Artificial Lift R&D Council

# DLC Application to Reduce Scale Deposition and Improve SRP Run Life


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- Summary

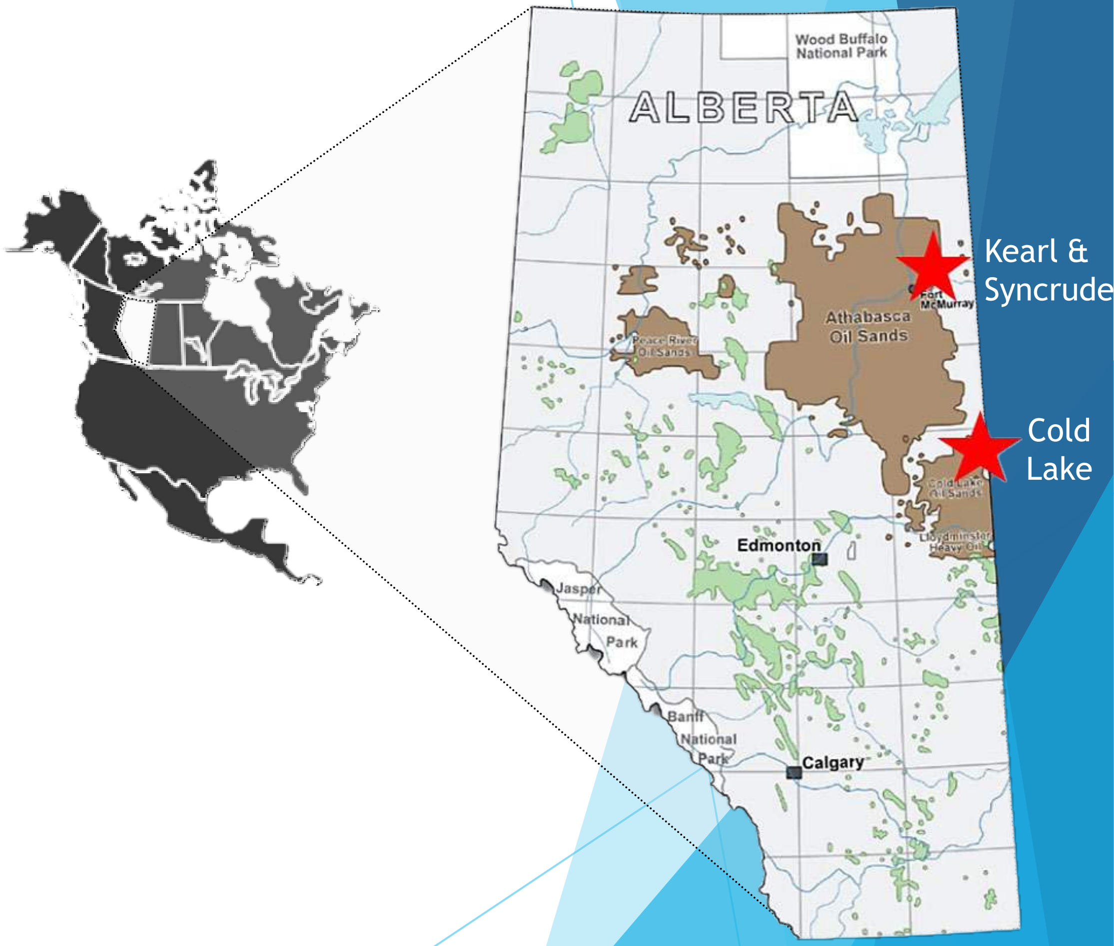
# Cold Lake – Introduction

## 3 Major Albertan Oil Sands

- Athabasca – Open-pit mines (Kearl, Syncrude)
- Peace River – Steam-Assisted Gravity Drainage (Aspen)
- Cold Lake – Cyclic Steam Stimulation (CSS) and Steamflood (SF)

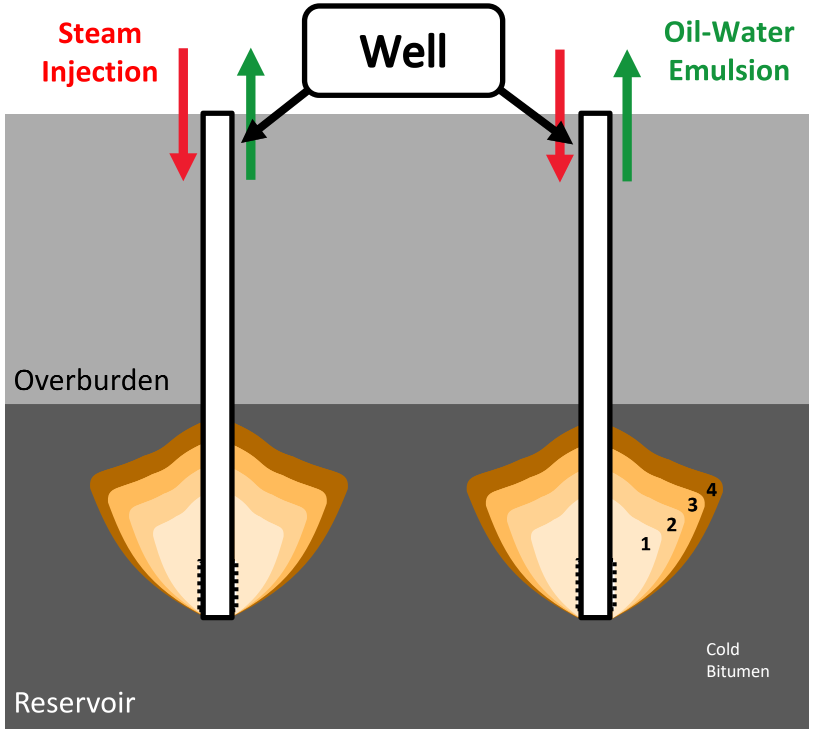
## Cold Lake

- Longest running operation in northeastern Alberta and one of the largest thermal in-situ heavy oil operations in the world
- Commercial development began in 1985
- 1300-1500ft reservoir (Clearwater)
- ~5000 active wells
  - 30% high-pressure CSS, 70% low-pressure CSS or SF

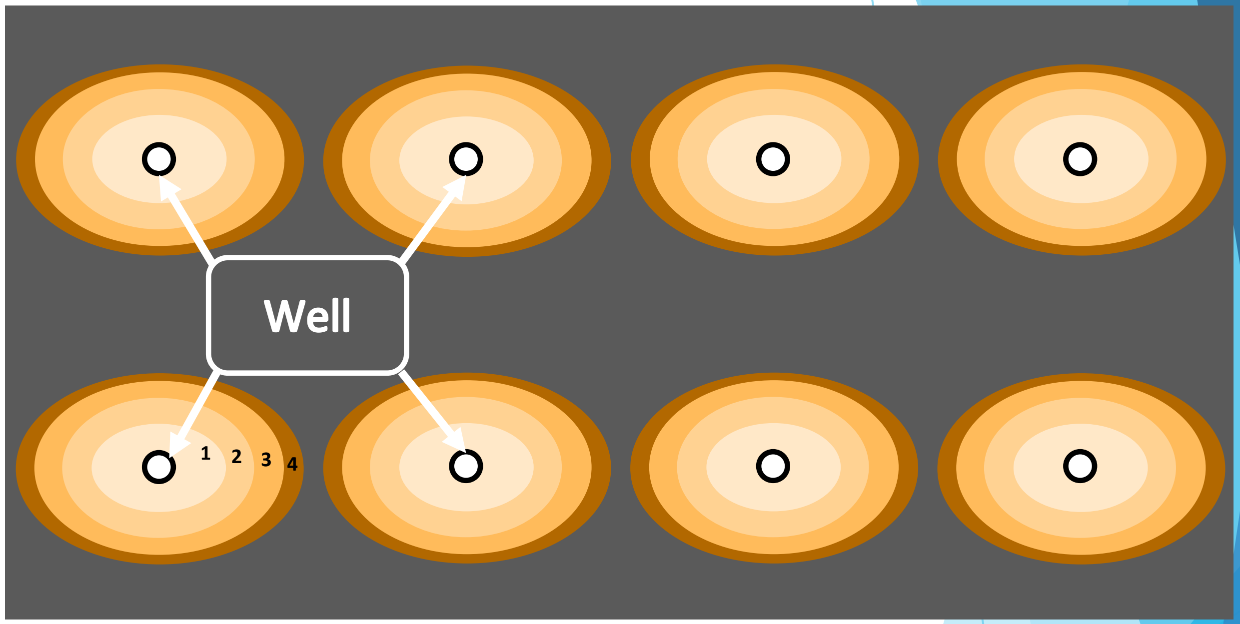


# Cold Lake – CSS Description



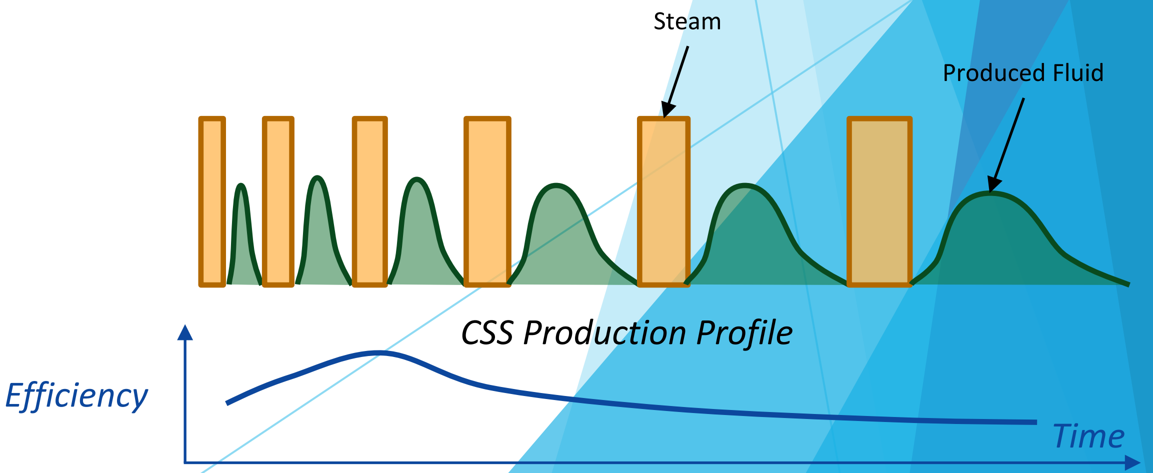



*Planar View*




*Aerial View*

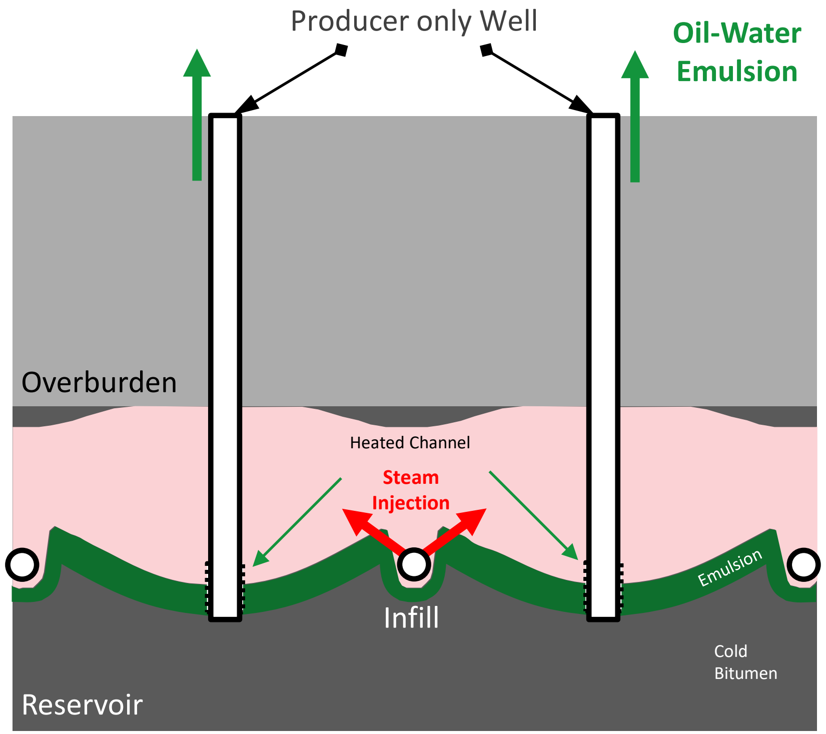
- Injection **then production** from same well
- **High pressure operation** (>1400 psi) in early cycles
- Increasing conformance with each cycle
- Early CSS cycles are efficient; bitumen close to wellbore
- Late cycles less efficient; bitumen far from wellbore
  - Energy expended in reheating depleted zone



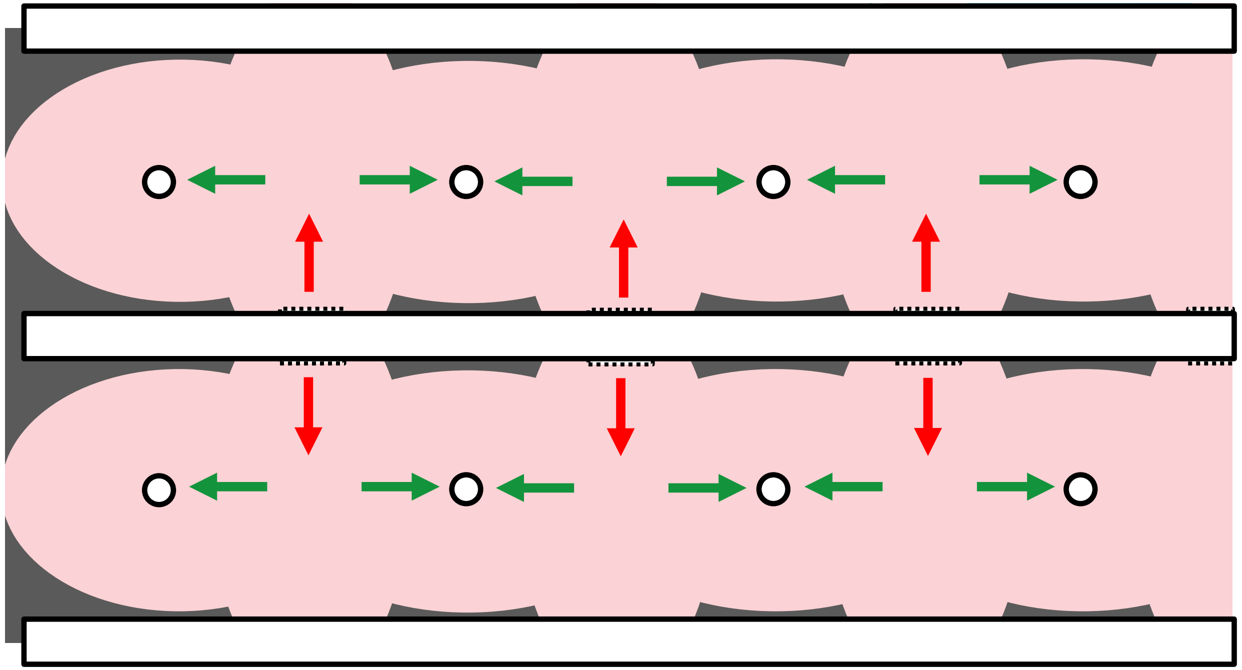

*CSS Production Profile*

# Cold Lake – SF Description



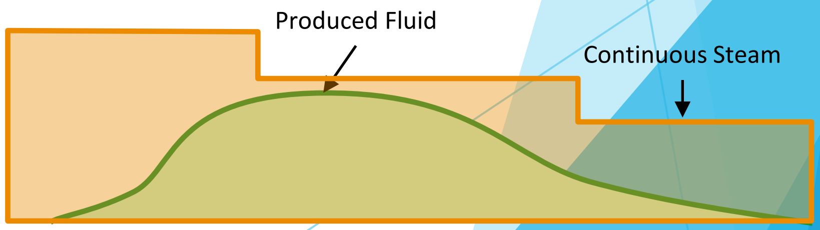



*Planar View*



*Aerial View*

- **Simultaneous** Injection from infills and Production from Producer only Wells
- **Low pressure operation** (<900 psi)
- Established conformance

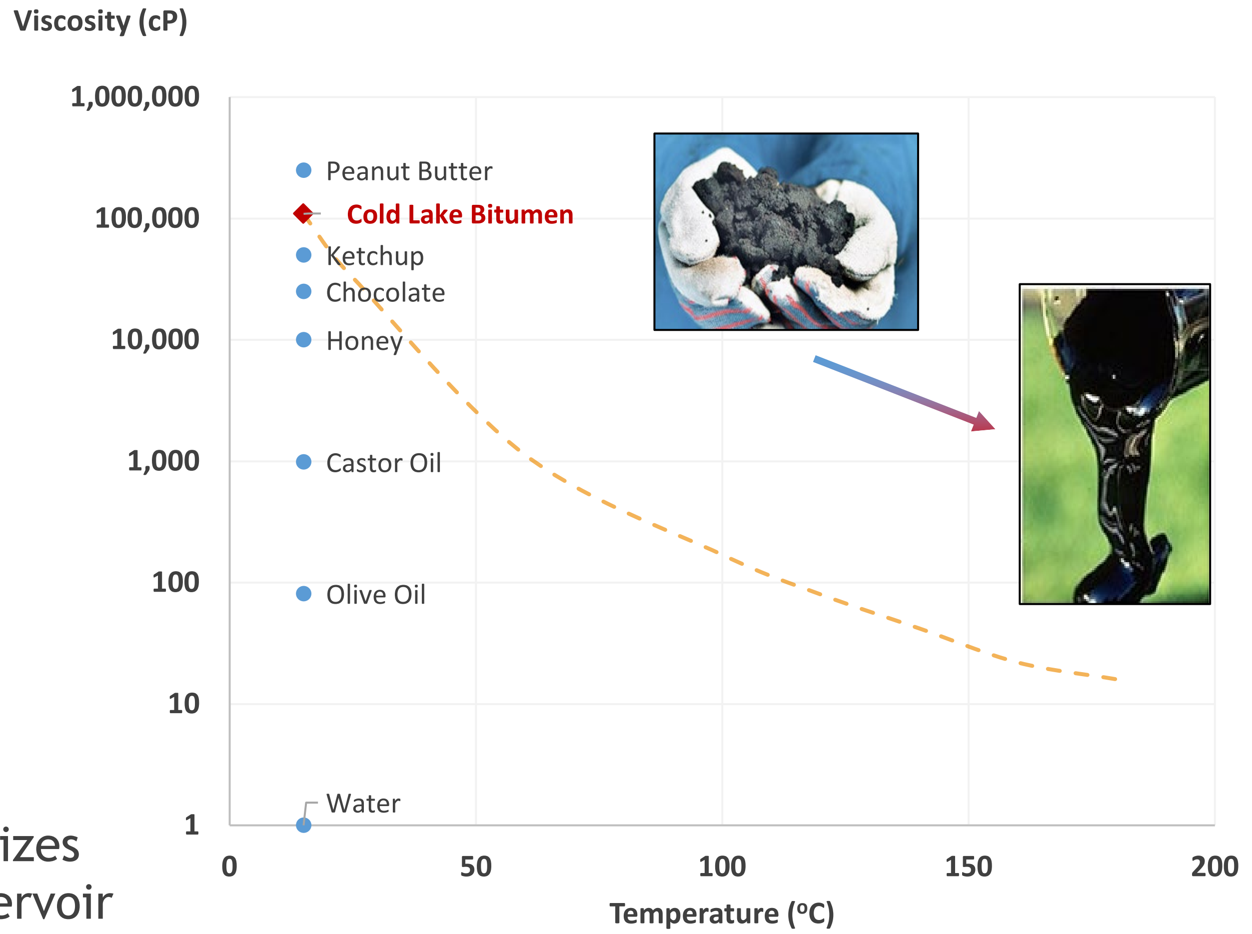



*Production Profile*

# Cold Lake – Challenges

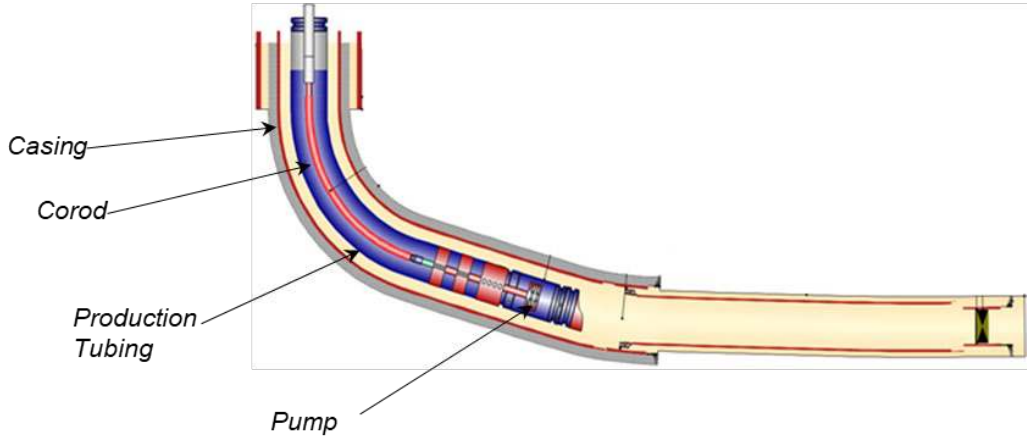
## Production Challenges

- High-viscosity oil: 100,000 cP
- 650°F/1600psi operation to make it flow
- Cold, remote, environmentally-sensitive area
- All wells are rod-pumped at some point in the production cycle




## Rod Pumping

- Range of pumping units (C160—1824) and pump sizes (2—4.25”) depending on the well geometry / reservoir targets and production phase
- Shallow deviated/horizontal wells, so all pumps are deployed with continuous rod strings
- Challenges with scale, sand, wear, gas interference
- Scale is the primary foreign material failure, wear is the main failure cause



# Cold Lake – Scaling



## Triggers for Scaling

- High temperature, low pressure
  - Initial production phase of mid to late cycle CSS wells
  - Steamflood wells
- Water production high, WC > 90%
- Needs surface imperfection to grow
- Turbulent flow
- At-risk wells typically lower production, 2” pumps

## Scale Indicators

- Build up in restrictions / pressure-drop areas
  - Perfs, intake, SV/TV, barrel top/bottom, plunger OD/ID
- Leaky pump (buildup in valve cages)
- Seized pump (plunger stuck in barrel)

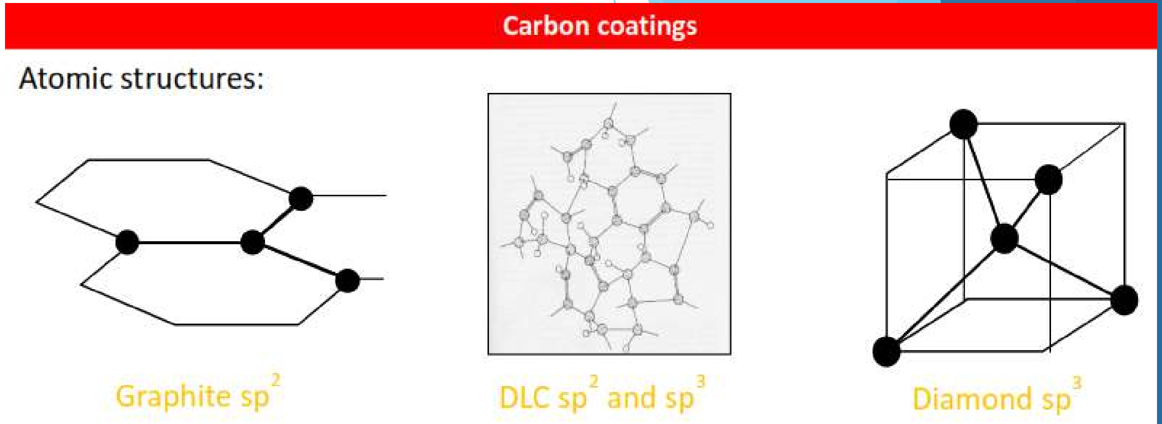
Valve Seat

Plunger OD

# Diamond-Like Carbon (DLC) Coatings



Courtesy of Oerlikon Balzers

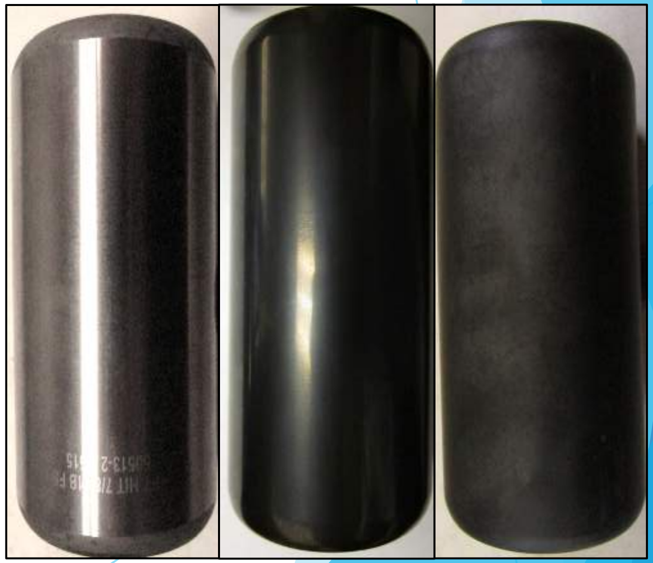



## DLC

- Carbon atoms have two bonding types, sp2 (graphite) and sp3 (diamond)
- Combining the two at the nanoscale allows creation of flexible coatings that have properties of both
- Mixture can be optimized for desired performance

## Benefits for SRPs

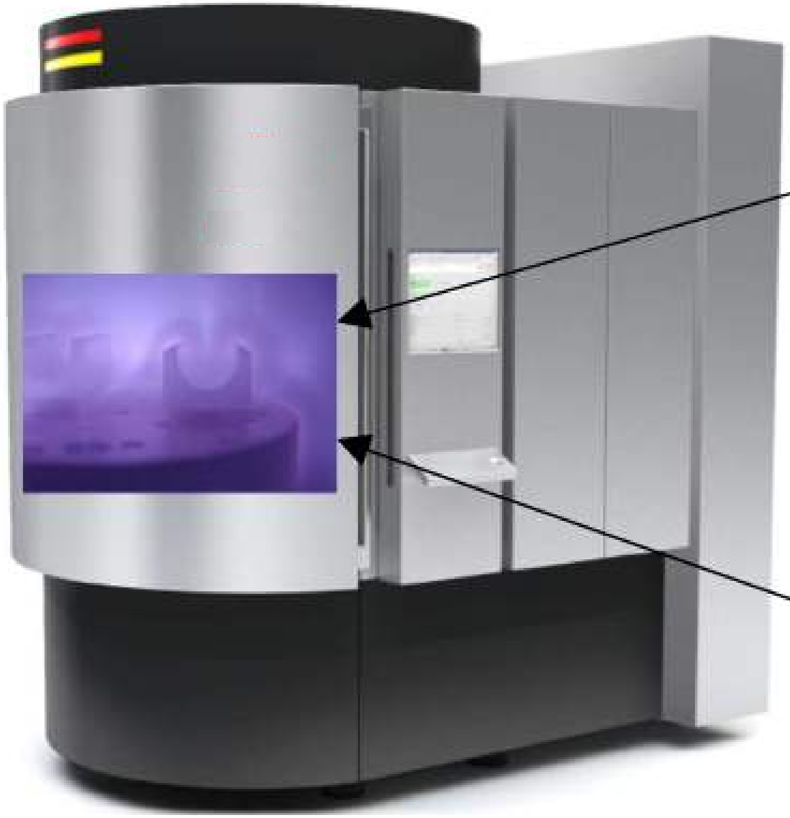
- Hardness – Reduced erosion from sand production
- Wear Resistance – Low coefficient of friction (0.05-0.15)
- Slickness – Considerably smoother than initial surface
- Hydrophobicity – Ability to resist water contact
- Corrosion Resistance – Protection for layers beneath
- Chemically Inert – Not reactive to produced fluids

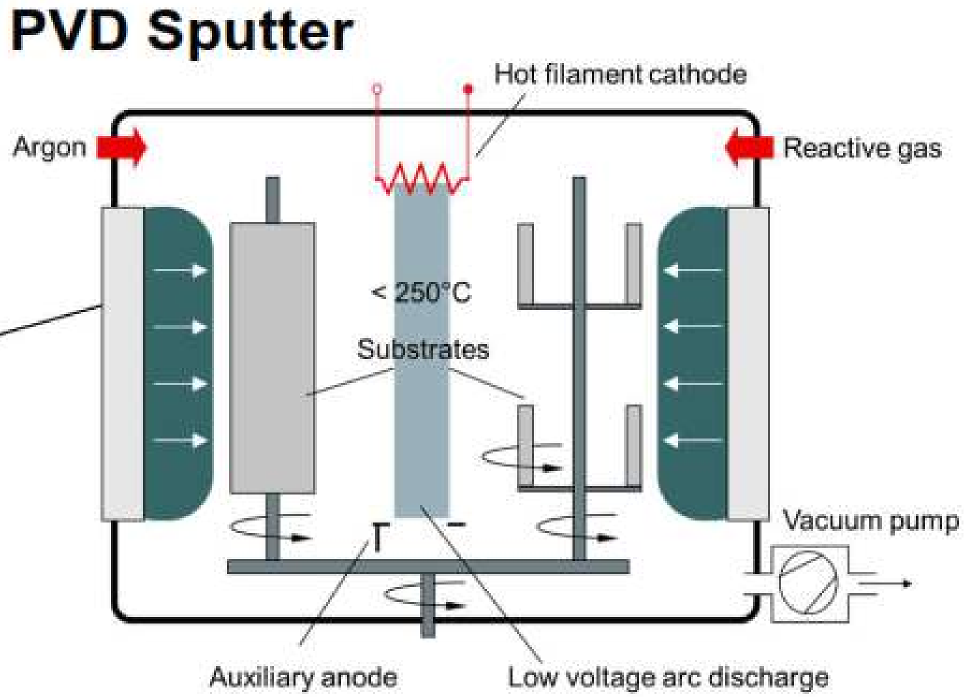


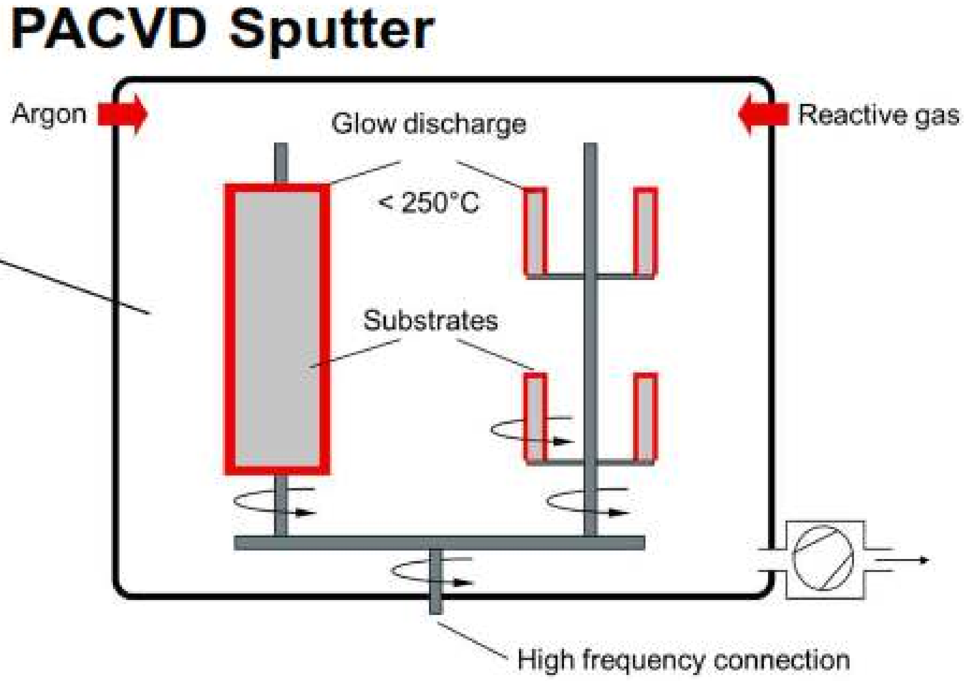
Spray Metal Coating A Coating B

*2018 ALRDC SRP WS DLC Couplings (Romer et al.)

# DLC Coatings – Application






Images Courtesy of Oerlikon Balzers

PVD = Physical Vapor Deposition
CVD = Chemical Vapor Deposition

PACVD (Plasma assisted CVD) is used for **DLC** (diamond like carbon) coatings

# DLC Coatings – Application

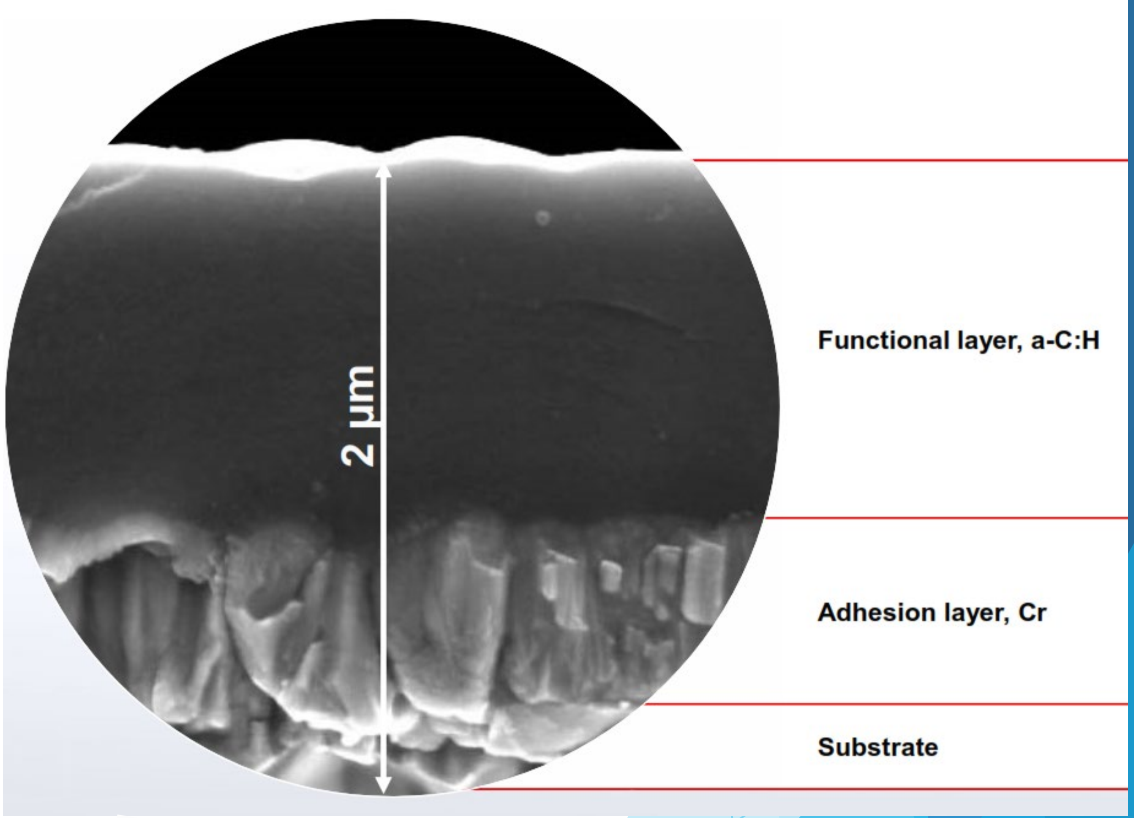


## Process Limitations

- High-temperature, vacuum
- Line-of-sight process—parts may be spun in multiple axes to evenly distribute coating
- More suitable for small components
  - Big things = Big vacuum chamber
  - Batch time measured in hours—more cost effective to coat many small components than few large ones
  - Anode geometry can be tricky with high aspect ratios, e.g. long, small ID items (barrels)

## Resulting Coating

- Generally up to +570°F (300°C) service temp.
- 1-10 micron active DLC layer, depending on coating techniques used




Courtesy of Oerlikon Balzers

Courtesy of Ionbond

# Parts – Strategy



### At-Risk Areas

- Highest pressure-drop components
- Focus on small parts for application/cost
- Traveling/Standing Valves
  - Balls/Seats
  - Cages

### Stretch Goal

- Could a 3ft plunger ID/OD could be coated?
- Expected challenges with aspect ratio
- Also coated seat plugs

DLC-Coated Cages

# Parts – Cages

## Single-Piece Cage

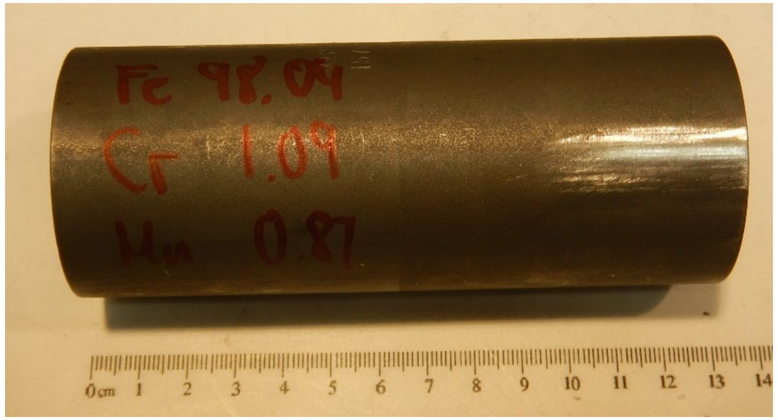
- High-flow, guided insert cage
- Reduces pressure drops, helps with scaling
- Geometry reduces wear, impact forces
- Trialed with success prior to DLC addition

Courtesy of Q2

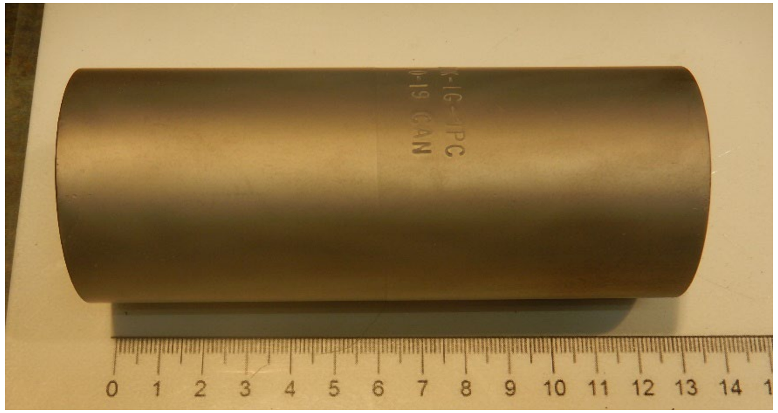
DLC-Coated Guided Inserts

# Parts – Cages





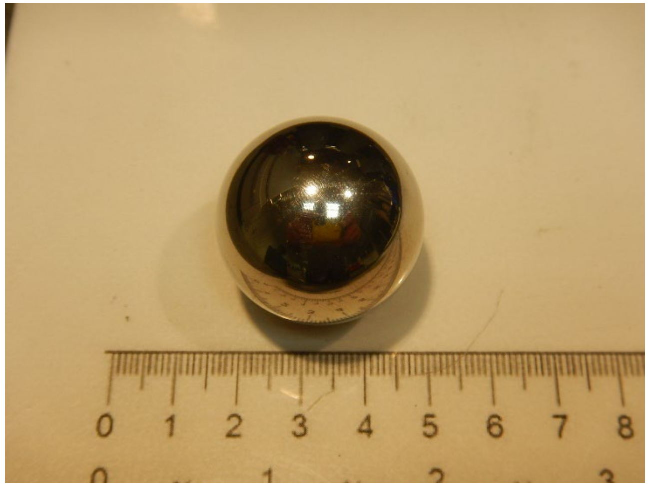

DLC-Coated Cages – Before (top) and After (bottom)



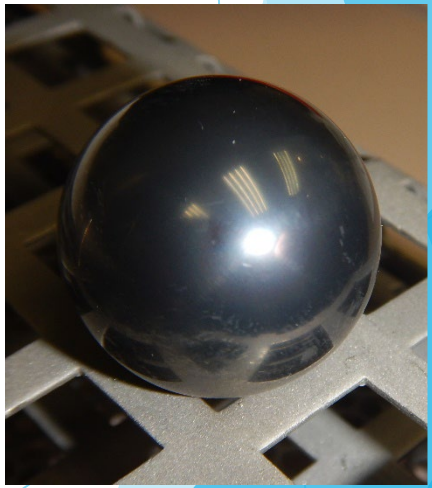
# Parts – Balls/Seats

**Standard**

- Cast cobalt alloy
- Fixturing process a challenge—How do you fully coat the ball and hold it in place at the same time?
- Each coater had their own approach to the process




DLC-Coated Balls – Before (left) and After (right)

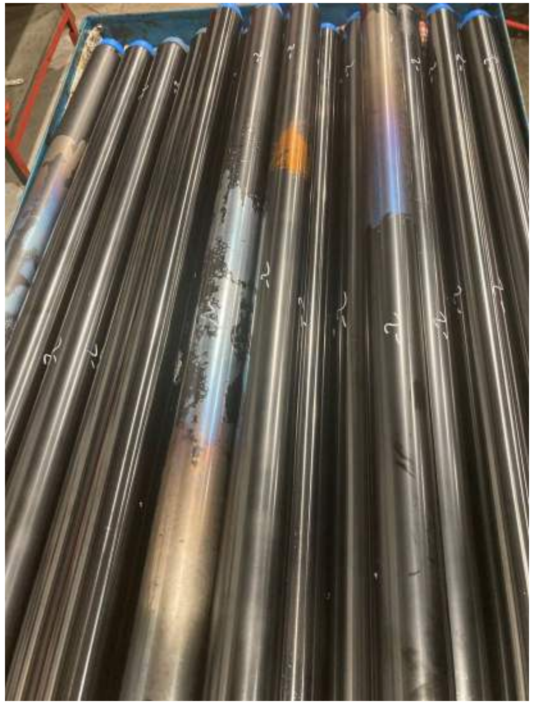


# Parts – Plungers

## Process

- DLC application was challenging
- Several iterations of adhesion layer design and treatment process were needed before finalizing

Early DLC Coating Attempt



Revised DLC Processes (below, right)

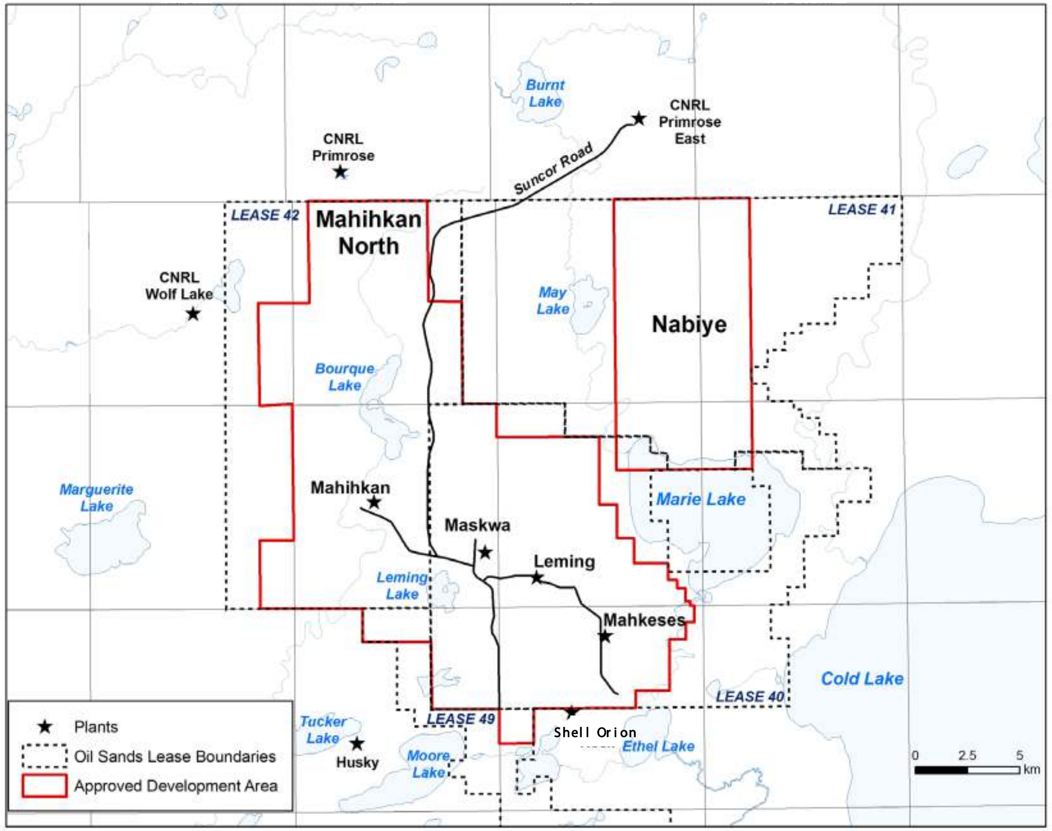
# Parts – Distribution

## Vendors

- 3 DLC coaters participated, split among wells
- ~15-25 wells per coater
- 1 coating strategy (recipe set) per coater
- Two DLC installation types
  - TVs and SVs
  - TVs, SVs, and plunger

## Wells

- Spread out among pads with scale problem wells
- Pumps deployed as equipment and candidates became available

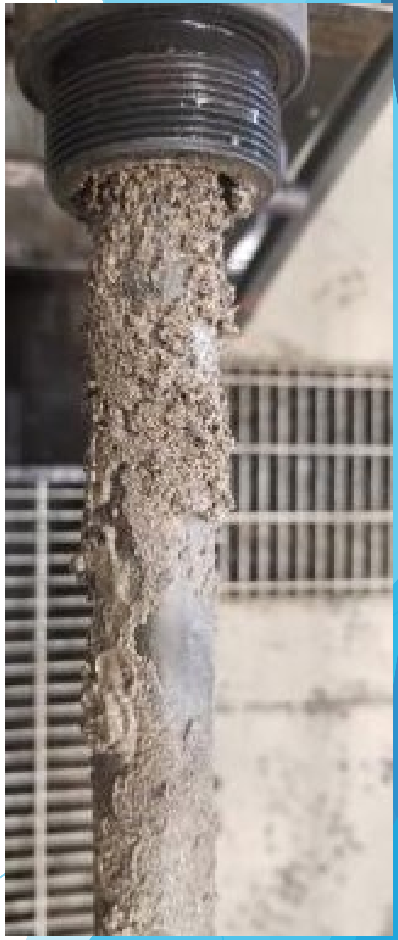


# Failure Examples – Well 1



Plunger Pin End Plugged with Scale

Cages Plugged with Scale



Sand on Plunger OD

Run Life: <2 Weeks

DLC will not solve all of these problems!

# Failure Examples – Well 2

Barrel Connector Scaled and Worn

Scale Buildup and Flaking
of DLC Coating on Standing Valve

Run Life: <2 Weeks

# Failure Examples – Well 3

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Plunger Pin End Scored

Seat Barrel Bushing (Strainer) Plugged with Scale

Flaked and Worn Traveling Valve

Mandrel Hold Down Scaled and Sanded

Worn Valves

Run Life: <2 Weeks

# Failure Examples – Wells 4/5

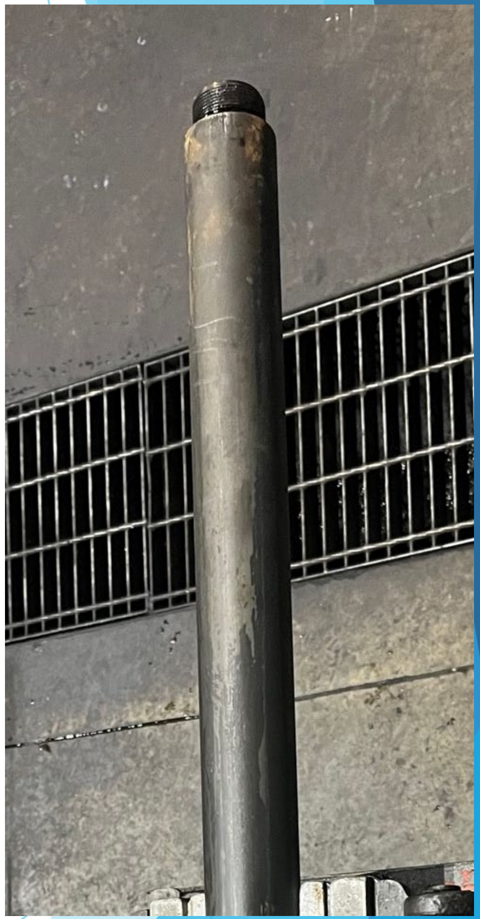
Clay Mixture in Upper Barrel Connector

Standing Valve, Some Coating Missing

Scale Buildup in Cage

Clay/Scale Mixture Found in Pump

Run Life: <1 Month



Worn Plunger

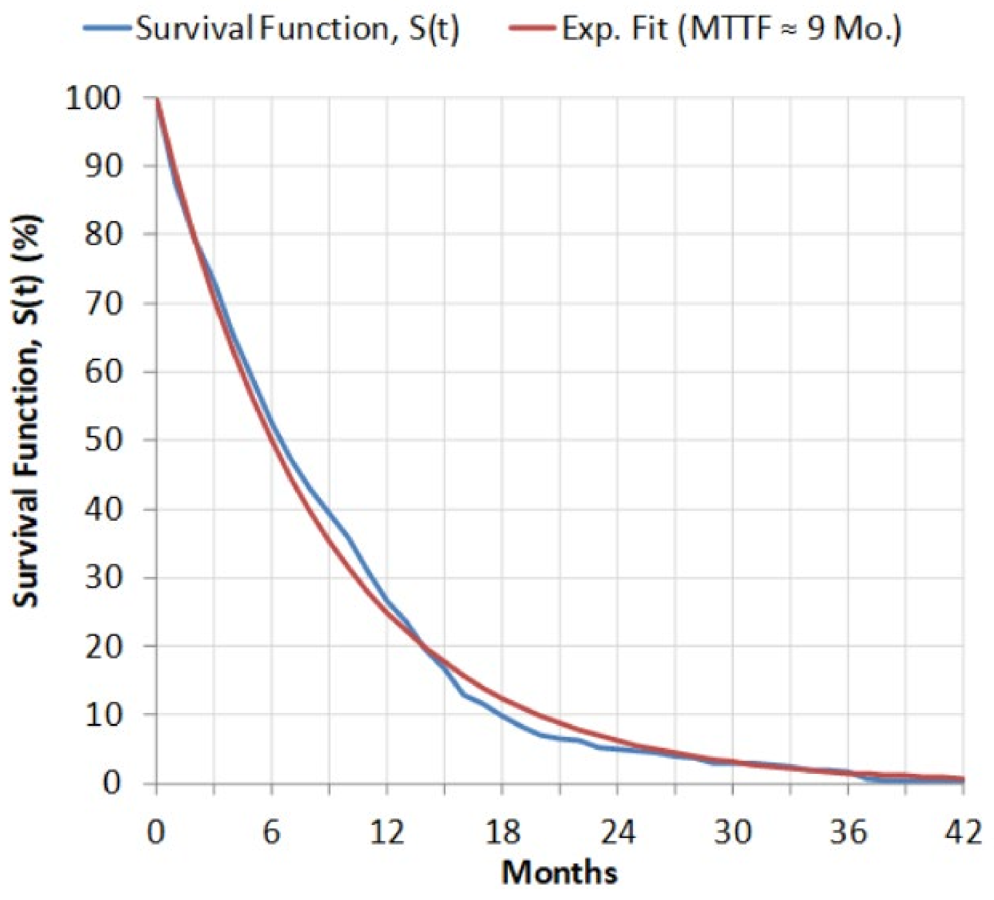
Run Life: 4.5 Months

# Results – Reliability



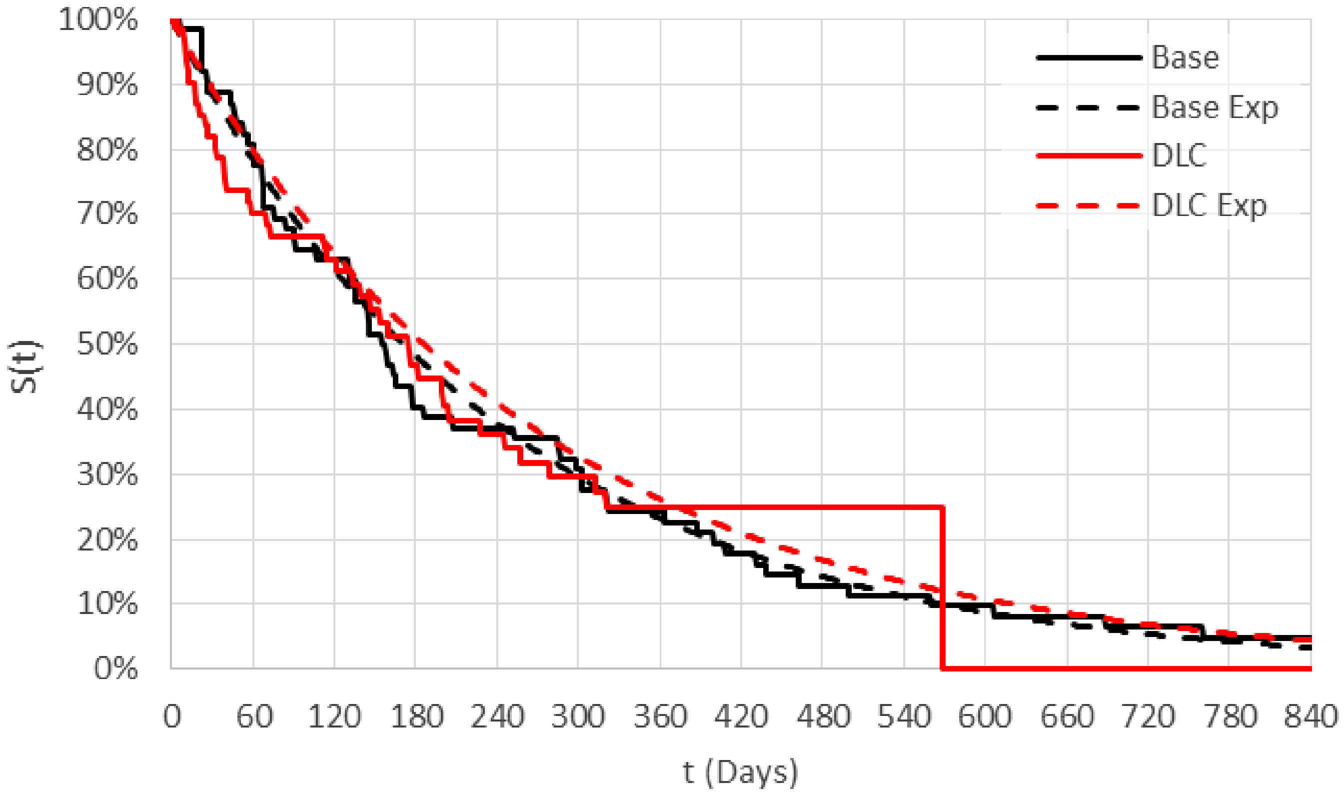
## Kaplan-Meier Survival Function

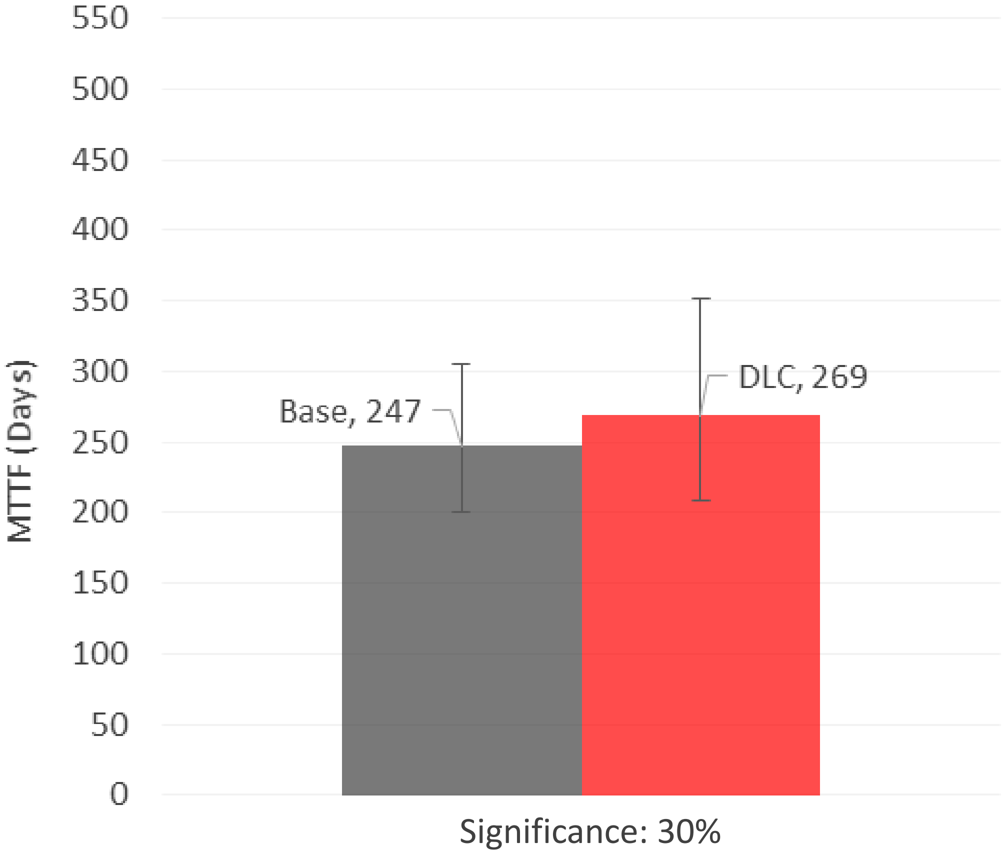
- Gives probability that a system will survive beyond a certain operational time “t”
- $S(t) = S(t\text{-}1) \times (N_t\text{-}F_t)/N_t$, where
  - $S(t\text{-}1)$ = value of the function at time “*t-1*”
  - $N_t$ = Number of systems surviving until time “*t*”
  - $F_t$ = Number of failures between time “*t-1*” and “*t*”
- Area under a “complete” Survival curve represents the Mean Time to Failure (MTTF), also calculated by the total runtime divided by the number of failures
- Lifetime distributions, such as exponential [*exp(-λt)*, where *1/λ* = MTTF] can provide a reasonable fit to *S(t)* and help account for systems that have not yet failed
- Statistical significance of perceived change due to DLC calculated using Fisher F-Distribution, result is dependent on failures in study and before/after MTTF




Courtesy of C-FER

# Results – All Base vs. All DLC

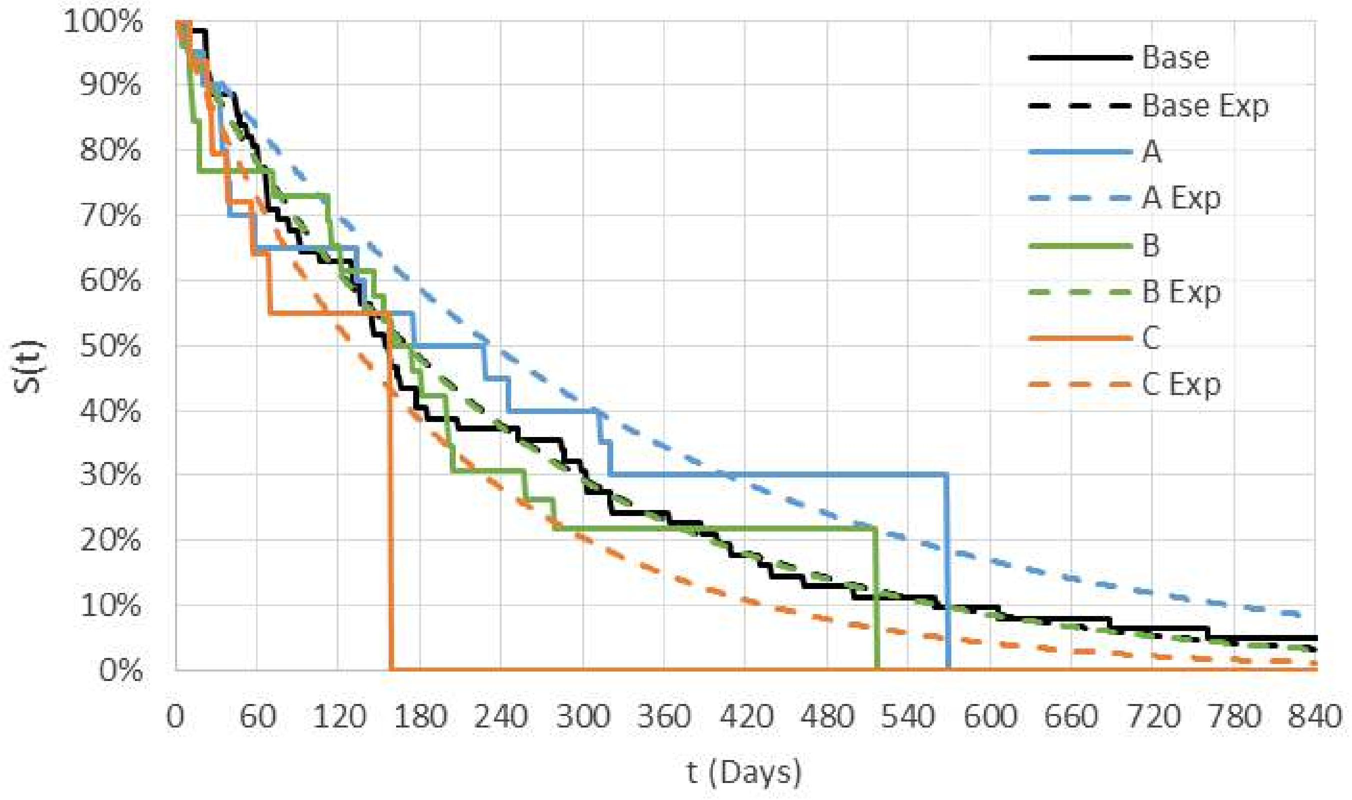


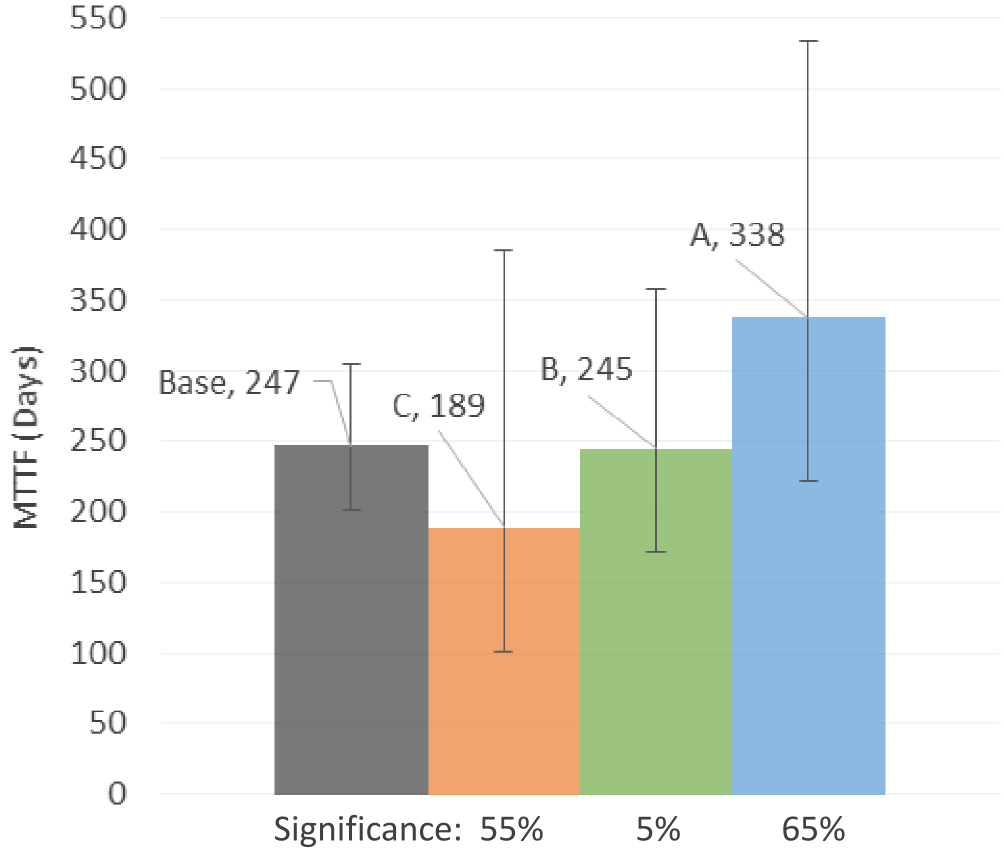




- Base and DLC *S(t)* include all 60+ wells in the pilot, base failure frequency is avg. of last 3 pump installs
- DLC wells had some early failures, but appeared to perform better overall
- Exponential distribution and MTTF calculation show a 9% DLC improvement
- However, MTTF error bars (90% confidence) overlap and significance calc. is low

# Results – All Base vs. Individual DLC



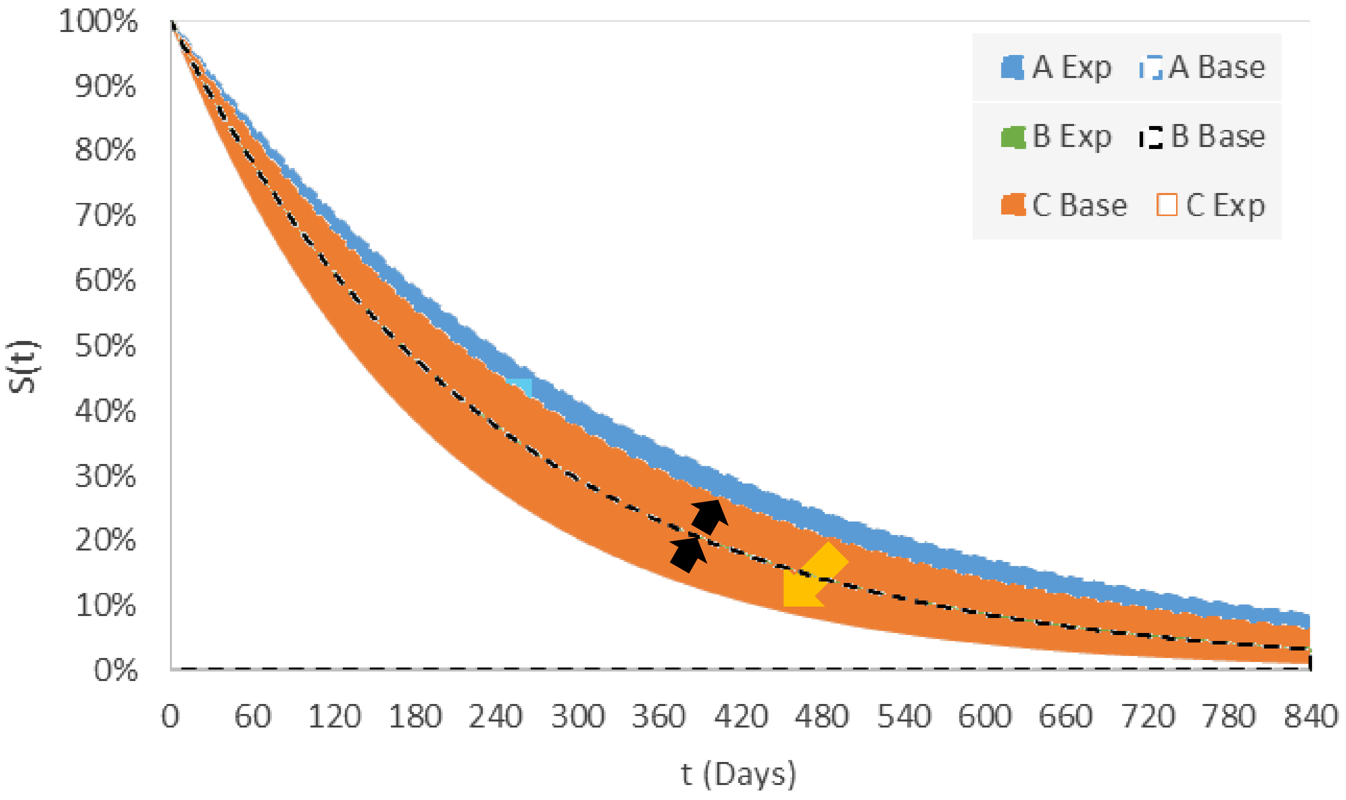


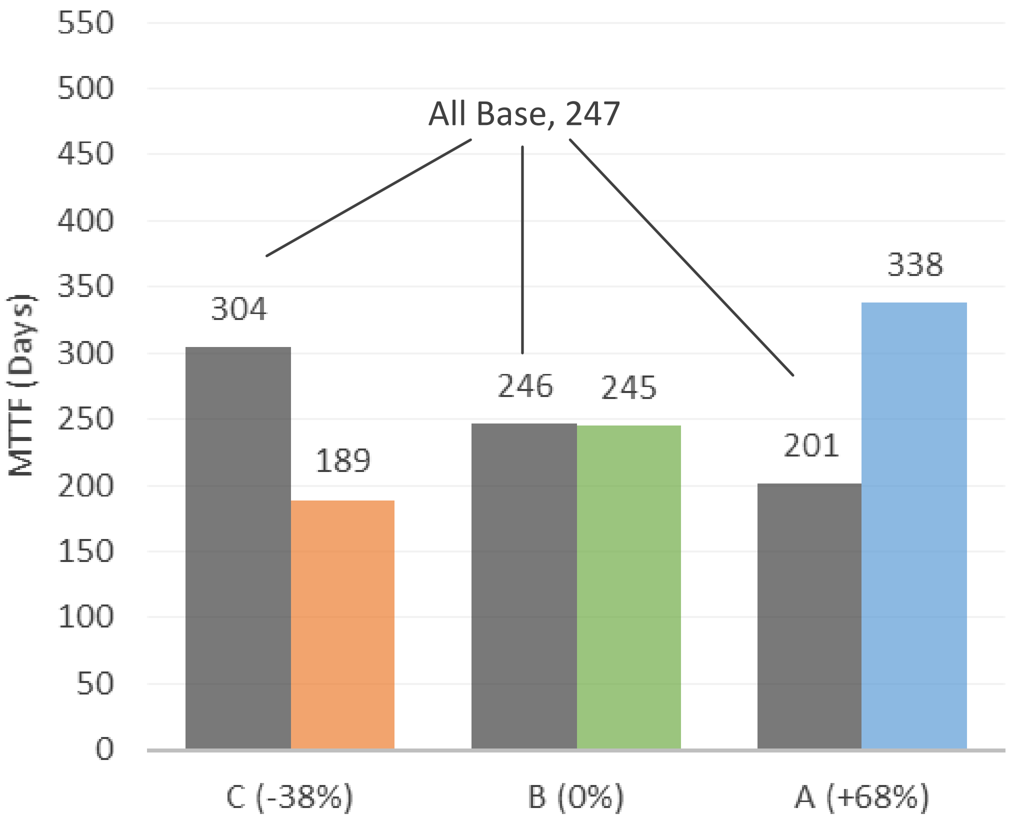




- Coater *S(t)* become "chunkier" as there are fewer systems, C has least exposure time
- Clear that C is below base and A is above, B is nearly the same
- Exponential distribution and MTTF calculation confirm visual inspection
- Significance calculation is fair-good for A and C, and is as expected for B

# Results – Individual Base vs. Individual DLC






- Do all of the pilot candidates provide the same challenge?
- No – Base MTTF for C < B < A (black arrows)
- A had the most difficult wells and most improvement in a relative comparison
- Statistical significance is more certain with the smaller group comparison

# Summary



## DLC Applied to Scaling

- Identified scaling as a key detriment to SRP reliability
- Hypothesized that application of DLC to SRP areas with largest pressure drops could reduce scale deposition
- Applied DLC from 3 coaters to valve assemblies and plungers
- Installed DLC SRPs in **60+** wells

## Results

- DLC couldn't stop scaling/failures, but did help
- Highest-performing coating increased MTTF by ~**70% (137 days)**
- Coating of valve assemblies provided the most benefit
- High statistical significance of improvement from DLC application even with relatively small batches
- Plan to continue running DLC pump components in scaling wells
- Other DLC chemistries / application processes may be evaluated for further improvement

# Acknowledgements, Thank You, & Questions

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