25th Annual CO_2 Conference

Theme Session I:
Unconventional Reservoir Cyclic Injection Projects

Presented at the 25th Annual CO_2 Conference

Thursday Dec 12th, 2019

Bush Convention Center

Midland, Texas

Eagle Ford Shale Cyclic Gas Injection

Evaluation of Field Results and Economics

25th Annual Midland CO_2 Conference December 12, 2019

Summary

- **2019 Eagle Ford Evaluation Report: by Shale IOR LLC**
- The Process and How we work unconventional EOR
- Early Pilot history matched compositional model
- Field Results from 1st Project started in 2014
- Field Results from recent Project started in 2017
- Economics Example: Profiles from History Matched Pilot
- Conclusions

Shale IOR Eagle Ford 2019 Report

- **Extensive Data Mined from RRC and Field**
  - Digital Data: H-12, H-13 data, Lease filings, Production, Injection
  - Engineering Report, DCA plots, drone pictures, research and files
- **Pad Level Production: EUR and IOR Evaluation**
  - 30 Pads/Units conducting Huff-n-Puff by 6 operators, since 2013
  - Systematic evaluation of EUR decline
- **Reservoir Simulation Guidance**
  - Expected IOR profile and behavior via Pilot History Match
  - Gas Injection Cycles, Time, Rates, etc. Compared to Field Results
- **Results**
  - Systematic conclusions based on all projects are revealing
  - Pilot outcomes vs. Commercial Project Operations
  - Economic analysis and Operational efficiency understanding

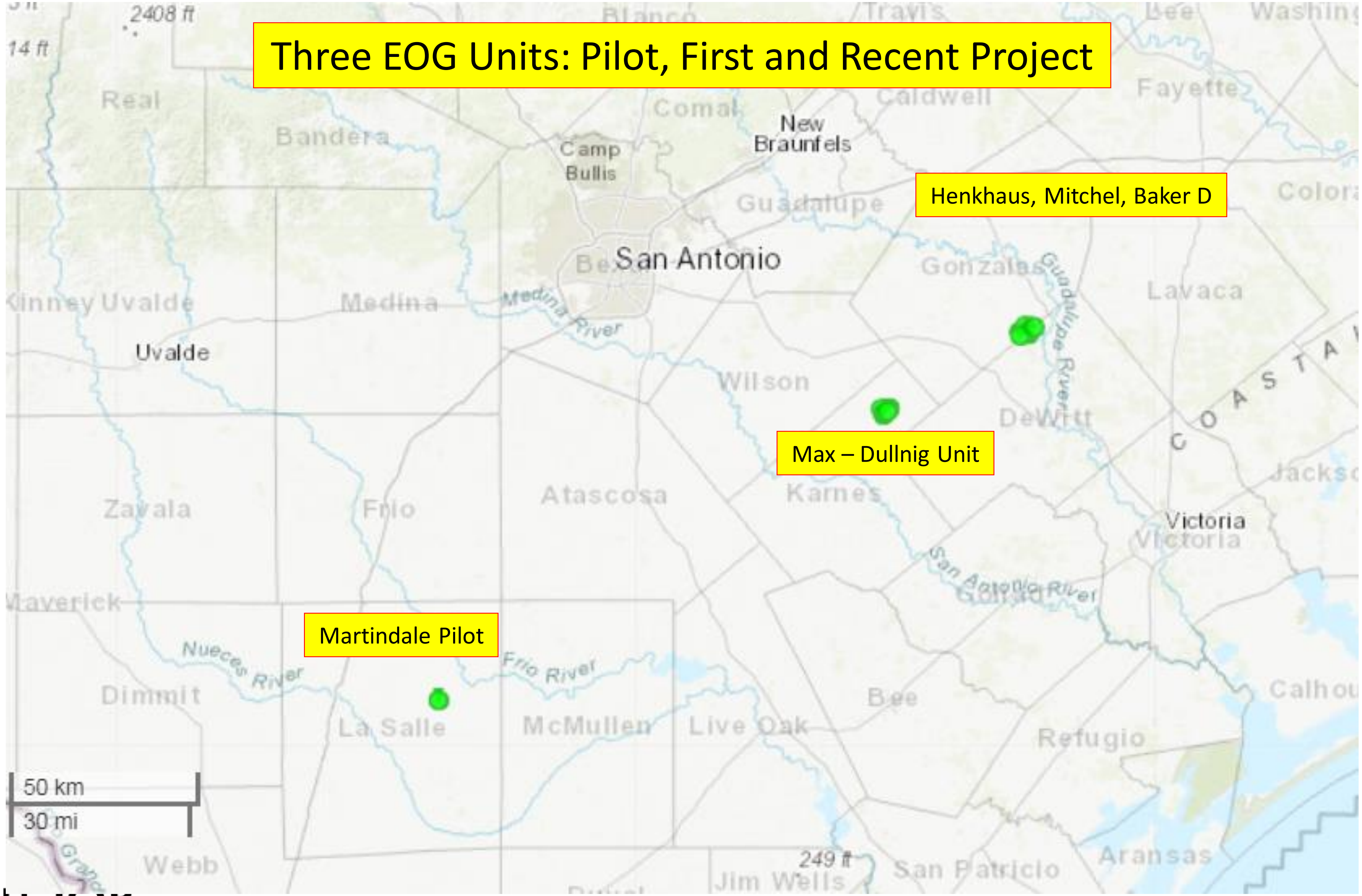
Cyclic Gas Injection: Process

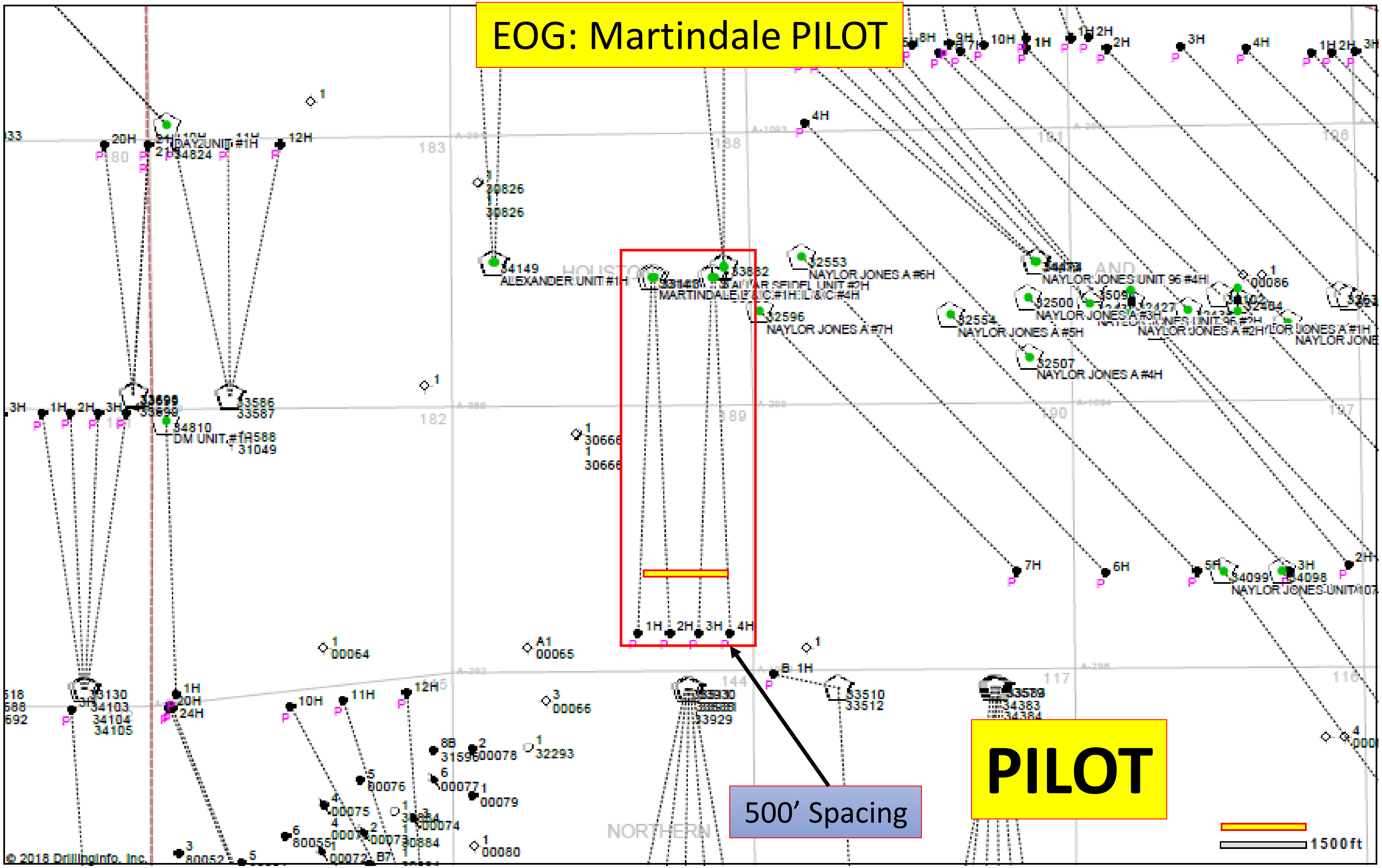
- **Inject hydrocarbon gas at maximum pressure**
  - Swell, vaporize, and mobilize: Single Phase Flow above critical condition
  - NOT displacement - > Not Miscible (see Whitson: URTeC 539)
  - Dissolve/vaporize C6+ oil components into gas
  - Cyclic injection > Servicing the SRV or fracture network
  - Matrix penetration > 1 foot / year
  - Project life 15+ years
- **Inject for 30-40 days, then Produce 30-40 days**
- **100%: Oil Rate Benefit after first injection period (fill-up)**
- **Requires Compositional Reservoir Simulation**
  - **Design, Operate, Optimize-> Value C6+ Components**

How we work Unconventional EOR/IOR

- Understand Process: PVT Phase behavior
  - World class experience: from Shale IOR, IRT, Whitson
- Understand Field Results: Eagle Ford IOR Evaluation Report
  - 30 IOR Projects: Document, analyze, reservoir model, evaluate
- Match Wells & Process: Pilot History Match
  - High resolution element 14 component process predictions
- Scale Process: Wells then Field/Pad
  - IOR Scaling tool in Excel
- Project Evaluations and Economics
  - AFE Cost, Project Optimization, Maximize Value

Three EOG Units: Pilot, First and Recent Project




EOG: Martindale PILOT
PILOT
500' Spacing
MARTINDALE
ALEXANDER UNIT #1H
NAYLOR JONES A #6H
NAYLOR JONES A #7H
NAYLOR JONES A #5H
NAYLOR JONES A #4H
NAYLOR JONES UNIT 96 #4H
1H 2H 3H 4H
1500ft
NORTHERN
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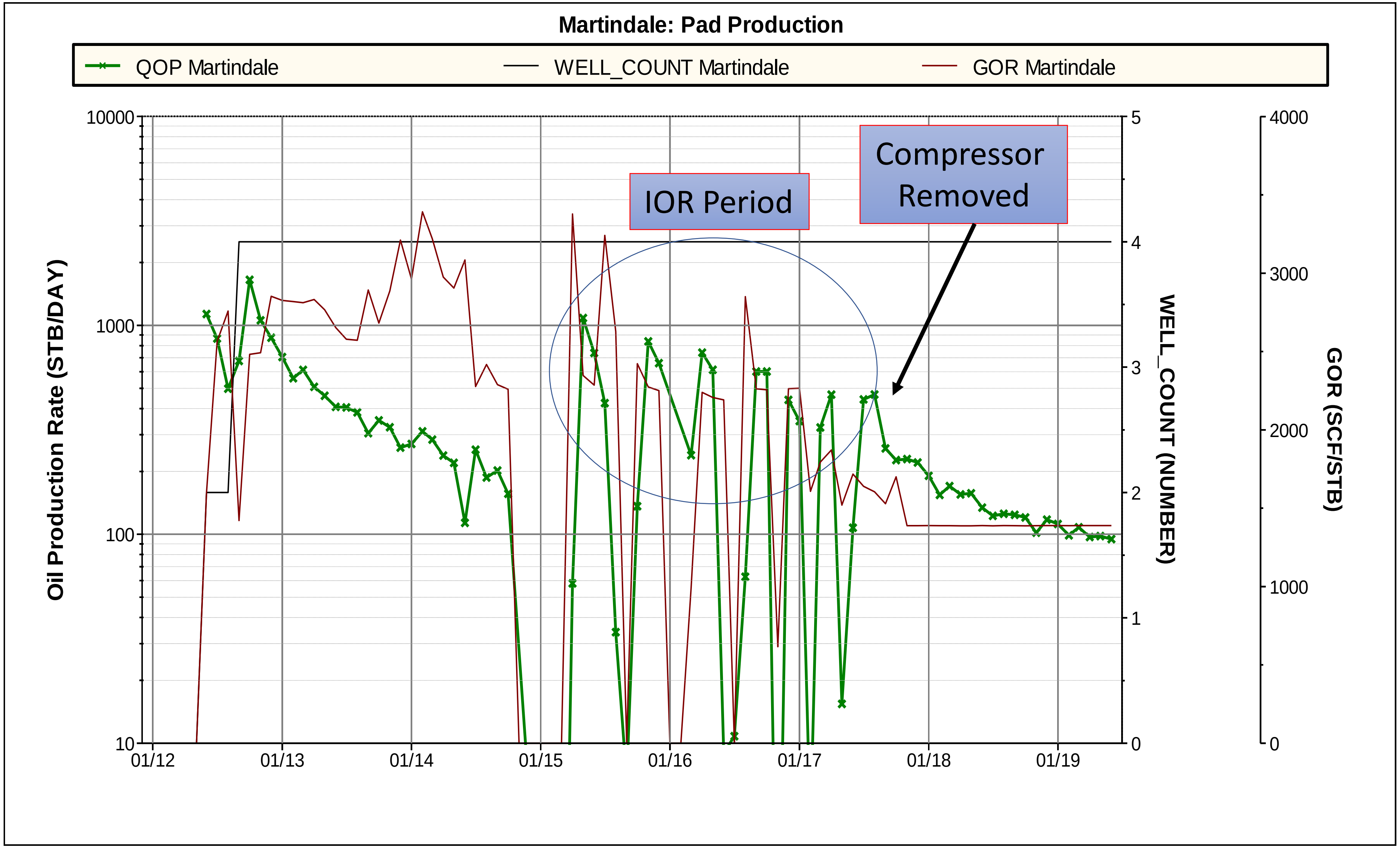
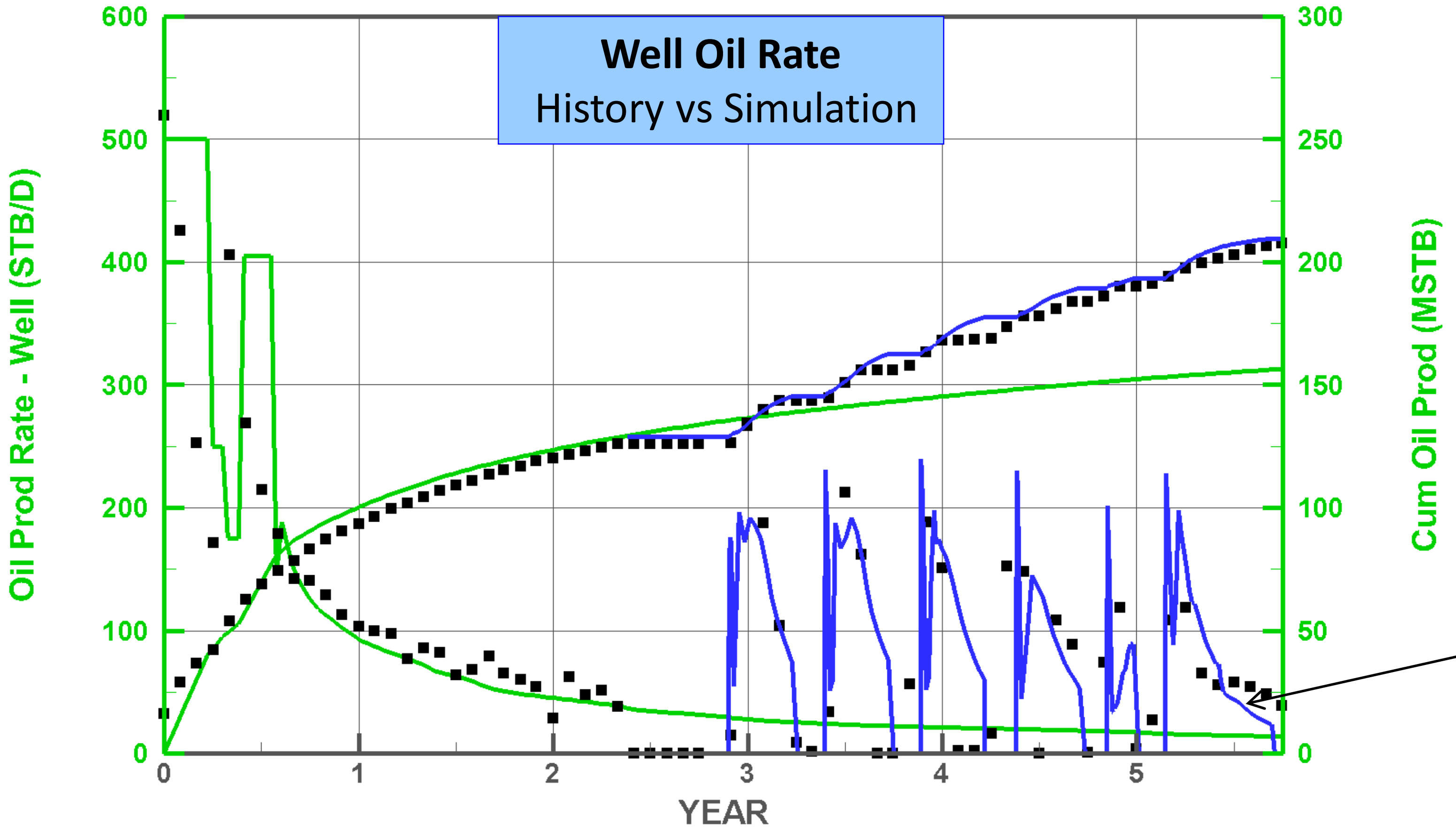

Martindale: Pad Production
QOP Martindale
WELL_COUNT Martindale
GOR Martindale
Oil Production Rate (STB/DAY)
WELL_COUNT (NUMBER)
GOR (SCF/STB)
10000
1000
100
10
5
4
3
2
1
0
4000
3000
2000
1000
0
01/12
01/13
01/14
01/15
01/16
01/17
01/18
01/19
IOR Period
Compressor Removed

Martindale History Match



Fully compositional, detailed mechanistic model

Green – Base Depletion
Black – Historical Data
Blue – IOR Match

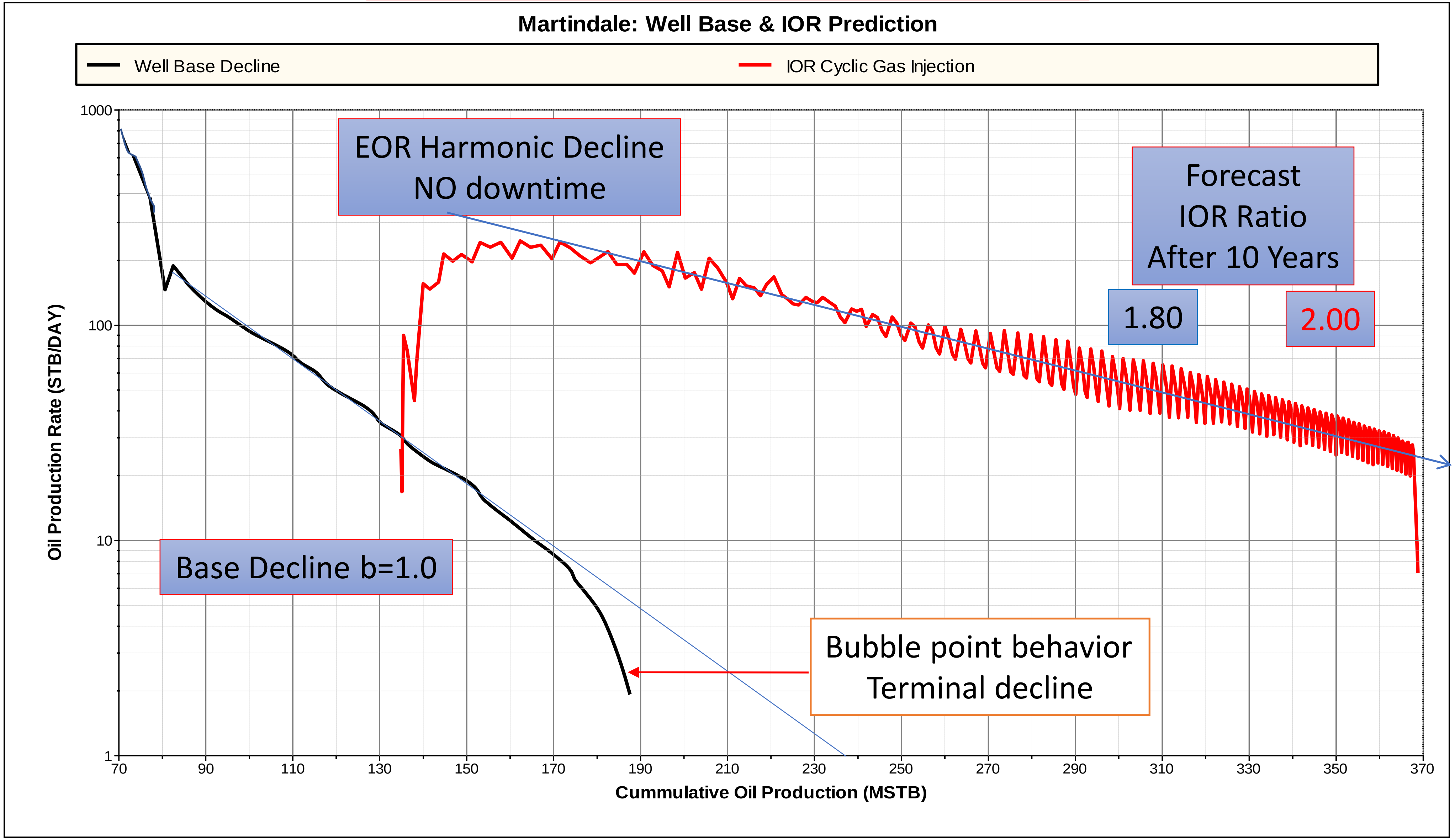
Matches IOR benefit

Reasonable late time behavior after compressors removed

Martindale Pilot: Simulation history match

- We believe that **there is room for EOR improvement** based on our compositional understanding
- EOG projects are yielding IOR Ratio = 1.80+ (80% increase in recovery) after 10 years
  - If gas injection volumes are maintained
- Simulation results also show large uplift with optimal gas composition and cycle operations
- The compositional prediction is best practice

Simulation Results: WELL Base & EOR



Shale IOR Improved Oil Recovery

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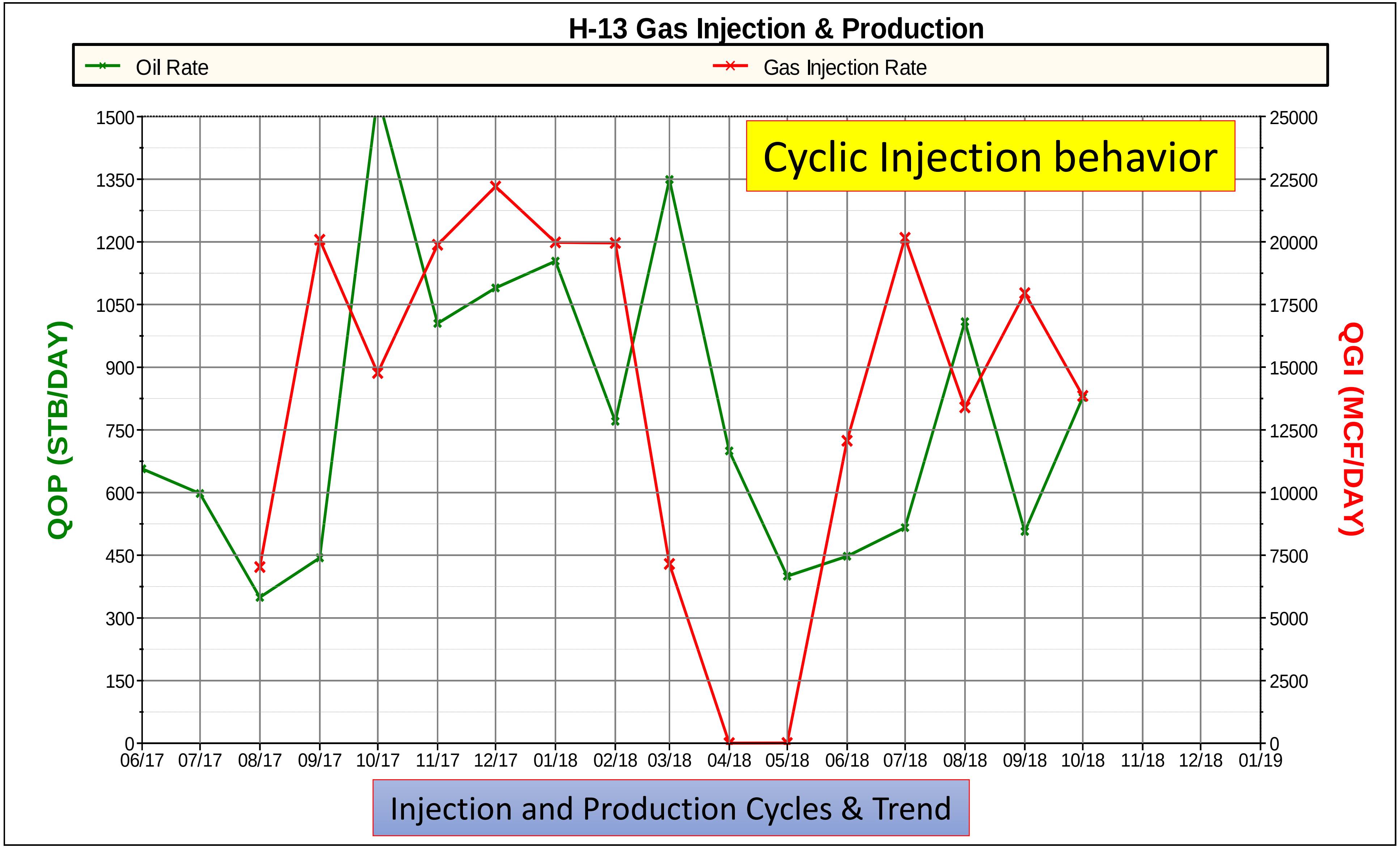
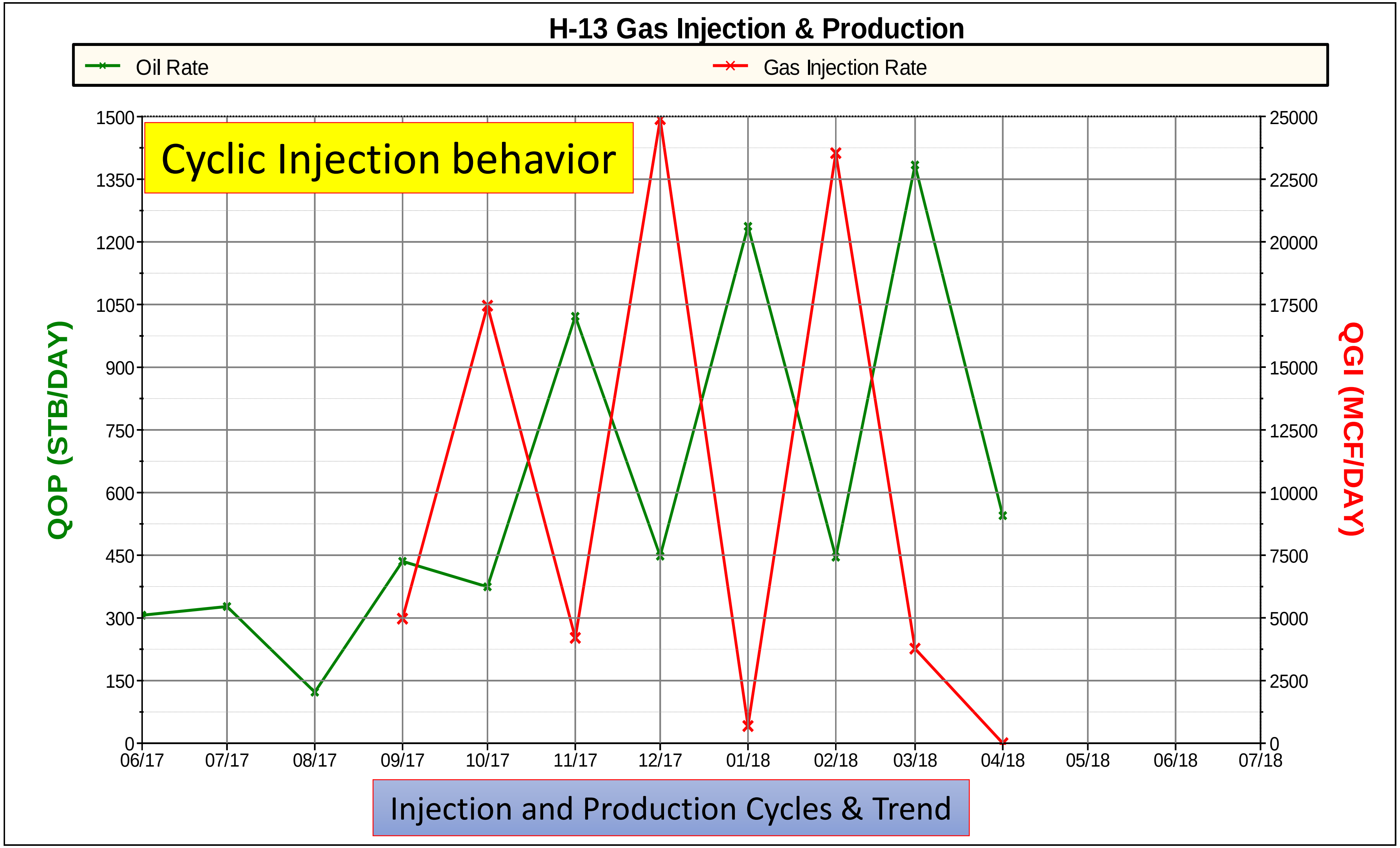

H-13 Gas Injection & Production
Oil Rate
Gas Injection Rate
Cyclic Injection behavior
QOP (STB/DAY)
QGI (MCF/DAY)
1500
1350
1200
1050
900
750
600
450
300
150
0
25000
22500
20000
17500
15000
12500
10000
7500
5000
2500
0
06/17 07/17 08/17 09/17 10/17 11/17 12/17 01/18 02/18 03/18 04/18 05/18 06/18 07/18 08/18 09/18 10/18 11/18 12/18 01/19
Injection and Production Cycles & Trend



H-13 Gas Injection & Production
Oil Rate
Gas Injection Rate
Cyclic Injection behavior
QOP (STB/DAY)
QGI (MCF/DAY)
1500
1350
1200
1050
900
750
600
450
300
150
0
25000
22500
20000
17500
15000
12500
10000
7500
5000
2500
0
06/17
07/17
08/17
09/17
10/17
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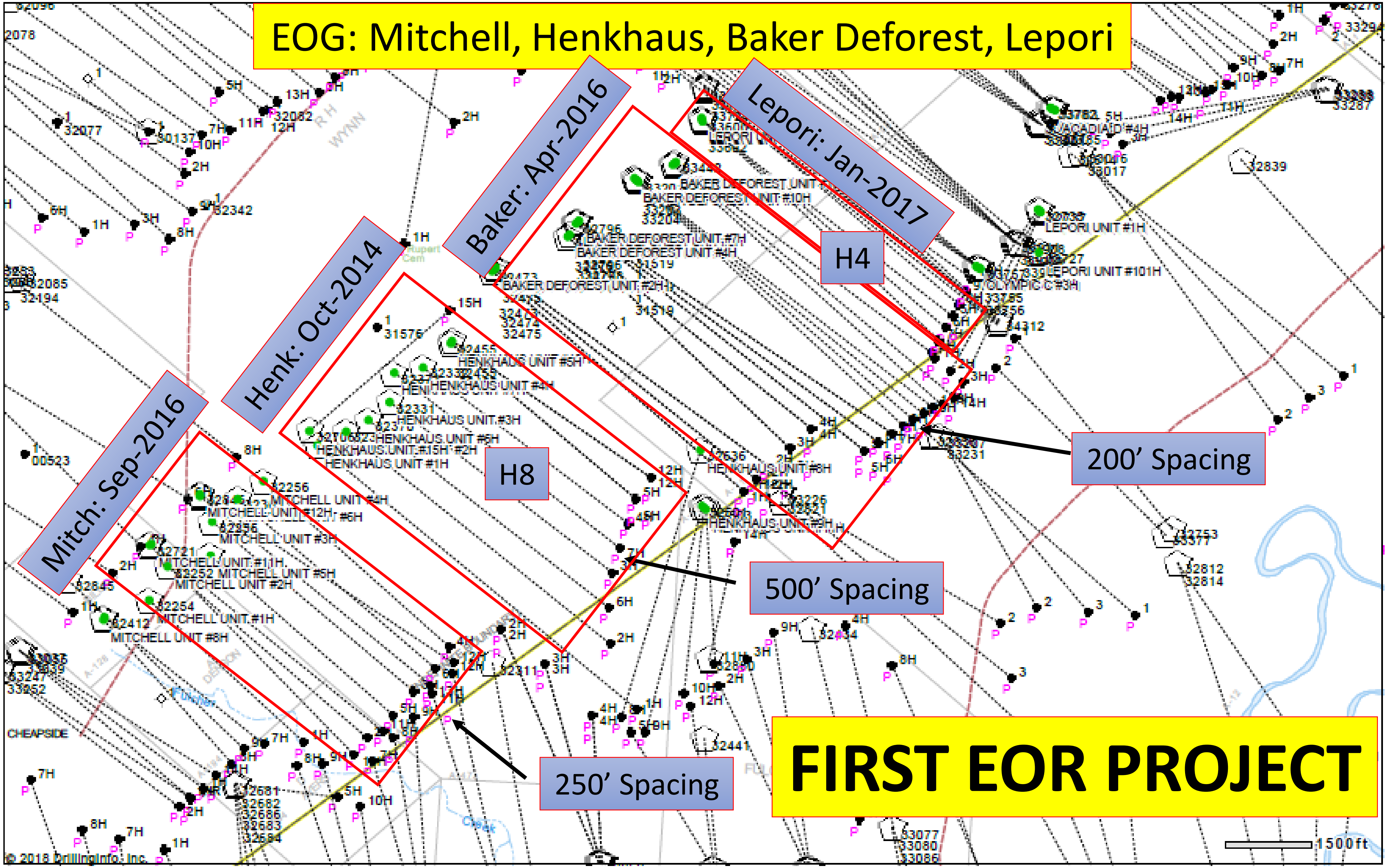
07/18
Injection and Production Cycles & Trend



SHALE TOR Improved Oil Recovery

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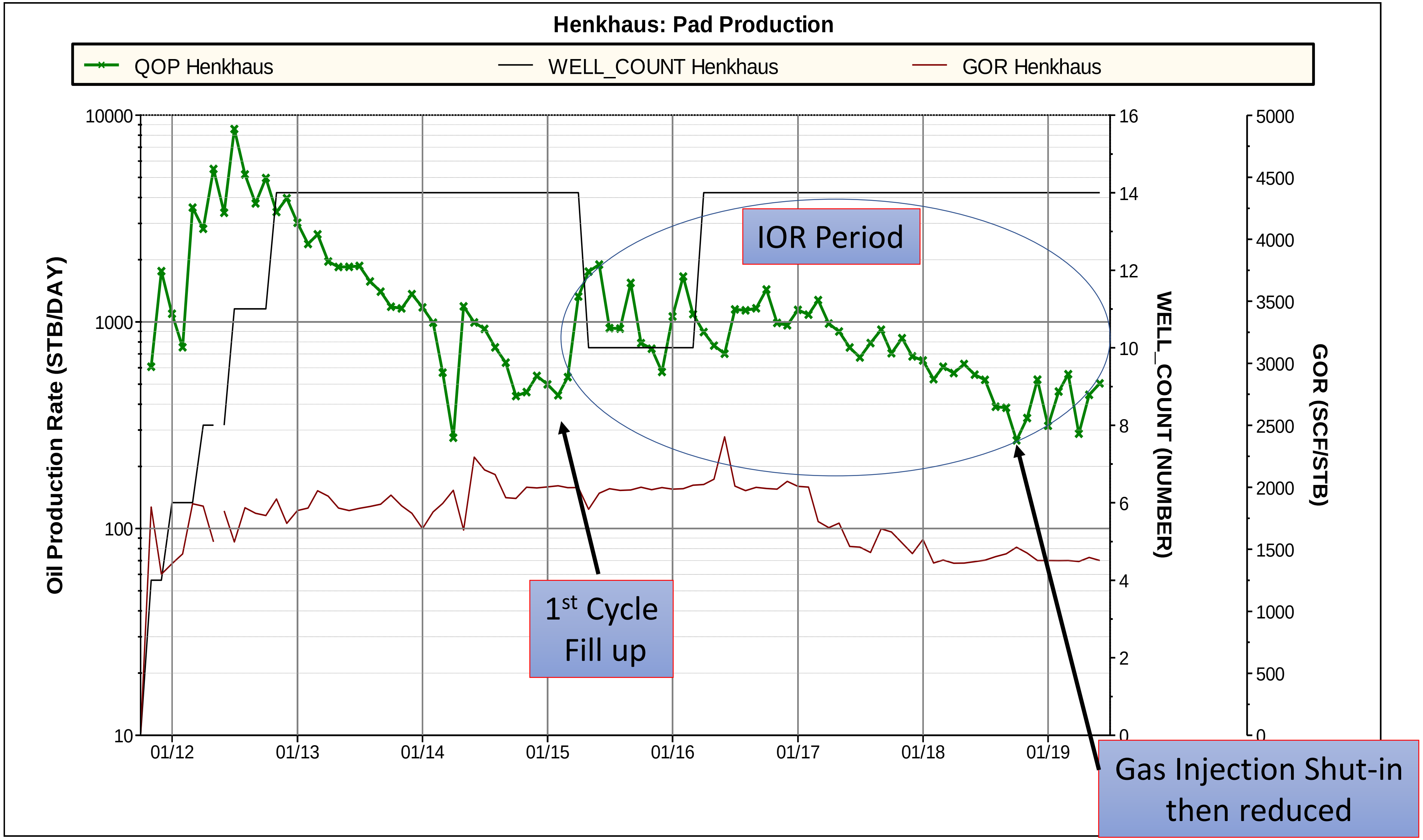
4.5 Years of CGEOR History



SHALE IOR
Improved Oil Recovery

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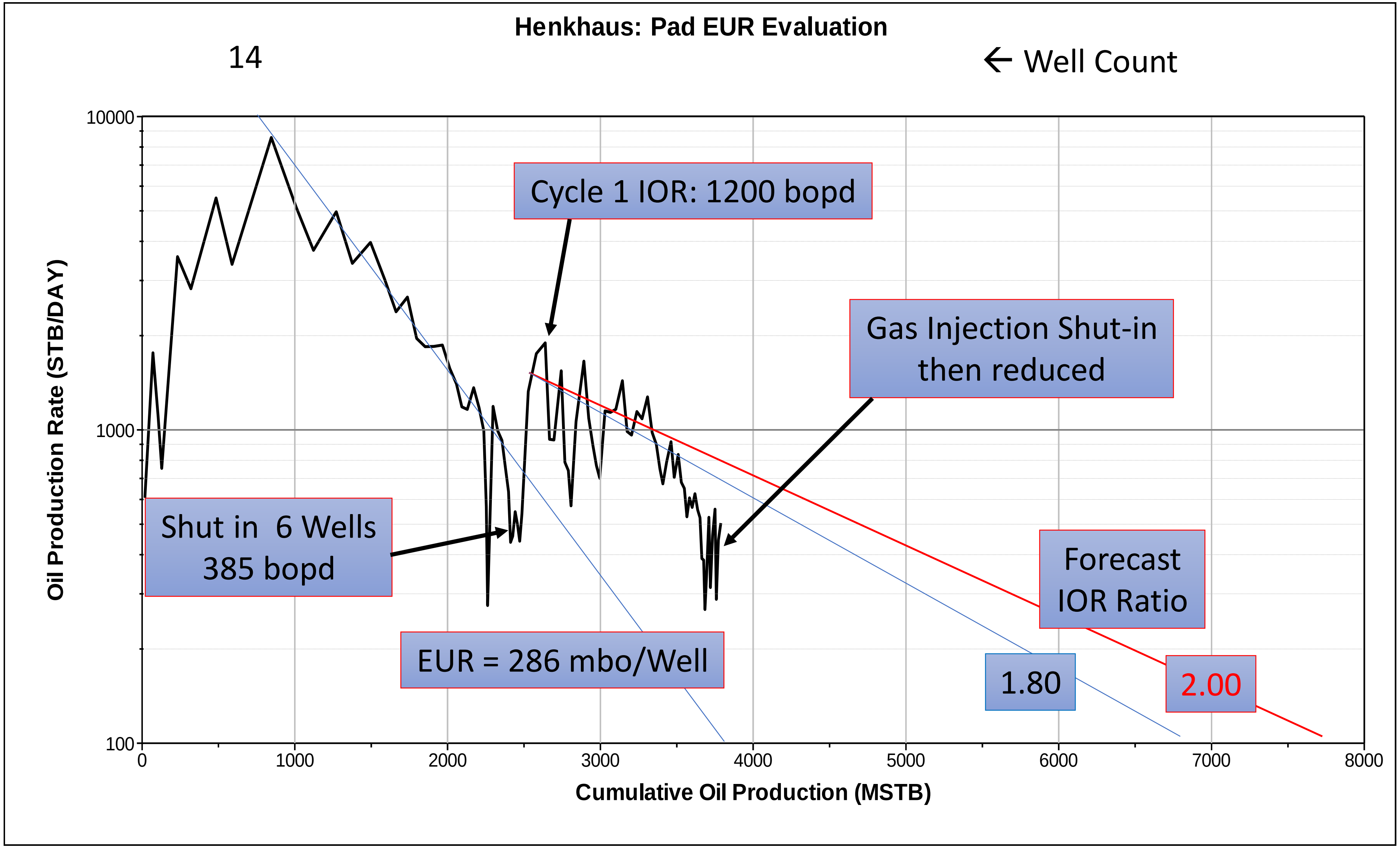
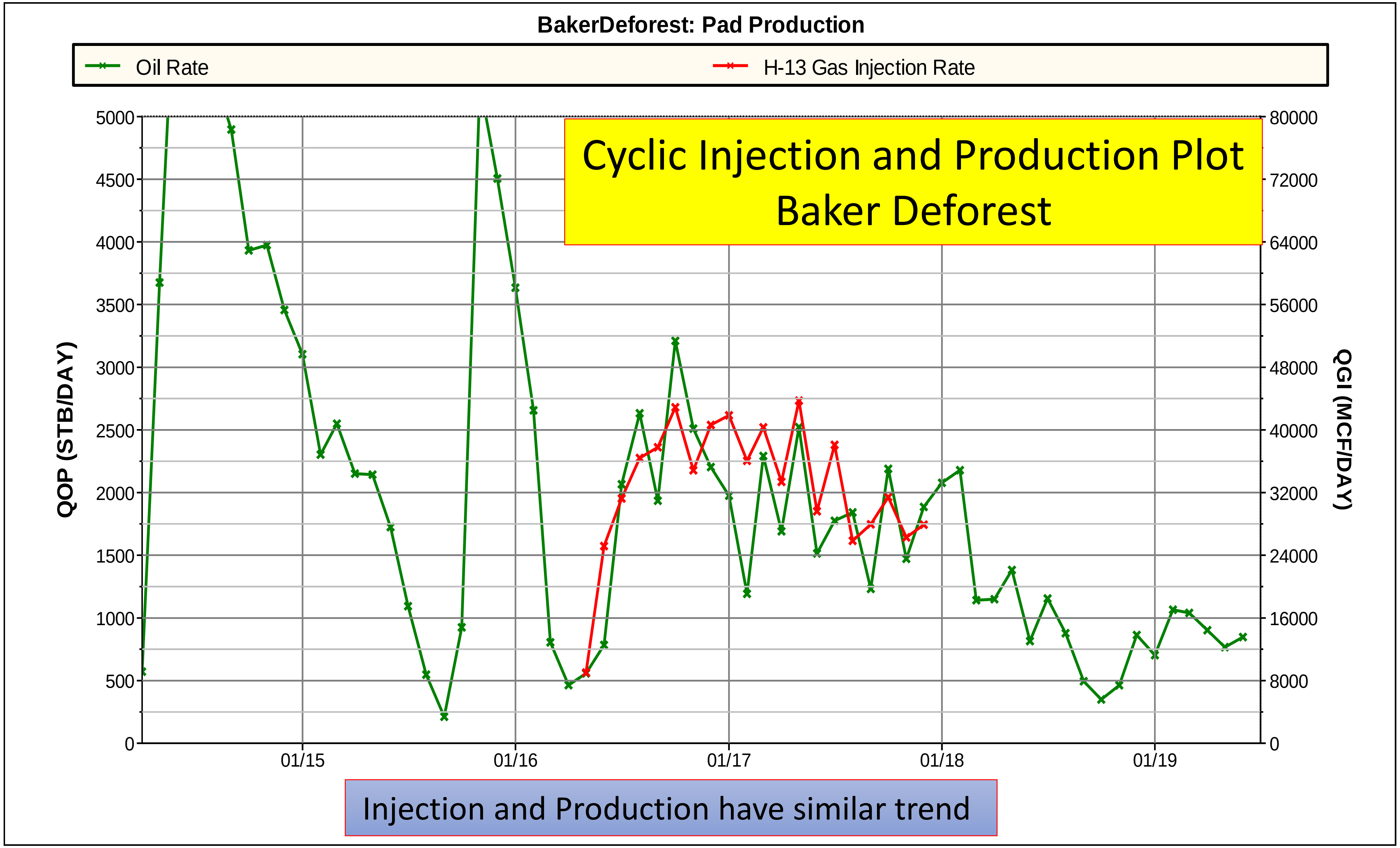
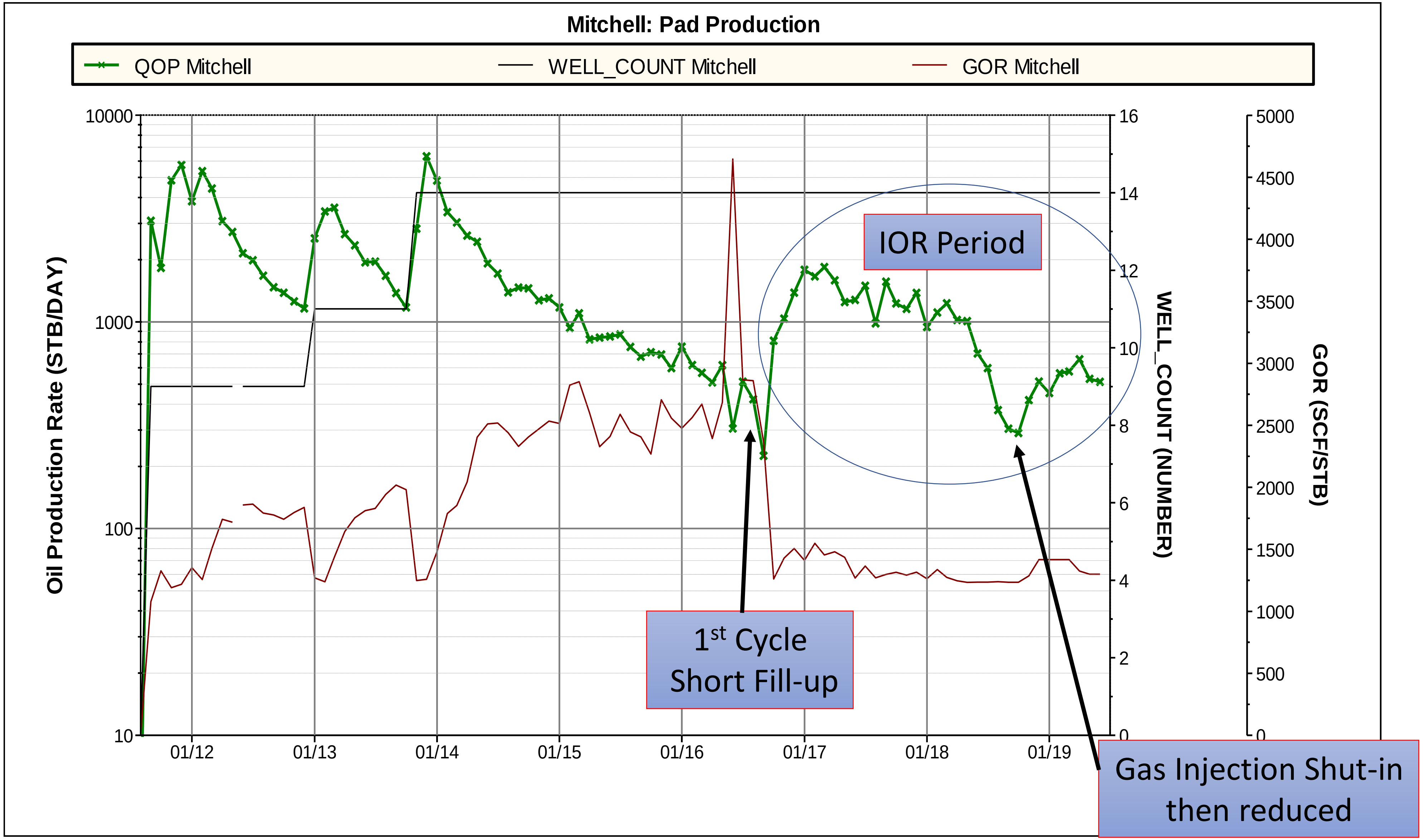
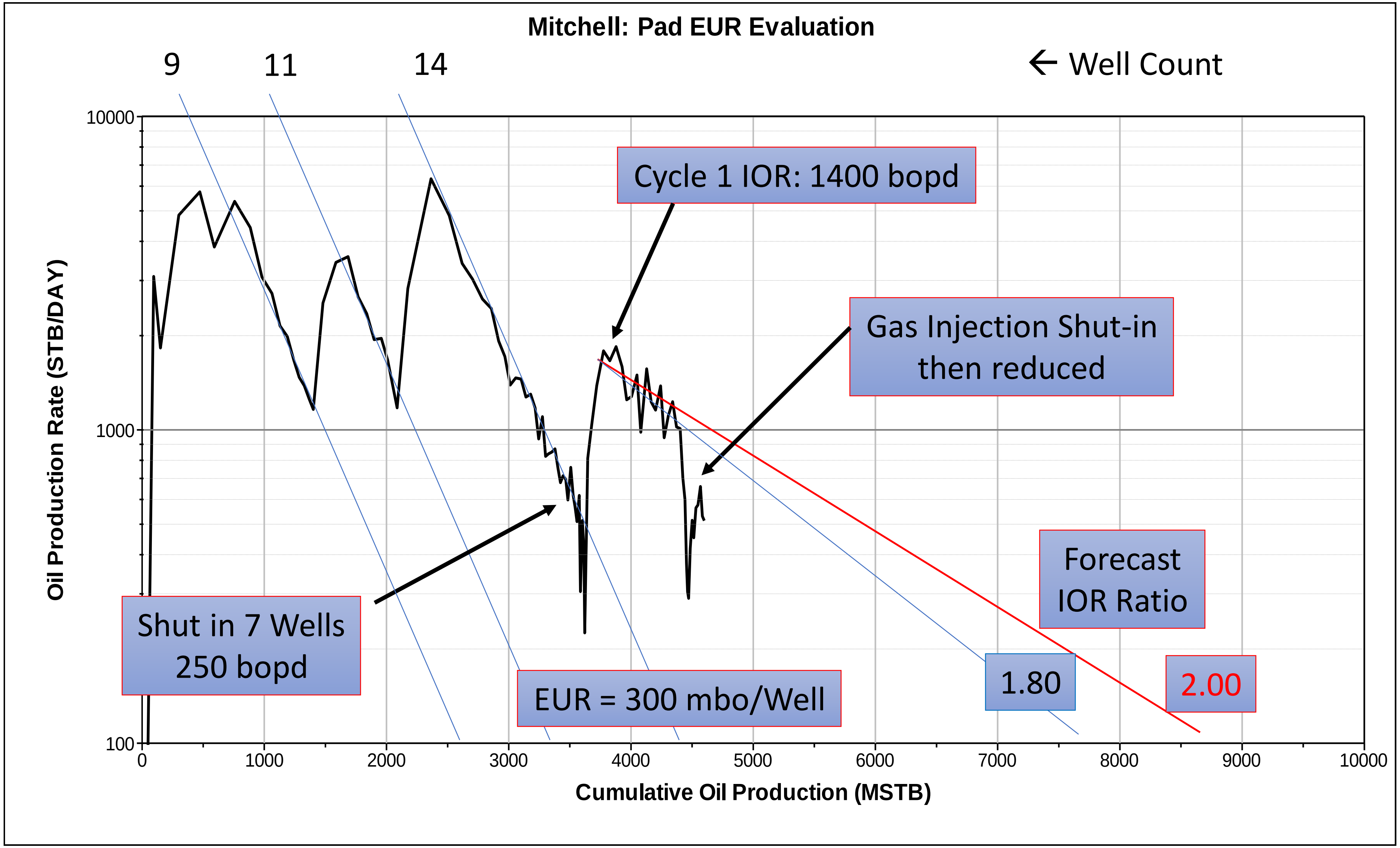

Henkhaus: Pad EUR Evaluation
14
← Well Count
Cycle 1 IOR: 1200 bopd
Gas Injection Shut-in then reduced
Shut in 6 Wells 385 bopd
EUR = 286 mbo/Well
Forecast IOR Ratio
1.80
2.00
Oil Production Rate (STB/DAY)
10000
1000
100
0
1000
2000
3000
4000
5000
6000
7000
8000
Cumulative Oil Production (MSTB)



BakerDeforest: Pad Production
Oil Rate
H-13 Gas Injection Rate
Cyclic Injection and Production Plot
Baker Deforest
QOP (STB/DAY)
QGI (MCF/DAY)
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
80000
72000
64000
56000
48000
40000
32000
24000
16000
8000
0
01/15
01/16
01/17
01/18
01/19
Injection and Production have similar trend

3 Years of CGEOR History





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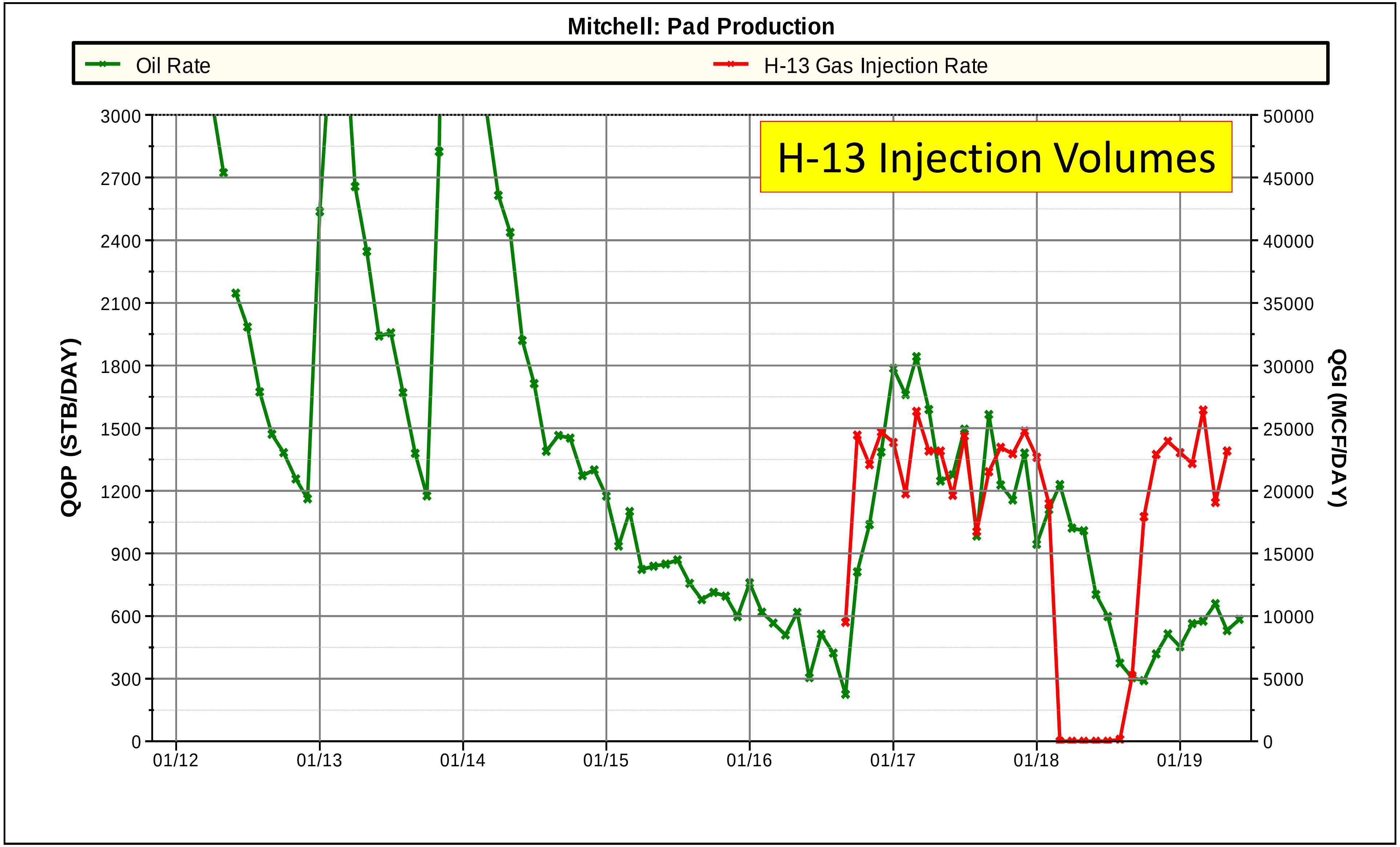


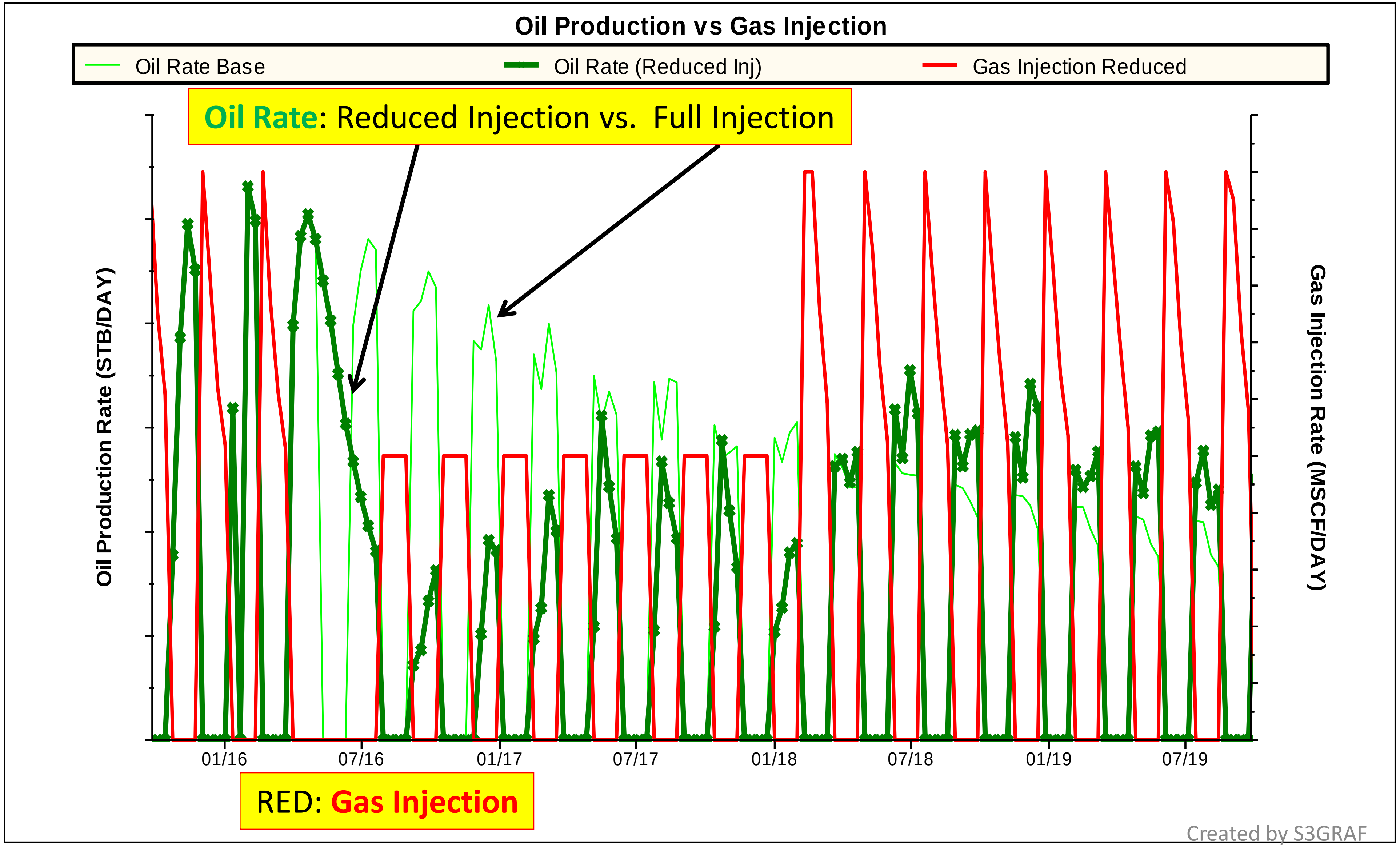
Mitchell: Pad Production
Oil Rate
H-13 Gas Injection Rate
H-13 Injection Volumes
QOP (STB/DAY)
QGI (MCF/DAY)
3000
2700
2400
2100
1800
1500
1200
900
600
300
0
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
01/12
01/13
01/14
01/15
01/16
01/17
01/18
01/19

Observations from Henkhaus, Baker, Mitchell

- The first CGEOR project now has 5 years of IOR history
- NO FAILURES: We find all projects have similar uplift per Well
- CGEOR is on track to achieve 80% additional recovery, as per history match, given gas injection is maintained
- EOG reported H-13's shows gas injection has been reduced for 6-9 months in 2018/19 and the oil production follows
  - Some operators have reported the issue being Well head leaks
- Operational efficiency while injecting gas appears to be difficult as compressors are far from Peak Utilization
  - Cycle Well Operations create issues to optimize Compression

Simulation of Gas Injection Downtime

- During 2018 EOG sites had significant injection downtime (slide 176)
  - We have shown that EOR oil also follows gas injection
- Reservoir simulation using the Martindale match was used to verify how injection downtime effects long term EOR oil production
- The simulation model was run with the following change in gas injection
  - Shut in injection for 2 cycle periods or 80 days
  - Start injection back up at 50% rate for 18 months
  - Full injection for remaining life
- The following plots compare downtime case with full injection
  - Results show that it takes 8 years to restore IOR Ratio (Cume Oil)



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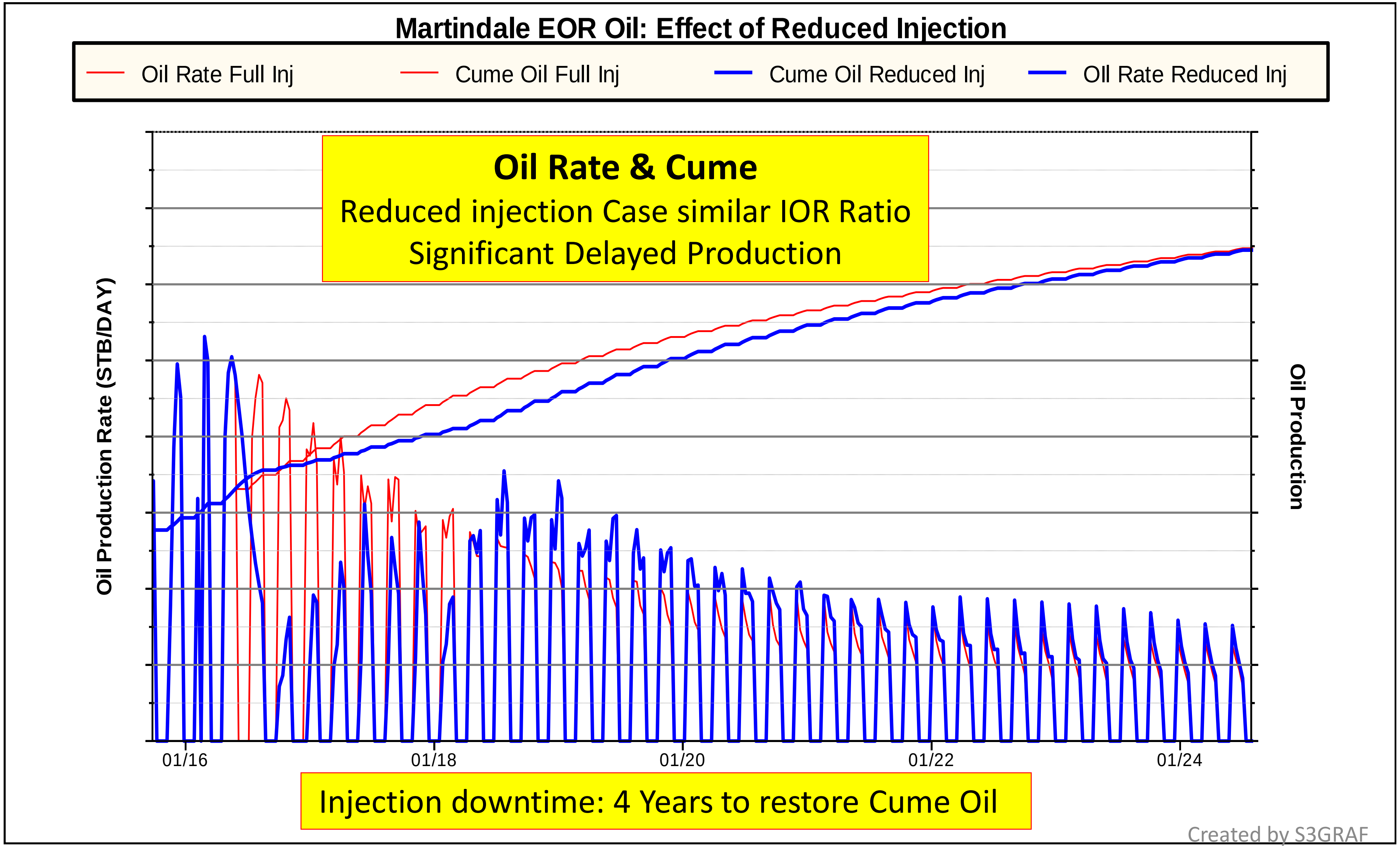

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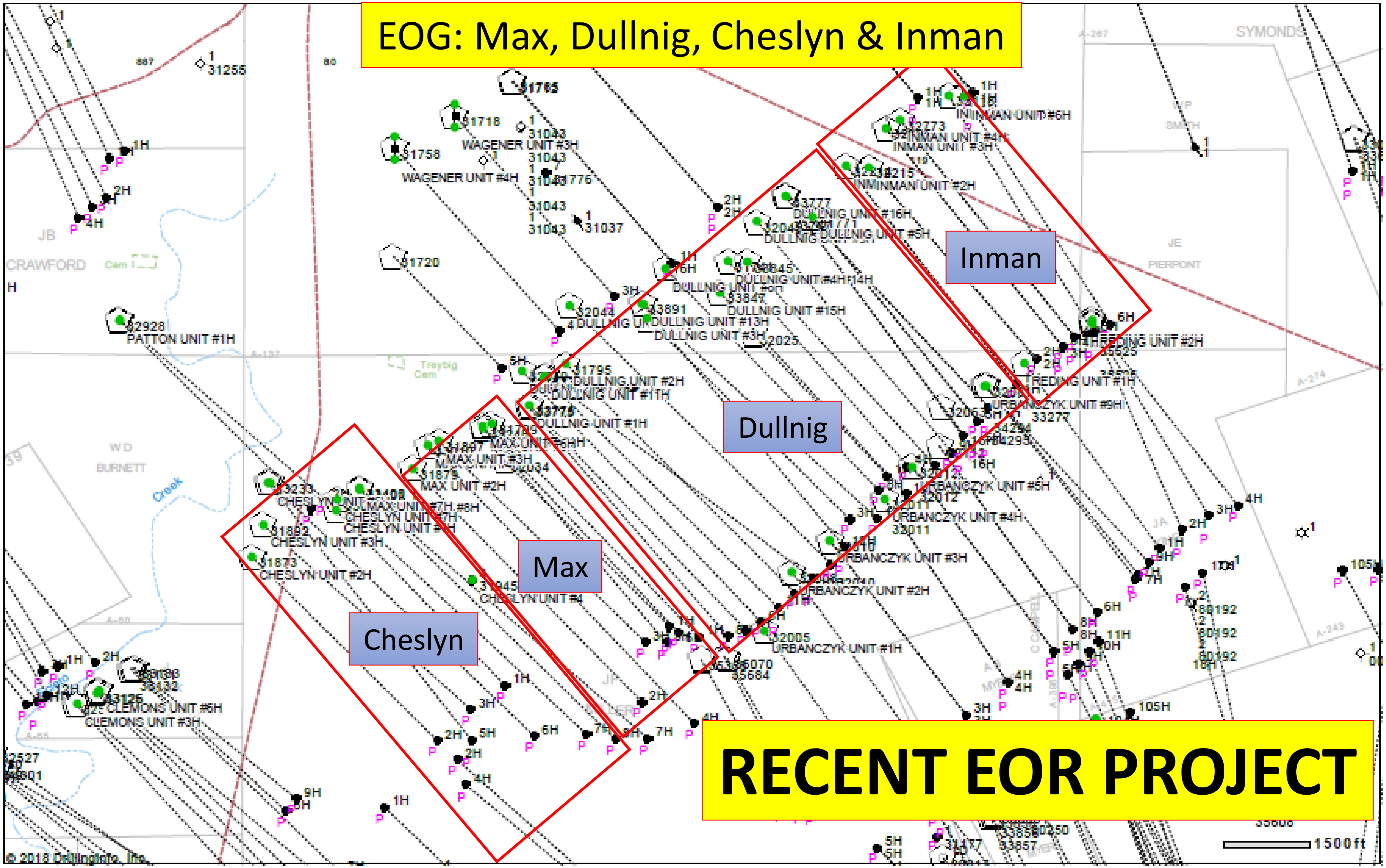
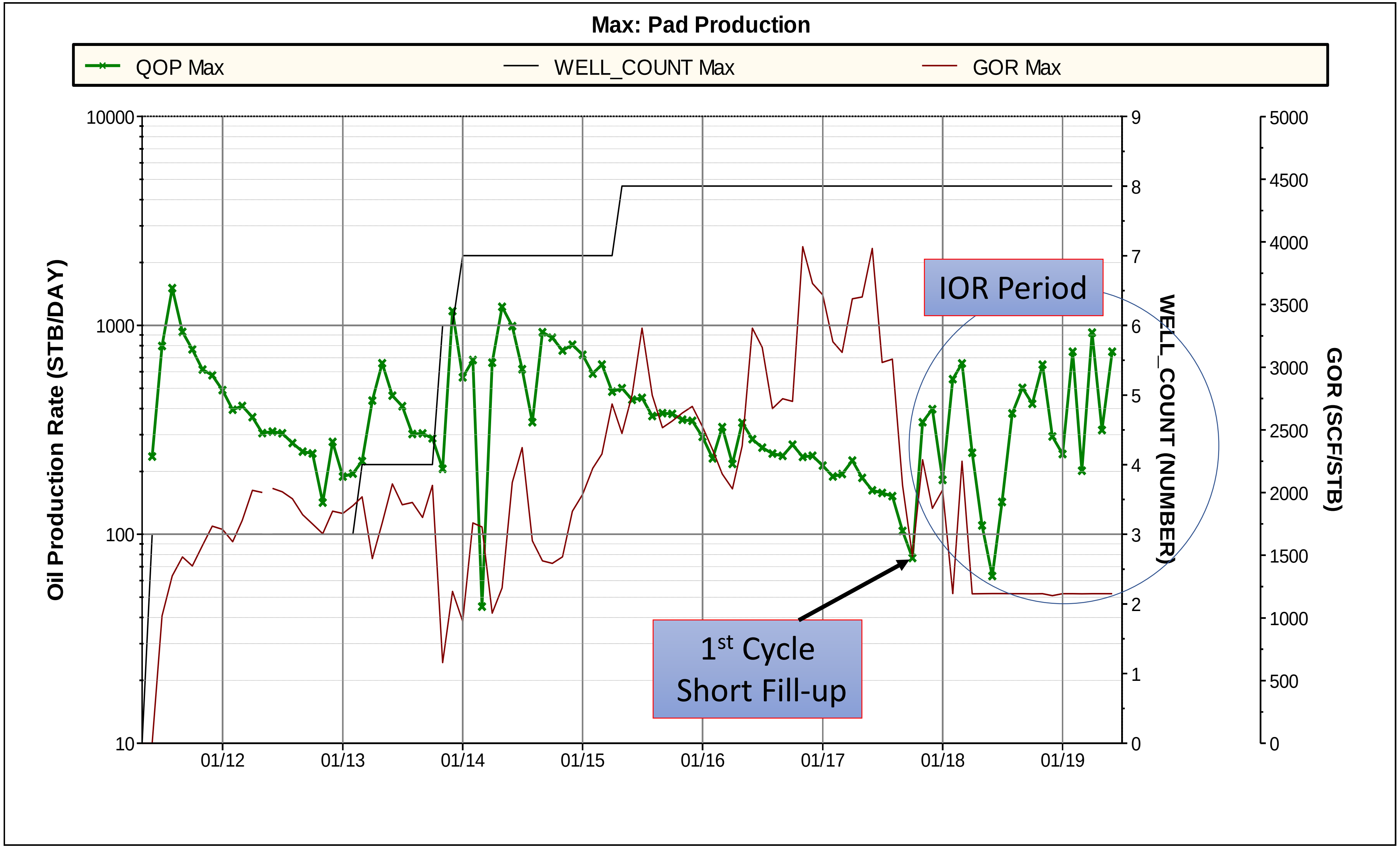
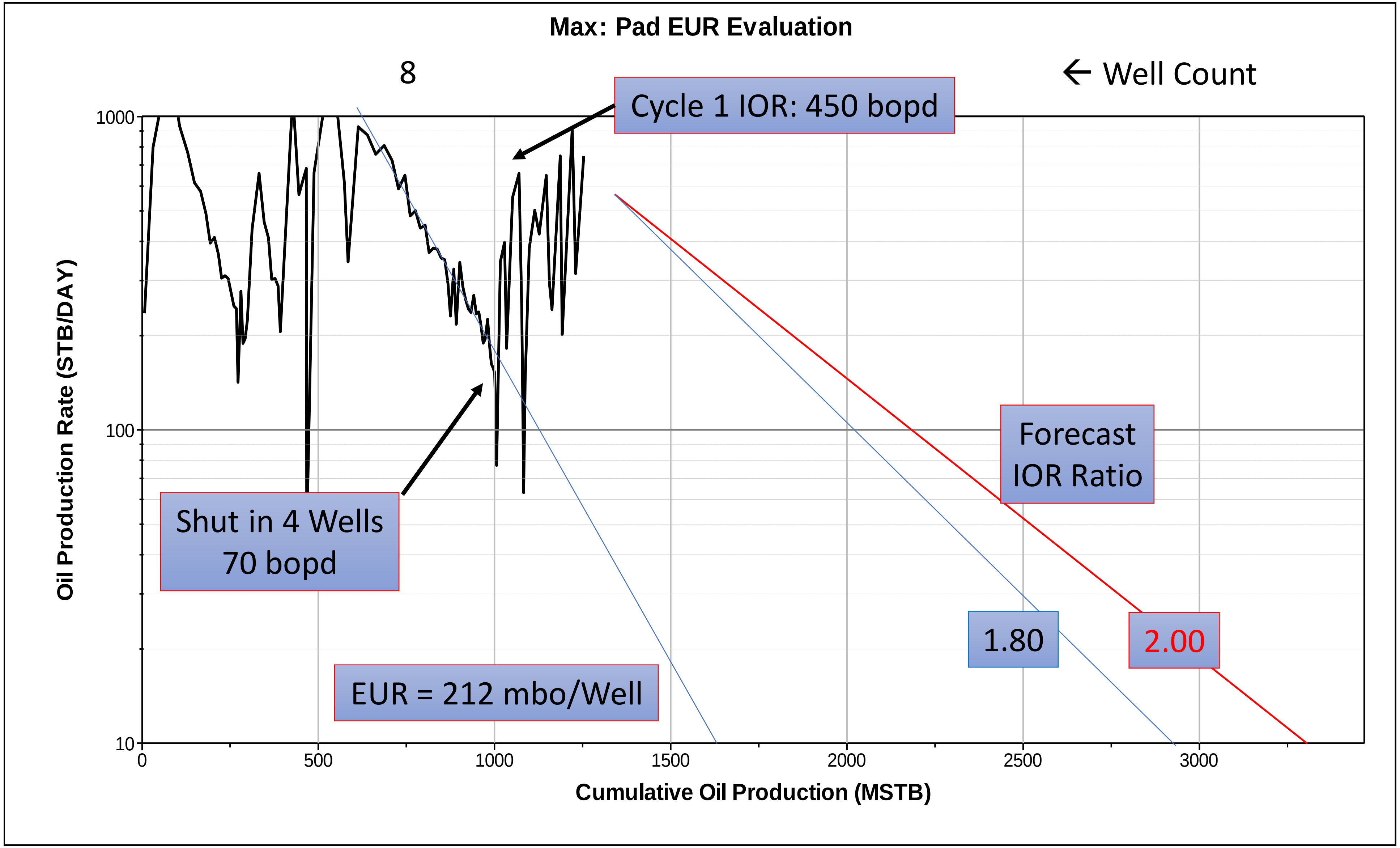
EOG: Max, Dullnig, Cheslyn & Inman



RECENT EOR PROJECT



Max: Pad Production
QOP Max
WELL_COUNT Max
GOR Max
Oil Production Rate (STB/DAY)
WELL_COUNT (NUMBER)
GOR (SCF/STB)
10000
1000
100
10
9
8
7
6
5
4
3
2
1
0
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
01/12
01/13
01/14
01/15
01/16
01/17
01/18
01/19
IOR Period
1st Cycle
Short Fill-up



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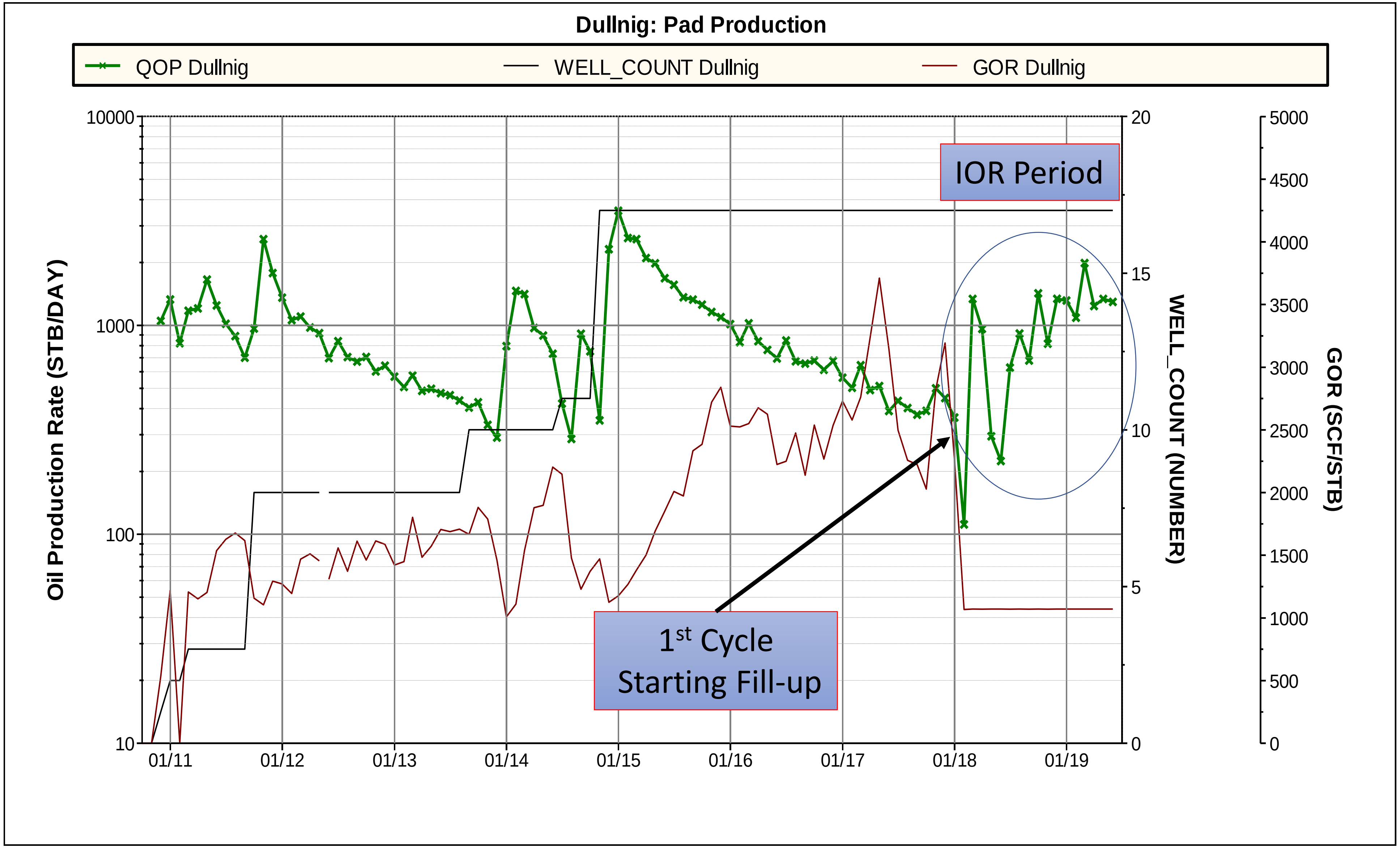

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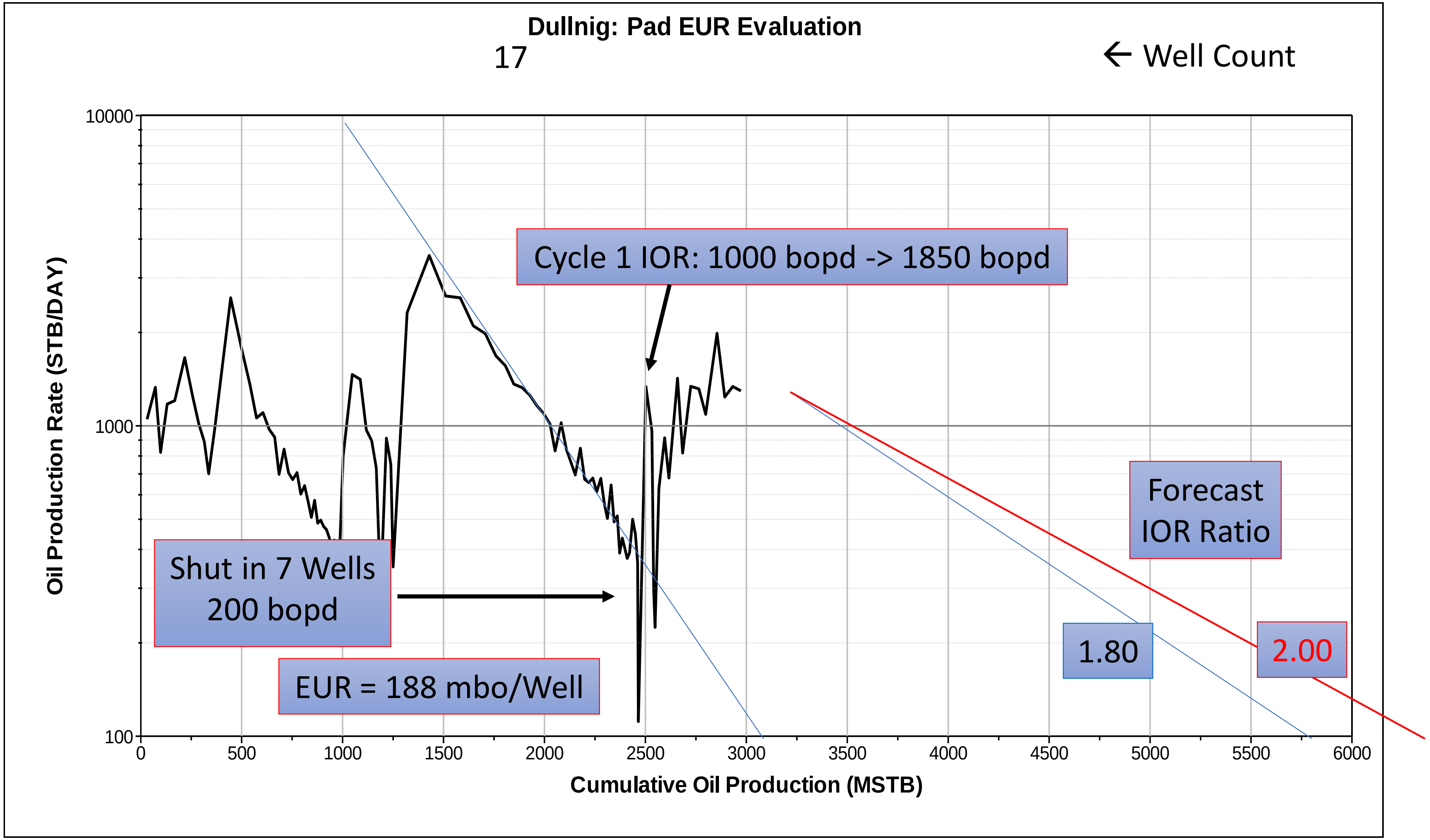

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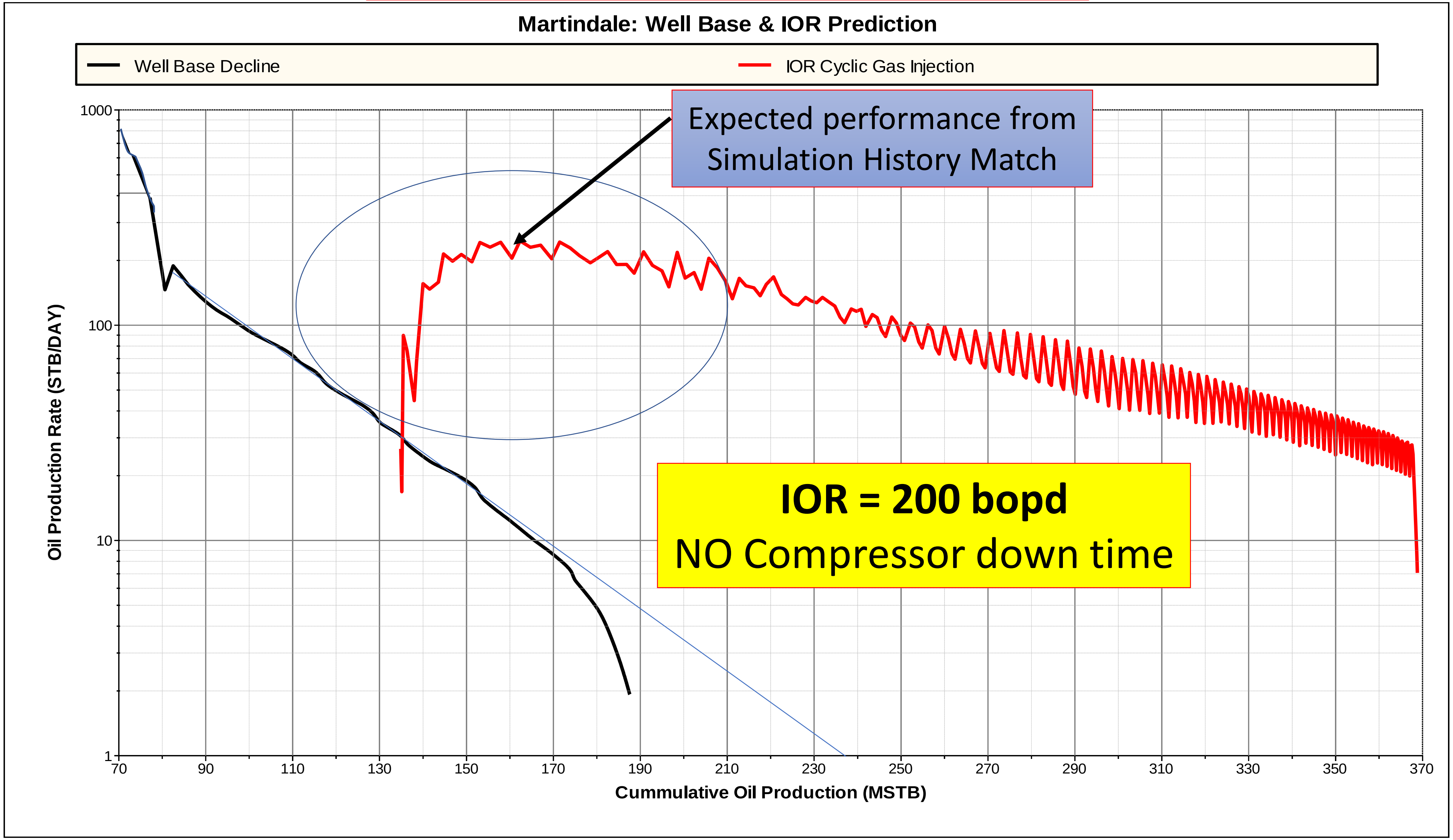
Observations from Max, Dullnig production

- IOR appears to be strong and following expected performance
- Production is steadily increasing in the first 2 years of gas injection
- 100% additional recovery is realistic (IOR Ratio = 2.00) given Cyclic Gas injection Rates/Pressures are maintained
- What affects the EOR/IOR recovery?
  - Process changes with Oil quality and depth (Parting Pressure)
  - Injected Gas Composition and pressure
  - Containment of gas: in zone and on lease
  - Gas Compression Rate: EOR Oil follows gas injection rate
  - Geo-mechanics: Faults and Natural Fractures
  - Well Operations: Cycle time, Rate, Well sequencing

Simulation Results: WELL Base & EOR



Scaling and Profiles

Reservoir Simulation: Profiles & Screening

- Predictions for IOR based on 14 Component Simulation Model
  - Element uses 6 inch – 3 ft grid blocks
- Scale Tool developed for prediction of Project and Economics
  - History match of base decline for average Well at Pad / Lease level
    - GOR and Pressure match of base decline
    - Production Match using Cartesian and Log Oil Rate vs. Cume oil
  - History match of EOR pilots using Base Decline Model
    - Match IOR and Yields
    - Determine Cyclic Operation > Injection Cycles, Times, Pressure, Compositions
  - Element scaled to EUR of Base Decline (10 bopd economic limit)
  - Wells (scaled by EUR) are then cycled to make Project Profiles
    - Cycles, Times, Pressures, Compositions > Pre-determined by EOR model runs

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How Shale IOR Screening Tool Works

- Applied to any Pad/Group of Wells to predict detailed Cash Flows
- Wells screened during detailed history matched
- Scales simulation element to Project via Average Well EUR -> Pad
  - EUR Based on 10 year life > close to economic limit
- Predict IOR Performance based on range of simulation cases
  - Static, Dynamic, and Operational uncertainty covered by the cases
- Predict project economic value with Scaling Tool
  - Projects are based Well EUR sum to determine Compression
  - Input Well EUR and Number of Cycle Wells > # Compressors
  - Input Taxes, Fee, Royalty, Capital & Operating costs
  - Optimal projects fully utilize compression capacity

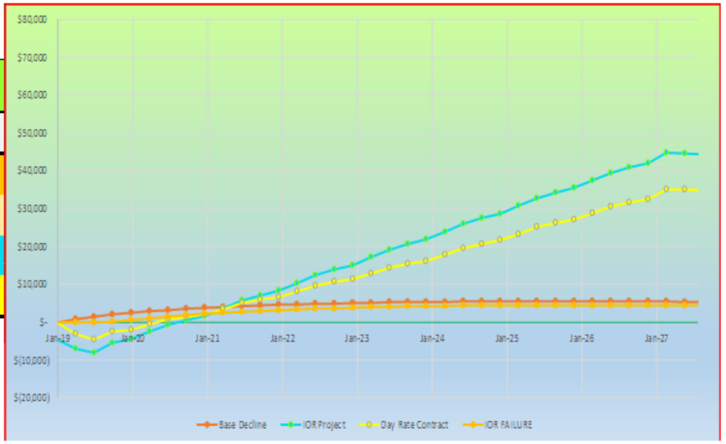
Economics

Screening Tool: Input & Output Example

1st 3 Cycles Ave Gas Injection Rate:			22.79 mmscf/d			2nd 3 Cycles Ave Gas Injection Rate:			21.53 mmscf/d				Cost and Revenue						Project CAPEX			Fees	Interest				Economic
Pad	Lease Information		IOR	Base Case	Base Case		Taxes		Fee	Royalty	Commodity Price		Operating Cost		Shale IOR		Compressor	Piping Manifold	Wells	Pipelines	Total Capital	Rental	Shale IOR	Discount Rate	Rev Share	Prod Share	Indicators
Total	Cycle	Completion	5 Year Ratio	Well EUR	Well EUR	Adval Tax	Sev Tax Oil	Sev Tax Gas	Shale IOR License				Monthly $	Monthly $	Full Service	Compression	Purchase Mob	meter runs	Pkr, Tree, TH, rig	Import Line	Expense	Monthly $	Equity	for NPV, %	INV Share of	INV Share of	PVI / PI (disc)
Well count	Well Count	Scale Factor	IOR/Base	10 Year	15 Year	%	%	$/MCF	Day Rate	Net Interest	Flat Oil Price	Flat Gas Price	Compressor	Well	Day Rate	Day Rate	$	$/well	$/well	$	$	Compressor	After PO, %	0.2740	Net Profit	Net Sales	Payout, yrs
7	3.5	127	2.02	228	244	2.00%	4.60%	$0.075	$719	75.5625%	$60.00	$3.00	$69,457	$15,400	$12,687	$9,154	$5,360,000	$101,875	$182,438	$0	$7,350,188	$158,790	25%	10.00%	50.00%	50.00%	NPV, M$
																											IRR, %
Date	Time	Pad Base Production		IOR FAIL: Pad Production			Pad IOR Production			Calculated	Net Incremental IOR		Price		IOR Sales			Base Sales	TAX IOR sales	Compression & Operations				Day Rate		Engineering Costs	
Start		Gross		Gross			Gross			Blowdown	Net				Oil	Gas Blowdown	Total	Less Tax	Net Adval &	Gas	Gas	Compression	Well	Full Service	Compression	Phase III+IV	Phase I+II
Date	TIME	Oil Volume	Gas Volume	Oil Volume	Gas Volume	Gas Injection	Oil Volume	Gas Prod	Gas Injection	Gas Prod	Oil Volume	Prod Gas Vol	Oil Price	Gas	Sales	Sales	Sales	Sales	Production	Purchase	Compression	Rental	Operations	Amount Pd	Amount Pd	Costs	Costs
10/13/2018	Days	STBO	MSCF	STBO	MSCF	MSCF	STBO	MSCF	MSCF	MSCF	STBO	MSCF	$/bbl	$/Mbtu	$M	$M	$M	$M	Tax $M	$M	$M	$M	$M	$M	$M	$M	$M

Reservoir Volumes and Process Yield								Financial Net to Operator			
Well IOR and EUR		*IOR Period Production Volumes					Yield	Gas Purchased	Gas Sales	Oil Sales	**Net Yield
IOR 5yr	EUR	Gas Prod	Gas Inj	Gas Import		IOR Prod	Ratio	Import	Blowdown	Net IOR	$mcf/stbo
mbo	mbo	mcf	mcf	mcf		stbo	mcf/stbo	$M	M	$M	$/bbl
217	228	37,933,619	43,472,217	5,538,598		3,089,057	1.79	$16,616	$4,190	$140,050	$4.02

Project	OPERATOR $M				
	CAPEX	CF 10 Yr	CF 5 Yr	NPV 5 Yrs	NPV 10 Yrs
Base Depletion	$0	$5,176	$5,343	$4,629	$4,699
IOR Failure	$150	$4,235	$4,220	$3,373	$3,516
IOR Project	$3,817	$42,888	$22,928	$15,695	$26,967
Day Rate Contract	$150	$33,350	$16,980	$11,986	$21,374



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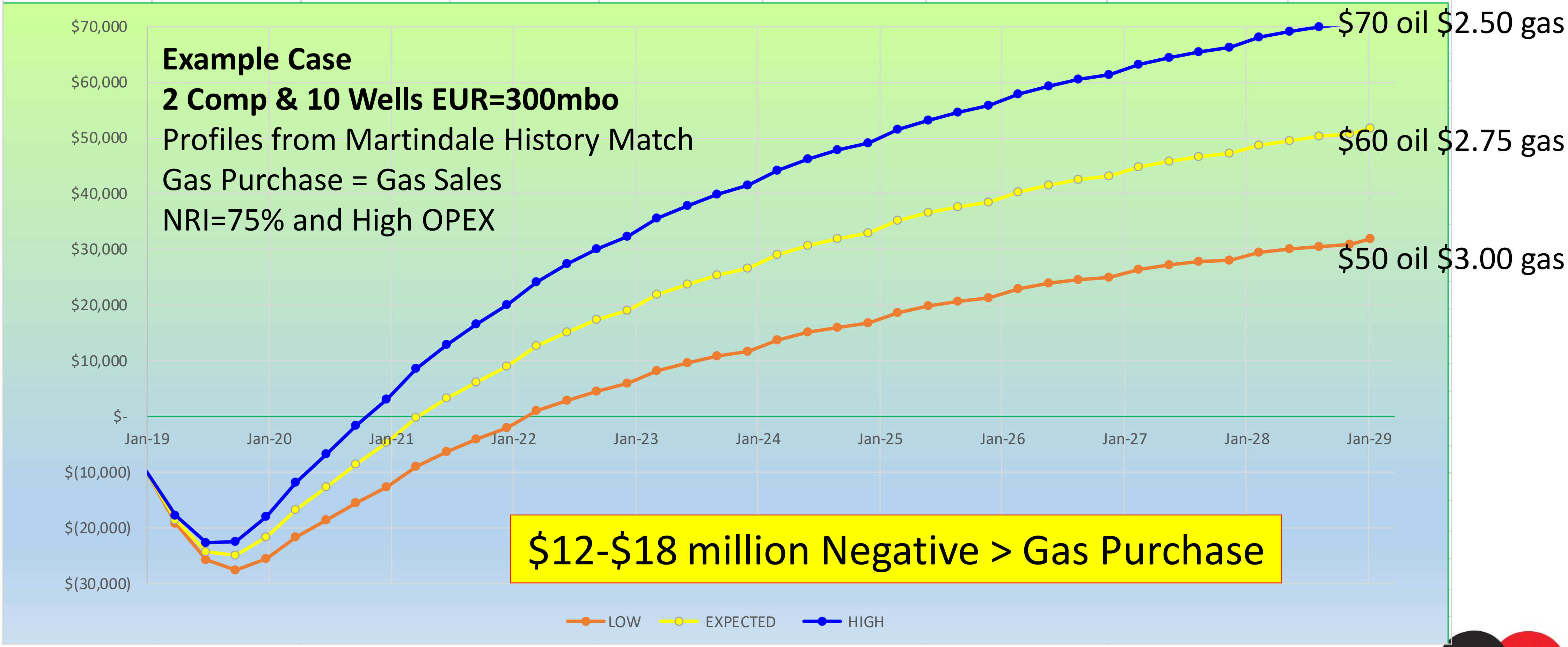
Eagle Ford Economics and Cash Flow: Produced Gas EOR Project

Project	EOR PROJECT CASES				Input Variables	
Description	CAPEX	Cash Flow	NPV10	PV/I	Oil Price	Gas Price
LOW CASE	$9,906	$25,702	$9,065	0.92	$50	$3.00
EXPECTED CASE	$9,906	$38,082	$18,488	1.87	$60	$2.75
HIGH CASE	**$9,906**	**$48,711**	**$26,727**	**2.70**	**$70**	**$2.50**



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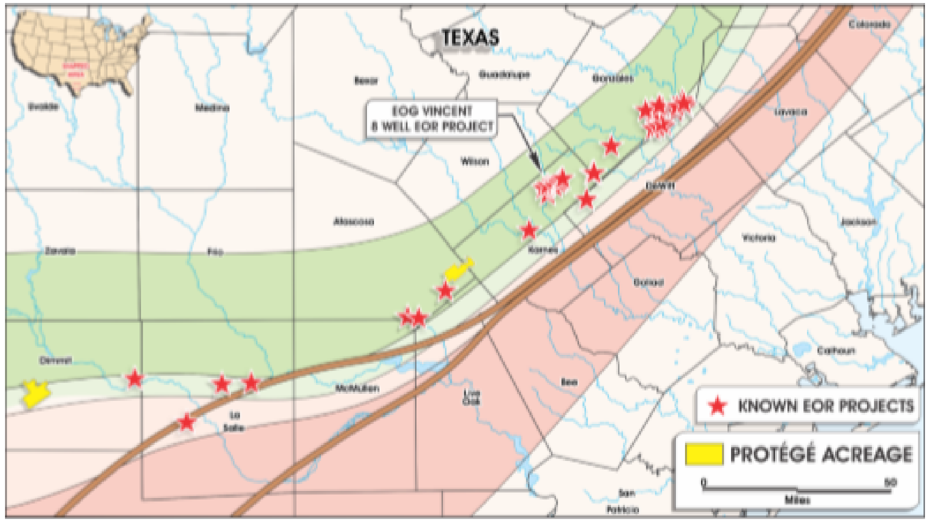
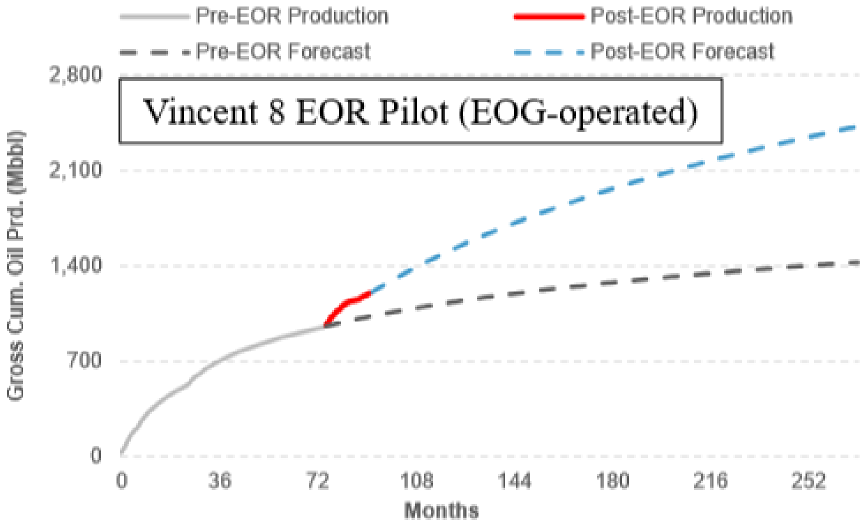
Protégé acreage relative to existing Eagle Ford EOR projects





- EOR projects have been successfully employed in several areas of the Eagle Ford
  - All known pilots have been executed in the oil window
- A total of 25 projects involving 395 wells have been applied for at the Texas Railroad Commission
  - 25 H-12 applications have been submitted (application for new or expanded EOR project)
  - 5 H-13s have been submitted (EOR positive response certificate)
- Projects with H-13s are in various stages of EOR
  - Range of incremental oil recovery varies from ~120 Mbbl to ~520 Mbbl over periods of 15 to 31 months
  - Based on data reviewed, productivity uplift for an optimized EOR project is expected to be 65%
- EOR economics are robust in a $55/bbl environment (>80% IRR)
  - Break-evens are low (IRR >40% at $40/bbl WTI and $2.50/MMBtu HHUB)

Protégé's acreage is on trend with existing successful Miscible Gas Injection (EOR) projects

Eagle Ford Conclusions

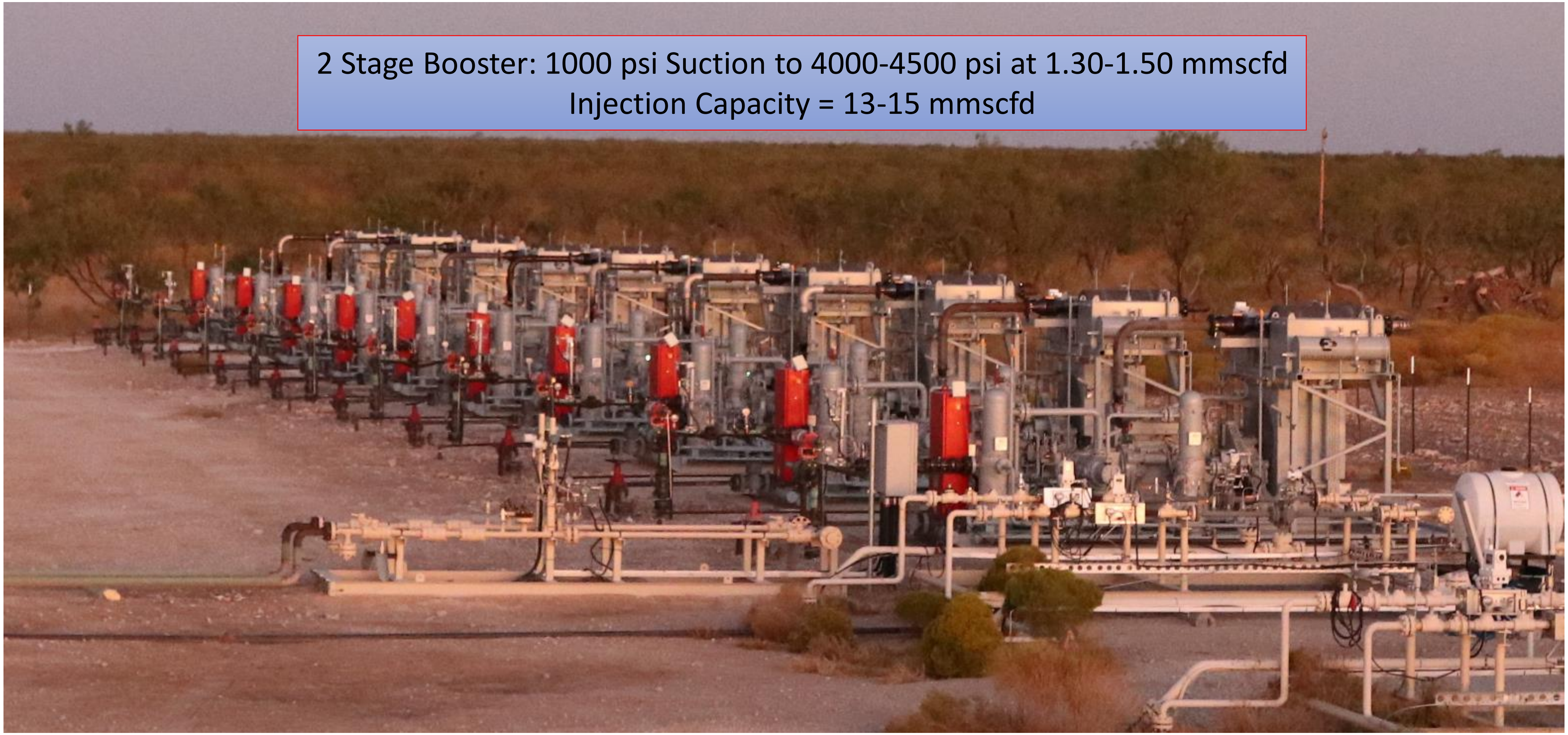
- The Eagle Ford EOR evaluation report demonstrates that cyclic gas injection projects in the volatile oil window deliver consistent and robust results;
  - Average first cycle IOR response is approximately 200 BOPD/well
  - Consistent IOR recovery ratio of 1.80 to 2.00 of base pad EUR is achievable
  - IOR oil production volume is proportional to gas injection volume
  - Field IOR results show 6.5 years of successful pilots/projects by EOG resources
- Shale IOR and associates believe that the Eagle Ford volatile oil window is beyond the Pilot stage and Operators should build upon existing knowledge.
- Shale IOR LLC has world class ability for understanding and prediction of this process for development projects

Permian, Bakken, Scoop

Shale IOR: Permian, Bakken, Scoop Summary

- Current EOR Pilots in these 3 basins are focused on Displacement EOR
  - Displacement is drive between injection and production wells
  - Unconventional displacement pilots may not the final injection scheme (Cyclic H-n-P, MWAG Injection, Patterns, etc.), but they provide a way to design the injection scheme.
- The Permian has conducted 3 or more pilots and the public data is minimal to evaluate results, however the pilots provide important facts
  - Oxy started pilots with CO2 WAG and now we believe they are proceeding with produced gas
  - EP Energy has started CGEOR using produced gas injection via gas lift compressors
  - Several Operators have been reported to be purchasing low pressure gas lift compression to inject gas which is being flared (these projects would not be designed for full EOR potential)
- The Bakken has also conducted 6 or more gas injection pilots
  - The first 3 pilots were stated with CO2 and Water
  - Recent work is focused on enriched gas: Hess (3 pilots) and Liberty Resources (1 pilot)
- The Scoop has conducted 1 produced gas pilot for CGEOR where high pressure was desired
  - Gas was injected for over 1 year at very low rates, therefore resulting EOR will be reduced

EP Energy University East Compression: 10 Estis HPGL Booster Compressors



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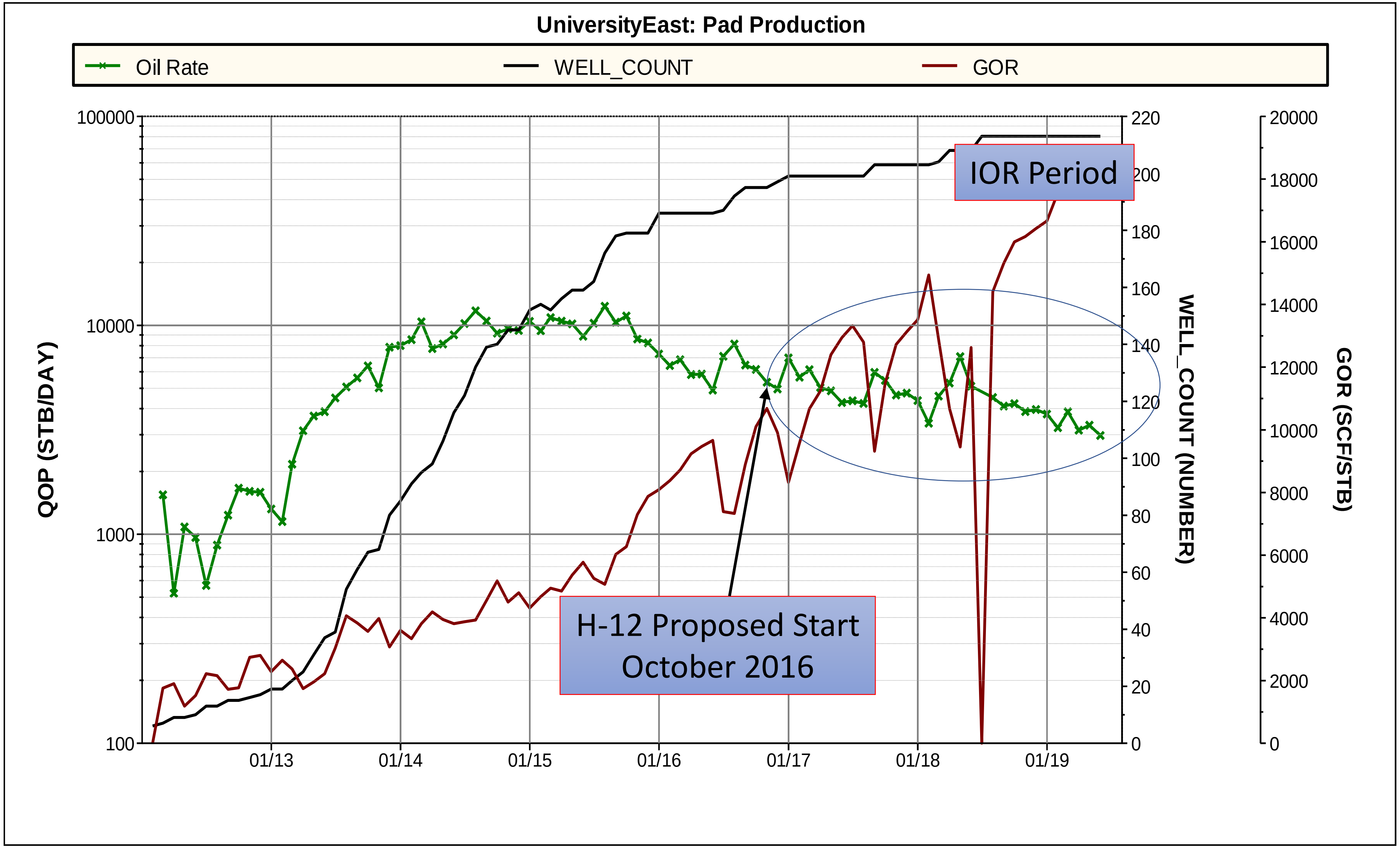

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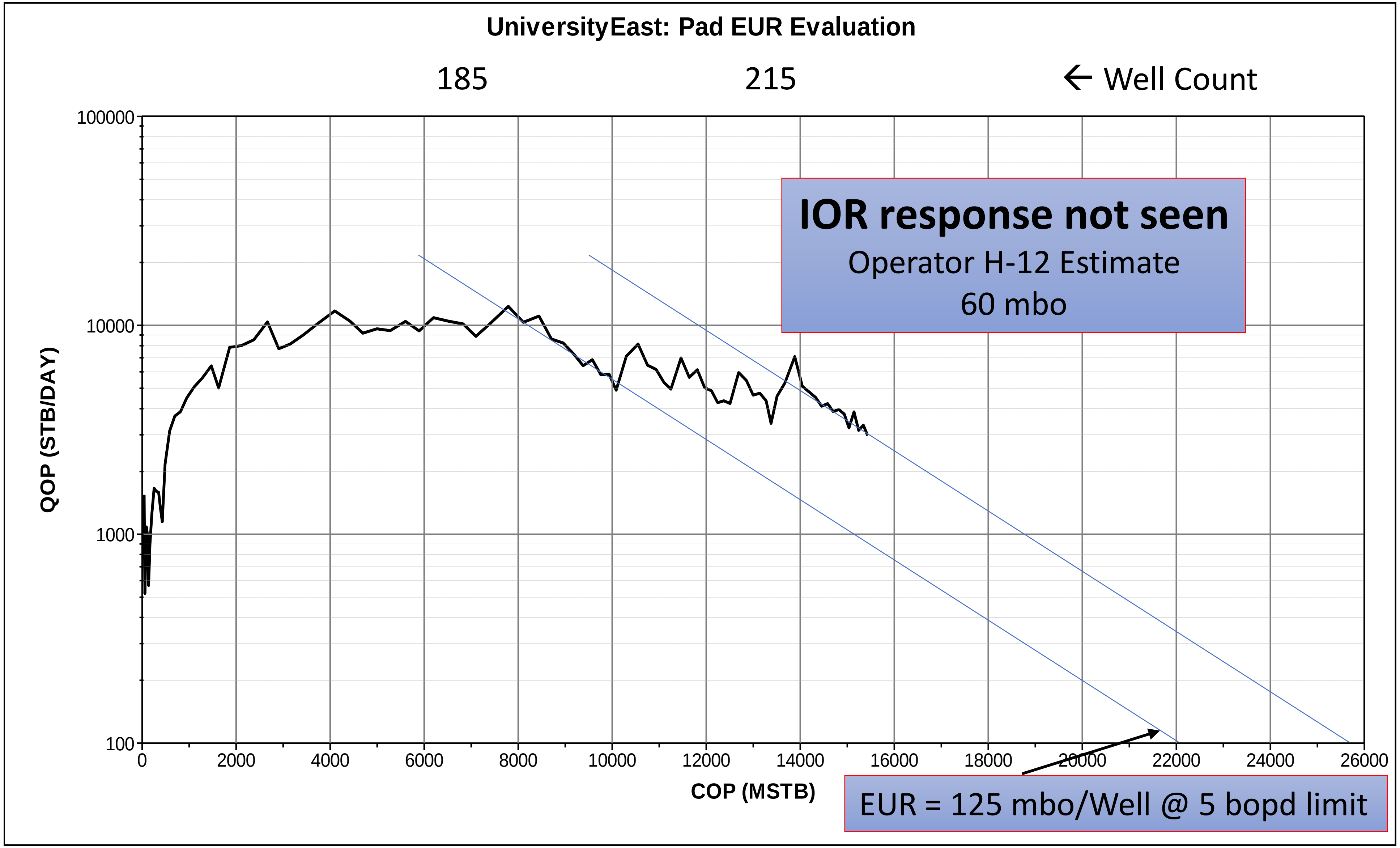

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Permian EOR Conclusions and Recommendations

- EOR Pilots with Displacement EOR
  - Displacement could be a primary mechanism to conduct EOR, however the geology in the Permian will be a key determining factor. Some benches will likely act as the Eagle Ford which lends itself to high pressure CGEOR, where other benches may act more conventional.
  - Existing Oxy CO2 WAG pilots have targeted displacement, but results are inconclusive for EUR uplift
  - Miscible WAG displacement in tight fractured rocks does not appear to be a good mechanism for EOR.
- EOR Pilots with Produced Gas CGEOR
  - EP has started in the Permian (University East) after learnings and success in the Eagle Ford. The EP lease is reported to have completed the first cycle 10/2019. We believe that Oxy is starting to use produced gas based on discussion with their engineers. Injecting lease and/or flare gas is expected to be the EOR of choice for Permian.
  - We recommend that Operators perform due diligence and work the design with proper experience, geology, and tools. Pumping lease gas at low pressure may not be designated as an EOR project, rather it is a temporary operation to store gas.

Bakken Unconventional Gas Injection EOR

Bakken EOR Well Pilots													
Well	**Type**	**Operator**	**Test Year**	**Max Inj Rate**		**Max Pressure surface or bhp**		**Inj Rate water or gas**		**Zone**	**Cume Injected**		**Type**
9660	Horizontal	Meridian/Burlingtor	1994	500	bpd	5000	bhp	200	bpd	UBS	13.1	Mbbl	Water
16713	Horizontal	EOG	2008	700	Mscfd	1500	sdp	580	bpd	MB	30.7	MMscf	CO2
Burning Tree	Horizontal	Enerplus	2009	3000	Mscfd	1848	bhp	1000	Mscfd	MB	45.0	MMscf	CO2
17170	Horizontal	EOG	2012	3000	bwpd	4000	bhp	1500	bpd	MB	447.0	Mbbl	Water
16986	Horizontal	EOG	2014	1500	bwpd	5000	bhp	1500	Mscfd	MB	84.0	Mbbl	Water
24779	Vertical	Whiting	2014	31	gpm	3500	bhp	10.5	gpm	MB	3.4	MMscf	CO2
11413	Vertical	XTO	2017	12	gpm	9480	bhp	9	gpm	MB	1236.0	Mbbl	Water
32937	**Vertical**	**HESS**	**2017**	**227**	**Mscfd**	**5500**	**sdp**	**105**	**Mscfd**	**MB**	**19.9**	**MMscf**	**C3+ Rich**
30619	**Horizontal**	**Liberty Resources**	**2018**	**689**	**Mscfd**	**1200**	**sdp**	**1080**	**Mscfd**	**MB**	**13.8**	**MMscf**	**Rich Gas**
30620	**Horizontal**	**Liberty Resources**	**2018**	**703**	**Mscfd**	**1000**	**sdp**	**950**	**Mscfd**	**MB**	**10.8**	**MMscf**	**Rich Gas**

- Shale IOR do not see the value in evaluating the past water and CO2 Bakken projects, our report only deals with current gas injection EOR pilots and projects (highlighted above).

Thank You

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