Design and Optimization of PAGL and GAPL

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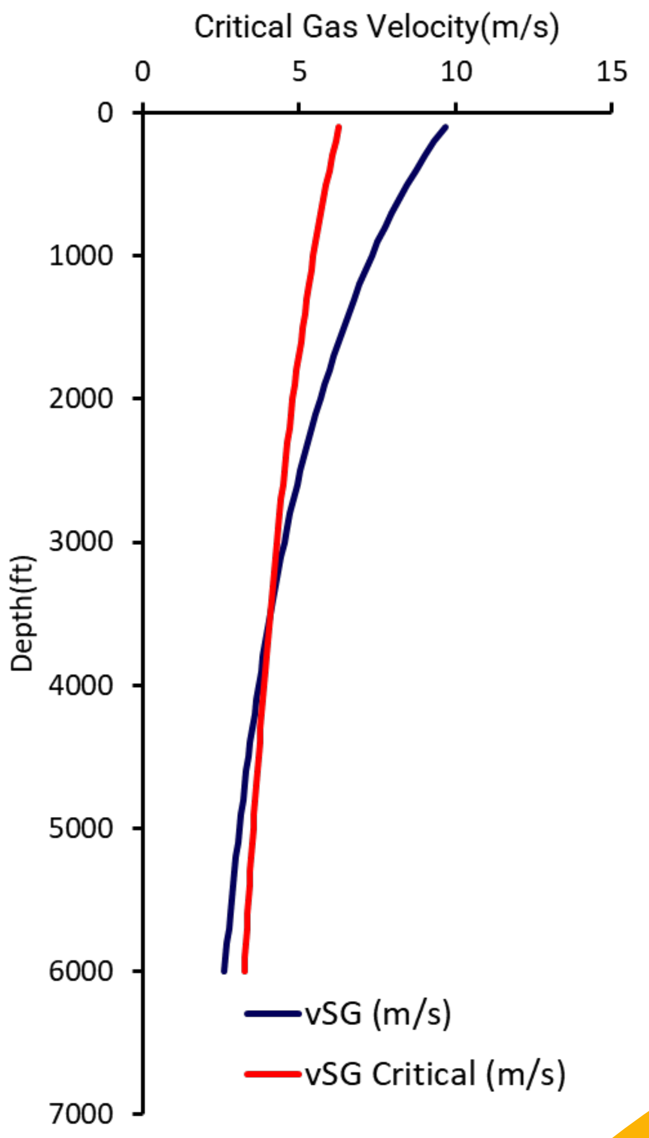
Liquid Loading

- Insufficient gas velocity
  - $Vsg < Vsg_{critical}$ (Turner)



Annular flow

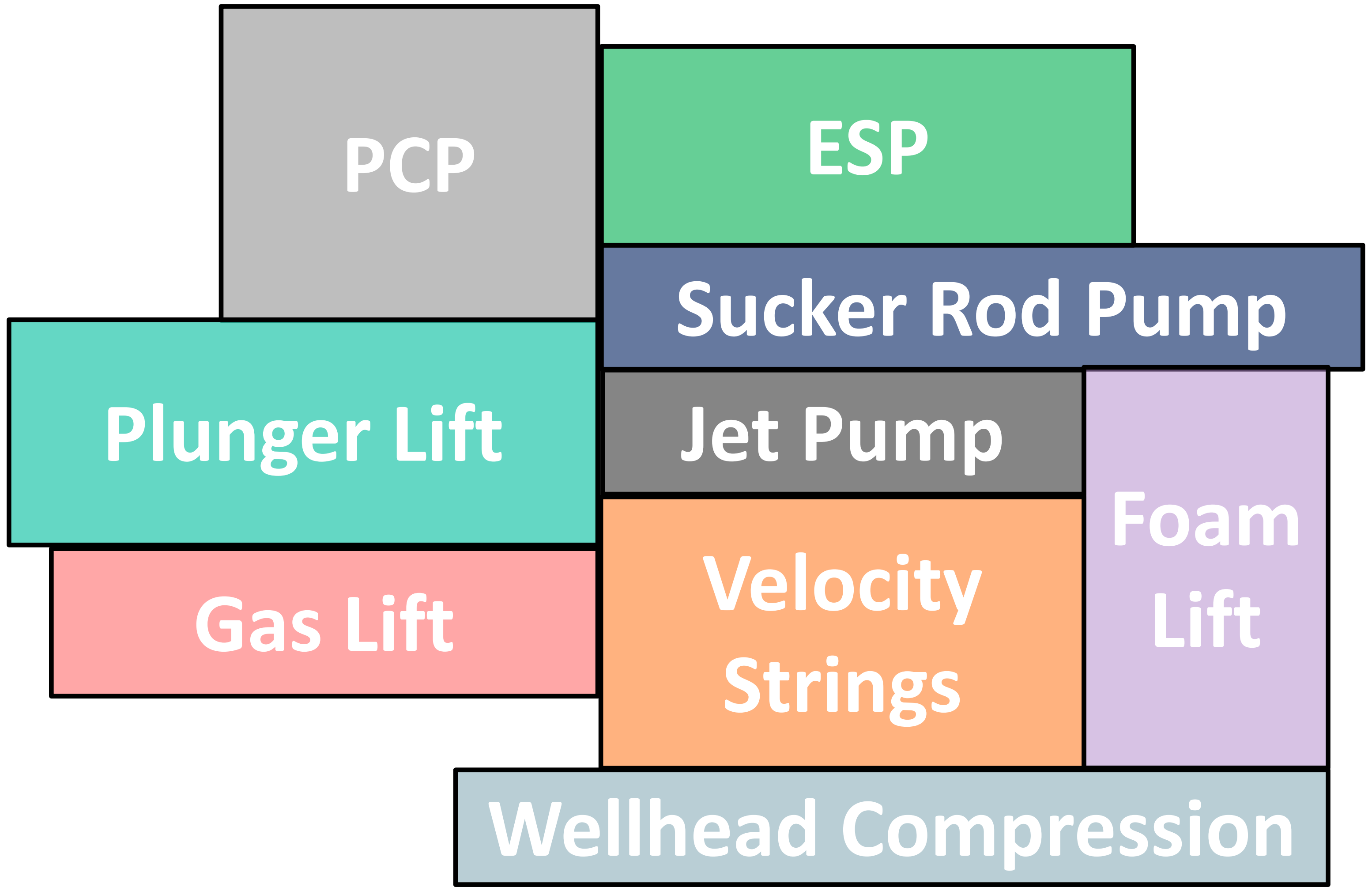
Churn/Slug

Artificial Lift Methods

- Fluid properties
- GLR and deviation
- Production increase
- Paraffin remediation
- Limited application
  - Chemical composition

Deliquification

- Unconventional plays
  - After three months
  - Gas lock
  - Deviated completions
- Low cost
  - Cut lift expenditure
  - Works for short period



Intermittent Gas Lift vs GAPL

Gas Lift v PAGL

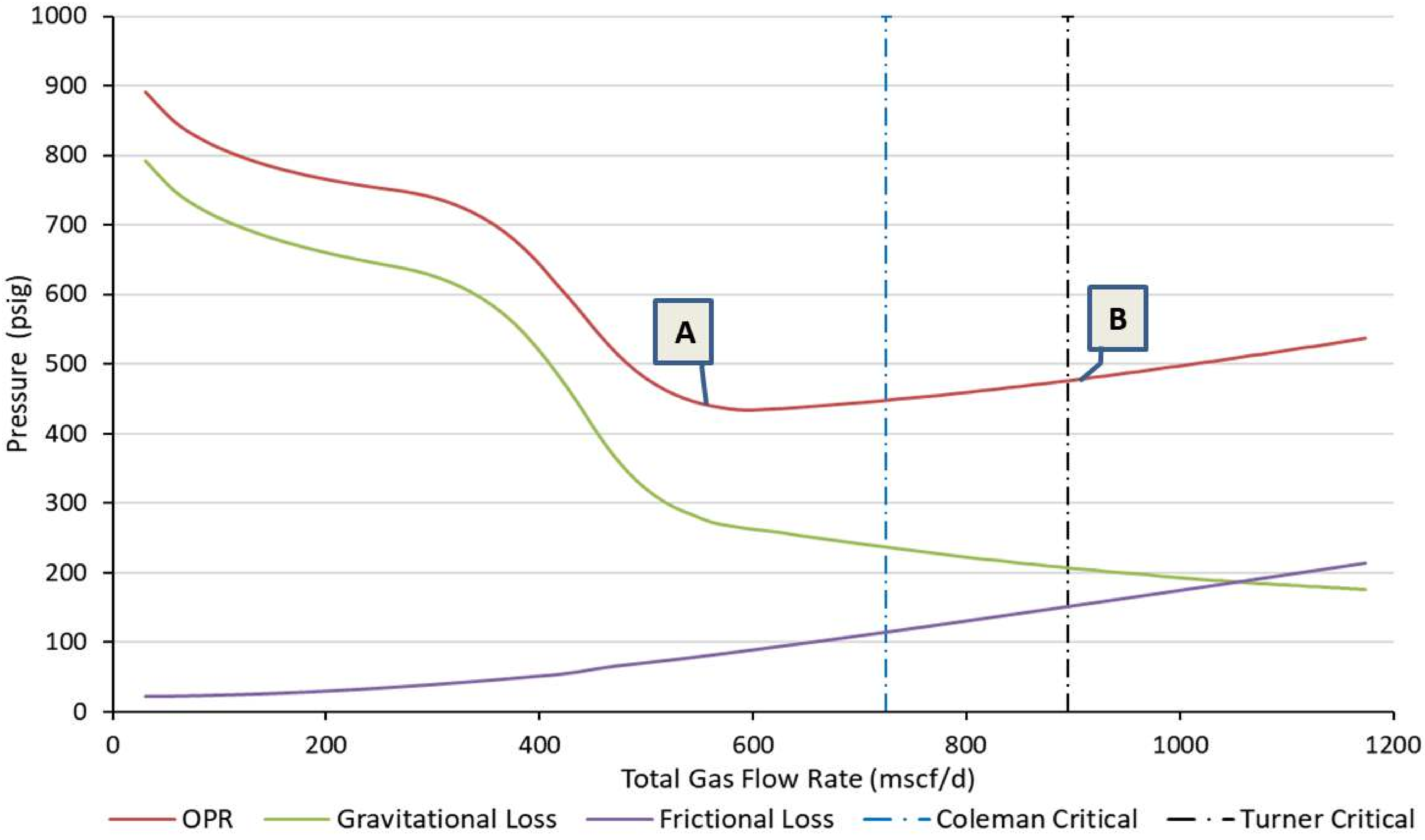
No plunger (intermittent gas lift)

Conventional (GAPL)

Continuous (PAGL)

Nodal Analysis

- Outflow performance curve
  - Minimize bottomhole pressure
    - Point A
- Avoid liquid loading (point B)



The frictional, gravitational pressure loss, and outflow performance (OPR) curve plotted for different gas production rates with Turner et al. (1969) and Coleman et al. (1991) critical gas velocity. (Sayman et al.,2022)

Plunger Lift Types


Two-piece

Lift Types	Continuous Flow Plunger Lift	Conventional Plunger Lift
Deployment	Pre-liquid loading	Late life of the well
Production	Higher production rates *(2+ mmscf/d , 600+ STB/d)*	Lower production rates
Intermittency	Continuous	Intermittent (shut-in)
Characteristics	Little to no shut-in	Shut-in *(10 min to hours)*
	Fall against flow	Better sealing

Plunger Types	Continuous Flow Plunger Lift	Conventional Plunger Lift
Bypass	x	x
Two-piece	x	x
Barstock		x
Pad		x
Brush		x


Dual Pad

Plunger Fall

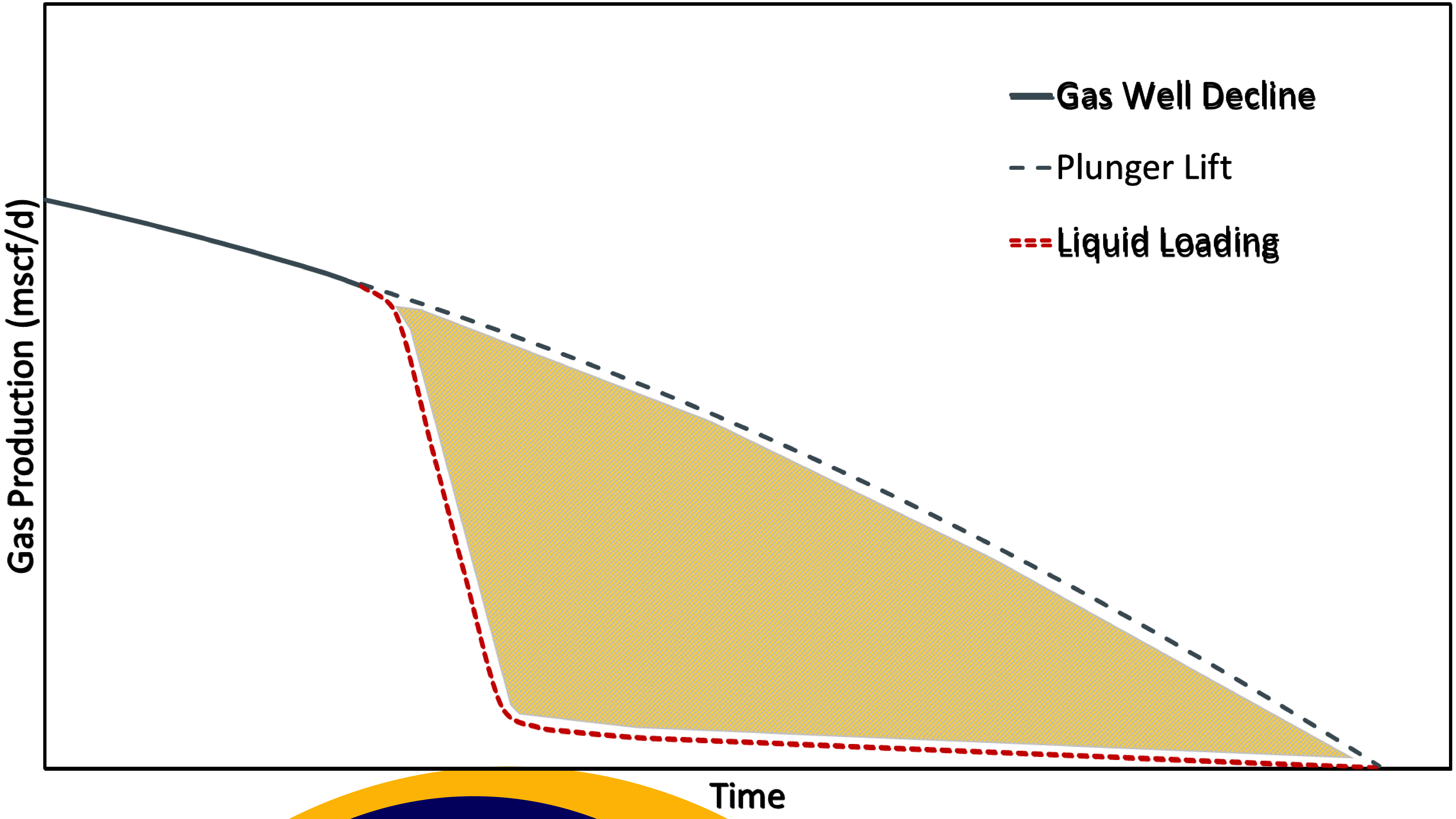
Upstroke Stage

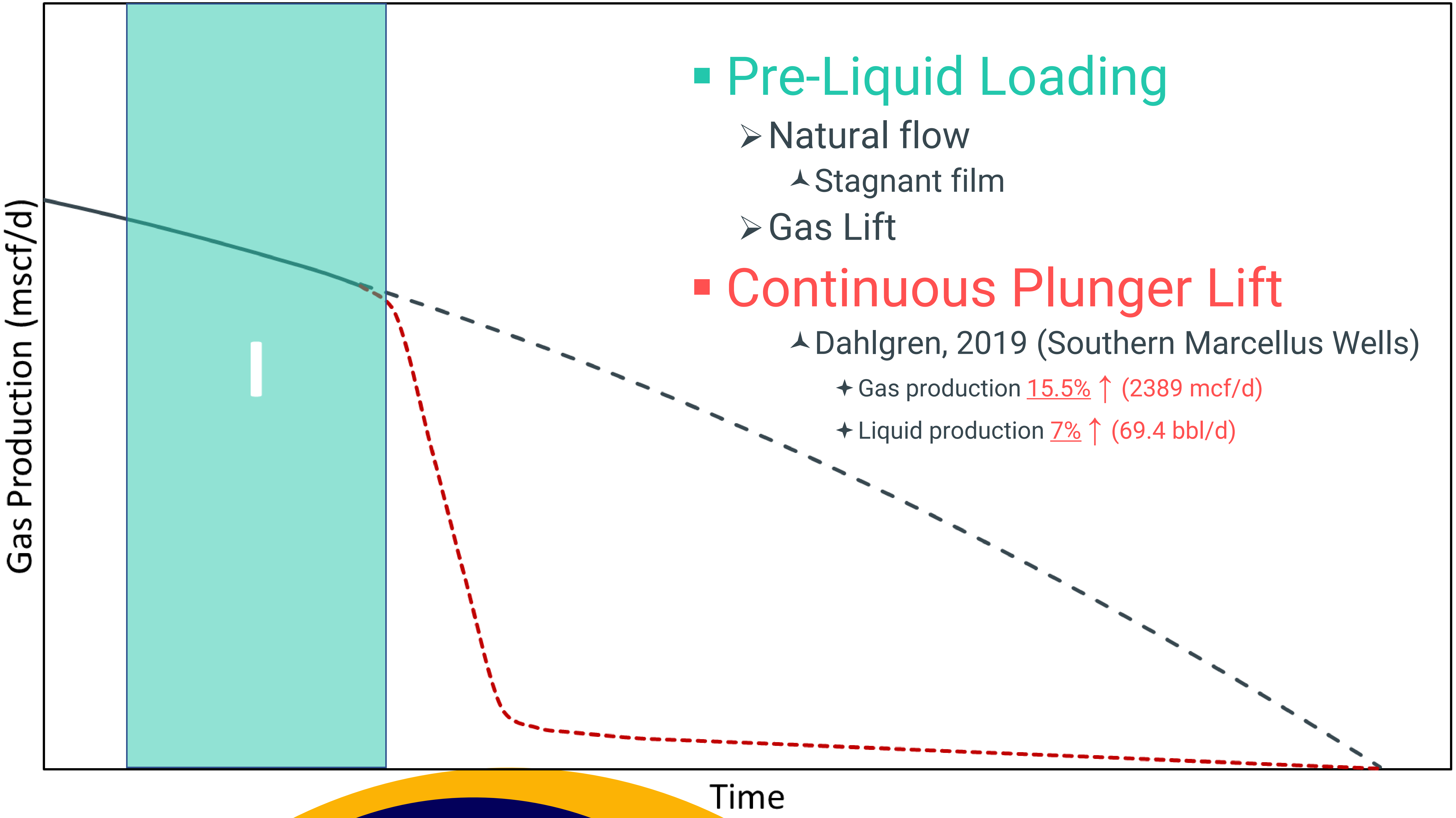
- Continuous Flow
  - Accumulated liquid **+ catching liquid film**
  - Drag generated gas and liquid flow
    - Sayman (2019)
  - PAGL (Plunger-assisted gas lift)

- Conventional
  - Accumulated liquid **– liquid fallback**
  - Casing pressure build-up
    - Foss&Gaul (1965), Lea (1982), Akhiiartdinov (2020)
  - GAPL (Gas-assisted plunger lift)

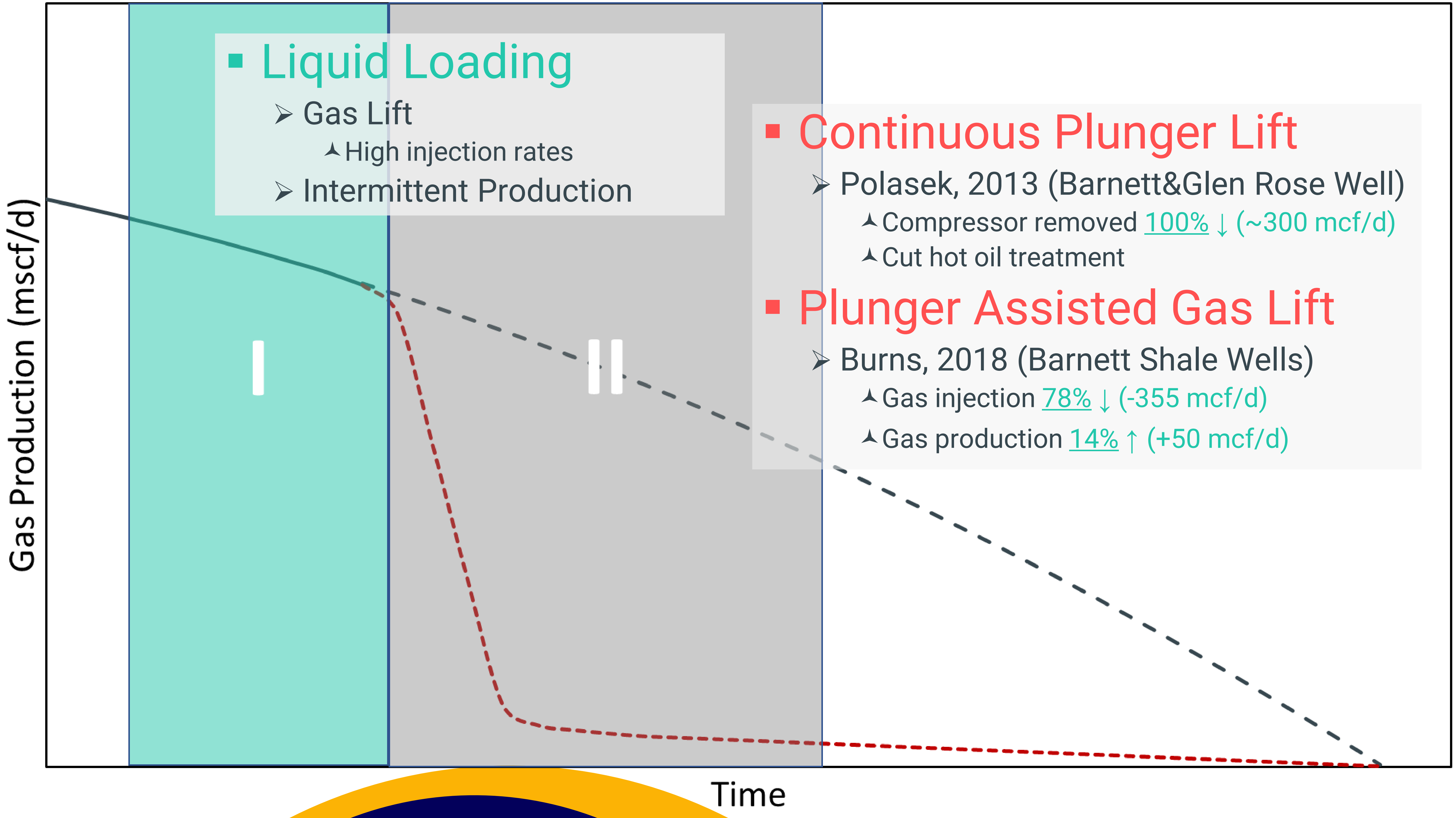
Continuous Flow (PAGL)

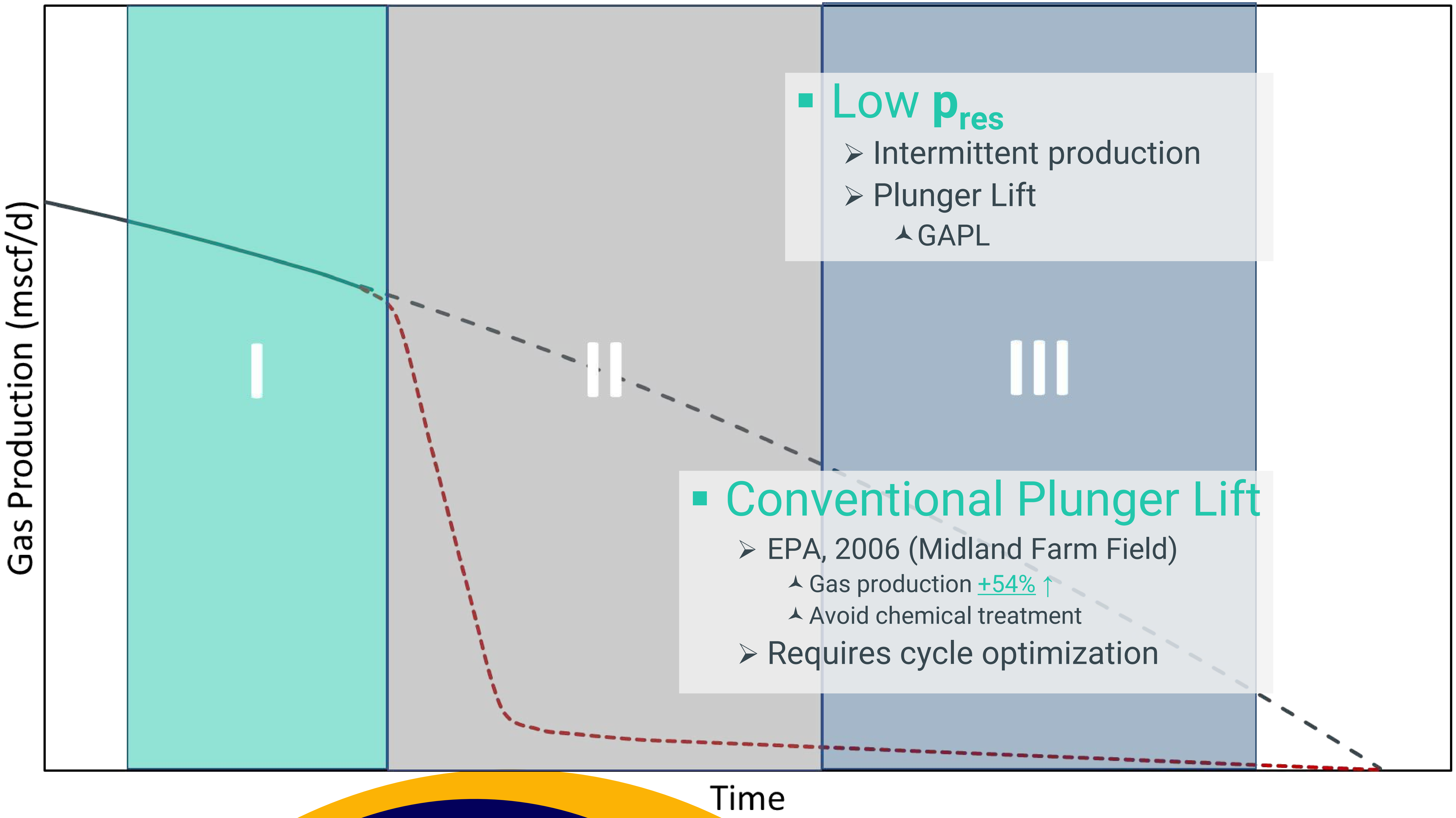
Conventional (GAPL)


Gas Well Decline
Plunger Lift
Liquid Loading
Gas Production (mscf/d)
Time



- Pre-Liquid Loading
  - Natural flow
    - Stagnant film
  - Gas Lift
- Continuous Plunger Lift
  - Dahlgren, 2019 (Southern Marcellus Wells)
    - Gas production 15.5% ↑ (2389 mcf/d)
    - Liquid production 7% ↑ (69.4 bbl/d)


Liquid Loading
Gas Lift
High injection rates
Intermittent Production
Continuous Plunger Lift
Polasek, 2013 (Barnett&Glen Rose Well)
Compressor removed 100% ↓ (~300 mcf/d)
Cut hot oil treatment
Plunger Assisted Gas Lift
Burns, 2018 (Barnett Shale Wells)
Gas injection 78% ↓ (-355 mcf/d)
Gas production 14% ↑ (+50 mcf/d)
I
II
Gas Production (mscf/d)
Time


Gas Production (mscf/d)
Time
I
II
III
Low p_{res}
Intermittent production
Plunger Lift
GAPL
Conventional Plunger Lift
EPA, 2006 (Midland Farm Field)
Gas production +54% ↑
Avoid chemical treatment
Requires cycle optimization

Optimization

- Ongoing plunger lift operation
  - Gas injection
  - Shut-in/afterflow (controller) time settings
  - Plunger type

Design

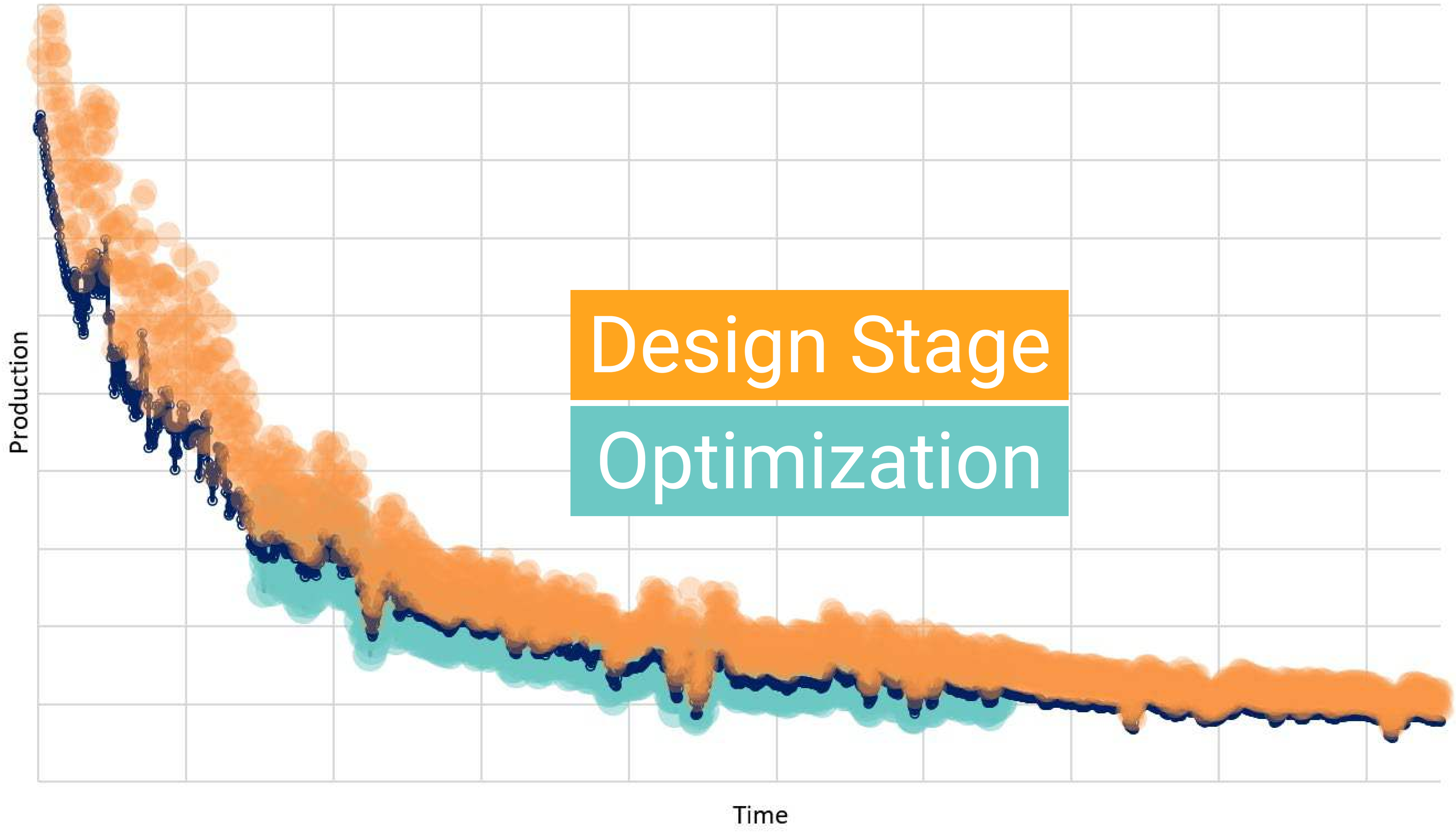
- Analytics for artificial lift selection
  - Well selection
  - When to deploy?
  - BHA location
    - With the consideration of plunger type, shut-in/afterflow.

Optimization

- Trial and error
  - Time consuming, man-hour
  - Risk for well integrity problems
- Mechanistic and AI models
  - Reduce cost and time

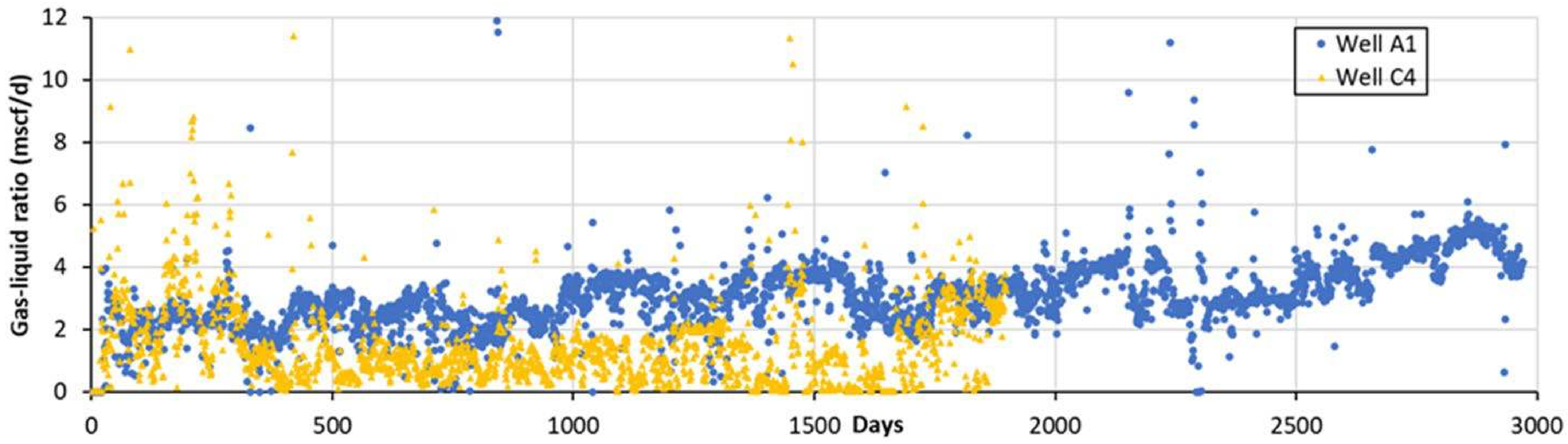
Design

- Plan early
  - Significant cumulative production increase
  - Similar to EOT, gas lift valve, tubing design
    - Changing later? May not be feasible



Design - When to deploy?

- Artificial Lift Selection (ESP, Rod lift or PAGL?)
  - Mechanistic models
    - Plunger fall stage boundary
    - Upstroke and liquid slug unloading
  - Field data
    - Liquid production up to 600 STB/day
    - Gas-liquid ratio (GLR) as low as 500 scf/bbl



SPE 209760-MS

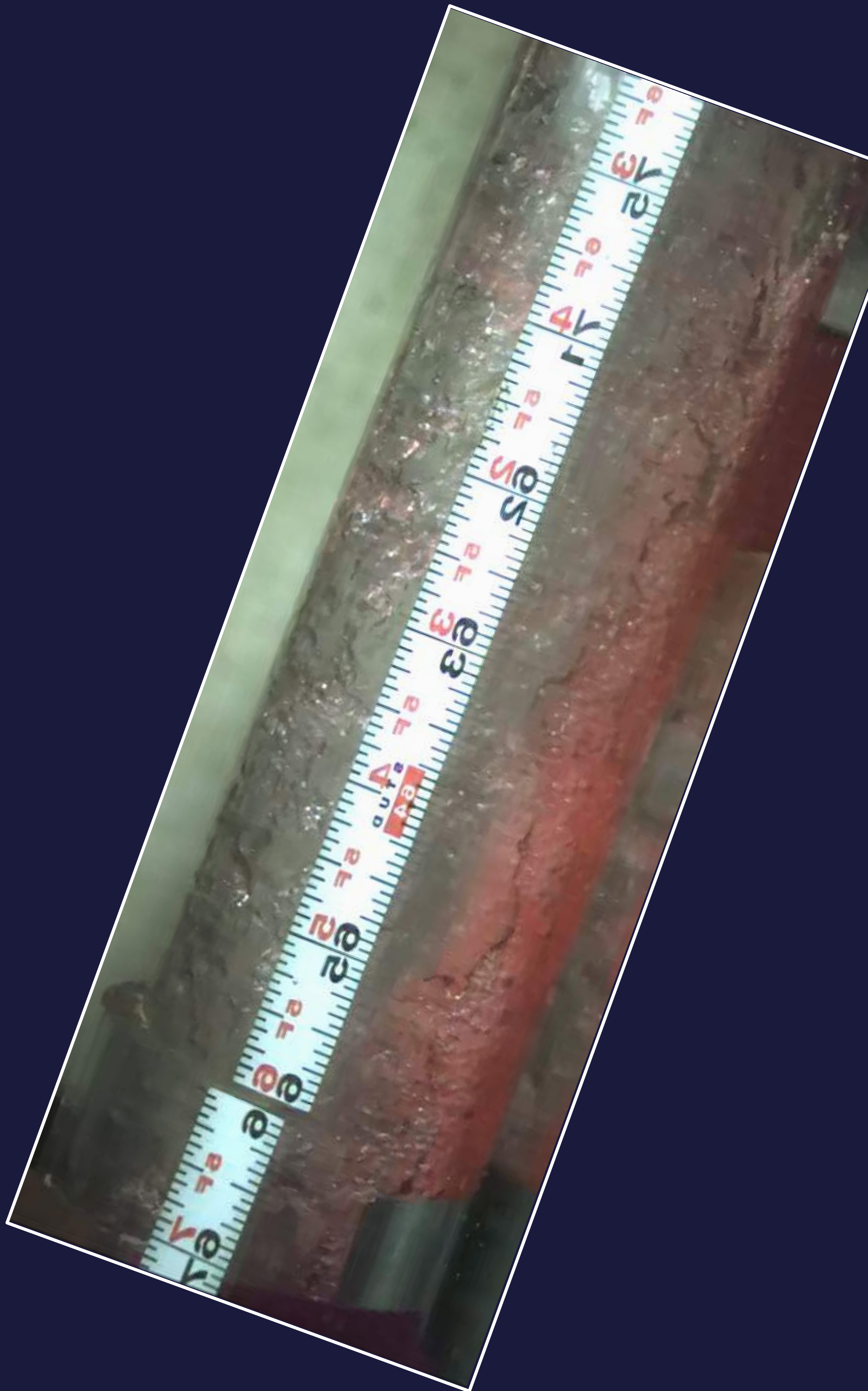
Design - BHA Location

- Hydrostatic removal
  - Vertical component
- Cycle time
  - Longer distance -> slower fall duration
  - Dog-leg severity

Plunger Type

- Shut-in/afterflow time settings
  - Changes the operational range
- Field conditions
  - Sand, scale

$\theta = 0°$

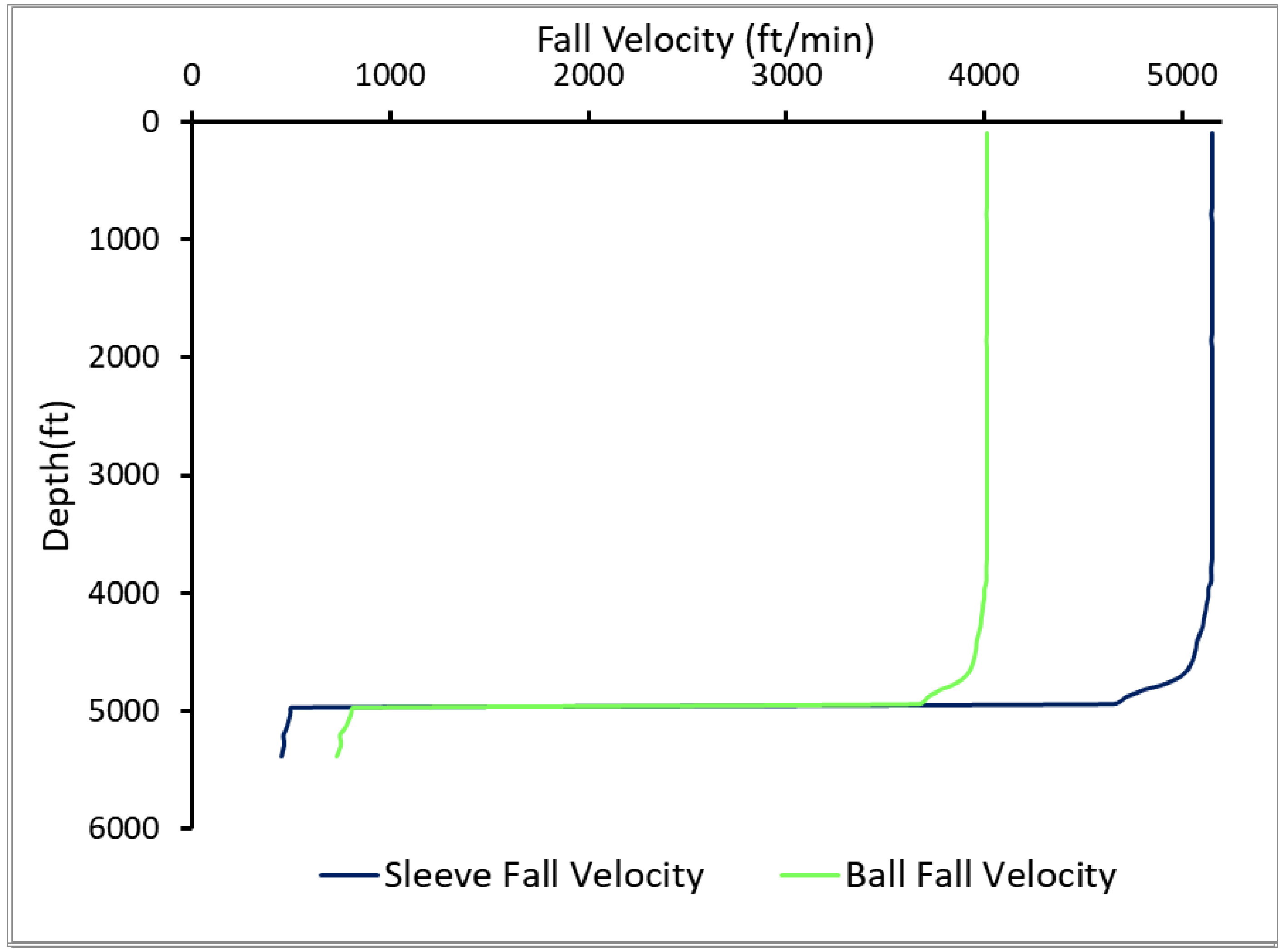


$\theta = 20°$

Shut-in and Afterflow

- Fall Stage
  - Shut-in time
    - Fall against static gas (faster)
      - Slows down in liquid column
  - Prod. valve open
    - Fall against multiphase flow
  - Afterflow time
    - Avoid early merging of ball and sleeve

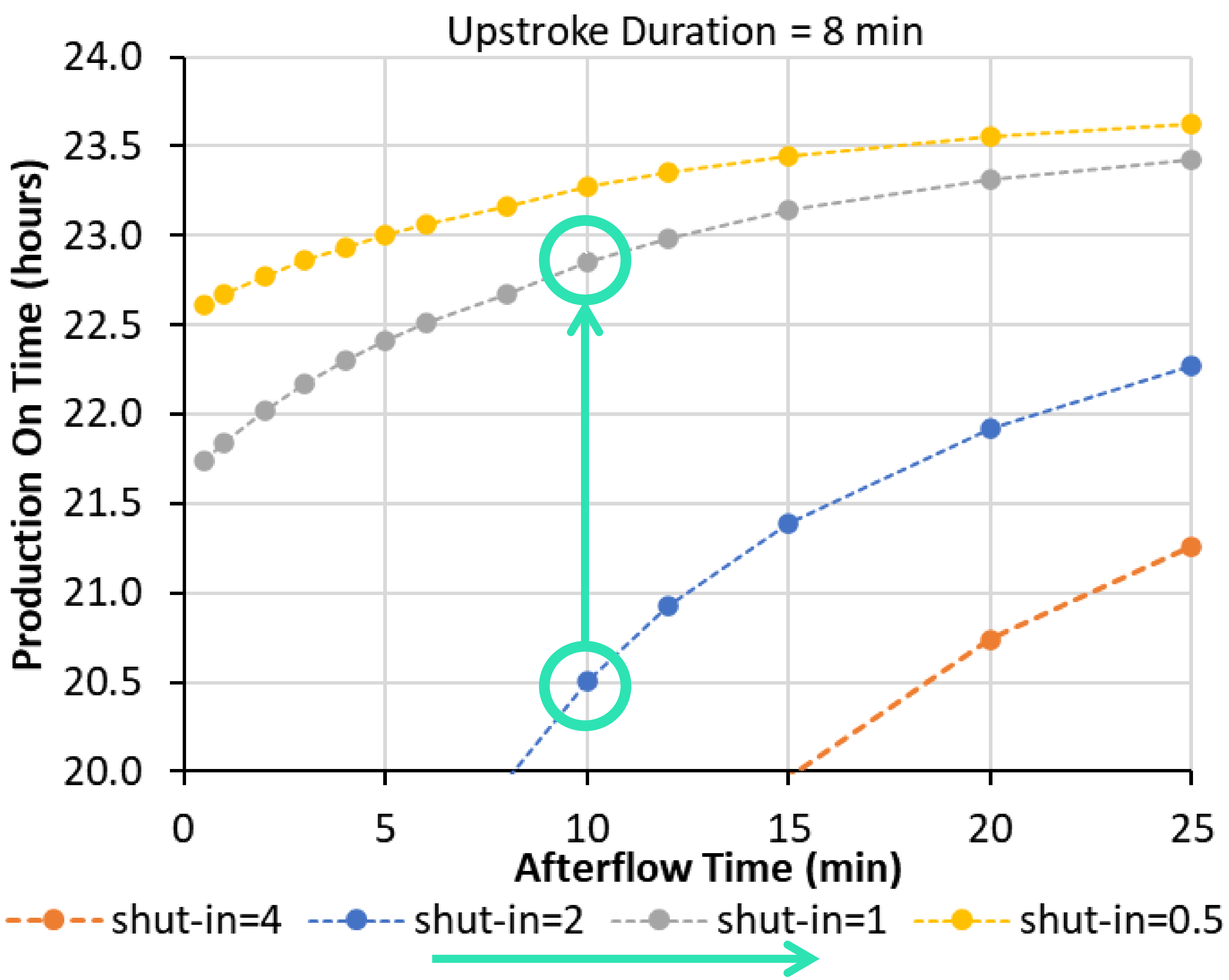
Shut-in = 13 seconds



Fall Results			Ball Results	
Fall Duration	0:01:58	h:mm:ss	0:01:52	h:mm:ss
Fall Velocity (Avg)	2750.35	ft/min	2882.89	ft/min
Fall Velocity (Max)	5146.83	ft/min	4010.92	ft/min
Kinetic Energy	8.86	J	0:00:00	h:mm:ss

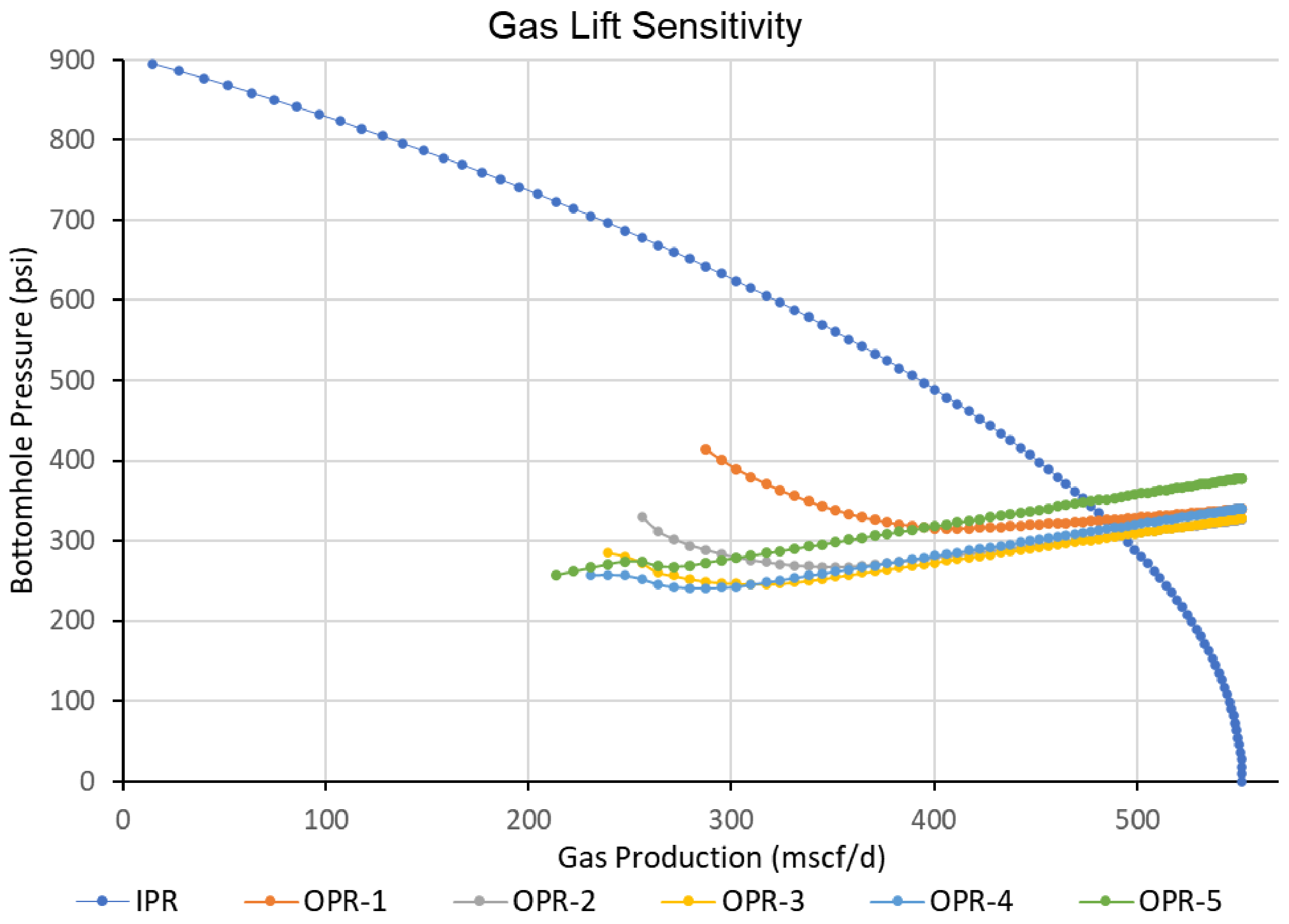
Shut-in and Afterflow

- Production On Time
  - More cycles -> More off-time
  - Afterflow time
    - Increasing the on time
    - Liquid loading
  - Shut-in time



Injection Rate

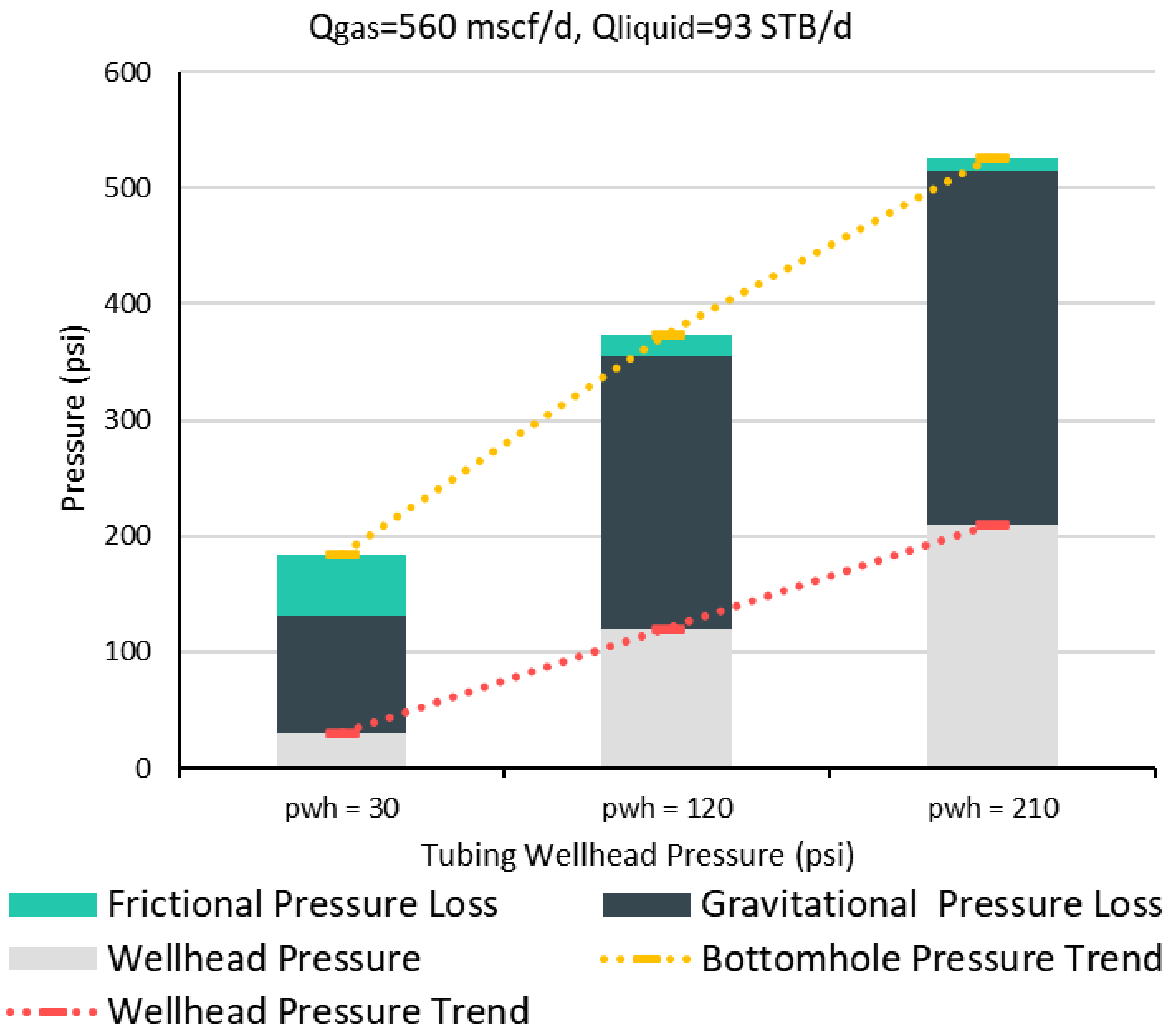
- Production optimization
  - Bottomhole pressure
    - Multiphase flow simulation
    - Plunger liquid slug removal
  - Plunger cycle time
  - Casing pressure
- Gas injection reduction
  - Minimum flow rate to surface
    - Well pad compressor down -> Allocate spare capacity



	Injection Rate (mscf/d)	Bottomhole Pressure (psi)	Cycle Duration (min)
Injection 1	0	325.84	16.2
Injection 2	140	307.23	12.1
Injection 3	260	306.38	10.3
Injection 4	420	316.00	9.0
Injection 5	720	347.39	7.6

Surface Compression with PAGL

- Decrease flowing bottomhole pressure
- Reduce gravitational pressure losses
  – Higher gas velocity, lower liquid holdup profile
  – Frictional pressure loss increase found to be marginal
- Lower separator pressure
  – More gas send to sales line
  – Less emissions from the tank
- Extend PAGL lifetime more than 2000 days
  – Lower tubing wellhead pressure
    - SPE 209760-MS



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Well Integrity

- Upstroke
  - Surface too fast (GAPL)
    - Pressure build-up
    - Dry runs
- Fall stage
  - Impartial cycle
    - Plunger not reaching bumper spring
    - Sleeve catching ball
  - Fall velocity
    - Bumper spring
    - Tubing deformation (Sayman et al., 2022)

Acknowledgements/Thanks & Questions

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