Advancements in Hydraulic Fracturing Technology

GPAC/PJVA Conference, November 2nd 2016- Andrew McMurray, P.Eng

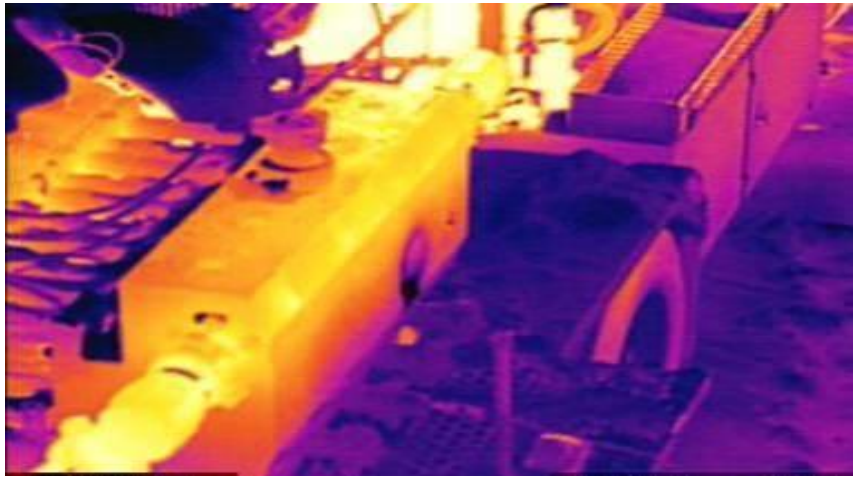
Agenda

- Health Safety and Environment
- Well Design Evolution
- Learning from Fibre Optics
- Stage Count and Proppant Intensity
- Refracturing

Health & Safety

Safety Advancements - decrease personal exposure to high pressures

- Remote satellite monitoring and remote pump control up to 16 units
- Infrared cameras utilized to help find leaks and hotspots



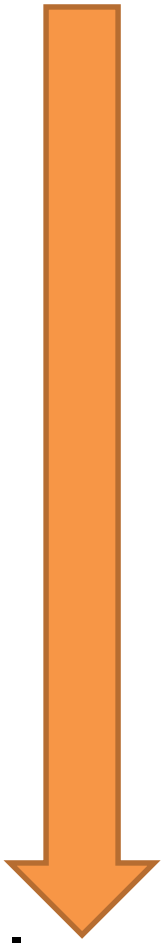
Environment

Dust Control and Chemical Containment:

- Belt Conveyed proppant loading
  - Decrease product agitation = increasing product performance
- Dust Control
  - Proppant and dry chemical exposure to environment and personal

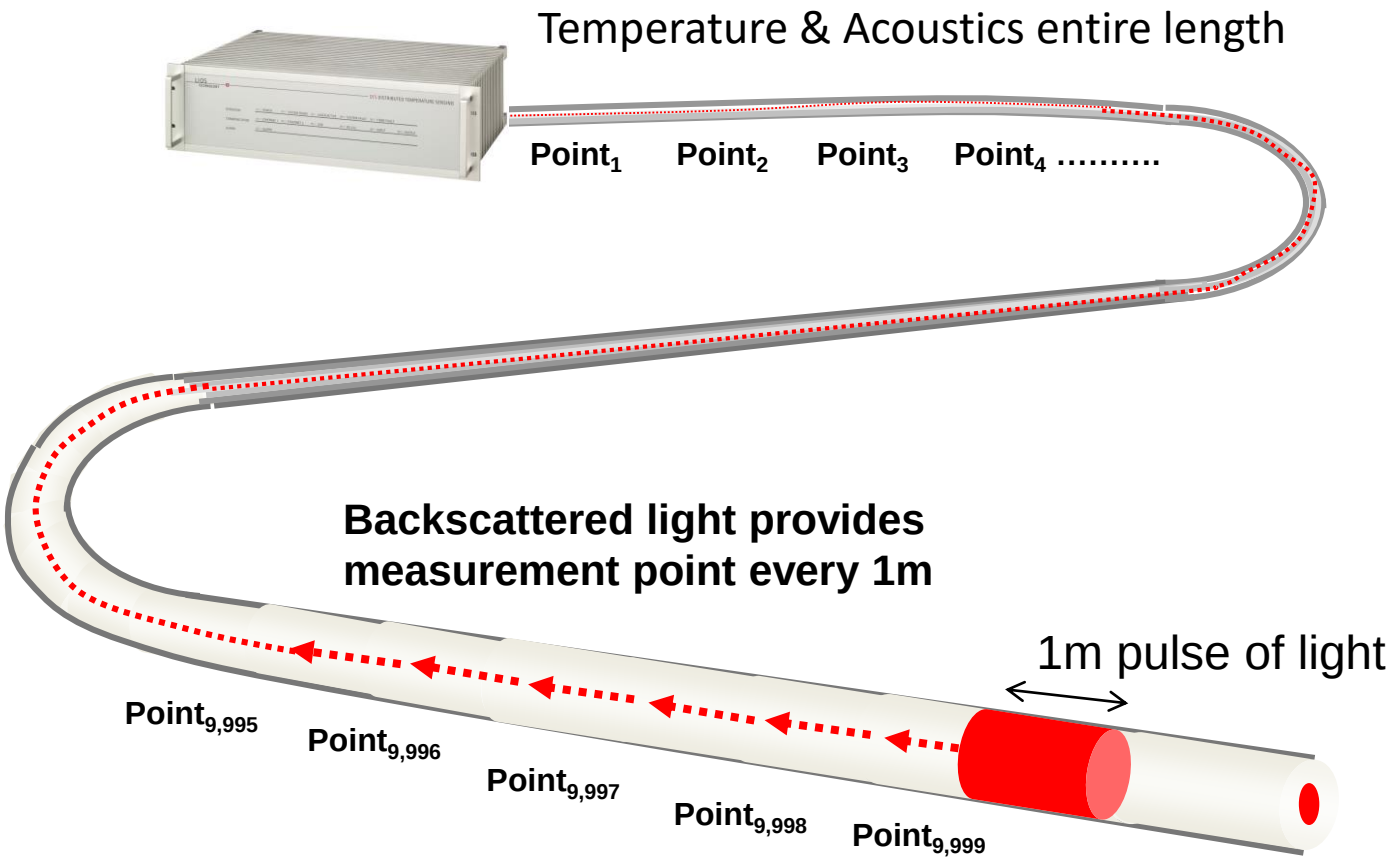
Well Design Evolution

1. Vertical Wells – Barefoot
2. Vertical Wells – Cemented and Perforated
3. Vertical Wells – Cemented and Perforated and Fraced
4. Horizontal Wells - Barefoot
5. Horizontal Wells – Cemented and Perforated
6. Horizontal Wells – Cemented and Perforated and Fraced
7. Horizontal Wells – Cemented and Plug and Perf (P&P)
8. Horizontal Wells – Openhole Ball Drop & Cemented Ball Drop
9. Horizontal Wells – Pin Point Frac using Coiled Tubing or Jointed Pipe

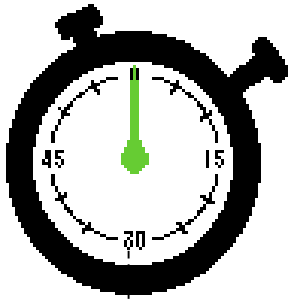


Theme: Increase Proppant and Fluid Placement **Control**

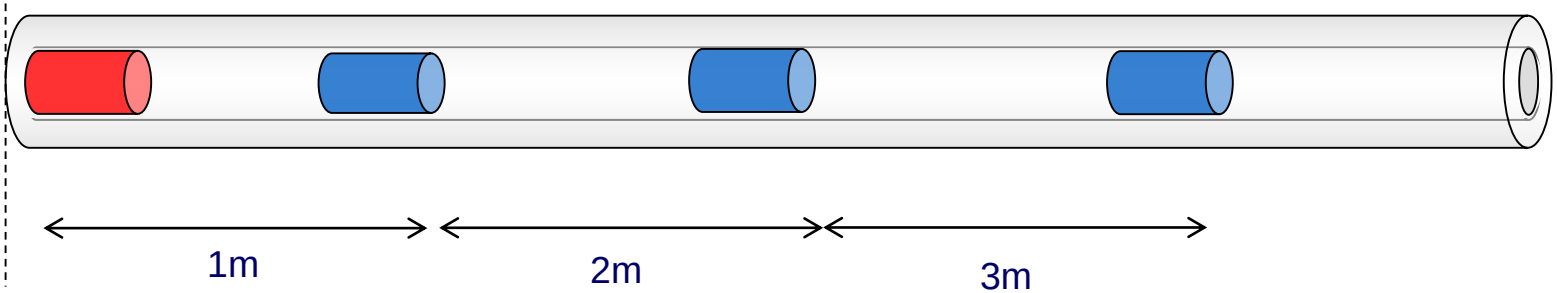
Fibre Optics - How it Works



Time of Flight Principle

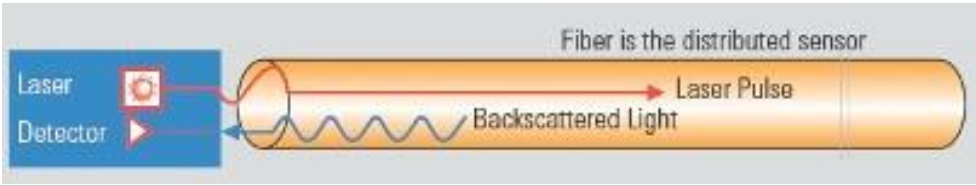


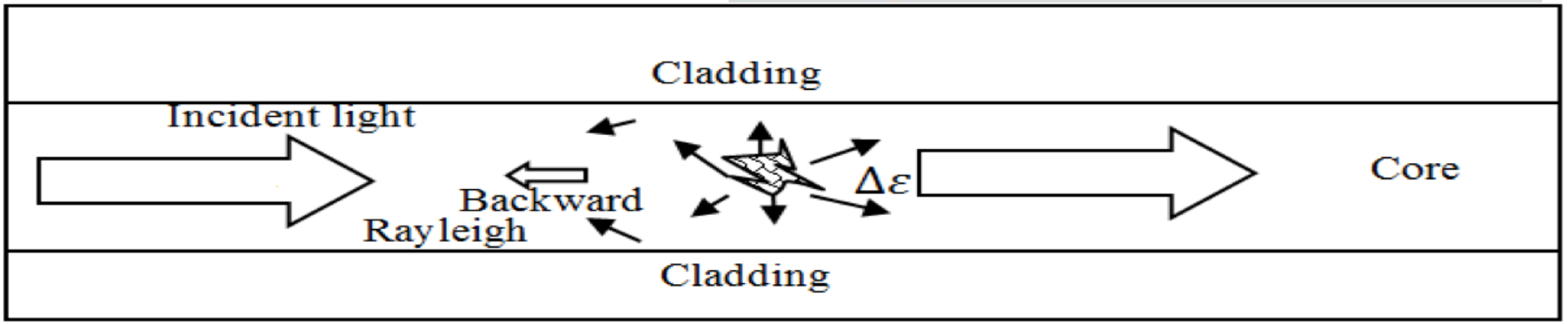
Simple principle similar to time of flight (Radar)



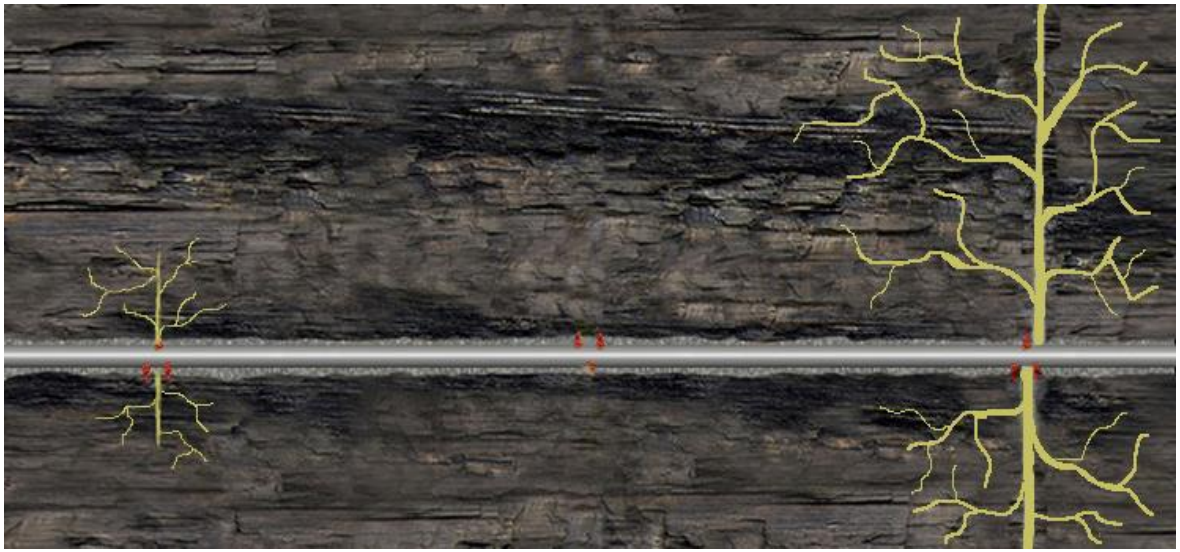
1/100,000 seconds = 1m

3/100,000 seconds = 3m



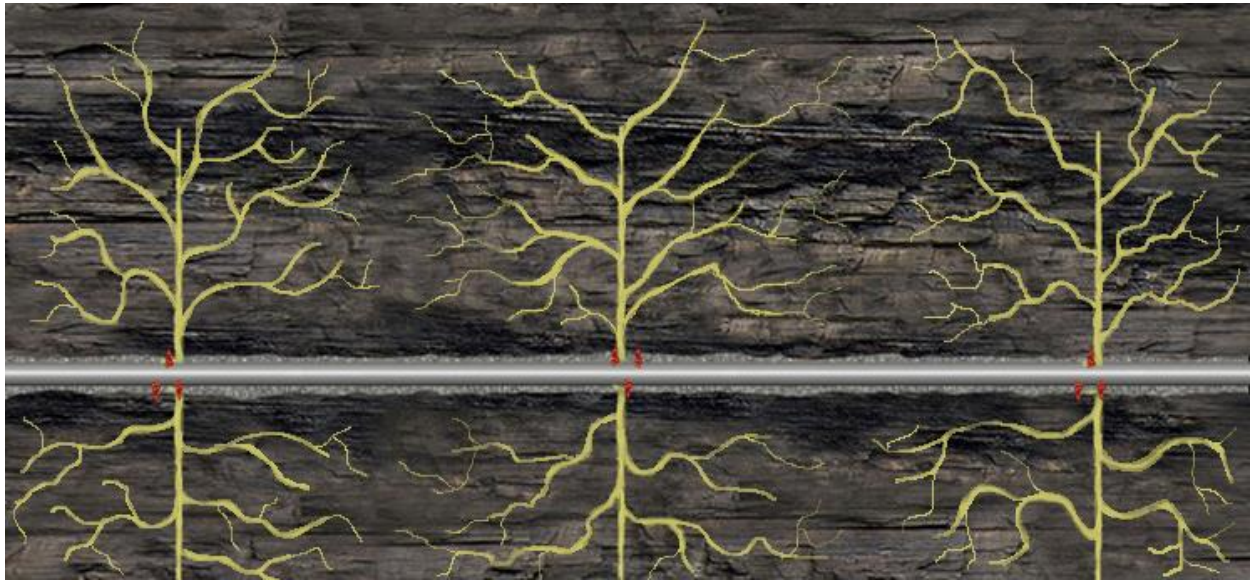


Increase Fracture Complexity



1) Plug & Perf
   - 1 stage, 3 clusters
   - 50- 60% efficiency

2) Pin Point
   - 3 stages, 3 ports
   - 100% efficency



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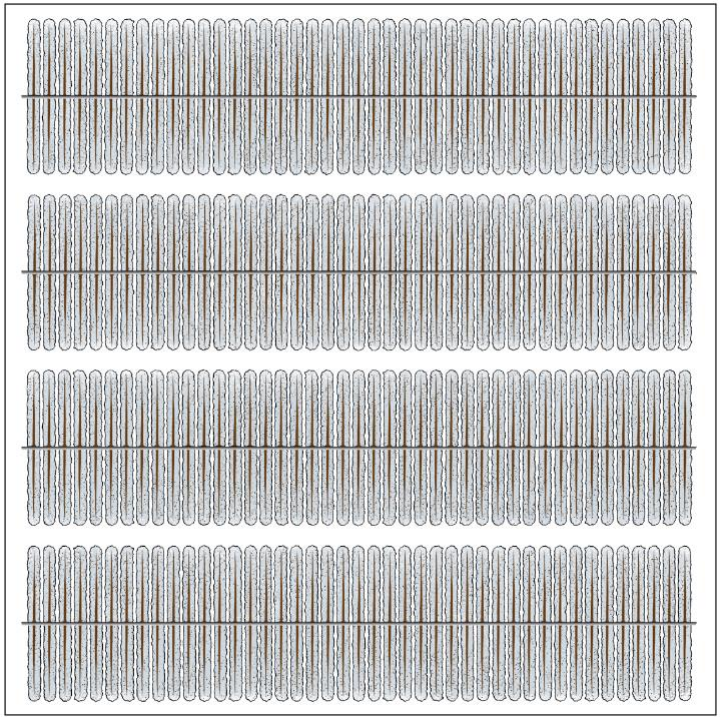
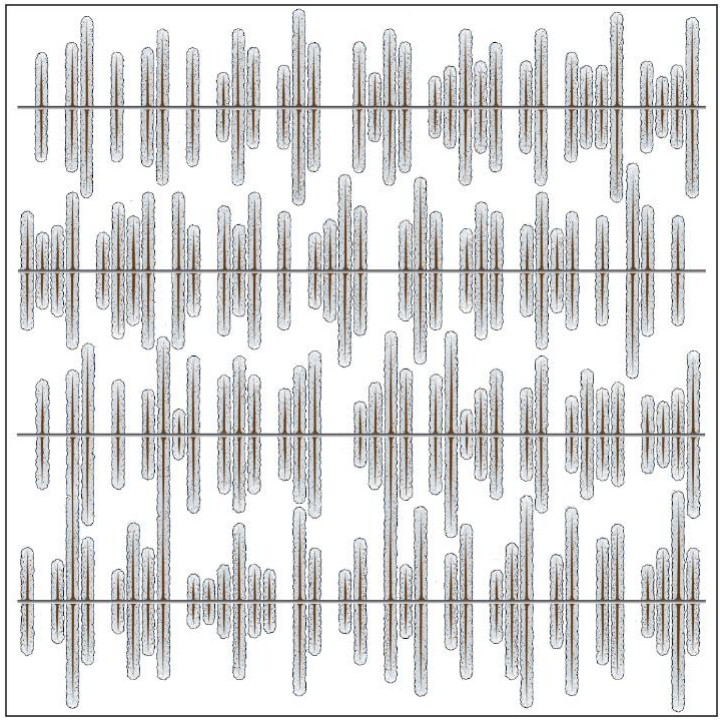


Pinpoint – Uniform and predictable

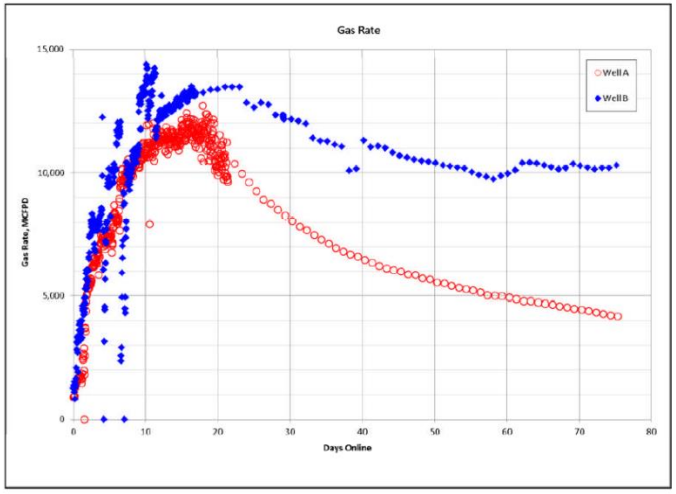


PnP & Open hole– Non-uniform and unpredictable

Production Results

SPE 163820 Summary

- Sleeves reduced treating pressures by 30%
- Sleeves utilized 66% less HHP
- >30% of perf clusters were un-stimulated
- Sleeves increased expected EUR by 108%



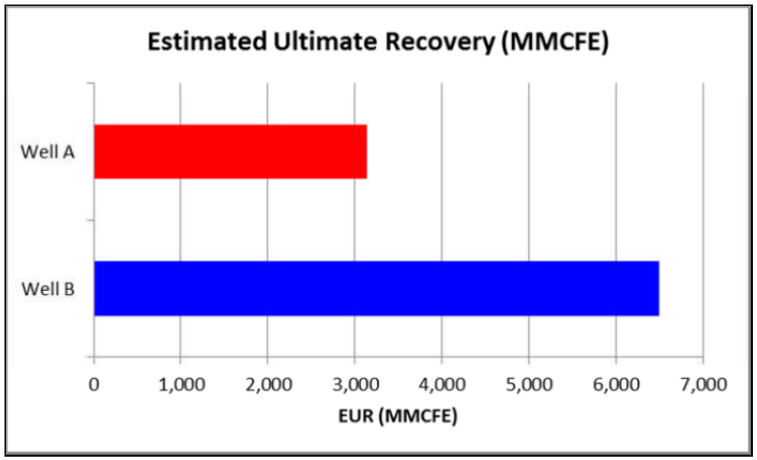
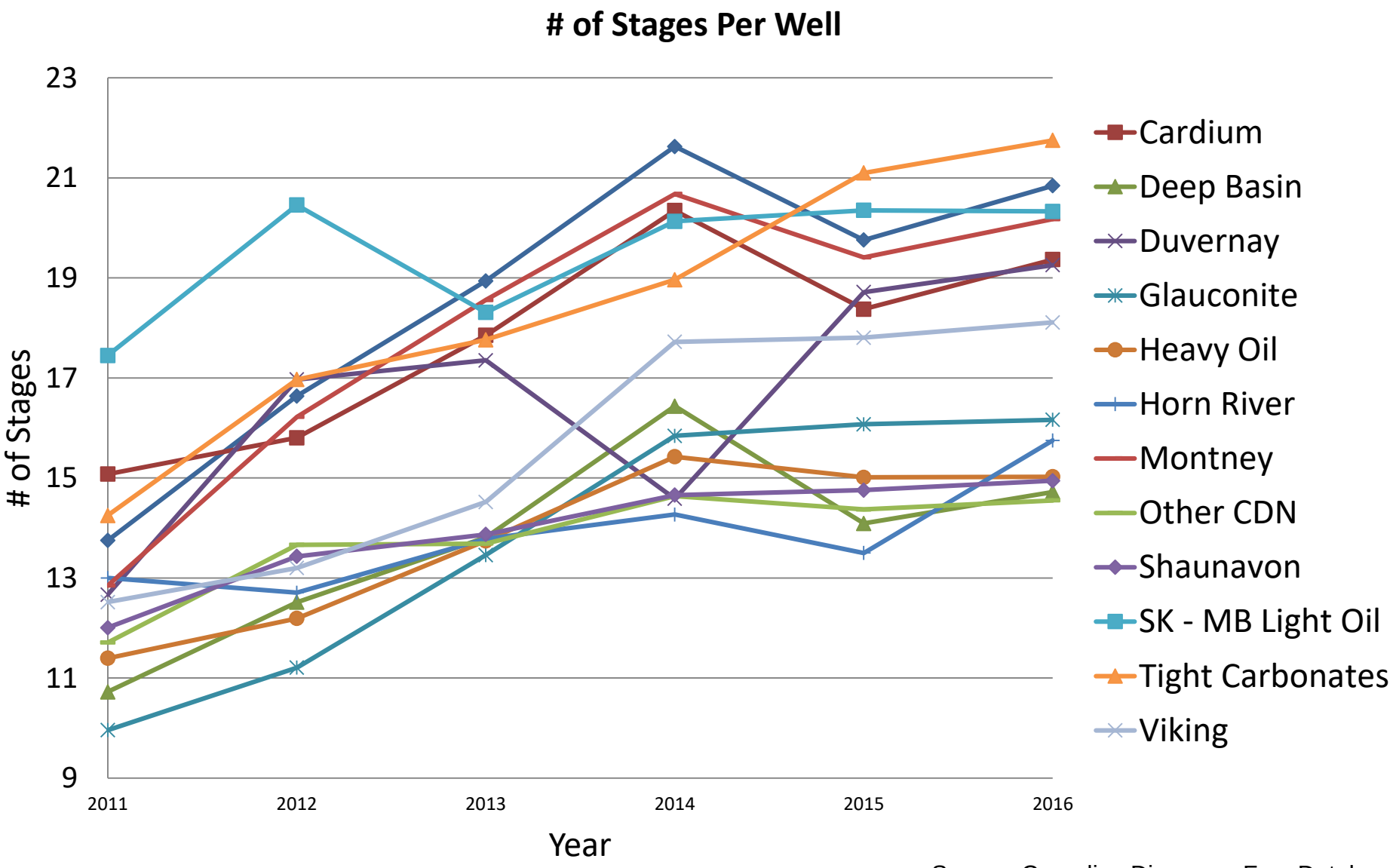


Figure 9. Estimated Ultimate Recovery

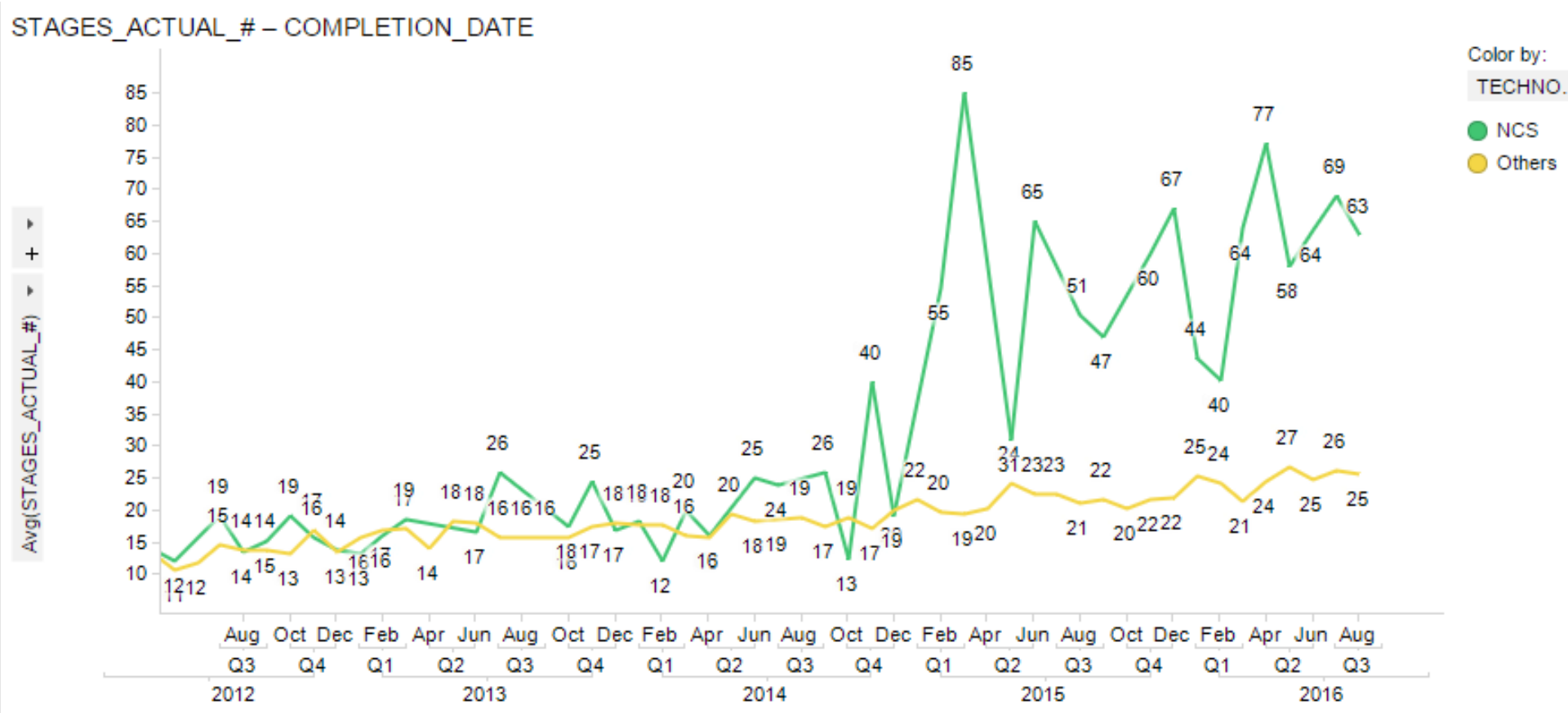
Stage Evolution In Canada



Source: Canadian Discovery Frac Database

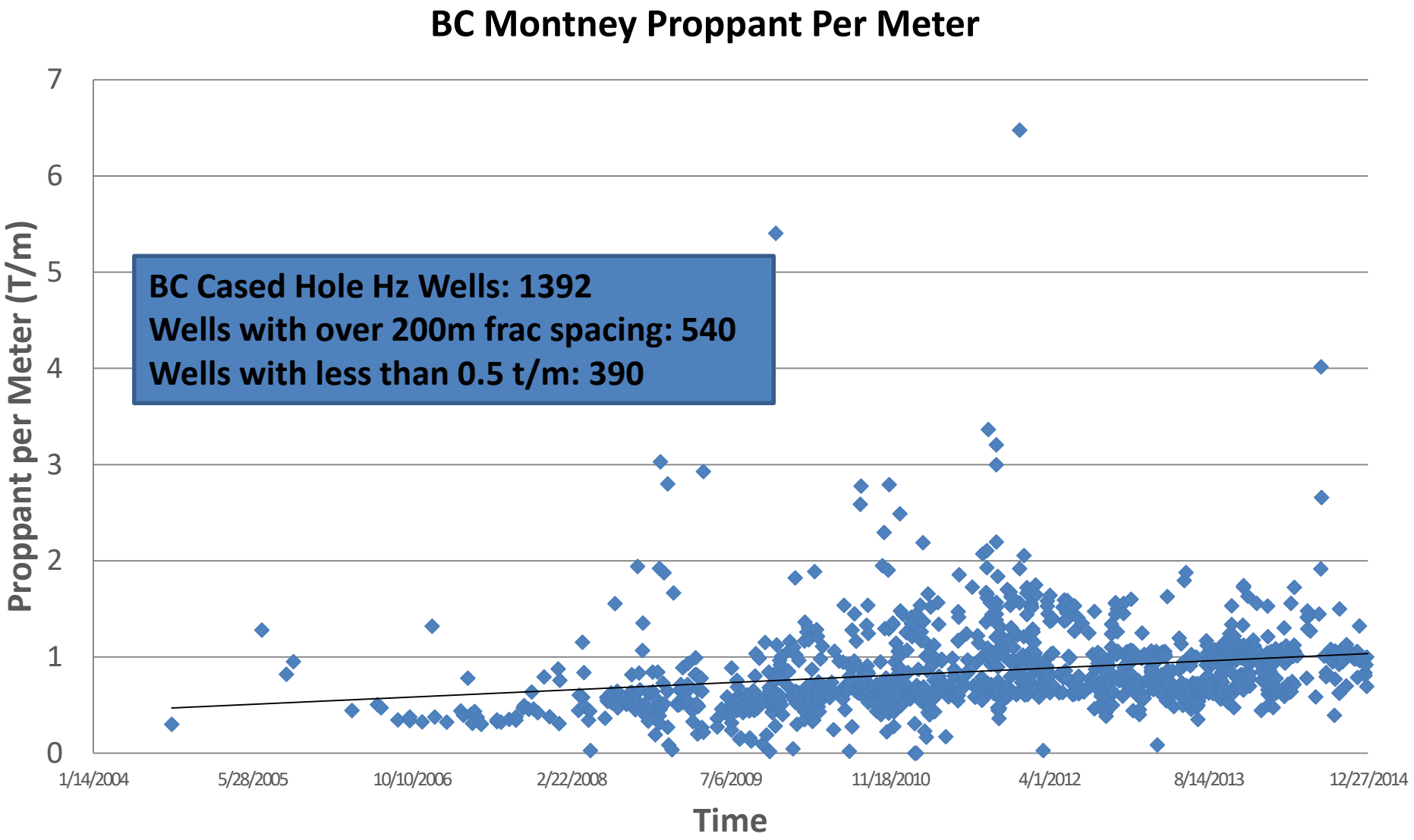
More Frac Intensity

Montney Play Avg. Stages/Well



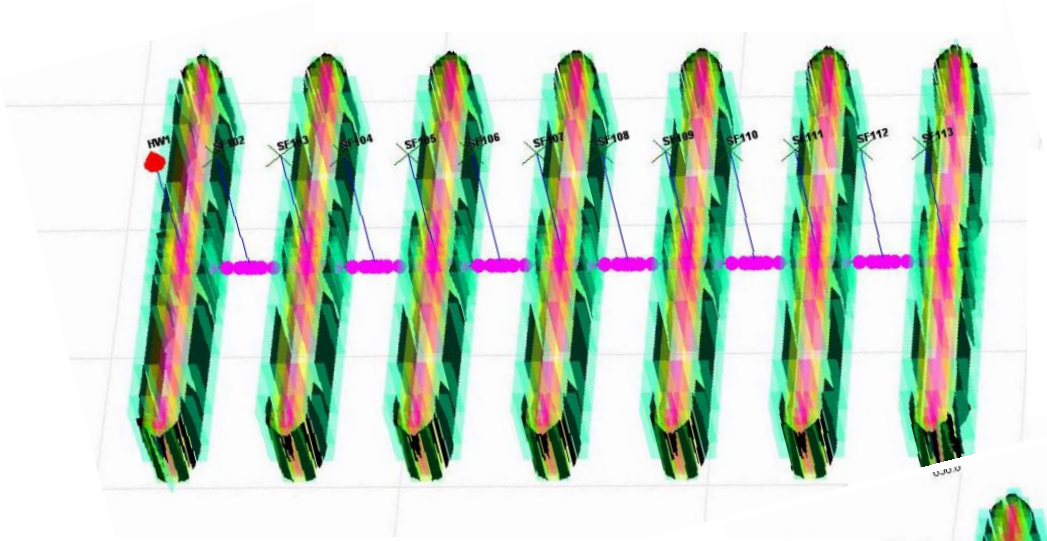
Source: Canadian Discovery Frac Database

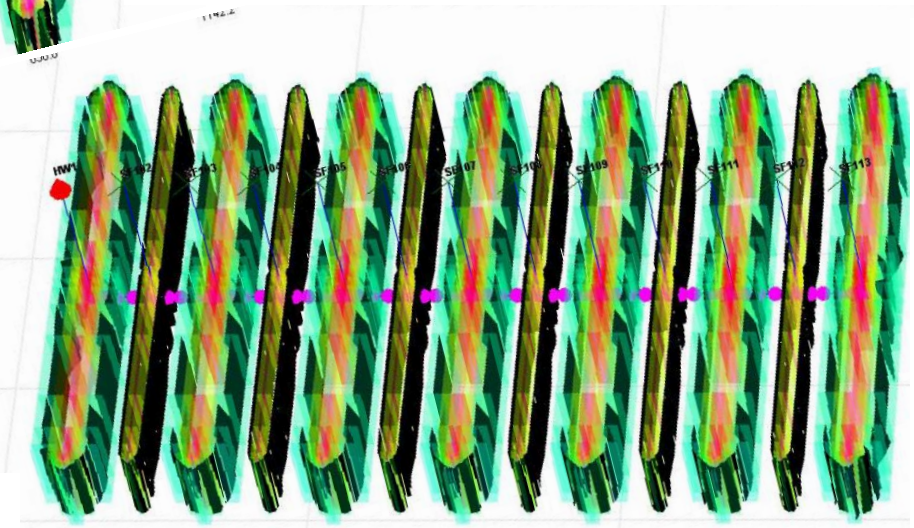
More Frac Intensity



Source: Canadian Discovery Frac Database

Fracture Down spacing





SPE 154669

Barnett Shale Horizontal Restimulations: A Case Study of 13 Wells

Mark Craig, SPE, and Steve Wendte, SPE, Devon Energy Corp; Jim Buchwalter, SPE, Gemini Solutions

Refracturing - Why Refrac?

1. Access new rock

- Either by adding more perforation in bypassed pay or pumping larger fractures in existing perforations to increase fracture half length. Both of these concepts plan to increase stimulate rock volume (SRV) by contacting virgin reservoir.

2. Fix a conductivity problem

- This conductivity problem could be a function of proppant crushing and movement, or due to the precipitation of solids in the fracture. **The optimal refrac strategy should be tied to the suspected *damage mechanism*.**

Refrac Mechanism Checklist

Stimulated Rock Volume

- ❑ Insufficient fracture geometry (width, height, length)
- ❑ Insufficient fracture spacing (bypassed pay, poor cluster/openhole breakdown)

Proppant Pack Damage

- ❑ Insufficient proppant strength and durability (degradation over time, fines plugging)
- ❑ Insufficient proppant concentration near-wellbore
- ❑ Continued rock creep; frac face after closure impacting continuity
- ❑ Failure to place sufficient proppant concentrations throughout the created network; discontinuous bank caused by proppant settling

Frac Fluid Damage

- ❑ Gel residue or durable gel filter cakes deposited using crosslinked fluids
- ❑ Fluid sensitivity: some frac fluids “soften” the formation allowing more significant embedment and/or spalling (clay swelling, fluid recovery)

Production Damage

- ❑ Precipitation of scale, salt, asphaltenes, wax, barium sulfate and calcium carbonate scales inside fracture or wellbore
- ❑ Aggressive production techniques to report high IPs (drawdown management)
- ❑ Migration of fines (formation fines)
- ❑ Relative permeability/condensate banking/capillary pressure/water block emulsions

Well Design

- ❑ Perf or port design, poor alignment with frac or other issues
- ❑ Failure to land lateral in strata that will accommodate completion practices

Do Refracs Work In Canada?

- **Pembina (mature waterflood, >45 years development)**
  - Krasey and Jackson, 1992
  - 64 of 83 refracs successful (77%)
  - No increase in WOR, added 2130 m^3 oil per refrac
- **Foothills Cardium (oil wells and gas wells)**
  - McMillan and Suffron, 1995
  - 15 oil wells, 2 gas wells; all 17 increased 62% to 1043%
- **Glauconite (oil) and Viking (gas)**
  - Leshchyshyn et al, 1999
  - 2 wells slated for abandonment restimulated successfully
- **Medicine Hat and Milk River (Shallow Gas)**
  - Gutor et al, 2003
  - 15 wells successfully refractured despite 25 years of depletion
  - 600-900% increases, 6 of 15 exceeded IP, 10 of 15 within 25% of IP
- **Saskatchewan Bakken**
  - Vincent, 2010. SPE 136757
  - Examined 9 refracs in Viewfield area; oil ↑ in all 9; watercut ↓ in 7! (uncemented liners)
- **BC Montney**
  - Makowecki, 2013
  - 1 well, openhole – 5 new perfs, 10 stage Diversion, 200% ↑ production, 1.7BCF ↑ EUR

Proppant Selection

Proppant Degradation Papers:

- SPE 164082 (Aven), 110451 (Handren), 15067 (McDaniel), 14133 (Cobb), 12616 (Montgomery)

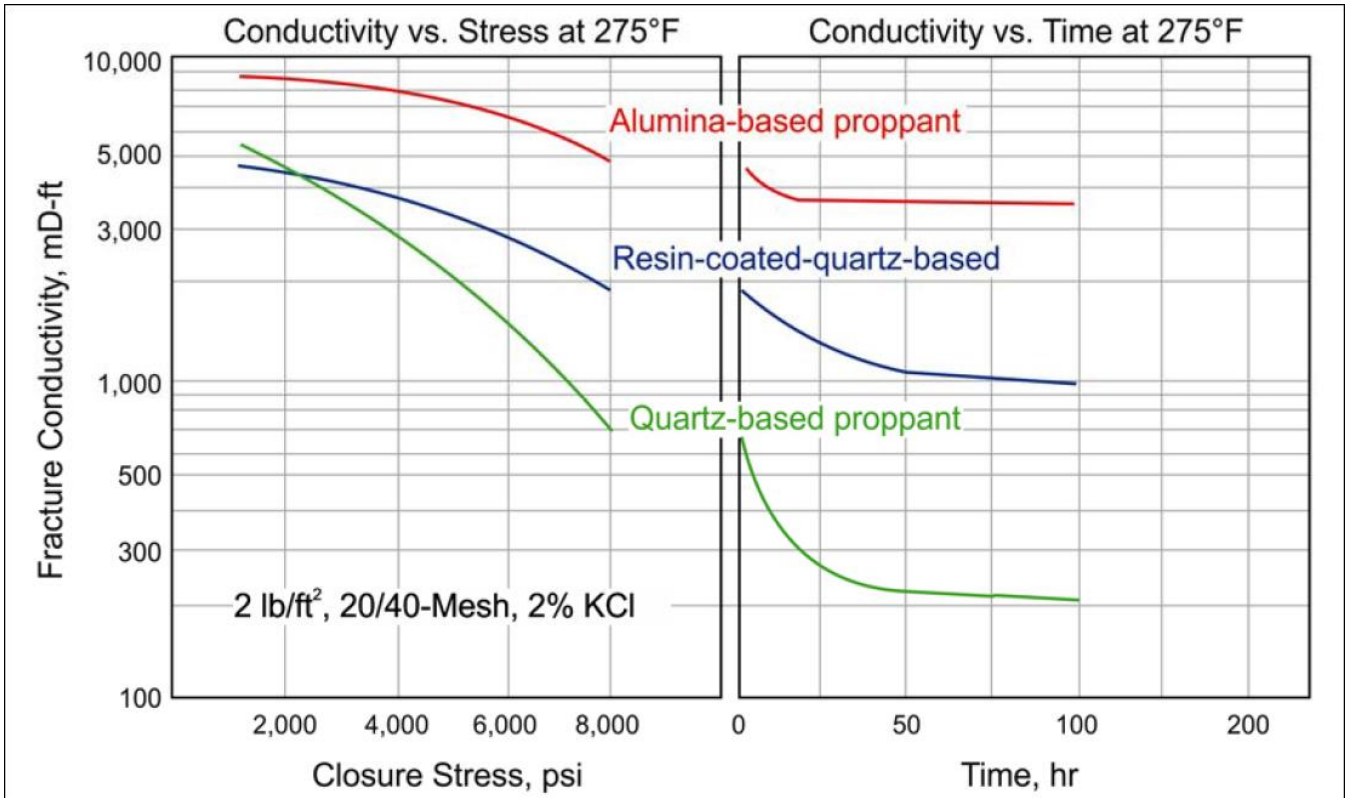


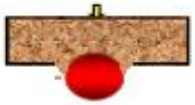
Fig. 1—Plot of conductivity versus time from an API long-term conductivity measurement (Penny 1987).

Fracture Continuity

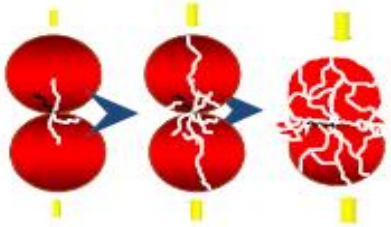
Why am I losing continuity after drawdown?

Collapse of poorly propped sections?

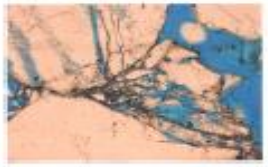
Salt or scale?



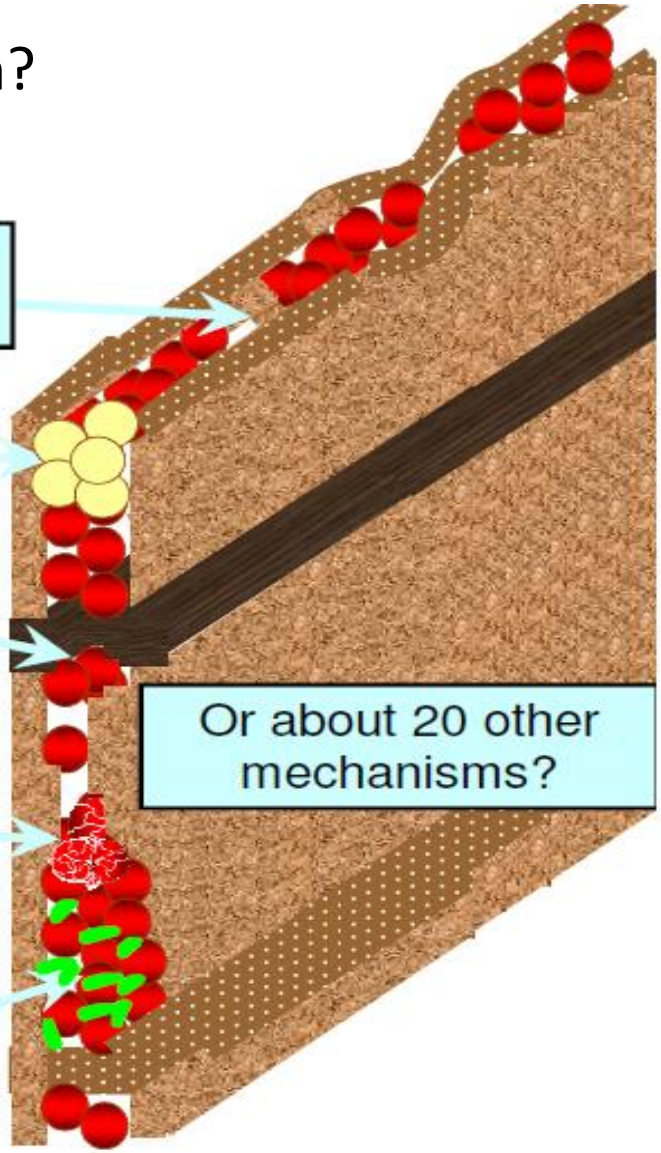
Embedment?



Insufficient strength?



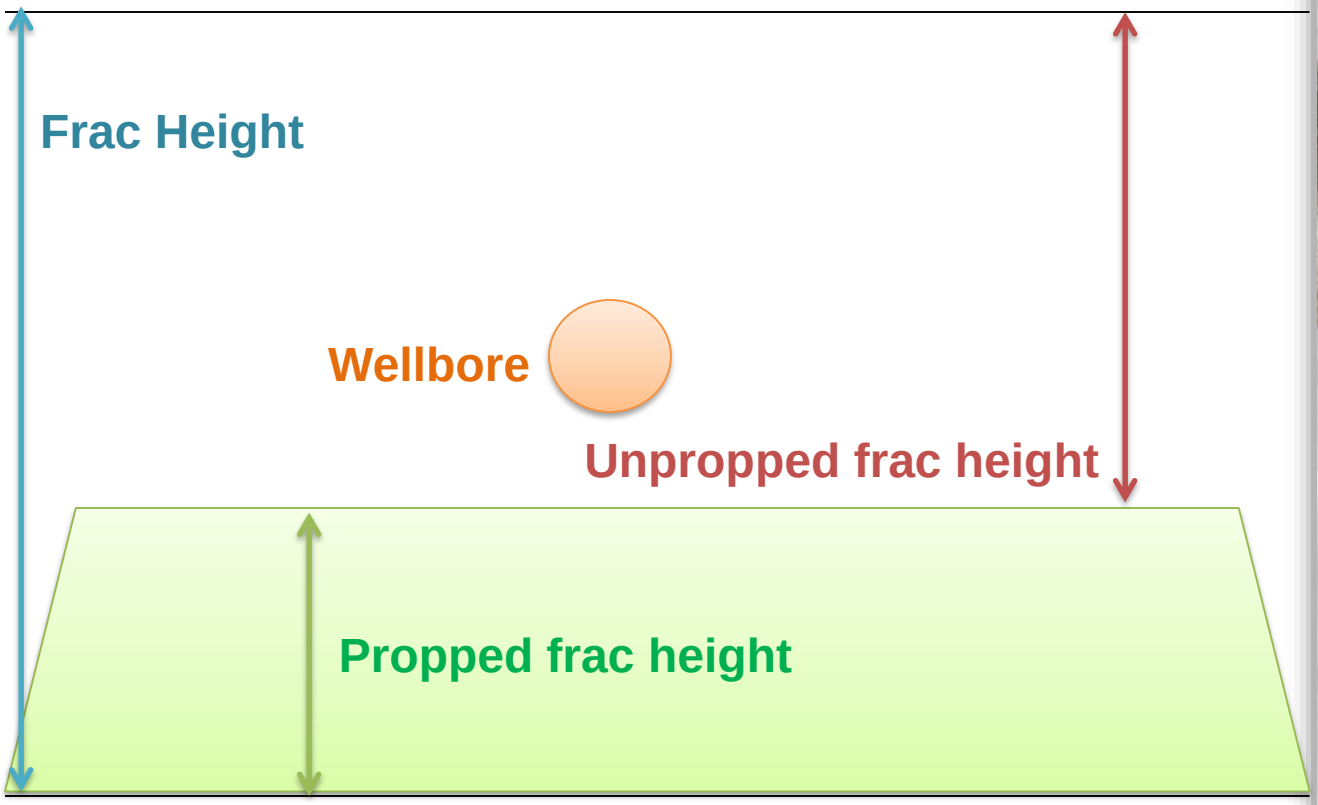
Fines plugging?



Or about 20 other mechanisms?

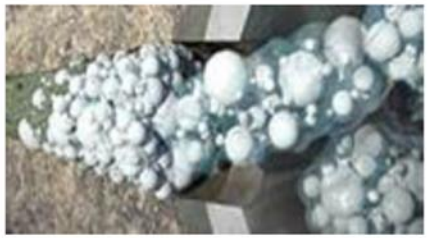
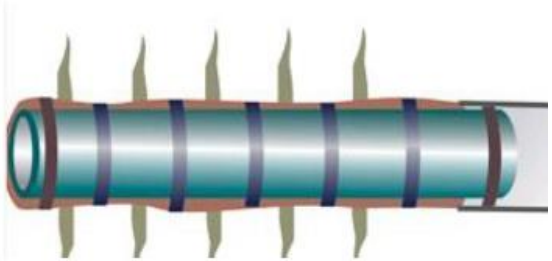
Wellbore Placement

Does my proppant need to connect with the wellbore?



Source: Fairmount Santrol SSP (Self Suspending Proppant)

How Do You Refrac?

Method	Image	Description/Comments
Diversion		• Use of diverting agents to plug fractures or perforations, allowing frac to move to new areas, but difficult to control • Both traditional diverting agents and newer products from major service companies
Straddle Frac		• "Straddle frac" through-tubing technique with resettable packers better targets frac in cement wellbores but at low rates • Also annular frac techniques available, often combined with use of diverting agents
Mechanical Isolation		• Options to use full new liner or individual casing patches, depending on existing completion design • Extensive hardware increases costs substantially

Sources: IHS analysis; SLB; NCS Multistage; Enventure

Diverters

What are we trying to divert?

- Casing – completion type
- Reservoir – fracture modeling

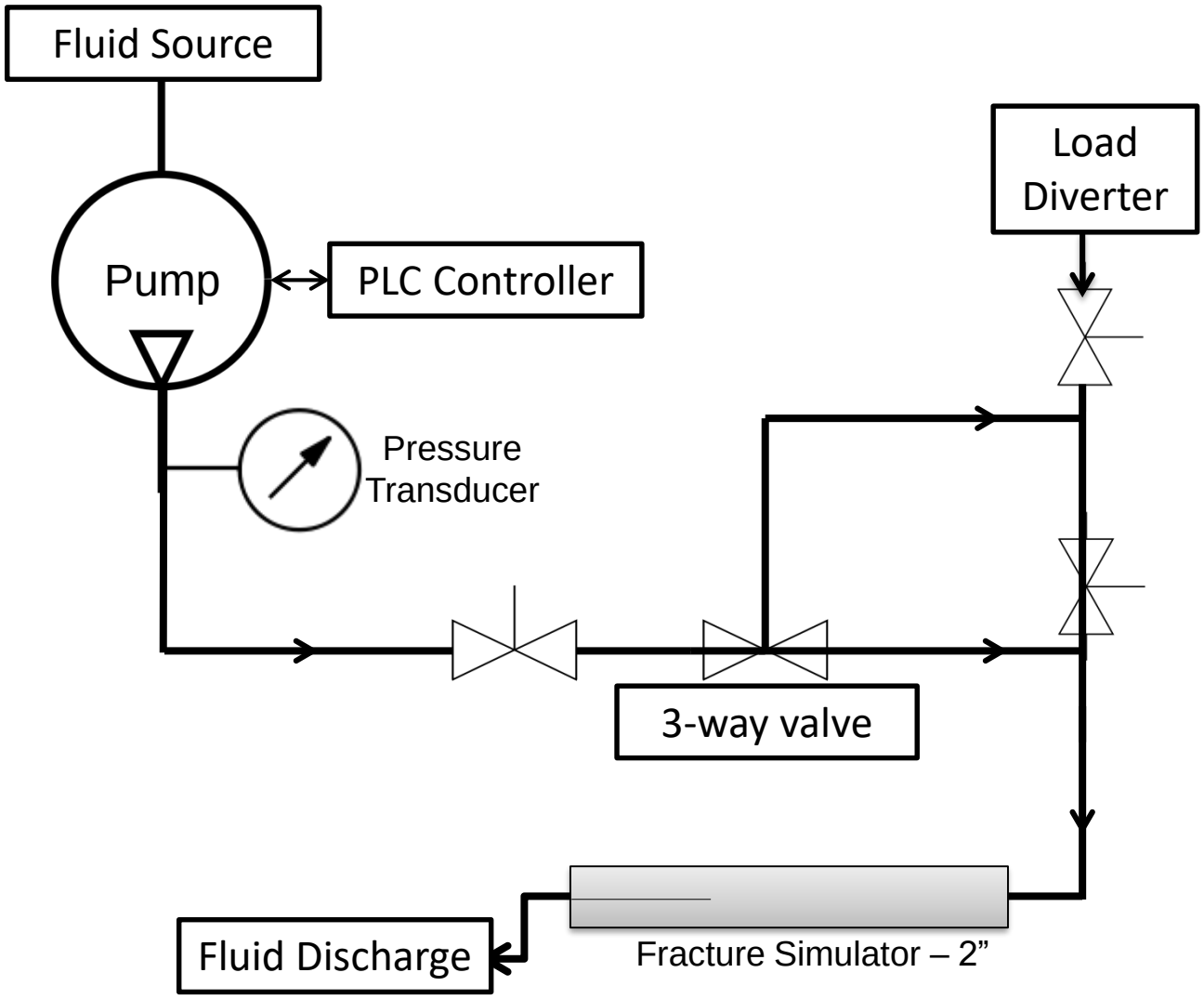
Pump down Diversion Types

- Perforation diversion
- Near-wellbore diversion
- Far field diversion

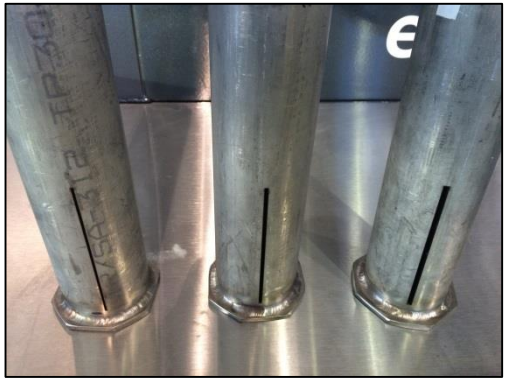
Diverting Agent Usage

- **New Well Completion –** increase fracture complexity in any fracture job.
- **Wellbore Rescue** – recovering stages of a new well completion; liner not making it all the way to bottom; ball seat or plug and perf operation incidence; treat multiple open hole sections in one stages.
- **Bullhead Refracture** – diverting agent is needed to divert full bottomhole fracture pressure against depleted fractures; heel treated first with diversion towards toe.
- **Straddle Refracture** – diverting agent is used to function tool and lower risk; pumped down the backside during operation or spotted while RIH in existing fractures.

STEP Diverter Testing

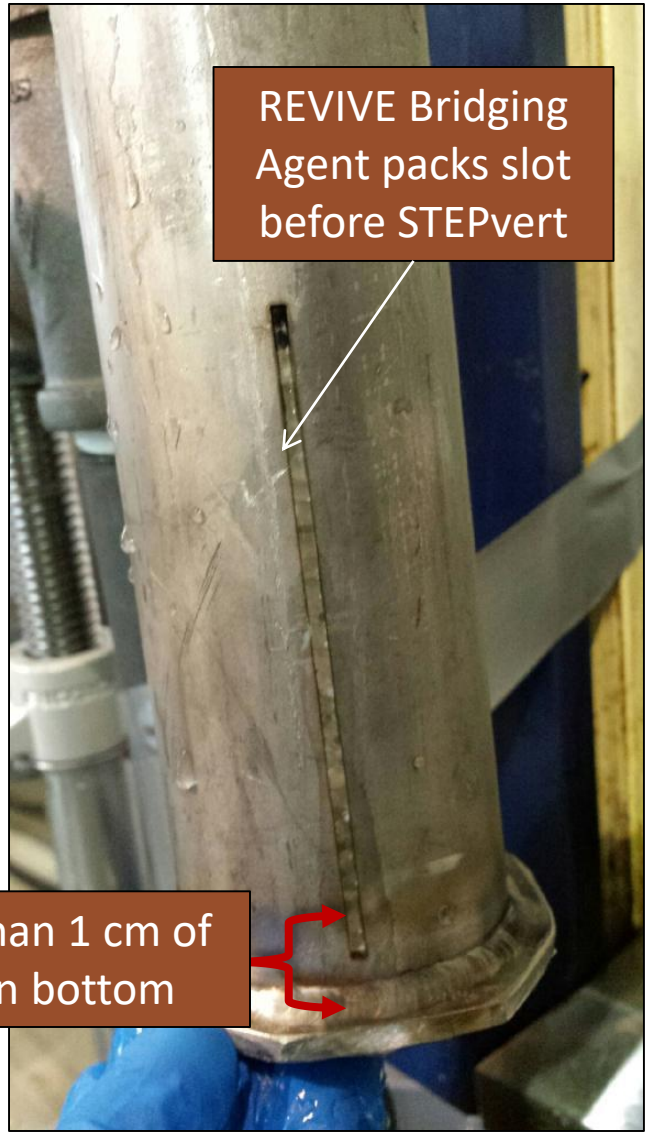


1mm | 2mm | 3mm



**Patent Pending*

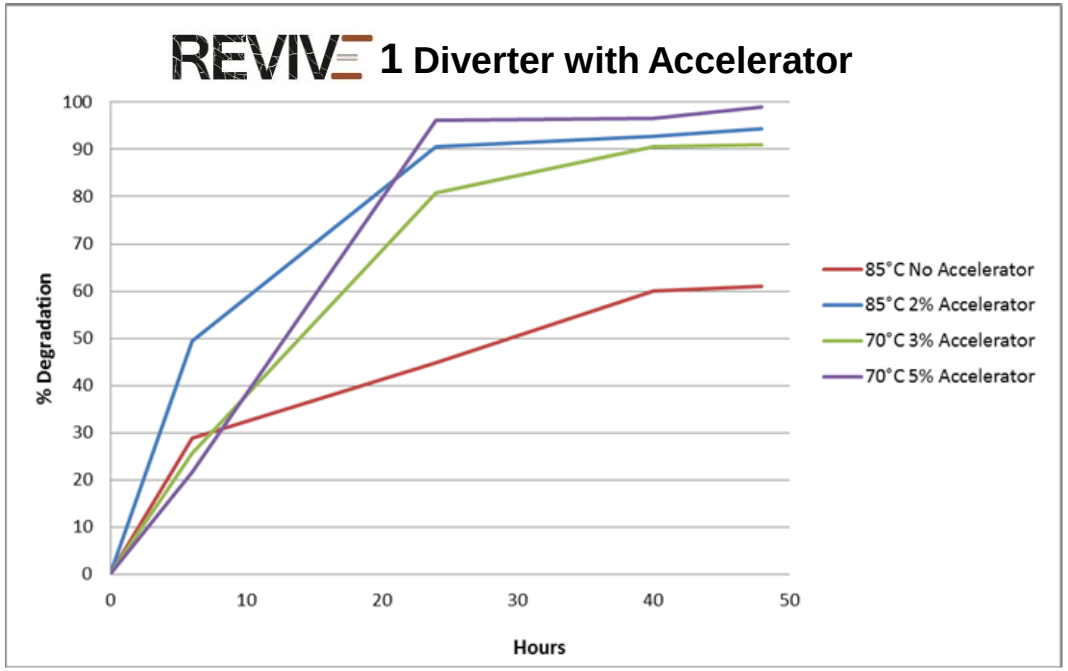
Observations

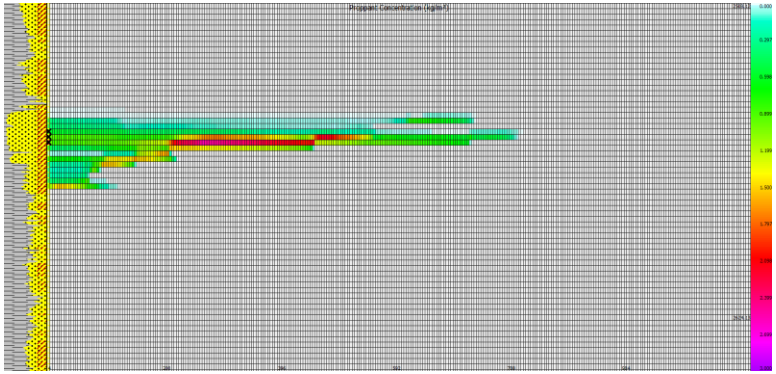


1- 10mm slot sizes tested

STEP REVIVE Diverter Design

Dissolution Times Controlled: Time and Temperature



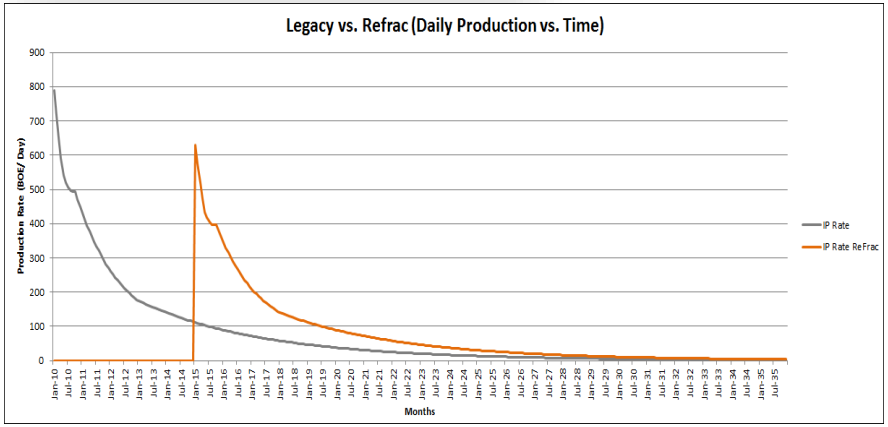


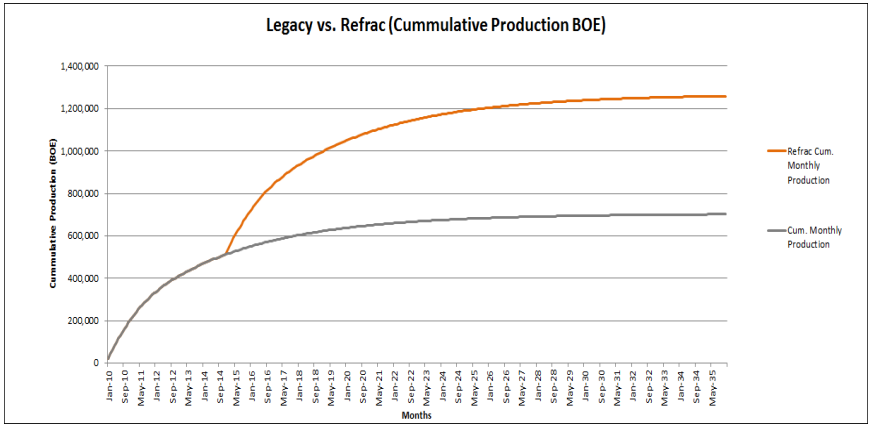
Volume and particle size determined using fracture model geometry: Height and Width

Economic Considerations

- EUR – Cumulative production vs. time, slope and intersect
- Job Cost – Actually what was quoted
- Asymmetrical frac growth - Consider parent child relationship
- Shut in or frac hit - Downtime in offset production
- Risk-weighted analyses give you the option of replicating success
- Closed-loop learning efficiently cost reduction

DO NOTHIING NPV	$2,480,871.98
ReFRAC NPV Benefit	$4,990,157.26





STEP energy services

Thank you.

Contact: AMcMurray@STEP-ES.com

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