Proppant Selection in Unconventional Reservoirs

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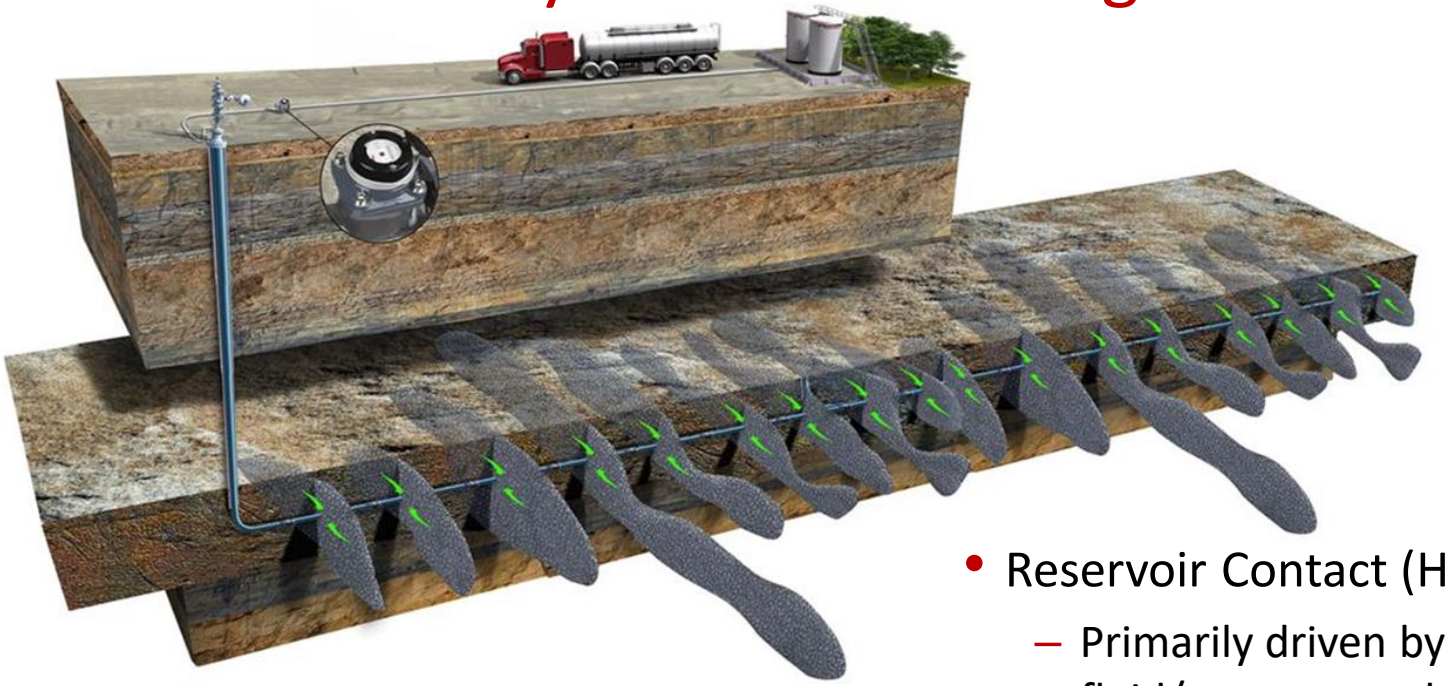
Two Goals of Hydraulic Fracturing



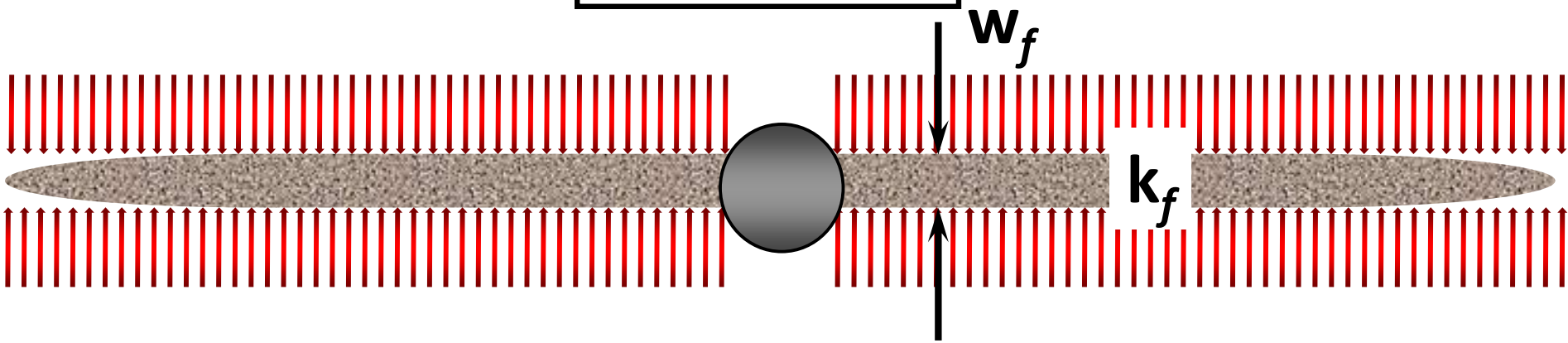
- Reservoir Contact (Half Length)
  - Primarily driven by fluid rate and fluid/proppant volume
- Enhanced Flow Capacity (Conductivity)
  - Primarily driven by the proppant

Proppant Selection Drivers in Unconventional Reservoirs

- Availability
  - 90 BILLION lbs. worldwide demand (vs 5 Billion in 2003)
  - Quality and cost impacts
- Fluid system
  - Slickwater vs XL fluids and impact on proppant size
- Conductivity requirements
  - How much conductivity do we need?
  - Cost vs benefit

How Much Conductivity Do I Need?

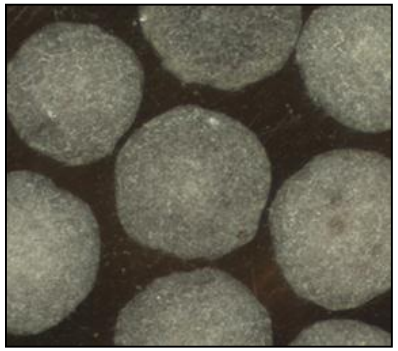
$$C_f = k_f * w_f$$

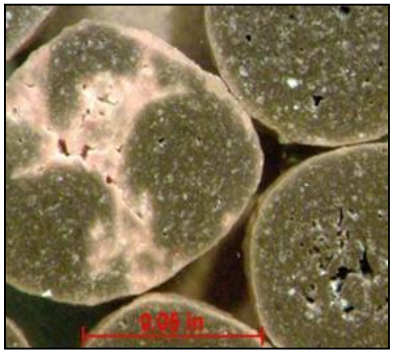


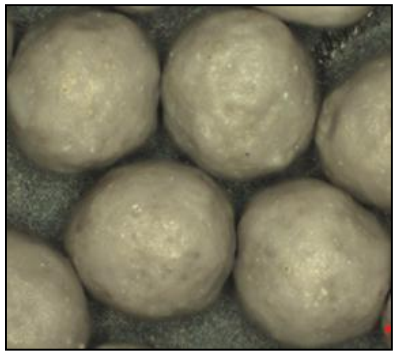
"How <u>wide</u> is the road and how <u>good</u> is the pavement"

Characteristics of High Conductivity Proppant

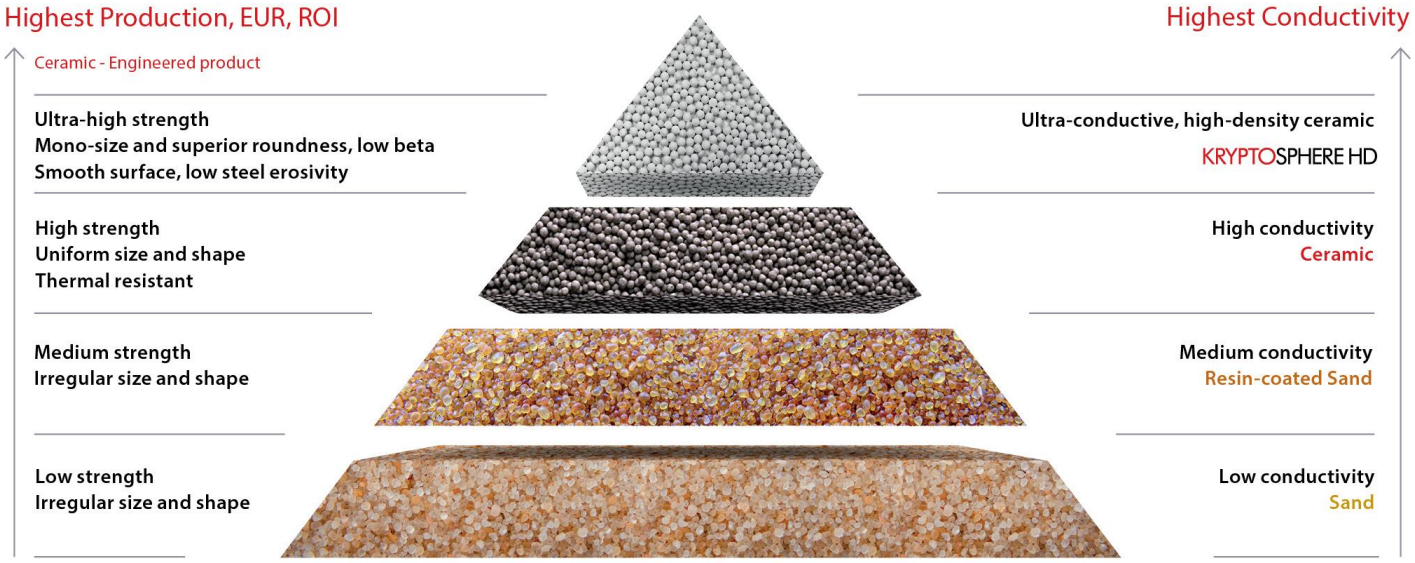
- Strength
  - Minimal internal porosity
- Shape
  - Spherical, round particles
- Size
  - Larger, coarser, uniformly sized
- Durability
  - Thermal stability, resistant to long term degradation







Hierarchy of Proppant Value

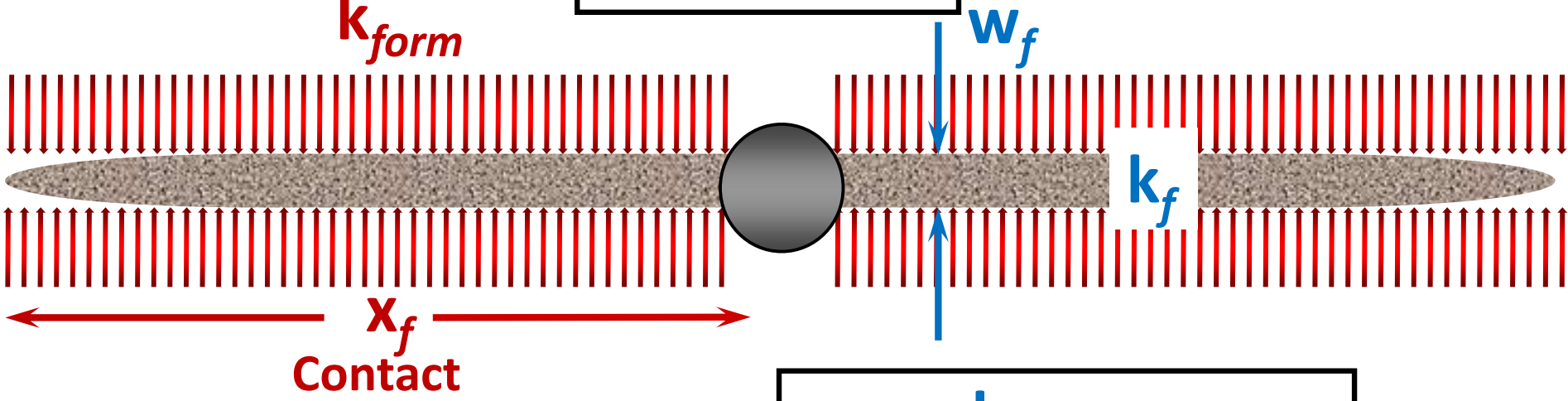


Conductivity = Permeability of the frac x width of the frac = K_{frac} x W_{frac}

Higher Conductivity ➡ Higher Production

How Much Conductivity Do I Need?

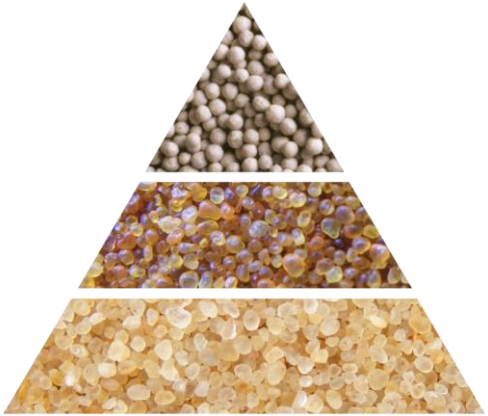
$$C_f = k_f * w_f$$



$$F_{CD} = \frac{\text{Fracture Flow Capacity}}{\text{Reservoir Deliverability}} = \frac{k_f * w_f}{k_{form} * x_f\,(\text{Contact})}$$

Why Would Something That Looks Like This…

..be affected by which of these is selected?



~2000 md-ft

~700 md-ft

~350 md-ft

***30/50 Baseline Conductivity @ 8000 psi**

Current Conductivity Test

API/ISO conductivity test

- Ohio Sandstone
- 2 lb/ft^2 proppant loading
- Stress maintained for 50 hours
- 150 or 250° F
- Extremely low water velocity (2 ml/min)

Holistically accounts for:

- Proppant size
- Proppant strength and crush ‘profile’
- ‘Wet’ system
- Some temperature effects
- Some embedment

API/ISO conductivity cell

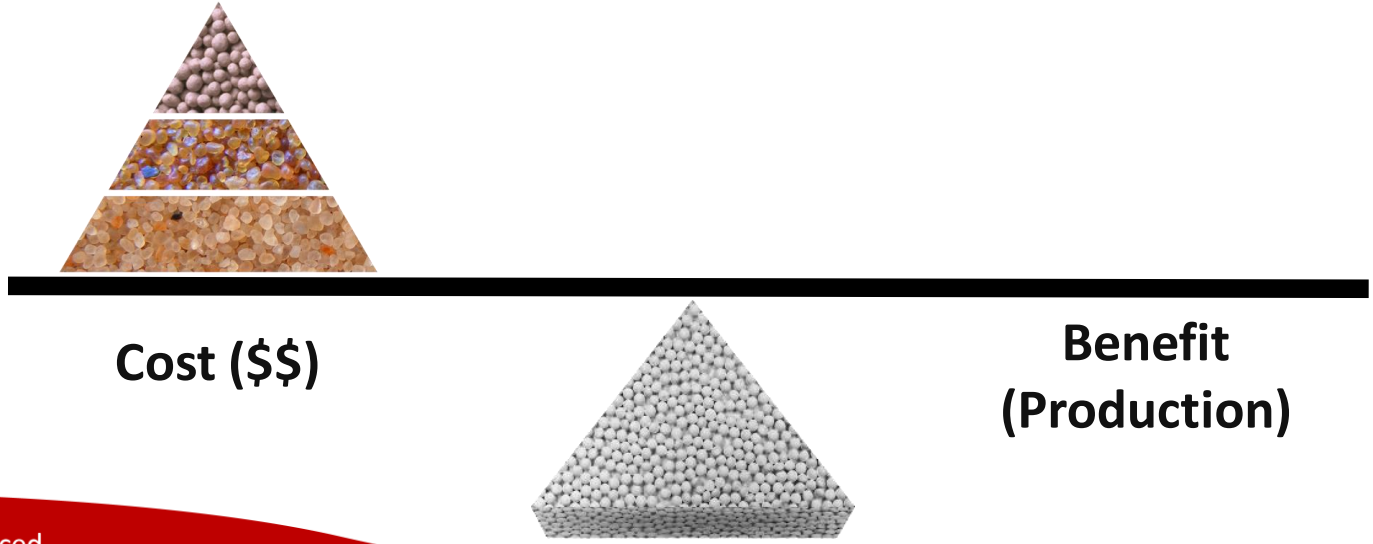
…Does not account for downhole conditions

[more details in SPE 106301]

Reference: ISO 13503-5 & API RP19D

Conductivity Balance – Cost vs. Benefit

- Higher quality proppant
- Higher tier proppant
- Larger proppant volume
- Larger diameter proppant



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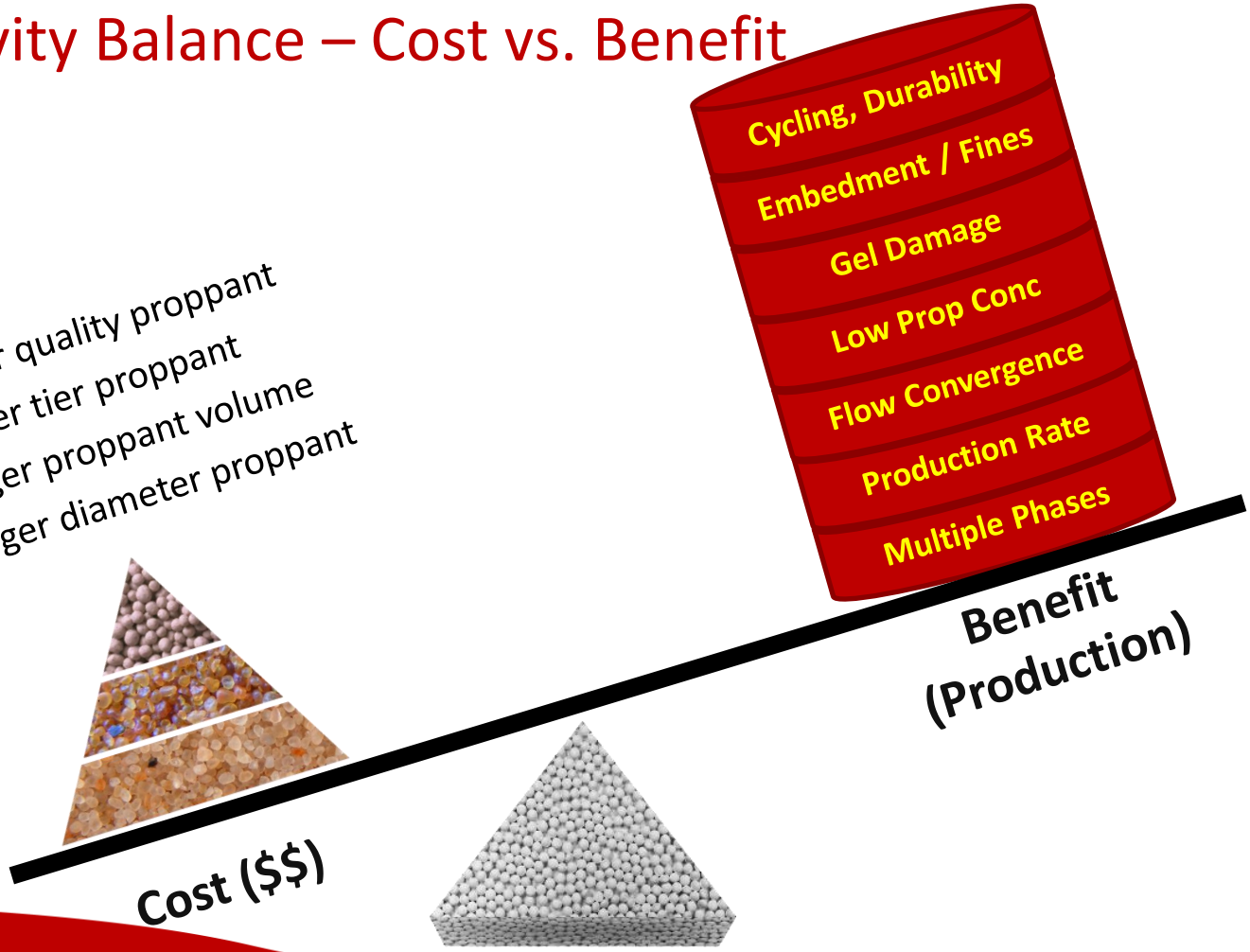

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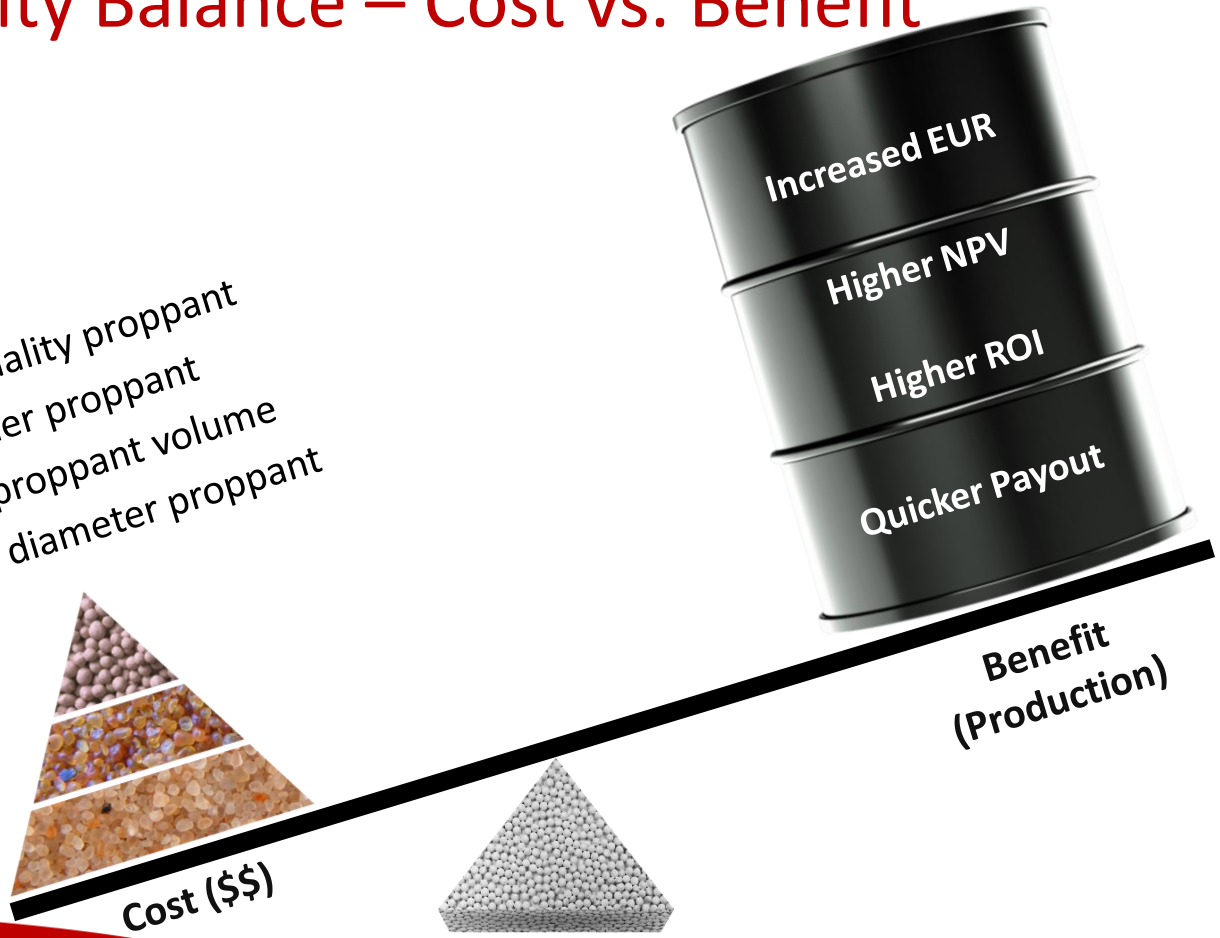

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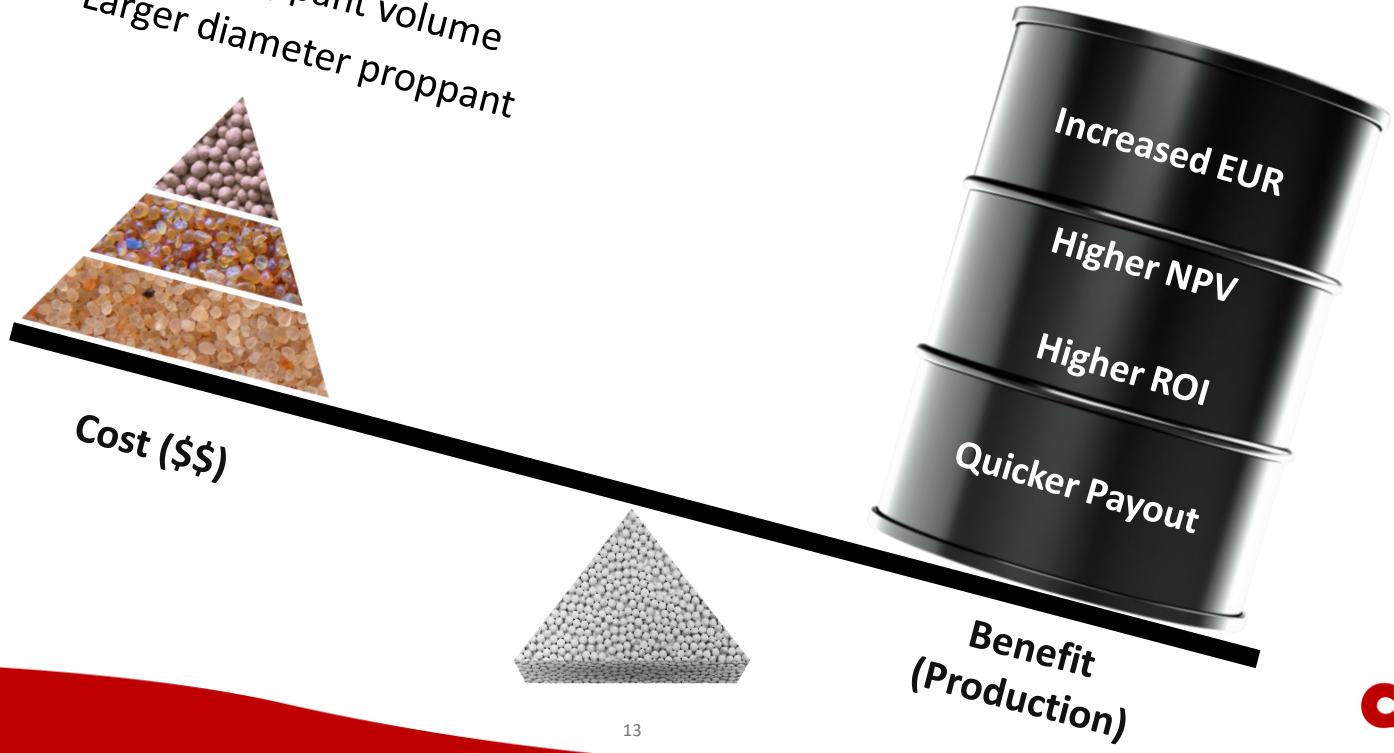
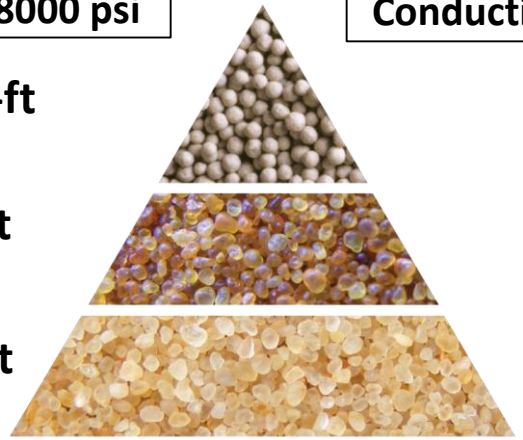


In Reality our Fractures are Conductivity Limited

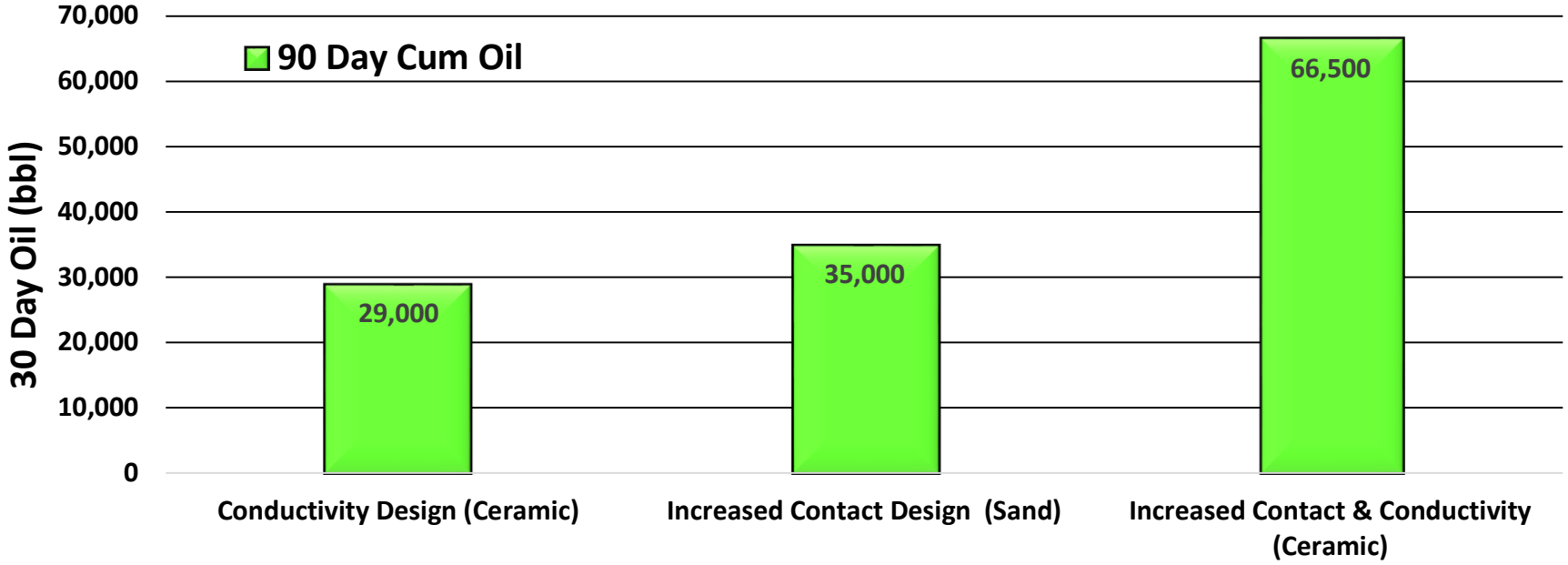
30/50 Baseline Conductivity @ 8000 psi	30/50 *Realistic Conductivity @ 8000 psi
~2000 md-ft	~50 md-ft
~700 md-ft	~15 md-ft
~350 md-ft	~5 md-ft



…..it is not uncommon to see a loss of >90%!

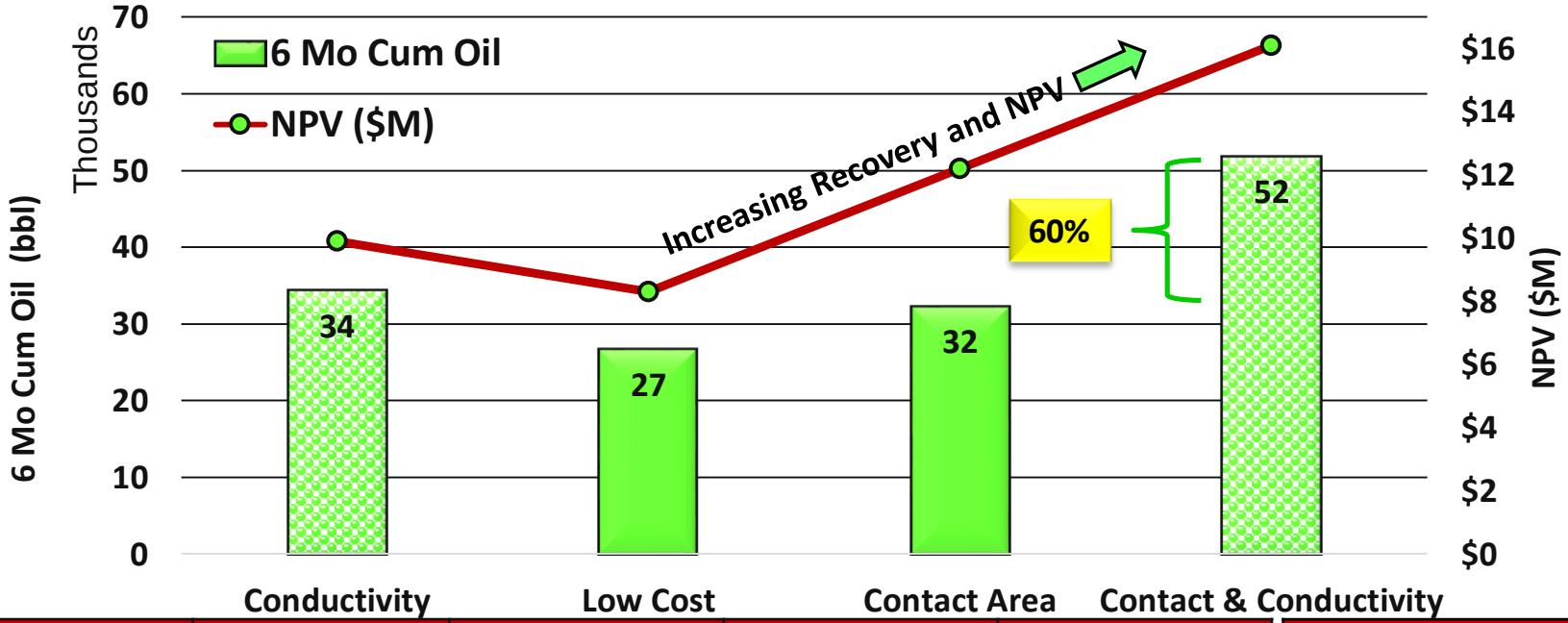
***Tight Gas Condensate Reservoir Conditions**
Prop Conc. – 0.75 lb/sqft
Frac Height – 200 ft
Rate per frac: 300 mcfd, 100 BOPD, 1 bwpd
Gel Damage, cyclic stress
Temp – 275° F

Contact and Conductivity – Eagle Ford Shale



Period of Time	2013	Incr Length, Stages, Sand	Incr Length, Stages, Ceramic
Avg # Stages	19	25	29
Proppant Type	Ceramic	Sand	Ceramic
Well Count	13	3	2

Contact and Conductivity - Bakken Shale



Period of Time	Initial Wells	Tested Sand	Tested More Stages	Today's Design
Stages	20	20	30	30
Proppant Type	Ceramic	Sand	Sand	Ceramic
Well Cost	$5.5M	$5.0M	$5.4M	$6.7M
Model EUR	409 MBO	359 MBO	469 MBO	605 MBO

6 Month Production Gain	~ 20,000 bbl oil per well
Net $ Gain @ $75 oil	$1,500,000
Payout on Conductivity	~ 5 Months

Summary

- Hydraulic fractures require contact and conductivity in unconventional reservoirs
  - Fracture conductivity is driven by proppant
- Conductivity requirements should drive proppant selection
  - Proppant performance determined by strength, shape, size & durability
- Actual Fracture Conductivity is much lower than lab
  - Most fractures are conductivity limited
- Increasing Conductivity Increases Production
  - Typically outweighs the cost and enhances EUR, NPV, ROI and payout

Thank you!

QUESTIONS?