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Eagleford Cuttings as Cement Replacement Material

Alexandra Cedola, Elizabeth Sones, and Cheve Meyer, Exero Well Integrity

Abstract

Cement production is one of the leading causes of CO_2 emissions. As operators strive to minimize their carbon footprint, reducing cement volumes will be both beneficial from a CO_2 and cost-efficiency standpoint. Pozzolanic materials such as silica fume and fly ash have become commonplace in cement systems due to their cementitious properties and lower cost. Another type of pozzolanic material is shale, which is prevalent in nearly all wells drilled today. In this paper, an investigation on using Eagleford cuttings as a cement replacement material in Texas surface systems has been conducted. Mixability, rheologies, pumpability, and compressive strength testing were performed on the cement-cuttings systems and compared to a conventional surface cement system. It was found that systems containing up to 50% cuttings achieved the necessary properties required by the state of Texas. There have been nearly 4,500 new drill permits issued in the state of Texas from January to August 2024; for each surface job requiring 100,000 pounds of cement, replacing half of this with cuttings would lead to nearly 100,000 tons of CO_2 reduction across the state of Texas. Not only would this replacement reduce emissions, but utilizing drill cuttings would also lessen disposal and transportation costs and reduce potential risks to both the environment and population.

Introduction

Wellbore integrity is critical to ensuring safe practices throughout a well's life. One of the primary factors pertaining to wellbore integrity is cement; from slurry design to job execution and beyond, cement is critical to ensuring that a wellbore can withstand the harsh downhole conditions during completion, production, workover operations, and abandonment. Slurry design is dictated by several factors, including but not limited to operator requirements, government regulations, downhole conditions, material availability, and cost.

Globally, cement manufacturing is responsible for approximately 8% of global carbon dioxide (CO_2) emissions and is expected to increase 4% by 2050 (Zhaurova et al., 2021; Andrew, 2019; IEA, 2018). In an attempt to minimize emissions associated with cement, companies will often use alternative pozzolanic or supplementary cementitious materials (SCM) in cement designs. Pozzolanic materials are alumino-silicious in nature and react with calcium hydroxide during hydration to form calcium-silicate-hydrate (C-S-H), calcium aluminate hydrate (C-A-H), and/or calcium aluminosilicate hydrate (C-A-S-H) (Kasaniya et al., 2020; Gartner, 2004; IEA, 2018). Common types of pozzolanic material used in wellbore cement systems include but are not limited to fly ash, metakaolin, silica fume, silica powder, ground granulated blast furnace slag (GGBFS), and pumice (Jaskulski et al., 2020).

While many of these pozzolans are readily available due to how they are sourced, others, such as fly ash and GGBFS, are dependent upon variable processes. Fly ash is a by-product of coal combustion, and as coal continues to be phased out as an energy source, the availability of fly ash will decline; projections show that the baseline forecast of fly ash production from 2018 to 2039 will have decreased by 14.9% and have a projected average annual growth rate of -0.8% while utilization is set to increase by 38% (Black & Nada, 2020). GGBFS is a by-product of iron or steel manufacturing, a process highly dependent on demand. Natural pozzolans (NP's) include volcanic ash (pumice), clay, and shale. These NP's can be added to cement as a raw material or after calcination (Barger et al., 2001). In today's wellbores, it is thought that approximately 75% of formations drilled are shale, meaning, in theory, that roughly 75% of all drill cuttings are also shale (Gholami et al., 2020). The United States is the global leader in shale production with the Eagleford being one of the highest contributing basins (U.S. E.I.A., 2024). Mineralogy of the lower Eagleford shale shows that the composition consists of calcite and quartz with lesser amounts of plagioclase, pyrite, and muscovite/kaolinite, among other minerals (Cho et al., 2016).

This paper investigates the feasibility of using Eagleford shale drill cuttings as an SCM in wellbore barrier sheaths. Laboratory testing on cement systems with varying cement-cuttings ratios has been conducted to understand the feasibility of using cuttings as a barrier material and viable concentrations.

Benefits of Using Cuttings as an SCM in Wellbore Barrier Systems

For each well drilled, tons of drill cuttings are produced; the actual volume can vary based on depth of well and hole cleaning capabilities. Once the cuttings are brought to surface, they must be cleaned to remove any residual drilling mud and disposed of; both are costs that fall on the operator. For onshore operations, disposal can be done via landfarming or landspreading, incineration, injection, stabilization or solidification, burial, landfill, or reuse (Clements et al., 2010). In North America land, not all of these options are regulatorily feasible, and regardless of the method, risks are present to both the populace and the environment.

It has been estimated that for every foot drilled, approximately 1.21 barrels of waste is created, 26-50% of which is solid waste (API, 2000). A new estimate for E&P drill cuttings waste generation in 2016 was 33.5 million barrels (U.S. E.P.A., 2019). In the Eagleford basin, formation depths can range anywhere from 2,000 feet to 14,000 feet, and measured depths of the wells can be in excess of 25,000 feet (U.S. E.I.A., 2014). For a 25,000-foot well, there is a possibility for up to 15,125 barrels of drill cuttings to be produced; disposal costs can range from $2-$40 per barrel, meaning that it could cost operators upwards of $600,000 to get rid of the cuttings (Puder & Veil, 2007). While not all cuttings are from the target shale formation, replacing 25% of cement in a wellbore barrier surface system with cuttings could considerably decrease disposal costs.

Outside of cost, another benefit to using cuttings within a wellbore barrier system is the reduction in greenhouse gas emissions associated with cement. While there is no absolute number, for every ton of cement produced approximately 1 ton of CO_2 is generated (Hanle et al., 2004). Using the Eagleford as an example, if a surface cementing job requires 100,000 pounds of cement, replacing 25% with cuttings would amount to over 12 tons of CO_2 emissions reduction in a single wellbore. Additional emission reduction due to transportation to the cuttings' cleaning and/or disposal facility is also likely.

Experimental Methods

The cement-cuttings systems described in this work were based on the current surface and intermediate tail system designs used by Exero Well Integrity in South Texas. The cuttings were obtained from an operator in the Eagleford basin and transported to a recycling center outside San Antonio, Texas, where they were cleaned and allowed to dry.

Cuttings samples were sent to the Exero Research & Development lab, where both system design and laboratory testing occurred. A 15PPG density design is used for the surface tail systems, and 25% and 50% of the cement was replaced by Eagleford cuttings. This is similar to adding fly ash to barrier systems in that an alternative pozzolanic material replaces a portion of the necessary blend material. All other additive concentrations were kept the same. 15.5PPG intermediate tail systems containing cuttings were designed per the same process. Due to the material properties of the cuttings, the volume of mix fluid decreased as cuttings concentration within the blend increased. An example of the Eagleford cuttings used for this research can be seen in Figure 1.

Figure 1. Eagleford cuttings sample,

The dry materials were weighed out and combined. Mix water is then weighed, and the system is blended according to API standard RP-10B2. Mixability is observed for all systems to ensure workability. After the systems were found to be mixable, additional testing was performed to determine whether the systems met TRRC requirements. An ultrasonic cement analysis (UCA) is done on each system to determine compressive strength (CS) during the early hydration period. CS values must meet TRRC 24- and 72-hour CS requirements to be pumped within the state. The systems are conditioned for 30 minutes and placed on an R1B1 viscometer setup; shear stress is found over varying shear rates, and both plastic viscosity and yield points are determined. Additional tests that have been conducted on the systems for this initial study are free water or fluid testing; this is done by conditioning slurries at downhole temperatures for 30 minutes, then 250mL of the heated slurry is poured into a glass graduated cylinder and allowed to rest untouched for 2 hours to determine the amount of water that is coming out of the system downhole. For the surface and intermediate strings, the graduated cylinder was kept at 90 degrees to simulate the hole inclination. Thickening time testing was done on the 25% cuttings surface tail system to determine how the cuttings affect pumpability when compared to the conventional cement system.

Results

Laboratory testing on surface and intermediate tail systems containing 25% and 50% cuttings is performed to determine whether TRRC cementing requirements are met. The CS, rheology, and free water results are described below.

Surface Tail Systems

Testing on South Texas surface tail systems began by taking an existing surface tail system and incorporating 25% and 50% cuttings. Mixability of the cuttings systems is performed during the blending process and appeared comparable to the conventional 15PPG surface tail system; vortex size is noted for the systems during the high speed mixing portion of blending and there is no visible separation of the cuttings once mixing was complete. An image of the 25% cuttings system during blending is shown in Figure 2.

Figure 2. Mixability of the 25% cuttings surface tail system.

The surface tail systems are put on the UCA and subjected to downhole temperature and pressure for 72 hours. CS measurements are recorded every minute for the duration of the test. UCA results for the conventional (no cuttings) surface tail system, 25% cuttings surface tail system, and 50% cuttings surface tail system are shown in Figure 3.

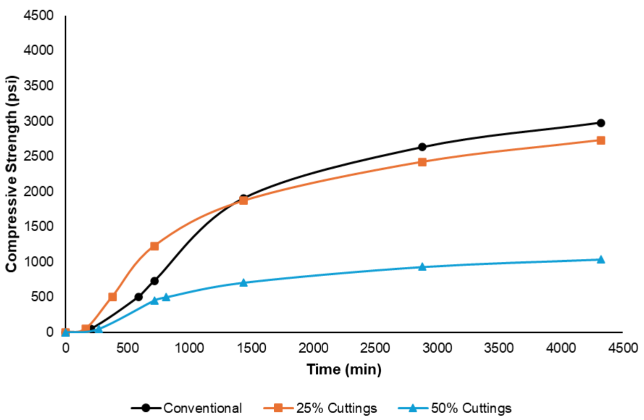

Figure 3. UCA results for the conventional, 25% cuttings, and 50% cuttings Eagleford surface tail systems.

Table 1 summarizes CS values with time for the three 15PPG surface tail systems.

Table 1. Summary of surface tail slurry compressive strength results.

	Conventional	25% Cuttings	50% Cuttings
Time to 50psi (hh:mm)	3:26	2:46	4:30
Time to 500psi (hh:mm)	9:48	6:18	13:35
24-Hour C.S. (psi)	1,905	1,868	707
48-Hour C.S. (psi)	2,630	2,420	930
72-Hour C.S. (psi)	2,978	2,729	1,036

Both surface and downhole rheologies are determined for the three surface tail systems; a comparison of the downhole rheology results for the systems is shown in Figure 4.

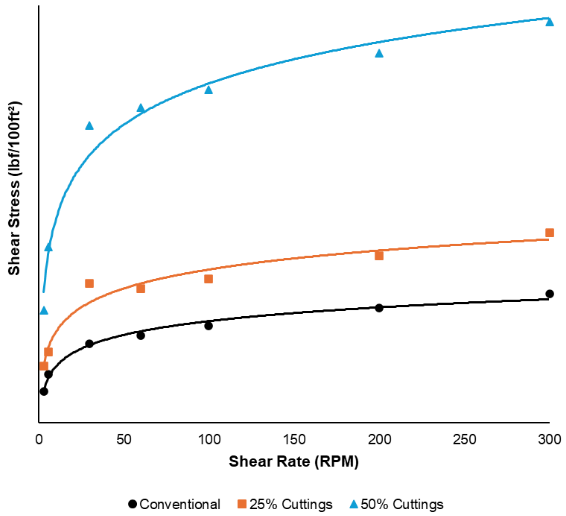

Figure 4. Downhole rheologies for the conventional, 25% cuttings and 50% cuttings surface tail systems.

Free fluid tests were performed on the surface tail systems. The 15PPG conventional surface tail exhibited 1mL of free fluid or 0.4%. For the 15PPG surface tail system with 25% cuttings, there was less than 1mL of free fluid. Free fluid results for the 15PPG surface tail with 50% cuttings yielded 1mL (0.4%) of free fluid. None of the surface tail systems exhibited settling and no channels or striations were visible.

Intermediate Tail Systems

Initial testing of cuttings replacement was done on 16.2PPG intermediate tail systems; mixability was poor with the additives and concentrations that were used in the conventional system. A lighter density system is also regularly pumped in the basin; for this reason, a 15.5PPG slurry was designed to observe the effect of cuttings replacement on cement for the intermediate string. Mixability of the 15.5PPG intermediate tail system containing 50% cuttings is shown in Figure 5.

Figure 5. Mixability of the 50% cuttings intermediate tail system.

CS testing was done on the conventional 16.2PPG intermediate tail, conventional 15.2PPG intermediate tail, 15.5PPG 25% cuttings tail, and 15.5PPG 50% cuttings tail, and the 72-hour UCA results for the aforementioned systems are shown in Figure 6.

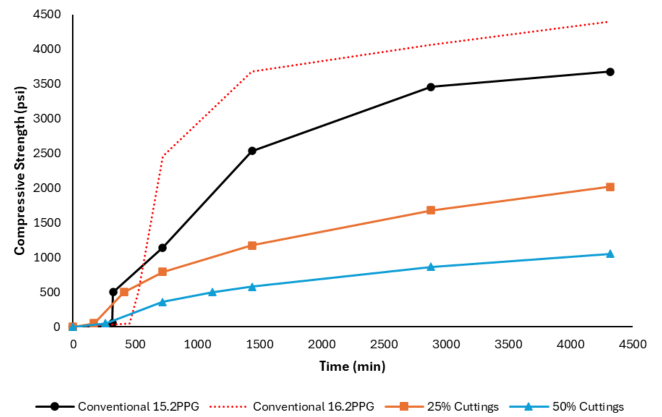

Figure 6. UCA results for the conventional 15.2PPG, conventional 16.2PPG, 15.5PPG 25% cuttings, and 15.5PPG 50% cuttings Eagleford intermediate tail systems.

CS over time for the four intermediate tail systems is shown in Table 2.

Table 2. Summary of intermediate tail slurry compressive strength results.

	Conventional 15.2PPG	Conventional 16.2PPG	25% Cuttings	50% Cuttings
Time to 50psi (hh:mm)	5:17	7:36	2:48	4:23
Time to 500psi (hh:mm)	5:24	8:46	6:49	18:39
24-Hour C.S. (psi)	2,535	3,680	1,173	578
48-Hour C.S. (psi)	3,453	4,062	1,680	863
72-Hour C.S. (psi)	3,677	4,394	2,018	1,053

Downhole rheology results at varying shear rates for the 15.2PPG and 16.2PPG conventional cement intermediate tail systems and the two 15.5PPG cuttings systems are shown in Figure 7.

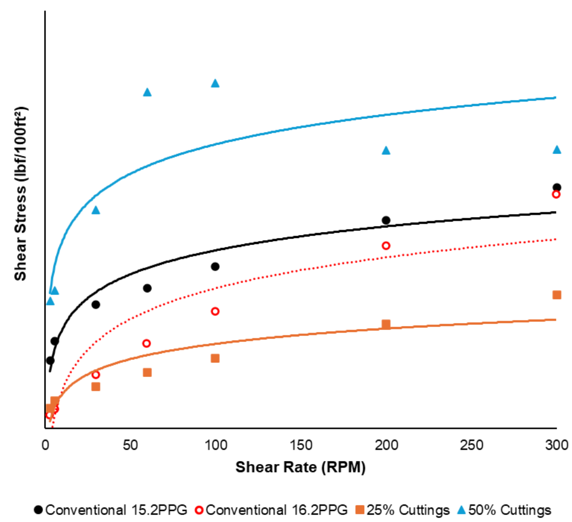

Figure 7. Downhole rheologies for the conventional 15.2PPG, conventional 16.2PPG, 15.5PPG 25% cuttings, and 15.5PPG 50% cuttings intermediate tail systems.

Free fluid or free water tests were performed on the four intermediate tail systems. For both the 15.2PPG and 16.2PPG conventional intermediate cement tails, no free water was observed. For the 15.5PPG intermediate tail with 25% cuttings, there was less than 1mL, or below 0.4%, free water after the two-hour static period. The 15.5PPG intermediate tail system with 50% cuttings yielded 0mL of free water. None of the intermediate tail systems appeared to have any settling, channeling, or banding.

Discussion

The testing for both the surface and intermediate tail systems has been analyzed and is described in this section.

Surface Tail Systems

Mixability of the surface tail systems containing 25% and 50% cuttings proved unproblematic. Because particle size of the cuttings was not homogeneous, it was initially unknown whether the system would have mixing issues and how this would affect the water/solid ratio. A wide and deep vortex was present for both cuttings systems (Figure 2), and no settling occurred once blending was stopped. The systems could also be poured easily, and no large particles appeared to have conglomerated within the slurry.

UCA results show that both 15PPG surface tail systems with cuttings achieved CS over 1,000psi after 72 hours, as shown in Figure 3. The 25% cuttings system had compressive strengths that were not vastly different from those of the conventional surface tail system; 72-hour compressive strengths varied by less than 250psi. The surface tail system containing 50% cuttings showed a lower 72-hour compressive strength, reaching only about a third of what the conventional system achieved.

The system containing 25% cuttings hit 50- and 500psi before either the conventional or the 50% cuttings slurry, indicating that the cuttings may aid in hydration and strength enhancement at this concentration. This could be due, in part, to the particle size of the cuttings; smaller particle sizes have larger surface areas and allow for higher nucleation sites during hydration. After 24 hours, the conventional system began to exhibit higher compressive strengths with time, likely due to the functionality of the additives. While the 50% cuttings system began to build strength early on, strength development slowed after 24 hours. There are a number of reasons that could cause this, including but not limited to composition/mineralogy of the cuttings, residual oil on the cuttings that could hinder strength development, the cuttings not promoting C-S-H formation and critical microstructure, and/or the UCA was not able to accurately determine the compressive strength of the system with that high of cuttings concentration.

Rheological testing showed that the surface tail system containing 25% cuttings had slightly higher shear stress than the conventional 15PPG tail, but this difference has the potential to be minimized with dispersant (Figure 4). The 50% cuttings system had much higher shear stress compared to the traditional and 25% 15PPG surface systems; this indicates that the addition of cuttings to a 15PPG system leads to an increase in viscosity, potentially due to the decrease in mix fluid with increasing cuttings concentration.

Free fluid results for the conventional surface tail system and the 50% cuttings surface tail system were identical. The slurry with 25% cuttings had the lowest free fluid of the three, with 0% loss. TRRC free water requirements must be less than 2mL per 250mL, meaning both cuttings' surface tail systems meet these conditions (TRRC, 2025). Thickening time tests for the surface tail systems with 25% cuttings were run to observe how the cuttings affect pumpability and placement time; it was found that the surface system with cuttings was significantly shorter than the conventional surface tail systems, indicating that the cuttings may have an accelerating effect. This can be adjusted by increasing the retarder concentrations in the slurries.

Intermediate Tail Systems

For the 25% and 50% cuttings 15.5PPG intermediate tail systems, mixability was adequate and comparable to the conventional intermediate tail systems. While the cuttings did appear to make the system thicker than with just cement, a sizeable vortex was able to be formed, as evidenced in Figure 5, and there was no issue pouring the cement once blended. No cuttings separation was visible post mixing, and no agglomerations were observed within the system.

UCA results for the 15.5PPG intermediate tail systems containing cuttings, which can be seen in Figure 6 and further described in Table 2, show that the development of early CS was achieved before the conventional intermediate cement systems. In comparison to the 15.2PPG conventional intermediate tail system, the 15.5PPG system with 25% cuttings reached 50psi in almost half the time while the 50% system was able to hit 50psi nearly an hour before; the 16.2PPG system took the longest of the intermediate tail systems to begin building compressive strength reaching 50psi in over 7.5 hours. Once the systems began building CS, the conventional 15.2PPG, 16.2PPG, and the system with 25% cuttings continued to build strength quickly, achieving 500psi in approximately 5.50 hours, 8.75 hours, and 6.82 hours, respectively. The 15.5PPG system with cuttings took 18.65 hours to reach 500psi, significantly longer than the other intermediate systems.

72-hour CS results show that the systems containing cuttings were lower than the conventional cement systems. For the 25% cuttings system, the CS reached over 2,000psi, meeting TRRC intermediate cement string CS requirements. The 50% cuttings system achieved over 1,000psi CS but did not meet the 1,200psi TRRC CS requirements. These results show that the cuttings do not inhibit hydration under downhole conditions and indicate that there is likely a maximum value of cuttings that can be used to meet the TRRC CS requirements. In conventional cement systems, CS values often stabilize before 72 hours; the 15.5PPG intermediate tail systems containing cuttings showed that CS continued to build past 72 hours.

Rheological testing on the conventional intermediate tail systems and the 15.5PPG system with 25% cuttings appear to follow similar trends. Plastic viscosity for the conventional 15.2PPG, 16.2PPG, and 15.5PPG 25% cuttings systems were 134.7cP, 184.7cP, and 92.4cP with yield points being 83.8lbf/100ft^2, 24.3lbf/100ft^2, and 25.3lbf/100ft^2, respectively. The 25% cuttings system and 16.2PPG conventional system had similar yield points, but the plastic viscosity of the 25% cuttings system was less than half of the conventional 16.2PPG system, meaning that these two systems would require the same force to be pumped; plastic viscosity of the 25% cuttings system was less than half of the 16.2PPG conventional system. For the 15.5PPG system with 50% cuttings, a spike in shear stress readings at 60 and 100 RPMs is seen. Knowing that the cuttings are not homogenous, it is possible that the R1/B1 viscometer geometry is too thin and should be altered to account for larger particle sizes (Kulkarni et al., 2016). The 25% cuttings system had lower shear stress than the two conventional systems, while the 50% cuttings system had higher shear stress; this could be due to the water-solids ratio and slurry thickness.

Free fluid results on the conventional 15.2PPG, 16.2PPG, 15.5PPG with 25% cuttings, and 15.5PPG with 50% cuttings intermediate systems all met TRRC free water requirements and suggest that the water within the systems is promoting hydration. Neither the 25% cuttings system nor the 50% cuttings system showed striations or settling after sitting static for the two-hour test period. From the free fluid test, the 15.5PPG intermediate tail systems with cuttings are stable and yield homogeneous properties when placed downhole (DeBruijn & Whitton, 2021).

Future Work

While initial testing on Eagleford cuttings as an SCM proved promising, further testing and analysis need to be done to ensure the feasibility of the cuttings for use downhole. In regard to standard laboratory testing, fluid loss and static gel strength testing will be done to ensure that the system is fit to be pumped, prevent fluid migration, and maintain wellbore integrity over the life of the well. Crush testing on the systems will also be conducted to validate compressive strength results; due to the nature of the UCA algorithm, novel materials such as cuttings may fully or partially invalidate the algorithm and result in incorrect compressive strength readings. This could be especially prevalent in the samples containing 50% cuttings; while the UCA asserts that compressive strengths for the systems with 50% cuttings are below the TRRC regulatory standards, crush testing could prove otherwise.

Optical microscopy will be done on the samples containing various ratios of cuttings to analyze surface porosity and permeability. Scanning electron microscopy (SEM) will also be performed to determine whether microstructural differences are occurring in systems containing cuttings and ensure that hydration products are present and stable. Electron dispersive spectroscopy (EDS) will be conducted to understand any abnormalities or anomalies in the cuttings systems when compared to conventional cement systems.

Yard trials will be carried out to ensure that there are no issues mixing and blending the cement-cuttings systems and to ensure that all personnel are aware of any necessary safety measures. If successful, a field trial on the systems will be performed and monitored over time. Material compatibility, specifically regarding additives, should also be studied. Additives that work well in cementitious systems may not work as well or at all in the presence of cuttings, and understanding the severity of this is beneficial for future designs.

Conclusions

Utilization of Eagleford drill cuttings as supplementary cementitious material has been investigated to determine practicality in downhole barrier sheath systems. Results from the testing indicate the following:

- UCA results showed that the systems containing 25% cuttings had compressive strengths that met or exceeded TRRC requirements while the systems with 50% cuttings did not; this indicates that there is a limit to the amount of cuttings that can be used in the current surface and intermediate tail systems. Altering additive concentrations, densities, water-solid ratios, and cuttings composition could change this upper limit.
- The addition of cuttings on compressive strength needs to be further studied via crush testing to ensure accurate results. This should also be done on samples cured for various lengths of time to determine how the cuttings affect strength during the early hydration period and beyond.
- Both surface and intermediate systems containing cuttings showed minimal free water and met TRRC requirements. This could indicate that the cuttings promote hydration over time and barrier systems containing cuttings are stable under downhole conditions.
- Future work to continue understanding the effect that the cuttings have in wellbore barrier systems needs to be done to ensure that systems are feasible downhole material for the life of the well. In addition to lab testing, microscopy should be performed on both the cuttings and the barrier systems containing cuttings to understand composition and any compositional abnormalities within the cuttings, microstructure of the hardened systems, and any variable by-products formed during hydration of the barrier systems.

Replacement of cement with cuttings has a number of benefits both from a cost and environmental standpoint. While the state of Texas currently does not condone the use of filler material within the surface string barrier system, there is a case for the utilization of cuttings. Unlike other materials, cuttings originate from the same downhole environment in which they can be returned, thus making them a native material. TRRC regulations do not have any specifications on materials for the intermediate and production strings, meaning that cuttings could be used within barrier systems for these strings in the near future.

Utilizing cuttings within a wellbore barrier system reduces material and transportation costs needed to obtain materials; this, in turn, can also reduce emissions associated with various forms of transportation. As global population increases and industries look to meet net zero emissions, cement availability for use in wellbores may become more scarce; using a readily available material often thought of as a waste could prove even more advantageous over time.

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