Webinars

Welcome!

The program will begin soon.

You will not hear audio until we begin.

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Webinars

Enhancing Unconventional Well Management through Continuous Performance Tracking with Hybrid Models

Utkarsh Sinha
Xecta Digital Labs

Oct 9, 2023

SPE International

xecta

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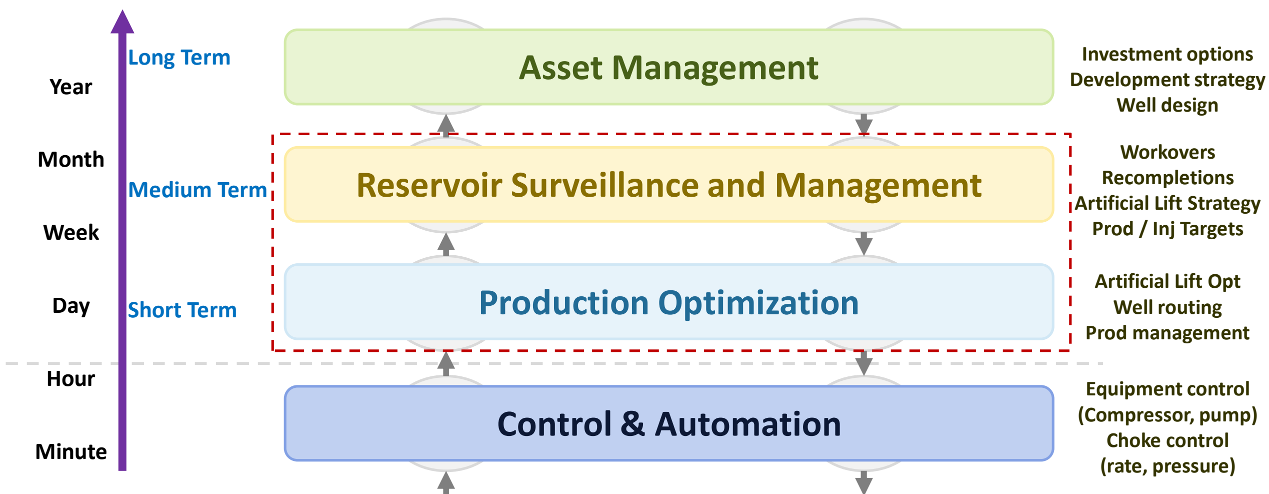
Towards Integrated Optimization

Webinars

Multi Level Control Hierarchy

Typical Decisions



Reference: Adapted from Sankaran et al (2009)

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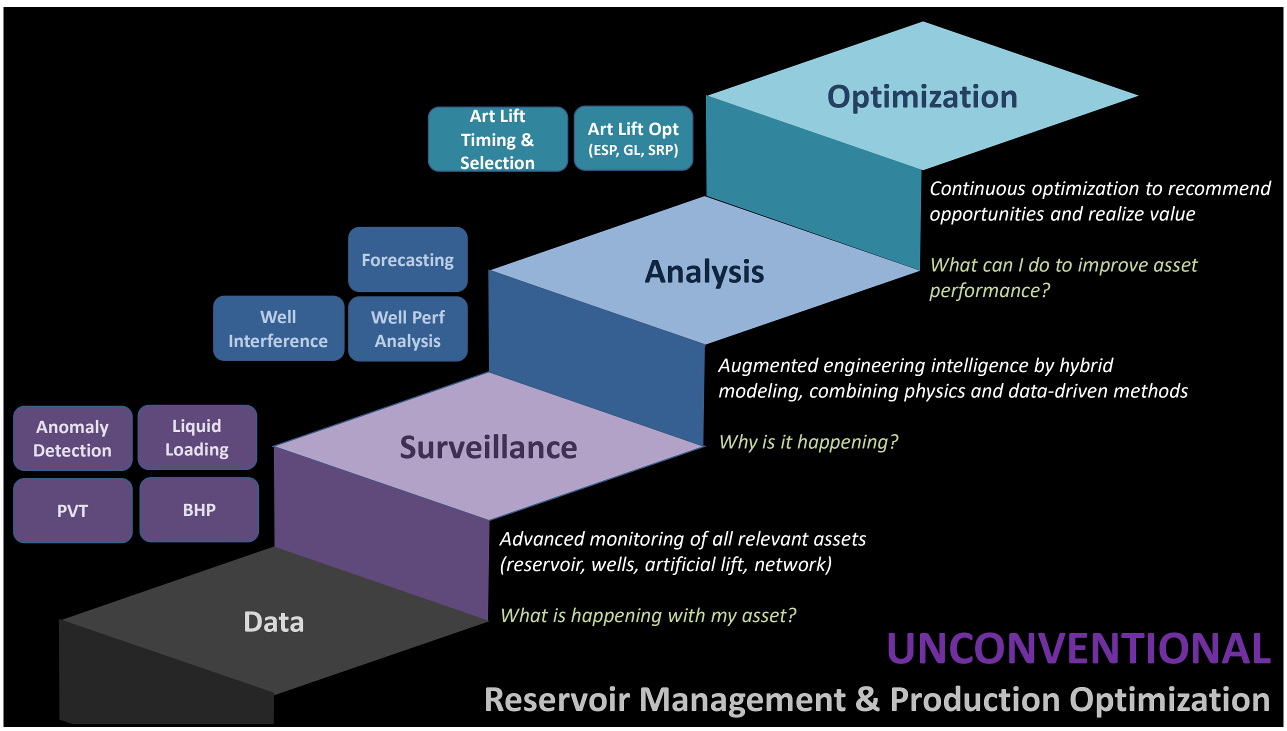
Optimization
Art Lift Timing & Selection
Art Lift Opt (ESP, GL, SRP)
Continuous optimization to recommend opportunities and realize value
What can I do to improve asset performance?
Analysis
Forecasting
Well Interference
Well Perf Analysis
Augmented engineering intelligence by hybrid modeling, combining physics and data-driven methods
Why is it happening?
Surveillance
Anomaly Detection
Liquid Loading
PVT
BHP
Advanced monitoring of all relevant assets (reservoir, wells, artificial lift, network)
What is happening with my asset?
Data
UNCONVENTIONAL
Reservoir Management & Production Optimization

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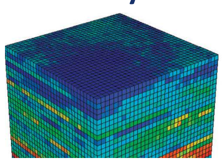
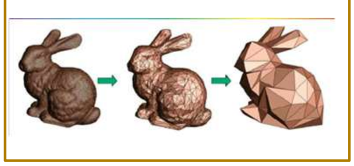
Hybrid Modeling in Unconventionals

Physics-constrained, data-driven modeling

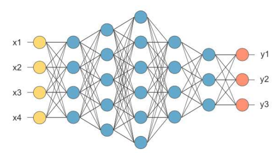
Full Physics



Hybrid Models



Data-Driven



References
- Hybrid bottomhole pressure (URTeC 5261)
- Transient well performance (URTeC 5023, 3723189)
- Multi-phase forecasting (URTeC 5023, 3723189, 371899, SPE 213103, 212981)
- Production optimization (IPTC 22493, URTeC 3724117)
- Parent-child interference (SPE 195813, URTeC 3864683)
- Reservoir graph network-based forecasting (URTeC 3718999, 3855422)
- Artificial lift timing and selection (SPE 213089, 213040, URTeC 3864002)
- Data-driven discovery of unconventional physics (SPE 213004, URTeC 3858897)

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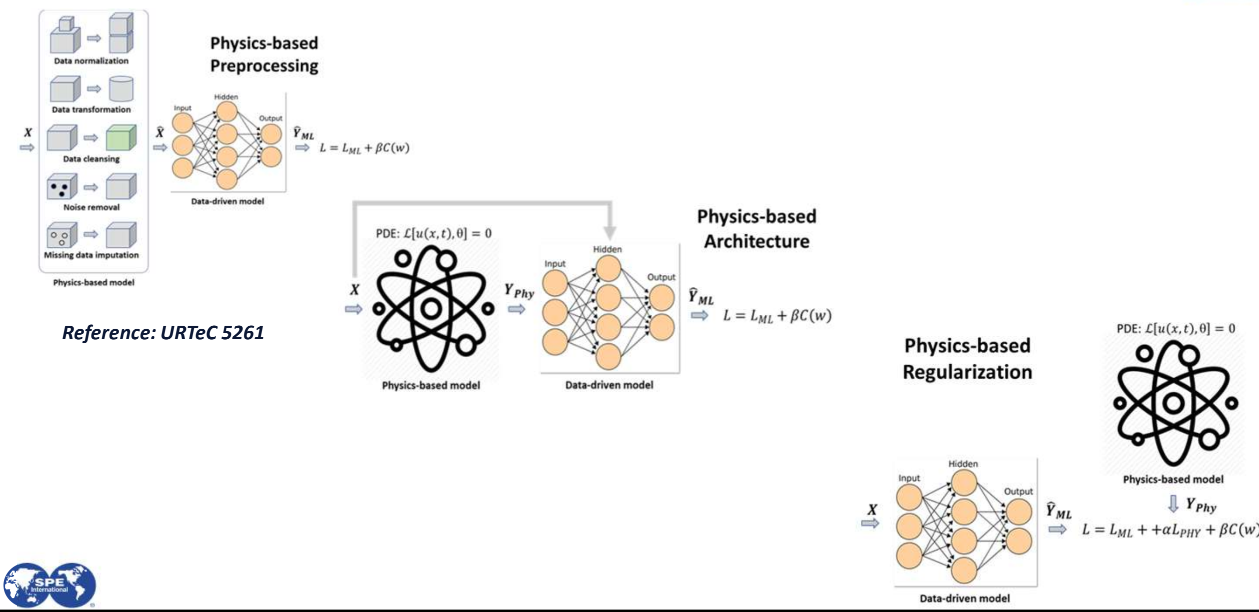
Hybrid Modeling Strategies



Reference: URTeC 5261

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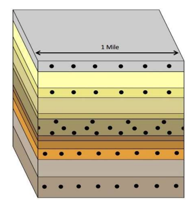
Unconventional Well Performance Analysis

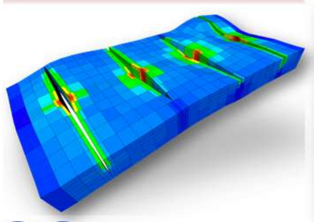
Webinars

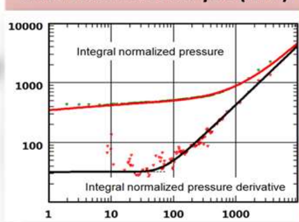


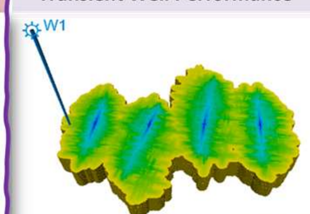
Objective

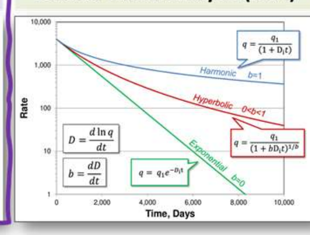
Determine transient well performance from routine unconventional operational data (rates and pressure)

PRESSURE BASED			RATE BASED
PHYSICS		HYBRID	DATA DRIVEN
Numerical Simulation	Rate Transient Analysis (RTA)	Transient Well Performance	Decline Curve Analysis (DCA)









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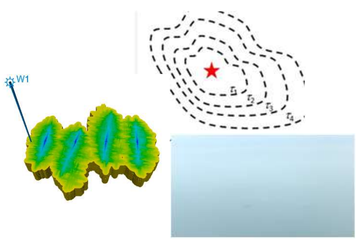
Unconventional Well Performance Analysis

Methodology (Transient Well Performance**)**

Diffusive Time of Flight

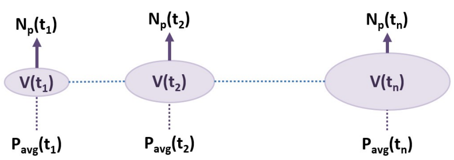
(Pressure contour propagation)



$$V_d \approx \frac{1}{c_t \frac{d}{dt_e}(RNP)}$$

Succession of pseudo-steady states

(Expanding control volume)

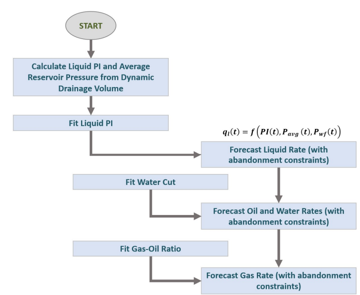


$$\frac{\partial(\rho\varphi)}{\partial t} + \nabla \cdot (\rho v_r) = 0$$

$$p_i - p_{avg} = \mathcal{F}(N_p, V_d)$$

PI-Based Forecasting

(Pressure-aware, multiphase)



$$PI_t = f(t, N_p, PI_{t-k})$$

Transient Productivity Index (PI) normalizes well performance from surface operational effects

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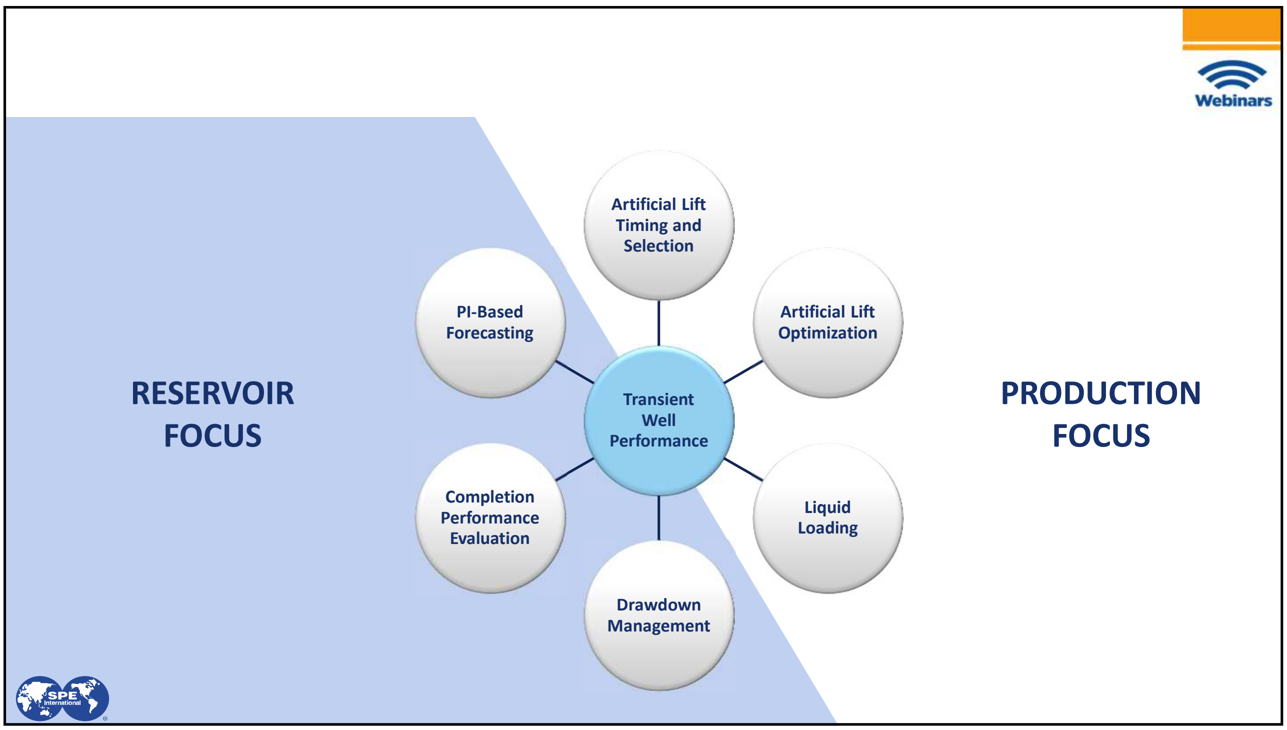
RESERVOIR FOCUS
PRODUCTION FOCUS
Transient Well Performance
Artificial Lift Timing and Selection
Artificial Lift Optimization
Liquid Loading
Drawdown Management
Completion Performance Evaluation
PI-Based Forecasting
Webinars

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VIRTUAL BHP & LIQUID LOADING

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1. Bottomhole Pressure

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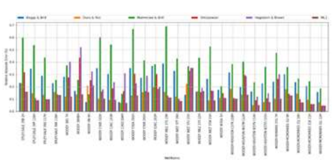
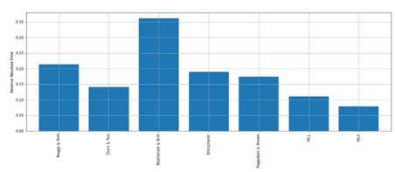
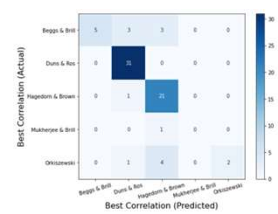
- Physics-informed machine learning







1. Calculate BHP using multiple flow correlations

- Beggs & Brill
- Hagedorn & Brown
- Mukherjee & Brill
- Orkiszewski
- Duns & Ros

2. Identify best correlation for wells with clean gauge data

- Static (for each well)
- Dynamic (for each timestep)

3. Fit ML model to predict BHP from input features

- Oil API
- Gas Gravity
- Solution GOR
- Latitude
- Longitude
- GOR*
- Watercut*

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1. Bottomhole Pressure

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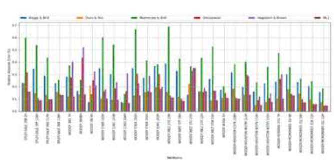
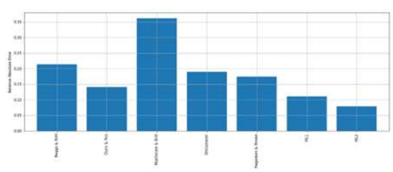
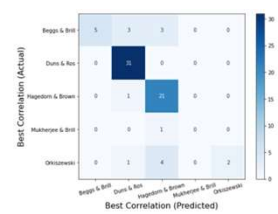
- Physics-informed machine learning







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- Watercut*

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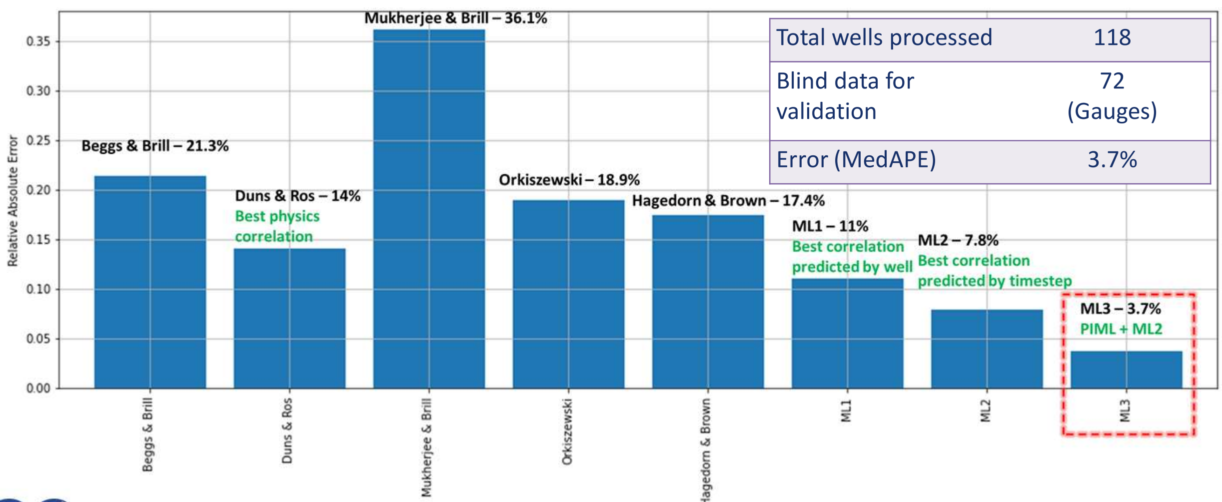
1. Bottomhole Pressure

- Permian Basin (118 wells)



Total wells processed	118
Blind data for validation	72 (Gauges)
Error (MedAPE)	3.7%

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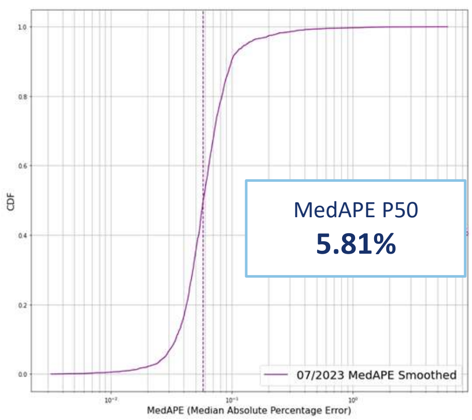
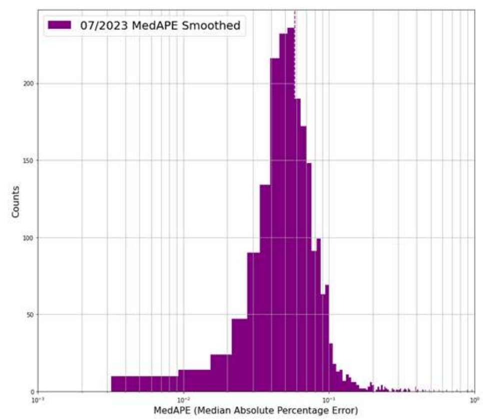
1. Bottomhole Pressure

- Permian Basin (3290 wells)
  - Blind test validation (xx wells)





"Virtual gauge" for BHP estimation with high accuracy and consistency

1. Liquid Loading

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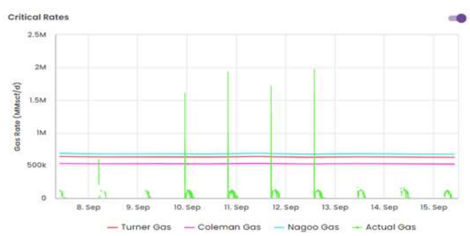
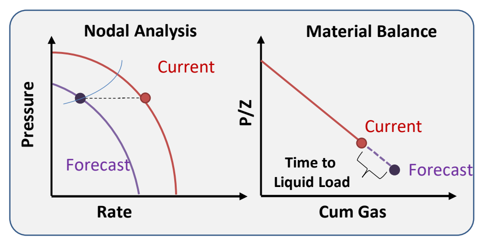
Objective: Detect and predict proclivity to liquid loading events in producing wells

Detection	Critical Rate Tuning	Prediction
• Identify wells currently experiencing liquid loading • Empirical and data-driven detection methods	• Dynamic critical rate tuning factor • Optimization-based estimation of corrected critical gas rate	• Identify wells tending towards liquid loading (insufficient energy) • Estimate time to liquid load

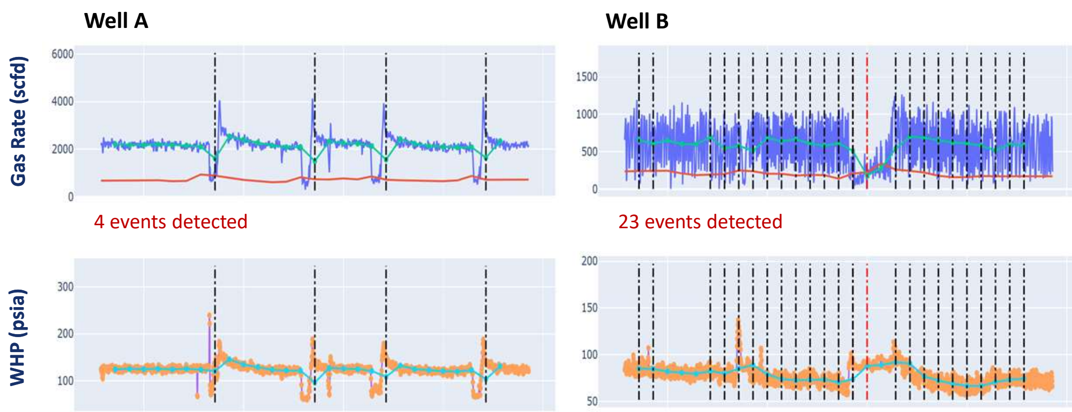




Empirical correlations may not always accurately predict liquid loading

1. Liquid Loading

Woodford Shale



Well instabilities are automatically detected to catalogue liquid loading events

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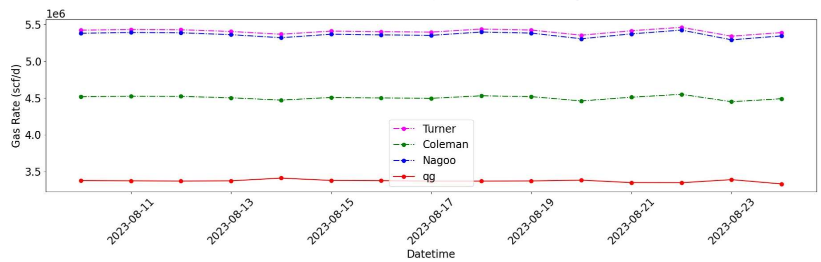
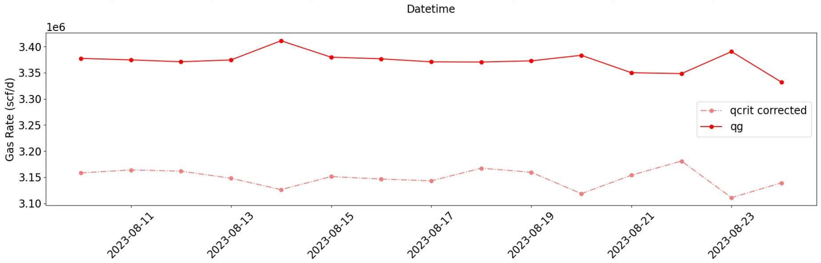
1. Liquid Loading

Woodford Shale – Well C (no liquid loading)





Calibrate critical rate tuning factor to reduce false alarms and improve accuracy

No liquid loading detected – critical rate tuned to correct empirical correlation

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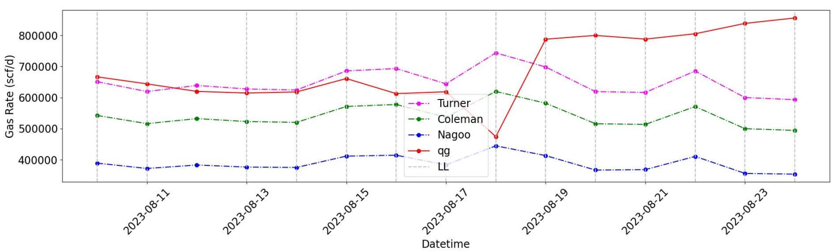
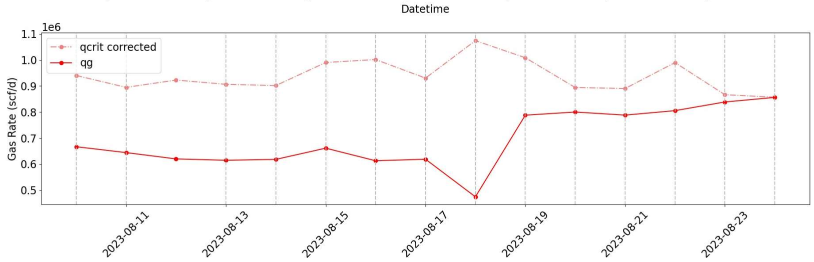
1. Liquid Loading

Woodford Shale – Well D (liquid loaded)



Calibrate critical rate tuning factor to reduce false alarms and improve accuracy



Liquid loading detected – Turner critical rate tuned to reduce false signals

1. Liquid Loading

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Woodford Shale (87 wells)

Auto Tuned Critical Rate

Total Gas Rate < Critical Rate

Liquid Loading	True	False
True	506	113
False	152	1411

Accuracy = 88%
Sensitivity = 82%

Empirical Critical Rate

Total Gas Rate < Critical Rate

Liquid Loading	True	False
True	450	780
False	207	743

Accuracy = 55%
Sensitivity = 37%

Significantly improved liquid loading detection accuracy and sensitivity

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PI-BASED FORECASTING
(WITH PARENT-CHILD INTERFERENCE)

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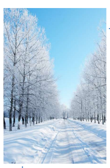
2. PI-Based Forecasting with Well Interference

Objective: Detect interference and infer well performance to improve forecasting accuracy

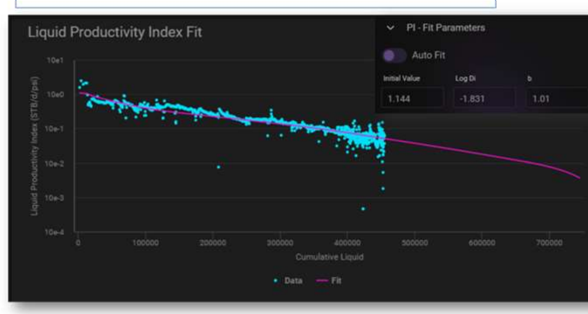


Improve forecasting accuracy compared to rate-based methods

- Normalize surface operational effects
- e.g. choke changes, surface constraints, artificial lift, well interference

Quantify impact of interference on well performance

- Field-wide, consistent metrics
- e.g. interference events, drainage volume, productivity index, avg reservoir pressure



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2. PI-Based Forecasting with Well Interference

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PI-Based Forecasting

(Pressure-aware, multiphase)

START

Calculate Liquid PI and Average Reservoir Pressure from Dynamic Drainage Volume

Fit Liquid PI

$q_l(t) = f\left(PI(t), P_{avg}(t), P_{wf}(t)\right)$

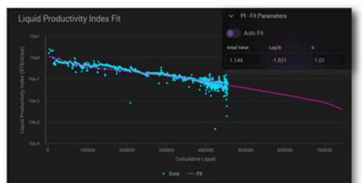
Forecast Liquid Rate (with abandonment constraints)

Fit Water Cut

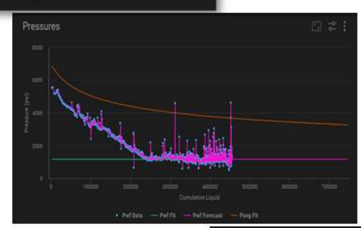
Forecast Oil and Water Rates (with abandonment constraints)

Fit Gas-Oil Ratio

Forecast Gas Rate (with abandonment constraints)

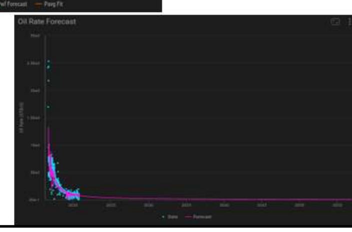


Transient Productivity Index



Reservoir Pressure Depletion

Oil Rate Forecast



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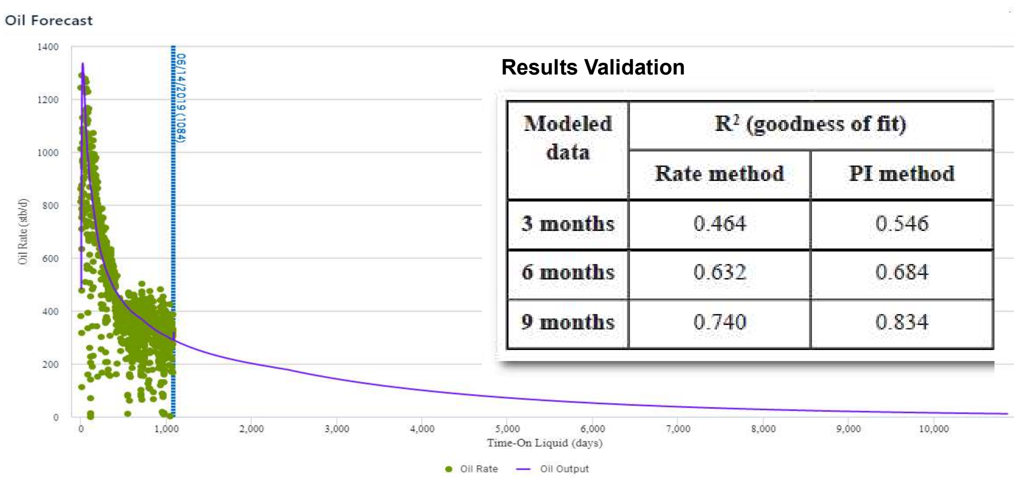
2. PI-Based Forecasting with Well Interference

Permian Basin



Results Validation

Modeled data	R^2 (goodness of fit)	
	Rate method	PI method
3 months	0.464	0.546
6 months	0.632	0.684
9 months	0.740	0.834

PIBF improves forecasting accuracy compared to decline curve analysis

2. PI-Based Forecasting with Well Interference

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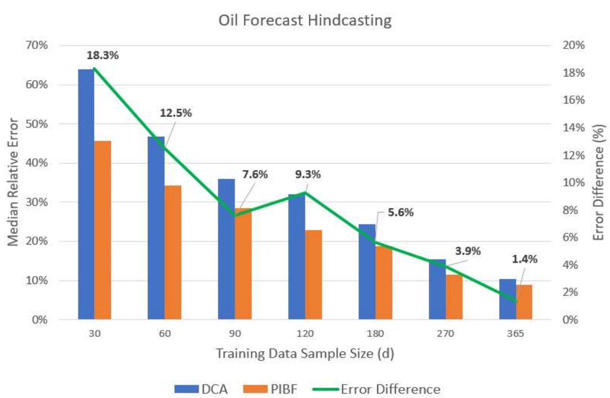
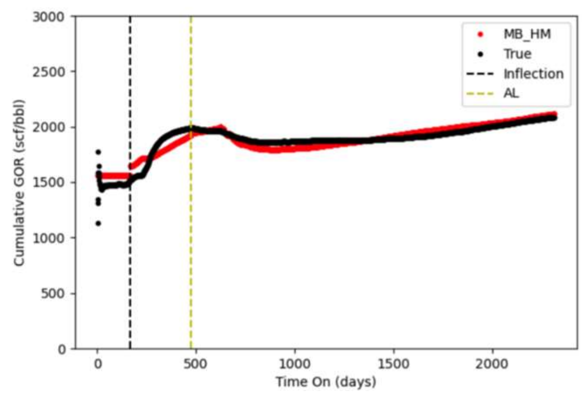
Bakken (~1200 wells)



PIBF outperforms DCA in hindcasting especially during early time



Improved GOR forecasting with PVT and pressure depletion effects

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2. PI-Based Forecasting with Well Interference

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Multi-Segmented PI-Based Forecasting (ms-PIBF)

Breakpoint Detection

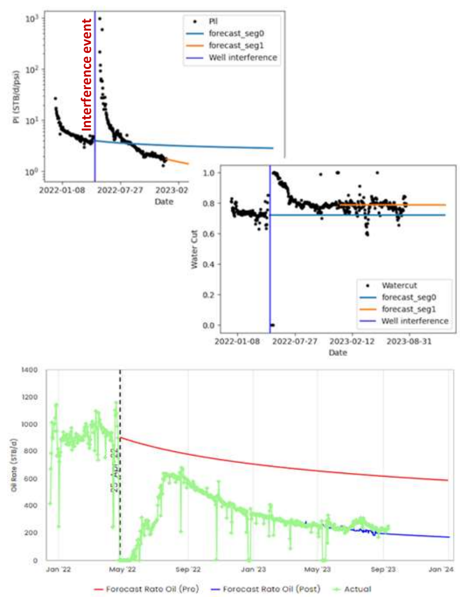
Plot PI vs cum fluid produced → Apply multi-segment PI fit detection algorithm → Recursively identify all segments and breakpoints

Segment Verification

Calculate change in watercut and PI at the breakpoints → Frac-hit event? → Apply single segment PIBF for production forecast / Apply MS-PIBF for production forecast

Impact Quantification

Calculate difference in pre and post event forecasts → Catalog all events and delta cum production forecasts



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2. PI-Based Forecasting with Well Interference

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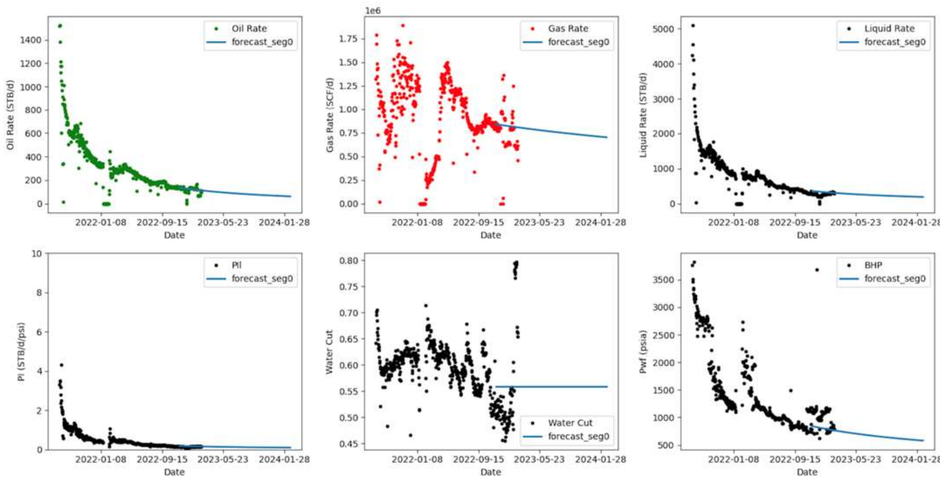
Permian Basin – No interference



No well interference detected

Hindcasting	Oil Rate MedAPE
PIBF	8.8 %

PI-based forecast improves rate prediction by normalizing operational variations

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2. PI-Based Forecasting with Well Interference

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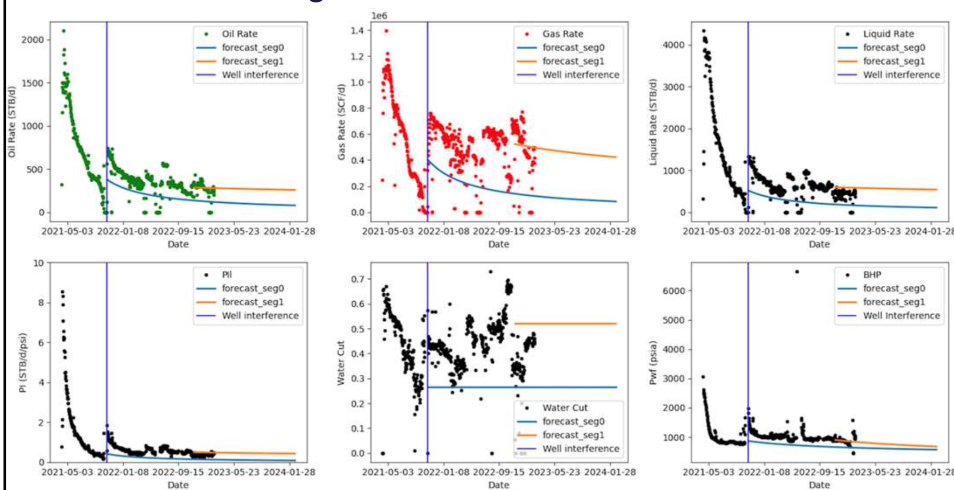
Permian Basin – Single interference event



Hindcasting	Oil Rate MedAPE
PIBF	16.5 %
ms-PIBF	7.0 %

* Hindcast period – last 90 days

Forecasting	Cum Oil (MMSTB)
Pre-event	0.27
Post-event	0.42
Difference	**0.15**

* Forecast period – 1 year

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Interference impact on cumulative oil volume forecast +0.15 MMSTB (after 1 year)

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2. PI-Based Forecasting with Well Interference

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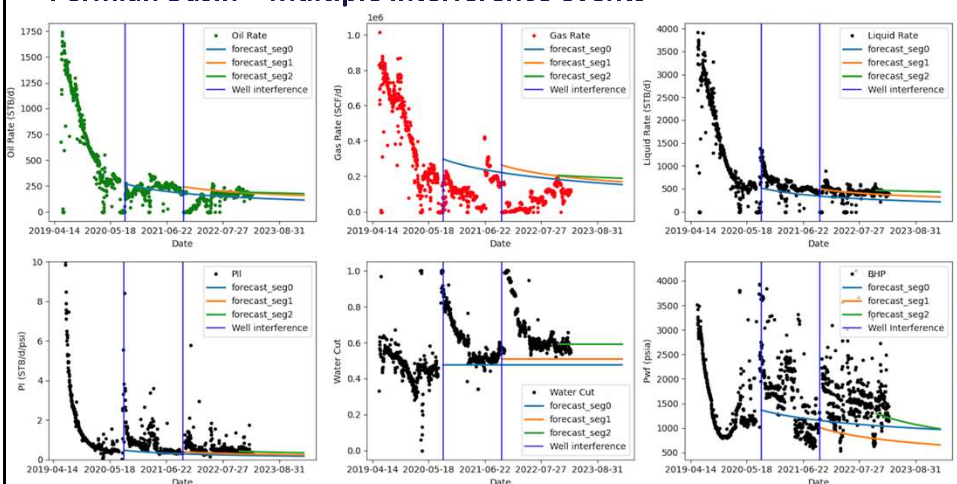
Permian Basin – Multiple interference events



Hindcasting	Oil Rate MedAPE
PIBF	10.1 %
ms-PIBF	8.6 %

* Hindcast period – last 90 days

Forecasting	Cum Oil (MMSTB)
Pre – 1st event	0.49
Pre – 2nd event	0.54
Post – 2nd event	0.51
Net Difference	**+0.02**

* Forecast period – 1 year

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Net interference impact on cumulative oil volume +0.02 MMSTB

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2. PI-Based Forecasting with Well Interference

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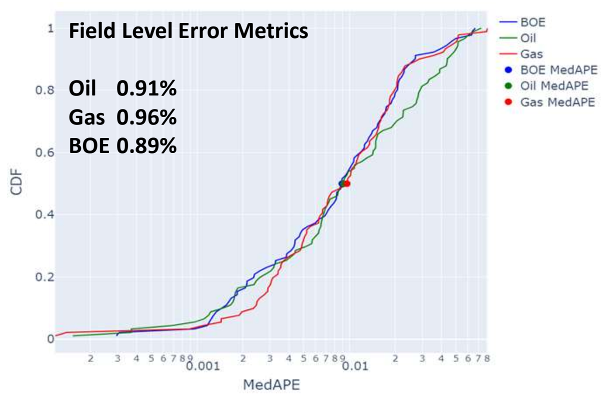
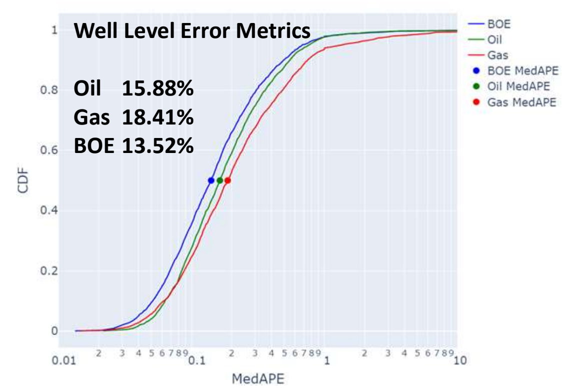
Permian Basin (2424 wells, Q2 2023)





Automated, consistent and scalable forecasting method from well to field level

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ARTIFICIAL LIFT TIMING AND SELECTION (ALTS)

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3. Artificial Lift Timing and Selection (ALTS)

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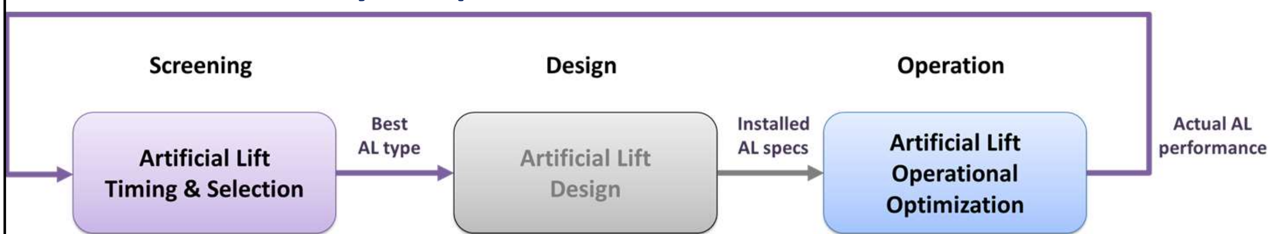
Artificial lift – Life cycle optimization



- Screen for best long-term AL type
- Estimate timing based on expected subsurface and AL performance
- Compare base case (do-nothing) with alternate scenarios on economic basis

- Optimize design based on selected AL type
- Detailed economic modeling
- Vendor sourcing and supply chain optimization

- Estimate actual AL performance (efficiency, wear factor etc.)
- Update base case with actual AL performance
- Operational recommendations to maximize production (e.g. pump speed, gas lift rates)

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3. Artificial Lift Timing and Selection (ALTS)

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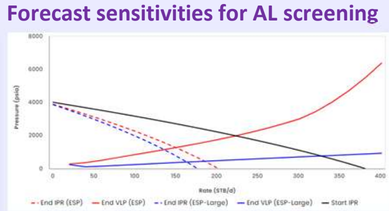
Objective

Automated solution to predict and recommend optimal timing and artificial lift selection for field-wide production optimization and user-defined sensitivity analysis (Natural Flow, ESP, Gas Lift, Sucker Rod Pump)

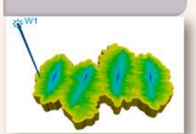
Nodal sensitivities for AL scenarios

Forecast sensitivities for AL screening

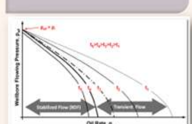


Economic Analysis

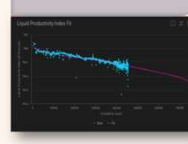
Dynamic Drainage Volume



Transient IPR



PI-Based Forecasting



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3. Artificial Lift Timing and Selection (ALTS)

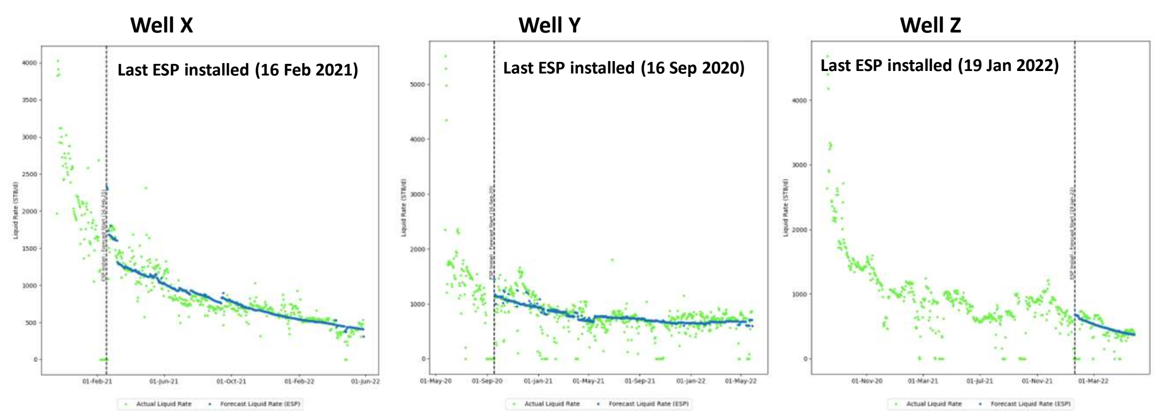
Bakken (50 wells)

- Hindcasting error analysis
- Use actual WHP and ESP frequency history for hindcasting

Overall good prediction compared to actual production

Liquid rate MedAPE	*Oil rate MedAPE*
13%	**16%**

*since last ESP installed date



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3. Artificial Lift Timing and Selection (ALTS)

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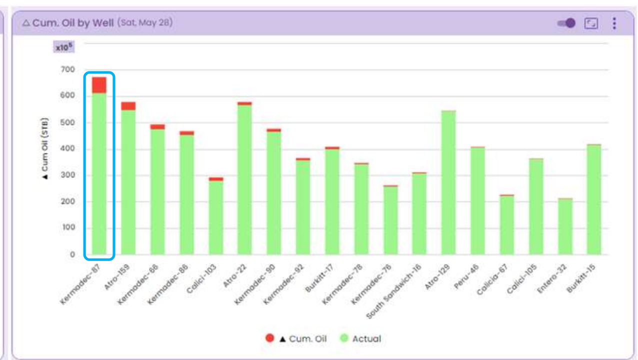
Bakken (50 wells)

- Forecasting analysis with 3 ESP sizes (small, medium, large)



3. Artificial Lift Timing and Selection (ALTS)

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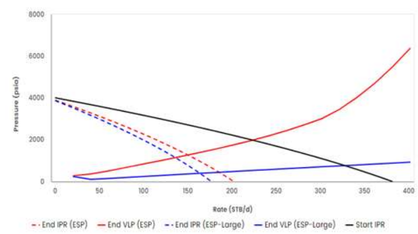
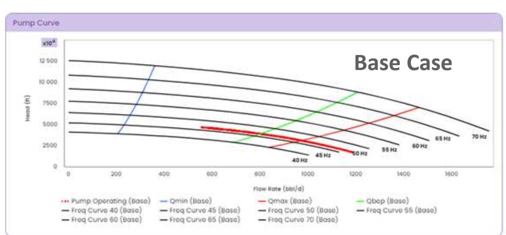
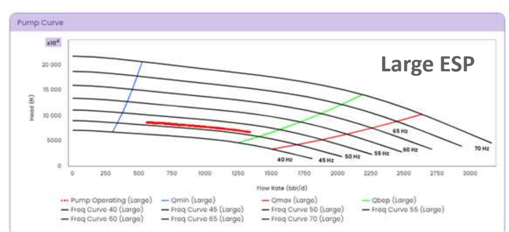
Bakken (50 wells)

- Forecasting analysis with 3 ESP sizes (small, medium, large)







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Summary

- **Hybrid models enable field-scale automation**
  - Balances speed, fidelity, physical consistency and interpretability for field optimization
- **Data-driven discovery of reservoir physics could lead to better interpretations for traditional workflows or new understanding**

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