Beneficial Reuse Roadmap for Used Drilling Fluids

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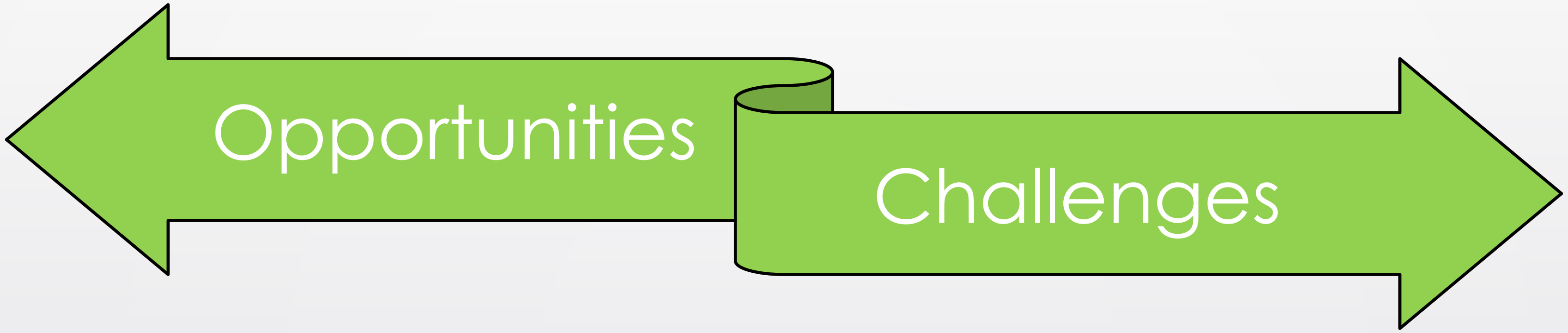
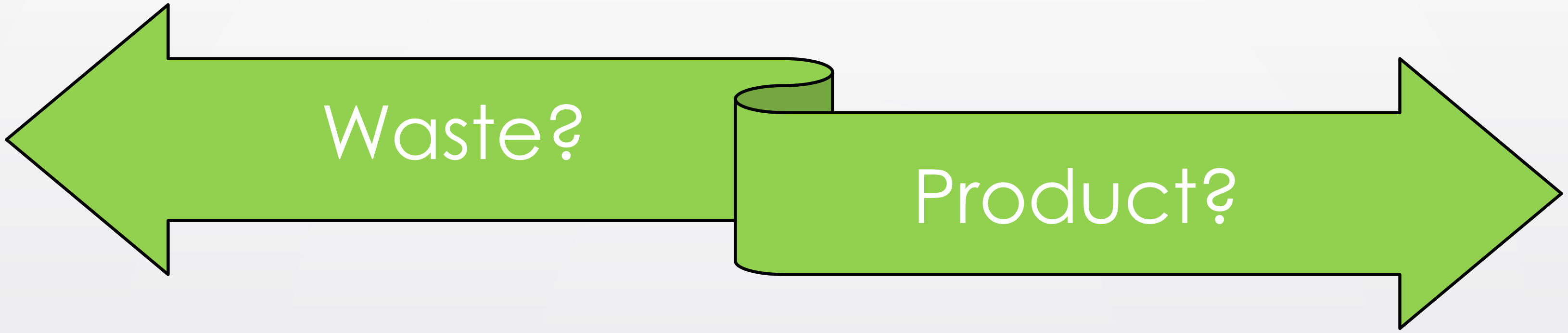
Beneficial Reuse



- Reduce the cost
- Reduce resource consumption
- Improve overall environmental performance
- Enhance community relationships

- Protecting human health and the environment
- Technical feasibility
- Regulatory barriers
- Sham recycling threats
- Finding a market for reuse

Management Options



- Identify harmful characteristics
- Impalement strategies to mitigate harm to human health and the environment
- Track waste cradle to grave
- Comply with applicable law

- Demonstrate that it is effective substitute for virgin product
- Establish that it can be safely used
- Find a market for it (value)
- Store and transport it safely
- Comply with applicable law

Roadmap for Beneficial Reuse of Drilling Fluids

- Integration of reusable drilling fluids design in operations
- Identification of chemical and physical drilling fluid targets
- Identification of regulatory compliance targets
- Management of challenges and limitations

Non-Aqueous Based Muds

- Function
  - Weight materials - barite
  - Viscosity - provided by invert emulsion and clay
  - Filtration properties provided by emulsion
  - Lubricity provided by base fluid
- Limitations and Developments
  - High cost/cubic meter
  - Physical properties
  - Reduced logging quality
  - Lost circulation
  - Environmental stewardship

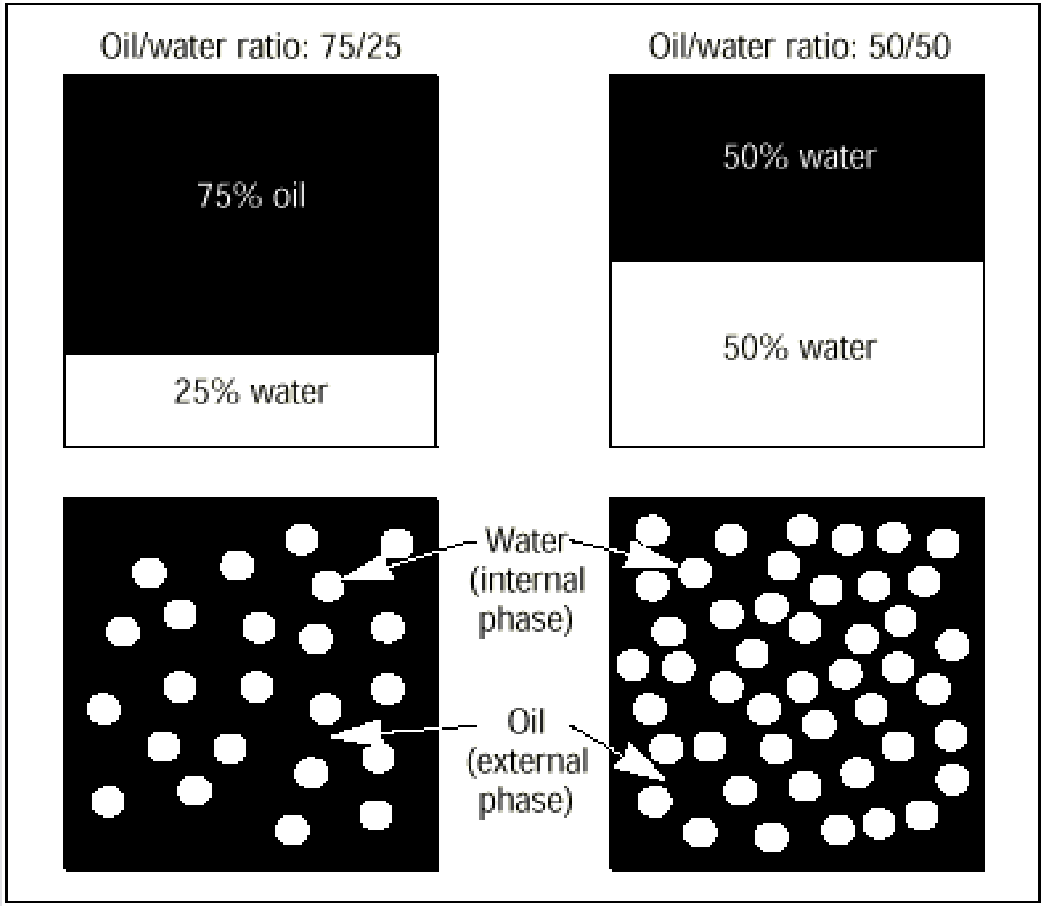
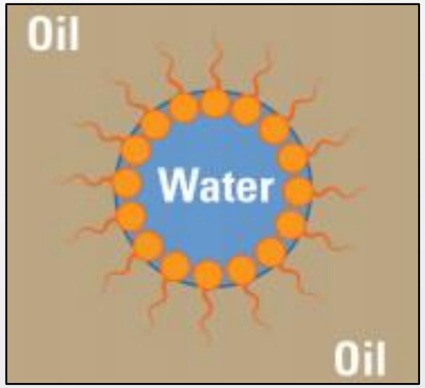
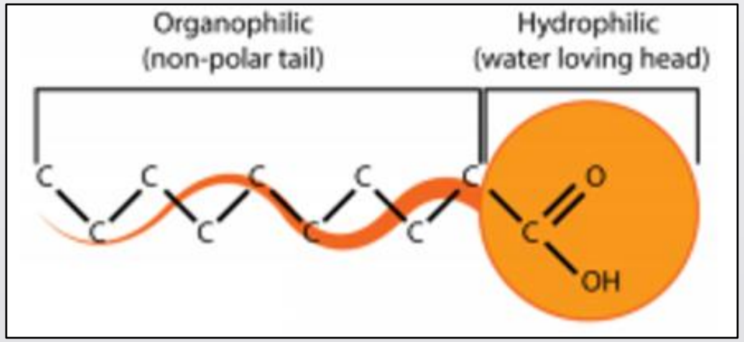


Figure 2: Effect of water content on water-in-oil emulsion.

Emulsions

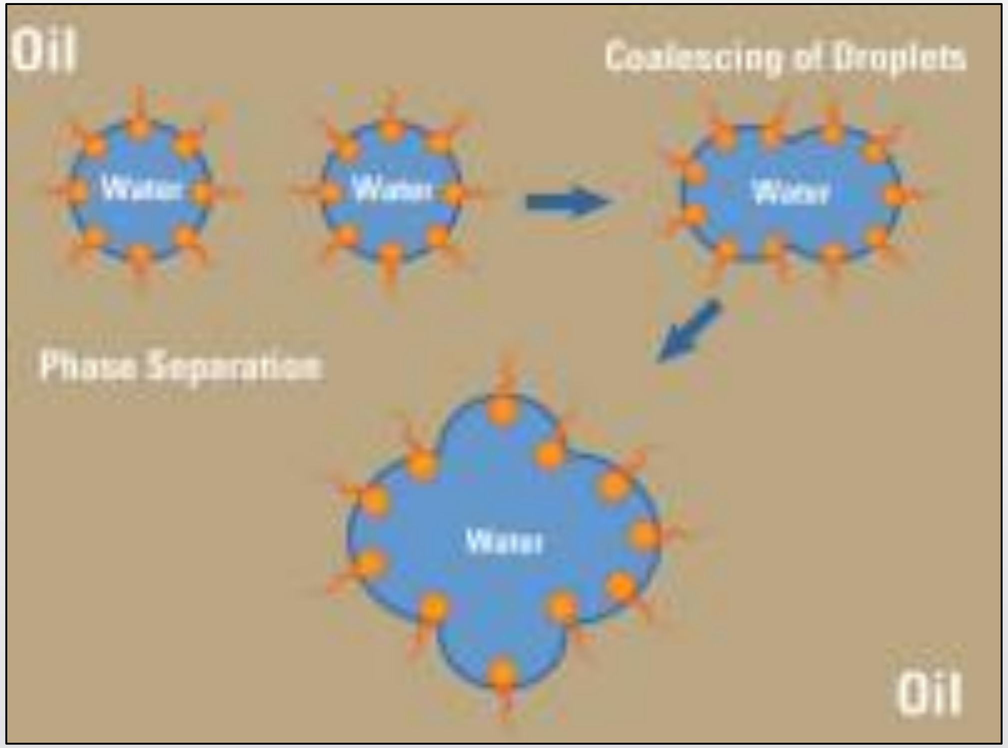
- Emulsifiers reduce surface tension between the water droplets and oil (or synthetic).
- They stabilize the mixture by being partially soluble in both water and oil.
- One end of the emulsifier molecule has an affinity for water while the rest of the molecule has an affinity for oil or synthetic fluid.
- Emulsifier particles form a coating around the water droplets to keep them from coalescing.





Importance of Shear

- Sufficient shear and small droplet size are critical for mud stability. Small, uniform water droplets generate viscosity and gel strengths.
- These water droplets also help support weight material and reduce fluid loss by becoming trapped in the filter cake.
- Proper shear (forming a stable emulsion) is often difficult to achieve in liquid mud plants and in mud pits. Varying amounts of shear can be achieved by utilizing specialized high-shear devices or circulating through the bit jets, mud guns, or with centrifugal pumps.



NAF Drilling Fluid Technical Targets

- Rheology
- HTHP Fluid Loss
- ES Electrical Stability
- Synthetic/Water Ratio
- Total Solids/High Gravity Solids/Low Gravity Solids

Electrical Stability

- Electrical stability (ES) is a relative value affected by several factors, including droplet size and percentage of water present. The smaller the droplet, the more stable the emulsion, since large droplets coalesce easier than small ones. Uniform droplet size also makes the emulsion more stable. This is why mud must be sheared, obtaining small droplets of uniform size. Since temperature can affect ES as well, it is important to perform the test at a consistent temperature (Ex: 120°F or 150°F)
- The ES of new fluids will be low until the water is thoroughly sheared, resulting in smaller uniform-sized water droplets. Lower ES can also be caused by lack of emulsifier or lack of lime. Lime acts like a media, increasing the alkalinity and improving the emulsion.

Drilling Fluid Properties Comparison

- Lab Mud representing fresh mix

Fluid Formulation	*1*	*2*
Brenntag base oil, bbl	0.51	-
BIOBASE 300, bbl	-	0.51
VG PLUS, ppb	6.0	6.0
LIME, ppb	3.0	3.0
CaCl2, ppb	27.11	26.92
Water, bbl	0.21	0.21
MEGAMUL, ppb	8.0	8.0
Barite, ppb	303.49	311.08

Mud Properties	*1*	*2*
Heat Aging Temp, °F	150	150
Heat Aging Hours	16	16
Static/Rolling	Rolling	Rolling
Mud Weight, ppg	13.5	13.5
Rheo Temp, °F	150	150
600 rpm	72	67
300 rpm	52	48
200 rpm	42	40
100 rpm	33	31
6 rpm	17	16
3 rpm	16	15
PV, cps	20	19
YP, lbs/100 ft²	32	29
10 Second Gel	16	15
10 Minute Gel	17	17
E.S., Vts @ 120°F	483	432
Syn/Water Ratio	70/30	70/30
HTHP @ 250°, ml	2.2	0.4

- Field Mud representing used mud

Mud Properties	**Base**
Mud Weight, lb/gal	14.23
Rheology Temp, °F	150
R600/R300, °VG	63/33
R200/R100, °VG	24/14
R6/R3, °VG	3/2
PV, cP	30
YP, lb/100ft²	3
10-sec Gel, lb/100ft²	6
10-min Gel, lb/100ft²	12
HTHP @250°F, mL	3.4
E.S. @120°F, V	514
Excess Lime, lb/bbl	1.81
Solids, vol%	32
Oil, vol%	49
Water, vol%	19
Oil/Water Ratio	72.1/27.9
Corrected Solids, vol%	29.98
LGS, vol%	11.38
LGS, lb/bbl	105.56
HGS, vol%	18.59
HGS, lb/bbl	266.83
Wt Material Density, s.g.	4.1
$CaCl_2$, wt%	28.4
Cl^-, Whole Mud, mg/L	48000

Comparison of Fresh Mix and Used NAF

- ## Fresh Mix Mud Plant Muds
  - Fresh mix emulsions are limited by the shear that can be achieved in the mix plant with centrifugal pumps.
  - Fresh mix muds take much longer to prepare than starting with a used field mud that has been sheared at the rig.
  - The low stability is exhibited in mud properties is low Electrical Stability, high HTHP fluid loss and a lack of yield point available to suspend barite.

- ## Field Muds
  - Field muds have the shear provided by the high pressure mud pumps and the shear achieved though the bit.
  - Field muds have some drill solids that help stabilize the emulsion, suspend the barite.
  - The stability of field muds is represented in mud properties such has high Electrical Stability (ES), stable rheology and low HTHP fluid loss.

Why Field Muds Are Important To Smooth Mud Plant Operation

- It is most common to need more volume from mud plants to start a new well so it is common to start with some volume of used mud and then build more volume in the mud plant.
- Starting with a volume of stabilized used field mud allows for a mud plant mix that has the stability of a field mud with the specific volume, synthetic/water ratio, and mud weight that the well operation needs.
- Some muds are simply stored and then sent to the next job. They are rolled in the storage tanks to maintain a healthy emulsion.

Management of Drill Solids in a NAF

- As the mud weight increases, several aspects of the NAF formulation change, the SW ratio adds more base fluid to thin the fluid, the quantity of high gravity solids (barite) goes up. The PV goes up and less YP is needed to suspend barite.
- Drilled solids (low gravity solids) are part of drilling fluid design. NAF muds are designed to manage a wide range of drill solids (0 – 20%).
- Management of drill solids in field drilling fluids is a normally kept in balance using solids control equipment and building fresh volume of mud to replace mud lost on the cuttings that are discharged.

Control of Drill Solids in Mud at Rigsite

Drilling fluids in active mud system

Circulated Drilling Fluids,
Normal Low Gravity Solids range 0-20%

Base fluid, brine, emulsifiers added to maintain volume, adjust properties

Drill cuttings added to drilling fluids at the bit

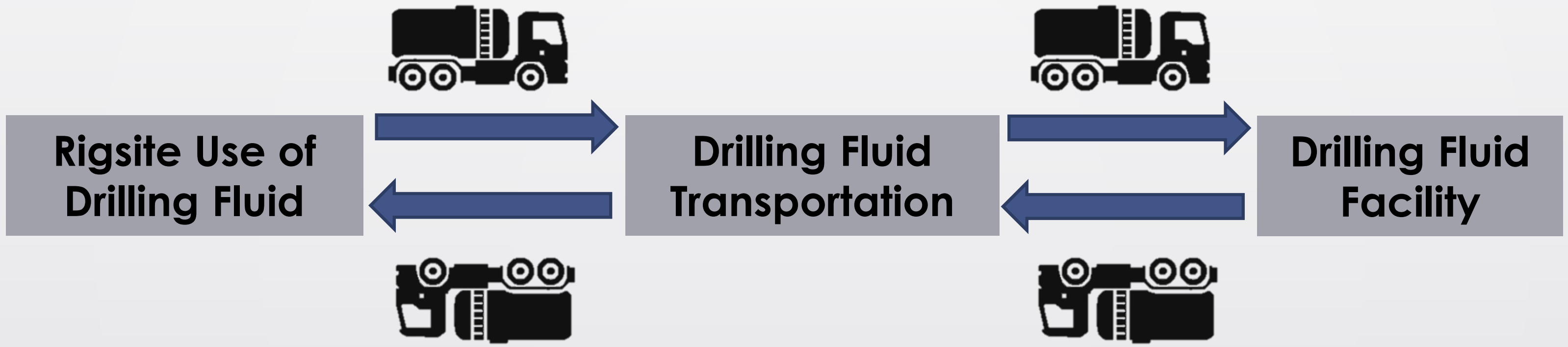
Drill cuttings removed at the surface using shale shakers and other mechanical solids control equipment

Average retention of base fluid on cuttings 10-20% base fluid, 80-90% solids

Liquid Mud Plants (LMPs) Support Efficient Mixture and Management of Drilling Fluids

- Preparing mud for the rigs. This means the LMP saves rig time because the rig does not have to prepare the mud.
- The LMP guarantees a continuity of mud supply which eliminates rig down time caused by mud shortage.
- The LMP allows the reuse of invert mud systems. The mud at the end of the well would have to be disposed if there was not a LMP.
- Because the mud can be reused and not discarded, pollution problems are avoided.

Drilling Fluid Management Between The Rig and Mud Plant



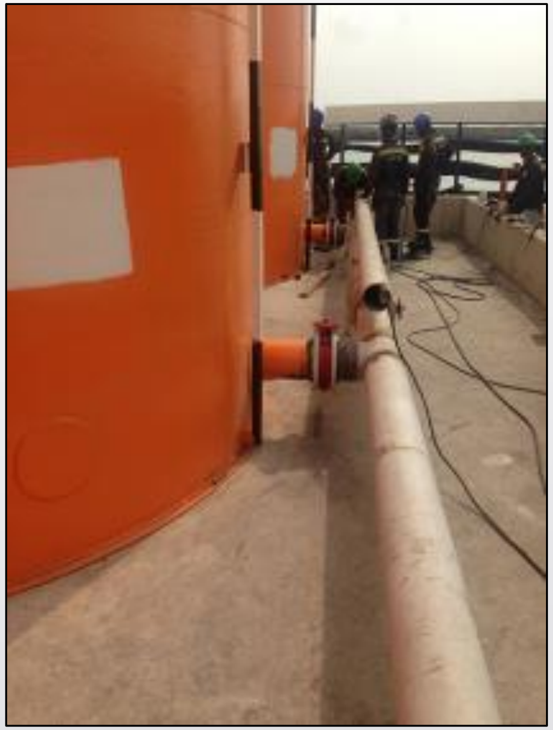
Continuous responsibility for the drilling fluids facility, transporter and rigsite

Mud Plant Equipment

- NAFs are typically processed and mixed at liquid mud plants, then shipped as liquid mud by truck or boat. Transporting large volumes of high density mud has unique logistic and transportation considerations. They require facility investments for building, handling, and storing liquid mud and makeup fluids.

Mud Plant Mixing Tanks

- Mixing Tanks
  Mixing tanks are usually around 250, 500, or 1,000 barrels. Smaller tanks provide better shear. However, larger tanks simplify operations by allowing more simultaneous processing and require fewer batches, reducing the chance of error.
- Mud Lines
  Suction lines are typically 8 inches in diameter with 6 inch diameter discharge lines (gun lines) from the pump to the storage tank guns. Lines are designed to aid tank flushing and draining.



Storage Tanks

- Storage Tanks
  The plant needs enough storage tanks (typically 500-1,000 barrels) to accommodate local demand. Gun lines should be placed as low as possible in the tank while maintaining a position that rolls the mud, keeping all additives mixed and the mud in good shape.

Common Misconceptions About Used Drilling Fluids Are Not Accurate

Misconception	Reality
Used drilling fluids at the end of a well are "spent" and need reclamation	Physical and chemical properties on the first day a fluids is used and the last day a fluid is used apply in a similar manner
Drilling fluids "wear out"	NAF muds do not wear out, they get better with more shear and circulation

Reused Drilling Fluids Do Not Pose A Significant Environmental Risk From TENORM

- The issue of NORM and TENORM is relevant to production waste.
- Drilling a well is different than producing a well and results in NORM being diluted though the drilling process and not concentrated.
- Low levels of naturally occurring radioactive material are maintained at background levels in used drilling fluids
- Pennsylvania Department of Environmental Protection in 2015: Fourteen drilling mud samples were tested from both the vertical and horizontal phases of drilling. The report found that "*All results were within the range of typical natural background found in surface soils.*"

Reused Drilling Fluids Do Not Pose A Significant Environmental Risk From Heavy Metals

- Heavy metals are also naturally occurring, and the concentration of heavy metals is an issue that has been previously studied and evaluated by the EPA in the offshore discharge environment.
- EPA identified barite as a potential source of heavy metals in drilling fluids and placed technology based limitations for Cd and Hg concentrations in barite.
- In 2019, EPA reported based on available data that many constituents in black shale (including heavy metals) were substantially higher than that typical of surface soils, often by an order of magnitude or more.
- While there are potential sources of heavy metals from barite and drilled solids, these are both managed by controlling the sources of barite used in the well and the management of drilled solids using mechanical separation equipment at the rig site.

Regulatory Requirements

State/EPA facility controls at Liquid Mud Plants (LMPs)

- LA DEQ
- TX TCEQ
- OK DEQ
- WY - DEQ

State NOW facility controls at waste management plants

- TX RRC
- LA DNR
- OK CC
- WY WOGCC

Regulatory handing of recycled materials

- Not a waste if:
  - Not abandoned (including incinerated or sham recycled)
  - Not inherently waste-like (e.g., dioxin)
  - Not recycled in certain ways:
    - In a manner constituting disposal
    - Burned for energy recovery
    - Accumulated speculatively

New Regulatory Challenges Concerning Used Drilling Fluid

- Risk for deviation from typical regulatory scheme for recycled materials
  - Define all used mud as waste
  - Determine that used mud is inherently waste-like
  - Determine that drilling with fluids is a use constituting disposal
- Defensive steps
  - Manage used mud as a valuable product
  - When used muds are no longer usable, handle appropriately as a waste
  - Monitor regulatory activity

Summary

- Used NAF fluids are important to use as a base stock to build more volume in mud plants.
- NAF drilling fluid properties are routinely measured to monitor performance.
- Because of the design of NAF emulsions, shear delivered downhole makes the system stable and healthy.
- A long standing focus of the US EPA and State agencies have been on waste minimization by using products for their intended purpose and not disposing of them as waste. Used drilling fluids meet the EPA definition of a product.

Conclusion

- All of the principals of drilling fluids and solids control at the rigsite are well known and well documented. Management of useable used mud as a valuable product at liquid mud plants is consistent with industry and government practice across oil and gas states.