Organic Shale Refrac Optimization using the Extreme Limited Entry Process and Expandable Liners

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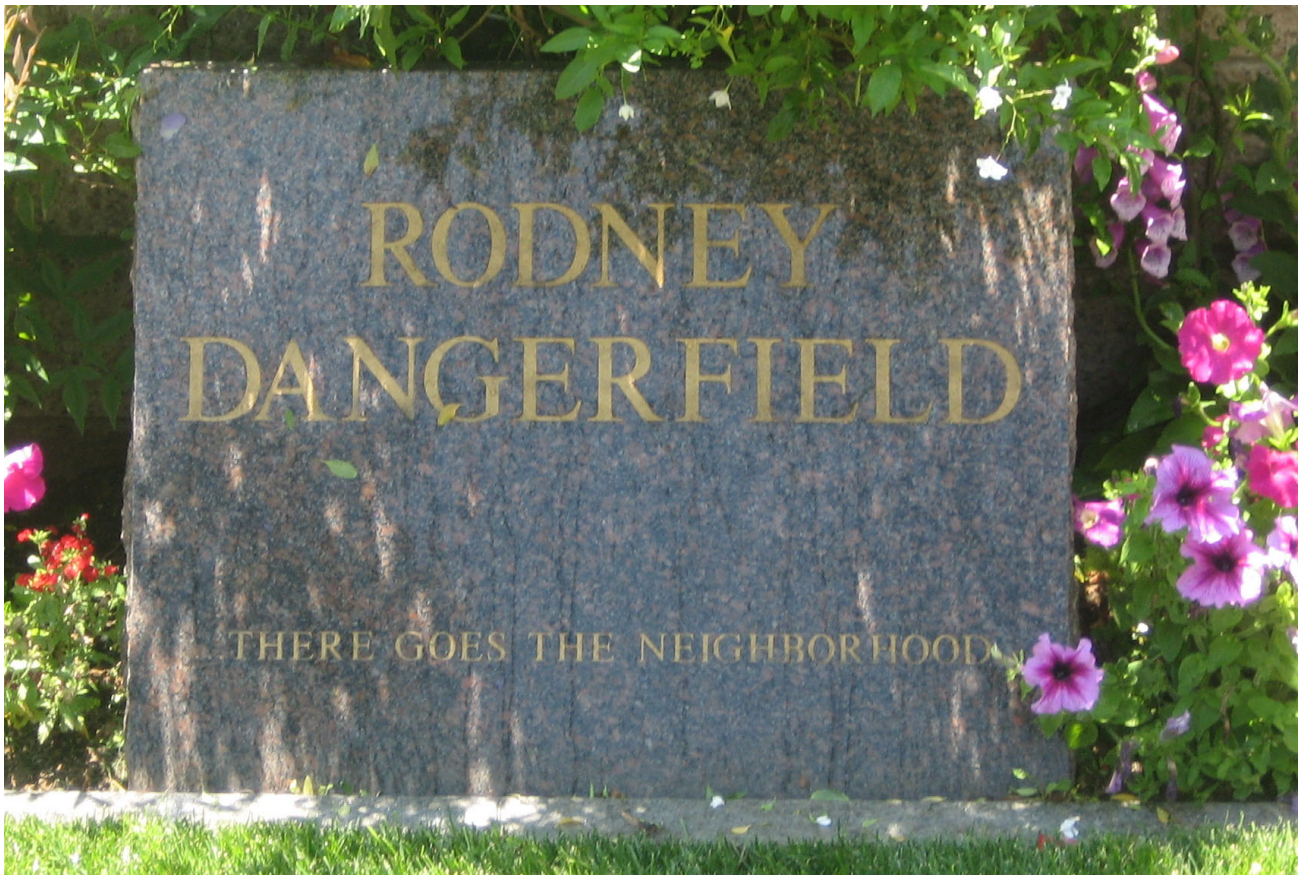
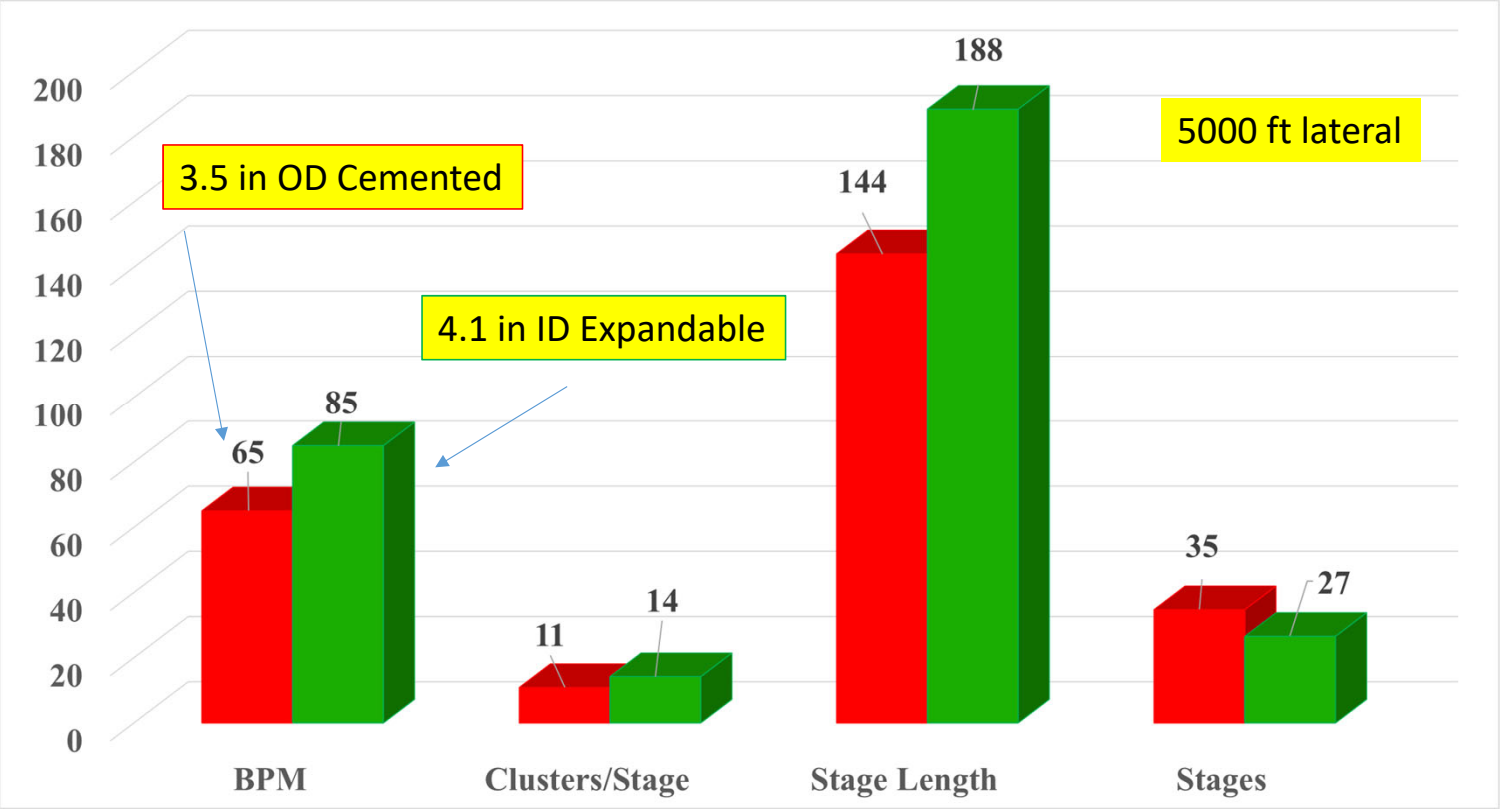
What do refracs and Rodney have in common?



Executive Summary

- Extreme limited entry (XLE) provides a mechanism to stimulate short spaced clusters (13.3 ft spacing proposed) with high cluster efficiency (85%)
  - Higher SRV=higher EURs 100% of the time
- If the number of perfs per cluster are limited (one is proposed) and the hole size is uniform stage lengths can be increased without decreasing the overall SRV with a 1500 psi pressure drop across perfs post erosion
- 85 BPM with an expandable liner can frac a 7500 ft lateral with 38 stages vs 47 stages required if the max rate is 65 BPM with a 3.5 in cemented liner
- While the expandable option up front AFE is higher than a cemented liner the elimination of 8 frac stages results in 2 fewer pumping days and a return on the incremental investment in the expandable of 6.5 to 1

Expandable vs Cemented Liner Comparison



Detailed Economic Summary

	5000 ft lateral	5000 ft lateral	Expandable	7500 ft lateral	7500 ft lateral	Expandable
Expandable vs:	Added Up Front Cost	Benefit	ROI	Added Up Front Cost	Benefit	ROI
3.5 cemented	$ 123,000	569,000	4.6	$ 150,000	$ 978,611	6.5
4 in FJ Cemented	$ 98,000	162,734	1.7	$ 120,000	$ 279,603	2.3

- **Refrac Main Value Drivers:**
  - Enhance and protect production of primary wells while avoiding up to 40% losses in infill well EURS ($6.8 MM PV10 loss for a 600 MBO Permian well)
  - $2.6 MM Refrac vs $1.0 MM water preload with water: $4.2 MM PV10 economic advantage for refrac (avg Permian shale refrac PV $5.7 MM*)
    - Full preload Gen 2 5000 ft lateral 178,000 BBL water needed, 7500 ft lateral 268,000 BBL
  - Access and contact significant volumes of unstimulated rock
  - Increase production at the minimum possible cost
  - Implement new completion learnings
- **Primary Execution Challenges**
  - Control fracture entry points to stimulate as close to 100% of the new rock and recharge 100% of the existing depleted intervals
  - Execute a premium optimized frac at the lowest cost per barrel possible

* Barba and Leshchyshyn, “Evaluating Refrac Potential in the Permian Wolfcamp Formation,” SPE/ICOTA Refrac Workshop April 2017

Eagle Ford Pressure Monitor Well Data

Producing Well Gen I Frac 50 ft Cluster Spacing

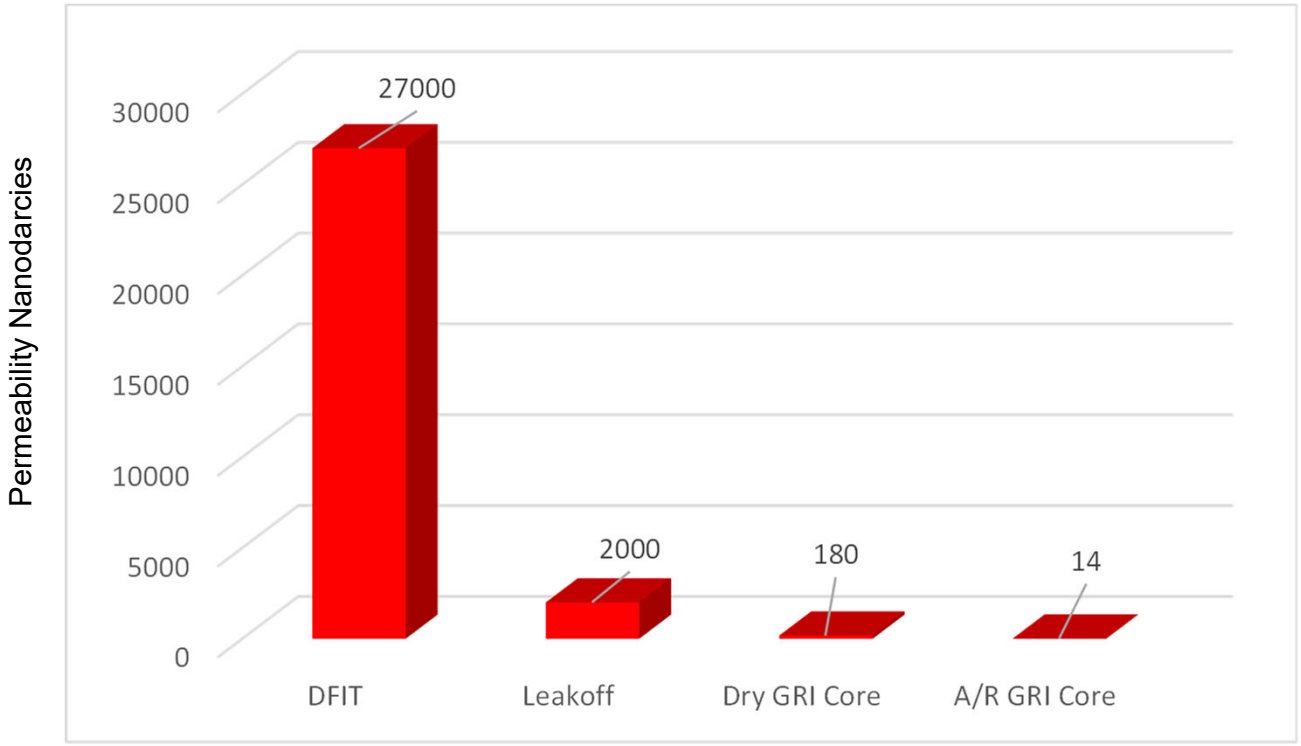
Pressure Monitor Well 70 ft Away Drilled +/- 4 yrs later (based on frac gen)

= drained area in offset pressure monitoring well (SRV)

7.5 ft of lateral drainage (SRV width) observed in monitor well
85% of rock not producing with 50 ft cluster spacing

Gas molecule in 100 nd rock-100 days to travel 1 meter
First Barnett horizontals 2001, first Wolfcamp horizontal August 2009
8 years passed before industry understood how organic shale fracs worked

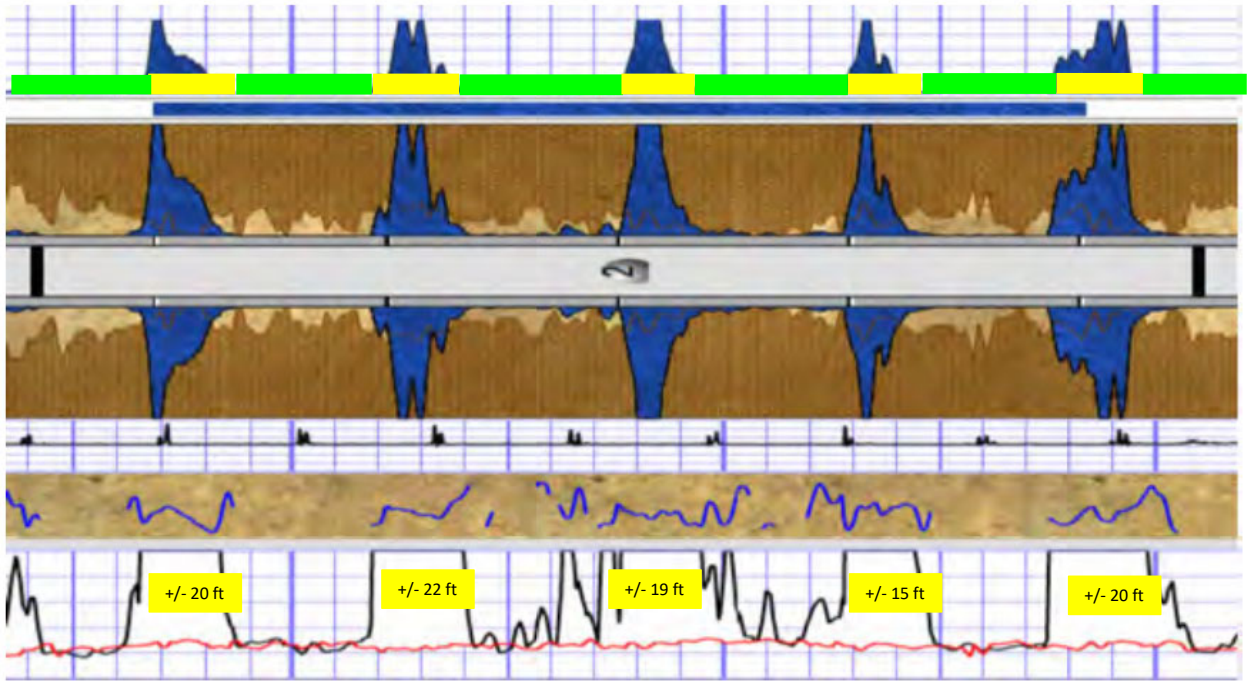
Organic Shale Permeability Comparison



Unlike conventional reservoirs, fracs in organic shales CAN increase the reservoir permeability
Natural fracture generation most likely mechanism, >80% of flow area unpropped

Midland Basin Wolfcamp RA Tracer Width

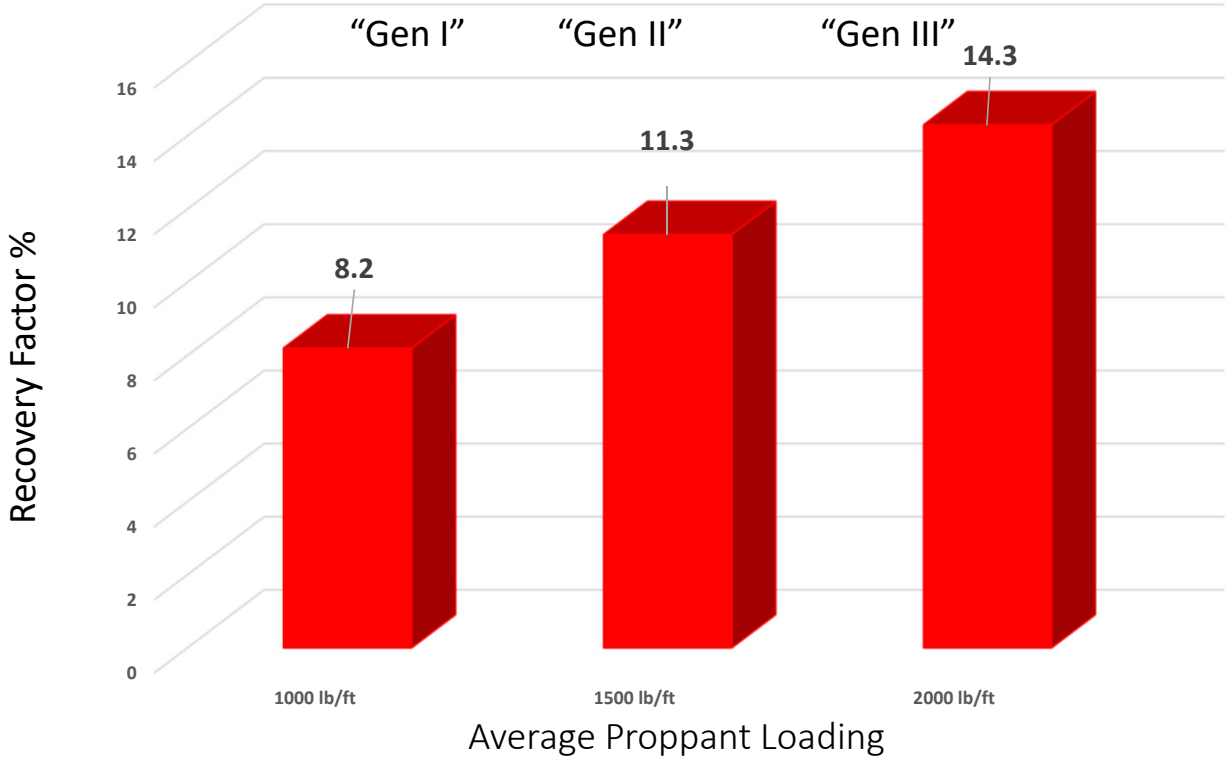
Green = Stranded Hydrocarbons



50 ft cluster spacing, 60% of rock volume unstimulated

URTEC paper 2902960

Wolfcamp Recovery Factor History



Infill well performance masked by increasing recover factors

Currently doing study to update with both generations and infill-parent results

Cluster spacing of equal or greater importance than proppant loading

Wolfcamp Recovery Factor vs Cluster Spacing

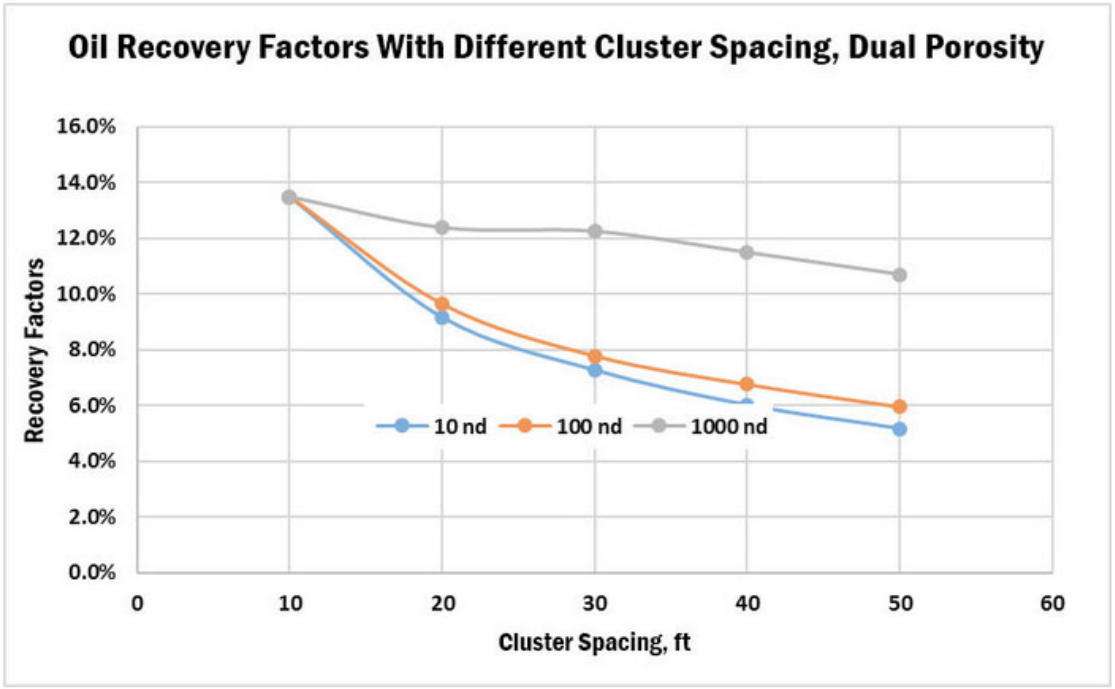
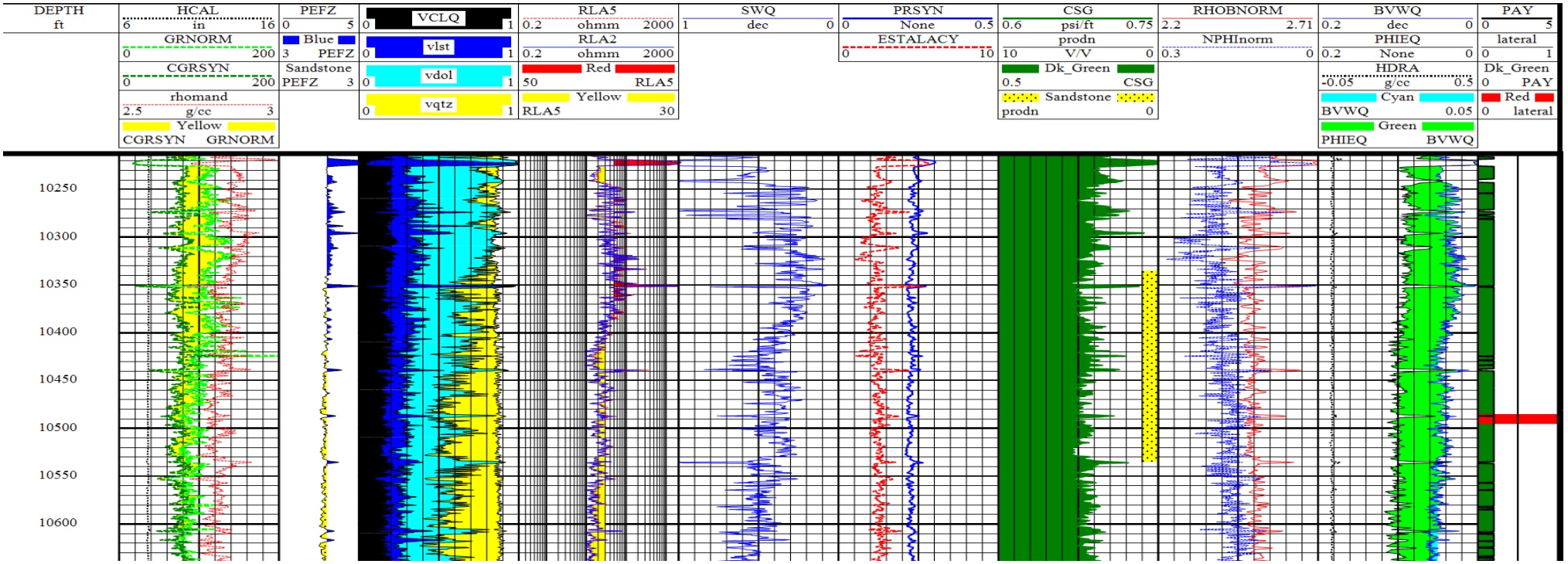


Fig. 10—Recovery efficiency based upon the dual-porosity model at the end of year 30.

"Gen 3" fracs are not all created equal, proppant loading only part of the mechanism
Survey of 25 H2 2018-2019 Completions: Median spacing 35 ft
Range 12 to 51 ft spacing

Xiong , 25 May 2017 SPE "The Way Ahead"

Pecos County Refrac Candidate Remaining OIP



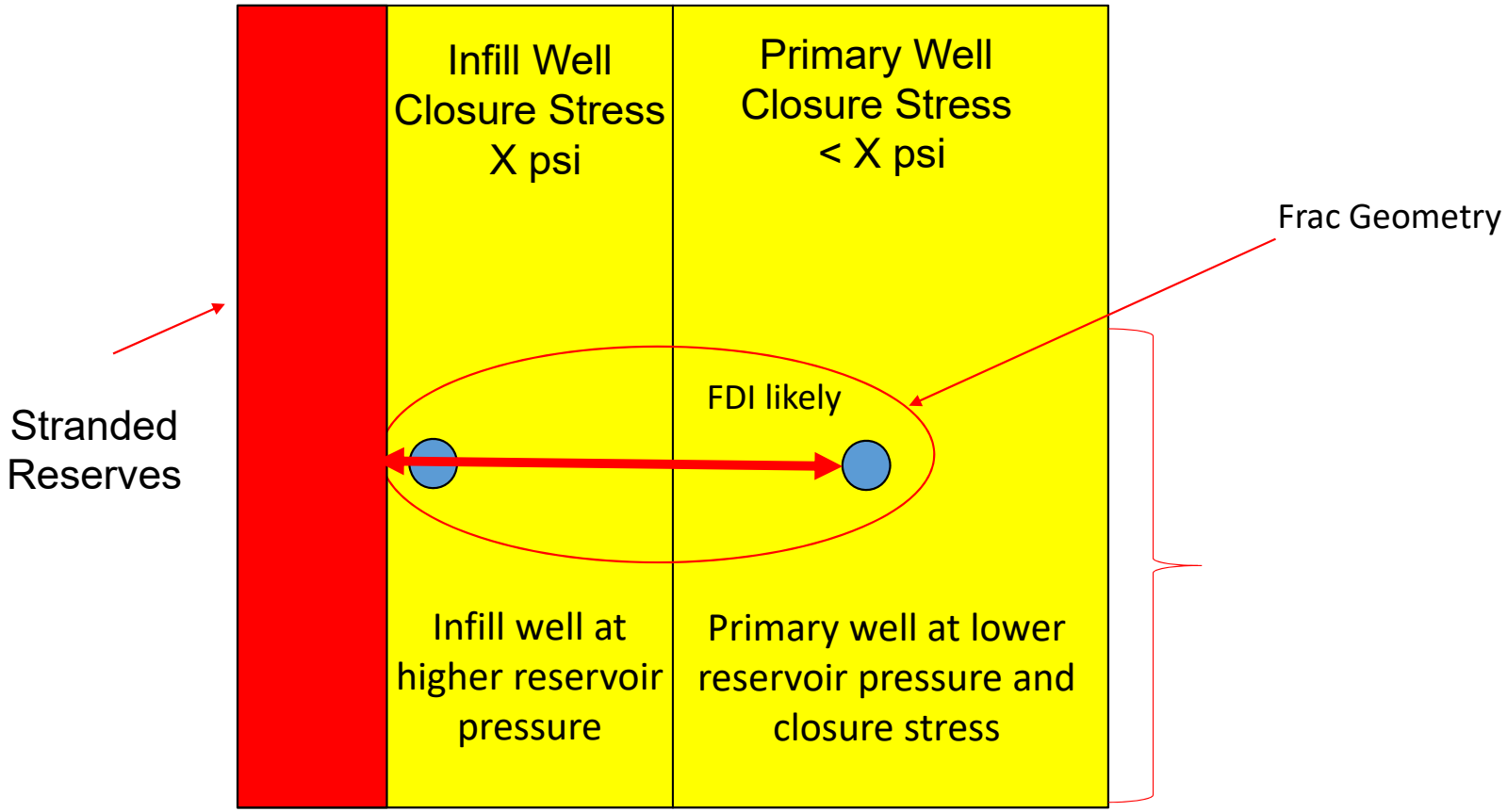
H	PHI	SW	BOIP/Ac	FVF	Ac	EUR BO	EUR/ac	RF	EUR 14.3%	Refrac EUR
192.5	0.102	0.383	55,892	1.682	79.0	192,842	2440	4.4%	631,658	438,815

Barba and Leshchyshyn, “Evaluating Refrac Potential in the Permian Wolfcamp Formation,” SPE/ICOTA Refrac Workshop April 2017

Horizontal Organic Shale Refracs

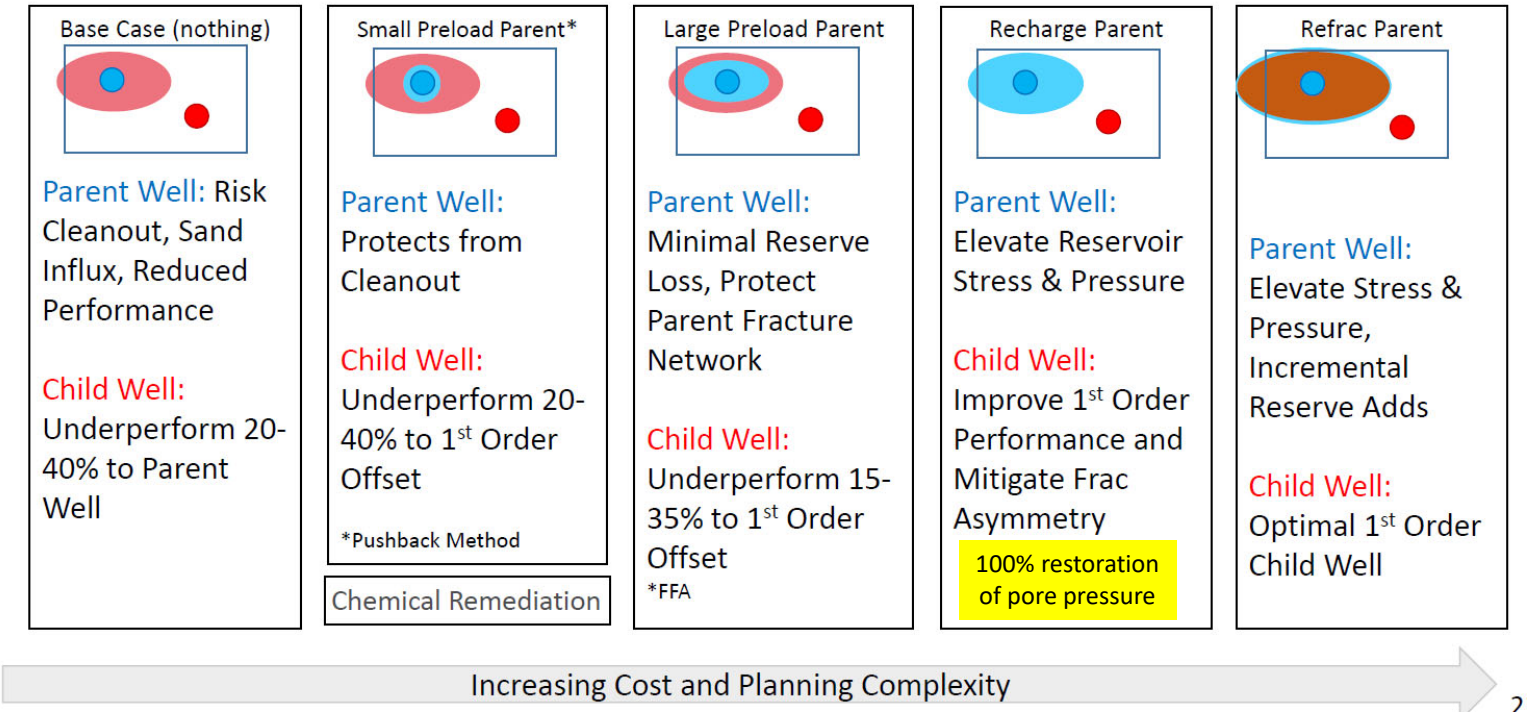
- As more infill wells were completed it became apparent that there were issues involved with Fracture Driven Interactions (FDI's or "frac hits")
- Initially the focus was on avoiding production losses in the primary wells as infill well FDIs often damaged or killed the primary wells
- As production was established it became apparent that the recovery factors of the initial infill wells were lower than what should be expected from the OIP and offset recovery factors normalized to the frac vintage
- Recent work done by Elliott (2019) suggests that the only viable options for primary well protection are refracs and full volume preloads with water
- The full volume preload requires replacement of a large % of the oil and water produced from where it was produced to restore original pore pressure

Infill Well Asymmetric Frac Closure Stress



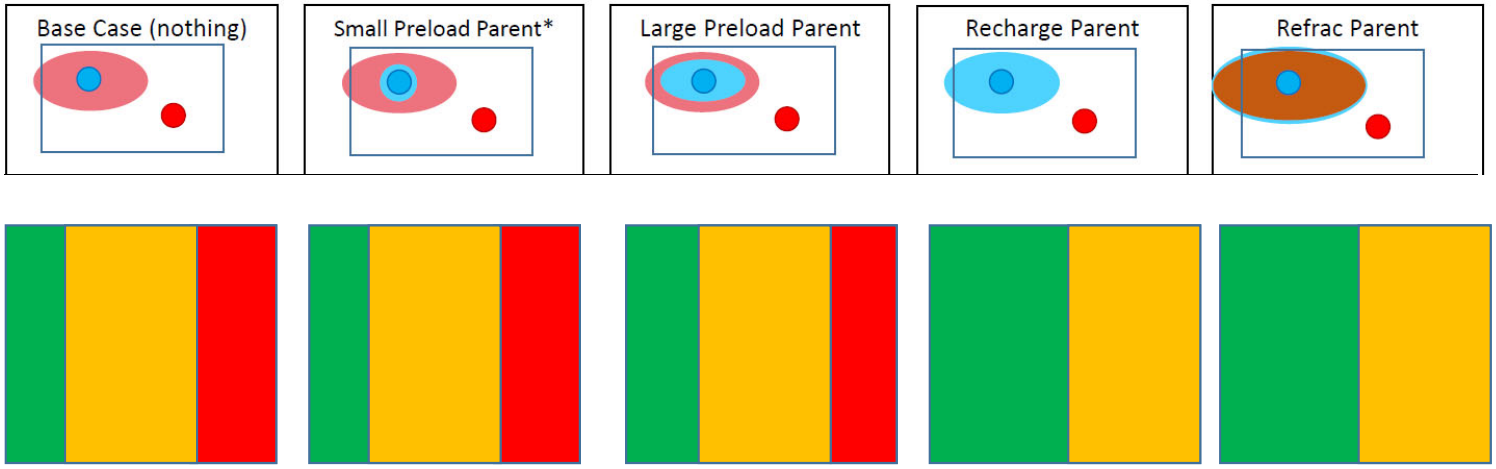
Level of depletion probably not an issue, if stress lower frac will go there

Depletion Mitigation Opportunities



Elliott, Brendan, Well Completions for Unconventional Resource Development Optimization and Parent Child Interaction Workshop, April 2019

Depletion Mitigation Results



Red = stranded hydrocarbons

Refrac vs Full Volume Preload Comparison

Refrac Option		
Refrac Cost	**$**	**(2,578,983)**
Refrac PV10	**$**	**5,746,847**
Prevent Infill 40% EUR Loss	**$**	**6,800,000**
Refrac Value	**$**	**9,967,865**
Preload Option		
Preload Cost	**$**	**(1,000,000)**
Prevent Infill 40% EUR Loss	**$**	**6,800,000**
Preload Value	**$**	**5,800,000**
Refrac Economic Advantage	**$**	**4,167,865**

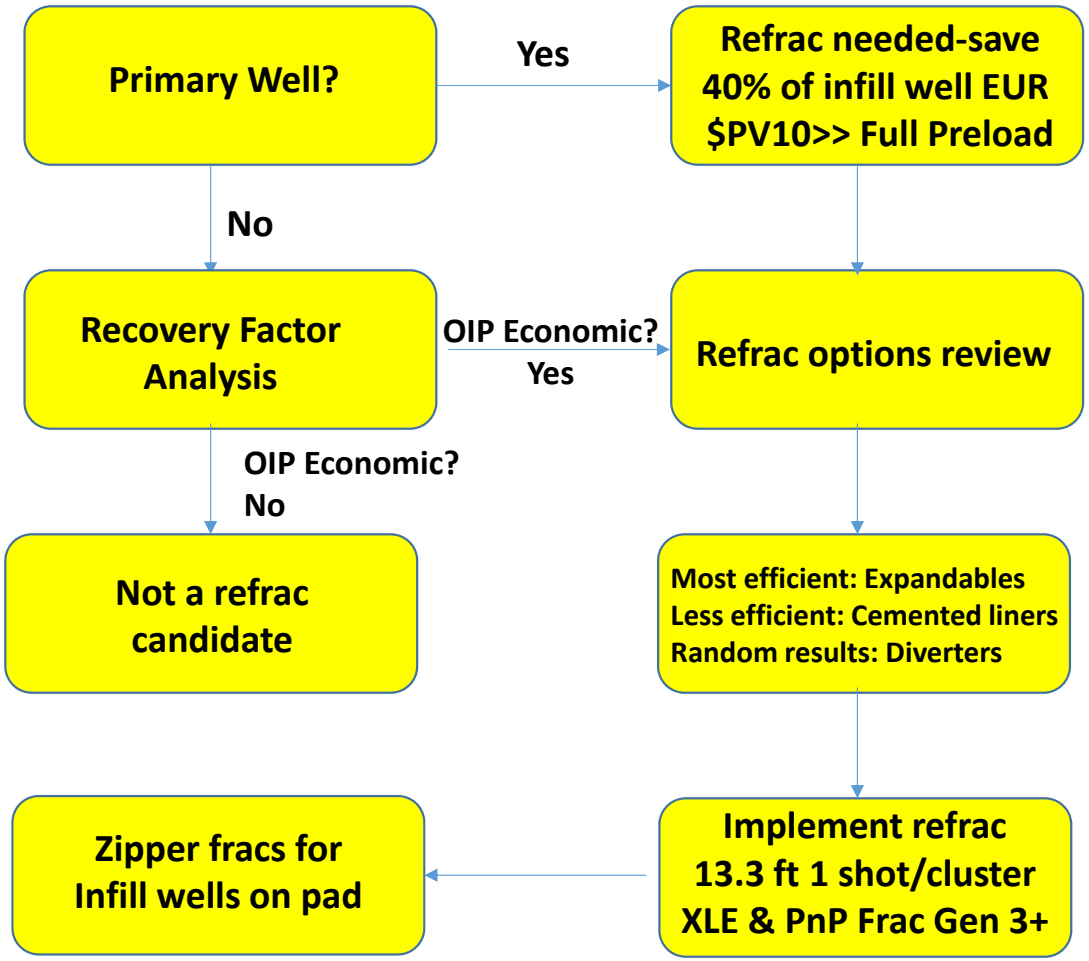
Permian Wolfcamp Data
Barba and Leshchyshyn
2017 ICOTA/SPE Refrac

Assumes 600,000 BO liquids
GOR 1081/Nymex Strip

Primary Well Refrac Issues

- The refrac treatment needs to recharge the existing clusters to prevent infill well asymmetric fractures
- The treatment should access as much “new rock” as possible to increase primary well production as much as economically possible
- Both mechanisms require complete isolation of the existing perforations to effectively stimulate both the new and existing clusters
- Mechanical isolation is strongly recommended vs attempting to divert with chemicals, fiber, or ball sealers
- The two viable options for mechanical isolation are expandable liners and cemented casing

Organic Shale Refrac Process Flow Chart



Refrac Isolation Options

- There are several options available for executing refracs using either diverters or mechanical isolation
- For mechanical isolation the two main options are cemented or expandable liners
  - The combination of Extreme Limited Entry and expandable liners provides a means for:
    - Fewer stages than cemented liners via higher pump rates allowing for more clusters per stage
    - Lower cost of stimulation than cemented liners
    - Lower cost per barrel of oil produced than cemented liners
- The process has similar benefits for new well completions

Perforating Best Practices Horizontal Wells

- Latest advances in fiber optic technology have validated the minimum pressure drop across the perforations to maximize cluster efficiency
- Two studies (SPE 189880/184834) have shown that 2000 psi is the minimum number for the pad and 1500 psi at the end of the job after perf erosion
- Designing the completion for the 1500 psi post erosion target is recommended and this will typically result in an initial pressure drop greater than 2000 psi (2700 psi +/-)
- Perforations need to be uniform size, conventional charges not used due to irregular hole sizes and unpredictable pressure drops
- A critical rate of 6 BPM/cluster is proposed and this typically overrides the number of clusters from the delta p calculation and larger holes are needed
- May need higher pressure drop if primary well highly depleted

XLE vs Conventional Perf Cluster Efficiency

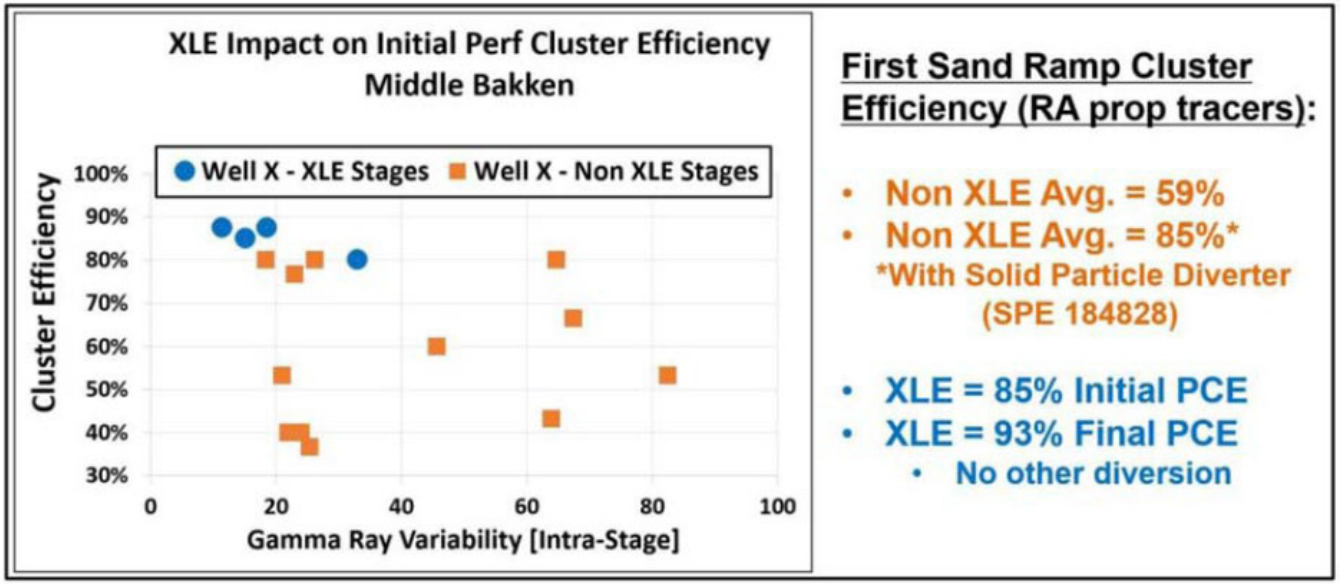


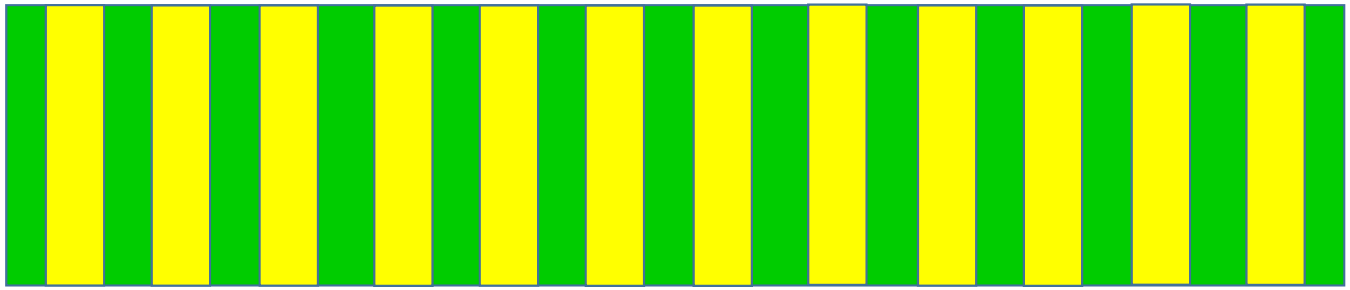
Figure 9—Perforation cluster efficiency (PCE) comparing stages with XLE vs non-XLE stages for Well X.

Cluster efficiency not function of stage length
With 6 BPM/cluster and 1500 psi post erosion stage length irrelevant

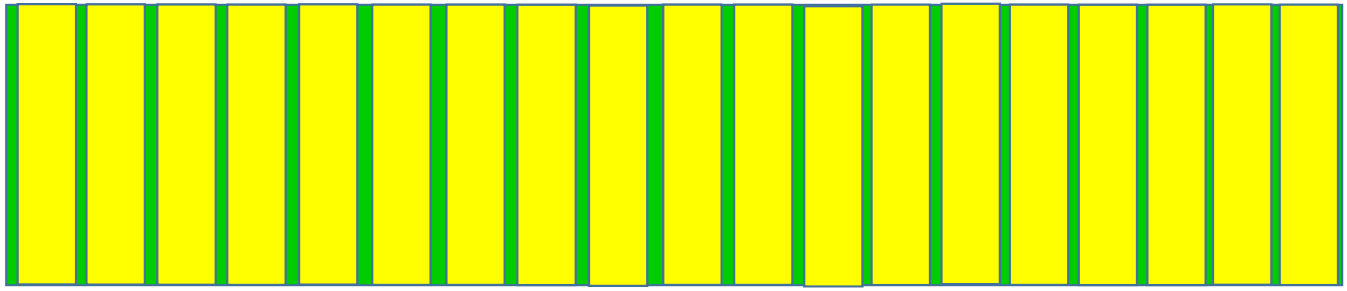
SPE 189880

Cluster Efficiency vs Drainage

Conventional completion 59% average cluster efficiency or less



XLE 85% average cluster efficiency



Green = stranded hydrocarbons outside the SRV

Values from SPE 189880

XLE Optimization Spreadsheet

EXTREME LIMITED ENTRY PRESSURE DROP CALCULATION		
Stage length vs Pump Rate		
Vary total number of perfs to obtain 1500 psi post erosion Delta P		
Number of clusters limited by 6 BPM critical rate to avoid screenouts		
		Post
Part 1 Number of Perforations to Obtain 2000 psi Delta P	Initial	Erosion
Rate BPM (input)	90	90
6 BPM/cluster allowable clusters	15	15
fluid density lb/gal (input)	8.44	8.44
Total number of perfs (variable to change in goal seek)(input)	16	16
Number of holes per cluster (recommend keeping this number)	1	1
Perf cluster efficiency (input)	0.85	0.85
Number of perfs active (calculated)	14	14
Perf diameter inches (input)	0.5	0.5
Coefficient of discharge (input)	0.70	0.95
Delta P perfs (use Goal Seek Alt-T-G 2000 psi or higher target)	2859	1500
BPM/perf (calculated)	6.62	6.51
Cluster spacing (input)	13.33	
Number of clusters	16	
Stage length	213	
Lateral length	5000	
Number of stages	23.4	

XLE vs Diversion and Engineered Completions

- While all three options have similar published cluster efficiencies in the 85% range, XLE is recommended over the other two options
- While intra-stage diversion is fine for new well completions, in a refrac they can prematurely plug off significantly depleted clusters and create an asymmetric fracture at that cluster
  - With typically large primary well cluster spacing (50 ft +/- Gen 1 wells) this can be significant and infill well EUR losses can occur
- For engineered completions the cluster spacing needs to be a maximum of 13-15 ft to avoid gaps in the SRV and to ensure proximity to depleted clusters
- Can probably increase the spacing to 20 ft for new wells in the Permian since recharging existing clusters is not needed

Summary and Conclusions

- Refraccing organic shale primary wells is critical to DSU economics
- If an infill well fracs into the primary well depleted zone asymmetric fracs = 40% EUR loss in the infill ($6.8 MM PV10 600 MBO well)
- “Preload” treatments do not prevent this loss unless a very large percentage of the fluid removed from the reservoir is replaced
  - Refraccing the primary well has a $4.2 million incremental PV10 over a full volume preload, that assumes all pressure sinks are refilled
- While mechanical isolation with expandable liners, short cluster spacing, and XLE is more expensive on the front end than cemented liners the return on the incremental up front investment ranges from 1.7 to 2.3 vs 4 inch flush joint cemented and from 4.6 to 6.5 for 3.5 inch cemented liners

Thanks to:

- Matt Meiners, Tina Tallant, Dustin Dell, and John Callais for their inputs