A NEW PRODUCTION PARADIGM: APPLIED MULTI-PHASE PNEUMATIC LIFT (AMPL)

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ABSTRACT

Unconventional oil and gas wells are inherently multiphase from the onset of production, yet artificial lift strategies are frequently deployed reactively and without explicit consideration of the pneumatic contribution of produced gas. These disconnects result in deferred optimization, accelerated decline, and, in many cases, permanent loss of recoverable hydrocarbons. The impacts are magnified under conditions of commodity price volatility, where early production performance strongly influences economic resilience.

This paper introduces Applied Multi-Phase Pneumatic Lift (AMPL), a life-of-well production methodology that integrates multiphase flow physics, nodal analysis, real-time surveillance, and adaptive artificial lift strategies from flowback through abandonment. AMPL reframes produced and injected gas as an operational asset, leveraging its pneumatic energy to reduce hydrostatic gradients, stabilize flow regimes, enhance liquid transport, and enable seamless transitions between natural flow, gas-assisted flow, continuous gas lift where applicable, plunger-assisted gas lift (PAGL/GAPL), velocity strings, and conventional plunger lift.

Quantitative economic scenarios demonstrate how delayed lift intervention results in irreversible value loss, even when subsequent optimization is applied. Case examples from the Eagle Ford and Marcellus plays illustrate improvements and opportunities in drawdown preservation, cumulative production, and operating efficiency achieved through early and continuous application of AMPL. The paper further describes how AMPL supports increasing industry demands for autonomous well operations and reduced engineering workload through a managed service delivery model.

INTRODUCTION

The rapid expansion of unconventional resource development has fundamentally altered well production behavior. Horizontal wells with multi-stage hydraulic fracturing typically exhibit high initial rates followed by steep declines, rapidly evolving gas-liquid ratios (GLR), and dynamic flowing pressures. Despite these realities, artificial lift planning often remains reactive—implemented only after production degradation or operational failures become apparent.

Historically, wells were classified as either oil or gas producers, with artificial lift systems selected accordingly. In unconventional developments, however, these distinctions are less useful, and adhering to them can result in significant production losses, operational complications, and other problems. Liquids-rich wells frequently produce large volumes of formation gas, while gas-dominant wells often produce water as the primary liquid phase and remain highly sensitive to liquid loading. Treating produced gas as a complication rather than a lifting asset results in sub-optimal production strategies. Furthermore, in liquids-rich plays there is often a focus on GOR with little mention of water cut, yet removing all liquids means the focus should shift to GLR as well as incorporate the gas fraction. This is another strong driver of the proposed multi-phase flow approach.

As operators face sustained capital discipline due to volatile oil and gas prices, preserving early-time production and maintaining long-term deliverability are critical. Delayed or inappropriate lift decisions are no longer merely operational inefficiencies—they represent material economic risk.

LIFE-OF-WELL

The life-of-well framework provides the foundation for building integrated systems of engineering processes to optimize hydrocarbon extraction from sandface to sales point and from cradle to grave. Traditional presentations relating to the life-of-well conundrum tend to focus on the artificial lift methods available and the literature contains many examples of new and novel lift methods with accompanying data that proves the presented method is effective. A deeper look at the data very often shows wells that have been under-produced for some time before the selected method is applied, leaving the question of timing of intervention unasked. This paper is less focused on the suitability of any specific artificial lift technology, but rather examines the question of timing and the benefits of a first principles approach to address the gaps that commonly remain between initial intervention and subsequent changes to different artificial lift methods over the well's life. Applying first principles engineering of reservoir, production, and midstream functions provides a blueprint with the following outputs:

- Forecasts
- Plans and Schedules
- Budgets
- Ownership / management
- Risk profiles

The life-of-well approach is proactive and should not increase net work but rather shift work forward in time and from operational to technical staff. Applying forward thinking and tools such as predictive modeling enable on-time intervention and result in improved adherence to forecasts, better efficiency, and higher cash flow while reducing downtime. resource load, and operational stress.

Figure 1 illustrates a generic life-of-well plot of production versus time and corresponding artificial lift methods that may be considered. This presents a typical list of options that may be available at any time in the well's history, but it leaves open the question of not only what options are best at any given point in time, but what the actual timing should be. One common thread that provides a large opportunity for improvement is ongoing monitoring and optimization.

The actual selected artificial lift methods used are often determined by:
- Traditional practices
- Limitations of energy input sources (e.g. gas for injection, electric power)
- Ease of application and operation
- Personal preferences of engineering or operations staff

The timing of any given intervention may be determined by:
- Established SOP's
- Reacting to observed production losses associated with liquid loading
- Resource availability (physical and financial)
- Engineering and operations staff skillset and availability
- Budget timing
- A planned and integrated multi-phase approach to each well and multi-discipline approach across the organization.

ECONOMIC IMPACT OF DELAYED LIFT INTERVENTION

Production Forecast Focus

Unconventional well production expectations are strongly forecast-focused. However, in the event bottom-hole flowing pressures increase due to liquid loading or inefficient liquid removal, fracture contribution and effective drainage area may be permanently reduced. Subsequent lift optimization cannot fully recover the lost drawdown. Even delayed recovery in any given period must be considered for its potential to defer that production to the end of the well life. This puts that volume, or some significant portion at risk by pushing it out to an economically non-viable rate, and therefore must be treated as a terminal loss.

Quantitative Economic Scenario

Table 1 illustrates a simplified economic comparison between early AMPL deployment and delayed lift intervention for a representative liquids-rich unconventional well. The delayed lift case assumes no artificial lift in months 6-12 and a 50% reduction in produced oil over this period. Even when lift is eventually optimized, the delayed case exhibits permanently lower cumulative production and net present value.

LIFT EVOLUTION THROUGHOUT LIFE-OF-WELL

Artificial lift selection should be dictated by wellbore geometry, reservoir fluids, production rates, pressures, and other parameters through the life-of-well. Horizontal wells in rapidly declining unconventional reservoirs often render conventional mechanical lift methods sub-optimal, particularly if formation gas is present in any appreciable volume. In these scenarios, pneumatic methods are recognized as optimal solutions.

Liquids-Rich Oil Wells With Significant Formation Gas (Permian / Delaware / Eagle Ford)

- Natural flow including associated gas-assisted flow during early drawdown
- Early deployment of continuous gas lift to stabilize flow regimes
- Transition to PAGL or GAPL as rates decline
- Late-life plunger lift where appropriate (GLR-dependent)
- Other late-life methods such as rod pumping or GALLOP

Gas-Dominant Wells with Water Production (Marcellus / Utica)

In dry- and wet-gas shale plays such as the Marcellus and Utica, water is typically the dominant liquid phase. Common practice—particularly at CNX Resources—reflects this reality:

- Initial natural flow up casing
- Installation of a capillary string for continuous foamer injection
- Transition to tubing installation as a velocity string to maintain critical gas velocity
- Implementation of plunger lift for intermittent liquid removal

Gas lift is generally not applied in these systems due to already high gas–liquid ratios. AMPL explicitly accommodates this lift pathway, emphasizing early liquid management and drawdown preservation.

MULTIPHASE FLOW REALITY AND THE PNEUMATIC COMPONENT

From initial flowback onward, unconventional wells operate as multiphase systems containing gas and liquids. The presence of free gas immediately introduces a pneumatic component that influences fluid density, pressure gradients, and flow stability.

Vertical and deviated wellbores exhibit distinct multiphase flow regimes (for example, dispersed bubble, slug, annular and mist, amongst others) each with different implications for artificial lift performance. Furthermore, these phases often exist simultaneously at different depths in a well due to the compression of the gas phase with higher pressures at depth versus lower pressures at surface, and the nature of these phases is also different in vertical versus inclined sections of tubing. Understanding these flow regimes early in the operating life and more importantly, predicting with reasonable certainty the point in time when the flow patterns are expected to shift to a sub-optimal condition, opens up opportunities to better and more responsibly manage these assets. Going forward into each stage of production, ongoing modeling and assessment allows the operator to stay ahead of these known and expected upset conditions which will contribute to inefficient liquid removal or liquid loading if left unaddressed.

AMPL begins with the explicit recognition that produced gas is a manageable and controllable source of lifting energy. Whether through natural expansion, chemicalassisted micro-bubble formation, continuous gas injection, or plunger assist, pneumatic energy which is present throughout the productive life of the well should be managed intentionally to approach optimal results.

APPLIED MULTI-PHASE PNEUMATIC LIFT (AMPL)

AMPL is a life-of-well production framework that integrates physics-based modeling, real-time surveillance, and adaptive operations. Rather than deploying artificial lift as a discrete event, AMPL manages lift as an evolving process aligned with reservoir depletion and changing flow behavior. The first step in this process is understanding and predicting well behavior under various producing scenarios.

Key AMPL elements include:

- Explicit understanding of multiphase flow and implied flowing bottomhole pressure management options (e.g. gathering system, chokes, surface systems, artificial lift).
- Large data set surveillance and longer term trending
- Ongoing periodic nodal analysis linking inflow and outflow, assessing effectiveness of then-current processes and updating predictions for off-trend well behaviors
- Routinely updating planned lift transitions as defined by technical assessments and refined by non-technical considerations to produce a dynamic and evolving implementation plan
- Real-time optimization of any operating lift technology supported by high-frequency surveillance data

NODAL ANALYSIS AS A ROUTINE OPTIMIZATION TOOL

In AMPL, nodal analysis is not a static design step but a recurring operational process. Real-time pressure and rate data are used to continuously reconcile inflow performance (IPR) and vertical lift performance (VLP).

By intentionally shifting the VLP curve through appropriate pneumatic mechanisms—whether natural gas expansion over the depth of the well, foamer-assisted flow, gas injection or plunger timing—AMPL aims to preserve drawdown and maintain adherence to forecasts.

AMPL in practice increases the frequency of nodal analysis, RTA and other physics-based modeling methods. The result is a more dynamic view of how a given well is performing from a fluid dynamics and reservoir standpoint at any point in time, and using this to guide the appropriate intervention. More importantly, it is the power of these tools when used in a predictive manner that informs the timing of subsequent interventions that avoids short-term production losses and longer term terminal losses.

CASE STUDY #1 – EAGLE FORD

Case Study Well #1 illustrates two lost opportunities due to late gas lift initiation, missed PAGL optimization and resulting underperformance. The well information was supplied by an operator that requested to remain anonymous. Monthly information was supplied and then decline analysis was applied to the data.

Reference Figure 2:

Period A: 2024Jan – 2024Jul
2024Jan: Observed liquid loading and production losses ~2,280 bbl oil.
2024Jun: Initiated gas lift, restored production to trend
Economic impact valued at -$192,000.

Period B: 2024Sep – 2026Feb
2024Sep24: Initiated Gas Assist Plunger Lift, restored production to trend
2024Q4: Observe modest underperformance
2025-2026: Observe underperformance and missed optimization opportunity of ~4,660 bbl oil.
Economic impact valued at -$391,000

Total Economic impact for both periods valued at -$583,000 with 6940 bbl oil lost.

CASE STUDY #2 – APPALACHIAN BASIN - MARCELLUS SHALE

CNX Resources has observed that delayed liquid management in Marcellus gas wells leads to persistent deliverability loss. Wells allowed to cycle through unstable liquid loading regimes often fail to recover even after corrective action.

Initial production methods included only casing flow, tubing flow, and plunger lift. During casing flow, liquid loading begins at significant production rates. Installing tubing ahead of liquid loading would result in production losses due to friction up the reduced internal diameter. As a result, observing unstable (slug) flow became normal.

Foamer injection through capillary string was introduced at CNX in 2022. As proof of concept, initial candidates were selected well after the onset of liquid loading and were chosen for uplift potential and due to tubing installation logistical delays.

Case Study Well #2 illustrates outdated thinking via both late capillary string installation and early tubing installation.

Reference Figure 3:

Period A: 2022Nov – 2023Oct
2022Nov13: Observed liquid loading and lost production below 9500 MCFD
2023Feb08: Frac hit (shaded grey)
2023Mar07: Frac hit
2023Apr28: RTP, rate quickly below critical
2023Oct19: Install capillary string and initiate foamer, returned rate to potential
Economic impact: Excluding lost production from frac hit, lost 240MMCF valued at $601M

Period B: 2024Oct – 2025Mar

2024Sep30: Pull capillary string, install 2-7/8” tubing, fell 800 MCFD below potential, sustained lost production through 2026Mar
Economic Impact: Excluding capital, as only timing is changed, lost 241MMCF valued at $603M

CASE STUDY #3 – APPALACHIAN BASIN - MARCELLUS SHALE

CNX current production methods have evolved into (1) casing flow, (2) capillary string placed foamer, (3a) velocity strings (tubing), (3b) velocity strings with sliding sleeves to enable annular flow when prudent, and (4) plunger lift. AMPL-aligned early deployment of capillary string foamer injection, delayed tubing installation, and on-time, optimized plunger control target optimal production and revenue streams. Legible downstream effects include reductions in downtime, intervention risk, and operation workload.

Reference Figure 4:

Period A: 2025Dec – current (2026Mar)

Production engineering predicted liquid loading up 5-1/2” casing @ 400 psi of 6020 MCFD and planned early intervention ahead of harsh winter conditions
2025Nov15: Initial observations of liquid loading at 8200 MCFD with no gas rate loss
2025Dec05: Installed capillary string and initiated foamer injection, immediate increase in water production, maintained potential gas rate

To optimize the transition from foam flow to tubing flow, a next step is application of both empirical and theoretical approaches to understand foam capabilities, build predictive tools, and incorporate into the AMPL methodology.

MORE FREQUENT AND REAL-TIME SURVEILLANCE AND AUTONOMOUS OPERATIONS

AMPL supports the industry’s transition toward more autonomous well operations by integrating regular periodic historic well performance assessments, real-time high-frequency surveillance, rules-based controls, and physics-informed optimization for each well in an asset. Engineers and operators adopt sequential operating strategies utilizing pre-planned alternatives in a proactive manner designed to minimize or eliminate costly downtime or periods of underperformance. This is a distinct change from typical management by exception or reactive intervention, improving scalability across large well inventories. A “Life of Well” strategy can be created with a goal of always remaining on curve as the well progresses though drawdown.
Although the focus here so far is very much on the “Life of Well” for each well individually, no well is operated in isolation from other wells in the asset, nor from the reservoir more broadly, nor the gathering system. This implies some added challenges, but also points out even greater opportunity when applied in a holistic sense. Understanding the physics

underlying conditions in a well at every step along the decline and establishing models to reliably predict the reaction to changes in reservoir pressures as well as downstream flows and pressures allows for the creation of larger models that can be iterated. For example, gathering system pressure reduction by increasing takeaway capacity generally implies an increase in production by wells on the system. This is often factored in to production estimates used to justify the time and cost of the changes. An iterative approach would change the inputs to the gathering system, recalculating the total volumes and associated pressures, feed these back into the individual well models and generate a new estimated total production. The iteration would run until it converges, providing a new baseline. The new conditions are fed back into the reservoir and individual well models allowing each of those elements to be re-assessed. Looking at an individual well, the model predicts the operating practice and artificial lift selection, if required. It also re-sets the timeline for interventions. Obviously, changes across an asset occur frequently, so it may be impractical to make this a continuous process. Instead, periodic reviews occurring quarterly (or perhaps monthly) could generate a stepwise improvement. Automating much of this process can increase review frequency without excessively taxing resources.

AMPL AS A MANAGED SERVICE

Weatherford and Well Master view AMPL as a viable managed production service opportunity, providing:

- Routine and regular engineering assistance with well assessments
- Surveillance and diagnostics assistance in collaboration with operator personnel
- Deployment of High-frequency Dataloggers as well as conventional and cloud-based single/multi-well control platforms with advanced edge capabilities.
- Optimization recommendations and suggested execution timing
- Data management and documentation

This model reduces internal workload while ensuring guidance for consistent Life-of-Well management.

Expanded application of the AMPL concept has been described above in ways that integrate reservoir and midstream. This aspect of AMPL most properly lies within the operator company’s purview and strategy. The services concept offering discussed here focuses on the optimization of individual wells from initial flowback through choke management and then predicting the timing of sequential artificial lift methods to best avoid common production gaps and underperformance. Ultimately the decision to apply any solution obviously rests with the operating company, but actionable proactive information is very often unavailable or unrecognized, therefore a reliable predictive service can add significant value at low cost and with low human resource demands.

CONCLUSIONS

Applied Multi-Phase Pneumatic Lift represents a shift from reactive artificial lift deployment to proactive, Life-of-Well production management. By recognizing the inherent pneumatic component of multiphase horizontal wells and acting early, operators can preserve value, improve economic resilience, and support autonomous operations.
CNX Resources has embarked on a “Life-of-Well” approach that incorporates features of the AMPL concept on a well by well basis and incorporates these into their broader goal of capturing all the available production in a timely manner.
Delayed action may carry irreversible economic consequences. AMPL provides a scalable, physics-based framework to optimize production continuously across the well life.

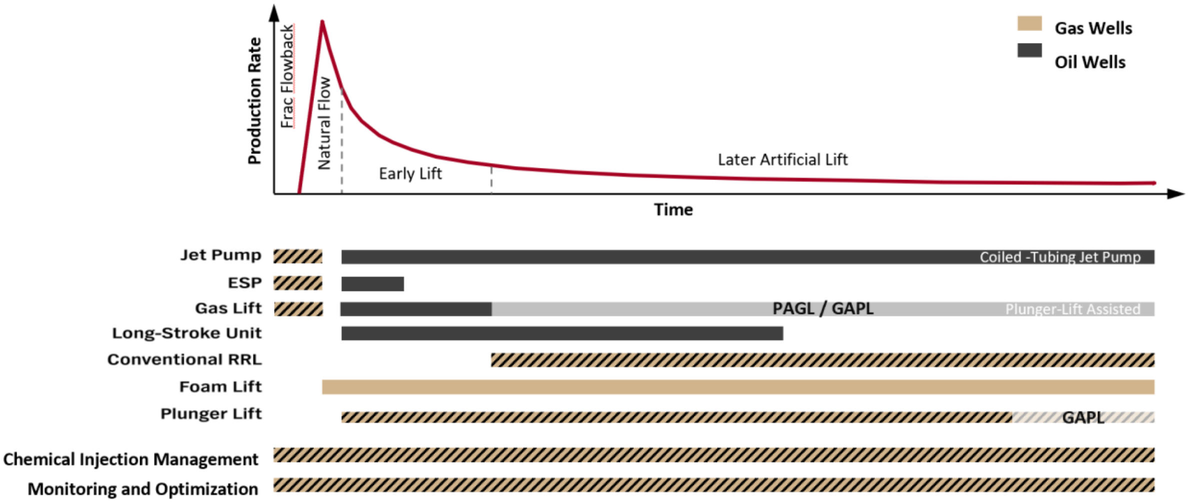

Figure 1 – Artificial Lift Options for Life-of-Well

Table 1 – Illustrative Economic Impact of Delayed Lift, Liquids-Rich Well

Parameter	**Early AMPL**	**Delayed Lift**
Initial Oil Rate (BO/D)	900	900
Time to Lift Optimization	Month 6	Month 12
12-Month Cum Oil (MBO)	200	168
Estimated EUR (MBO)	428	396
NPV10 ($MM)	5.5	4.81
Incremental Lost Value	—	**-$0.7 MM**

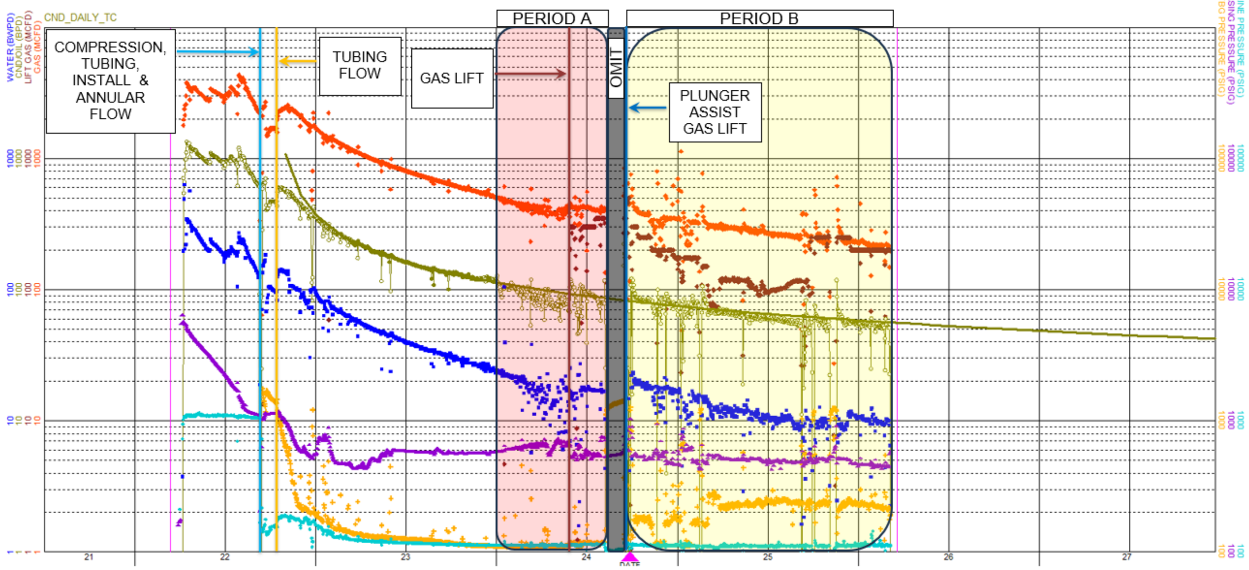

Figure 2 – Case #1 - Eagle Ford

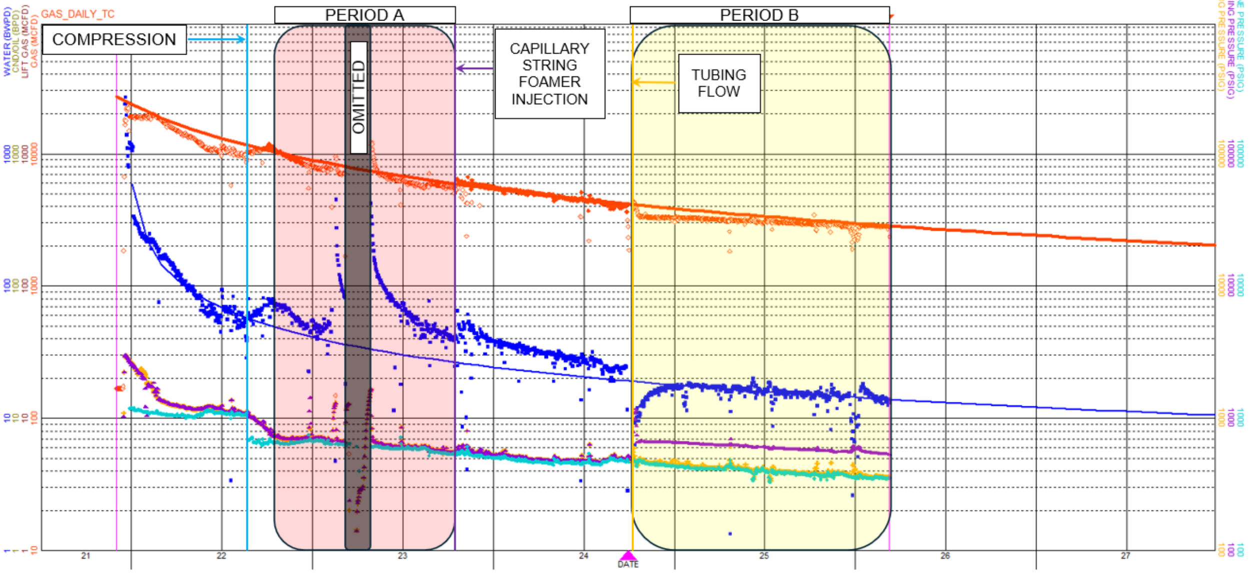

Figure 3 – Case #2 - Appalachian Basin, Marcellus Shale

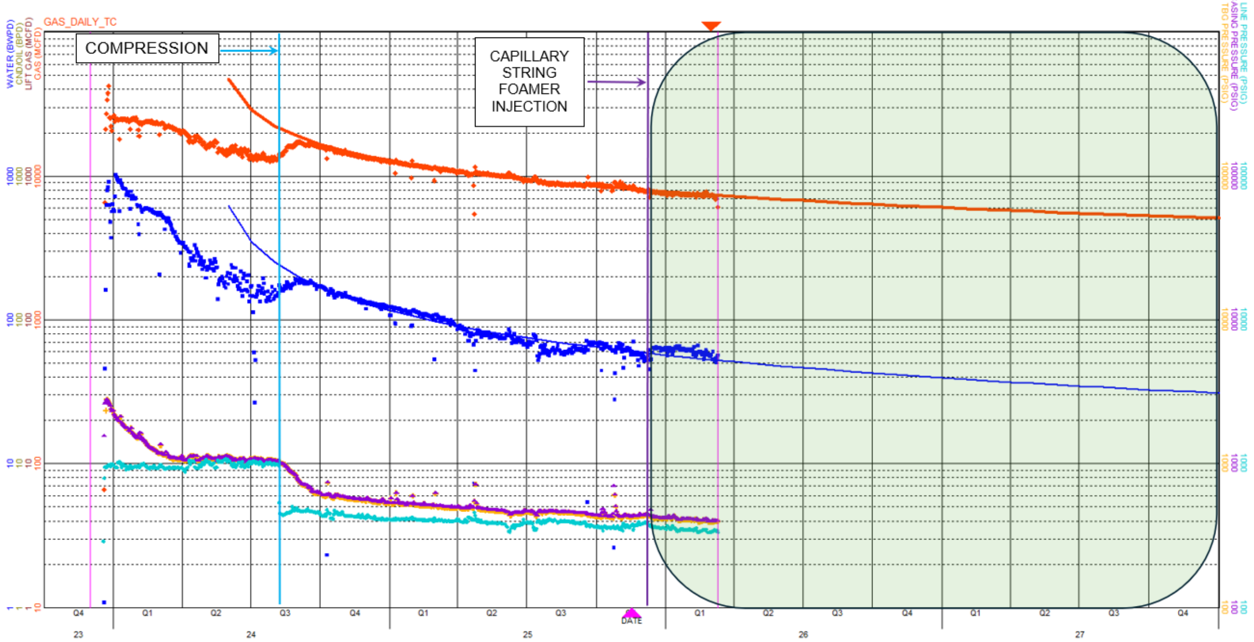

Figure 4 – Case #3 - Appalachian Basin, Marcellus Shale