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TECHNOLOGICAL ADVANCES IN DRILLING EFFICIENCY AND SUSTAINABILITY IN THE PERMIAN BASIN

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ABSTRACT

Recent advancements in drilling technologies have significantly improved operational efficiency and sustainability in the Permian Basin, one of the world's most important oil and gas production hubs. Innovations such as the integration of digital systems, optimization of bottom hole assemblies (BHAs), and Managed Pressure Drilling (MPD) have contributed to faster well completions, reduced operational costs, and minimized environmental impact. A record-breaking well was completed using real-time data analysis and high-performance drilling equipment, demonstrating how automation and continuous monitoring optimize drilling parameters, enhance rate of penetration (ROP), and reduce non-productive time (NPT). The integration of predictive analytics and machine learning has further enabled dynamic adjustments, improving overall efficiency. The application of MPD in deep wells, particularly in the Wolfcamp D formation, has shown promising results, increasing ROP by 23.8% while lowering drilling fluid costs. Additionally, new approaches in directional drilling have reduced the need for multiple BHAs, streamlining operations and cutting expenses. Beyond drilling performance, water management remains a critical challenge in unconventional oil production. Studies have highlighted the need for sustainable water use, including the reuse of produced water to reduce freshwater consumption and environmental risks. Monitoring groundwater quality is essential to mitigate contamination risks from hydraulic fracturing. As demand for efficiency and sustainability grows, these innovations mark a significant step in unconventional well drilling. With continuous technological advancements, the Permian Basin is set to remain a leader in the oil and gas industry, establishing new benchmarks for future exploration and production.

Keywords: Drilling Efficiency. Managed Pressure Drilling (MPD). Predictive Analytics. Water Management. Sustainability.

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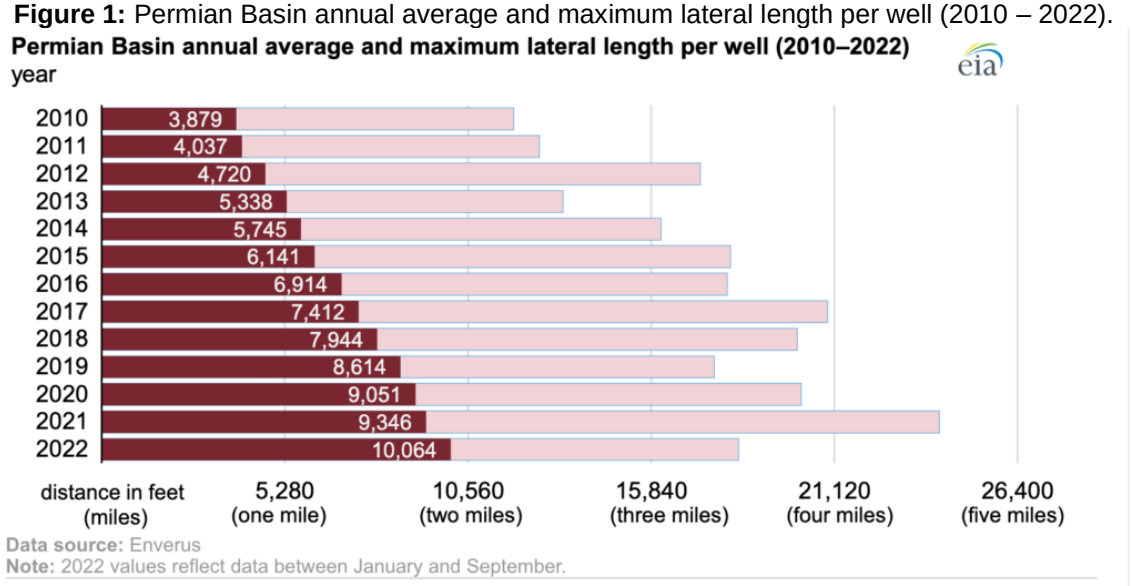
INTRODUCTION

The Permian Basin, located in West Texas, has long been one of the leading hubs for oil and gas production, recognized for its vast reserves and geologically complex formations. Recently, the region achieved a significant milestone in drilling efficiency, recording the fastest time to reach total depth (TD) for a conventional lateral well exceeding 5,000 feet. This progress highlights the continuous evolution of drilling technology and operational improvements in the oil and gas sector. Conventional lateral wells, which follow horizontal trajectories to access shale formations, face challenges such as the need for high precision in navigating complex geological layers. The adoption of advanced technologies, including rotary steerable systems (RSS), real-time monitoring, and automation, has been essential in overcoming these difficulties.

Figure 1: Permian Basin annual average and maximum lateral length per well (2010 – 2022).



Source: Enverus.

Breaking records, a recent well was completed using high-performance equipment and real-time data analysis. Automation and continuous monitoring played a crucial role in optimizing drilling parameters, ensuring operational efficiency, and reducing non-productive time (NPT). Additionally, advanced downhole tools and innovative drill bit designs enabled higher rates of penetration (ROP) without compromising well stability. A key factor in the success of this project was the integration of predictive analytics and machine learning, allowing for dynamic adjustments to drilling parameters based on collected data. This approach not only accelerated the process but also reduced costs and improved overall operational efficiency.

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This achievement represents a significant step toward maximizing the potential of unconventional resources in the region. The ability to drill conventional laterals to total depth in record time sets a new benchmark for future operations, especially in areas where efficient shale formation exploration is critical for production. With the continuous advancement of drilling technologies, further innovations are expected to enhance the speed and sustainability of oil and gas extraction in the Permian Basin and beyond.

Noel et al. (2023) introduced a major innovation in the region's drilling process, focusing on dogleg severity (DLS) and the long lateral sections required for exploration. Traditionally, drilling 8.5-inch wells requires two bottom hole assembly (BHA) setups: one for the curve and another for the lateral section, which increases costs, time, and operational risks. The proposed solution in the study enabled both phases to be completed in a single operation, enhancing efficiency and reducing expenses. Through proprietary digital modeling and dynamic drilling simulation, researchers evaluated design characteristics to optimize directional performance. Tests demonstrated that reducing the distance between the RSS actuators and the bit (L1) improved angle-building capability, trajectory control, and dogleg severity. The results were remarkable, with a faster curve section and an uninterrupted lateral completion. Moreover, the approach led to a 19% increase in footage drilled per day and a significant reduction in CO_2 emissions per well, reinforcing the solution's positive impact on operational sustainability.

Li et al. (2023) underscored the importance of drilling efficiency as a competitive differentiator in U.S. oilfields, emphasizing the need to minimize operational dysfunctions and maximize energy efficiency. Increasing rotation, flow, and weight on bit (WOB) often results in impacts and vibrations rather than improved drilling performance. To address this issue, researchers developed a closed-loop digital workflow based on proprietary sensors that capture detailed measurements of acceleration, torsional vibration, and rotation. This device, integrated directly into the drill bit without compromising BHA integrity, enables real-time data collection and analysis for precise digital modeling, optimizing design without reliance on trial and error. Initially applied in East Texas, the method resulted in a 69% increase in penetration rate, improved bit wear conditions, and a 67% reduction in local vibrations. In the Permian Basin, this approach boosted ROP by an average of 10%, overcoming traditional performance barriers and accelerating the development of optimized drill bits.

The growing challenges in produced water (PW) management and hydraulic fracturing water demands in the region were investigated by Scanlon et al. (2017), who

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examined the Permian Basin after it became the world's largest unconventional exploration field following the shale revolution. The study found that conventional wells generate approximately 13 times more water than oil, with this water typically reinjected for enhanced oil recovery. In contrast, unconventional horizontal wells, which require significantly larger water volumes for fracturing (10 to 16 times more per well between 2008 and 2015), have a lower water-to-oil ratio (3 versus 13 in conventional wells). However, this water cannot be reinjected into shale formations and must be disposed of in non-producing geological layers, potentially leading to overpressure and induced seismicity. The study suggests that reusing produced water with minimal treatment could meet fracturing demands and reduce reliance on new water sources, promoting more sustainable practices.

To address environmental concerns, Hildenbrand et al. (2016) assessed the long-term impact of unconventional oil and gas development (UD) on groundwater quality, filling a gap left by previous studies that did not consider temporal variations. Over 13 months, researchers analyzed water from 42 private wells in three Permian Basin counties, collecting samples at four distinct intervals to track changes as UD activities progressed. While some parameters remained stable, significant variations were observed in total organic carbon levels and pH, alongside occasional detection of compounds such as ethanol, bromide, and dichloromethane. The findings suggest that groundwater contamination can be transient, with substances appearing intermittently. The study underscores the need for continuous monitoring to better understand the environmental risks associated with hydraulic fracturing and horizontal drilling.

Cody et al. (2024) explored the innovative application of Managed Pressure Drilling (MPD) as an optimization technique in the Permian Basin, particularly for deeper wells in the Wolfcamp D formation. Traditionally used for early influx detection and control of over-pressurized zones, MPD has demonstrated potential for improving drilling efficiency by reducing conventional mud weights and compensating with surface-applied pressure. In Wolfcamp D, implementing this technique with a 2.5 ppg reduction in mud weight led to a 23.8% increase in penetration rate and a savings of 5.85 days per well. Additionally, lateral mud costs were reduced by 25% due to lower material requirements. MPD also enabled the execution of the curve and lateral sections in a single step, achieving a total drilling time of just 5.3 days until rig release. These results suggest that MPD could be crucial for the economic feasibility of deeper wells, enhancing environmental, social, and governance (ESG) metrics while ensuring more efficient operations in the Permian Basin.

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Recent advancements in drilling in the Permian Basin demonstrate how the combination of technological innovation, automation, and data analysis can transform operational efficiency in oil and gas exploration. The development of new techniques, such as the integration of digital systems, BHA optimization, and Managed Pressure Drilling (MPD), has not only reduced time and operational costs but also enabled a more sustainable approach by minimizing environmental impacts and maximizing resource utilization.

Moreover, studies on produced water management and environmental impacts highlight the importance of sustainable strategies to mitigate risks associated with hydraulic fracturing and aquifer contamination. The reuse of produced water and continuous water quality monitoring are essential measures to ensure the long-term viability of production in the region.

In the context of the growing demand for efficiency and sustainability in the oil and gas sector, the innovations discussed represent a milestone in the evolution of unconventional well drilling. As new technologies continue to be developed and implemented, the Permian Basin is expected to remain at the forefront of the industry, setting standards for future operations and solidifying its position as one of the world's leading energy production hubs.

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