# BORIDED TUBING SCANNING UTILIZING LASER TECHNOLOGY

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## INTRODUCTION

Borided tubing has become an essential component in the holistic design, operation, and chemical systems used to enhance run time in rod pump wells. The advantages of boronization, particularly its ability to significantly improve hardness and corrosion resistance of carbon steel and complement other system components to boost runtimes and production. The boriding process is critical for enhancing performance and improving economics by increasing pumping rates, extending runtimes, and moving failures from tubing to rods and pumps.

In the Bakken well design, borided tubing is a staple material selection. However, the cost of borided pipe necessitates strategies to maximize its reuse. Extending the lengths of borided tubing is vital in determining the optimal length required for each well to improve tubing failure rates.  In the Bakken, typical tubing failures in rod pumped wells occur at predictable depths and location in the tubing string; within the first 2000 ft above pump seat nipple and in the first joints above the borided tubing, respectively. Therefore, there is a sizable financial incentive to identify means to determine if borided pipe, typically considered junk i.e. green band (30% wall loss) or red band (+50% wall loss) by common scanning methods, can be reused. The combination of reused tubing and new installed pipe would increase the overall length of borided tubing, thereby, enhancing the probability of extending tubing run life.

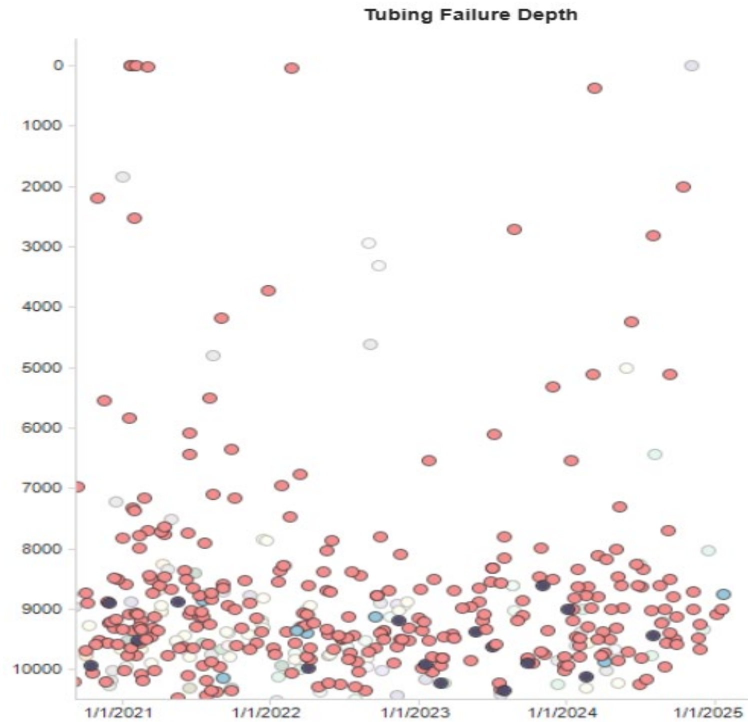


*Figure 1. Historical plot of tubing failure depths in ConocoPhillips Bakken rod pumped wells- pump set depth ~10,000. Pink/orange dots represent standard L80 tubing failure depths. Dark purple and light blue correspond to borided tubing failures.*

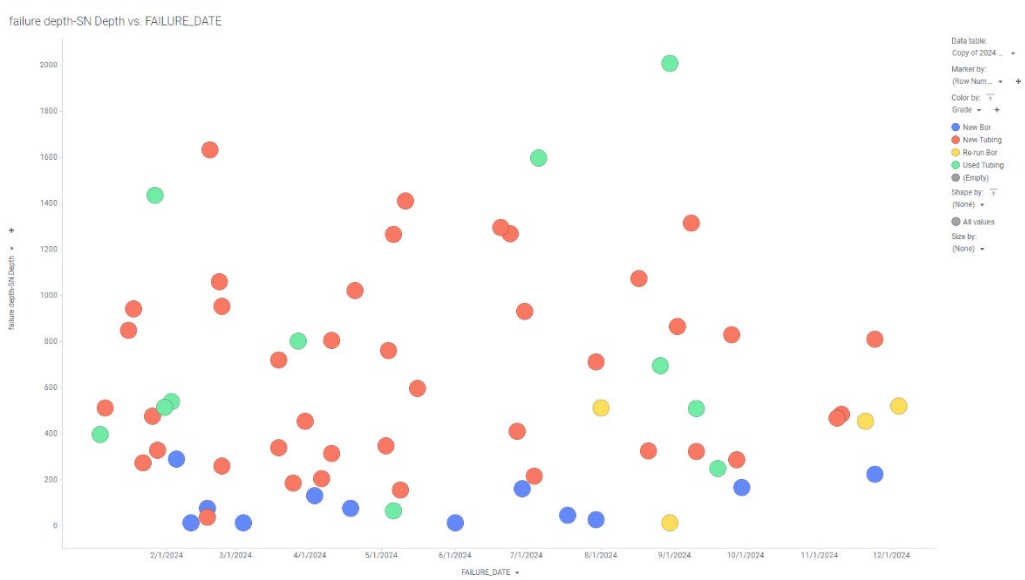


*Figure 2. Normalized failure depths relative to pump seat nipple in ConocoPhillips rod pumped - indicating that true problem area is not only TVD is a measure of higher risk areas for corrosion but wear but a 400' relative distance from SN proves to be most challenging section for tubing survival. Important to note that most common failed material is new and used L80 tubing.*

## BACKGROUND

Until 2023, ConocoPhillips relied exclusively on contactless Electromagnetic Inspection (EMI) scanning at the wellhead during tubing repairs to assess tubing quality. This method, as explored in this paper, has proven to be flawed for QA/QC purposes. To address this, ConocoPhillips Production Engineering partnered with Stress Engineering Services to introduce their laser scanning technology. Their high-resolution laser technology was utilized to scan the inner walls of over 200 joints of borided tubing joints from tubing repairs in the Bakken which were marked with significant wall loss and deemed junk (+30% wall loss per API 5D) by wellhead EMI. This paper will detail the exploration process, results, application, and impact of laser scanning borided tubing on tubing failures in the Bakken.

Initial pursuit of this project came from discovery work done in collaboration with Bluewater Thermal Solutions and Marathon Oil where caliper logs were conducted on borided tubing in a rod pump well. The results of the caliper logs were measured against traditional EMI wellhead scanning and determined that EMI scanning consistently measured higher wall loss readings. Ranges of the wall loss measurement discrepancies are shown in figure 3. Limitations of magnetic flux leakage testing on borided pipe are well known. The data obtained in this caliper study confirms that to determine the quality and integrity of borided pipe other means of measurement are required.

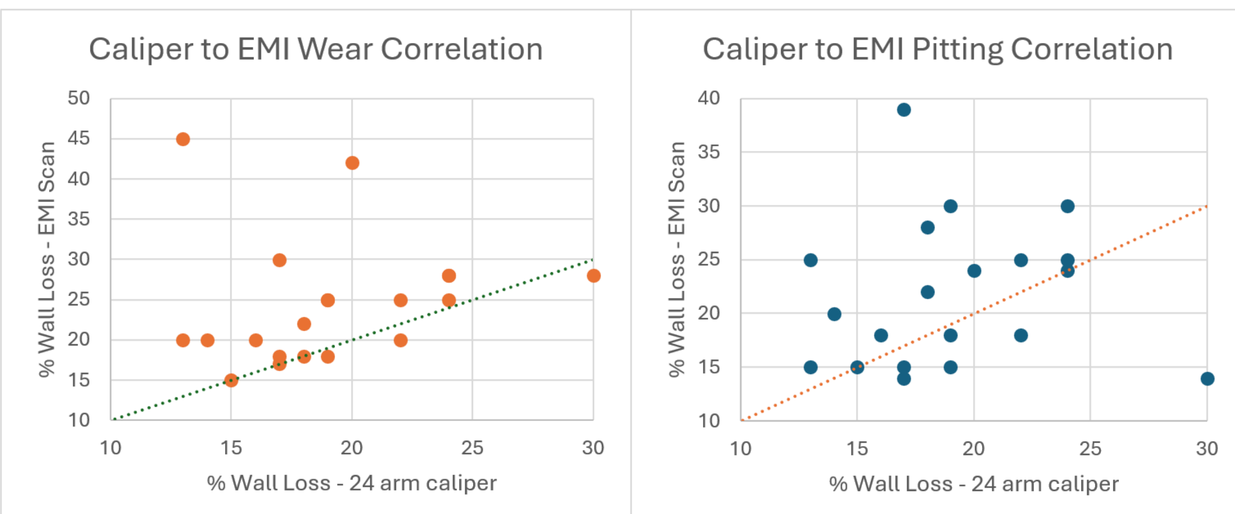


*Figure 3. Measurement discrepancies- values above the trendline indicate higher wall loss readings on EMI scanning relative to measurement acquired by caliper log. Data obtained by study conducted by Bluewater Thermal Solutions and heritage Marathon.*

While caliper logs provide accurate characterization of the bias of wall thickness measured by EMI scanning; a finer precision instrument is required to measure integrity of borided tubing. This necessitated the identification of high resolution, fit for purpose tools developed to precisely measure wall loss features in tubulars. Through discovery and collaboration with experts in the inspection field. ConocoPhillips determined that Stress Engineering Services' Laser Scanning System was the tool most fit for the high resolution and precision measurements needed for the internals of borided tubing. The specifications for the tool are provided in Figure 4. With the 5 micron resolution, this tool provides the granularity of resolution required to measure the integrity of the boride coating (20-200 microns).

**Specifications:**

- Axial Scan Resolution: Up to 0.004" (0.1mm) per increment
- Rotary Scan Resolution: Up to 0.004" (.1mm) per increment
- Sensor Resolution: 5 microns (0.00025")
- Sensor Linearity: 12 microns (0.0005")
- Laser Power: < 4 mW
- Laser Spot Size (max): 0.002" (0.05mm)
- Laser Power Classification: Class II
- Power: 110/240 VAC - 50/60 Hz
- Test Results Displayed: Contour view and Cross-Sectional

*Figure 4. Laser Scanner Specifications*

## METHODOLOGY

It is critical to note that all joints of borided tubing that were utilized in this study were marked green/red (>30% wall loss) band tubing by the wellhead EMI scanner and were to be junked. The trial was conducted in three phases with increasing scope to prove out the reliability and repeatability of the data acquired from the laser scanning equipment on larger scales in a shop and field setting.

| Phase | Quantity of Joints Scanned | Setting |
|---|---|---|
| 1 | 2 | Shop (Houston) |
| 2 | 38 | Shop (Houston) |
| 3 | 170 | Field (North Dakota) |

Table 1. Quantities of green/red band borided (+30/+50% wall loss) pipe scanned and location scanned

Due to the nature of the scanning technology relying on distance measurement utilizing laser transmitter and optical receiver internals of joints were rattled to provide a clean surface for the tool to pass through.  Once joints were prepped, the laser device tripped through the pipe at a rate of approximately 4 ft/min (~7 mins per joint). During the tripping period, the device’s rotating head, equipped with a mounted laser, operates at 300 rpm. It gathers axial measurements in 1/4-inch increments and radial measurement every 0.11 degrees, capturing 3600 data points per rotation with a resolution of 5 microns.  Once scanning was complete, Stress Engineering Service technicians process the data and generate a full report for each joint of tubing based on the deepest wall loss feature and quantity of features found during the scan. Tubing joints are then re-graded.

The regrading scale used is as follows:

| Wall Feature Loss % | Grade | Pass/Fail |
|---|---|---|
| ≤15 | Yellow | Pass |
| 15≤20 | Blue | Pass |
| >20 | Red | Fail |

Table 2. Quantities of green/red band borided (+30/+50% wall loss) pipe scanned and location scanned

## RESULTS

A total of 210 joints were scanned across three phases of the application, achieving a pass rate of 92%. For each joint where surface defects were identified, detailed images and heat maps of radial topographic wall loss were generated and documented for further analysis as shown in Figures 5,6 and 7.

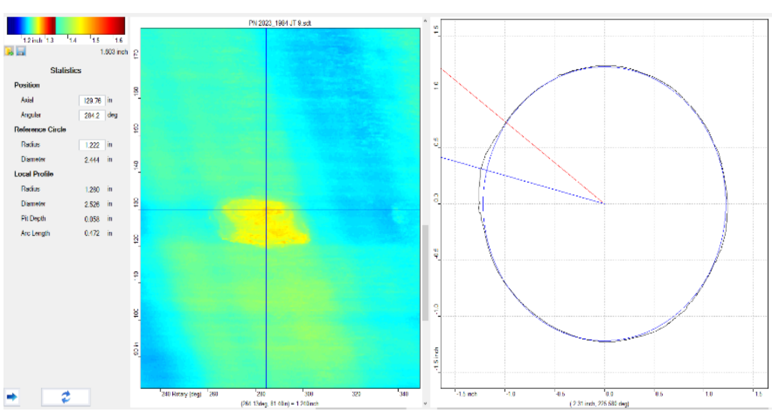

*Figure 5. Rod wear sample generated by image processing from laser scanning clearly showing rod wear at 9 o’clock position.*

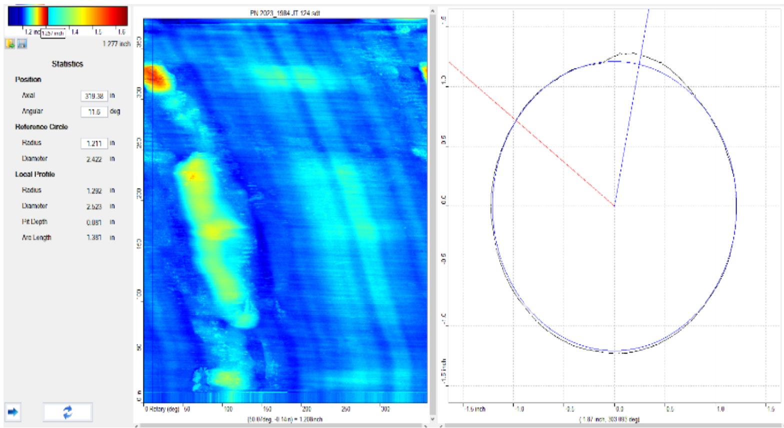


*Figure 6. Similar example of image generated by scanning tool showing more pronounced rod wear at 12 o'clock position.*

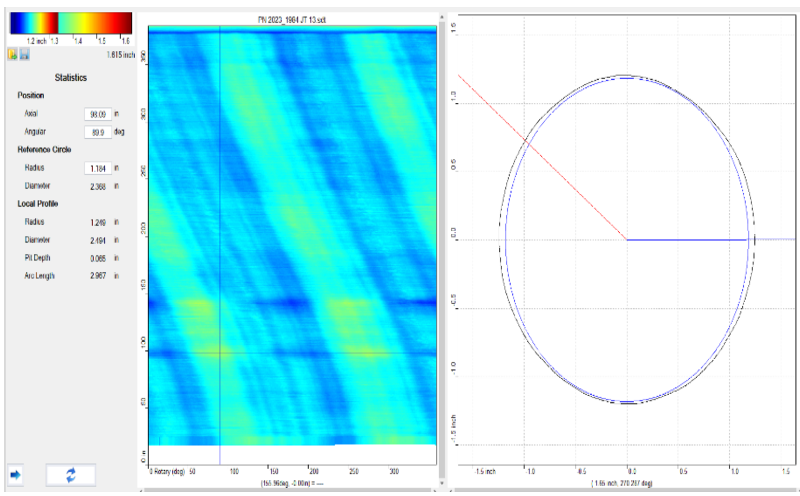


*Figure 7. Image from scanning tool demonstrating challenges in discerning ovality from wall loss.*

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Joints flagged as green/red (30 to +50% wall loss) during EMI scanning were predominantly found to be in usable condition, exhibiting minimal wall loss features. The initial two phases of inspection indicated that 90% of the tubing had no measurable surface defects. Random joints were segmented into 6-foot sections, and their internal diameters were visually inspected to qualitatively confirm wall loss. No significant thinning or wear was observed on the laser scanned joints.

Phase three revealed a notable increase in blue joints; however, the count of features remained minimal, with only 1-2 defects per joint of pipe. General corrosion and wall loss were predominantly localized, suggesting localized effects of compression, rod buckling, or deviation.

On samples where pits and wear were observed, the most common wear was identified in the middle of the pipe or near the upset, primarily manifesting as single channels of wear. The ovality arises from calibrating the tool to the nominal internal diameter of the pipe. Despite this calibration, it was readily determined from the rendered images whether the identified defects were related to the nominal differences.

Additional challenges encountered during the trial included areas where tubing was crimped or damaged, or where thread damage prevented the tool from drifting through the pipe. Furthermore, insufficiently cleaned surfaces and deposits of solids created shadows that hindered measurements. The tool was not originally designed to drift through 2 7/8” pipe and required modifications to do so, which imposed time delays in the scanning application.

Future improvements should focus on developing a tool housing specifically for 2 7/8” pipe to streamline the application and enhance reliability and efficiency. Stress Engineering provided corroborative data from borided tubing scans, which aligned with the findings from the ConocoPhillips scan study. Results in Table 3 of ConocoPhillips study are skewed high due to joint damage (i.e. crimping, thread damage, perforations, tool damage) adjusted pass rate is 92%.

| | **Total Joints Inspected** | Yellow (0 - 15%) | Blue (16 - 34%) | Red (35+%) |
|---|---|---|---|---|
| Job 1 | **146** | **105 (71.9%)** | **39 (26.7%)** | **16 (11.0%)** |
| ConocoPhillips | **170** | **71 (41.8%)** | **62 (36.5%)** | **37 (21.8%)** |
| Job 3 | **183** | **113 (61.7%)** | **54 (29.5%)** | **16 (8.7%)** |
| Sum | **499** | **289(53.7%)** | **155 (28.8%)** | **69 (12.8%)** |

Table 3. Results of Bakken field campaign conducted by Stress Engineering Services

## DISCUSSION

### Conclusion on EMI Scanning

The investigation concludes that Electromagnetic Inspection (EMI) is not a reliable method for determining the tubing grade quality of borided pipes. Data from a broader tubing scan study conducted by Stress Engineering Services and third-party operators opens broader questions to the basic differentiation of tubing grade based on EMI scanning results showing approximately 90% of borided pipe could be considered for re-use.

## Decision to Re-run Borided Tubing

Due to the inconsistency of results obtained from various phases of tubing scanning, EMI scanning has been deemed unreliable in ConocoPhillips' Bakken applications. Additionally, small scale laser scanning operations in the field are currently cost prohibitive. Consequently, ConocoPhillips has made a calculated decision to re-run all borided tubing, relying on visual inspection of pin ends and upset areas to identify any signs of wear or corrosion before re-running.  As a precaution, it is not recommended to utilize re-run borided tubing as blast joints. ConocoPhillips will still install joints of new tubing above pump seat nipple as this is the most aggressive section of tubing with respect to rod on tubing wear, fluid cut and corrosion.ك

## Blue Band Tubing

It is accepted that blue band tubing will have sections of the borided layer compromised. However, data from scans show minimal wall loss features, and most of the pipe's internal diameter still retains the borided layer. Partially compromised borided joints are proving to be more effective in wear and corrosion resistance than new/yellow bare tubing. The concerns of galvanic cell formation due to localized damage to borided coating are largely mitigated by formation of passivating scales (typically iron carbonate in Bakken conditions) and chemical treatment. Therefore, the benefits of corrosion mitigation and hardness are largely preserved in sections of reused borided joints.

## Re-use of Borided Tubing

Since 2023, reuse of borided tubing has significantly increased year over year, with current footage of borided tubing at approximately 120,000' in service. There has been no observed increase in tubing failure counts, although some failures have been noted in used borided tubing with an equivalent run life to last tubing pull. However, holes in tubing are still appearing in the first several joints above the borided section.ك

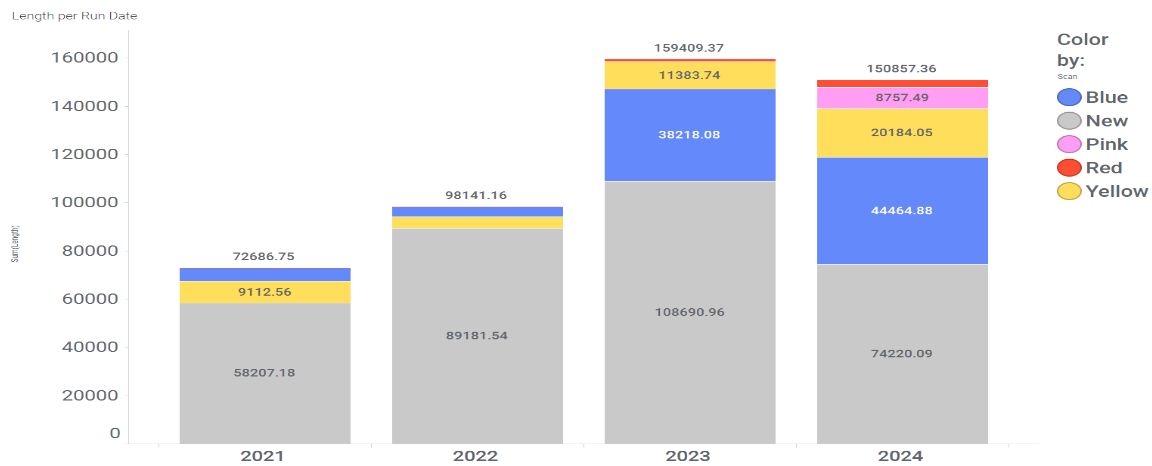


*Figure 8. Tubing tally data of total lengths of borided tubing installed in Bakken wells from 2021-2024 - showing significant growth in quantity of re-run tubing and reductions in quantity of new borided tubing run- note red/blue joints are typically used interchangeably in wellview configurations.*

## Tubing Failures in Wells

As mentioned in previous sections, wells may still experience tubing failures primarily in joints above borided tubing, however there are failures that have occurred at much lower frequency in the new and re-run borided sections of the tubing string. The objective is to stack borided tubing to optimize tubing design and enhance performance.

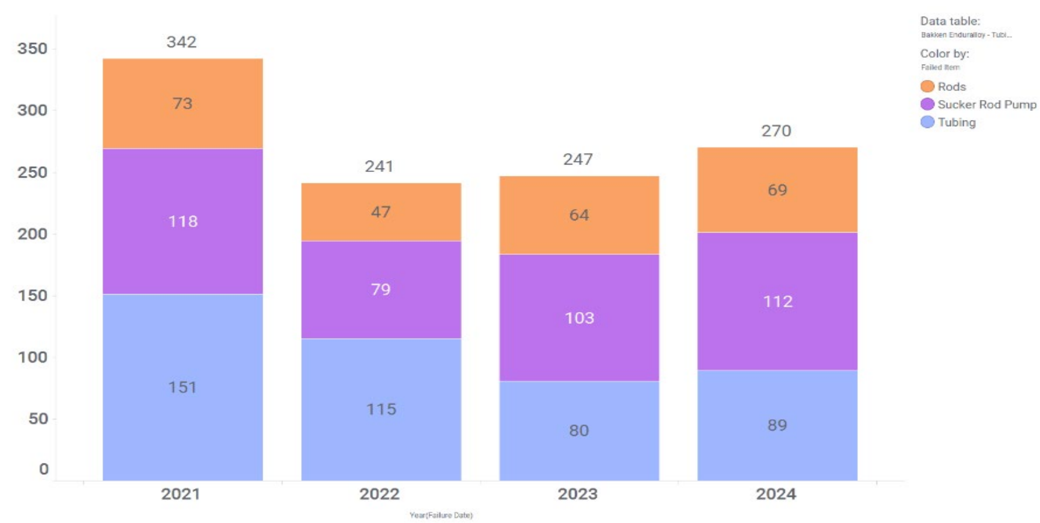


*Figure 9. Component failure trend from 2021-2024- note that tubing failure counts are on downward trend correlating with lengths of borided tubing run in wells- giving some lagging indication that tubing failure frequencies are decreasing.*

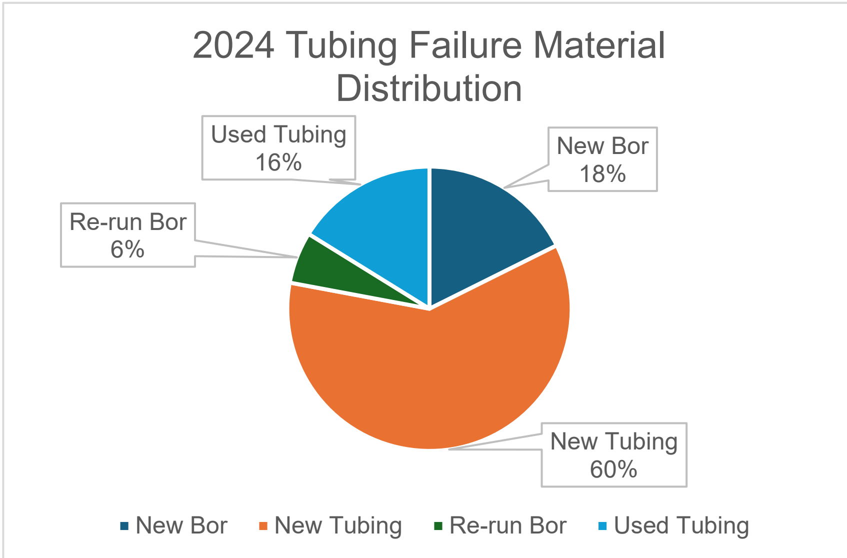


*Figure 10. Review of failed tubing components from 2024- note that new borided tubing is a more frequent failed component than newer tubing- emphasizing the challenging conditions of pipe joints withing 200-400' of pump seat nipple.*

### Aging Out Borided Tubing

ConocoPhillips has not yet established a definitive method or timeline for aging out certain joints of borided tubing. However, some guardrails have been implemented to discard joints of tubing that scan red twice. It is important to note that borided joints may scan differently between runs due to various issues discussed in the background section.

### Cost Savings

Significant cost savings are achieved by reducing the quantity of new tubing purchased, cutting section costs by approximately 50%, and stacking used joints on top. This approach optimizes resource utilization and minimizes expenses.

## CONCLUSION

In conclusion, the data obtained from Electromagnetic Inspection (EMI) scanning on borided tubing has shown to be unreliable and requires scrutiny for any grade identified from well scanning. This highlights the need for more accurate and dependable inspection methods.

Laser scanning technology stands out as a powerful tool, capable of fine measurements of wall losses down to a 5-micron resolution. Its application extends beyond borided layers to include epoxy coatings and other lined pipes, which provide effective corrosion and wear mitigation but cannot be measured accurately via Magnetic Flux Leakage (MFL) technology and similar methods.

However, several challenges hinder the widespread field application of laser scanning technology at scale. These include the inability to perform scanning onsite, the need for intensive surface preparation, and complex data processing requirements. Addressing these challenges is crucial for leveraging the full capabilities of laser scanning technology in tubular inspections.

Improvements are potentially in development, such as the addition of a second laser on the rotating mechanism and specifically designing a tool for 2 7/8” tubing. These advancements could enhance both the resolution and speed of laser scanning, making it a more viable option for field applications.

## AKNOWLEDGEMENTS

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