ENHANCED OIL RECOVERY INSTITUTE

SCHOOL OF ENERGY RESOURCES

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UNIVERSITY OF WYOMING

The Mission of EORI

EORI Headquarters
Business Innovation Center
Casper, WY

The Enhanced Oil Recovery Institute (EORI) was created pursuant to Wyoming Statute to facilitate research programs intended to increase recoverable reserves and the production of oil and natural gas in Wyoming. The Institute achieves its statutory purpose by facilitating the transfer of relevant technology, information and knowledge to operators producing Wyoming reserves, and by promoting research and technology transfers in conventional and unconventional oil and gas reservoirs.

Wall Street Firms Step Up Warnings About Distributed Energy's Threat to Utilities

Photo Credit: Stuart Monk / Shutterstock.com

Barclays calls it "a rare opportunity for investors to express views about a potential for a major change."

From defense to offense

Distributed energy and the challenge of transformation in the utilities sector

Bloomberg Markets Tech Pursuits Politics Opinion Businessweek

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Bloomberg Businessweek Markets Tech Pursuits Politics Opinion Businessweek

July 6, 2017, 4:33 AM CDT   Updated: July 7, 2017, 8:45 AM CDT

The Electric Car Revolution Is Accelerating

By Jess Shankleman

- Electric cars will be as cheap as gasoline models by 2025
- Battery manufacturing capacity will triple in the next four years

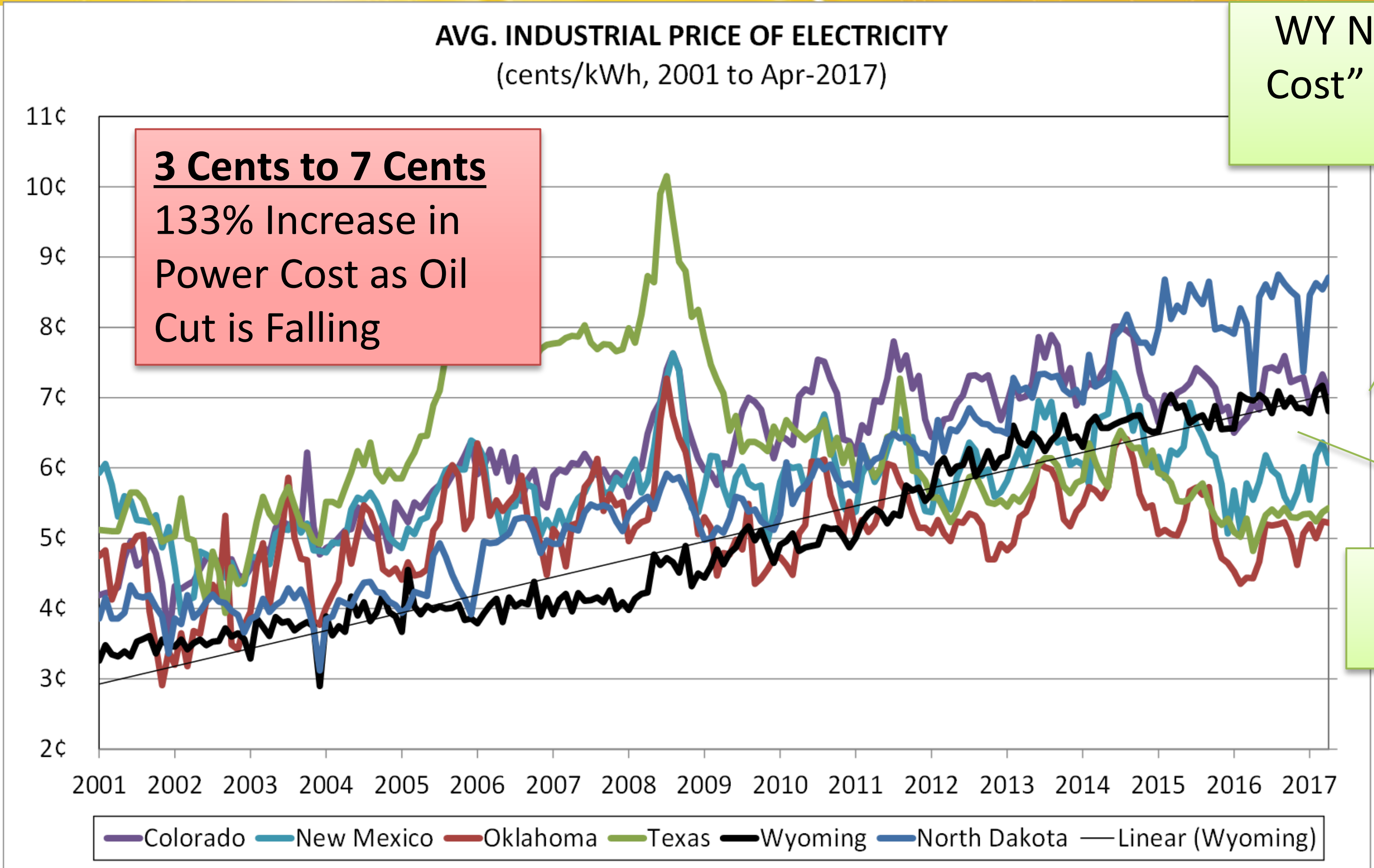
Slowdown in oil demand growth will cap prices, says energy agency

Alongside gloomy forecast by Opec, IEA report sent oil prices down to $47 a barrel

Electricity in the Oil Patch

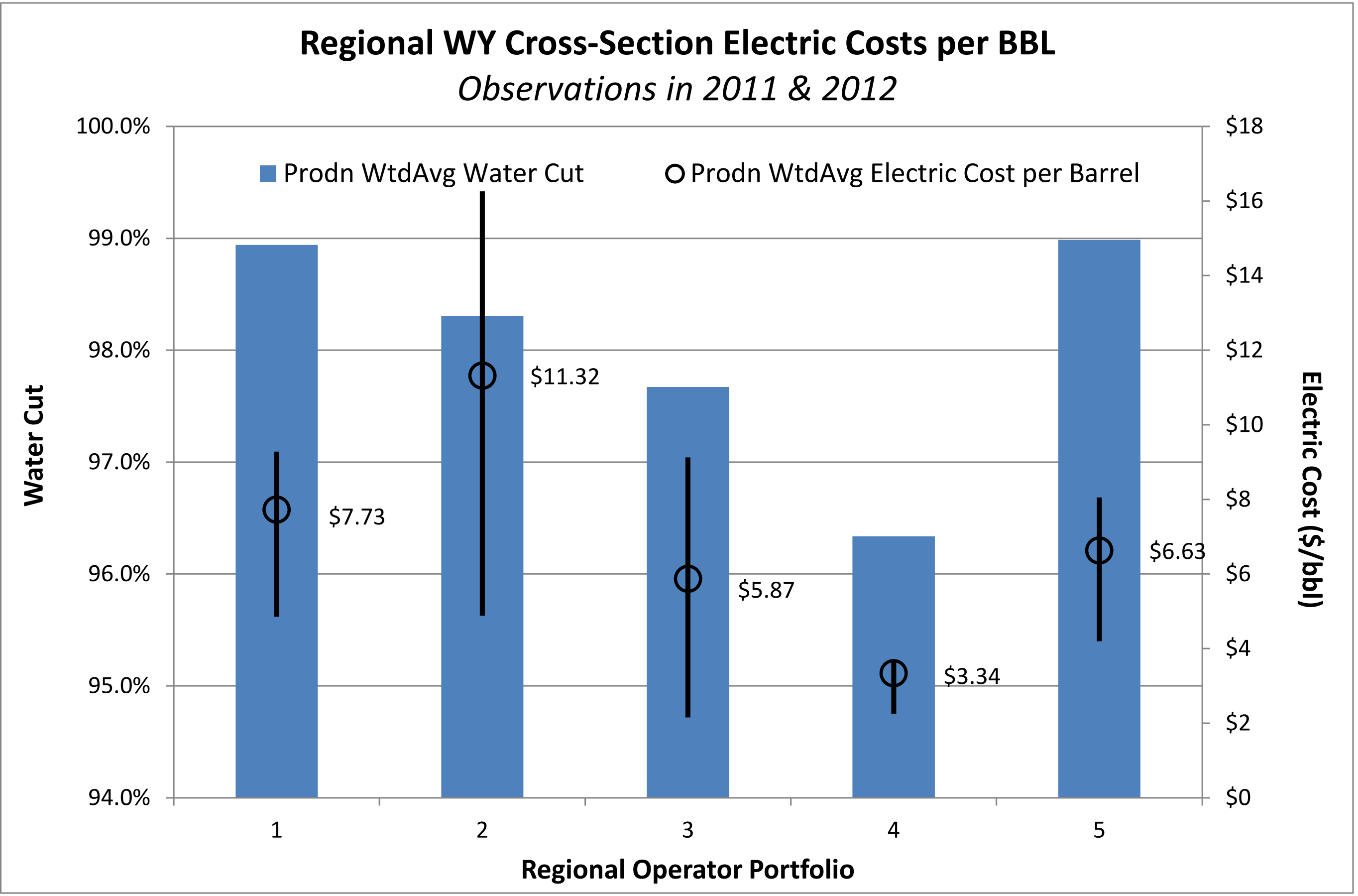
Major Share of Lifting Cost

Especially for conventional oil fields and water-floods, the electricity cost of pumping fluid to the surface can be deciding factor in when to shut-in a well.



WY No Longer the "Low Cost" State Compared to Energy Peers

WY Rates CAGR of 6.5+% since 2008



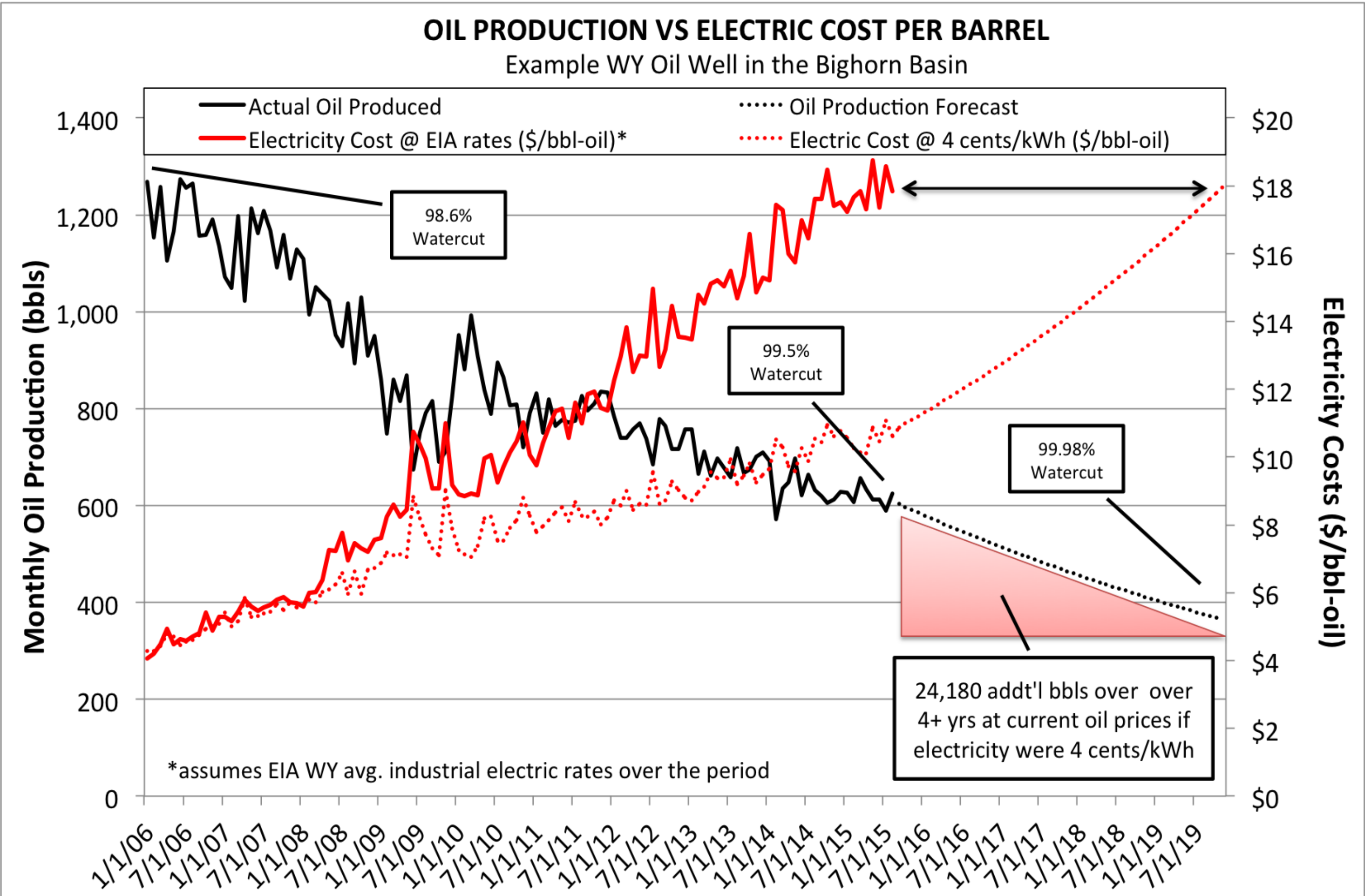
The Big Horn Basin has many productive waterfloods, but they make a bunch of water for each barrel of oil

A Weight Average (Pretty) WY Oil Well

- **A production weighted average WY oil well in July 2016 would be one producing 114 bpd of 35 deg. API oil and 604 bpd of water at a depth of 7,966'**
  - Would require 39,000 – 54,000 kWhs per month
  - 468,000 – 648,000 kWhs per year
  - Average U.S. home in 2014 using 10,932 kWhs per year.
  - This well uses the equivalent power of 43 – 59 homes
  - 9,950 wells ~= New Hampshire

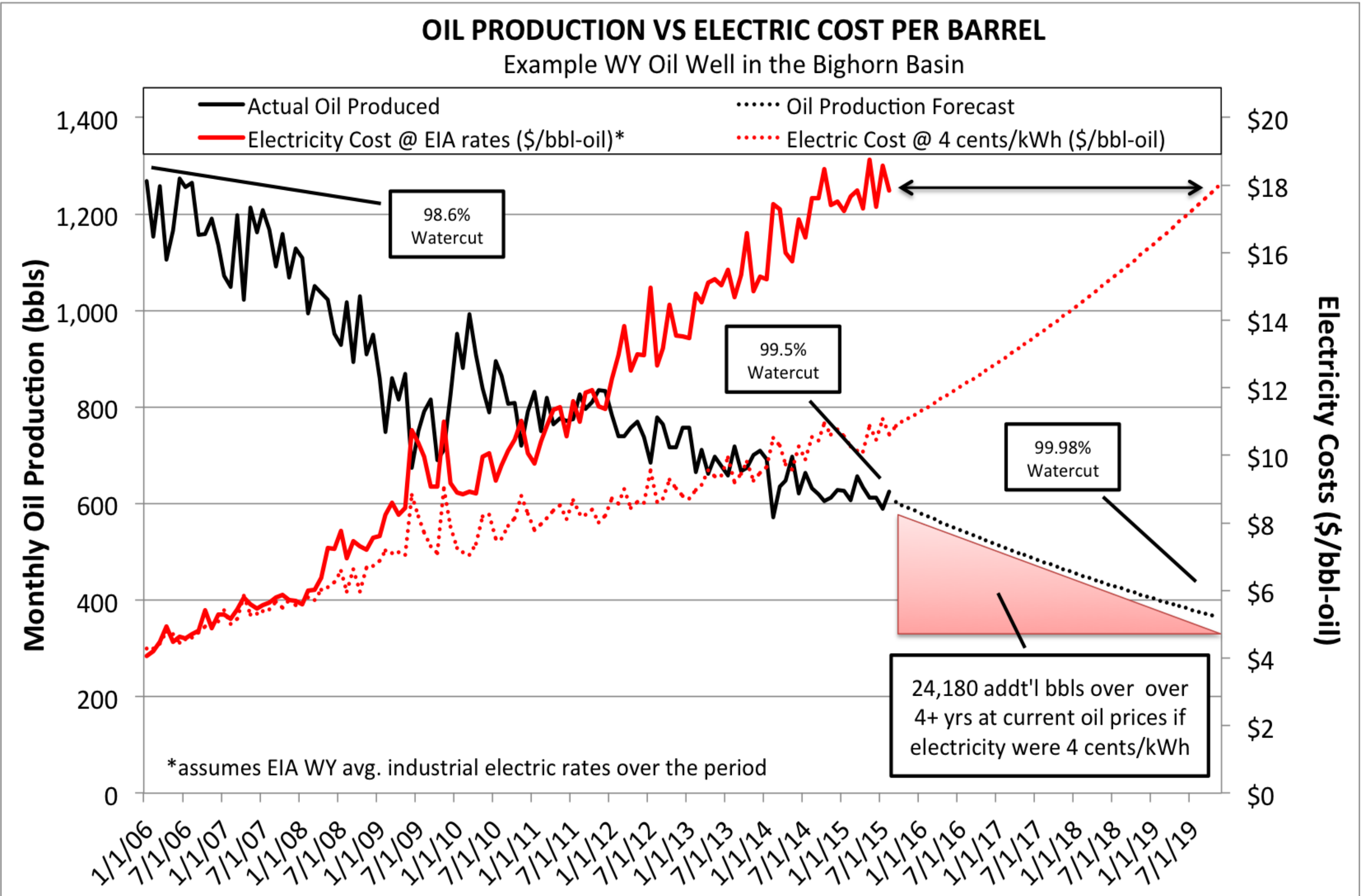
…and the Cost $/bbl

- **According to EIA.gov the average industrial rate in WY is around 7 cents per kilowatt-hour.**
  - Well electricity of $2,700 - $3,780 per month
  - Average of $39,060 per year
  - WY average worker pay in 2014 was $46,500
  - At 16% oil, 84% water the electricity only comes out to about $1/bbl-oil
  - 25% of WY oil fields, including 12 of the top 30 are 95% water-cut or more
  - In these cases, the electric costs may be $2.70 - $14.60 or more per bbl



Assuming that the economic limit on electricity costs is $18/bbl-oil….

…this well would continue producing 4+ years at 4 cents versus 7 cents/kWh.



Watercut	Electric $/bbl-oil
70.0%	$0.49
75.0%	$0.59
80.0%	$0.75
85.0%	$1.01
90.0%	**$1.52**
95.0%	$3.03
96.0%	$3.79
97.0%	$5.11
98.0%	$7.77
99.0%	$15.53
99.5%	$31.07

What if Utility Dropped the Rate?

- **Assume that the oil operator was somehow able to negotiate for a lower electric rate on this well rather than shut-in?**

Rate Schedule	Additional Prod. Months	Additional Oil Produced (bbls)	Additional Energy Used (MWhs)	Additional Electric Payments
EIA Rates…	-	0	0	0
then 6 cents	10	5,765	1,639	$98,000
then 5 cents	28	14,788	4,589	$229,000
then 4 cents	51	24,179	8,360	$334,000
then 3 cents	79	33,037	12,950	$388,000

"Ceteris Paribus" -> flat oil prices & $18 electric cost shut down.

$$Rates = \frac{Revenue\ Requirement}{Sales\ (MWhs)}$$

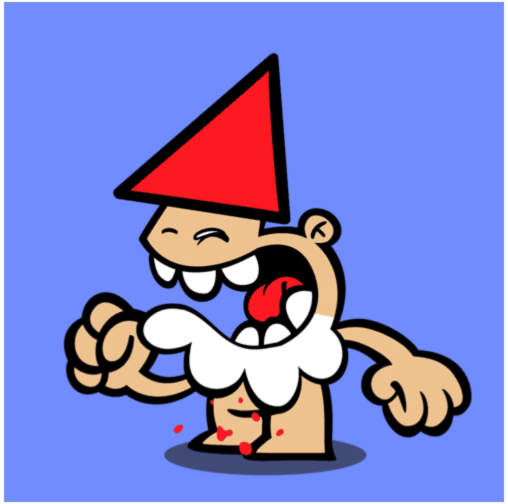
Rates Increase

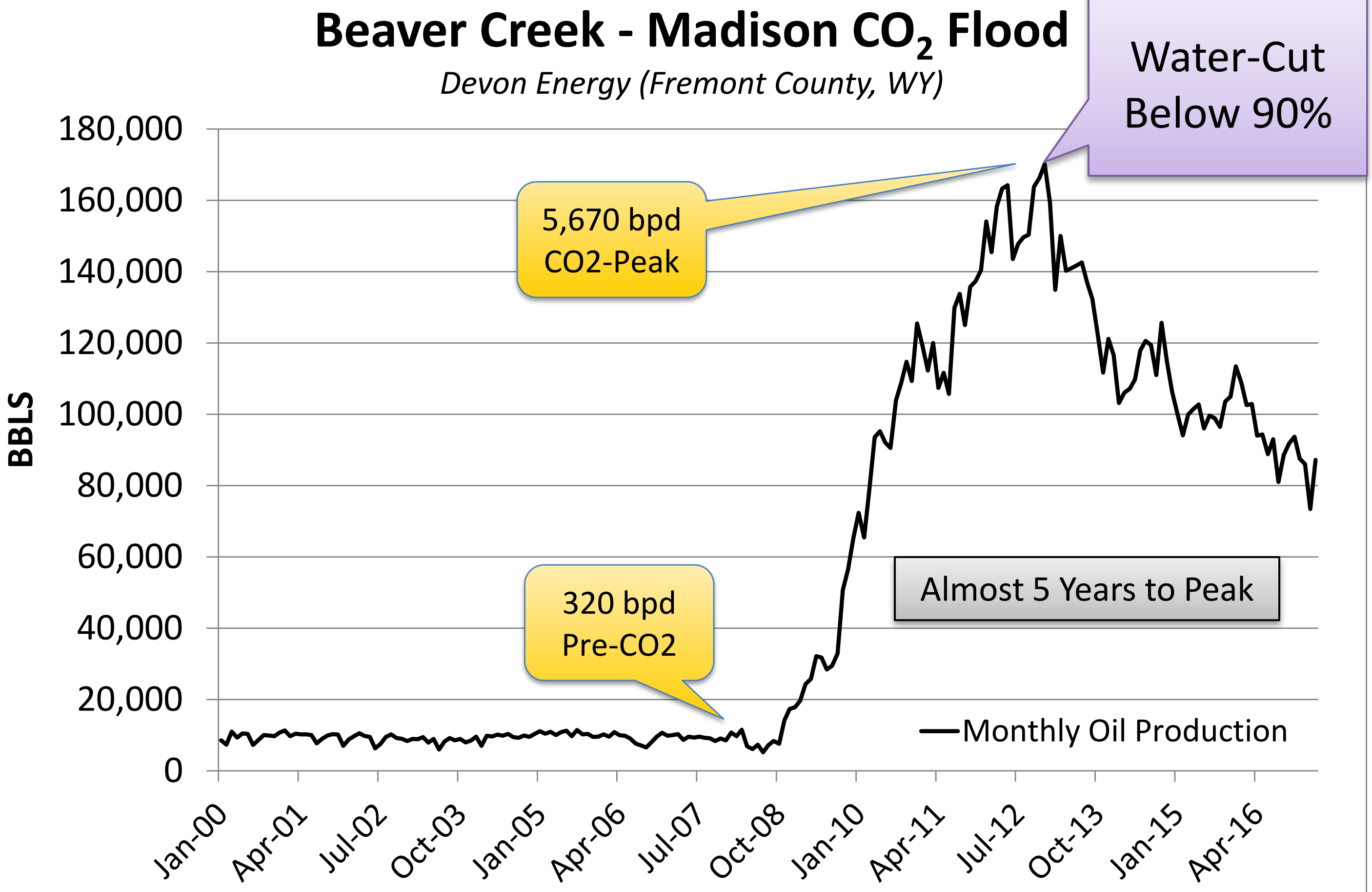
Low Cost Alternatives

(DER, CHP)

Grid Defection

Lower Grid Demand & Sales





Technically Feasible

+

Economically Feasible

+

CO_2 Available

Costs of Compression at Recylce

CO2 Volume (mmcfd)	HP of Compression	KWs (90% uptime)	MWhs/y ear	Annual Electric Cost ($60/MWh)
5	504	338	2,964	$177,855
10	1,007	676	5,923	$355,358
20	2,011	1,350	11,828	$709,657
30	**3,018**	**2,026**	**17,750**	**$1,065,016**
40	4,022	2,700	23,655	$1,419,315
50	5,029	3,376	29,578	$1,774,673
60	6,033	4,051	35,483	$2,128,972
70	7,040	4,727	41,406	$2,484,330
80	8,044	5,401	47,310	$2,838,630
90	9,051	6,077	53,233	$3,193,988
100	10,055	6,751	59,138	$3,548,287

Capital Budgeting (Allocation)

Regulated Generation/Utility	Upstream Oil & Gas
Integrated Resource Planning: "reliable and least-cost electric service to all of our customers while addressing the substantial risks and uncertainties inherent in the electric utility business."--PacifiCorp	Growing or replacing reserves (economically recoverable hydrocarbons) PLUS growing or replacing current production (improved oil recovery, new drilling or exploration, acquisitions)
Serving customer load, reliability and regulatory compliance.	Serving investors
Regulated return (8-10%)	Maximize return
Payback over decades	Usually the sooner the better

Preferences of Utilities versus O&G

Regulated Generation/Utility	Upstream Oil & Gas	Policy/Market Options?
Fixed price of CO_2 versus a variable price. Exposing customers to oil price risk in the electricity cost…	CO_2 prices tied to the oil price. Fixed prices create margin risk in low oil price environment.	Price Stabilization Policy… Utilities get constant price, oil operators pay variable price.
Interruptible CO_2 due to different markets.	Reliable/constant streams of $CO_{2.}$	CO_2 pipeline networks and diversification of sources.
20-40 year time horizon.	Shut-down if oil prices are too low. Reduce CO_2 purchases over time as recycle volumes increase.	Diversification of sinks, and incentives for storage.

Do Oil Operators Have Electric Grid Alternatives?

1. Efficiency and Alternative Pumps
    - Operators switching to Permanent Magnet ESPs and reducing power costs
    - ….extends the life of the wells and fields, at comparable pump costs

2. On-site Distributed Energy Resources (DER)
    - Natural Gas Reciprocating Engines at the wellhead…
    - ….are they cheaper than grid power?

What about NG Engine Generators?

Electrifying the Oilfield: The Comparative Economics of Grid Power and Onsite Gas Generators

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1. INTRODUCTION

Power requirements in the oilfield have traditionally been met one of two ways: onsite, using *diesel* powered generation technology, or with grid-based *line power*, which to this day meets the largest share of global power demand. A third technology, onsite *natural gas* powered generation, since 2008, has experienced increased use in remote and portable industrial applications, especially so in the oilfield. This trend has served to bring onsite generation in the oilfield more in line with the larger market. In 2012, *all* onsite industrial generation represented roughly four percent of the total megawatt hours (MWh) of electricity generated in the U.S., of which more than 80 percent was concentrated in just three industries: chemicals, paper, and petroleum and coal.[1] Today, nearly 60 percent of industrial onsite generation capacity comes from natural gas.[2]

In the oilfield, the onsite natural gas generator sector has historically focused on competing directly with diesel, avoiding for the most part direct competition with line power. This is due in large part to the fact that natural gas generators – when operated using untreated associated gas as a fuel source – hold distinct advantages over diesel, such as the reduction of flared or vented gases, regulated emissions, and excessive fuel costs.

Economically, the severity and duration of the most recent dip in oil prices have forced many upstream companies to cutback significantly on capital investments. Such actions have triggered a like response from distributors of natural gas powered generators who, in turn, have reduced the costs of their services and begun to push for the long-term application of onsite generation in place of line power.

While natural gas generator prices have fallen significantly in the current low oil price environment, it is still commonplace for oil and gas operators to view onsite generation as stopgap measure, a short-term power solution in advance of the arrival of line power. The disparity between the application of natural gas generators and the provision of line power seems to arise from the justification and, *possibly*, misconception: that line power remains the dominant power solution in terms of the cost and reliability to deliver electricity to oilfield operations.

1.1 Environmental Considerations

The U.S. oil and gas sector has come under renewed scrutiny regarding the increasing amounts of natural gas being flared and or vented into the atmosphere because of fossil fuel production. The Obama Administration's 2014 *Climate Action Plan* set the goal of cutting emissions of methane, volatile organic compounds (VOC), and toxic air pollutants from the oil and gas sector by 40 to 45 percent by 2025.[3]

In response, the Environmental Protection Agency (EPA) and Bureau of Land Management (BLM) promulgated rules that seek to reduce natural gas emissions. The EPA's new rules require operators to use the best system of emissions reduction on all well completions. Certain technologies – natural gas powered generators included – fulfill these requirements and qualify as reduced emissions completions (REC).[4] In addition to the EPA's finalized standards, the BLM recently published a proposed rule designed to both reduce the waste of natural gas from flaring and venting, as well as clarify when lost natural gas is subject to royalties.[5]

1.2 Objectives

This study seeks to answer the question: "Is grid-based line power still the lowest cost source of electricity for new oil

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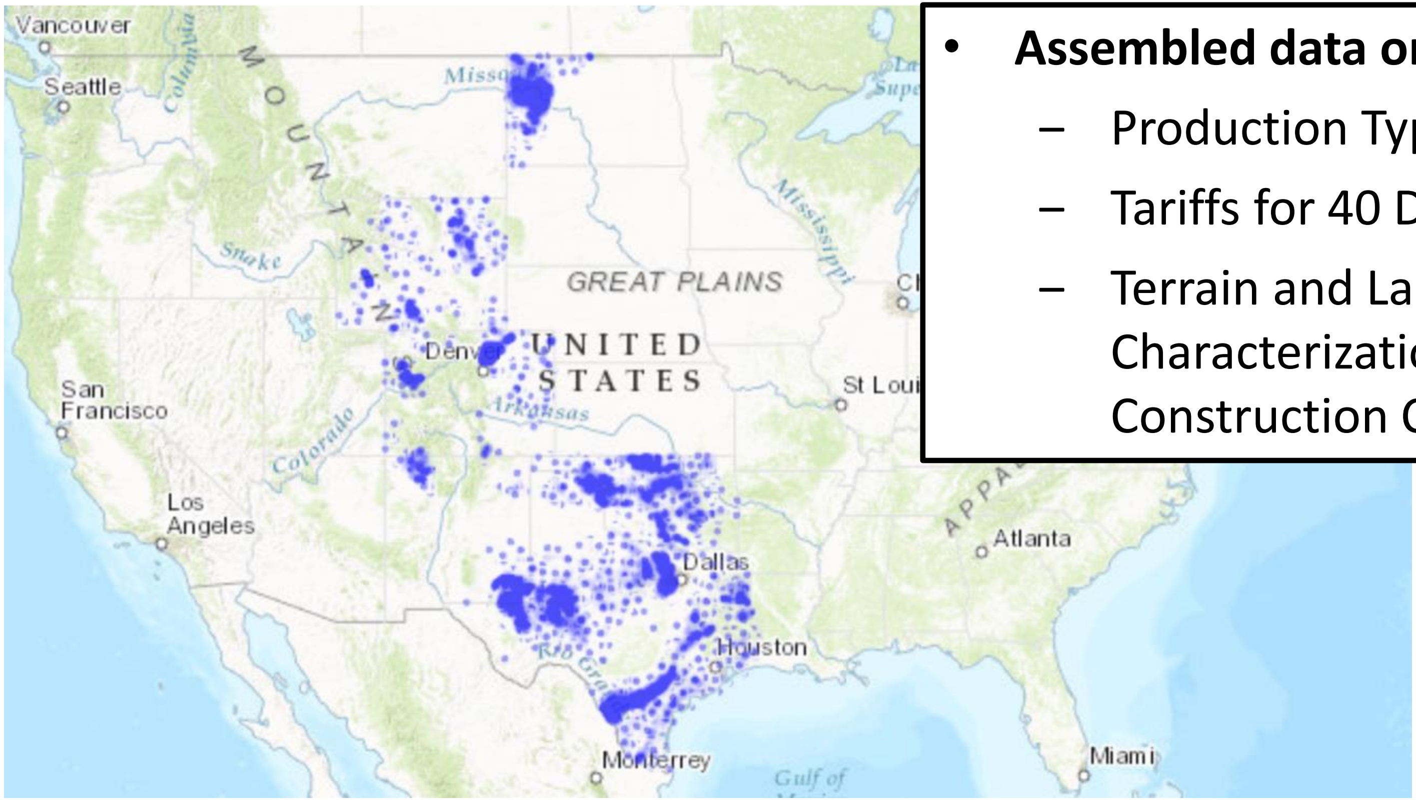
[1] Accessed August 15, 2016, available online at: http://www.eia.gov/todayinenergy/detail.cfm?id=16351
[2] Accessed August 15, 2016, available online at: http://www.eia.gov/todayinenergy/detail.cfm?id=8550
[3] Accessed August 15, 2016, available online at: https://www3.epa.gov/airquality/oilandgas/index.html
[4] Federal Register, Vol. 81, No. 107, Friday, June 3, 2016, Rules and Regulations, 35824, EPA, 40 CFR Part 60
[5] Federal Register, Vol. 81, No. 25, Monday, February 8, 2016, Proposed Rules, 6616, BLM, 43 CFR Parts 3100, 3160, and 3170

1

- **Comparative Economics of Grid vs NG Generators**
  - "Is grid-based line power still the lowest cost source of electricity for new oil developments in light of decreased leasing rates for natural gas reciprocating generators?"
- **Especially for Greenfields….**
  Right-of-Ways, Distribution Lines, Maintenance, Transmission Upgrades
- http://bit.ly/genvgrid

Six States



- **Assembled data on 93 counties**
  - Production Type Curves
  - Tariffs for 40 Different Utilities
  - Terrain and Labor Cost Characterization for Line Power Construction Costs

Line Construction & Tariffs

[TABLE 1 – Estimated Distribution Line Construction Costs]

Construction Component	Colorado	North Dakota	New Mexico	Oklahoma	Texas	Wyoming
Poles & Conductor	$26.5k	$26.5k	$26.5k	$26.5k	$26.5k	$26.5k
Labor & Vehicles	$15.7k	$14.2k	$13k	$11.8k	$11.9k	$14.5k
ROW, Engineering & Terrain Adjustment	$10.6k - $38k	$19.5k - $44k	$12.5k - $20.1k	$10.2k - $22.7k	$10.3k - $42k	$19.5k - $44.4k
Total Cost per Mile	**$52.9k - $80.3k**	**$60.3k - $84.9k**	**$52k - $59.6k**	**$48.6k - $61k**	**$48.7k - $80.4k**	**$60.6k - $85.5k**

[TABLE 3 – Summary of Utility Tariff's for a 2MW Customer]

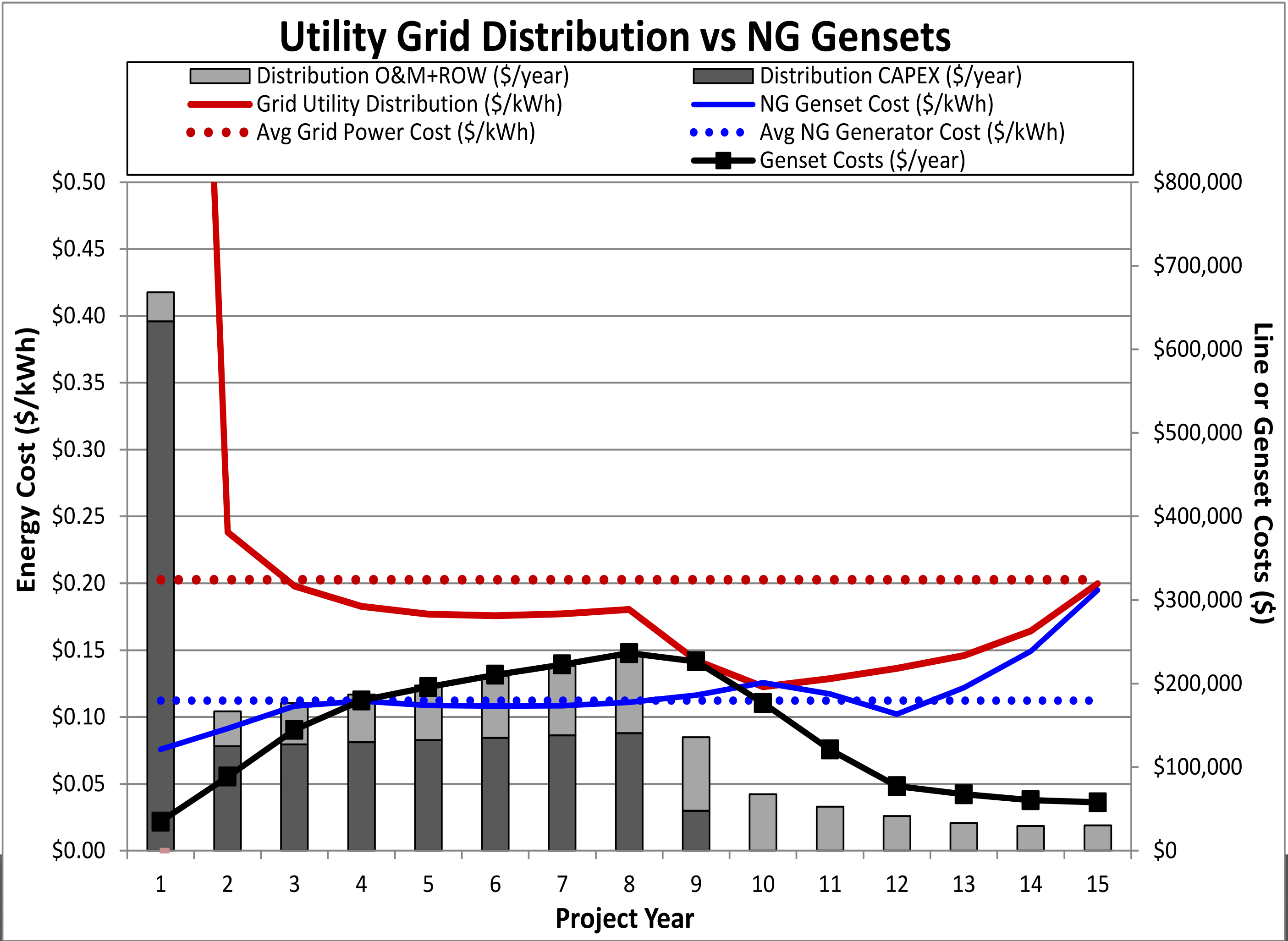
Tariff Component	Colorado	North Dakota	New Mexico	Oklahoma	Texas	Wyoming
Fixed Charge	$86.25 - $1,300	$25.74 - $350	$25.00 - $500	$10.00 - $287.17	$21.00 - $239.48	$42.25 - $810
Demand Charge($/peak-kW)	$0.00 - $16.46	$9.29 - $16.74	$1.49 - $12.30	$0.00 – $6.45	$2.13 - $16.50	$0.00 - $29.47
Energy Usage ($/kWh)	$0.034 - $0.145	$0.04 - $0.06	$0.038 - $0.066	$0.043 - $0.073	$0.025 - $0.076	$0.031 - $0.119
Total Rate per Month ($/kWh)	**$0.062 - $0.16**	**$0.067 - $0.094**	**$0.065 - $0.075**	**$0.065 - $0.075**	**$0.035 - $0.114**	**$0.044 - $0.131**

Genset Costs

[TABLE 4 – Monthly Generator Lease Rates]

Genset Engine	Prime Rating (kW)	Low Pricing ($/kW)	Average Pricing ($/kW)	High Pricing ($/kW)	Peak Pricing ($/kW)
8LNA	70	$18.10	$20.69	$23.27	$47.14
8LT	125	$18.99	$21.70	$24.42	$47.20
11LT	170	$18.49	$21.13	$23.77	$47.65
14LT	225	$18.86	$21.55	$24.25	$42.22
22LT	350	$21.01	$24.01	$27.01	$41.43

Example Output

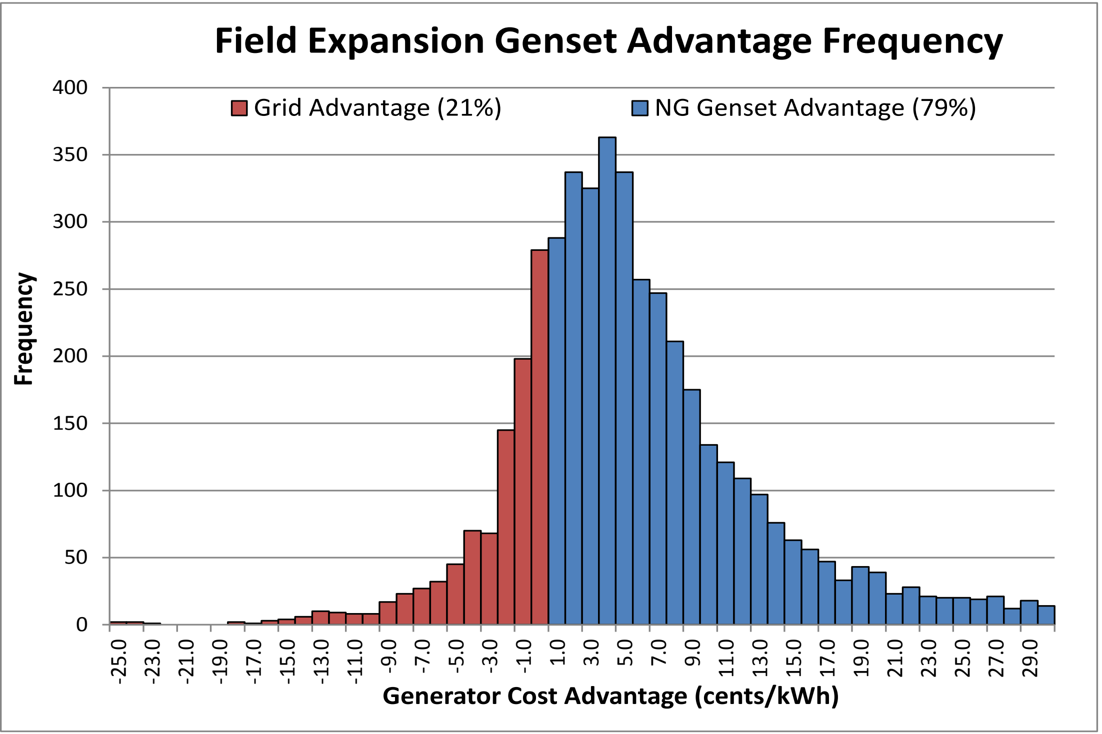


Example Output

[TABLE 5 – Example Results]

50 Well Colorado-Niobrara Development Example	Grid Power (Weld County-CO)	NG Generator
Est. Total Oil Production	7,813,688	7,813,688
Total Lease-Life kWhs	18,699,306	18,699,306
Utility Bill or Generator Leases	$1,340,010	$2,146,602
Energy Cost per kWh	*$0.07166*	*$0.11480*
Line Power CAPEX plus O&M	$2,451,086	
Total Electricity Costs	$3,791,097	$2,146,602
Total Cost per kWh	*$0.20274*	*$0.11480*
Cost per BBL of Oil	*$0.48519*	*$0.27472*

Results



- ~170,000 unique scenarios outcomes across counties and utilities
- NG Gensets have a cost advantage in 66% of cases.
- If you exclude the Infill Drilling cases gensets are favored in 80% or more of cases considered.
- Closer spacing, more wells, and higher production type curves shift advantage to the grid.
- Greenfields, trunk distance, larger spacing, fewer wells, and lower production type curves favor gensets.

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Thank You!

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Economically Feasible?

Costs Vary by Project Size

- Upgrading wells/facilities
- Infill drilling
- CO_2 recycling & compression
- Major or spur CO_2 pipelines
- CO_2 flow lines
- Monitoring stations
- CO_2 purchases

Other Considerations

- Long term projects & contracts
- Payback in years, not months
- Flood last decades, peak in 4-5 years
- Proximity to CO_2

Example Scoping Economics (small)

61.8 MMbbls Original Oil in Place

Total CAPEX of $28.7 million

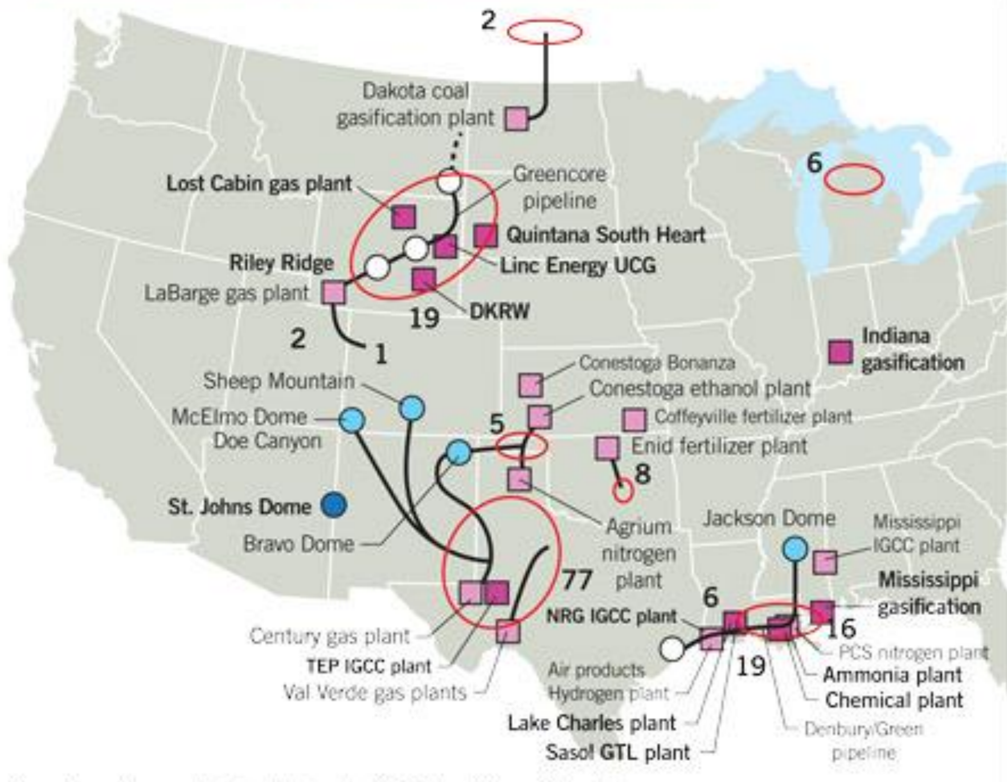
Addt'l OPEX of $1.4 million

Payback 5-6 years @ $50/oil

- 15 Existing Wells plus 5 New Wells
  ~$12 million
- <**5 MMcfd** of CO_2 injection
  ~$6 million for CO_2 plant
  plus $500k in OPEX
- 4-inch 30-mile pipeline
  ~$10.5 million for pipeline
- CO_2 Price = $0.50 + 2% of WTI
  $1.50/mcf ($29/tonne) @ $50/oil

PROJECTED CO_2, EOR OPERATIONS, AND CO_2 SOURCES: 2020

FIG. 4



Source: Advanced Resources International Inc. based on OGJ EOR/Heavy Oil Survey 2014 and other sources

Oil production, 2020	
CO_2 –EOR projects	147
Oil production, 1,000 b/d	638
CO_2 supplies, 2020	
Number of sources	30
• Natural	6
• Industrial	24
CO_2 supply, MMcfd	6.5
• Natural	3.4
• Industrial	3.1

147 Number of CO_2-EOR projects
Natural CO_2 source
Industrial CO_2 source
CO_2 pipeline
CO_2 proposed pipeline

Is the CO_2 Available?

Proximity to the CO_2 source can be a huge driver of costs. Assuming you get the permits pipelines cost \$80-100k per inch-mile.

Miscible CO_2 - Technically Feasible

Property	Recommendation
Crude Oil	
Gravity, Deg. API	>22 (and probably <45)
Viscosity, cp	<10
Composition	High Cut of C_5-C_{12}
Reservoir	
Oil Saturation, % PV	>20
Type of Formation	Sandstone/Carbonate
Average Permeability	Just need good injection rates
Depth & Temperature	Sufficient for Injection Pressure > MMP
>40 API	>2,500 ft
32 – 40 API	>2,800 ft
28 – 32 API	>3,300 ft
22 – 28 API	>4,000 ft
Fracture Pressure	Fracture Pressure > Injection Pressure

Source: "EOR Screening Criteria Revisited – Part 2", Taber et.al, SPE Reservoir Engineering, Aug. 1997

Failing to reach Minimum Miscibility Pressure (MMP) can slash incremental oil recovery by 50% or more.

Economically Feasible?

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  ~$6 million for CO_2 plant
  plus $500k in OPEX
- 4-inch 30-mile pipeline
  ~$10.5 million for pipeline
- CO_2 Price = $0.50 + 2% of WTI
  $1.50/mcf ($29/tonne) @ $50/oil

Mind the Gap – Industrial Capture vs EOR Pricing

Pricing (Metric Tonnes)	
Metric Tonne	MCF
$10	$0.52
$15	$0.78
$20	$1.04
$25	$1.30
$30	$1.56
$35	$1.82
$40	$2.08
$45	$2.34
$50	$2.60
$55	$2.86
$60	$3.12
$65	$3.38
$70	$3.64
$75	$3.90
$80	$4.16

Pricing vs WTI Oil Price			
WTI	$0.50+1%	$0.5+2%	$0.5+2.5%
$20	$0.70	$0.90	$1.00
$30	$0.80	$1.10	$1.25
$40	$0.90	$1.30	$1.50
$50	$1.00	$1.50	$1.75
$60	$1.10	$1.70	$2.00
$70	$1.20	$1.90	$2.25
$80	$1.30	$2.10	$2.50
$90	$1.40	$2.30	$2.75
$100	$1.50	$2.50	$3.00
$110	$1.60	$2.70	$3.25
$120	$1.70	$2.90	$3.50
$130	$1.80	$3.10	$3.75
$140	$1.90	$3.30	$4.00
$150	$2.00	$3.50	$4.25
$160	$2.10	$3.70	$4.50

“Commodity Price”

cost of atmospheric CO_2 at the source

“Delivered At Field Price”

= commodity price

+ processing/compression

+ pipeline/truck transport

“Oil Price Tie”

delivered CO_2 price is often tied to the WTI oil price

= $0.50 + 1-2.5% of WTI

*thanks for the idea Keith @ Chaparral Energy

Other Policy Initiatives

NEORI & Great Plains Institute

- Broad coalition of companies, NGOs and unions supporting CO_2-EOR.
- Major initiative is on extending, reforming and strengthening Section 45Q tax credit.

Other Policy Ideas

- Authorize private activity bonds (PABs) for CO_2 capture projects.
- Authorize MLPs for CO_2 projects.
- Price stabilization program.
- Incorporate CO_2 pipelines into national infrastructure agenda.
- Give CCUS plants more preferential ranking in electric power dispatch.

Units & Pricing

Volume per Day			
Metric Tonnes	Short Tons	MCF/d	MMCF/d
1	0.91	19	0.02
10	9.09	192	0.19
100	90.91	1,923	1.92
500	454.55	9,615	9.62
1,000	909.09	19,231	19.23
2,500	2,272.73	48,077	48.08
5,000	4,545.45	96,154	96.15
10,000	9,090.91	192,308	192.31

Volume per Year			
Metric Tonnes	Short Tons	MCF/yr	MMCF/yr
365	332	7,019	7
3,650	3,318	70,192	70
36,500	33,182	701,923	702
182,500	165,909	3,509,615	3,510
365,000	331,818	7,019,231	7,019
912,500	829,545	17,548,077	17,548
1,825,000	1,659,091	35,096,154	35,096
3,650,000	3,318,182	70,192,308	70,192

Pricing (Short Tons)	
Short Ton	MCF
$10	$0.57
$15	$0.86
$20	$1.14
$25	$1.43
$30	$1.72
$35	$2.00
$40	$2.29
$45	$2.57
$50	$2.86
$55	$3.15
$60	$3.43
$65	$3.72
$70	$4.00
$75	$4.29
$80	$4.58

Pricing (Metric Tonnes)	
Metric Tonne	MCF
$10	$0.52
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