

INTEGRATING PERMANENT MAGNET MOTORS AND POWER REGENERATIVE SYSTEMS ON LONG-STROKE PUMPING UNITS TO REDUCE ENERGY CONSUMPTION AND IMPROVE SAFETY

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1. INTRODUCTION

In today's energy landscape, companies are increasingly focused on improving operational efficiency, reducing environmental impact, and enhancing safety for personnel and equipment. As part of this push toward sustainability, Weatherford and two operators partnered to improve energy efficiency in rod-lift operations.

Weatherford, a global oilfield services and technology provider, contributes experience developing advanced artificial-lift solutions. The operators are focused on optimizing production while advancing more sustainable practices. This collaboration centers on retrofitting long-stroke pumping units with high-efficiency permanent magnet motors (PMMs) and power-regenerative systems (PRSi) to reduce energy consumption, improve system performance, and enhance safety.

The objective of this paper is to show how integrating PMMs with a power-regenerative variable speed drive on long stroke pumping units can improve the performance of existing rod-lift systems versus the use of conventional induction motors and standard drives. This technology enables better operating control, reduced energy waste, improved safety, and lower operating costs by modernizing existing infrastructure with advanced motor and drive capability.

2. OBJECTIVES OF THE PROJECT

The integration of long-stroke pumping units with high-efficiency PMMs and a power-regenerative variable speed drive was designed around core objectives that align with common sustainability, efficiency, and safety priorities.

1. **Enhanced energy efficiency.**

The primary goal was to improve energy efficiency across rod-lift systems. Compared with conventional induction motors, PMMs can deliver higher efficiency under the variable and often part-load conditions typical of pumping units. In addition, power regenerative systems capture and store excess energy (via ultracapacitors) and redistribute it during peak demand. Together, these technologies reduce power requirements and lower the overall energy footprint.

2. **Reduction of operating costs.**

Lower energy consumption and improved motor efficiency reduce operating costs. Because PMMs can be directly coupled to the gearbox high-speed shaft, belt wear is eliminated, which can reduce maintenance and component replacement. High torque density and precise control also support smoother operation and reduced mechanical stress, contributing to longer equipment life.

3. **Improved safety for personnel and equipment.**

The project aimed to reduce exposure to hazardous conditions by minimizing manual intervention. Direct-coupled PMMs reduce the number of moving components and can operate at lower temperatures, which helps prevent common motor failures. Reduced maintenance frequency keeps personnel farther from rotating equipment and other high-risk areas.

4. **Environmental responsibility and sustainable operations.**

By retrofitting pumping units with regenerative-drive technology and high-efficiency PMMs, operators can reduce emissions associated with electrical demand, reduce waste, and lower the number of maintenance visits. The project supports a broader shift toward more environmentally responsible production practices.

3. TECHNOLOGY OVERVIEW

This section summarizes the technologies used to integrate high-efficiency PMMs with the PRSi power-regenerative variable speed drive on long-stroke pumping units.

Together, these technologies form a closed-loop regenerative solution that captures excess energy during the pumping cycle and reuses it to reduce power consumption and improve operational performance.

3.1 Rotaflex Long-Stroke Pumping Units

The Rotaflex long-stroke pumping unit is a rod-lift surface system designed for deep, high-volume, and challenging wells where conventional beam units can experience high loads, poor pump fillage, or excessive wear. Its defining feature is a long, slow pump stroke that increases intake fill time and improves lifting performance.

Long-stroke, low-cycle advantage.

Rotaflex units operate with stroke lengths up to 421", significantly longer than conventional beam units. The extended stroke reduces cycle frequency while maintaining production rates, resulting in:

- 40 to 60% fewer reversals per day, reducing rod-on-tubing wear and downhole failures
- Improved pump fillage, especially in high-GOR or heavy-fluid wells
- Smoother rod loading due to near-constant velocity motion, lowering dynamic stresses

Energy efficiency characteristics.

The Rotaflex geometry and counterbalance system minimizes torque demand and improves efficiency:

- Mechanical design and efficient gear reducer can reduce power consumption by 20 to 40% versus conventional units
- Near-constant velocity motion lowers peak loads and required kW per stroke
- Large-stroke operation can enable earlier transition from higher-cost artificial lift systems (for example, ESPs)

By reducing mechanical stress and improving rod-string dynamics, Rotaflex systems can extend equipment life and improve production reliability.

3.2 Permanent Magnet Motors for Rod Lift Fundamentals

Permanent magnet motors differ from conventional induction motors by using embedded permanent magnets in the rotor. This design reduces rotor-current losses, lowers heat generation, and improves efficiency especially under the typical fluctuating loads of rod-lift systems. PMMs provide higher torque density and improved efficiency, supporting smooth torque delivery throughout the stroke profile.

Key attributes relevant to rod lift include:

- High efficiency across the full operating envelope, including low-speed operation.
- Minimal slip and reduced thermal losses, improving longevity of motor insulation and bearings.
- Superior speed and torque control, allowing the motor to respond quickly to load variations that occur during the upstroke and downstroke.
- Reduced mechanical stress on gearboxes and linkages due to smoother motor output.

These characteristics make PMMs well-suited to improving energy use and control precision when installed on existing rod-lift pumping systems.

3.3 Power-Regenerative VSD (PRSi) Architecture

PRSi is a regenerative-capable variable speed drive with an integrated ultracapacitor storage bank. Its closed-loop architecture captures regenerative energy produced during the pumping cycle and stores it locally rather than exporting it to the utility grid.

During downstroke deceleration, the rod string weight can assist motion and create regenerative energy. Conventional drives typically dissipate this energy as heat through braking resistors. In contrast, PRSi:

1. Captures this regenerative energy,
2. Stores it in ultracapacitors
3. Reuses it during the upstroke acceleration phase, when torque demand peaks.

This process stabilizes the power profile and reduces both instantaneous demand and total energy drawn from the grid or generator set.

Key benefits include:

- Reduced peak kW demand on utility or generator
- More efficient energy balancing between stroke cycles
- Cooler VSD operation due to elimination of braking resistors
- Improved electrical stability and lower mechanical wear

3.4 System Integration on Long-Stroke Pumping Units

Integrating PMMs and PRSi onto rod-lift pumping units requires coordinated mechanical, electrical, and control alignment. Installation is performed with minimal surface-unit modifications, preserving most of the operators existing infrastructure.

Mechanical integration.

- The PMM connects directly to the existing gearbox input shaft
- Higher starting torque and smoother acceleration reduce mechanical shock loads on the rod-string system.
- Lower motor heat output can improve gearbox temperature stability and lubricant life.

Electrical integration.

- The PRSi drive manages both power inversion and the ultracapacitor charge/discharge cycle.
- The system reduces heat load by eliminating braking resistors, which typically dissipate regenerative energy as heat in conventional drives.
- The ultracapacitor bank is sized to absorb full downstroke regenerative energy while maintaining high cycle life.

Control integration.

- Advanced algorithms coordinate the PMM torque profile with the capacitor energy flow to maintain cycle stability.
- The system improves control during acceleration and deceleration, producing smoother rod load profiles.

Together, PMM and PRSi integration converts a traditionally energy-dissipative rod-lift system into an energy-regenerative, high-efficiency artificial-lift asset. Field results show improved energy utilization, emissions-reduction potential, equipment performance, and operational safety.

4. METHODOLOGY

This section summarizes the methodology used to evaluate integration of PMMs and the PRSi power-regenerative variable speed drive with the Rotaflex long-stroke pumping unit performance. The goal was to quantify changes in energy consumption, power profile, operating performance, and safety relative to baseline rod-lift configurations.

4.1 Site Selection and Well Characteristics

Two field deployments were selected, one in the Bakken and one in the Permian Basin, to evaluate performance across similar well geometries, production conditions, and artificial-lift constraints.

Selection criteria included:

- Existing rod-lift installations where a PMM and PRSi system installation could be performed without major infrastructure changes.
- High power demand applications

- Wells that allowed comparison between baseline and post-installation conditions, including stable production trends and minimal operational disruptions during the measurement window

4.2 Installation Procedure

Installation included deploying a high-efficiency PMM and the PRSi regenerative VSD with ultracapacitor storage. These integrations were performed on Rotaflex units to leverage optimized geometry, high-load capability, and reduced cyclic reversals.

Steps included:

1. Equipment Installation
 - Mechanical alignment of a customized bracket and installation of the PMM
 - Electrical installation of the PRSi drive and protection systems.
 - Verification of unit geometry and settings for Rotaflex installations, leveraging its optimized long-stroke mechanism for energy and fillage efficiency.
2. Commissioning and Tuning
 - Calibration of torque limits, acceleration/deceleration ramps, and regen thresholds.
 - Validation of PRSi's closed-loop charge/discharge behavior to ensure ultracapacitors were capturing downstroke regenerative energy and reapplying it during the upstroke.
3. Post-installation Validation Period
 - A data collection window greater to the baseline period was used for accurate comparison.
 - Operator field teams confirmed stable conditions and absence of operational issues.

5. CASE STUDIES AND REAL RESULTS

5.1 Bakken - Koda Resources

This case compares performance from two wells. Well 1 is equipped with a long-stroke
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pumping unit paired with a PMM and a PRSi (AS3) variable speed drive. Well 2 uses the same long-stroke pumping unit but is driven by a standard induction motor and a conventional variable speed drive (A1000).

Although both wells are in close proximity, their operating durations are not identical. Figure 1 presents phase-A current measurements for both configurations, standard motor/VSD and PMM/PRSi.

Terminology used in this section:

- Standard VSD: **A1000**
- PRSi VSD: **AS3**

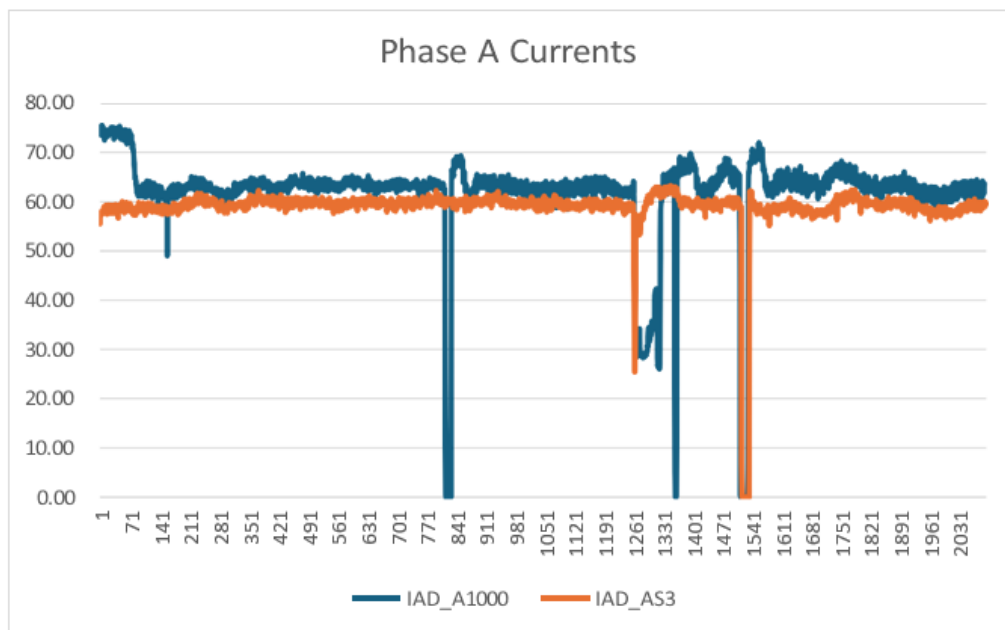


Figure 1. Phase-A current for A1000 and AS3 VSDs.

The phase-A current plot indicates several intervals during which both wells operated simultaneously. For consistency, the analysis was restricted to overlapping operating periods. Figure 2 highlights three distinct intervals during which both wells remained in steady operation, as indicated by relatively constant phase-A current.

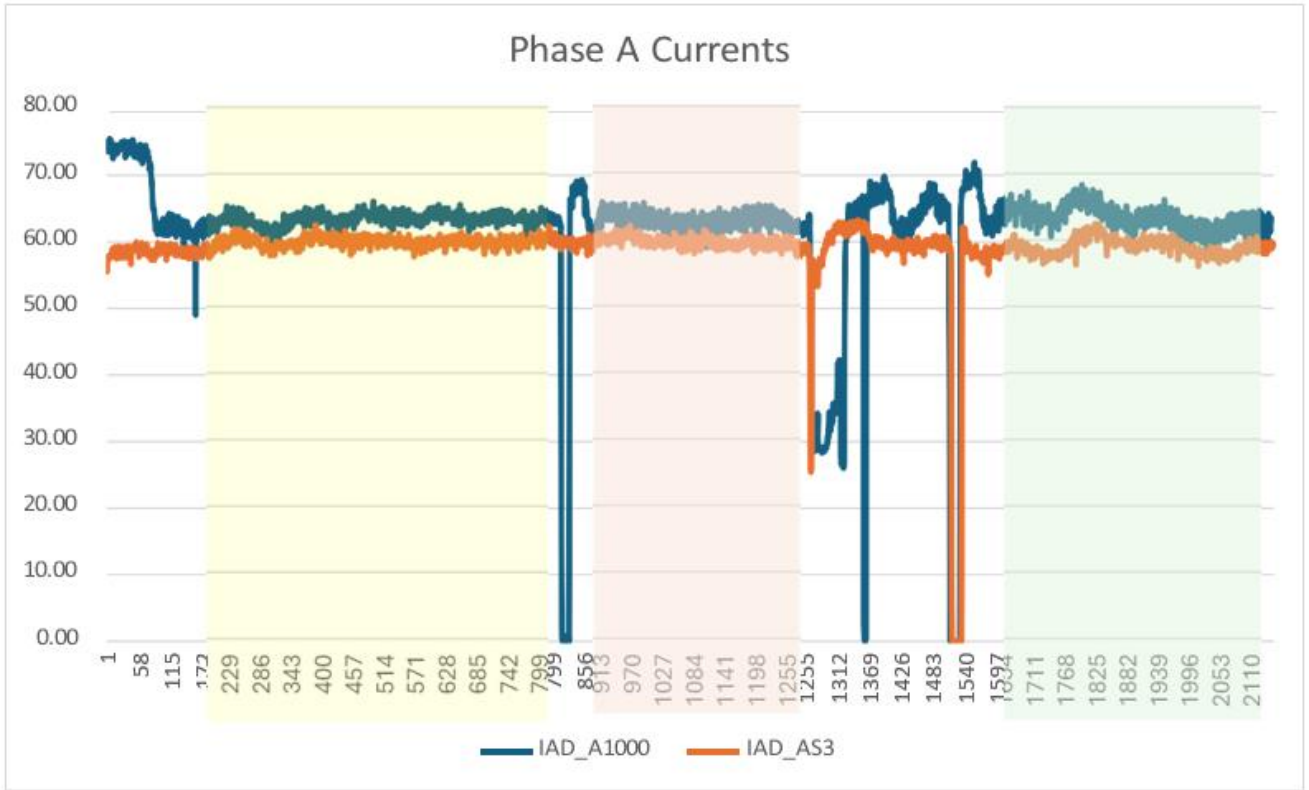


Figure 2. Periods during which both wells were stable and steady.

| | | |
|----------|-----------|-----------|
| Period 1 | 3/27/2025 | 3/31/2025 |
| Period 2 | 4/01/2025 | 4/03/2025 |
| Period 3 | 4/05/2025 | 4/09/2025 |

Production data

Tables 1 and 2 summarize production and energy consumption (kWh) for the three steady-state periods for both systems.

A1000 VSD

| | Oil | Gas | Water | Total | O&G | kWh |
|-----------|--------|--------|---------|---------|---------|---------|
| 3/27/2025 | 229.57 | 157.60 | 1617.50 | 2004.67 | 1847.07 | 5154.88 |
| 4/1/2025 | 193.61 | 90.64 | 647.75 | 932.00 | 841.36 | 2839.70 |
| 4/5/2025 | 180.57 | 122.78 | 938.95 | 1242.30 | 1119.52 | 3953.51 |

Table 1. Production and kWh consumption (A1000).

AS3 VSD (PRSi)

| | Oil | Gas | Water | Total | O&G | kWh |
|-----------|--------|--------|---------|---------|---------|---------|
| 3/27/2025 | 263.57 | 437.27 | 2304.53 | 3005.36 | 2568.09 | 4882.09 |
| 4/1/2025 | 182.55 | 283.27 | 1449.37 | 1915.19 | 1631.92 | 2696.31 |
| 4/5/2025 | 306.52 | 489.54 | 2311.81 | 3107.87 | 2618.33 | 3678.11 |

Table 2. Production and kWh consumption (AS3/PRSi).

Performance analysis.

Table 3 presents kWh consumption by production category. Across all categories, the PMM/PRSi configuration shows lower energy consumption than the standard induction motor/VSD configuration.

| | | kWh/Oil | kWh/Gas | kWh/Water | kWh/Total | kWh/O&G |
|----------|----------|---------|---------|-----------|-----------|---------|
| Period 1 | A1000 | 22.455 | 32.709 | 3.187 | 2.571 | 2.791 |
| | AS3/PRSi | 18.523 | 11.165 | 2.118 | 1.624 | 1.901 |
| Period 2 | A1000 | 14.667 | 31.329 | 4.384 | 3.047 | 3.375 |
| | AS3/PRSi | 14.770 | 9.519 | 1.860 | 1.408 | 1.652 |
| Period 3 | A1000 | 21.895 | 32.200 | 4.211 | 3.531 | 3.531 |
| | AS3/PRSi | 11.999 | 7.513 | 1.591 | 1.183 | 1.405 |

Table 3. kWh consumption by production category.

Based on these results, the PMM/PRSi system operates more efficiently than the standard induction motor/VSD system. Table 4 summarizes the average efficiency gain achieved by the PRSi/PMM configuration relative to the standard motor/VSD setup.

| | kWh/Oil | kWh/Gas | kWh/Water | kWh/Total | kWh/O&G |
|--------------------------|----------------|----------------|------------------|------------------|--------------------|
| Standard motor/VSD | 19.672 | 32.079 | 3.927 | 3.050 | 3.232 |
| PMM/PRSi | 15.098 | 9.399 | 1.857 | 1.405 | 1.653 |
| PMM/PRSi efficiency gain | 23.25% | 70.70% | 52.72% | 53.92% | 48.87% |

Table 4. Average efficiency gain from PMM/PRSi use.

To isolate the efficiency improvement attributable to PRSi, two power meters (SEL-849) were installed in the VSD cabinet: one on the input side and one on the output side.

Measurements during overlapping operating periods showed 29% higher energy at the output than at the input. This difference represents energy supplied from regenerative energy stored in the ultracapacitor bank rather than drawn from the grid.

If the PRSi system accounts for approximately 29% of the total energy savings, the remaining improvement (about 20%) is attributable to the PMM.

5.2 Permian - New Mexico Operator

For the Permian case, a different approach was applied. Using the same power meter deployed in the Bakken analysis (SEL-849), measurements showed that the energy at the VSD output was 17% higher than the energy at the input. As with the previous case, this efficiency gain is attributed to the PRSi system's ability to store and reuse regenerative energy through the supercapacitor bank.

This gain is observed after accounting for the continuous cooling-fan power requirement associated with the PMM, which is estimated to reduce overall efficiency by approximately 1%. Additionally, the 17% figure does not include the expected internal VSD energy-loss factor, assumed to be roughly 2%. When these factors are included and compared against a conventional VSD, the total PRSi-related efficiency

improvement approaches 20%.

Furthermore, as previously discussed, the 17% regenerative-energy gain does not account for the efficiency improvement delivered by the PMM itself. Based on the Bakken measurements, the PMM contributes an additional ~20% efficiency improvement. Therefore, the combined system efficiency gain is approximately 37% when excluding cooling-fan and VSD loss factors, and roughly 40% when these factors are included.

Data analysis

Meter data was downloaded by the field support team and graphed in Excel. This report reflects data available during the site visit; the meters continue recording, and data files can be downloaded in the future as needed.

Figure 3 shows the PRSi VSD input and output kWh trends. Because regenerative energy is stored and reused, input kWh is lower than output kWh; the positive difference between output and input reflects reuse of energy that would otherwise be wasted.

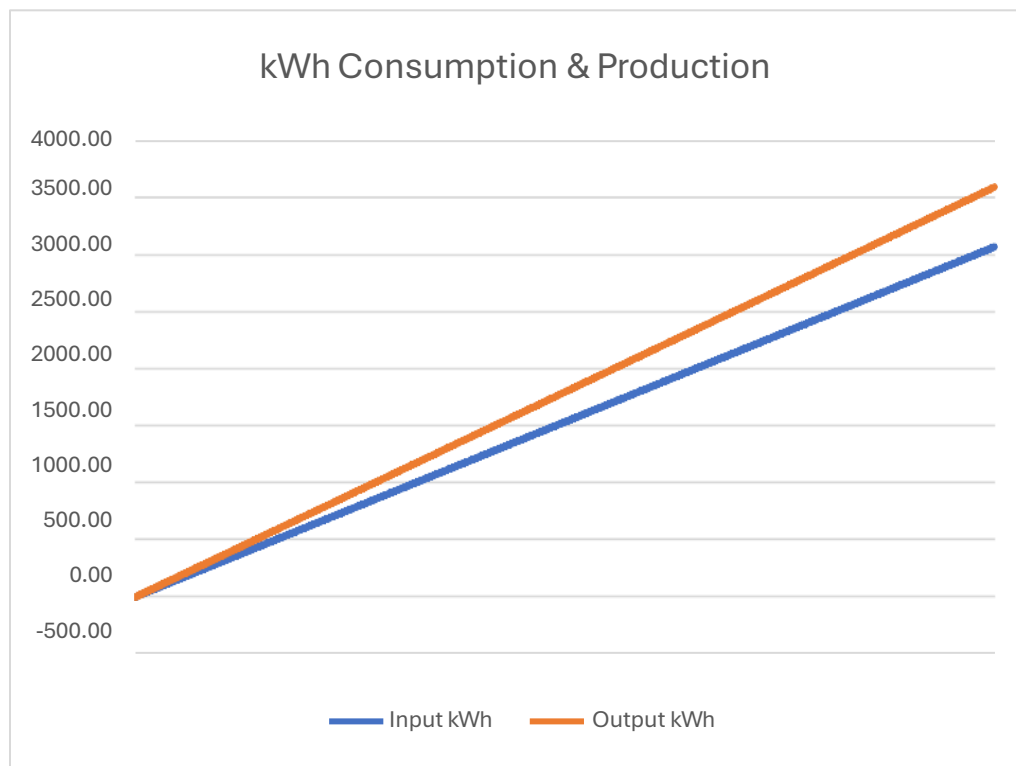


Figure 3 Input and Output kWh trend

6 Conclusions

The integration of Permanent Magnet Motors (PMMs), the Power Regenerative PRSi Variable Speed Drive (VSD), and long-stroke pumping technologies such as the Rotaflex® unit have demonstrated a transformative impact on rod-lift performance, energy efficiency, and operational safety across multiple field deployments. The combined system successfully converts traditionally energy-dissipative rod-lift equipment into a high-efficiency, regenerative artificial-lift solution.

Field results from two independent operators confirm substantial reductions in power consumption, including up to 49% energy reduction in the Bakken and 37% reduction in the Permian. These improvements translate directly into meaningful emissions reductions, with the Bakken deployment achieving an estimated 106,230 kg of CO₂ avoided annually through decreased electrical demand. Such reductions highlight the measurable environmental benefits of applying regenerative-drive and high-efficiency motor technology to existing rod-lift assets.

The PRSi system's closed-loop regenerative architecture, enabled by ultracapacitor energy storage, provides a critical advantage over traditional regenerative drives by capturing and reusing downstroke energy without exporting it to the electrical grid. This unique design makes the technology suitable not only for grid-connected wells but also for remote or genset-powered sites, expanding the applicability of regenerative artificial lift.

The integration of PMMs enhances the system's overall efficiency through higher torque density, reduced thermal losses, and improved low-speed performance—key factors for the cyclic loading profile of rod-lift systems. Similarly, the Rotaflex® long-stroke pumping unit contributes mechanical efficiency gains through longer stroke lengths, reduced cyclic reversals, improved pump fillage, and lower torque demand, supporting deeper, high-volume, and problematic wells. These mechanical advantages create a highly compatible operating environment for regenerative drives.

Beyond energy performance, the PMM + PRSi + Rotaflex integration delivered tangible safety improvements. The directly coupled (beltless) feature reduced maintenance requirements and enhanced overall safety by helping keep personnel out of high-risk zones and minimized exposure to hazardous rotating equipment. Additional Rotaflex

safety features—such as platform access, protective enclosures, and the hydraulic rollback system—further supported safer operations.

Overall, this study demonstrates that significant efficiency and safety benefits can be realized by retrofitting existing rod-lift installations with advanced motor, regeneration, and long-stroke pumping technologies. The results support a broader industry shift toward sustainable, energy-optimized artificial lift, delivering measurable economic value through lower power consumption, reduced equipment wear and maintenance, extended component life, and fewer operational disruptions.

The field-validated outcomes presented in this paper establish a clear pathway for operators seeking to modernize rod-lift assets and achieve meaningful progress in energy reduction, ESG performance, and operational reliability. The technology stack evaluated here represents a viable and scalable solution for elevating rod-lift efficiency across diverse production environments.