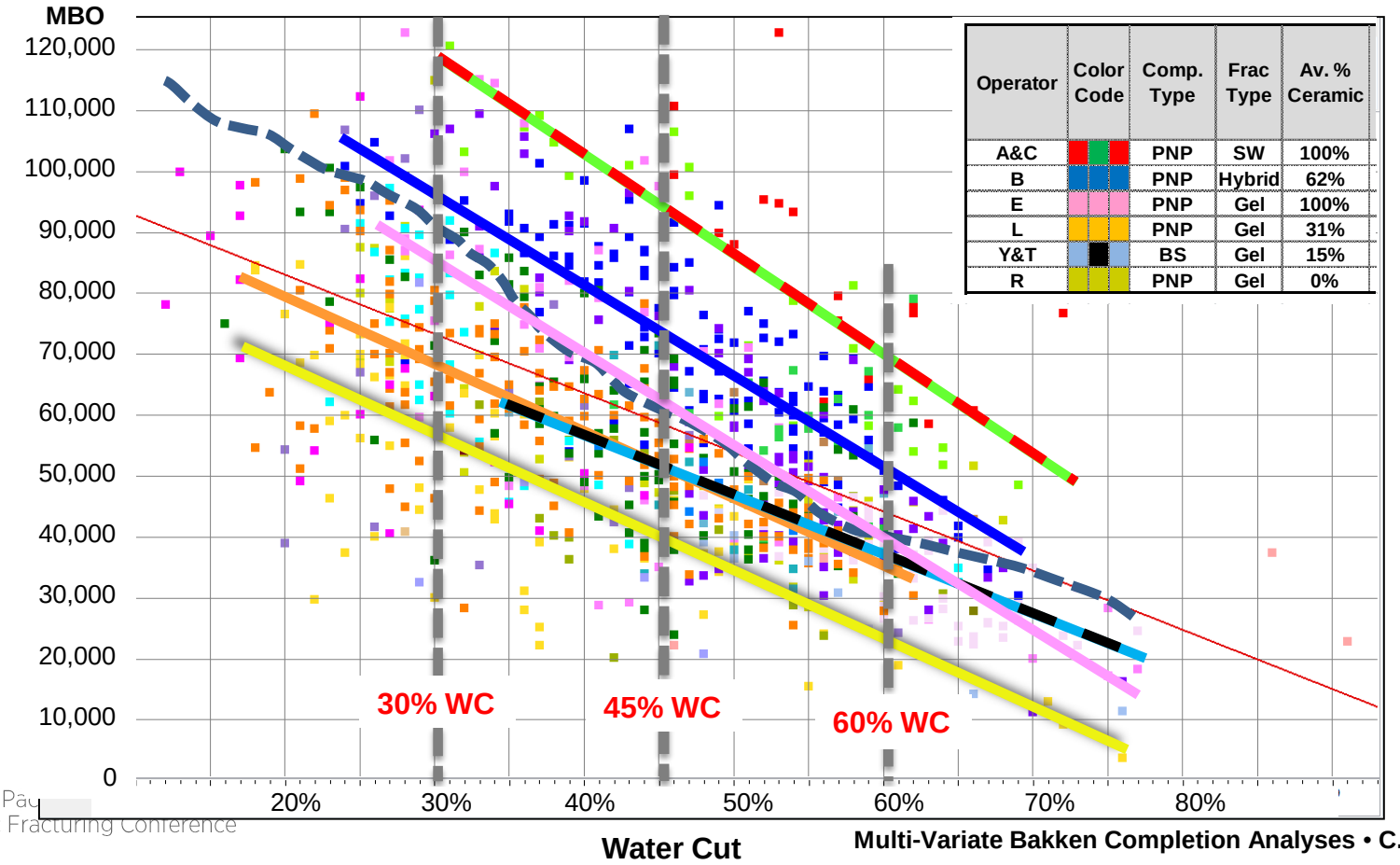
General Completion Type and Cost By Operator

- **Six different completion types run between 8 operators**

Operator	Color Code	Number Wells	Liner	Av. No. Stgs	Comp. Type	Frac Type	Av. lbs/ft	Av. bbls/ft	Av. % Sand	Av. % Ceramic
A&C		45	SP	35	PNP	SW	396	25.1	0%	100%
B		144	SP	34	PNP	Hybrid	395	7.9	38%	62%
E		56	Cmt	25	PNP	Gel	353	7.8	0%	100%
L		157	SP	30	PNP	Gel	288	5.7	68%	31%
Y&T		68	SP	28	BS	Gel	300	6.1	83%	15%
R		76	SP	25	PNP	Gel	264	6.5	**100%**	**0%**

Swell Packer	**SP**
Cemented Liner	**Cmt**
Plug and Perf	**PNP**
Ball and Sleeve	**BS**
Slickwater	**SW**
XL Gel	**Gel**
Hybrid Slickwater/Gel	**Hybrid**

Different Completion Methods
Operator 180 Day Production vs. Water Cut

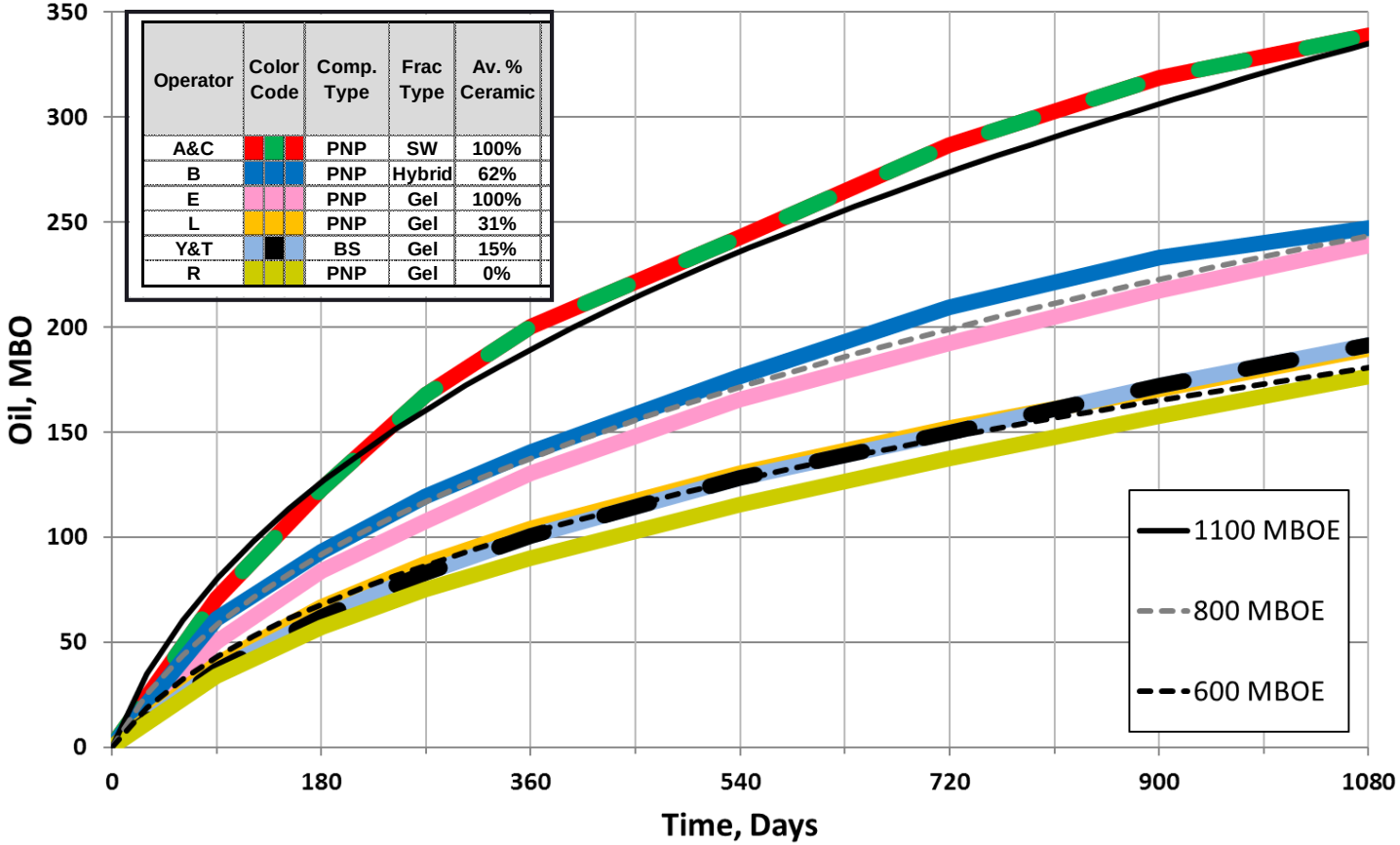


Operator	Color Code	Comp. Type	Frac Type	Av. % Ceramic
A&C		PNP	SW	100%
B		PNP	Hybrid	62%
E		PNP	Gel	100%
L		PNP	Gel	31%
Y&T		BS	Gel	15%
R		PNP	Gel	0%

EUR by Completion Technique

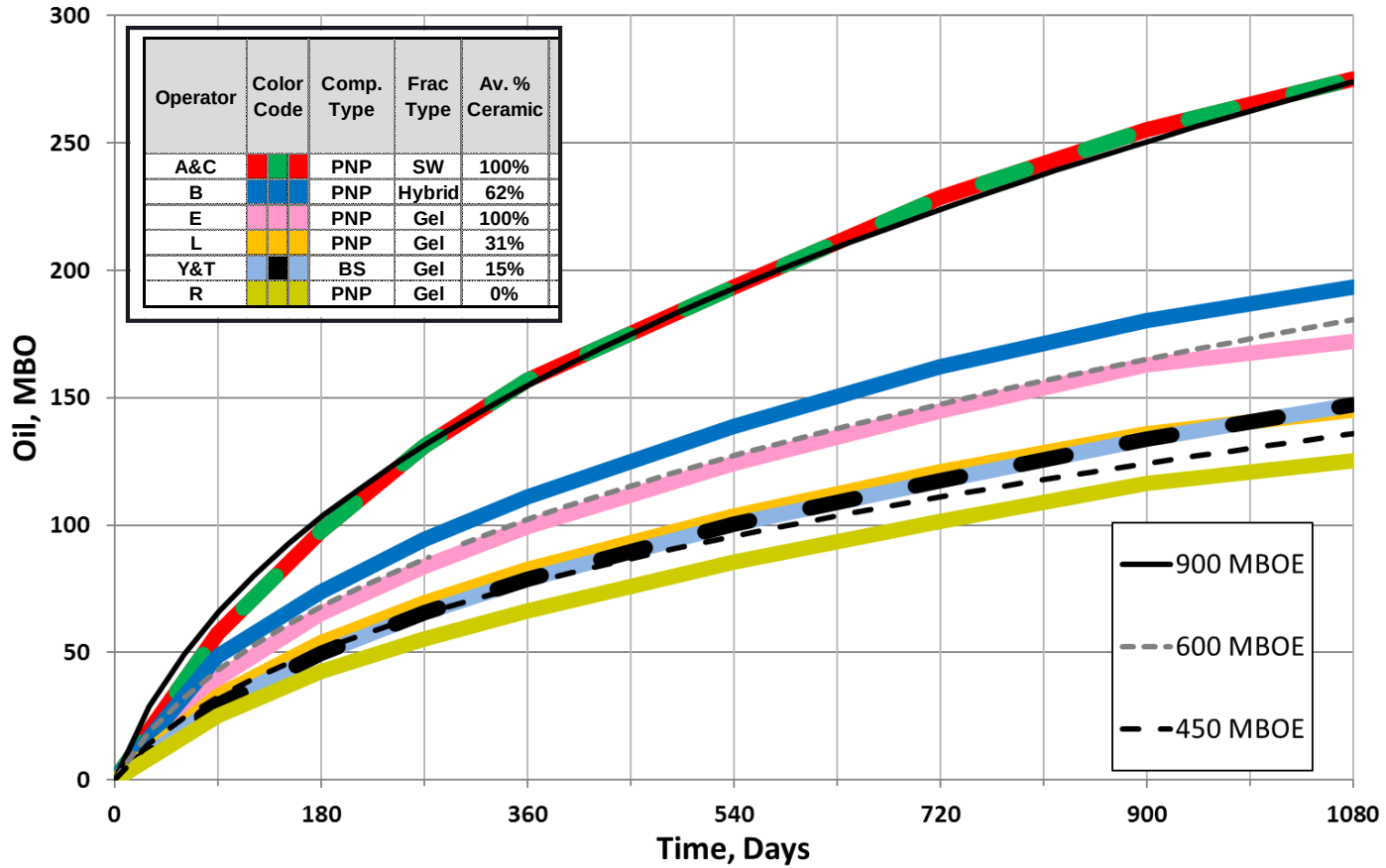
(2009-2012 Central Basin Wells; 30% Water Cut Areas)

Operator	Color Code	Comp. Type	Frac Type	Av. % Ceramic
A&C		PNP	SW	100%
B		PNP	Hybrid	62%
E		PNP	Gel	100%
L		PNP	Gel	31%
Y&T		BS	Gel	15%
R		PNP	Gel	0%



EUR by Completion Technique

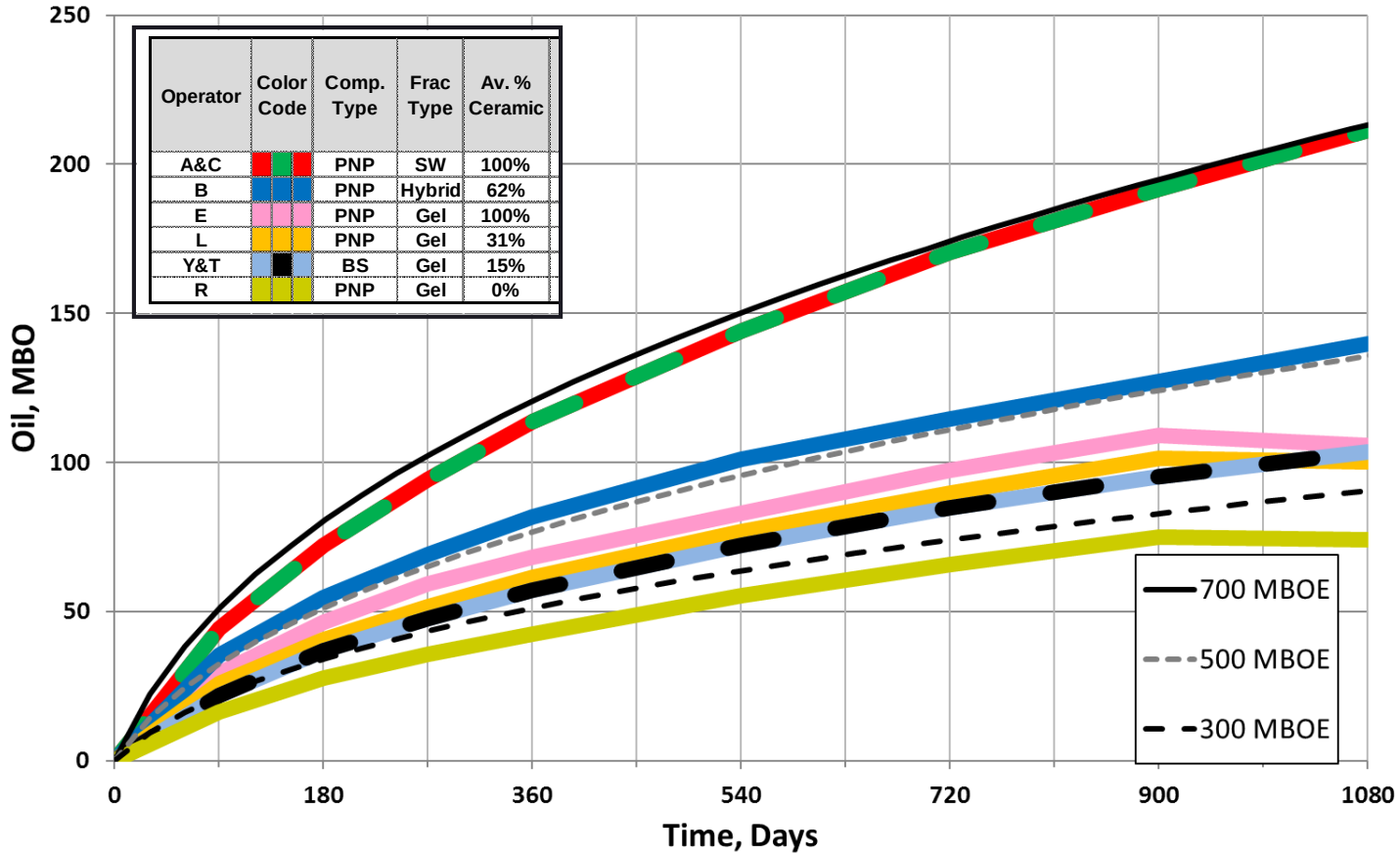
(2009-2012 Central Basin Wells; 45% Water Cut Areas)



EUR by Completion Technique

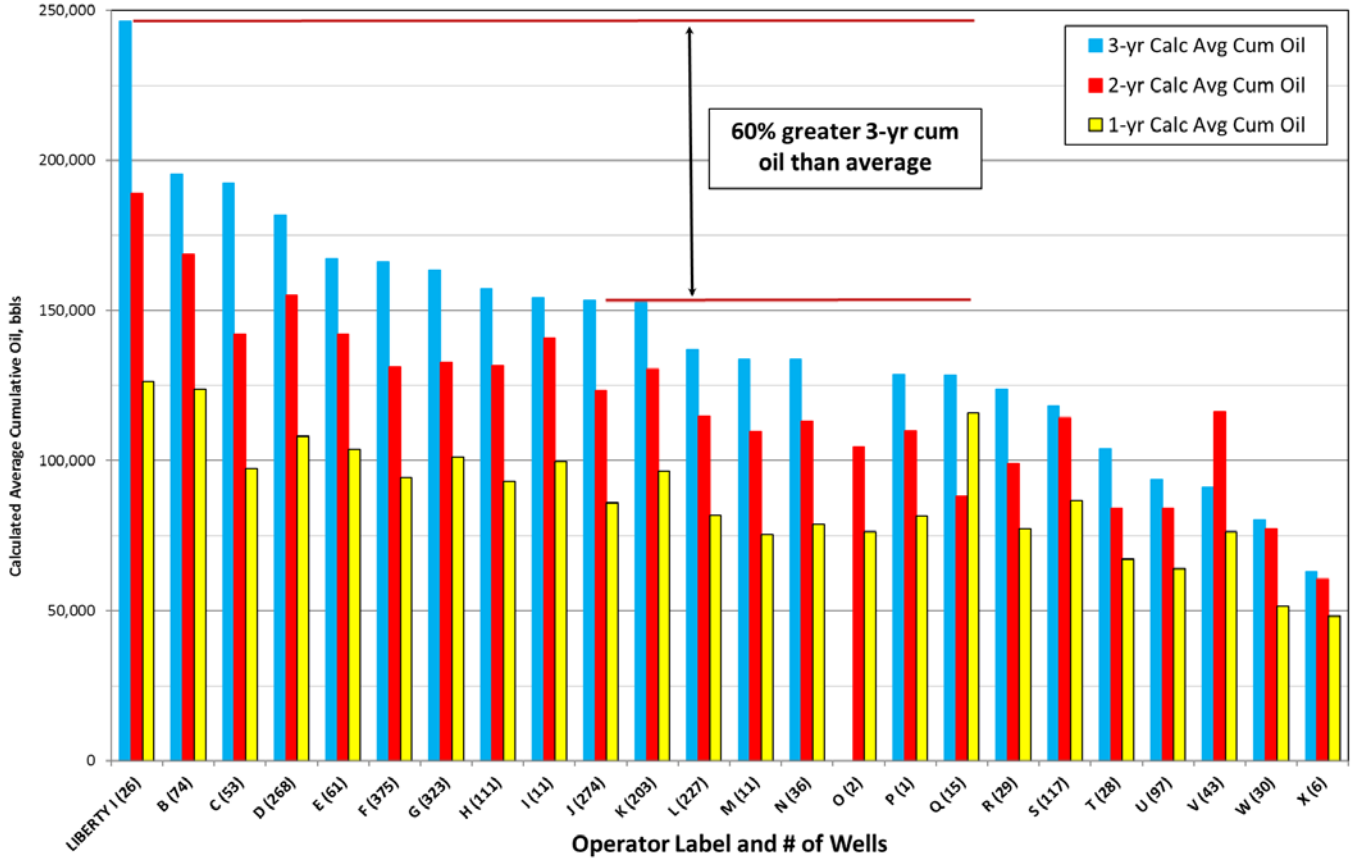
(2009-2012 Central Basin Wells; 60% Water Cut Areas)

Operator	Color Code	Comp. Type	Frac Type	Av. % Ceramic
A&C		PNP	SW	100%
B		PNP	Hybrid	62%
E		PNP	Gel	100%
L		PNP	Gel	31%
Y&T		BS	Gel	15%
R		PNP	Gel	0%



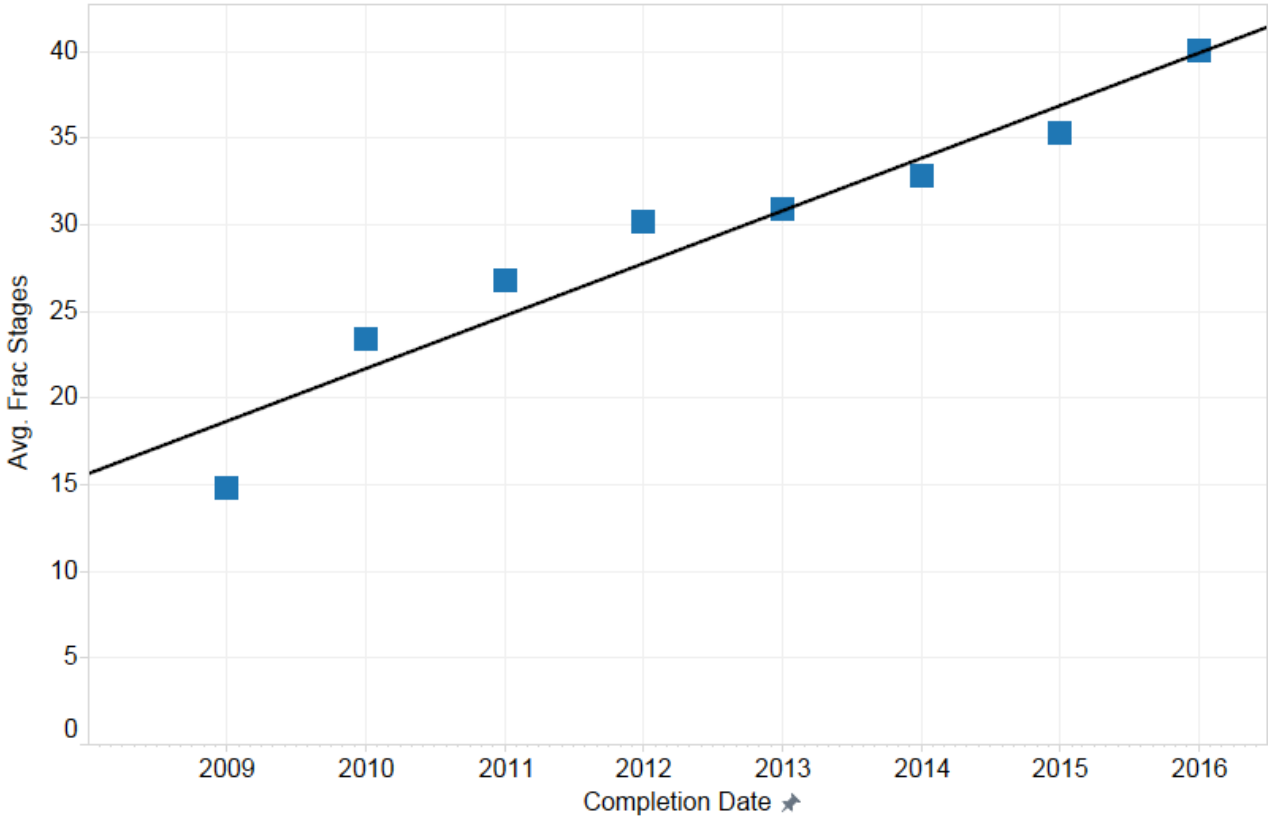
Central Basin (T148-159, R97-105) - 2421 Wells

(completions since 1/15/2009, production through May '16)

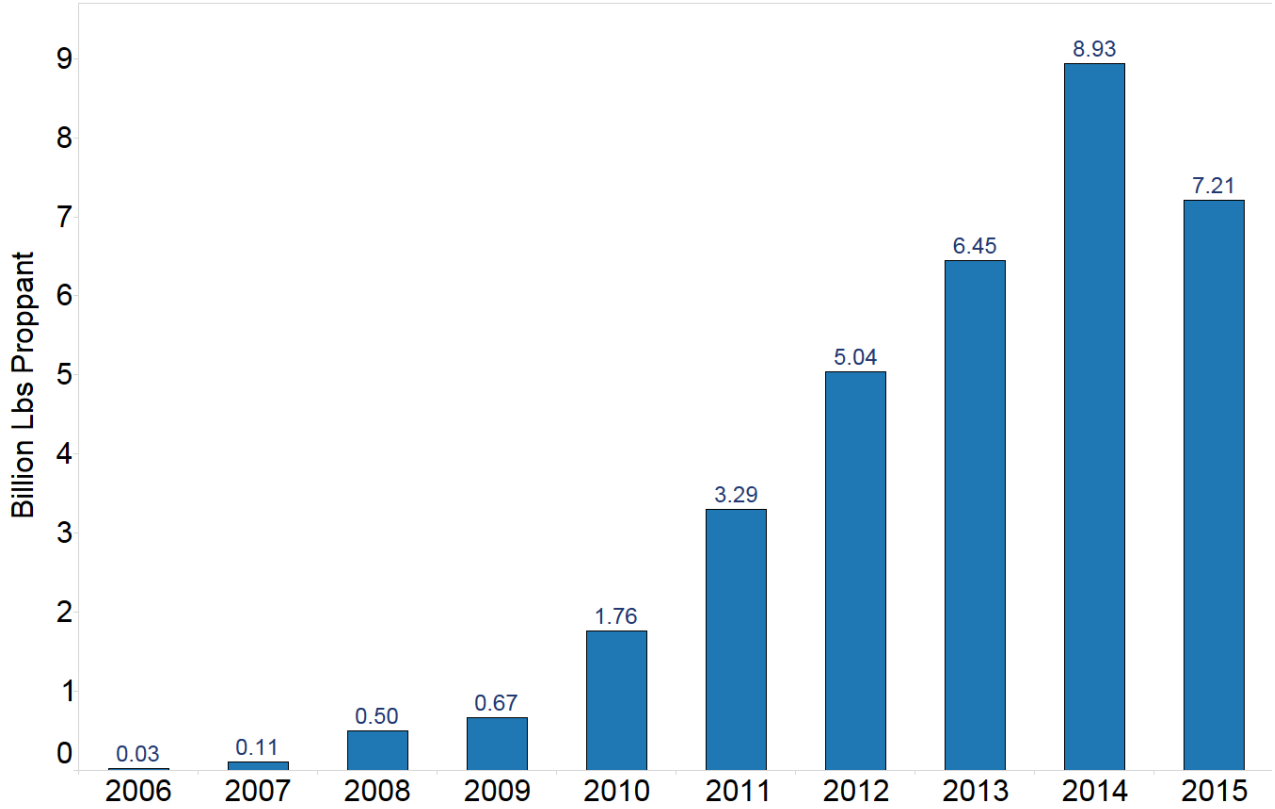


- How has Industry put these learnings to work?

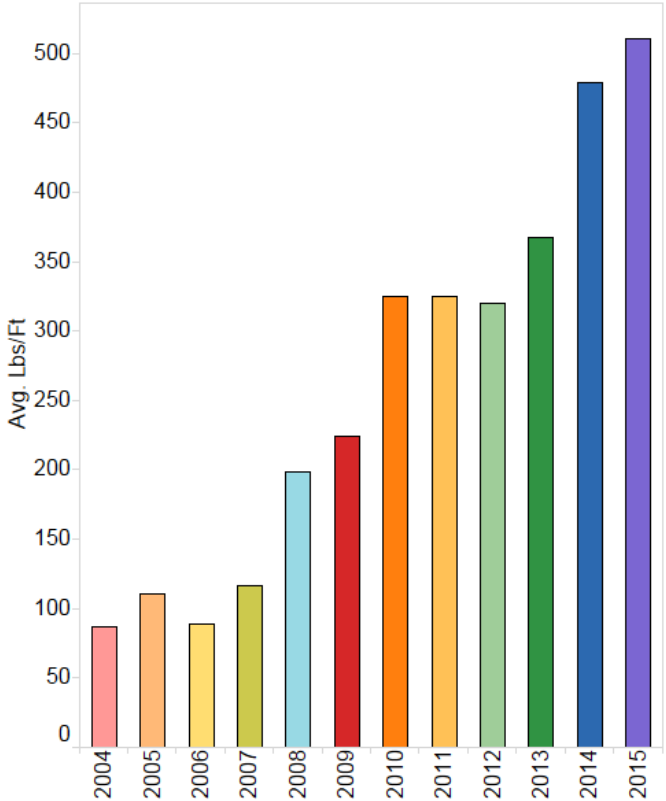
ND Average Stage Count (2-mile laterals) by Year

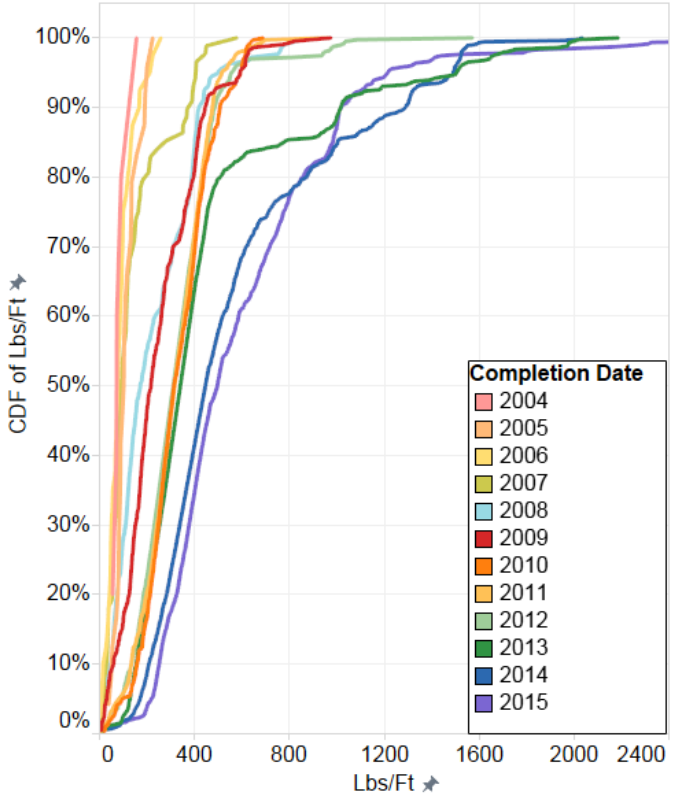


North Dakota Proppant Pumped by Year

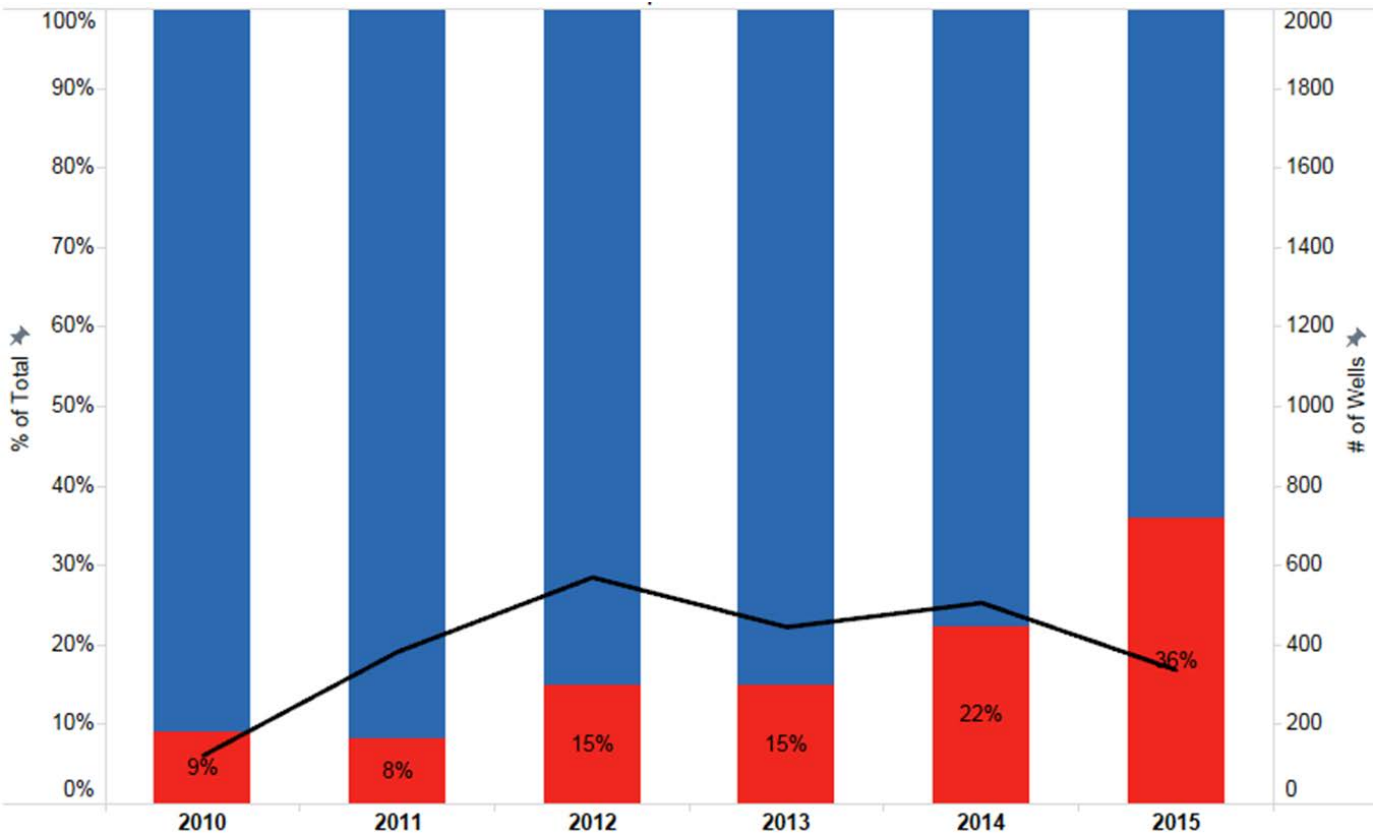


Middle Bakken Proppant, Lbs/Ft, by Year

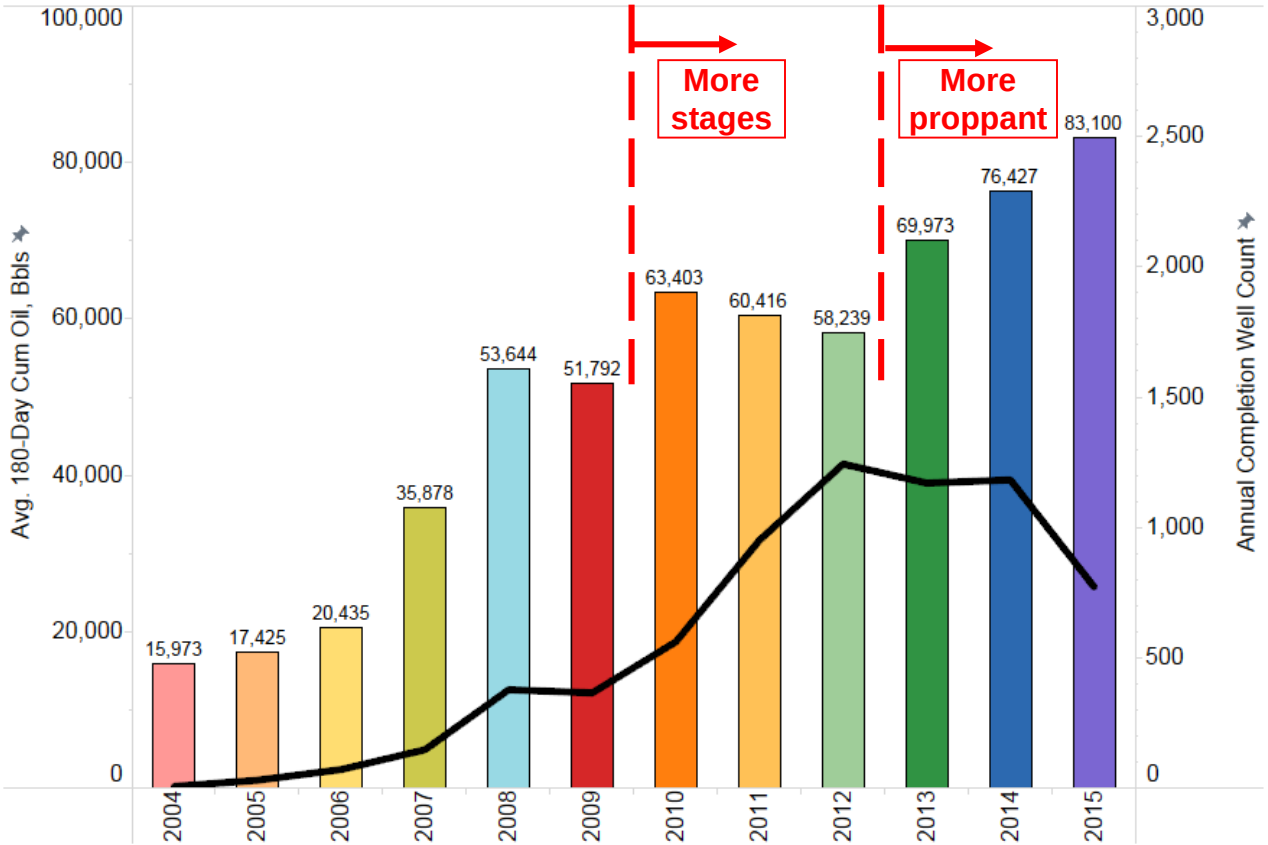




Increased Use of Slickwater Completions
(Cental Basin Middle Bakken Wells)



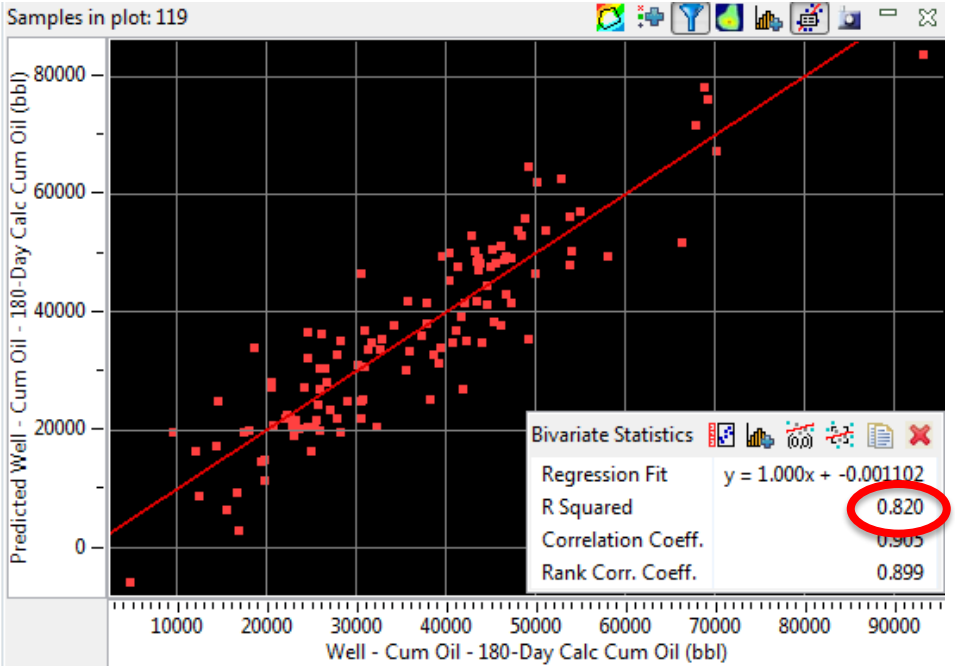
Average Middle Bakken 180-Day Cum Oil by Year

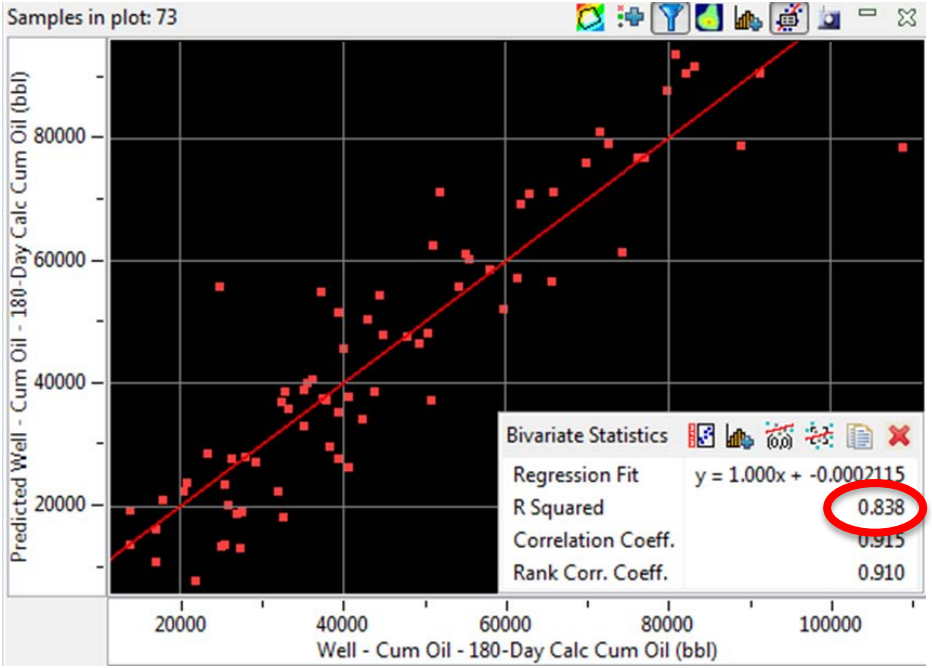


Current Multivariate Input Parameters

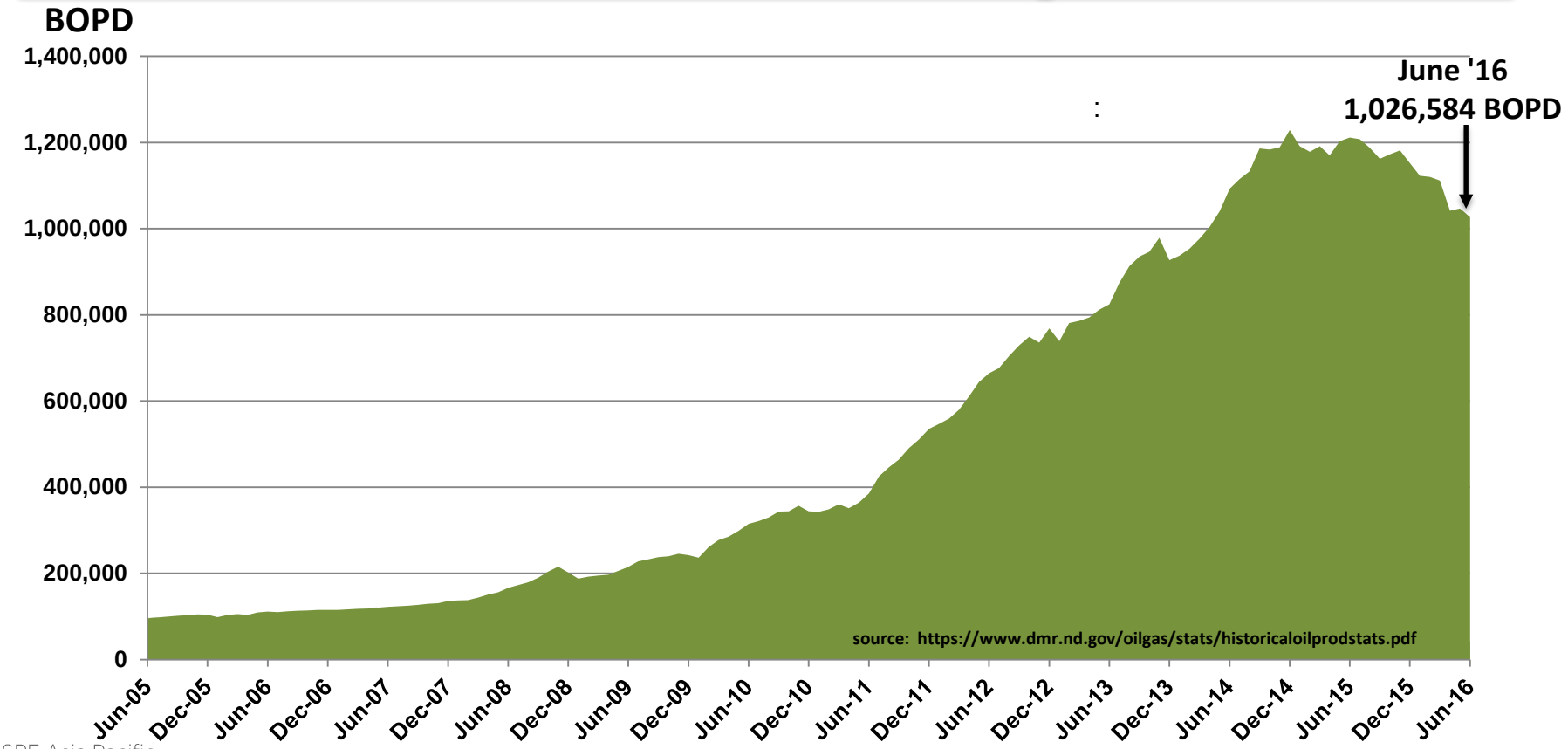
- **Reservoir / Geological / Production**
  - Township and Range
  - Cumulative ***Shifted*** Water Cut
  - Cumulative GOR
- **Completion / Frac Design**
  - Lateral Length, ft
  - Cemented Liner
  - Well Order
  - Stage Length, ft/stage - (number stages)
  - Proppant Amount, lbs/ft
  - Average Proppant Concentration, ppg
  - Fluid Volume, bbls/ft
  - Proppant Type, % sand

Current Multi-Variate Example Modeling Results



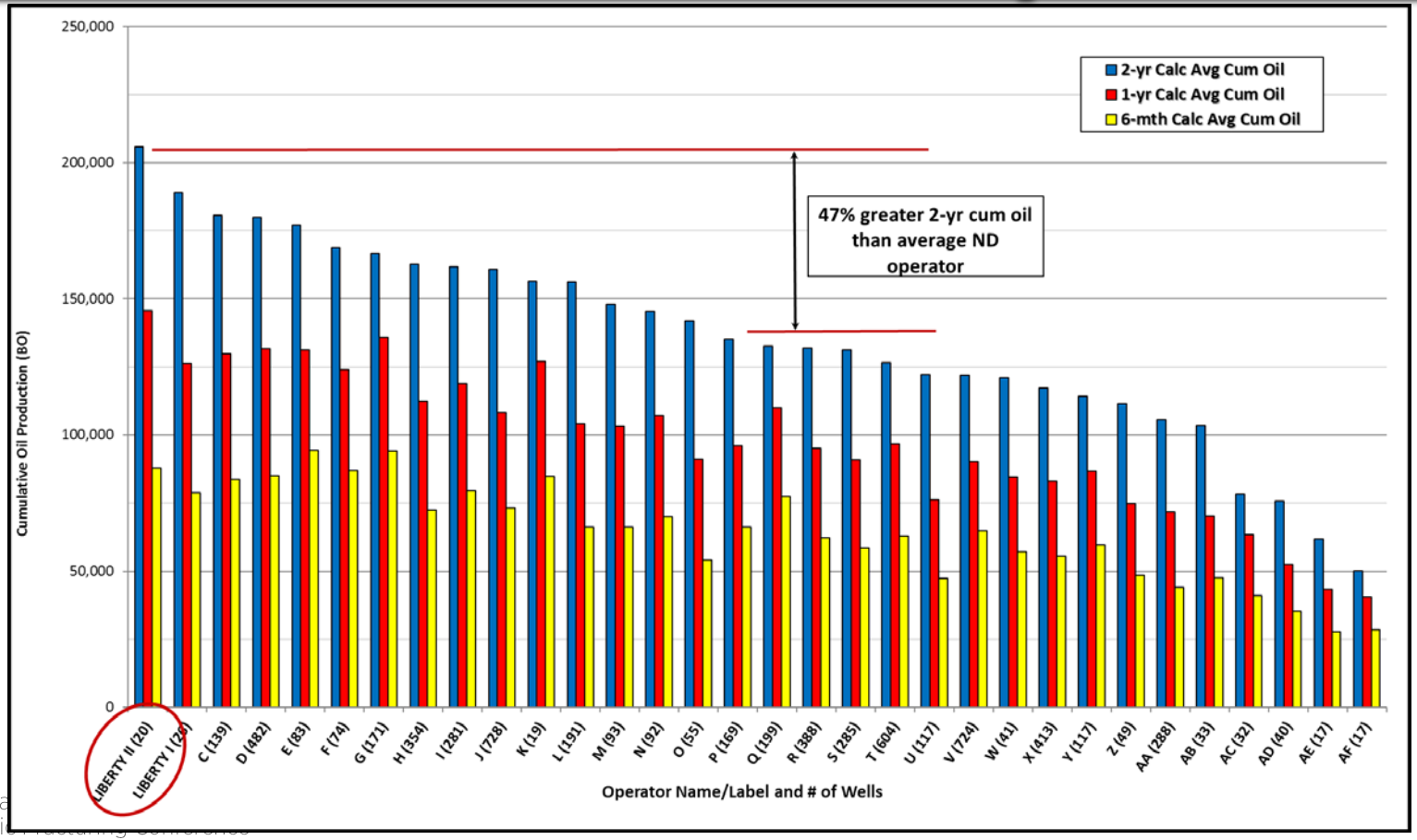


North Dakota Oil Production



Middle Bakken – Entire Williston Basin - 6341 Wells

(completions since 1/15/2009, all operators >10 wells; NDIC production through May '16)



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Thank You / Questions