Frac Trends in Liquid-Rich Basins: A Focus on Further $/BOE Minimization and Efficiency Gains

Leen Weijers, Liberty Oilfield Services

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SPE-194345

Trends in the North American Frac Industry: Invention through the Shale Revolution

Updated w/ DJ Basin Focus

Leen Weijers, Chris Wright, and Mike Mayerhofer; *Liberty Oilfield Services*

Mark Pearson, Larry Griffin and Paul Weddle; *Liberty Resources*

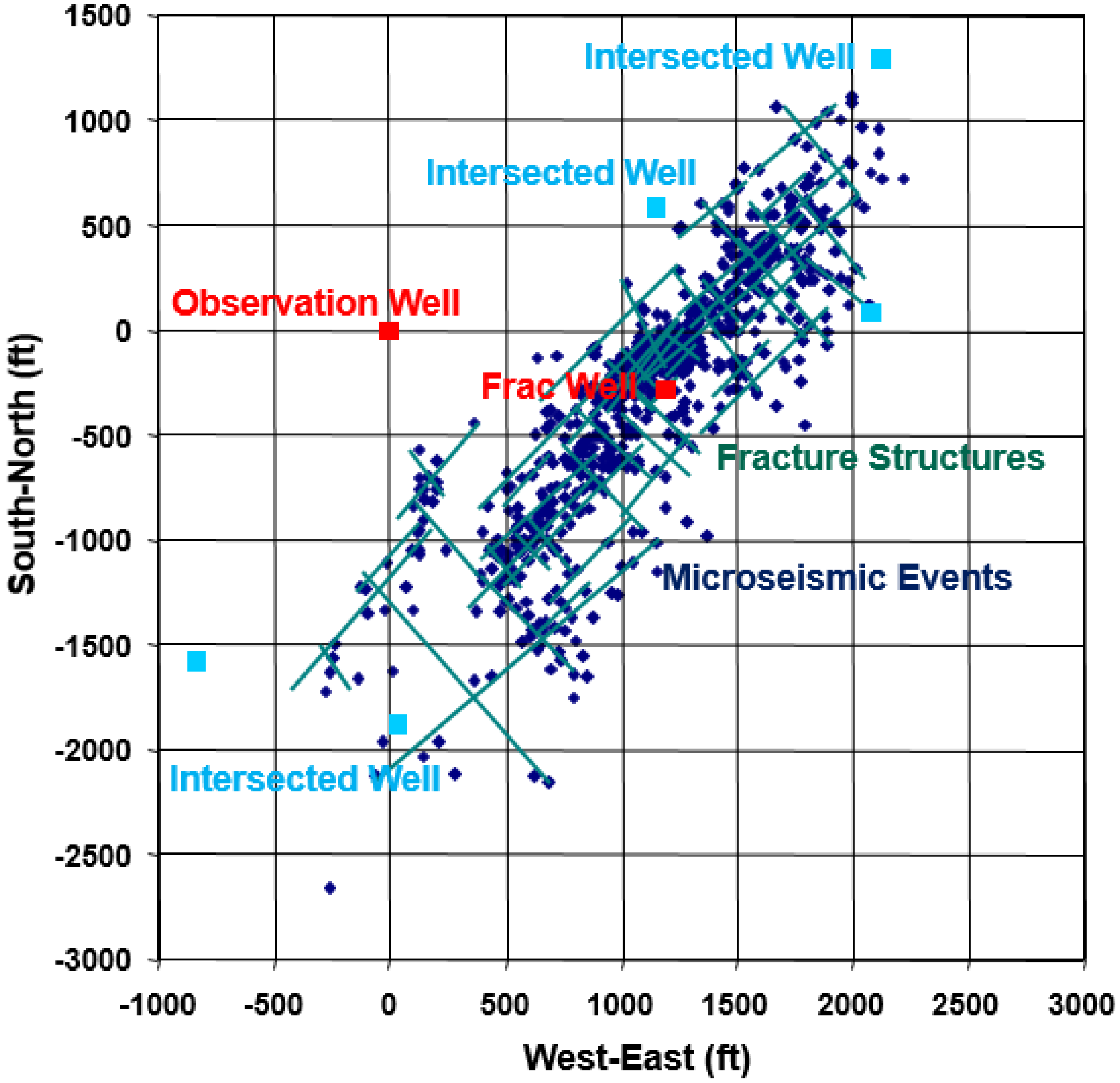
Conventional vs Shale Frac'ing

- 1947 – present
- Higher permeability sand – **Moving the hydrocarbon molecule to the frac**
- Vertical wells, mostly single stages
- Focus on conductivity

Dawn of the Shale Revolution

“The Frac that Changed Everything”

- Persistence, ingenuity & luck
- Thin fluids; Almost no proppant
- Multi-directional networks
  - Interaction w/ natural fracs
  - Massive network from single stage in vertical well: 4,000 x 1,000 ft
- Proof: Killed offset wells and had “eyes” to see what happened “down there”

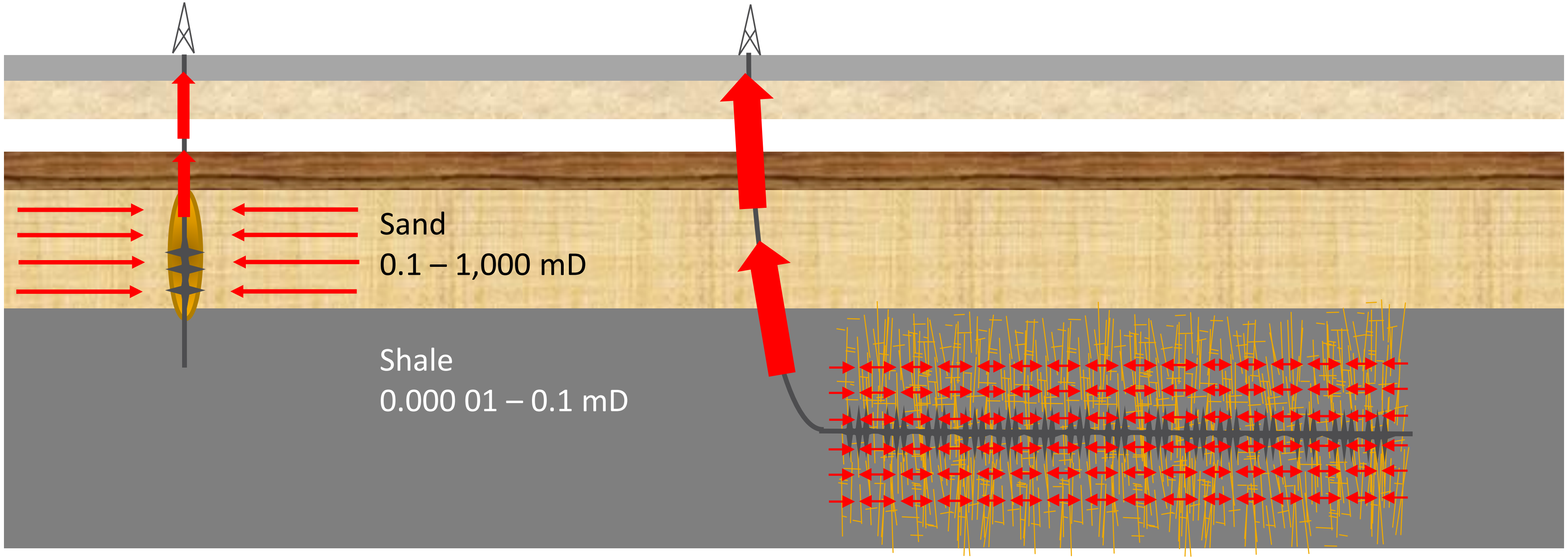


From: SPE 77441 & 90051 (2001)

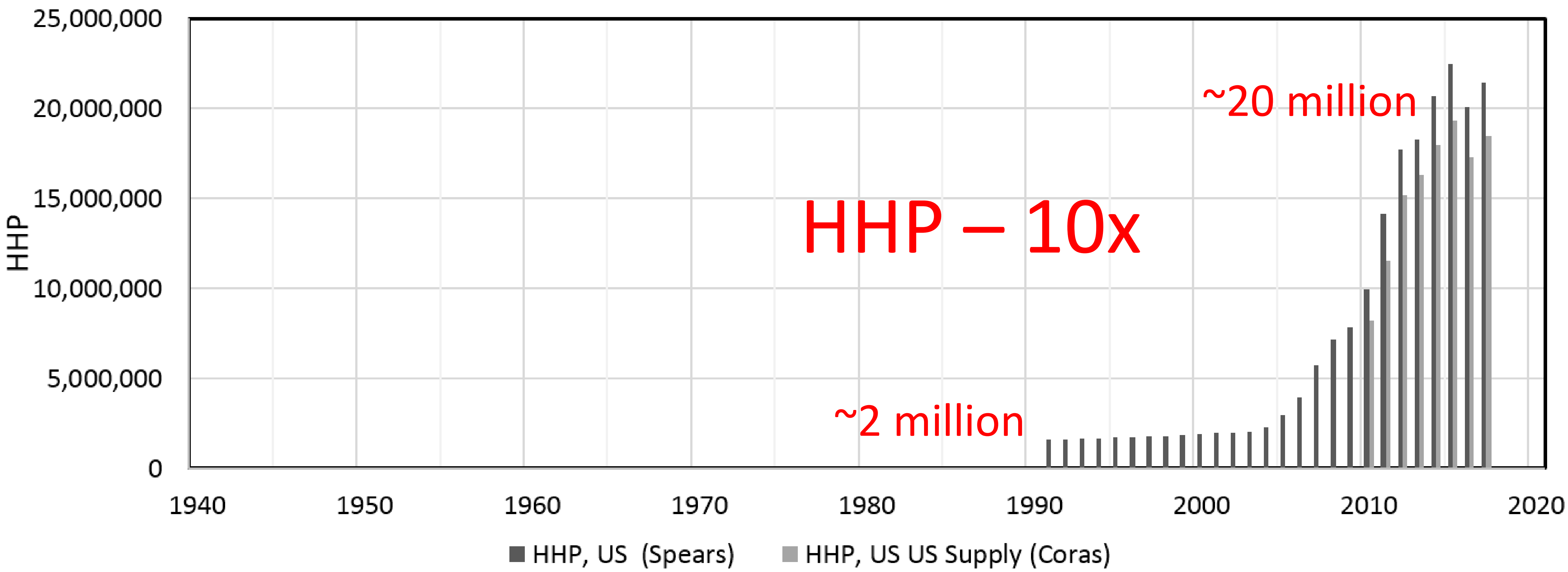
Conventional vs Shale Frac'ing

- 1947 – present
- Higher permeability sand – **Moving the hydrocarbon molecule to the frac**
- Vertical wells, mostly single stages
- Focus on conductivity

- ~2000 – present
- Low permeability shale – **Bringing the frac to the hydrocarbon molecule**
- Multi-stage horizontal wells
- Focus on complexity – "2 miles of plumbing"



Increase in Fractivity through the Shale Revolution



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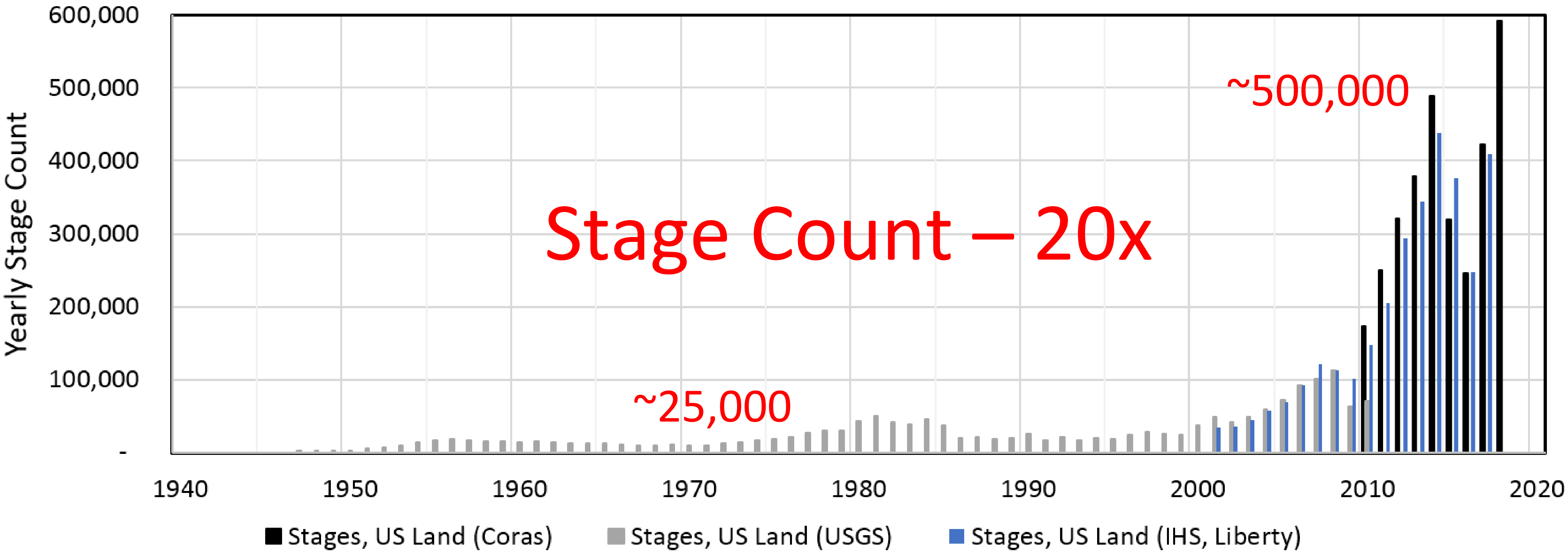

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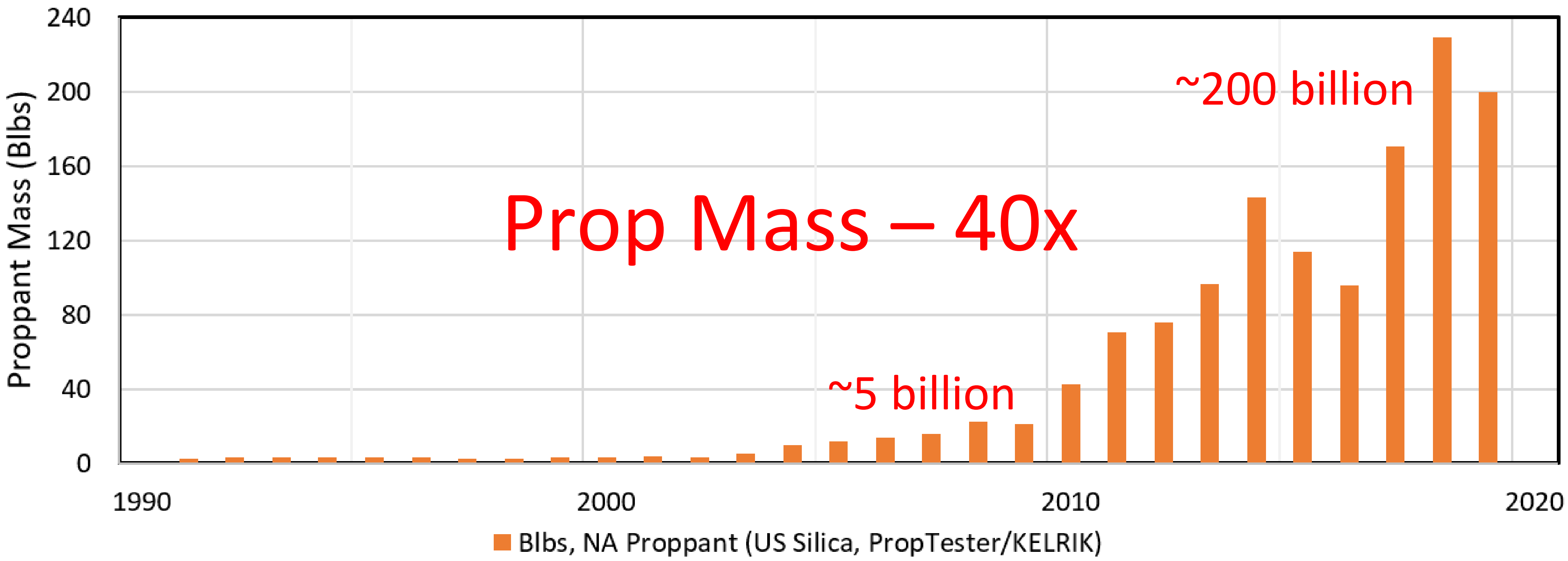
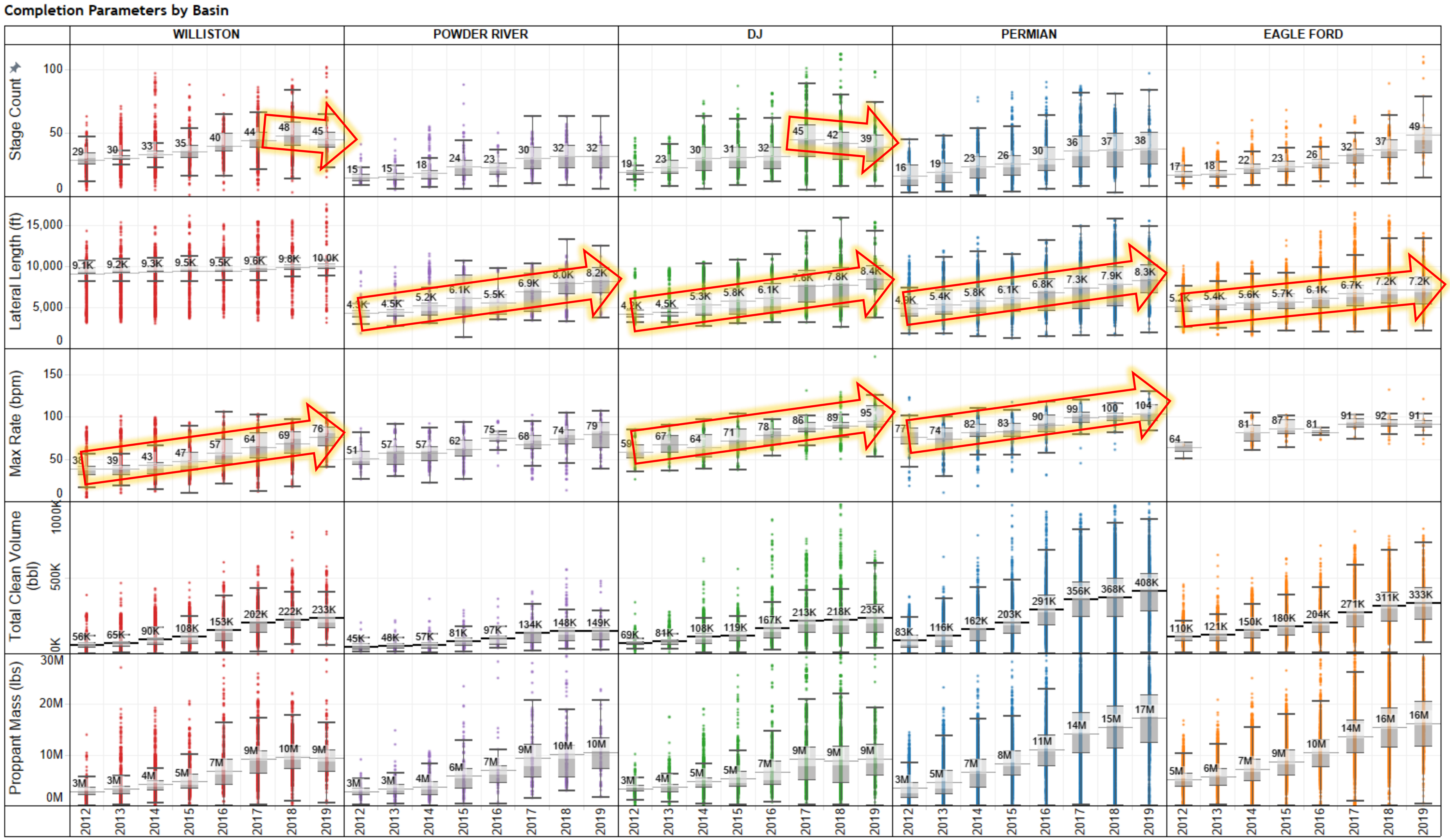
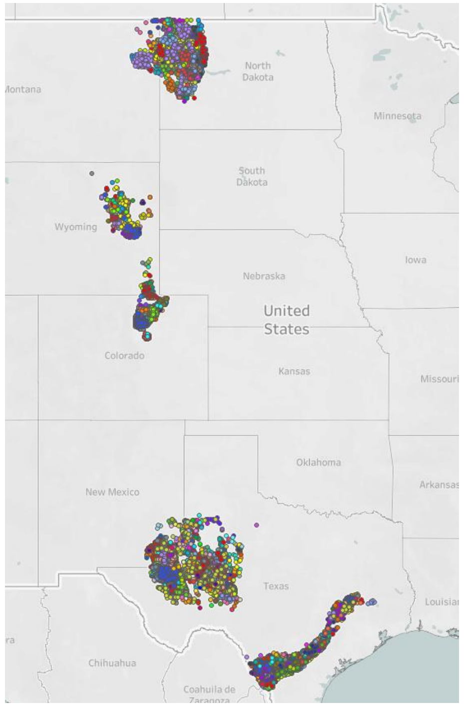


"Big Picture" Liquid-Rich Frac Trends

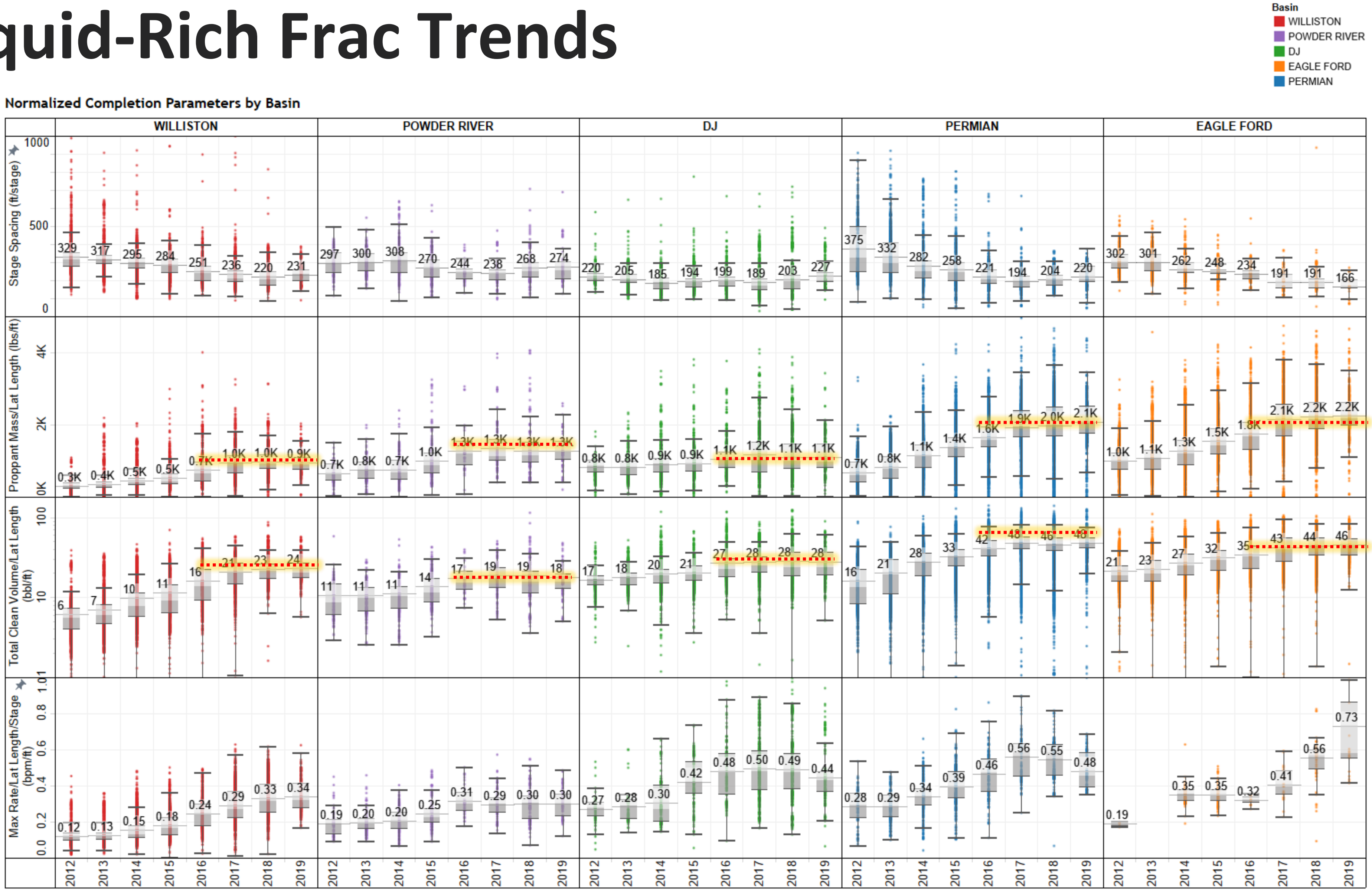
- Stage count stabilizing and declining in some basins
- Lateral lengths catching up to Williston
- Rates keep increasing





"Big Picture" Liquid-Rich Frac Trends

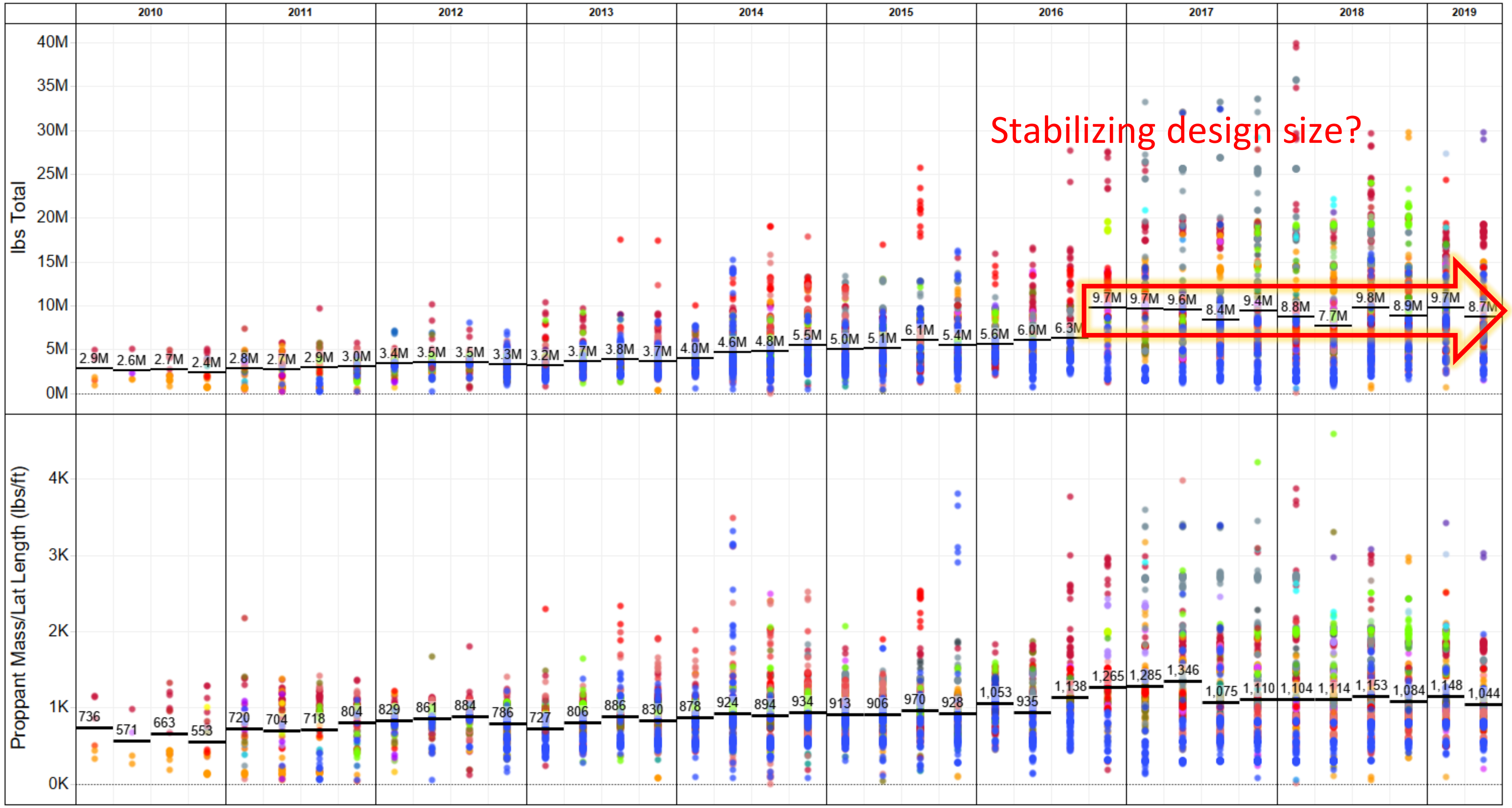
- Stage count stabilizing and declining in some basins
- Lateral lengths catching up to Williston
- Rates keep increasing
- Rockies basins have stabilized fluid volume and proppant mass at ~1,000 lbs/ft
- Texas basins approaching ~2,000 lbs/ft



Shale Revolution Frac Trends

- Larger fracture network
  - Horizontal wells
  - Longer laterals
  - **Increase in proppant mass**
  - Increase in fluid volume
- Denser fracture distribution
  - Higher stage count
  - Higher pump rate
  - Changes in perf clustering
- Cost-sensitive
  - Fewer additives
  - Local proppant

DJ Basin

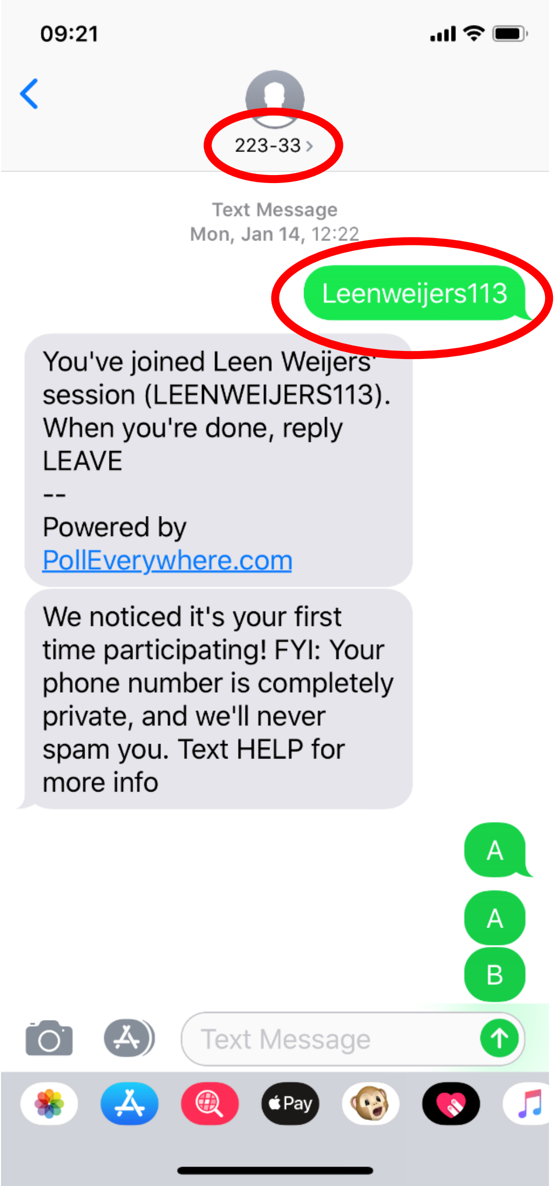


Further increase if basin swaps to local proppant ?

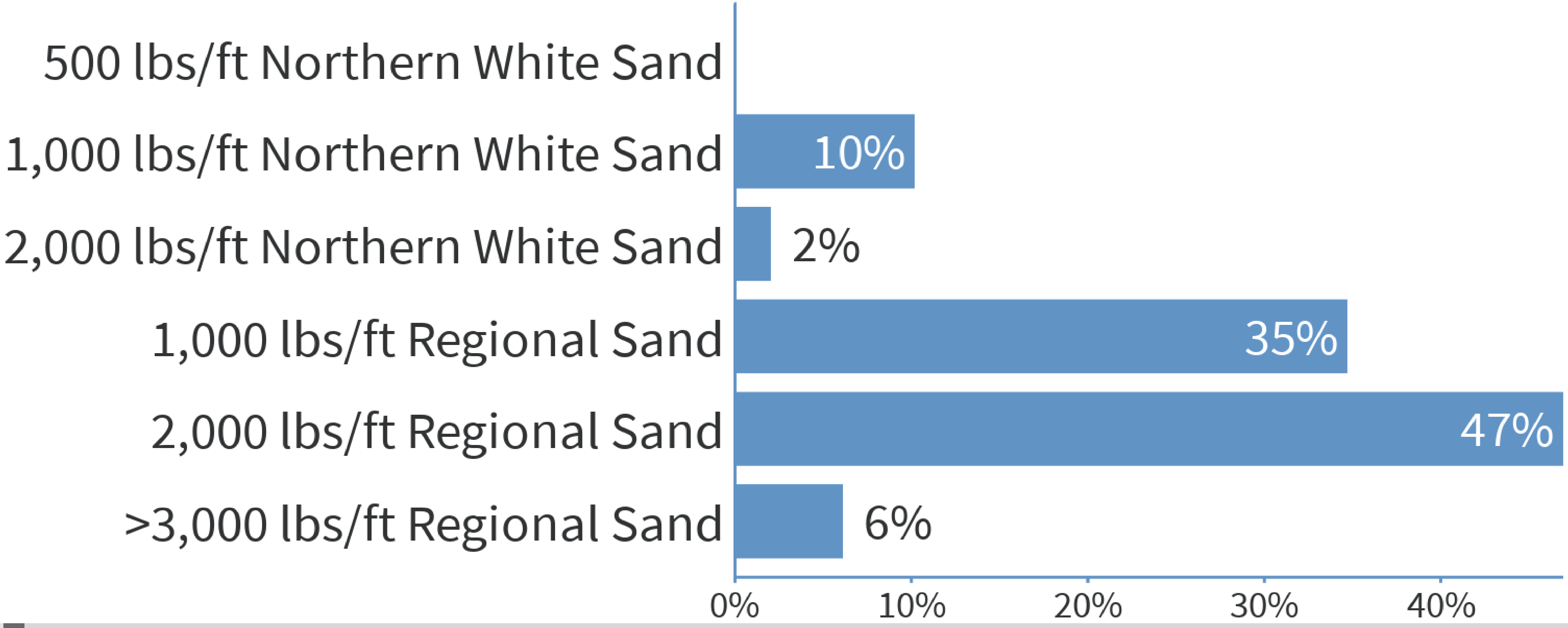
Poll

Text to: 22333

Leenweijers113



Where Will the DJ Sand Train Stop (in Proppant Mass per Lateral Foot)?



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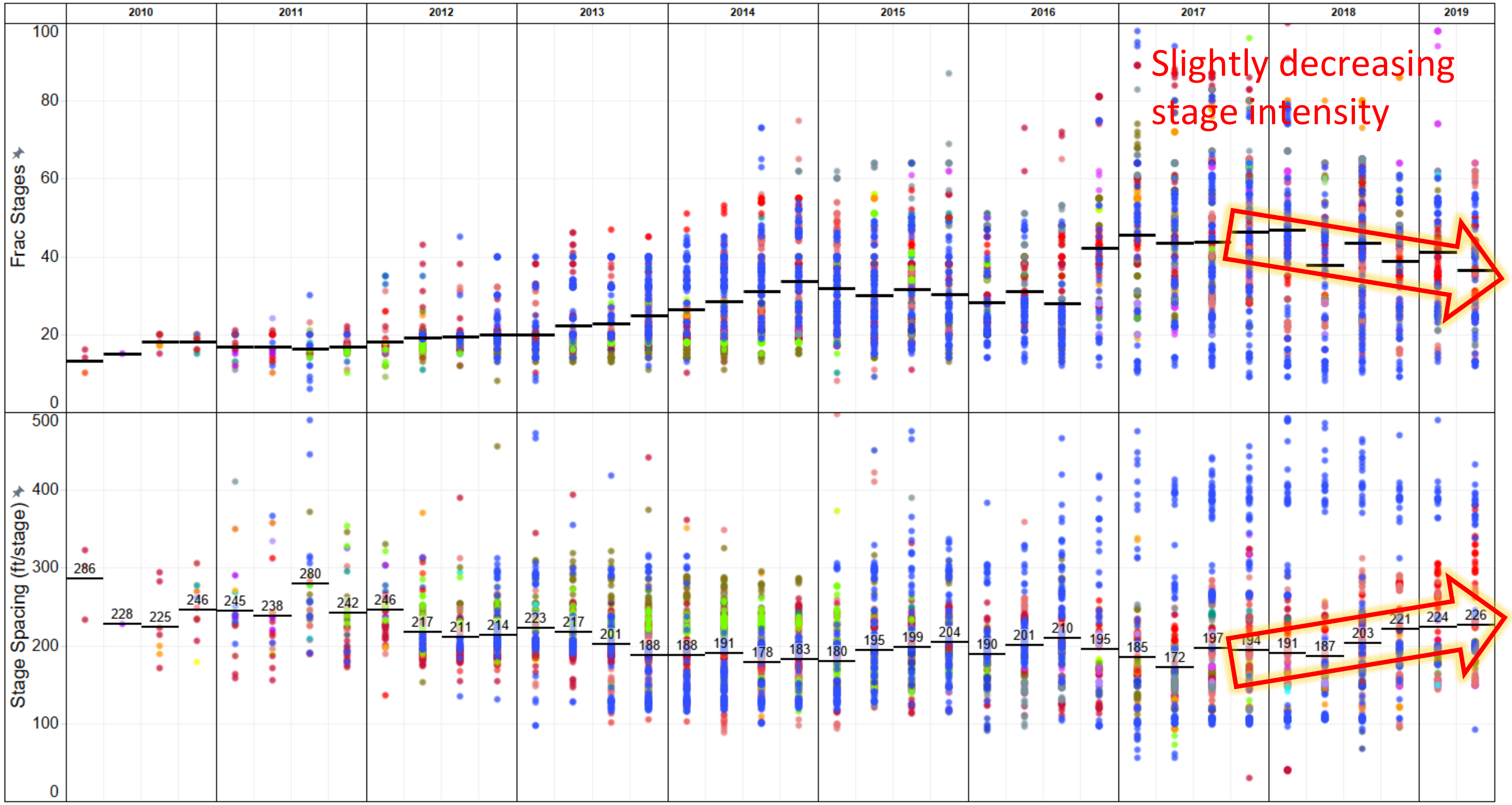

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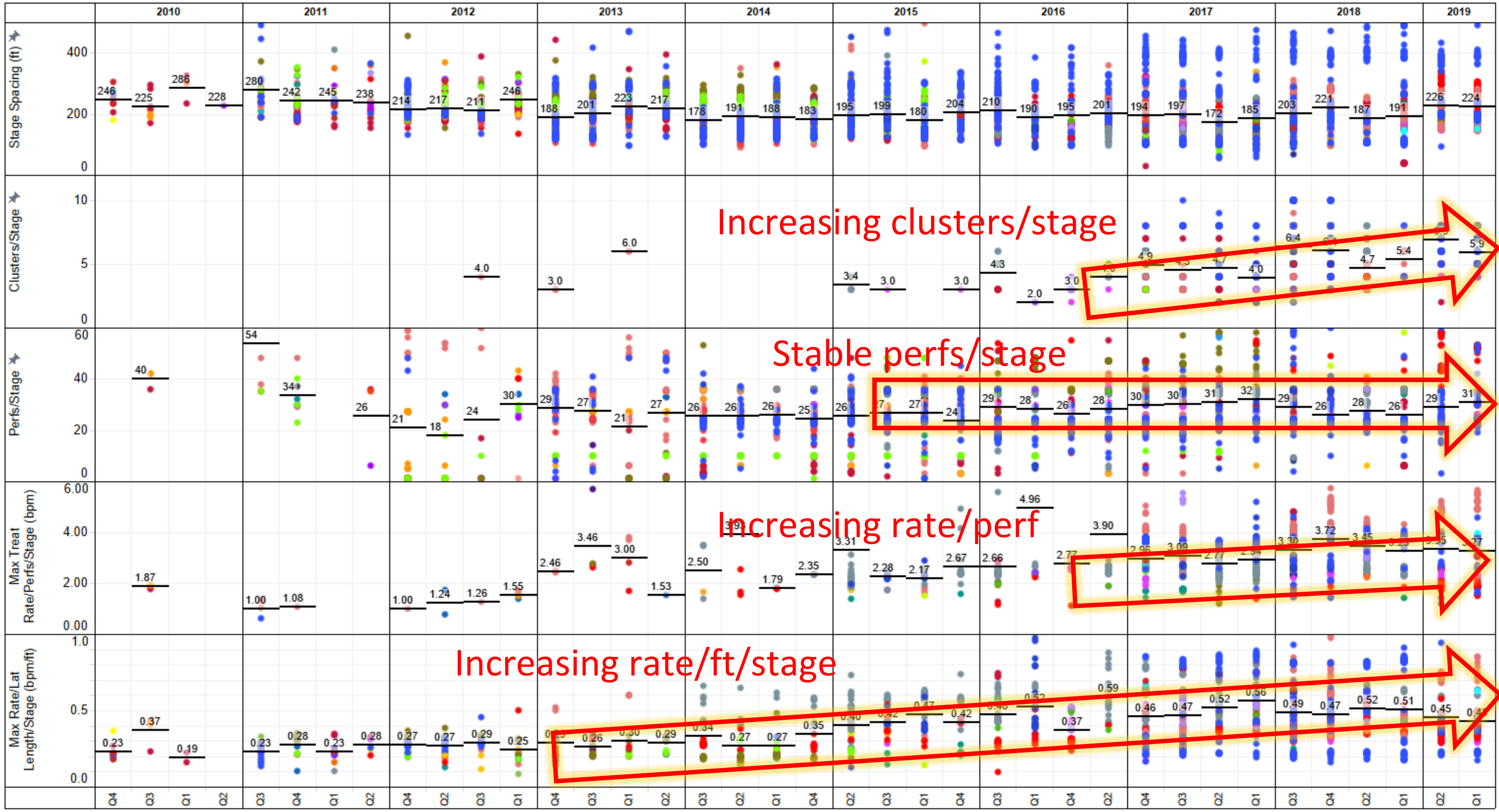
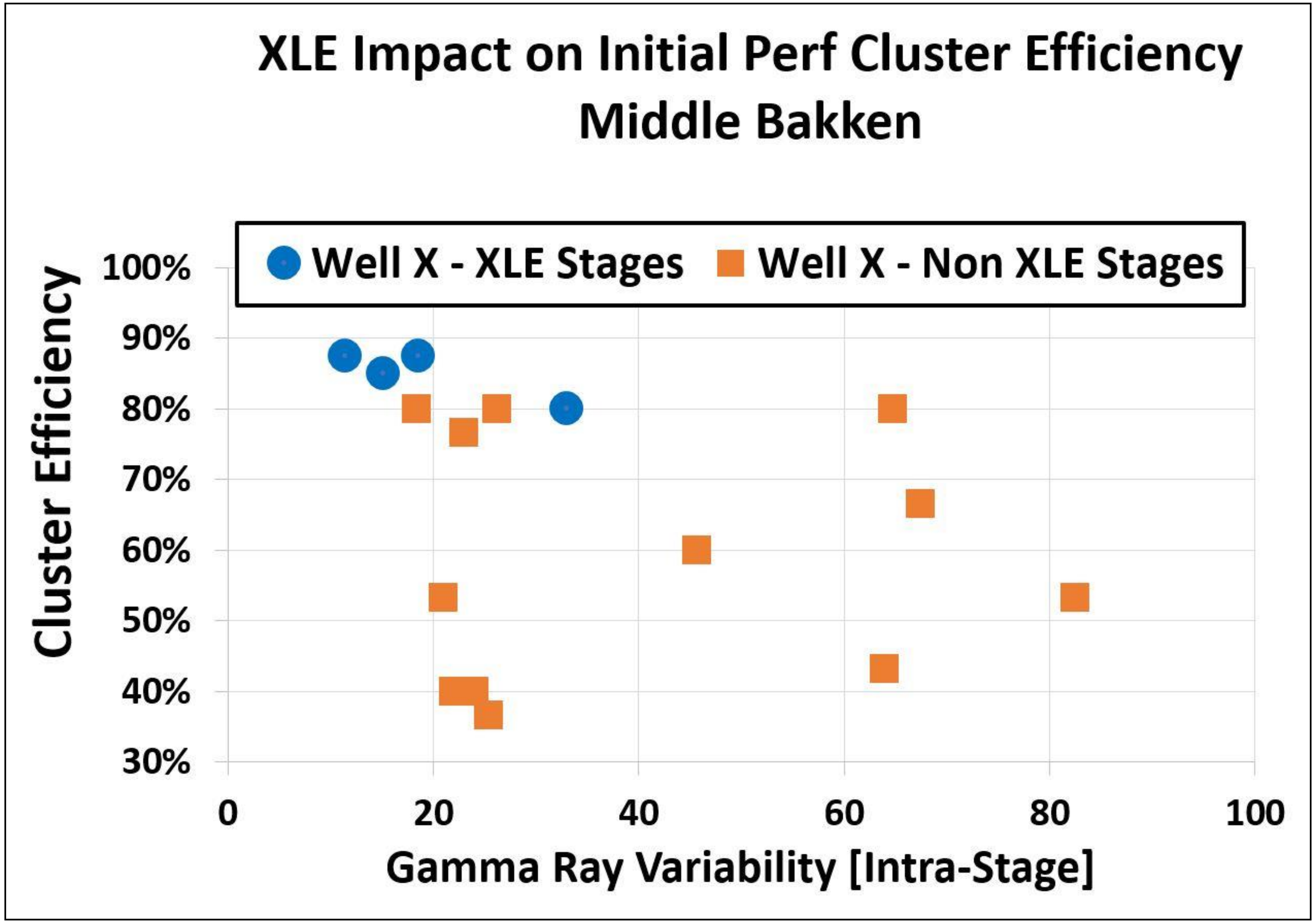
Williston Basin



eXtreme Limited Entry – INITIAL 4 STAGE TRIAL – Q1 2016



First Sand Ramp Cluster Efficiency (RA prop tracers):

- Non XLE Avg. = 59%
- Non XLE Avg. = 85%*

  *With Solid Particle Diverter (SPE 184828)
- XLE = 85% Initial PCE
- XLE = 93%* Final PCE

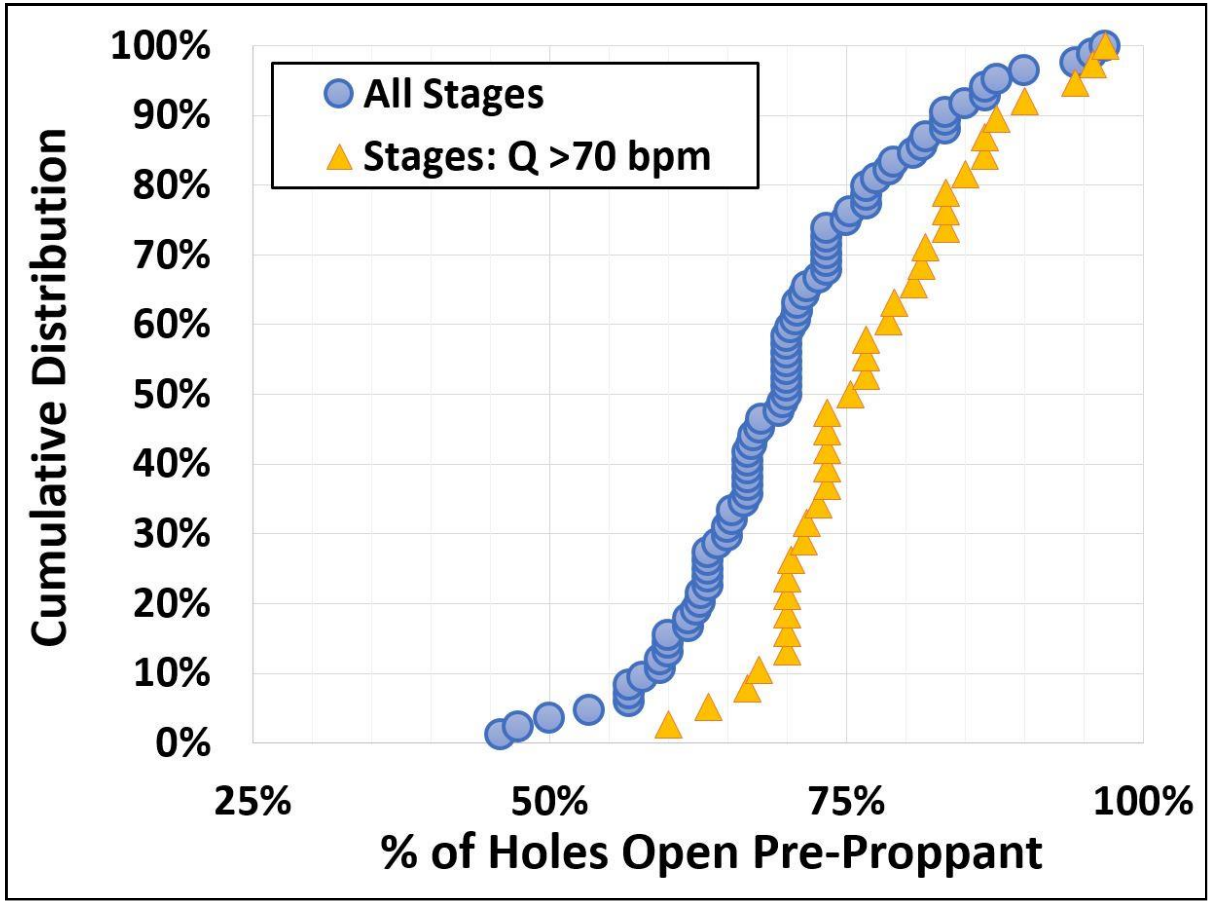
  *No other diversion

XLE ΔPperf Trials:

- 2,000 psi – 4,000 psi
- End of Stage Step Down Analysis

Courtesy: SPE-189880 – Weddle et al.

eXtreme Limited Entry – CALIBRATING HOLES OPEN – N_p



Step Down Analysis:
The Step Rate Test performed pre- & post-proppant

- SPE 62549 L. Weijers, C.A.Wright…et al)

Multi-well calibration of N_p has resulted in a 75% holes open design assumption:

- Max rate before SDT impacts the number of holes initially open.
- Intra-stage S_{Hmin} variability impacts % of holes open.
- Calibration of N_p gives ability to consistently achieve desired pump rate.

$$\Delta P_p = Ppf = \frac{0.2369\ \rho\ Q^2}{D_P^4\ N_P^2 C_D^2}$$

Where:

ΔPperf = Total perforation friction, psi
Q = Total Flow Rate, BPM/perf
D_P = Diameter of perforation, in.
C_D = Perforation coefficient
ρ = Fluid density, lbs/gal
N_P= Number of *open* perforations

Courtesy: SPE-189880 – Weddle et al.

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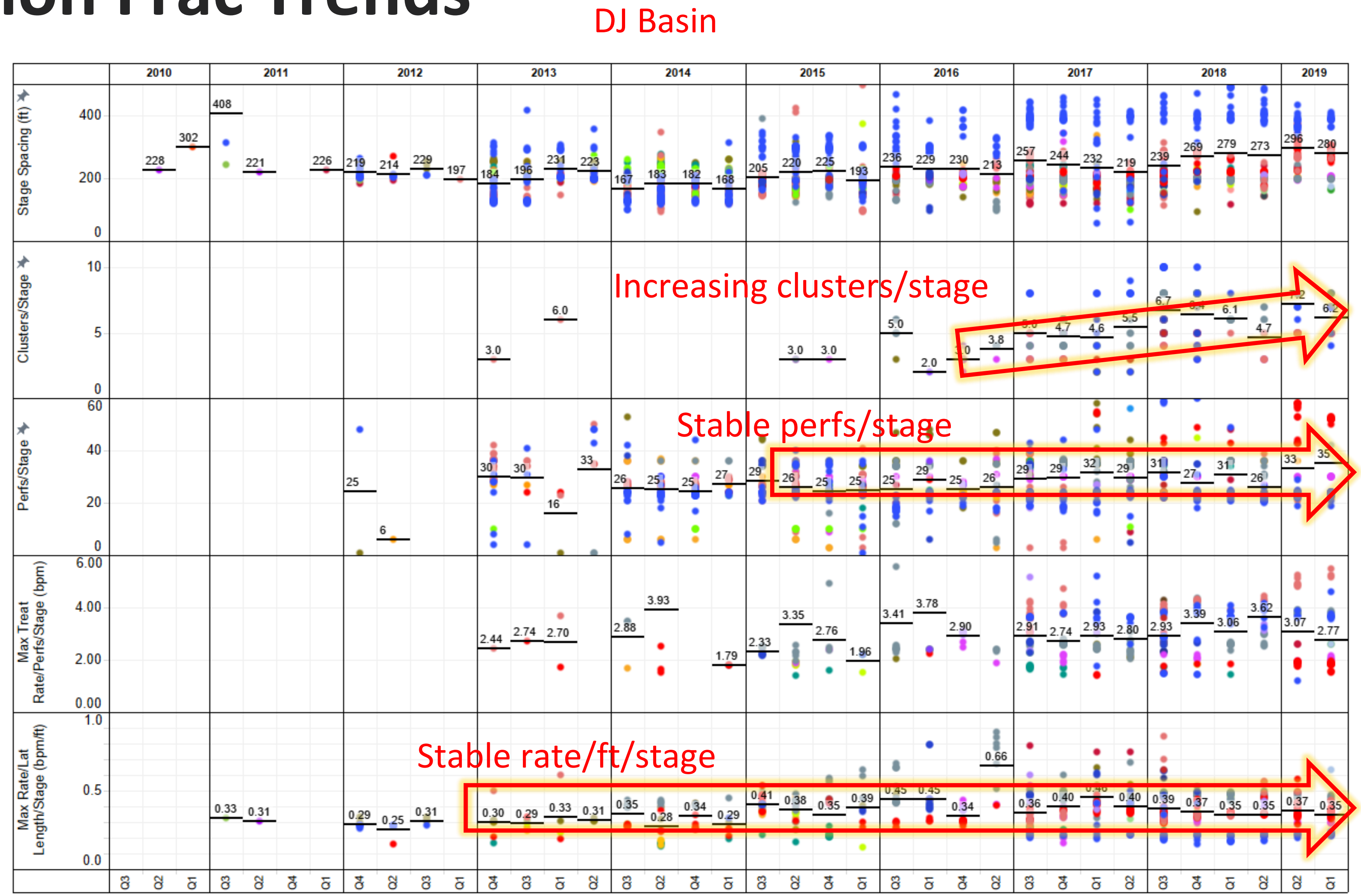

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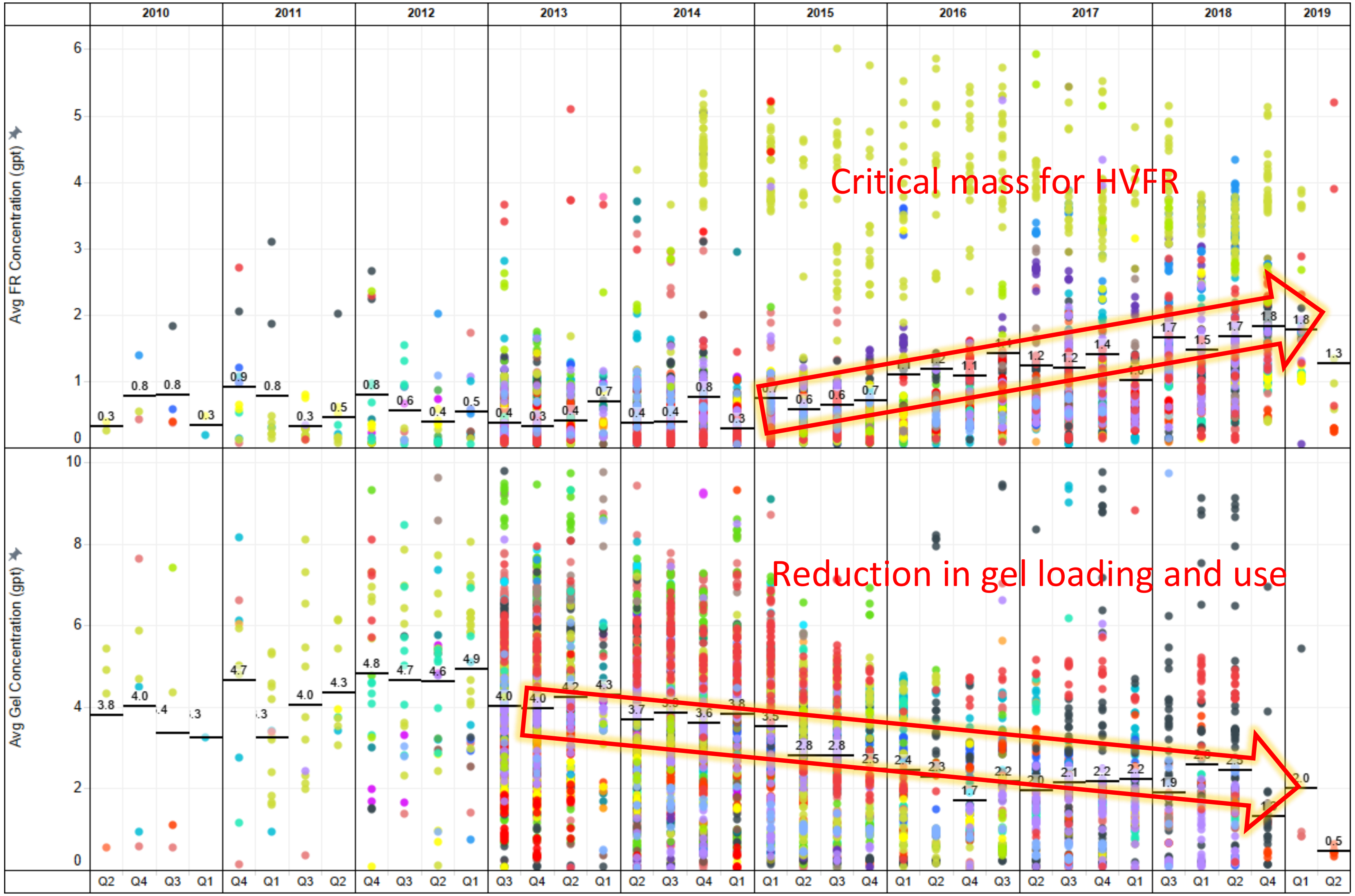

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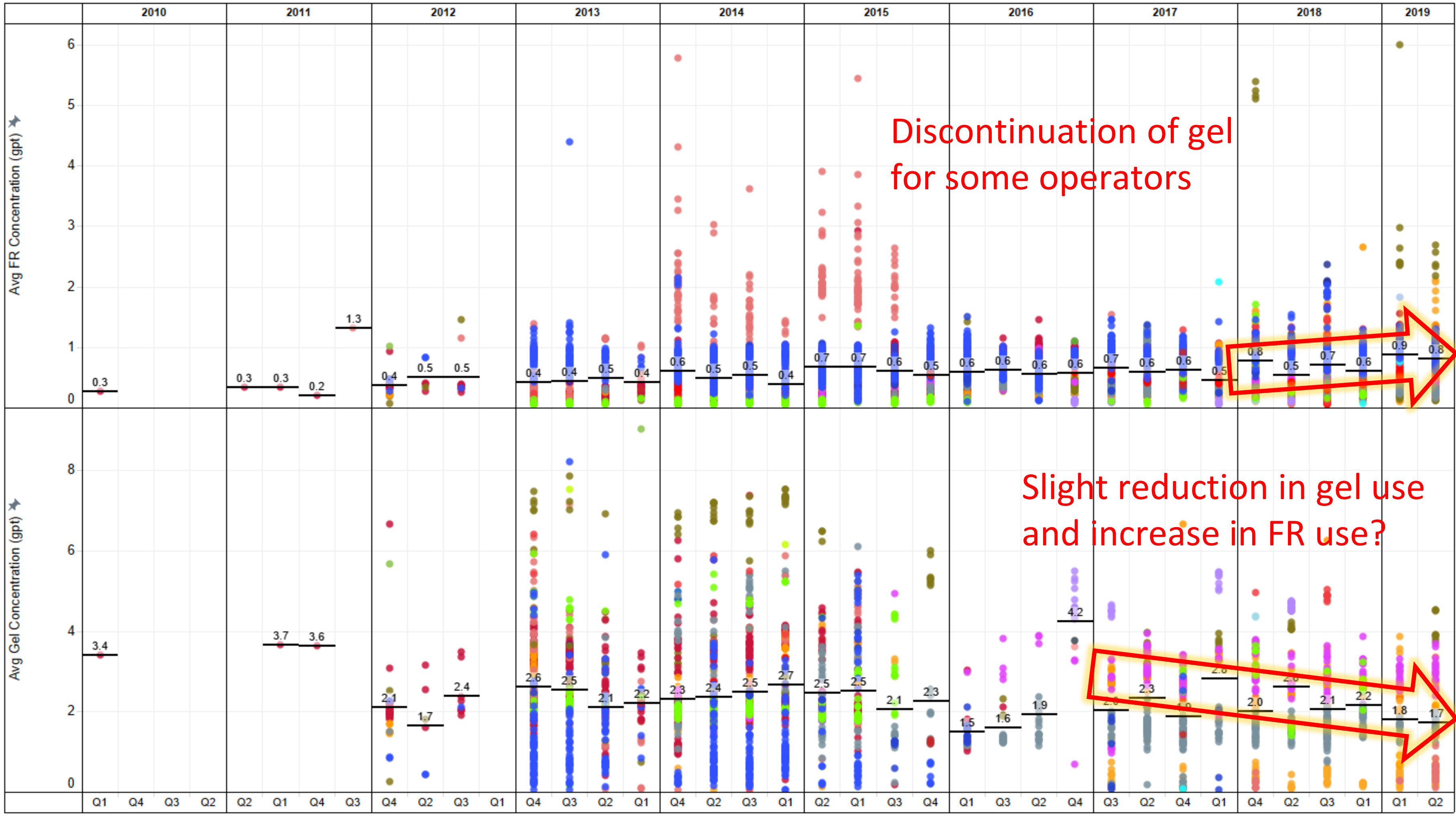

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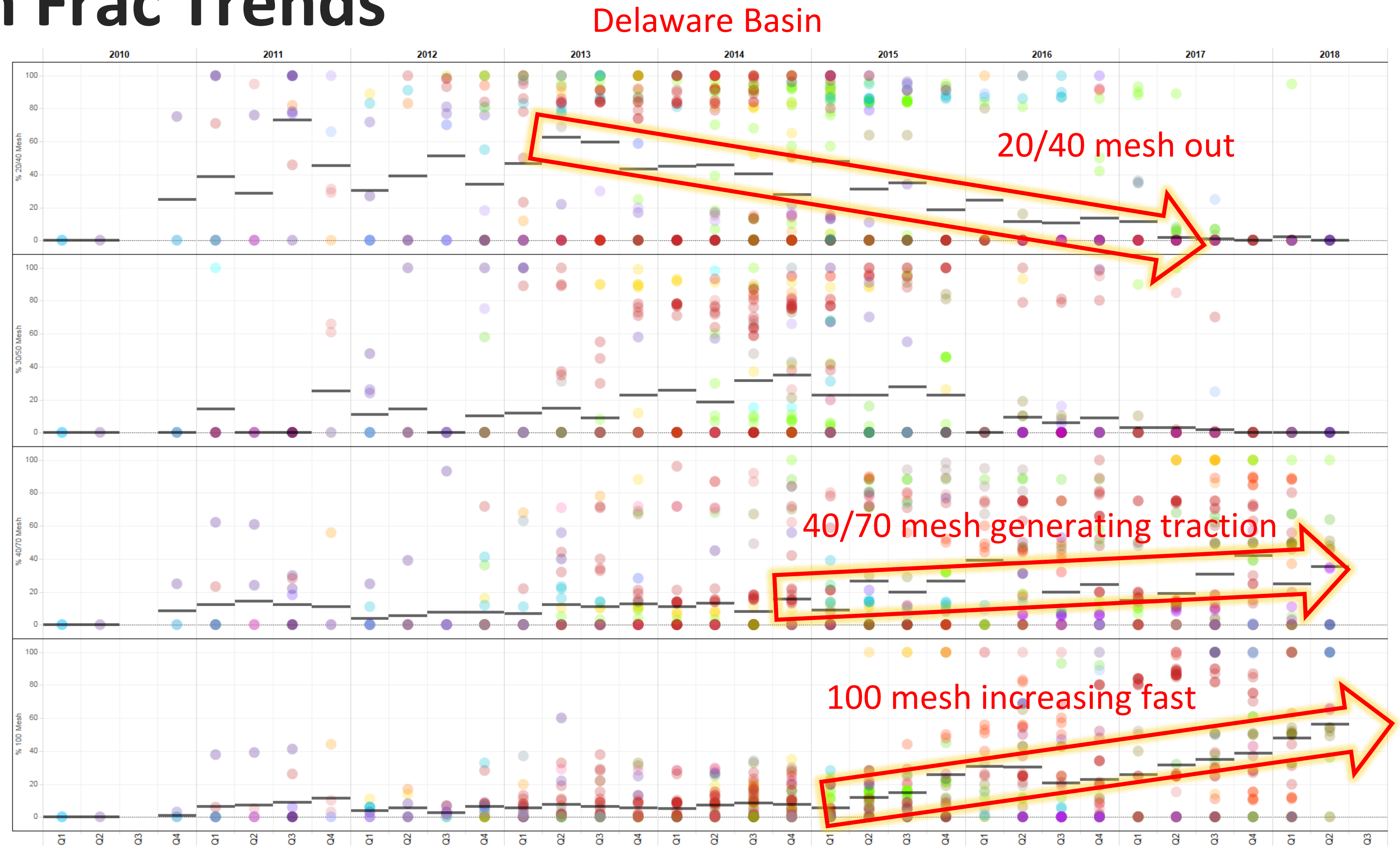

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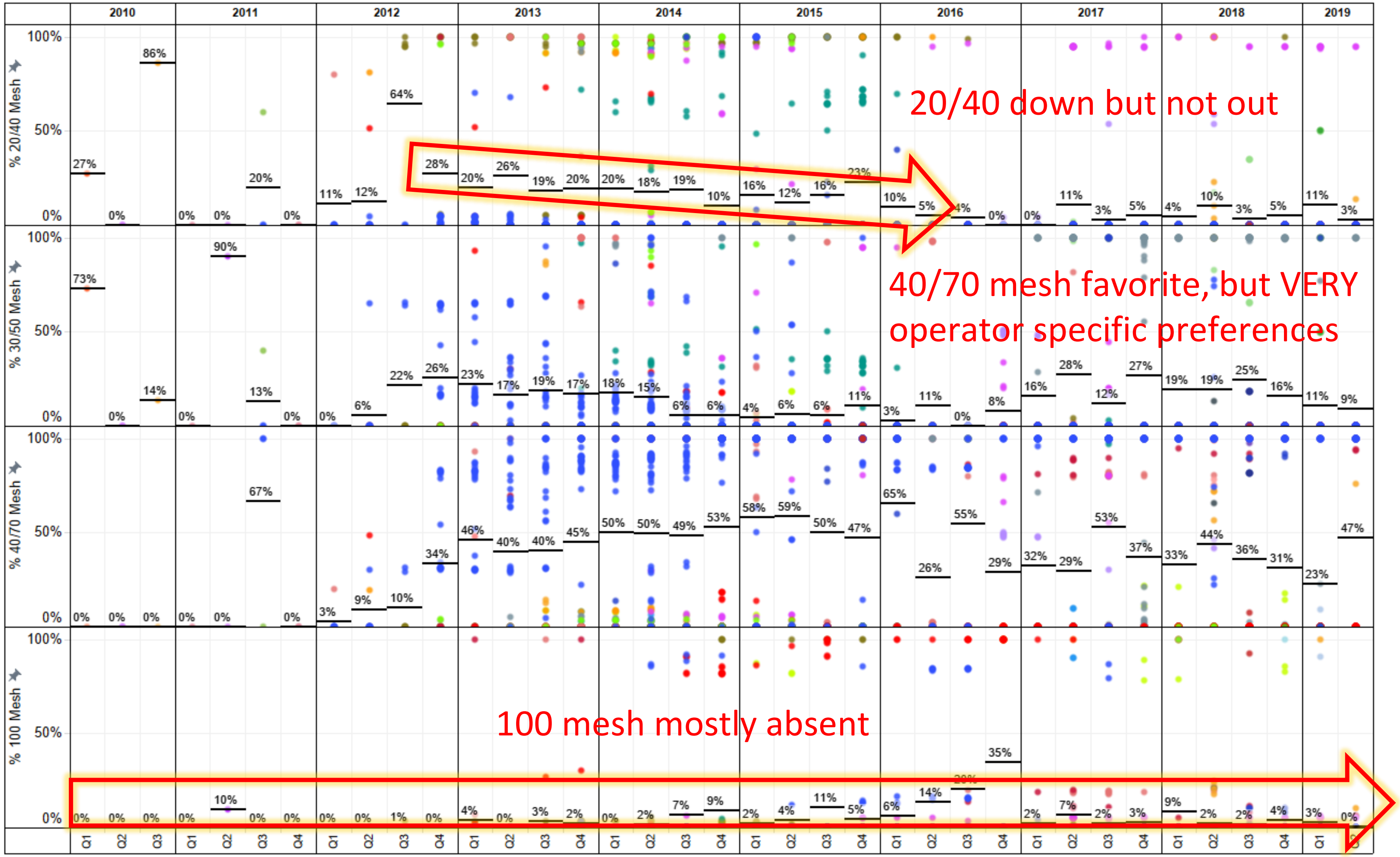
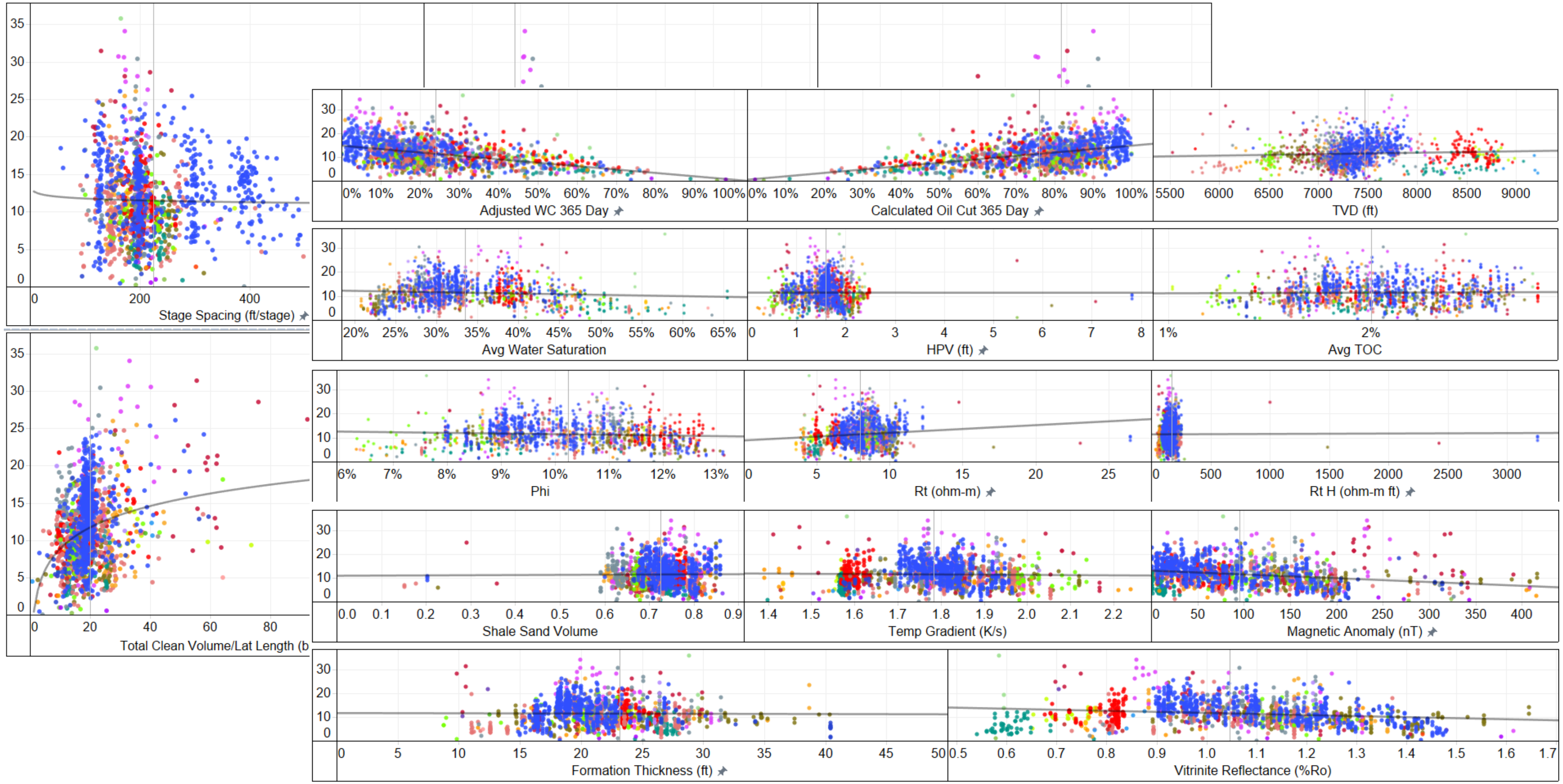
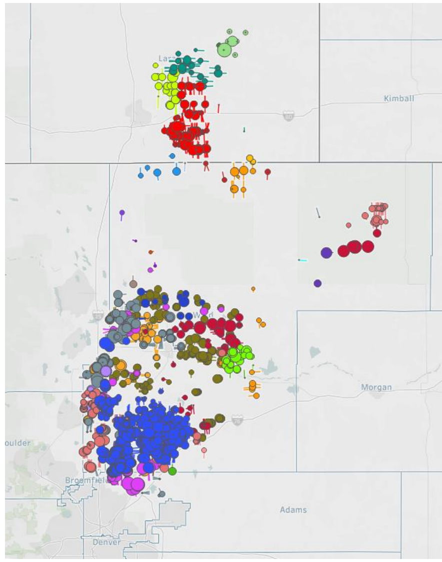
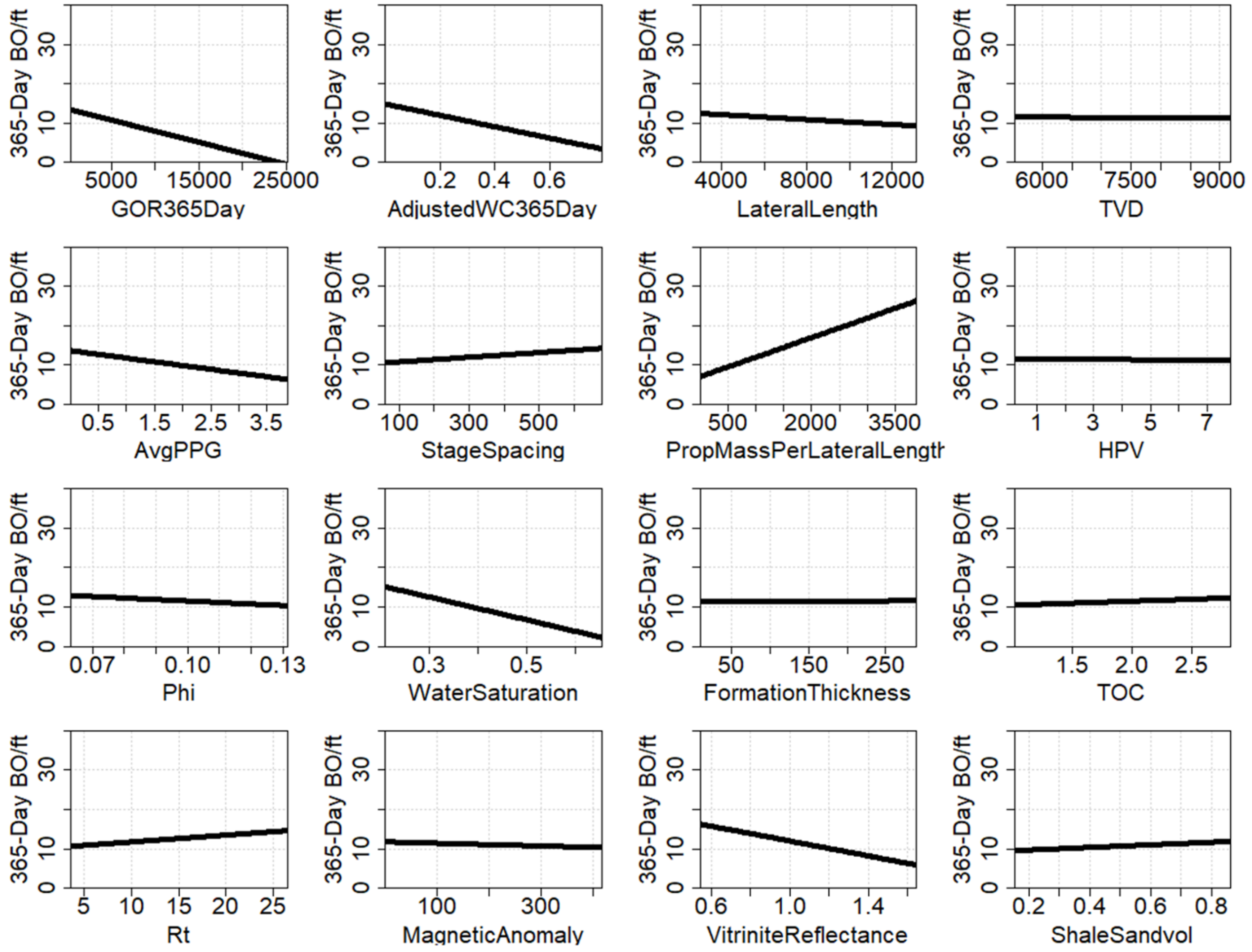


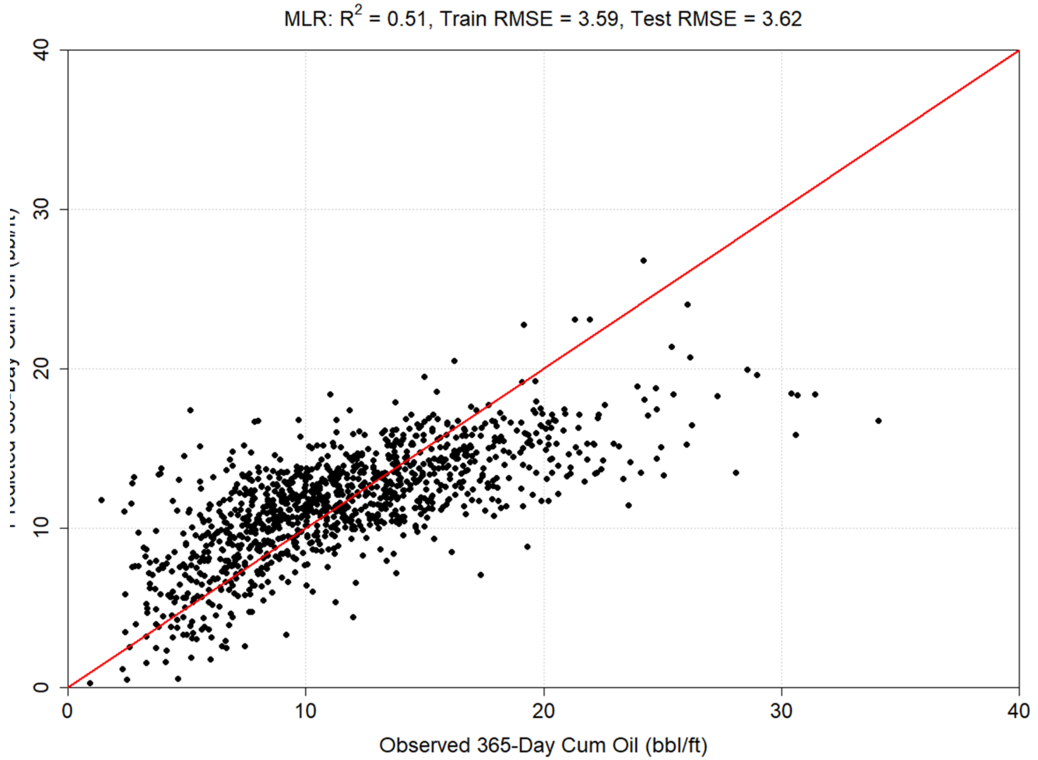
But What Drives Production? Trends





Multiple Linear Regression: Codell





RMSE as % of Mean Response = 31%

What Drives Production - Statistics (Codell Example)

Ranked Value as a % of the Total That Each Predictor Lends to the Regression

Variable	MLR	PB MLR	ACE	GAM	MARS
AdjustedWC365Day	31%	30%	18%	38%	20%
PropMassPerLateralLength	28%	27%	21%	27%	14%
GOR365Day	13%	13%	15%	15%	11%
VitriniteReflectance	11%	11%	11%	7%	17%
AvgPPG	6%	8%	13%	1%	10%
WaterSaturation	6%	6%	5%	4%	12%
LateralLength	3%	3%	8%	<1%	8%
StageSpacing	1%	1%	5%	<1%	<1%
TOC	1%	1%	3%	2%	<1%

1	2	3	4	5	6	7	8	9

MLR = Multiple Linear Regression
PB MLR = Physics-Based Multiple Linear Regression
ACE = Alternating Conditional Expectations
GAM = Generalized Additive Model
MARS = Multivariate Additive Regression Splines

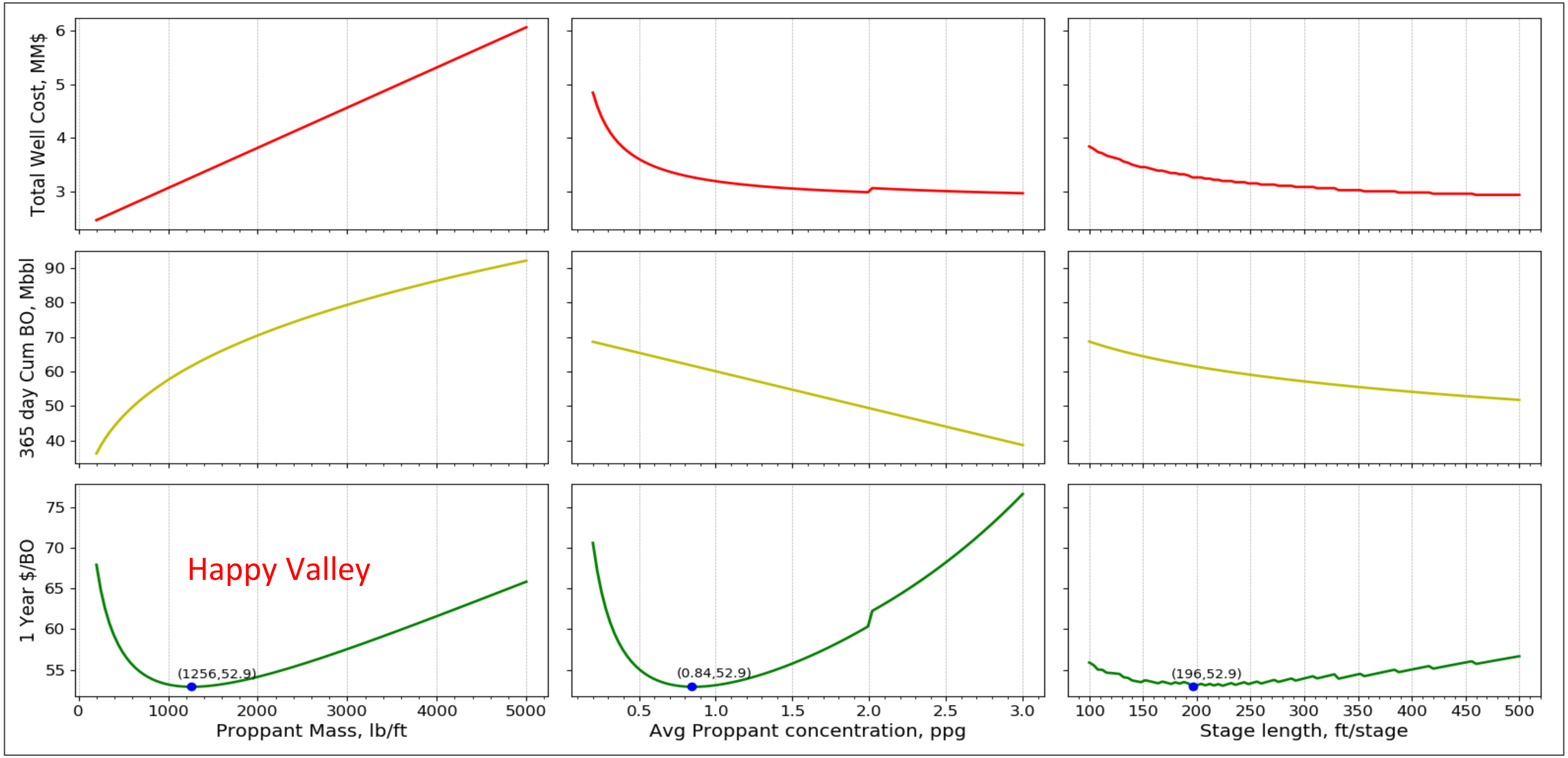
What Drives Production? $/BO Optimization

“There’s a Fine Line Between a Numerator ($) and a Denominator (BO)”, Yogi Berra

$

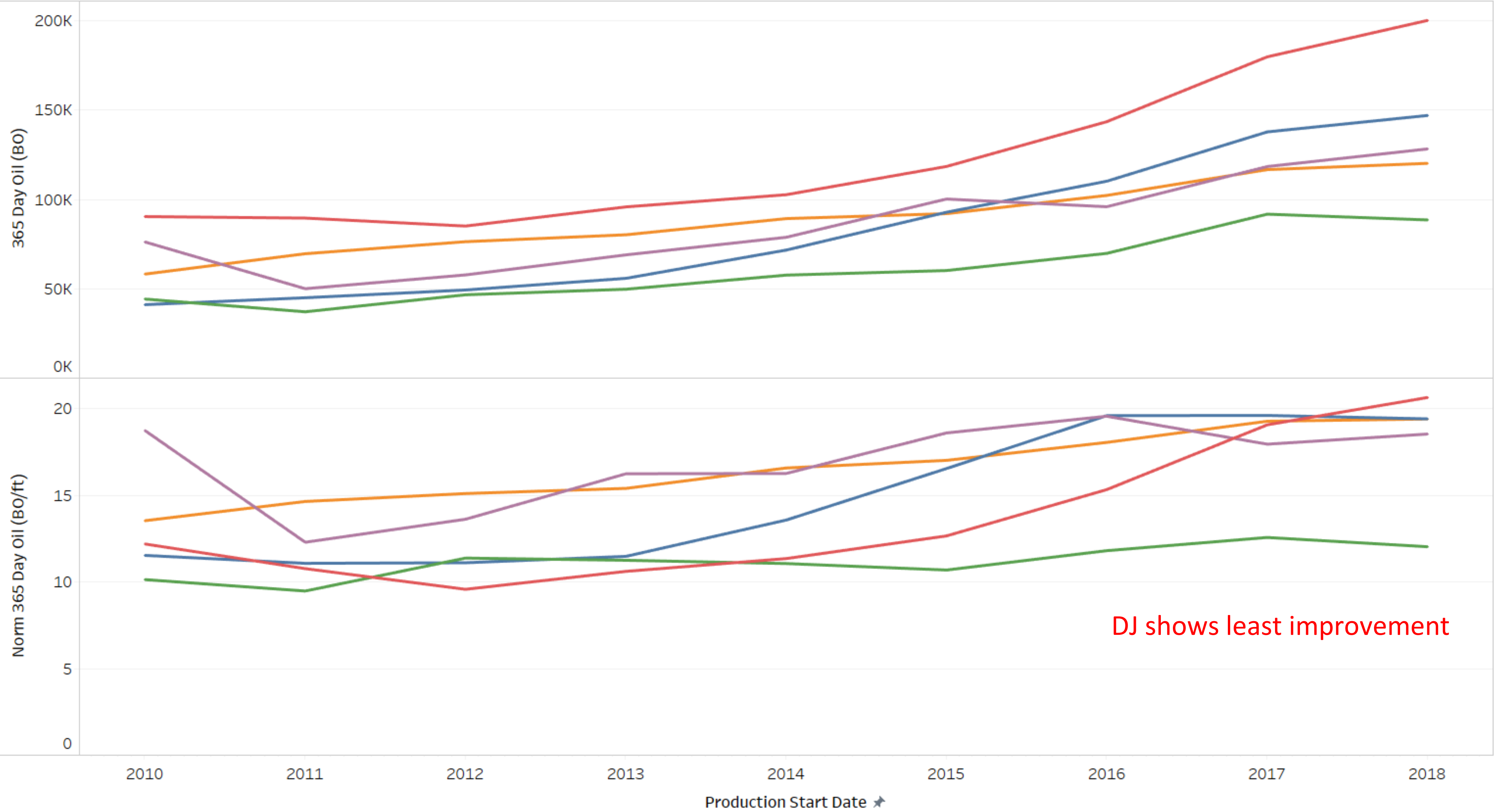
BO

$ / BO



The American Shale Revolution

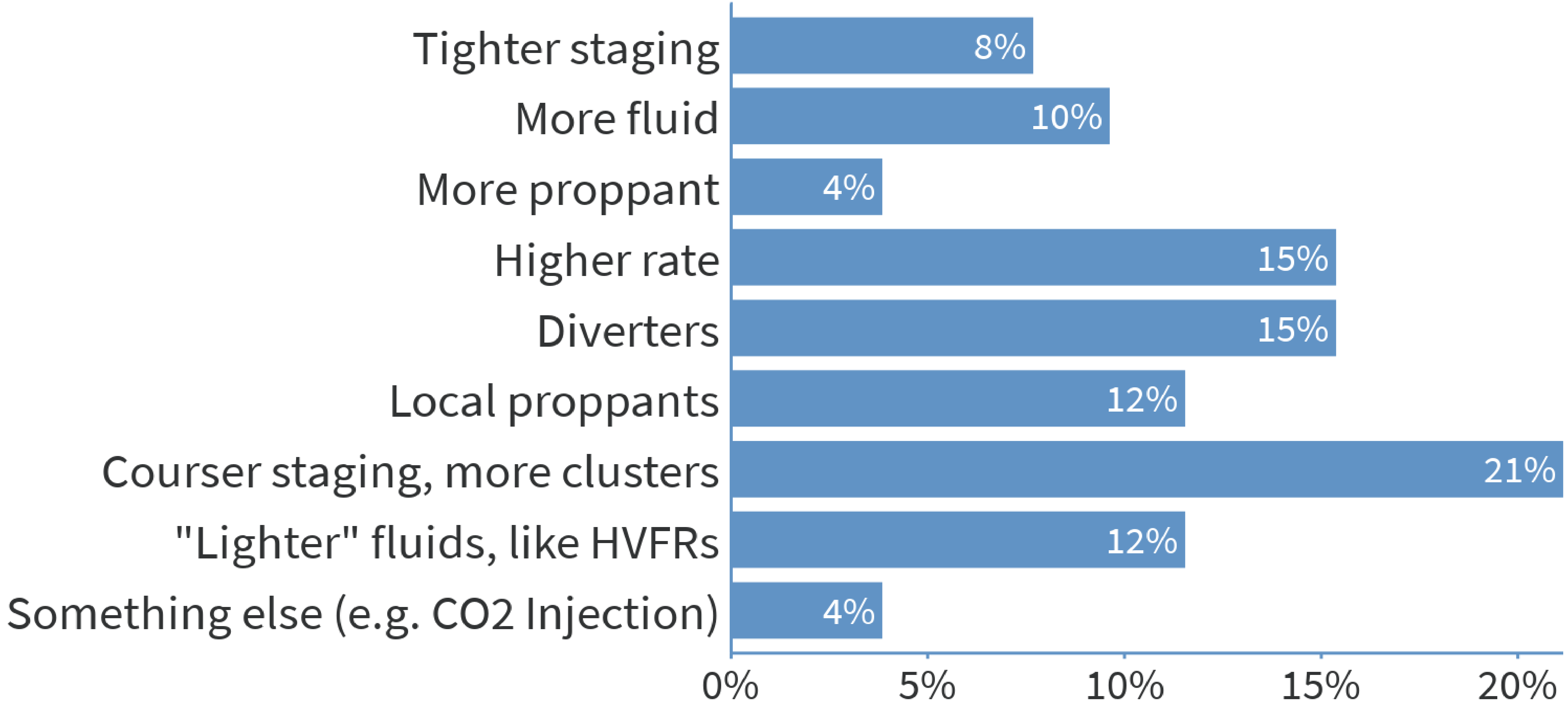
Better Wells



+70%
since 2012

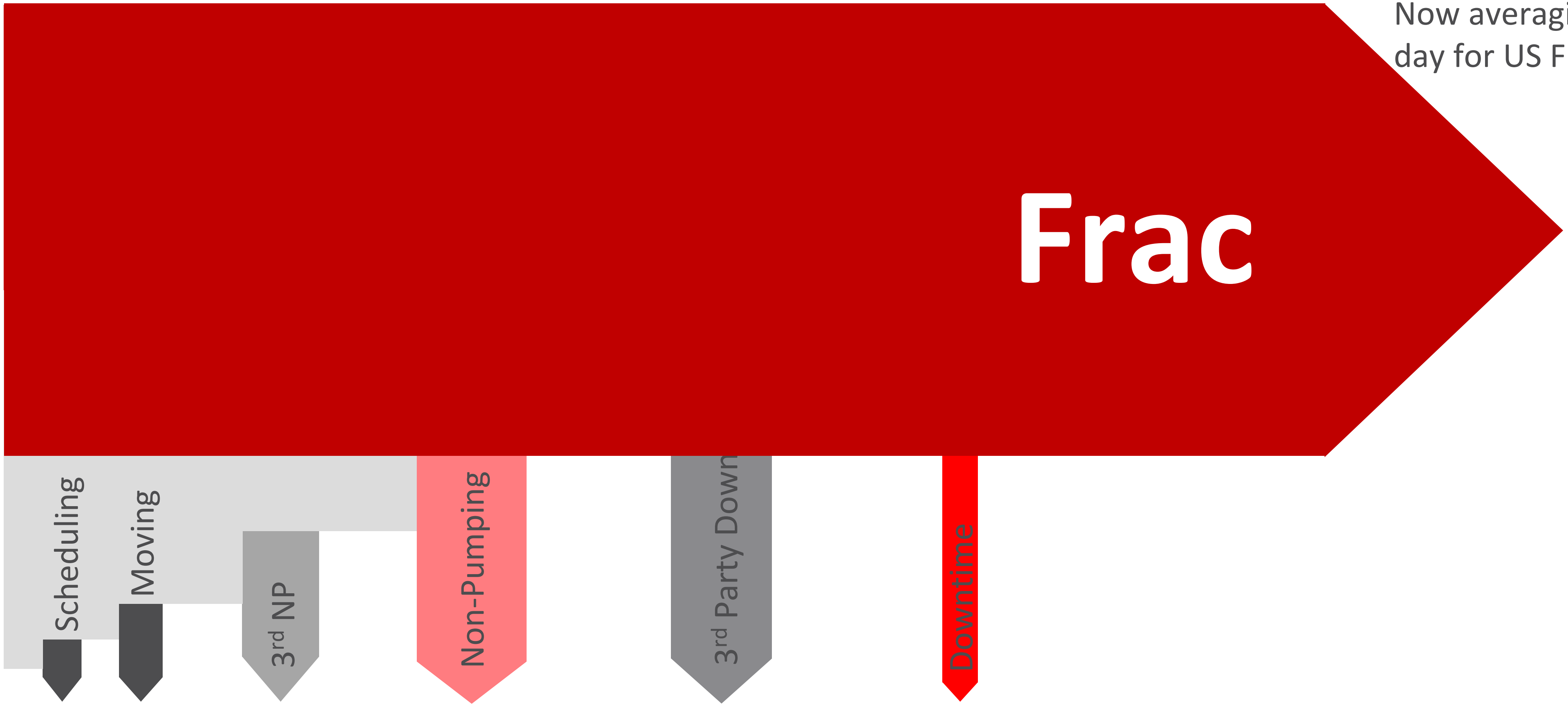
+28%
since 2012

What Will Drive You to Happy Valley?



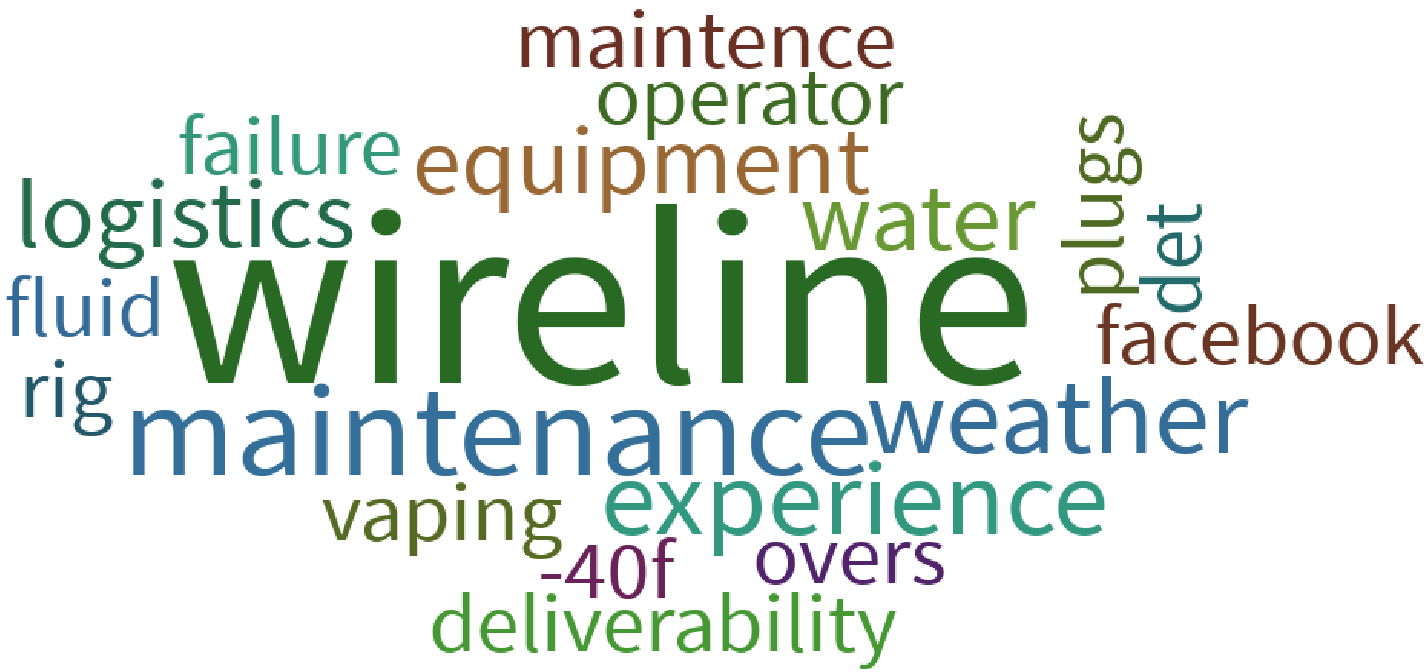
Let’s Frac…

…a Sankey Diagram for Efficiency Loss



Now averaging ~35% of every day for US Frac industry

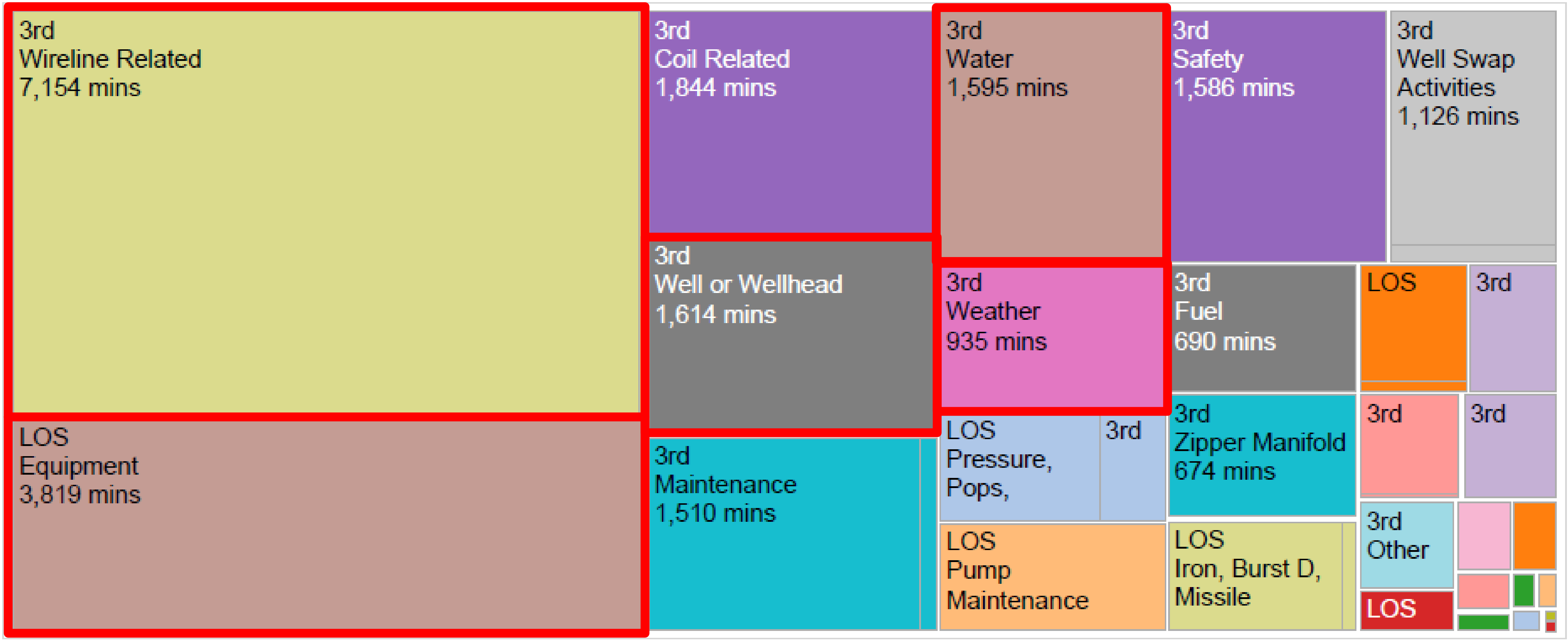
What Are the Main Sources of Downtime on Your Frac Location (1 Word)?



Throughput & Downtime

The Usual Suspects – The W's

Downtime-Summary



Modern Frac Operations = Bulk Logistics

An Average Frac Day for ~350 US Frac Fleets

- Water – 3 Olympic-size swimming pools
- Diesel – 10,000 gal
- Sand – 10 to 15 train cars
- Additives – 2,500 gal

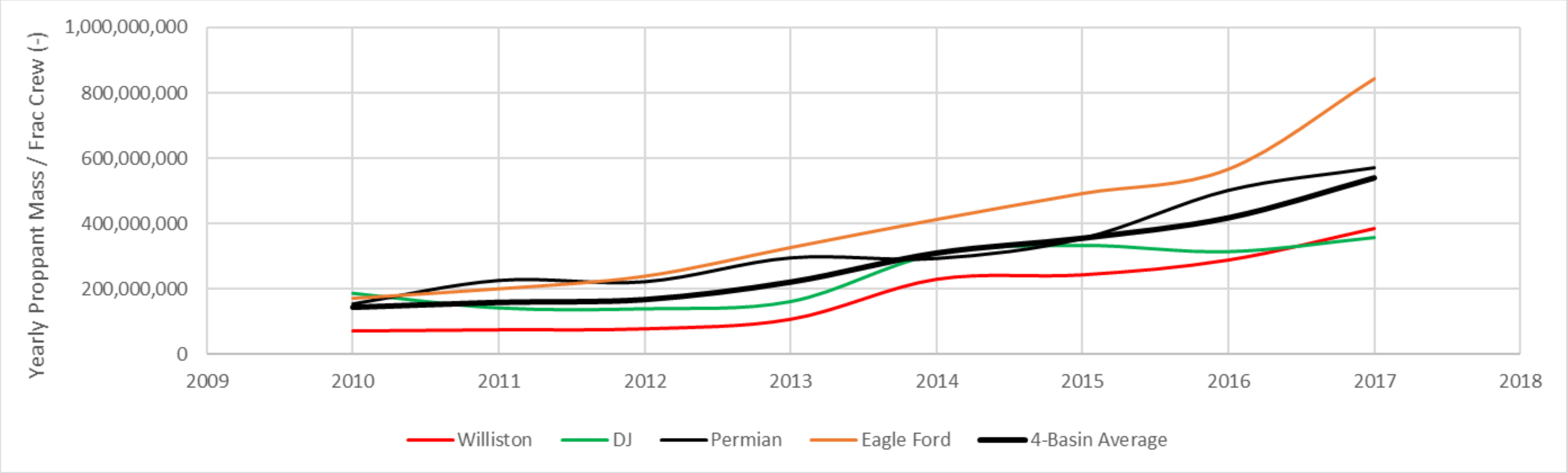
Modern and Efficient Frac Operations

It's a Frac'ing Factory

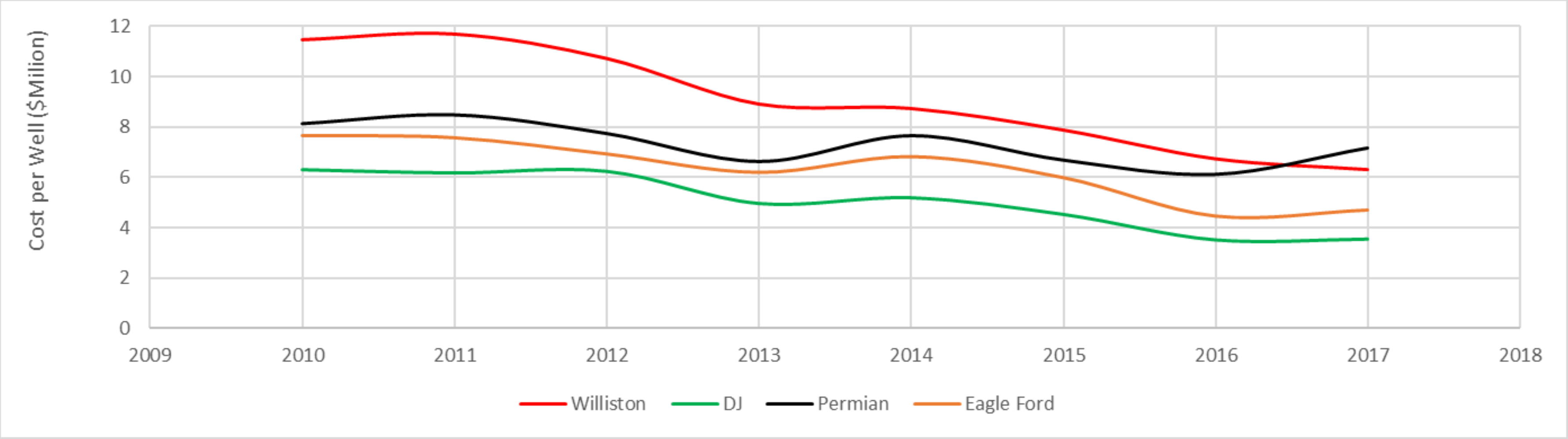
- Redundancy
- Made for purpose
- Extended lifetime
- Efficient delivery
- Better neighbor

Volume Discounting

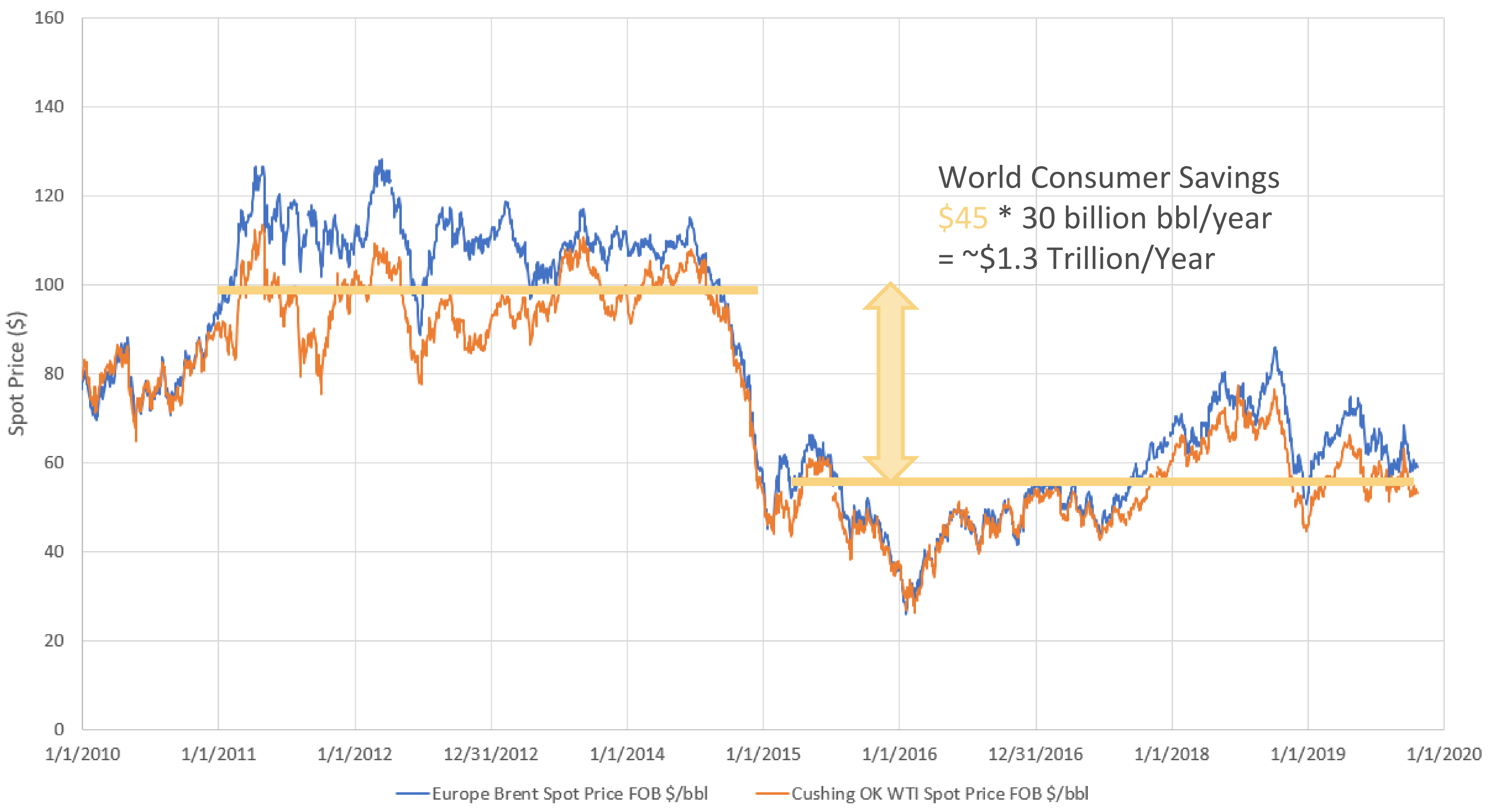
Thank Your Service Company Representative Today!



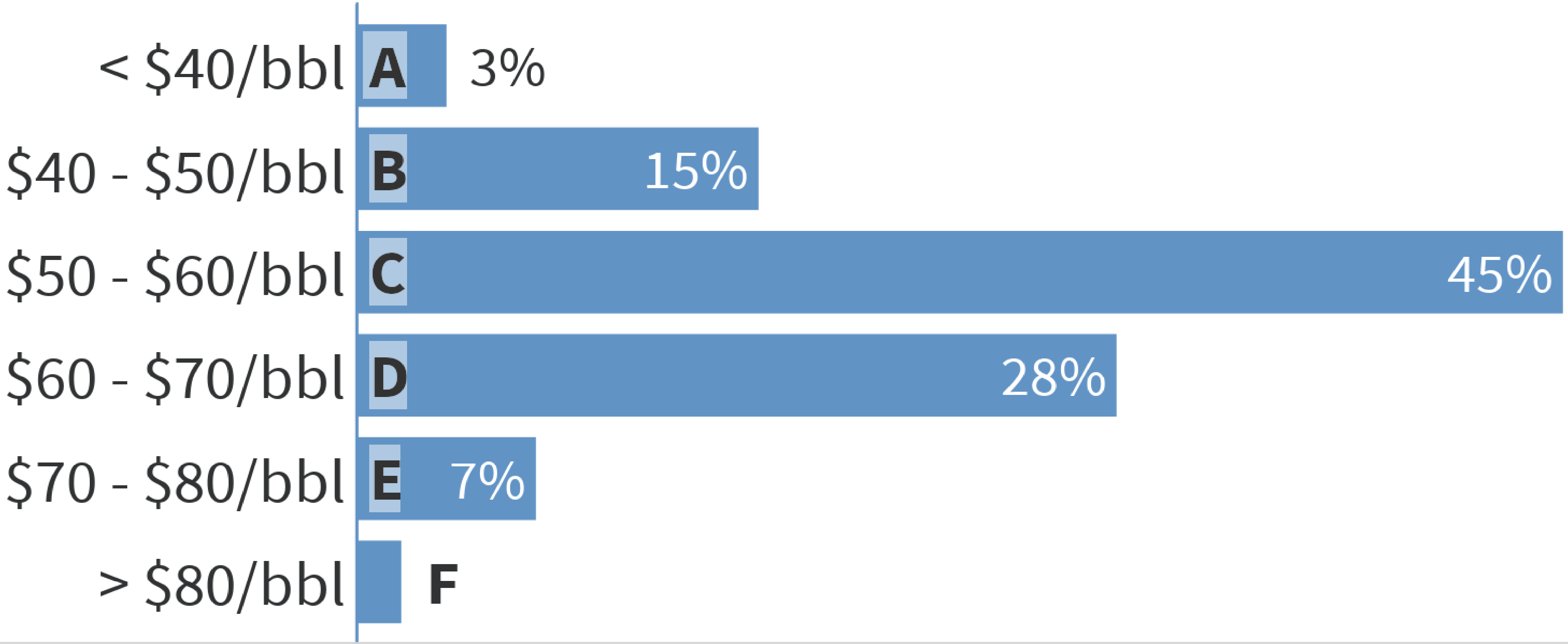
+206%
since 2012



-29%
since 2012


World Consumer Savings
$45 * 30 billion bbl/year
= ~$1.3 Trillion/Year
Spot Price ($)
160
140
120
100
80
60
40
20
0
1/1/2010
1/1/2011
1/1/2012
12/31/2012
1/1/2014
1/1/2015
1/1/2016
12/31/2016
1/1/2018
1/1/2019
1/1/2020
Europe Brent Spot Price FOB $/bbl
Cushing OK WTI Spot Price FOB $/bbl

A Barrel of WTI Crude Oil Will Trade for .... by the End of 2020



In Summary - The American Shale Revolution

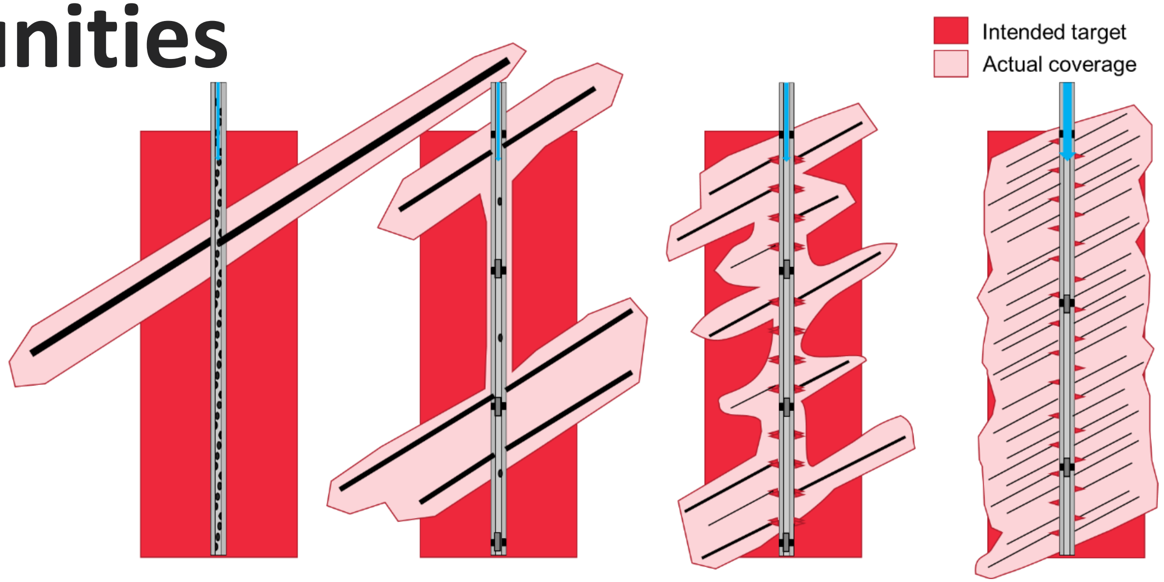
Technology & Efficiency Have Improved Our Competitiveness

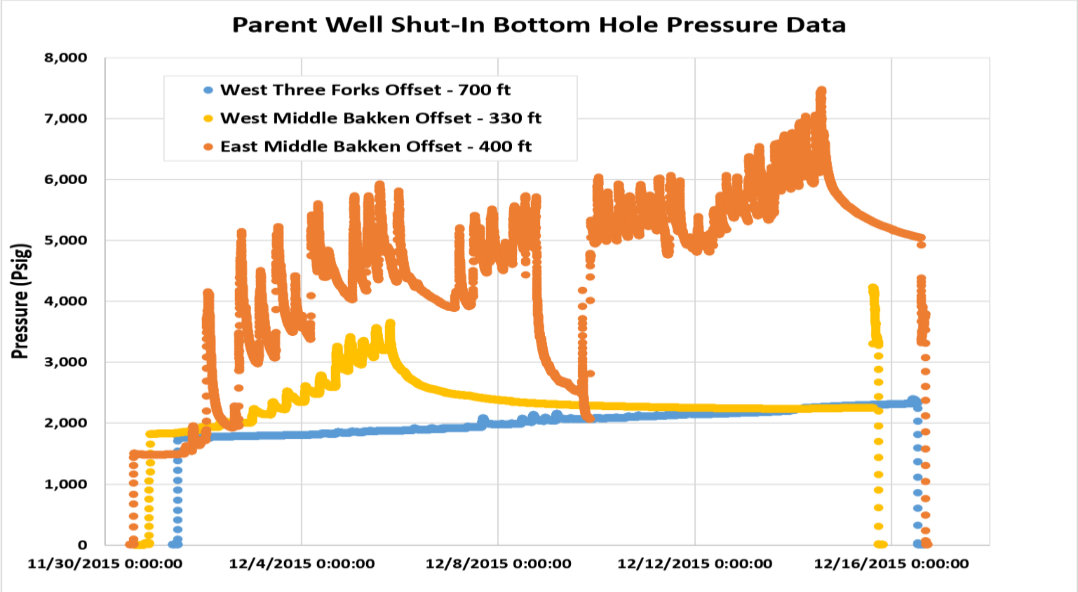
Parameter	Unit	2012 Average*	2017 Average*	Change
Lateral Length	ft	5580	7625	37%
Stage Count		19.3	38.6	100%
Stage Intensity	ft/stage	296	208	-30%
Proppant Mass	lbs	3,506,284	11,891,000	239%
Proppant Mass per Lateral Foot	lbs/ft	677	1,632	141%
Fluid Volume	bbl	74,411	243,983	228%
Fluid Volume per Lateral Foot	bbl/ft	14.4	33.2	131%
Average Proppant Concentration	PPG	1.17	1.21	3%
Max Rate	bpm	57.6	81.7	42%
Max Rate per Lateral Foot	bpm/ft/stage	0.20	0.42	105%
365-Day Cumulative Oil	BO	61,044	108,209	77%
365-Day Cumulative Oil per Lateral Foot	BO/ft	12.2	17.7	46%
365-Day Cumulative Oil Equivalent	BOE	91,465	159,942	75%
365-Day Cumulative Oil Equivalent per Lateral Foot	BOE/ft	18.2	25.7	41%
Well Cost	Million$	$7.2	$5.1	-29%
Cost per Barrel Oil Equivalent	$/1-Year BOE	$86	$32	-63%
Cost per Barrel Oil	$/1-Year BO	$128	$46	-64%

*Averaged over 10 basin / formations: Williston Middle Bakken and Three Forks, PRB Niobrara and Frontier/Turner, DJ Codell and Niobrara, Delaware Basin Wolfcamp and Bone Spring, Midland Basin Wolfcamp and Eagle Ford; Production metrics from 2016 wells.

Industry Challenges & Opportunities

- Production Interference
  - Can exemplary kids and save their hippie parents?
  - Can re-fracs / frac protects with some surfactant / CO_2 start a "huff 'n puff" EOR shale revolution?
- Can perforation strategies further reduce stage count to save completion cost?
- Can we replace more "viscosity" with "velocity" in the DJ Basin and save on chemicals?
- Is Regional Sand the next big change in the Rockies for "just-good-enough" proppant economics?
- Efficiency improvements (pumping >50% of all time)
  - Opportunity for downtime and non-pumptime reduction
  - Electric fleet pie in the sky?





Conclusions

- US Shale Revolution has transformed US and World Energy
  - Still remains an almost exclusive American Revolution
- Technological changes continue as operators find better ways to minimize $/BO(E)
  - Similar changes in most US basins, with gradual move to larger volumes, “spread the wealth” delivery in the reservoir and cheaper materials
  - “Big picture” statistical analysis support these changes
  - Possibly seeing diminishing returns in some basins
- Environmental footprint of oil & gas production is shrinking
- Together, operators and service providers are improving pumping efficiencies
  - Room for improvements with the W’s – Wireline, Water, Wellhead and Weather – and Pumps
- Economic and humanitarian benefits are massive
  - Biggest benefit for lower-income citizens of the world

Thank You! Questions?