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The U.S. Shale Gas Resource: Outlook for the Industry Reshaping Global Energy

by

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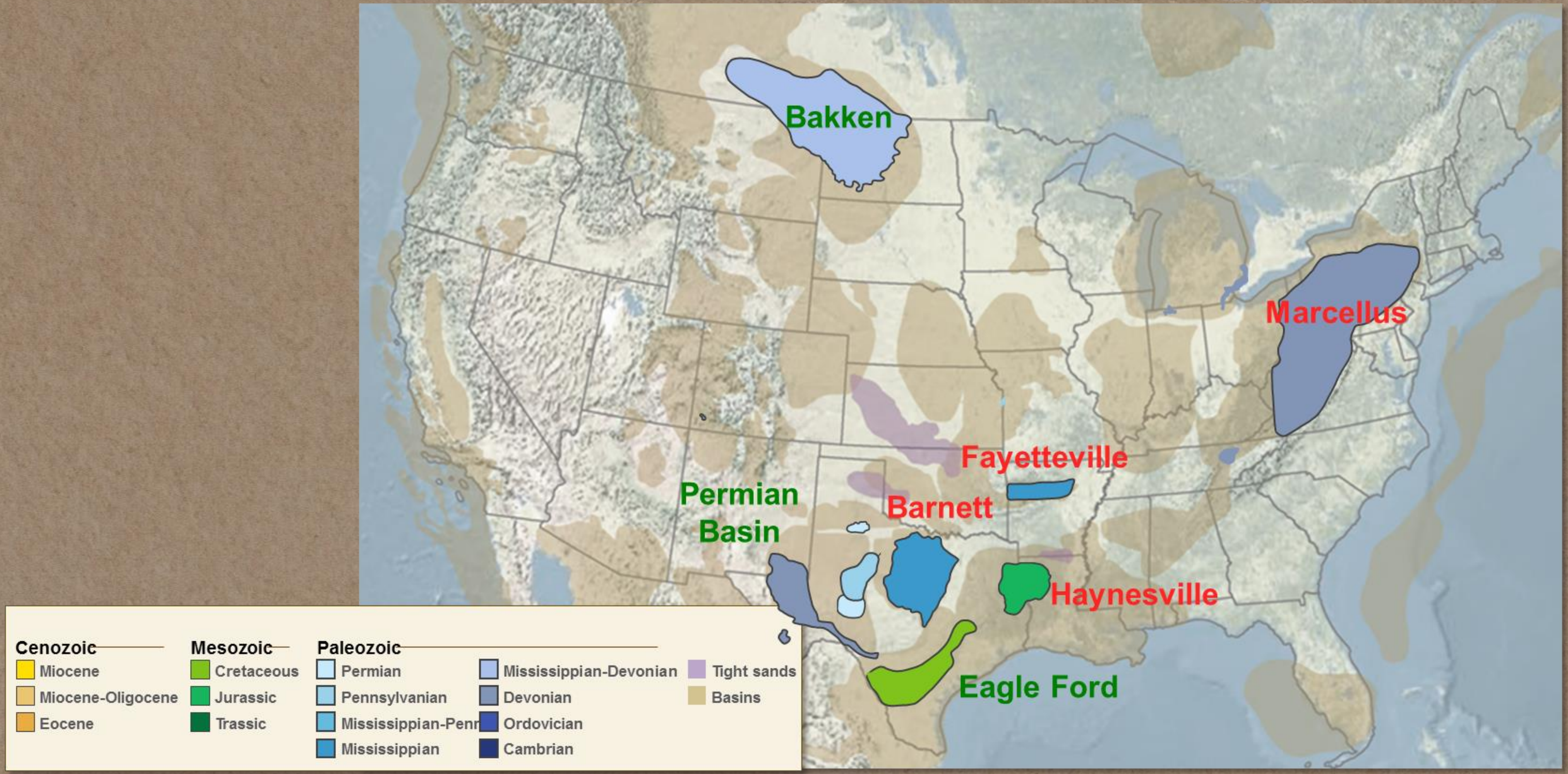
Background

Supported by the Sloan Foundation, Mitchell Foundation, DOE, and oil&gas companies BEG's team of geoscientists, engineers, statisticians and economists conducted an inter-disciplinary study of shale gas & oil resources.

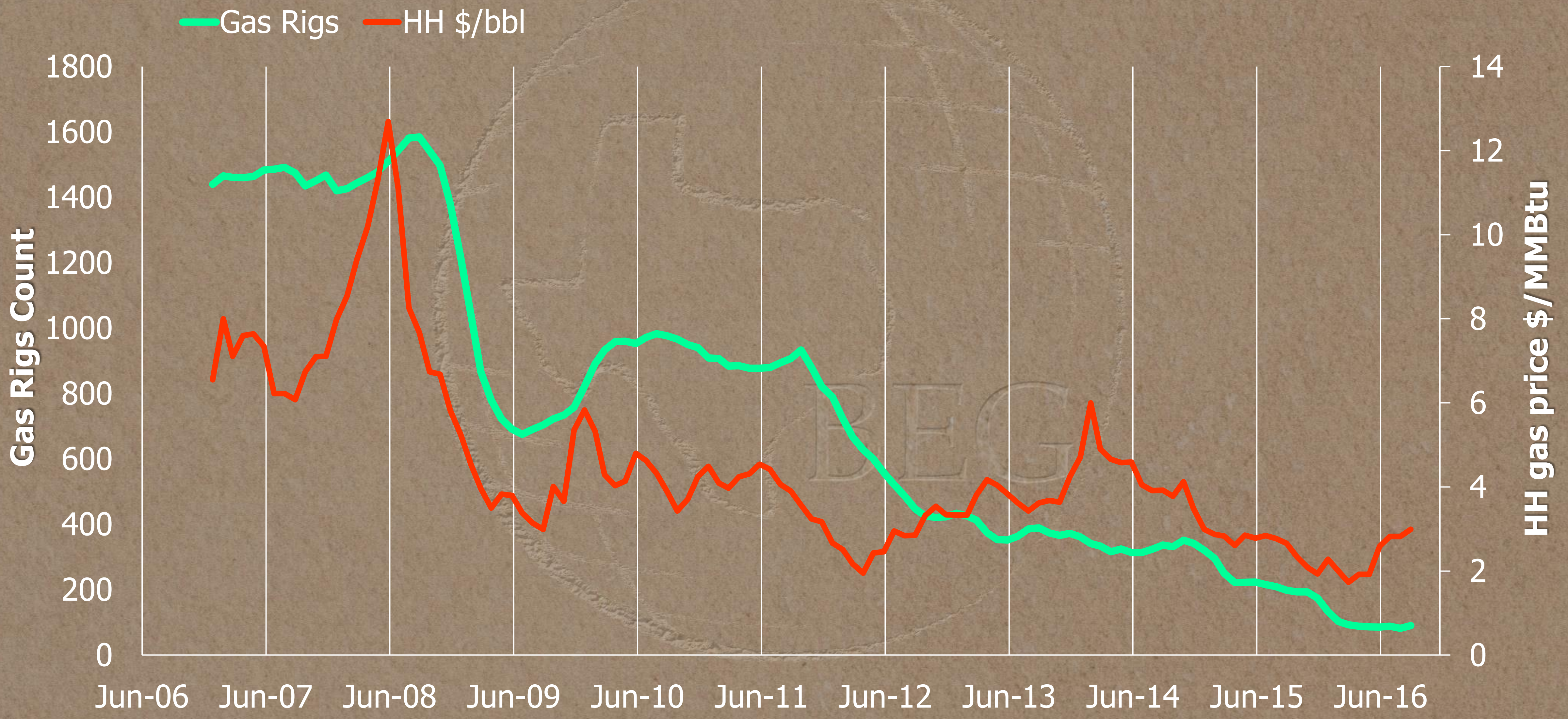


Study Questions

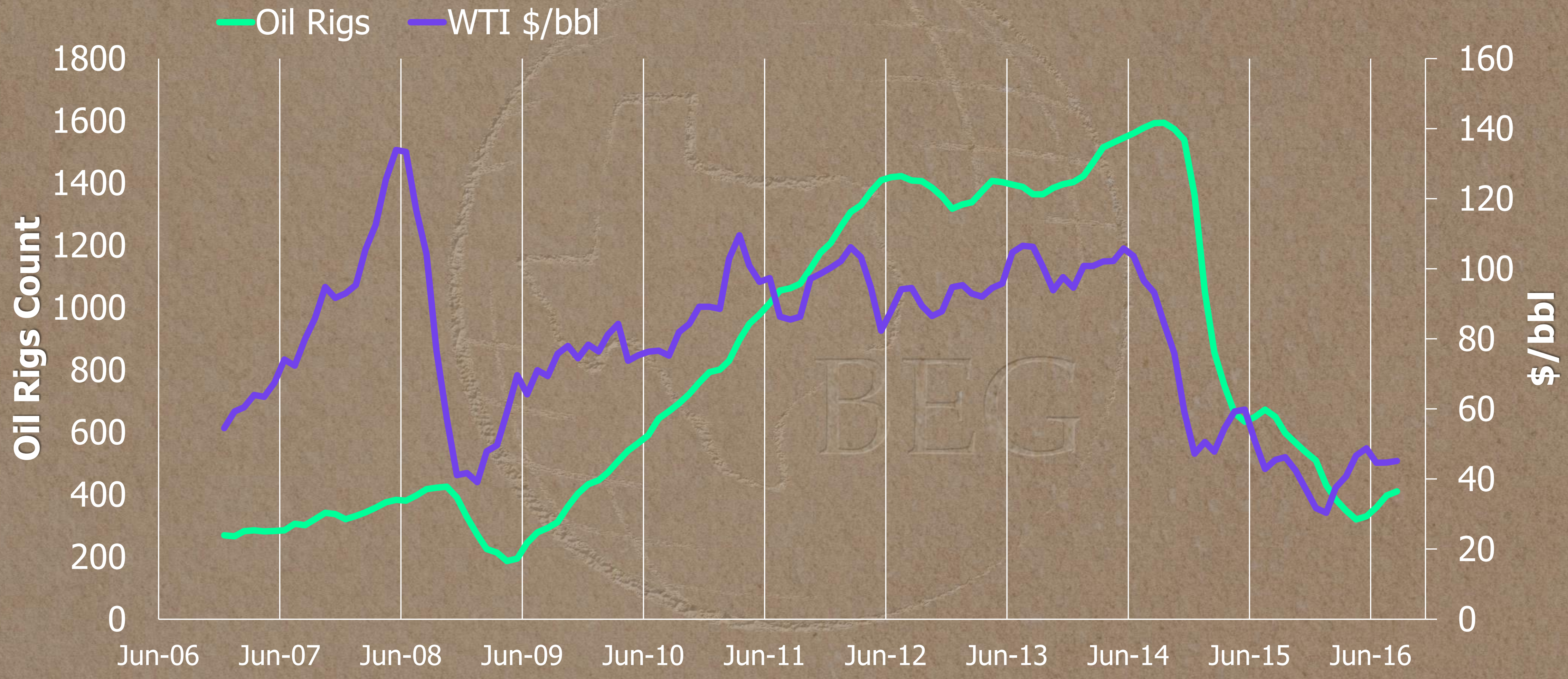
To provide **rigorous and granular assessment of the future** we developed an integrated approach studying:

- **What is the original resource in place (OGIP, OOIP)?**
- **What portion of the resource is technically recoverable *in the past, present and future*?**
- **What portion of the resource is economically recoverable *given technical and economic assumptions*?**
- **What are the long-term production outlook scenarios *under various energy prices, costs, technology, regulations*?**

U.S. Natural Gas Turmoil



U.S. Oil Turmoil



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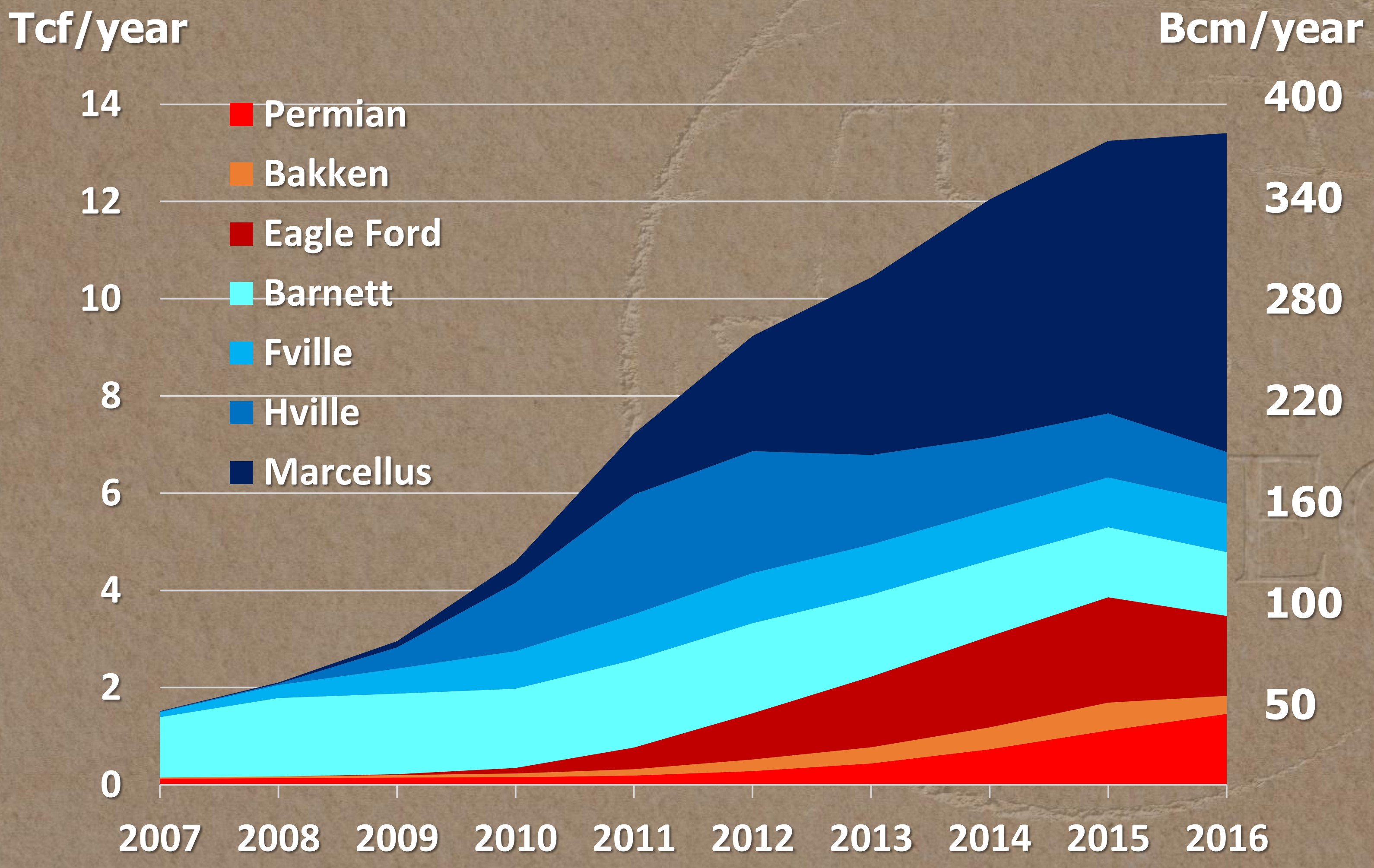
U.S. Natural Gas Production



- Natural gas from shale and tight formations comprises ~50% of the U.S. consumption
- About 30% of gas is produced from tight and shale oil plays
- Despite the low natural gas prices, production continues to grow in many regions

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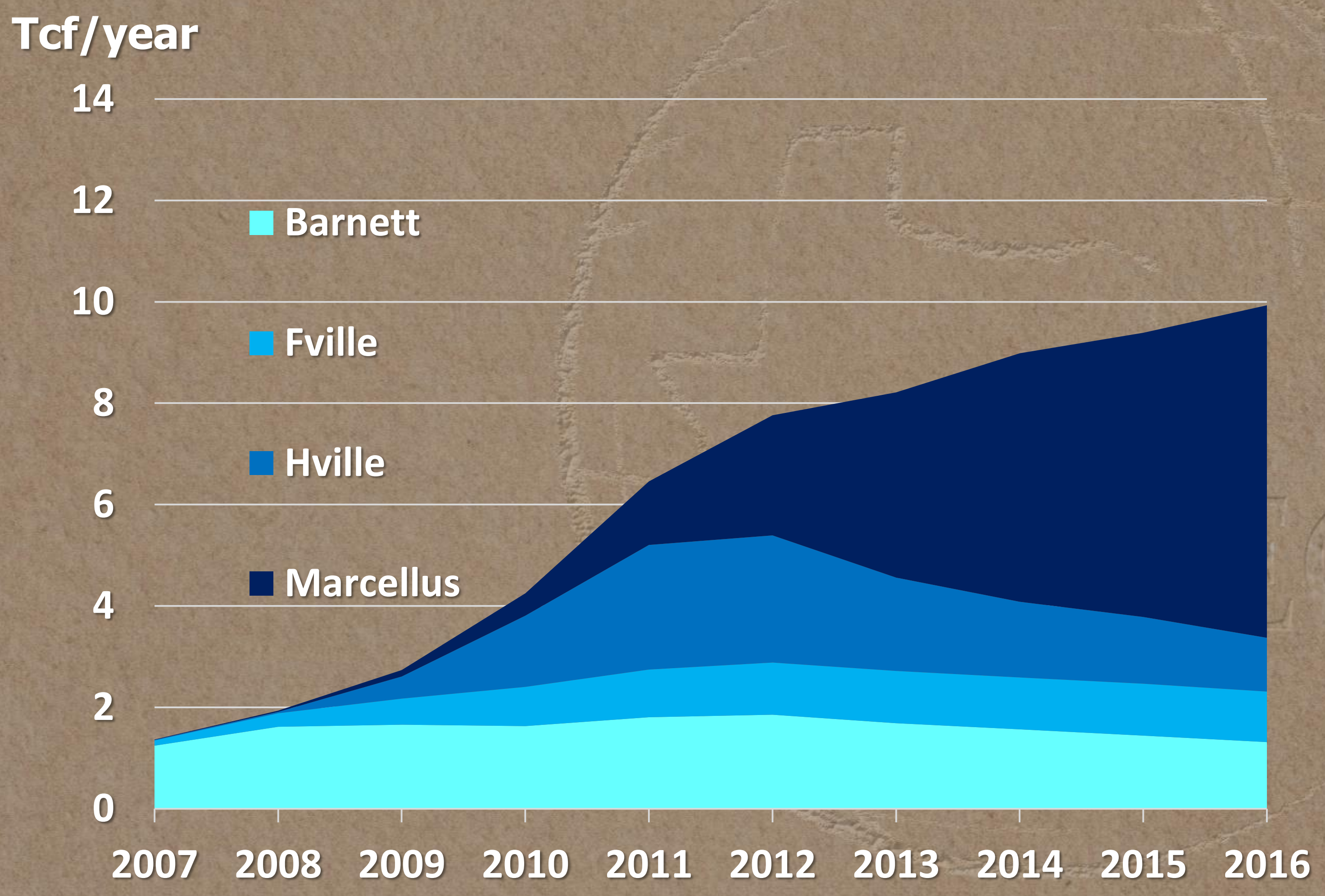
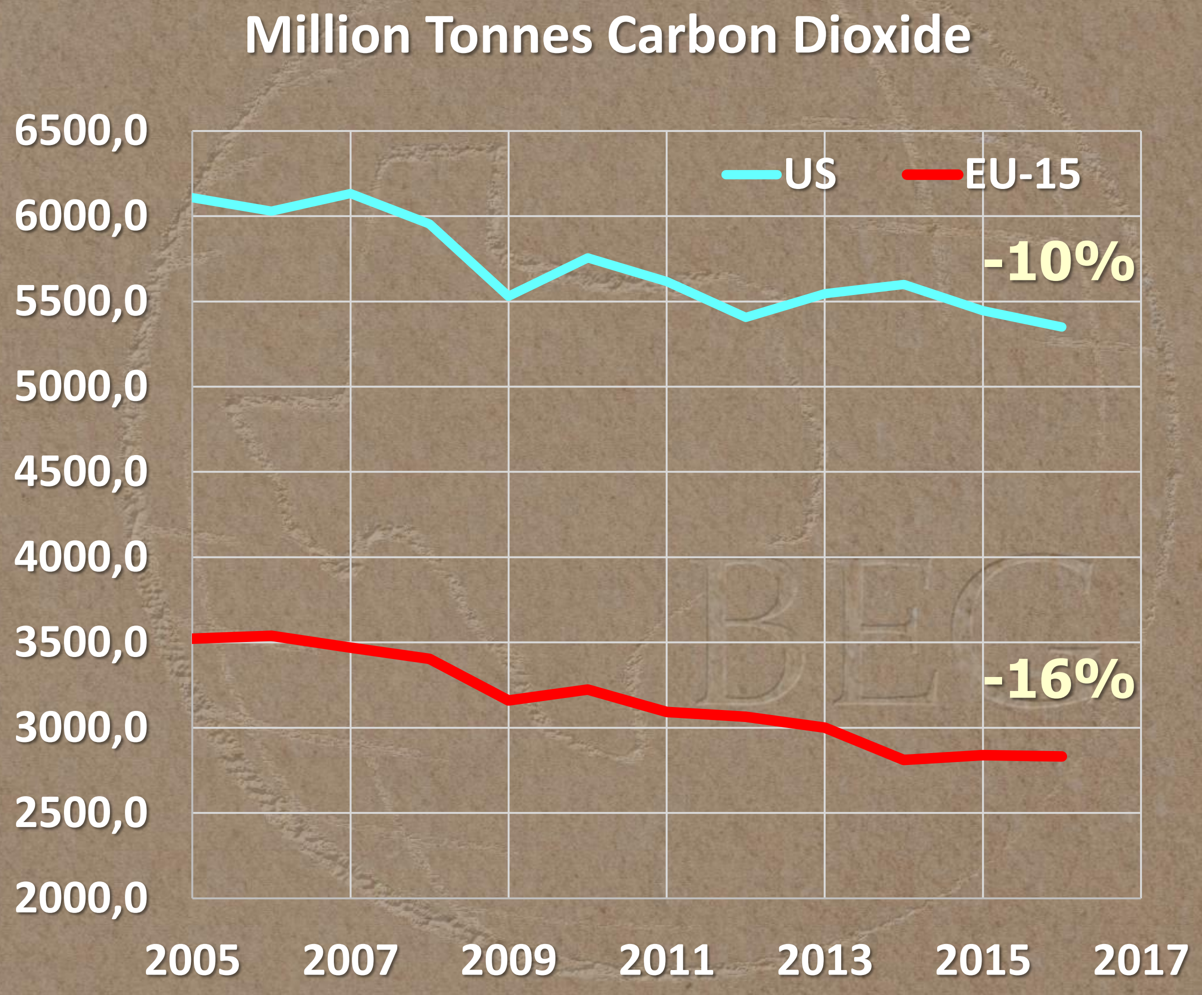
Production from Gas Plays only Grows



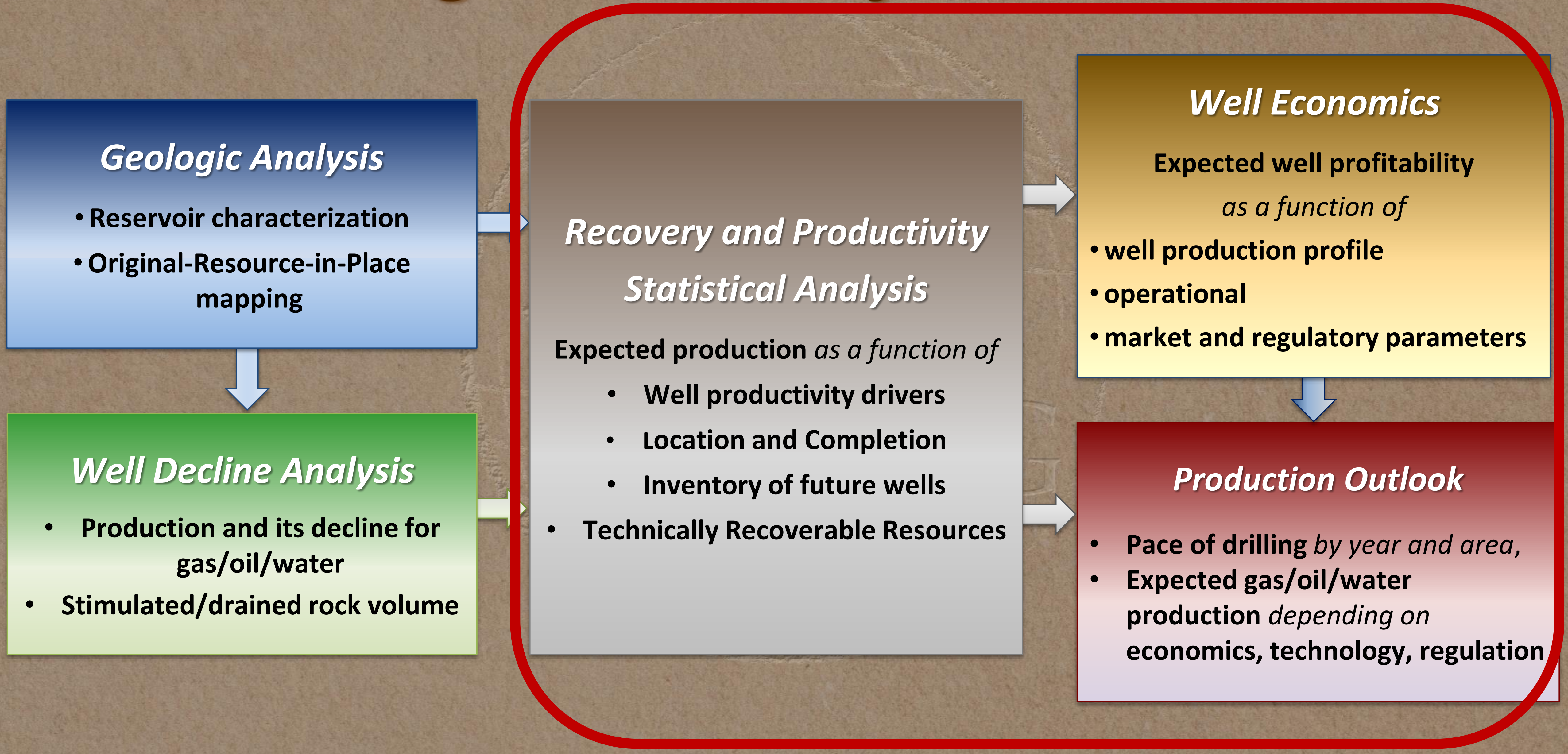
- ➢ Technology
- ➢ Economies of Scale
- ➢ Decreased rig costs (thanks to low oil prices)

Major Implication: Reduction in Emissions



BP Statistical Review, 2016

Integrated Study Workflow



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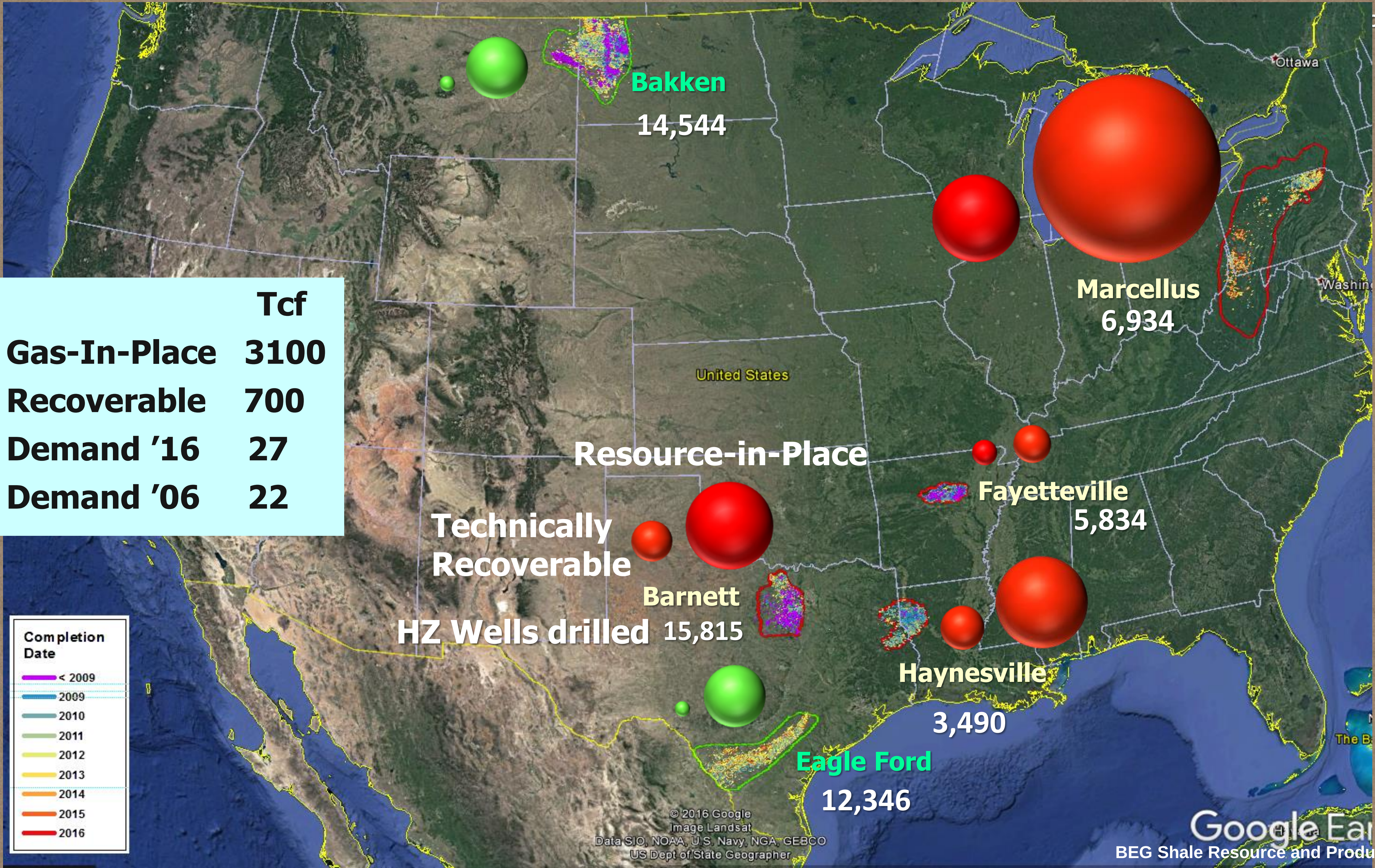
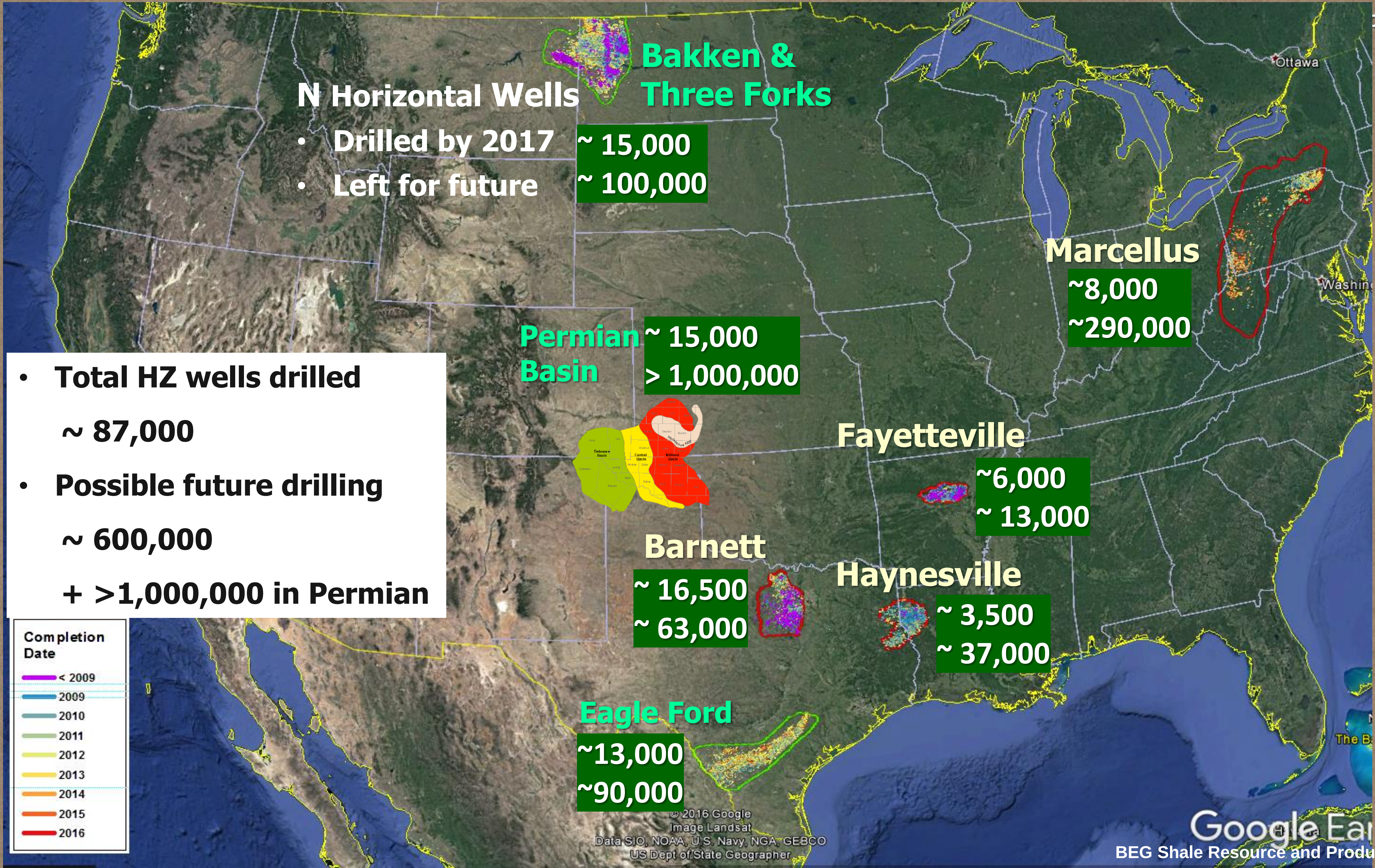
	Tcf
Gas-In-Place	3100
Recoverable	700
Demand ’16	27
Demand ’06	22



BEG Shale Resource and Production Team


N Horizontal Wells
• Drilled by 2017
• Left for future
Bakken & Three Forks
~ 15,000
~ 100,000
Marcellus
~8,000
~290,000
Permian Basin
~ 15,000
> 1,000,000
Fayetteville
~6,000
~ 13,000
Barnett
~ 16,500
~ 63,000
Haynesville
~ 3,500
~ 37,000
Eagle Ford
~13,000
~90,000
• Total HZ wells drilled
~ 87,000
• Possible future drilling
~ 600,000
+ >1,000,000 in Permian
Completion Date
< 2009
2009
2010
2011
2012
2013
2014
2015
2016
Ottawa
© 2016 Google
Image Landsat
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
US Dept of State Geographer

- 24 horizontals drilled within 1 year

each

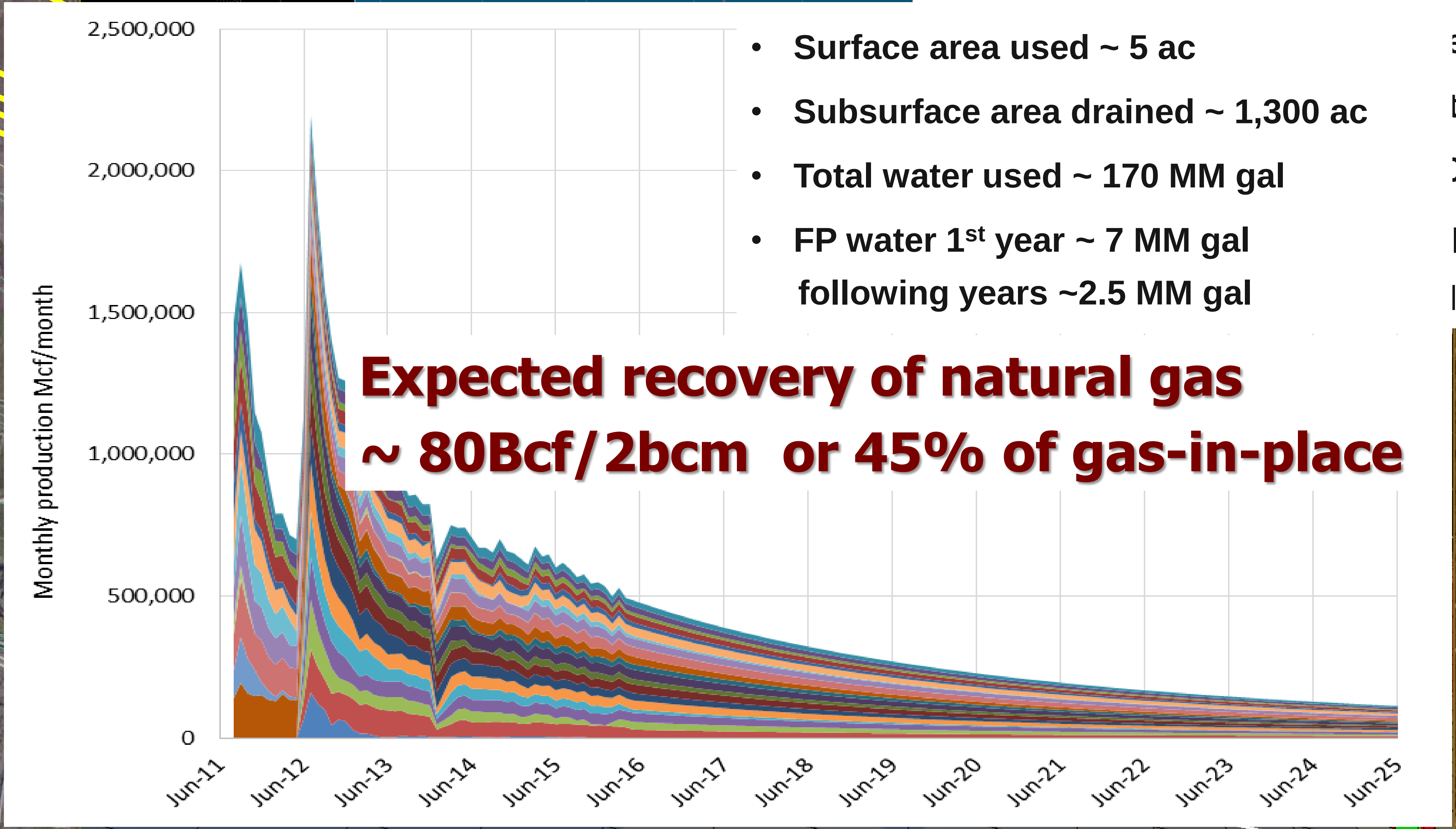
t

)00 ft

proppant

l per well

- Surface area used ~ 5 ac
- Subsurface area drained ~ 1,300 ac
- Total water used ~ 170 MM gal
- FP water 1st year ~ 7 MM gal
  following years ~2.5 MM gal



Expected recovery of natural gas ~ 80Bcf/2bcm or 45% of gas-in-place

Barnett example: IHS data on well length, depth, proppant, fracWater, production

Well Economics Model

We use a standard discounted cash flow model to calculate

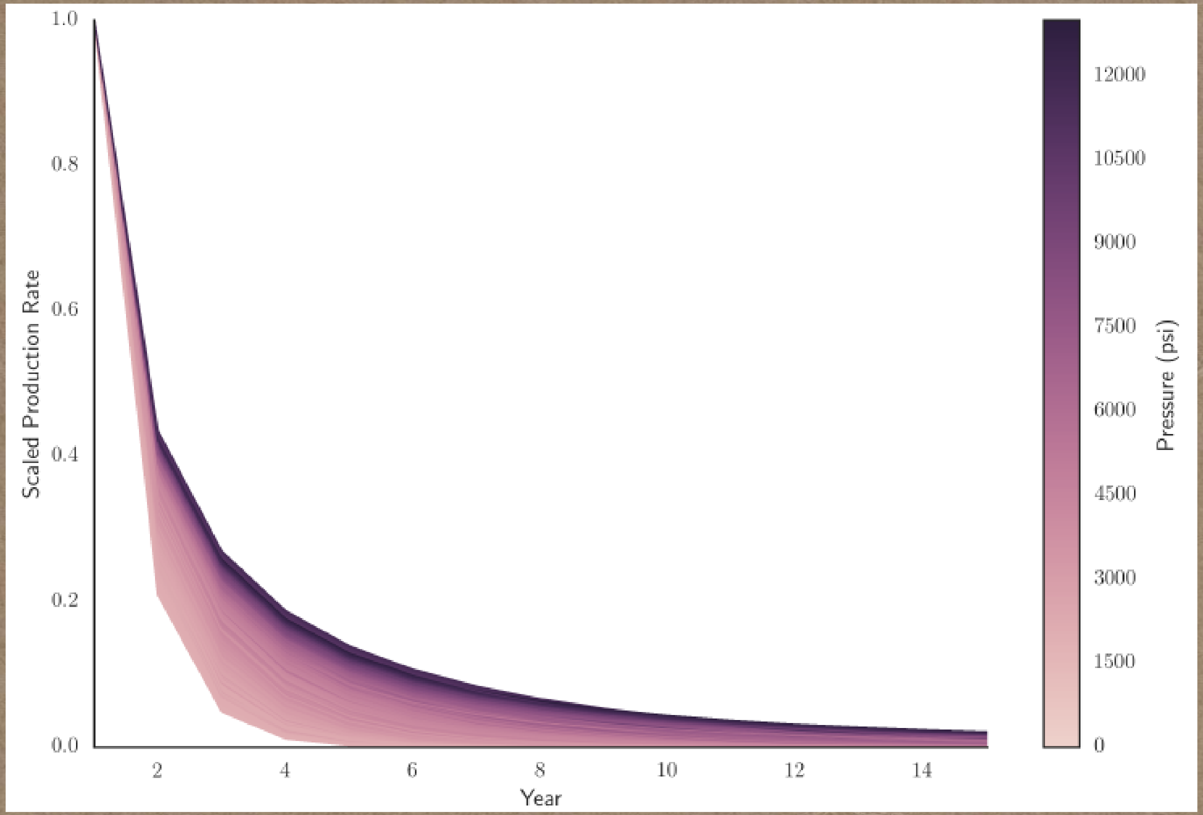
$$\textbf{Profitability Index: PI} = \frac{Present\ Value\ of\ Expected\ Cash\ Flows}{Investment\ Cost}$$

assuming a ***price expected*** at the time of drilling, 8% discount rate, and shut down period/economic limit determined by a positive cash flow, with

Drilling and Completion: **DC** ~ F (Depth, Length, Fluid, Proppant)

Well production over time: $\mathbf{q_t} \sim q^{1year}$(natural gas, liquids,water) $\cdot$ Decline_t

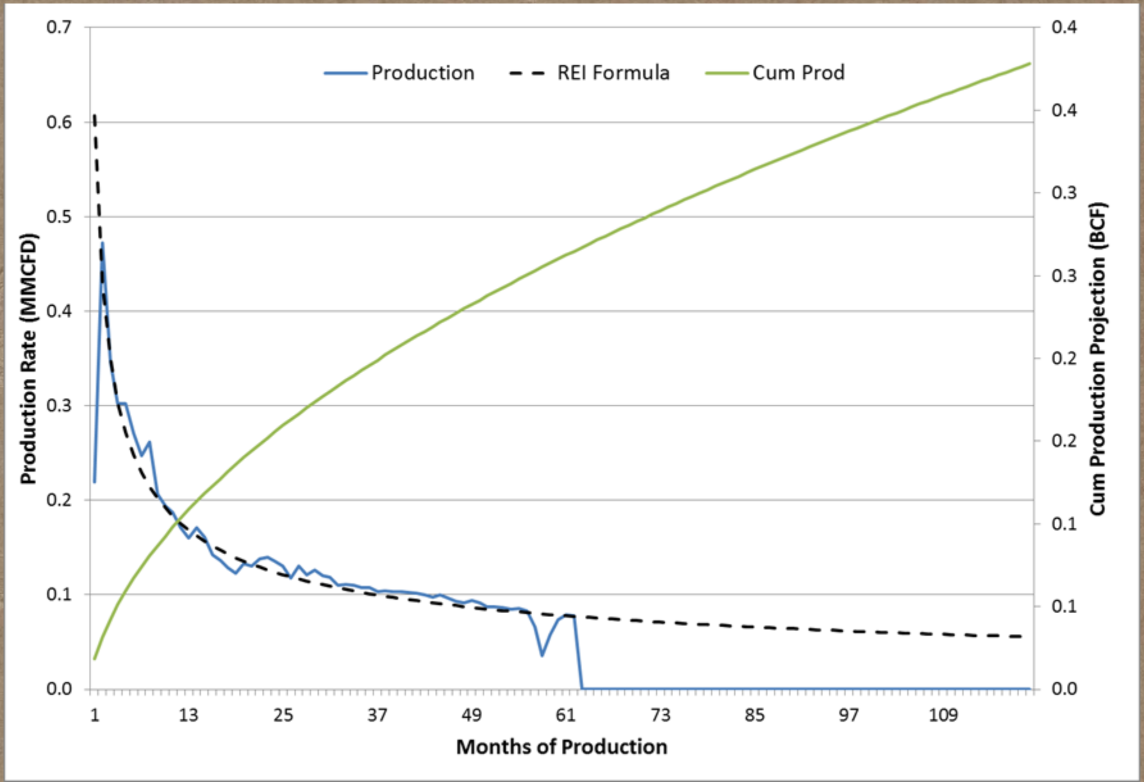
Per-well Production and its Decline



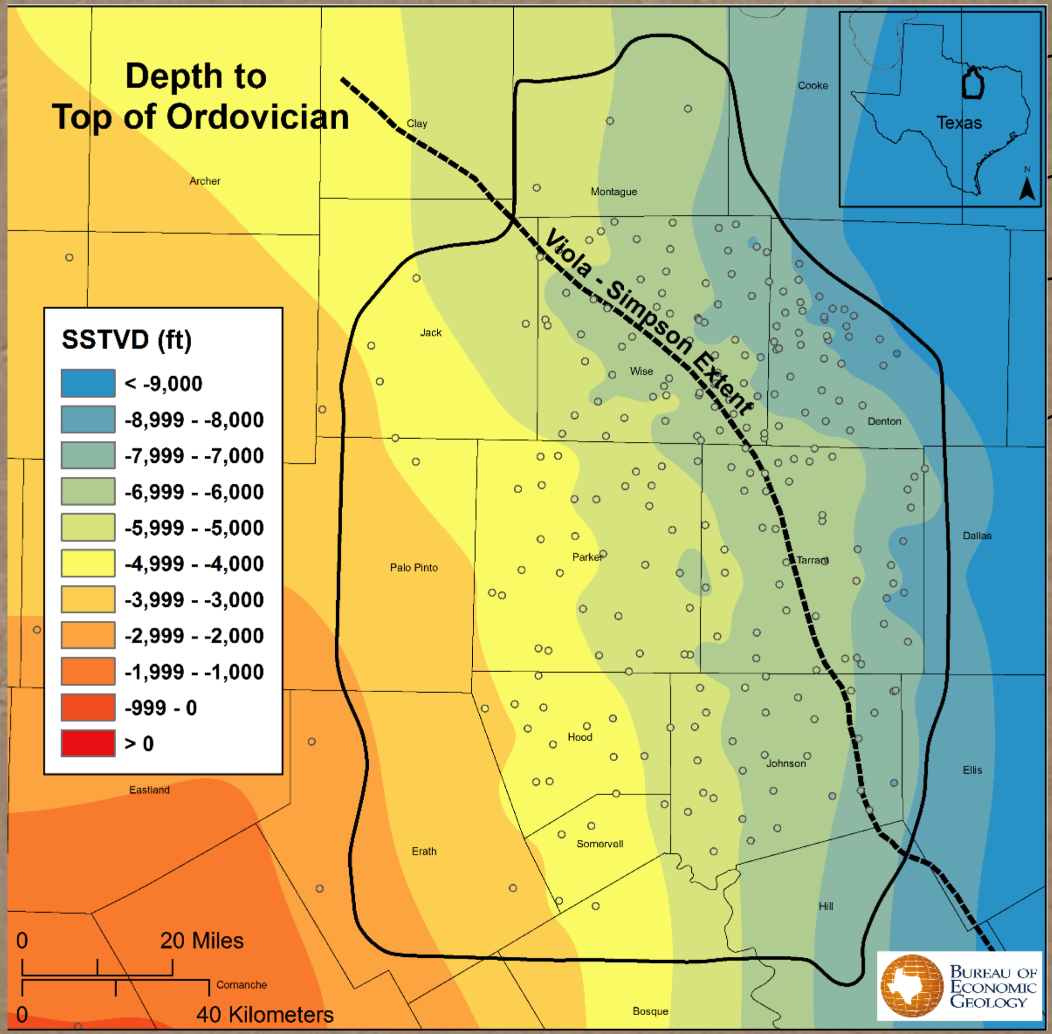
- geologic parameters,
- rock and fluid properties,
- completion design,
- technology

Patzek et al., 2013

Male et al., 2015



Variance in Reservoir properties



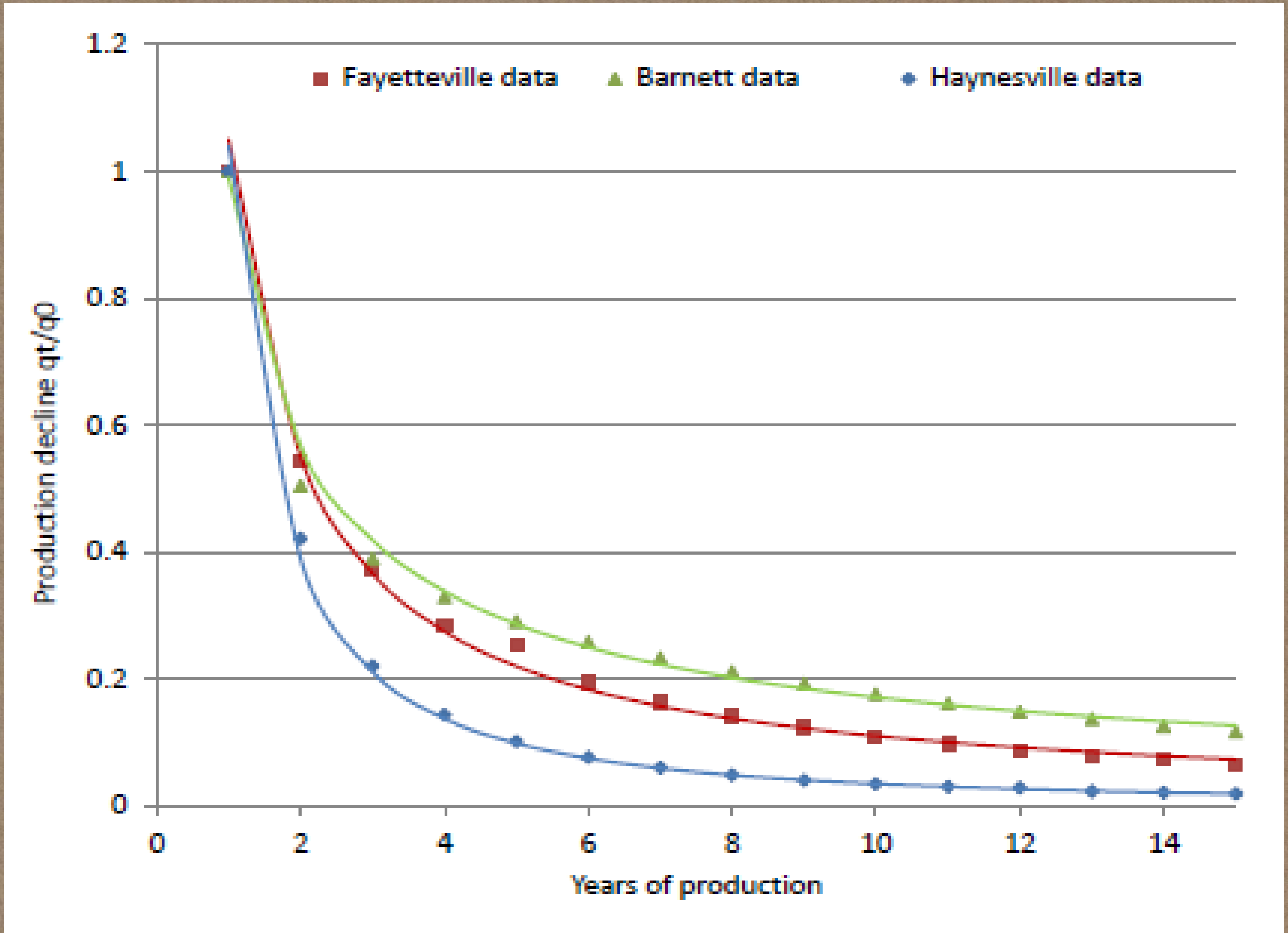
Oil

Rich Condensate

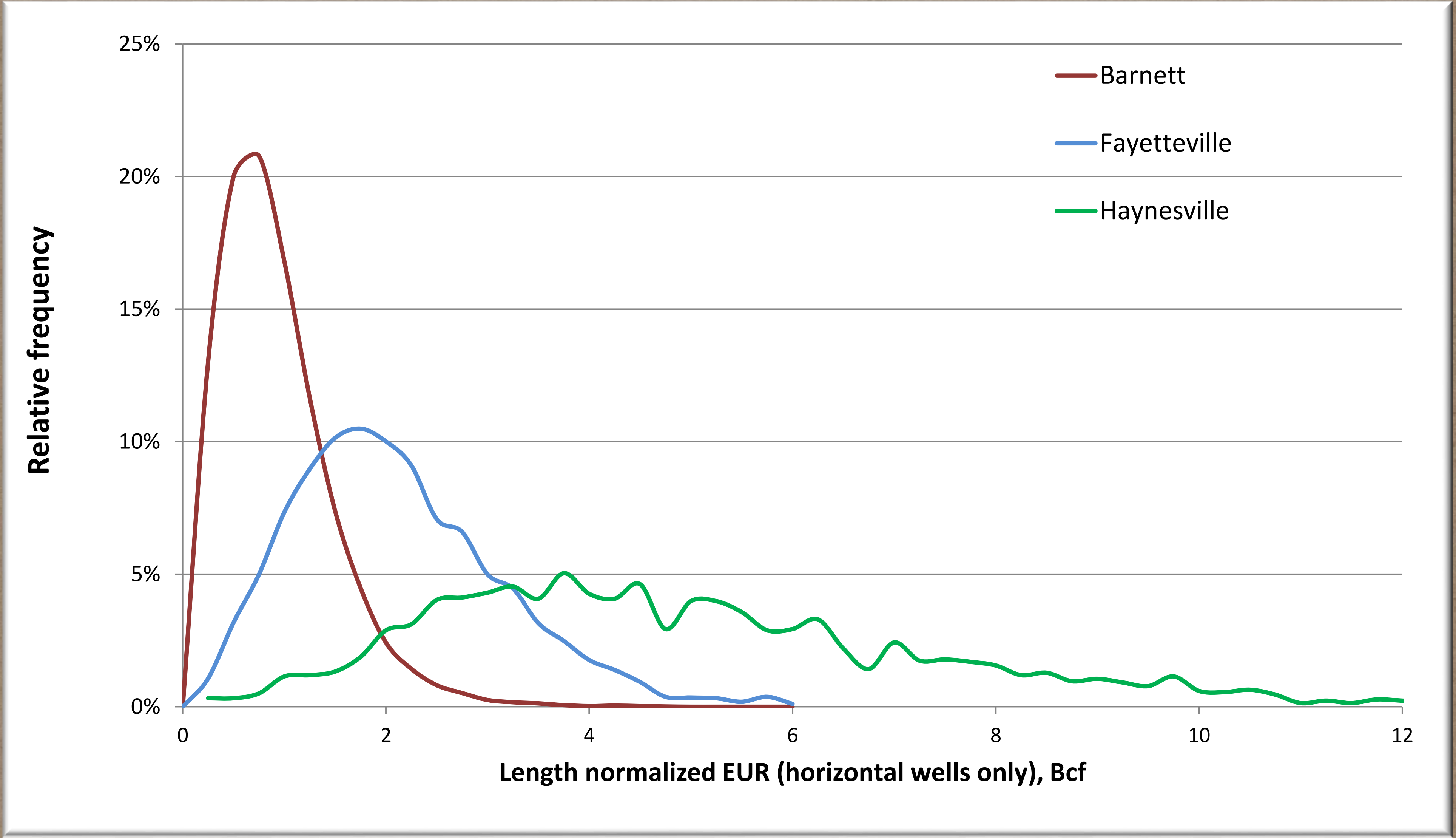
Lean Condensate

Dry Gas

Differences in Declines across the Plays



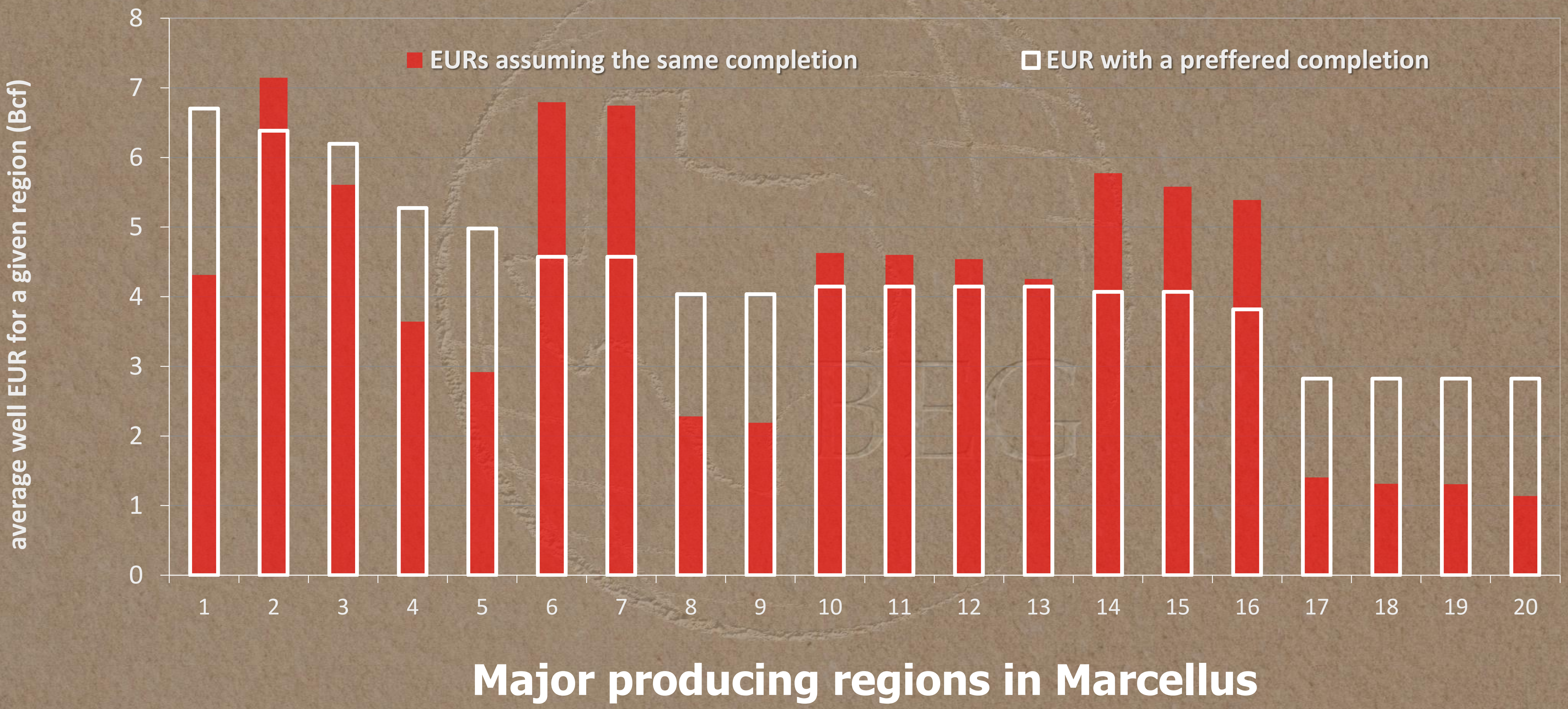
Distributions of Individual Well Recovery



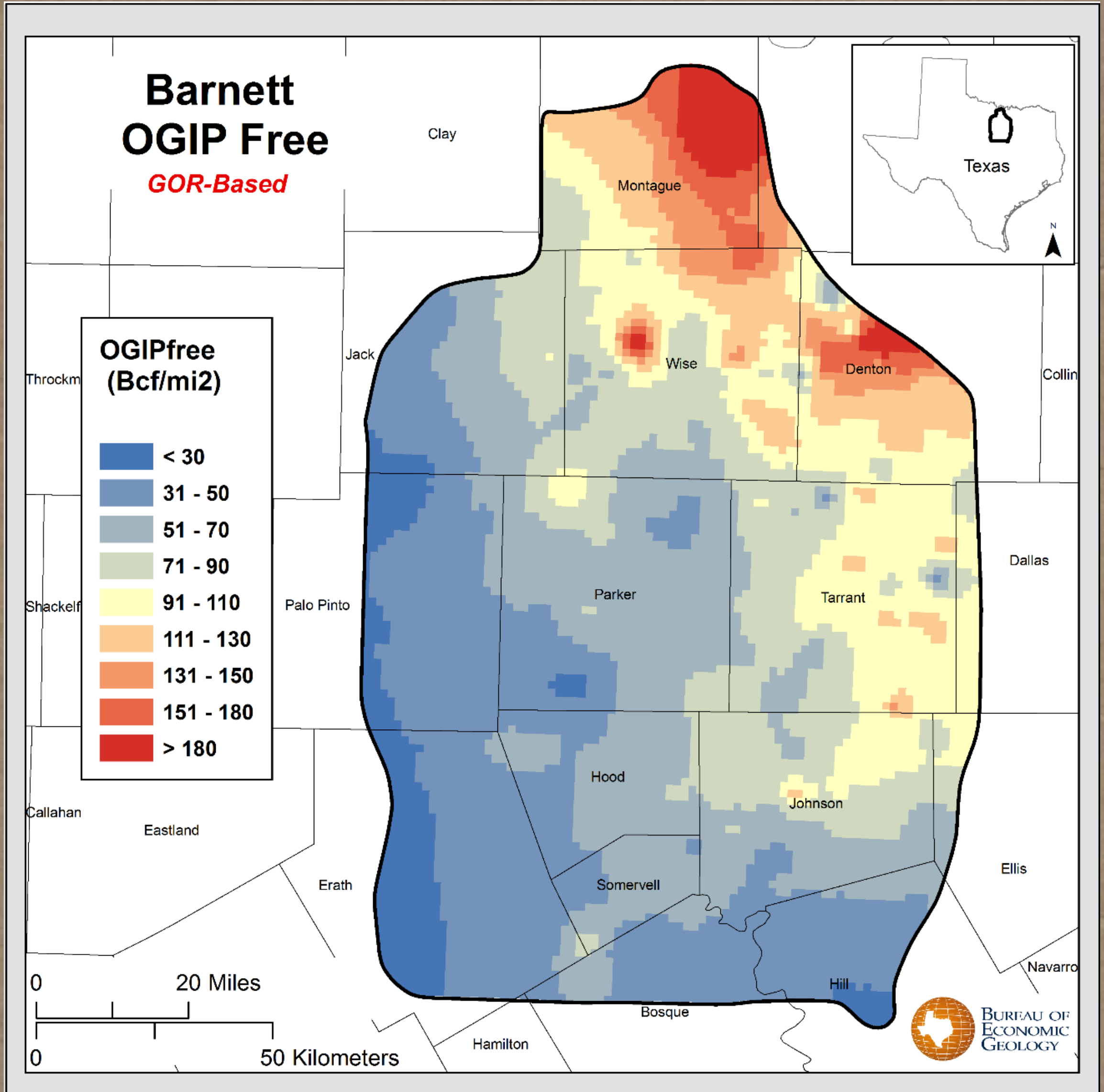
Ikonnikova et al., 2015

Ikonnikova 2017

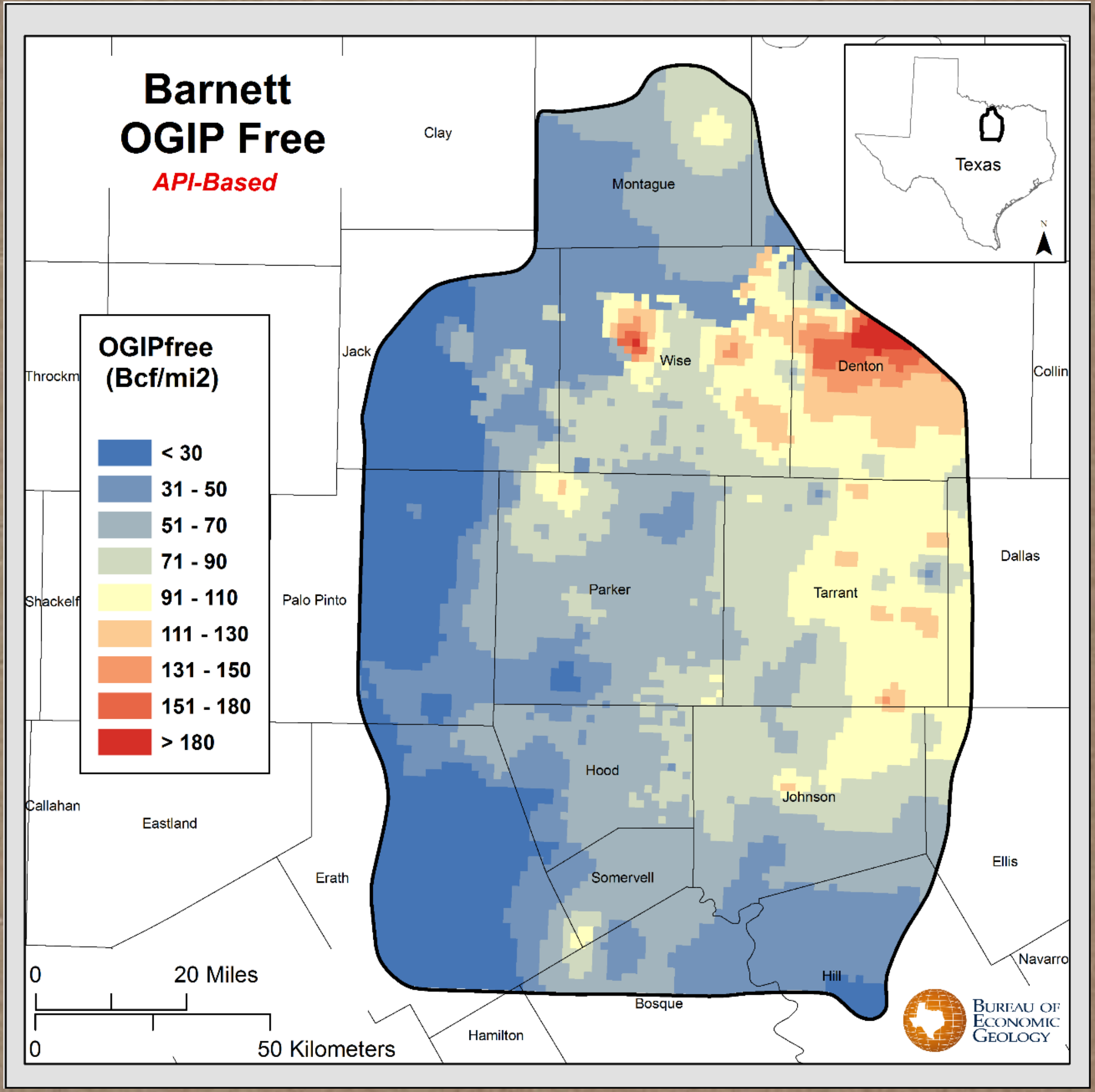
Effect of Completions of Expected Recovery

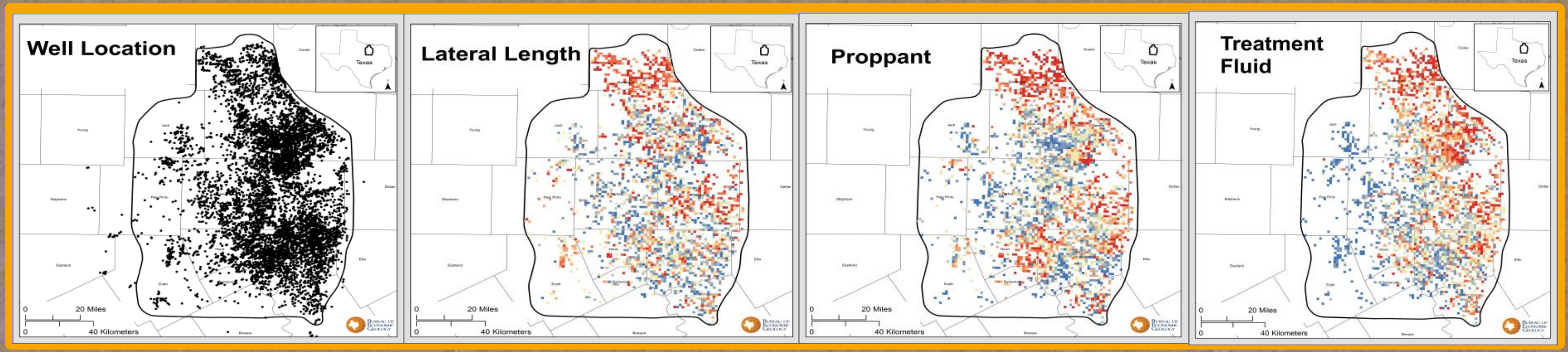


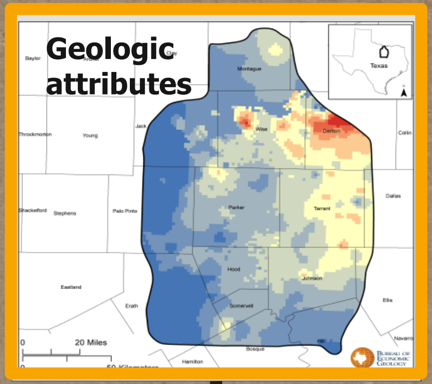
GOR-based



Gravity-based







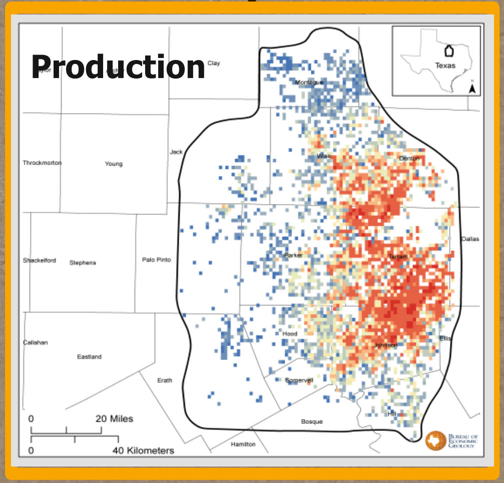
+ Energy Prices / Cost Indexes

Use statistical tools:

- Random Forest
- Model-based recursive partitioning

To find Productivity Drivers

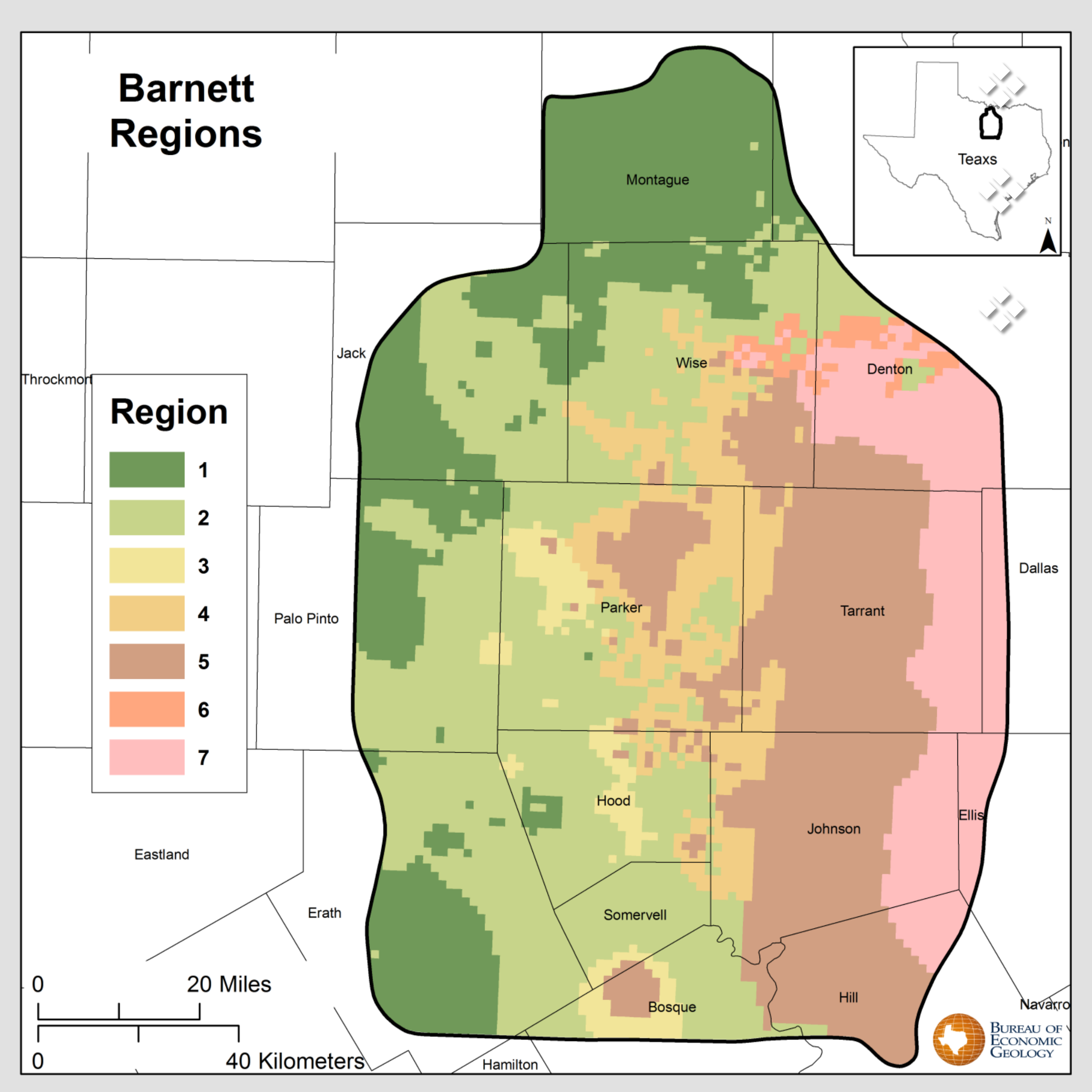
f



Vankov et al, 2017

Productivity Regions

Ikonnikova 2017



Production Function:

$$EUR = f(GIP, Completion, Age)$$

$$f = c \cdot W^{b_1} L^{b_2} P^{b_3} GIP^{b_4} Age^{b_5}$$

- 7 Production Regions, each region described by a single production function
- Regional splits:
  - gas / fluid properties
  - Pressure
  - time
- Change in functional parameters over time allows to analyze change in technology

Model Performance

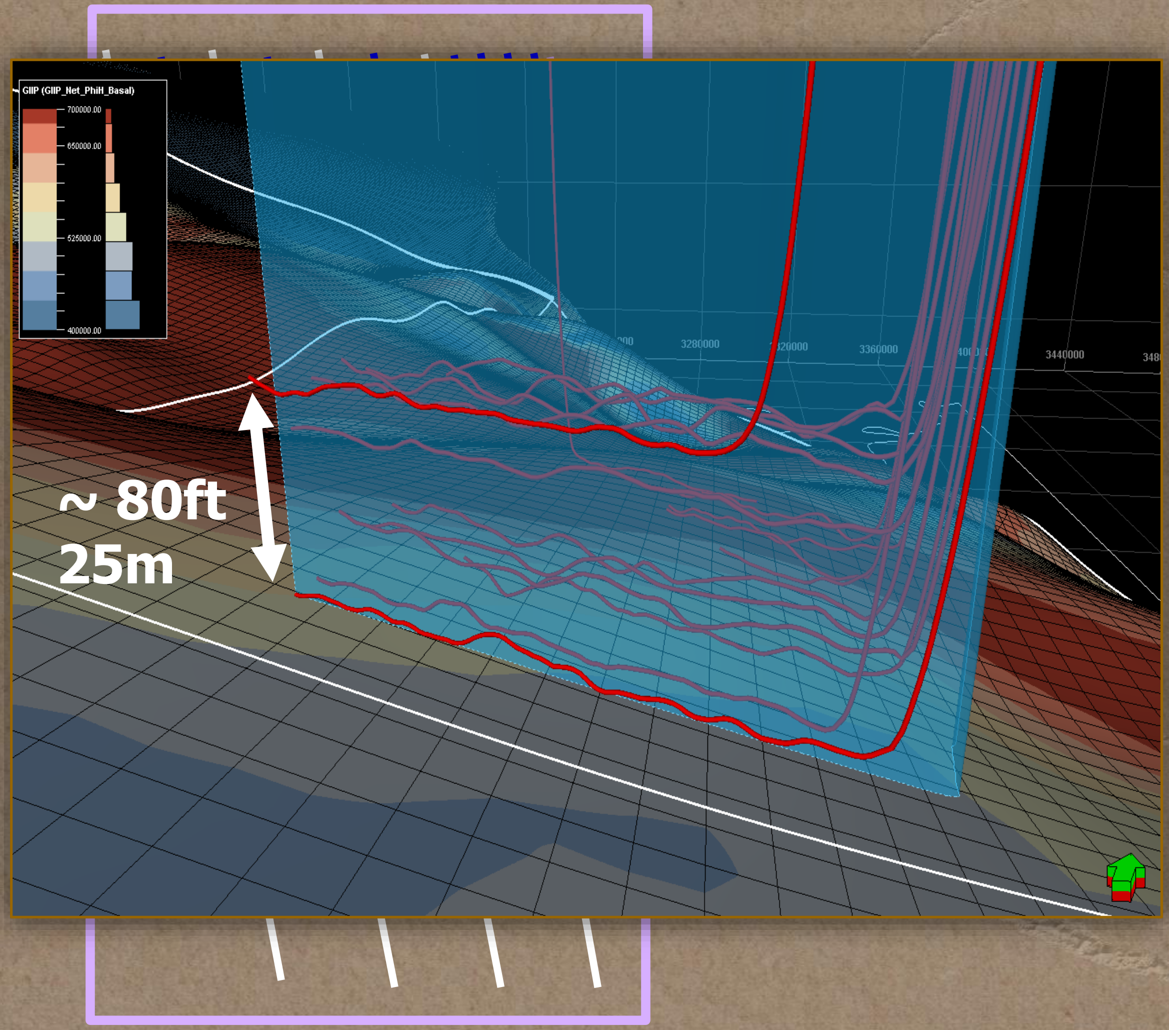
- New technology harder to predict initially, though some models adjust quicker
- Using larger training data does not necessarily results in better prediction in the presence of technology changes

Train	Test Year	MSE
2007-2008	2009	0.37
2007-2009	2010	0.45
2007-2010	2011	0.34
2007-2011	2012	0.25
2007-2012	2013	0.33
2007-2013	2014	0.30
2007-2014	2015	0.66

Train	Test Year	MSE
2007-2008	2009	0.37
2008-2009	2010	0.46
2009-2010	2011	0.33
2010-2011	2012	0.25
2011-2012	2013	0.34
2012-2013	2014	0.23
2013-2014	2015	0.47

Mean Squared Error (MSE) based on cross validation used to assess model performance changes between years

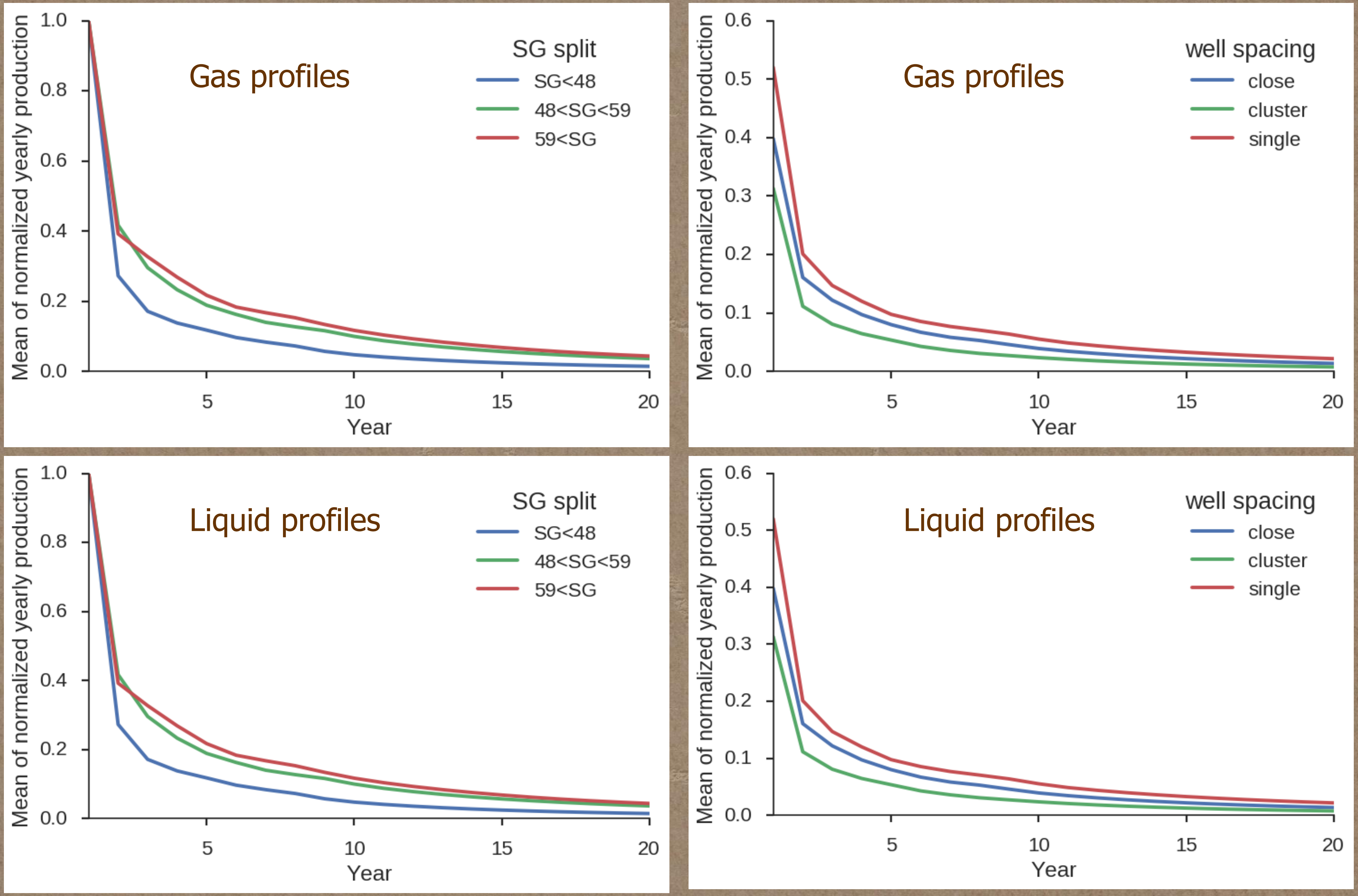
New Completion Strategies



- Established drilling patterns change with technological advances and new economic realm
- New drilling and completion techniques affects the cost and recovery reshaping the supply capabilities
- *and supply elasticities*

Ikonnikova et al., 2016

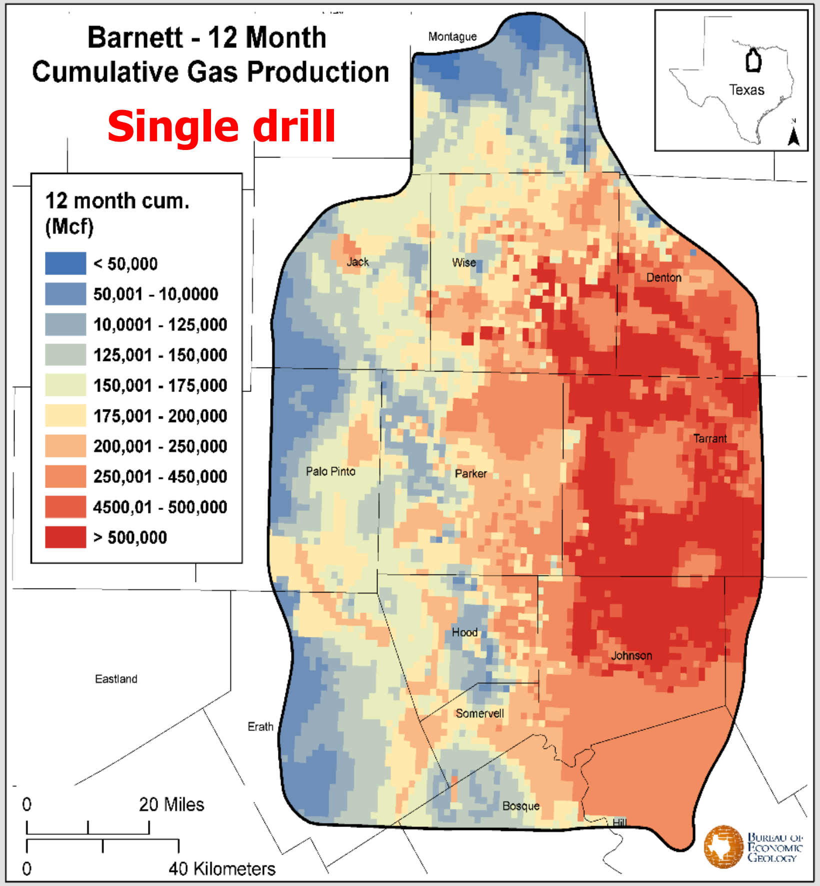
Ikonnikova, 2015

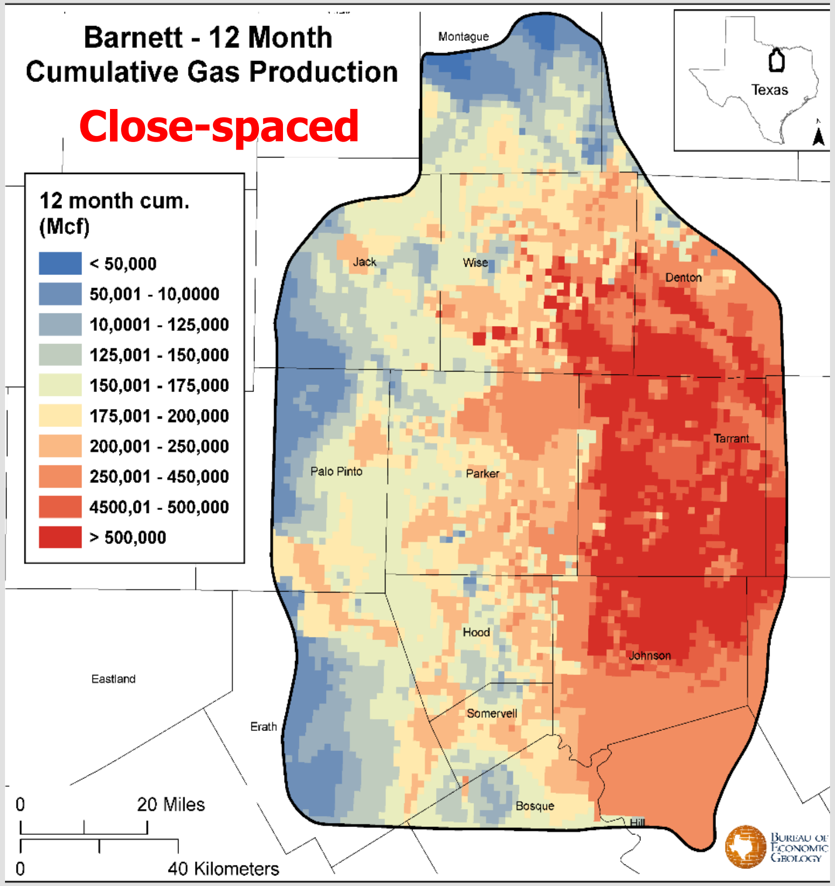


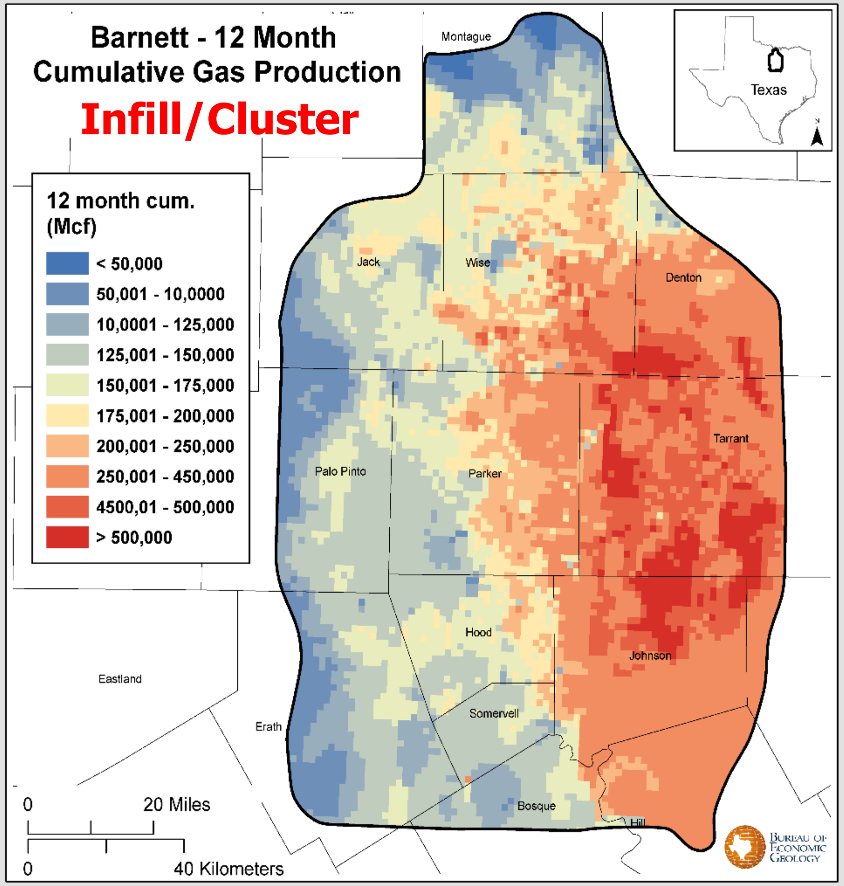
Ikonnikova, 2015

Drilling Approach and Results

- We find that operator often use not max NPV completions because of capital and land constraints
- We use time & location dependent imputations to assign input factors and local geo attributes







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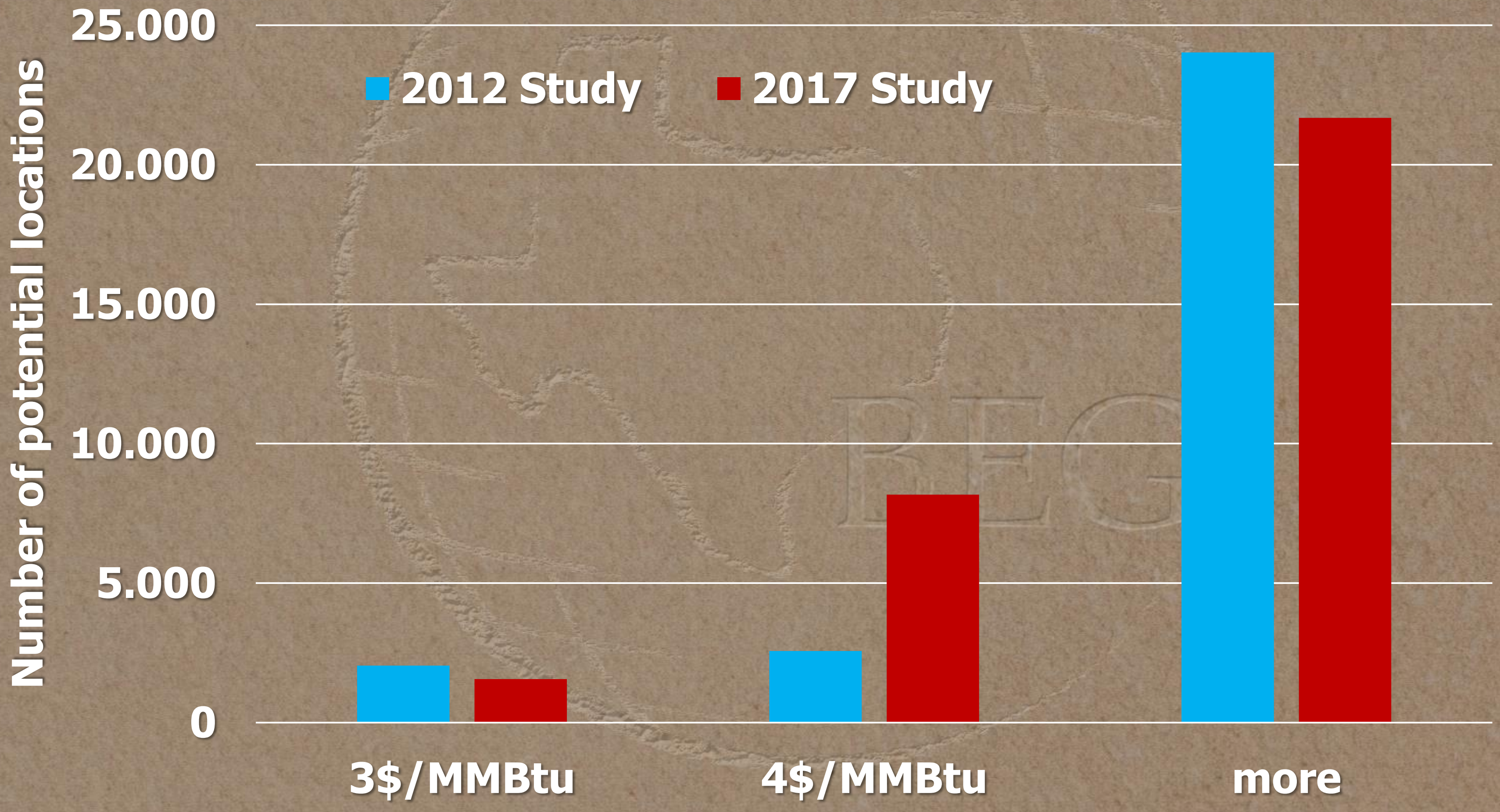
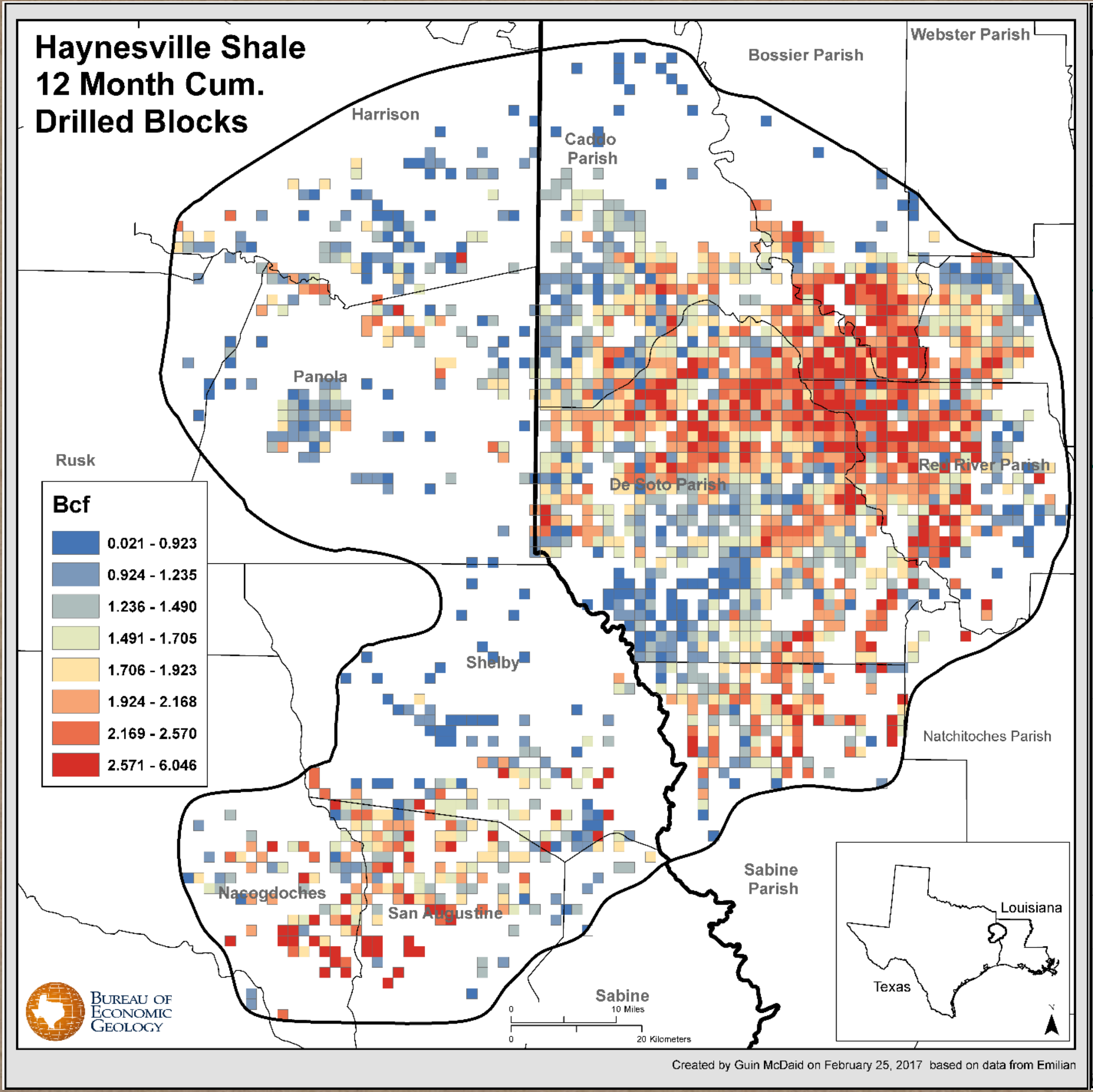
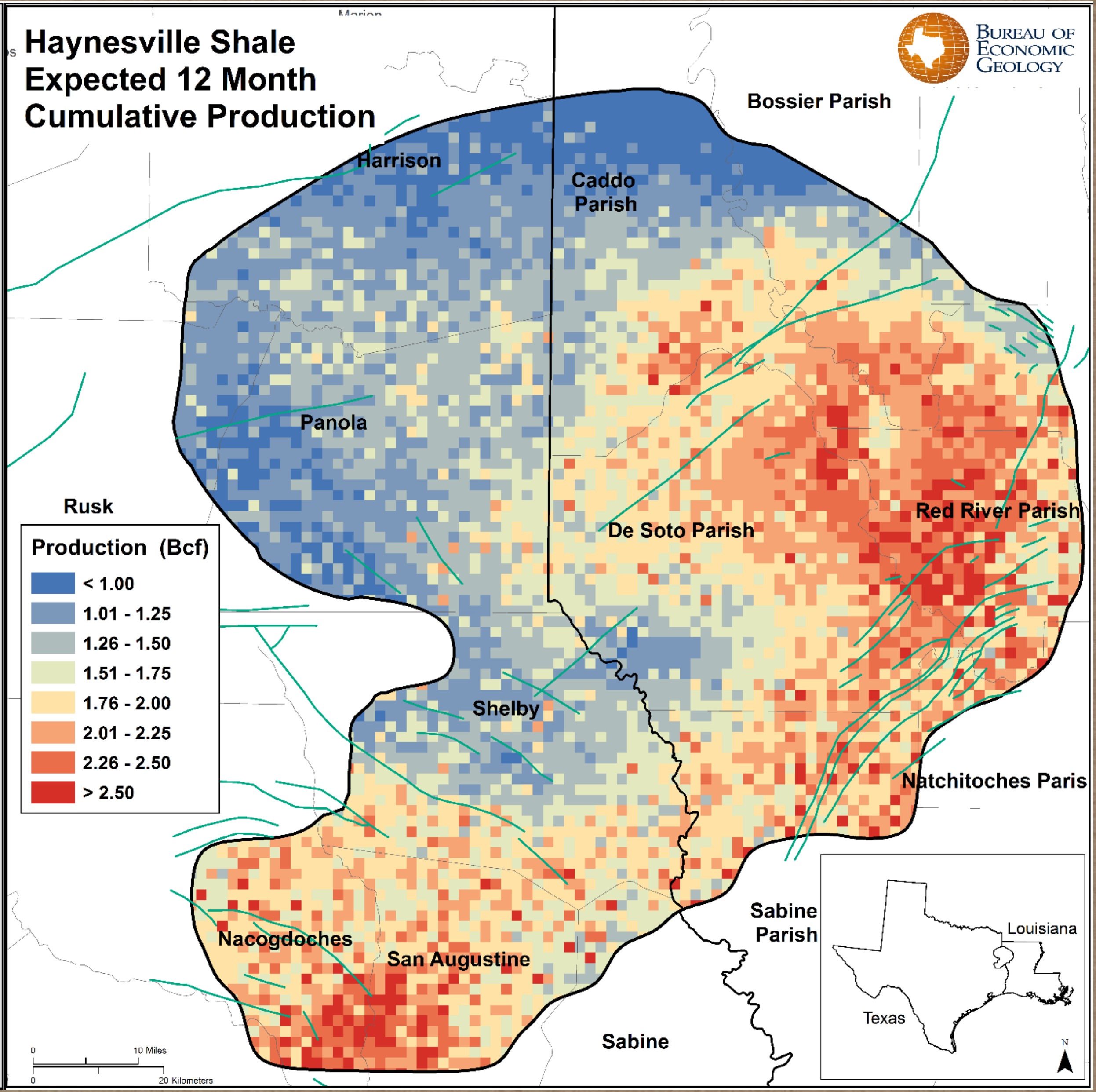
Change in Productivity and Profitability:

Haynesville Example

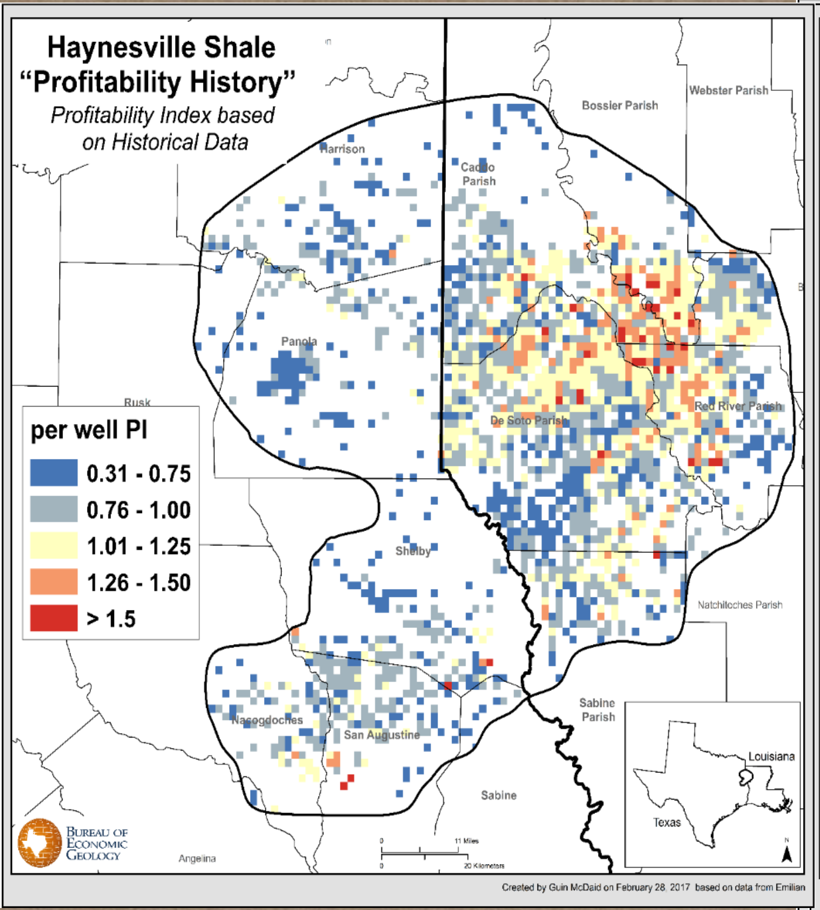


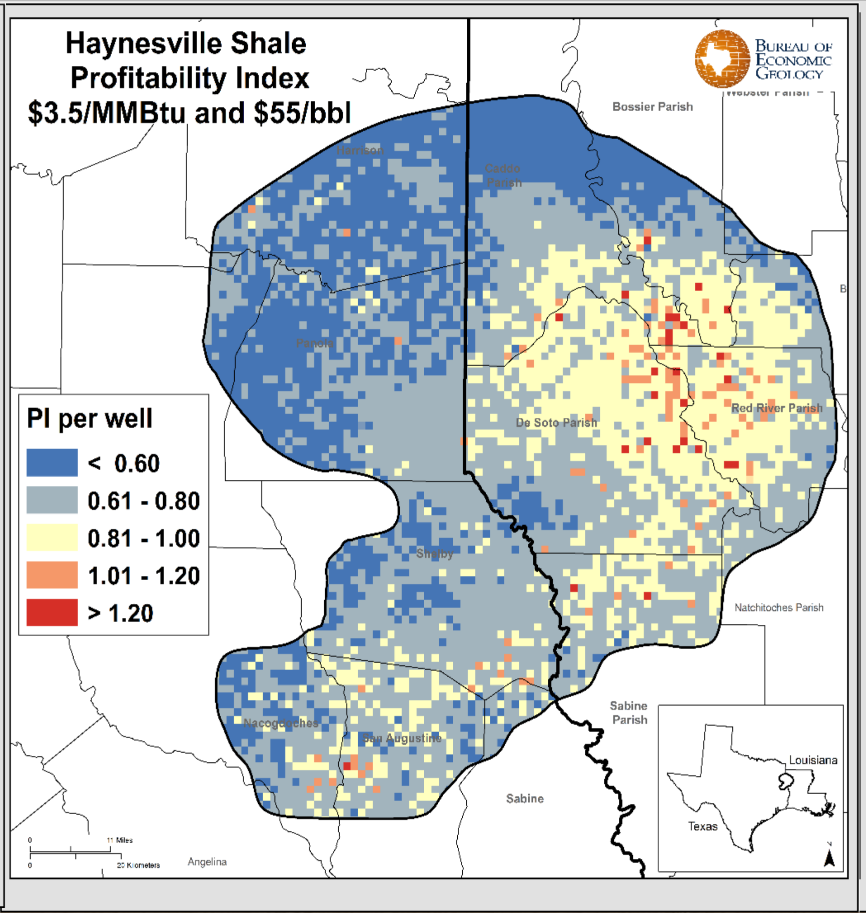

Haynesville Shale
12 Month Cum.
Drilled Blocks
Webster Parish
Bossier Parish
Harrison
Caddo
Parish
Panola
Rusk
Red River Parish
De Soto Parish
Bcf
0.021 - 0.923
0.924 - 1.235
1.236 - 1.490
1.491 - 1.705
1.706 - 1.923
1.924 - 2.168
2.169 - 2.570
2.571 - 6.046
Shelby
Natchitoches Parish
Sabine
Parish
Louisiana
Texas
Nacogdoches
San Augustine
Sabine
10 Miles
20 Kilometers
Bureau of
Economic
Geology
Created by Guin McDaid on February 25, 2017 based on data from Emilian

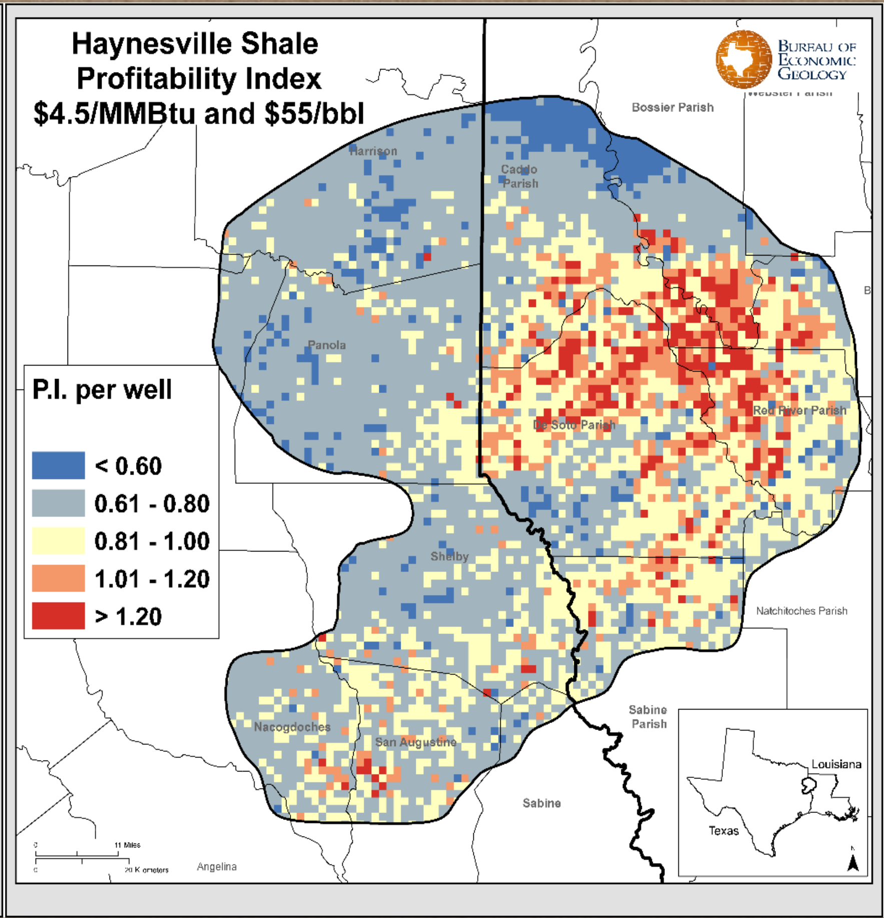

Haynesville Shale
Expected 12 Month
Cumulative Production
Bureau of
Economic
Geology
Bossier Parish
Harrison
Caddo
Parish
Panola
Rusk
Production (Bcf)
< 1.00
1.01 - 1.25
1.26 - 1.50
1.51 - 1.75
1.76 - 2.00
2.01 - 2.25
2.26 - 2.50
> 2.50
De Soto Parish
Red River Parish
Shelby
Natchitoches Paris
Sabine
Parish
Nacogdoches
San Augustine
Sabine
Louisiana
Texas
10 Miles
20 Kilometers

Ikonnikova, 2015

Profitability

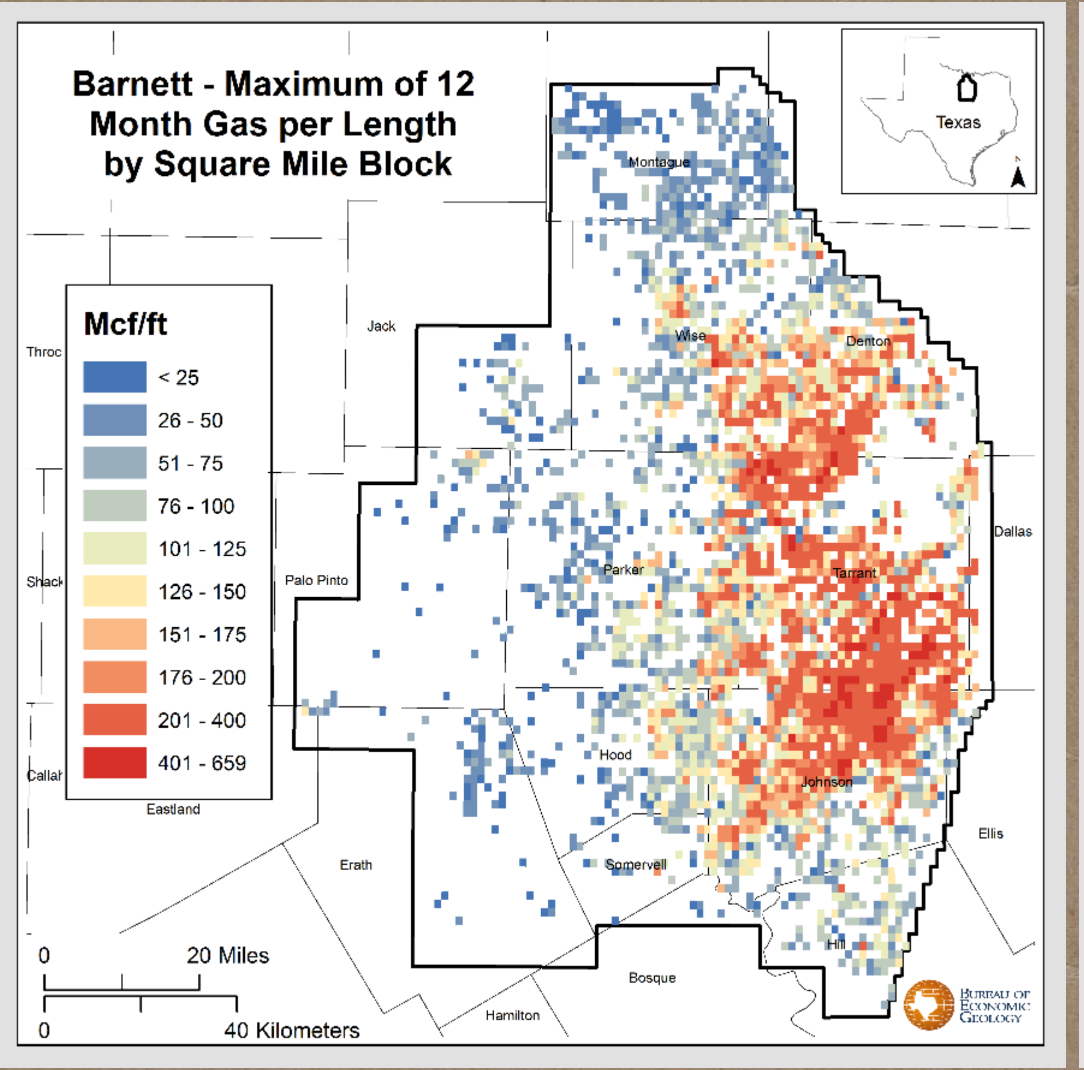


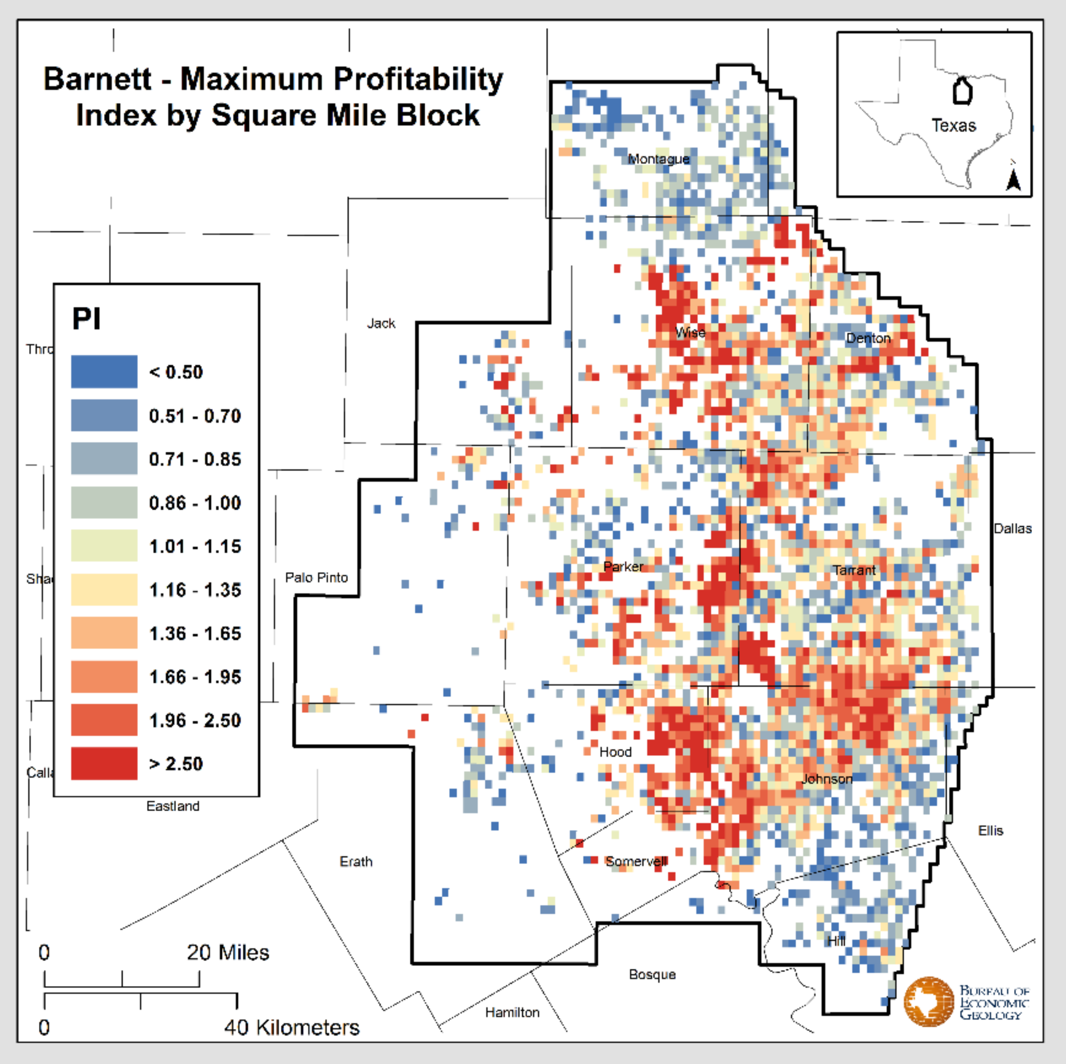




Ikonnikova, 2015

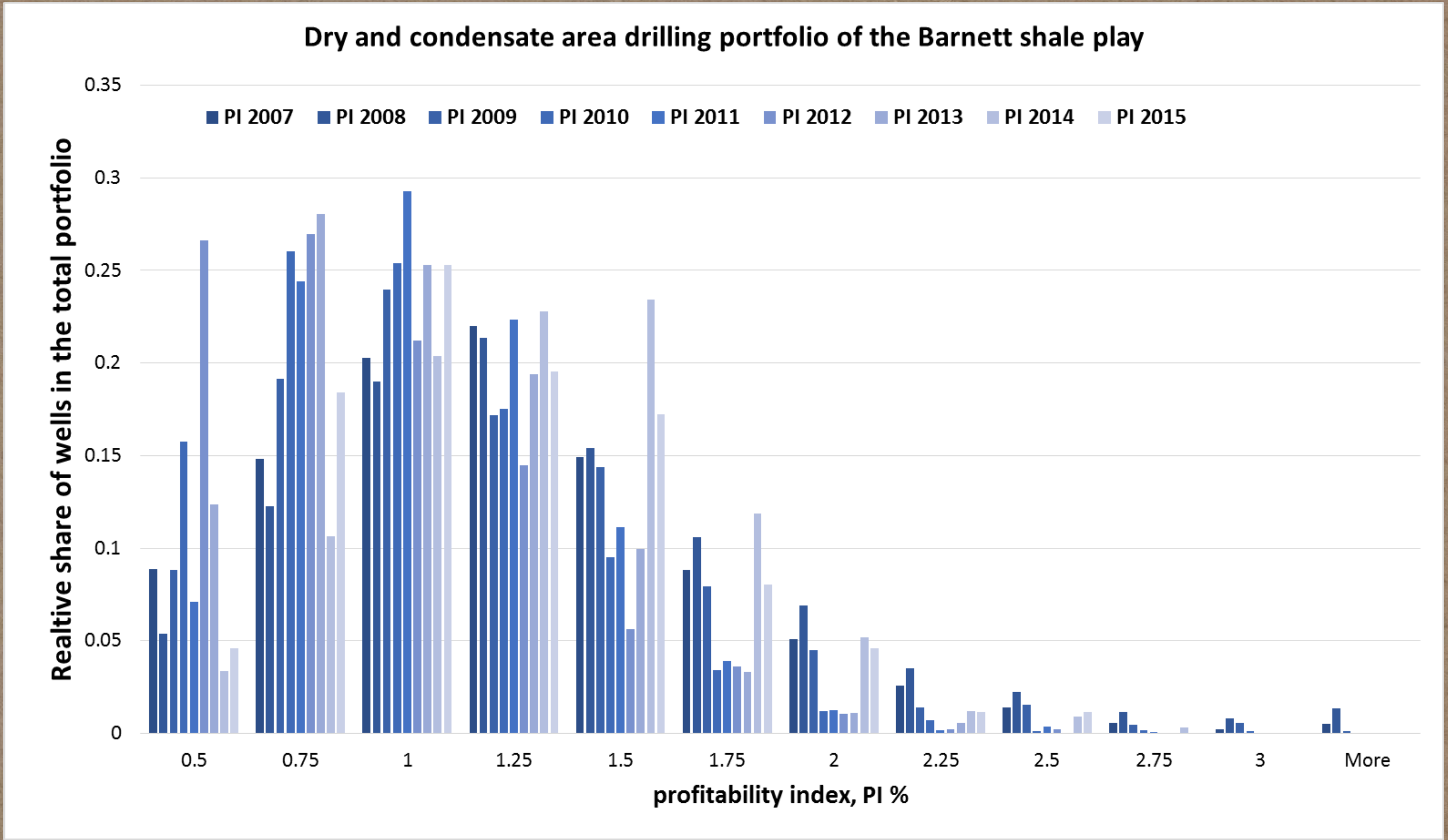
Historical Maximums





Ikonnikova, 2015

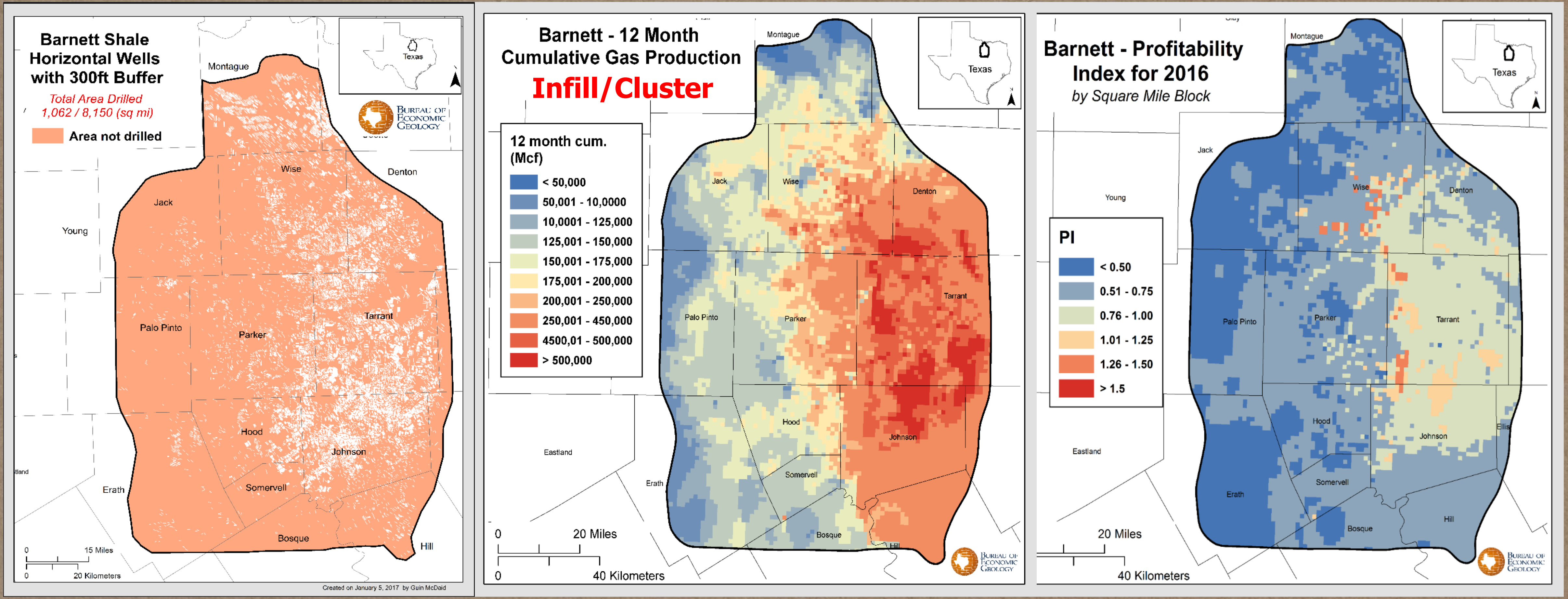
Drilling Portfolio for Dry and Condensate



Inventory and Future Drilling

N_t wells $\sim a \cdot \hat{p}_t^{\,b} \cdot N_{t-1}^{c}$

drilling locations are assigned based on their PI, drilling portfolio and spacing availability



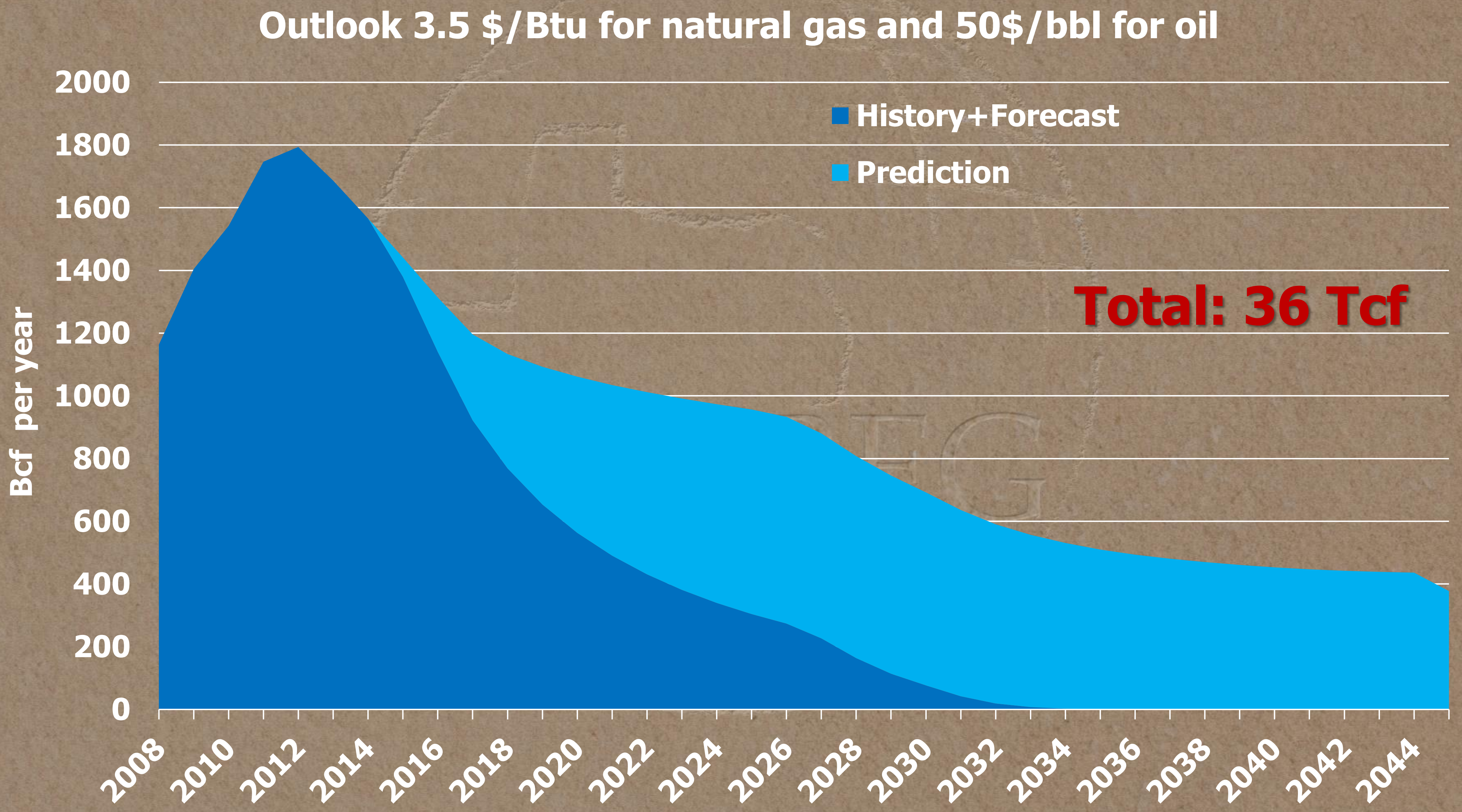
Well Economics and Production Outlook

Expected profitability of a well is a key indicator of investment attractiveness, depends on

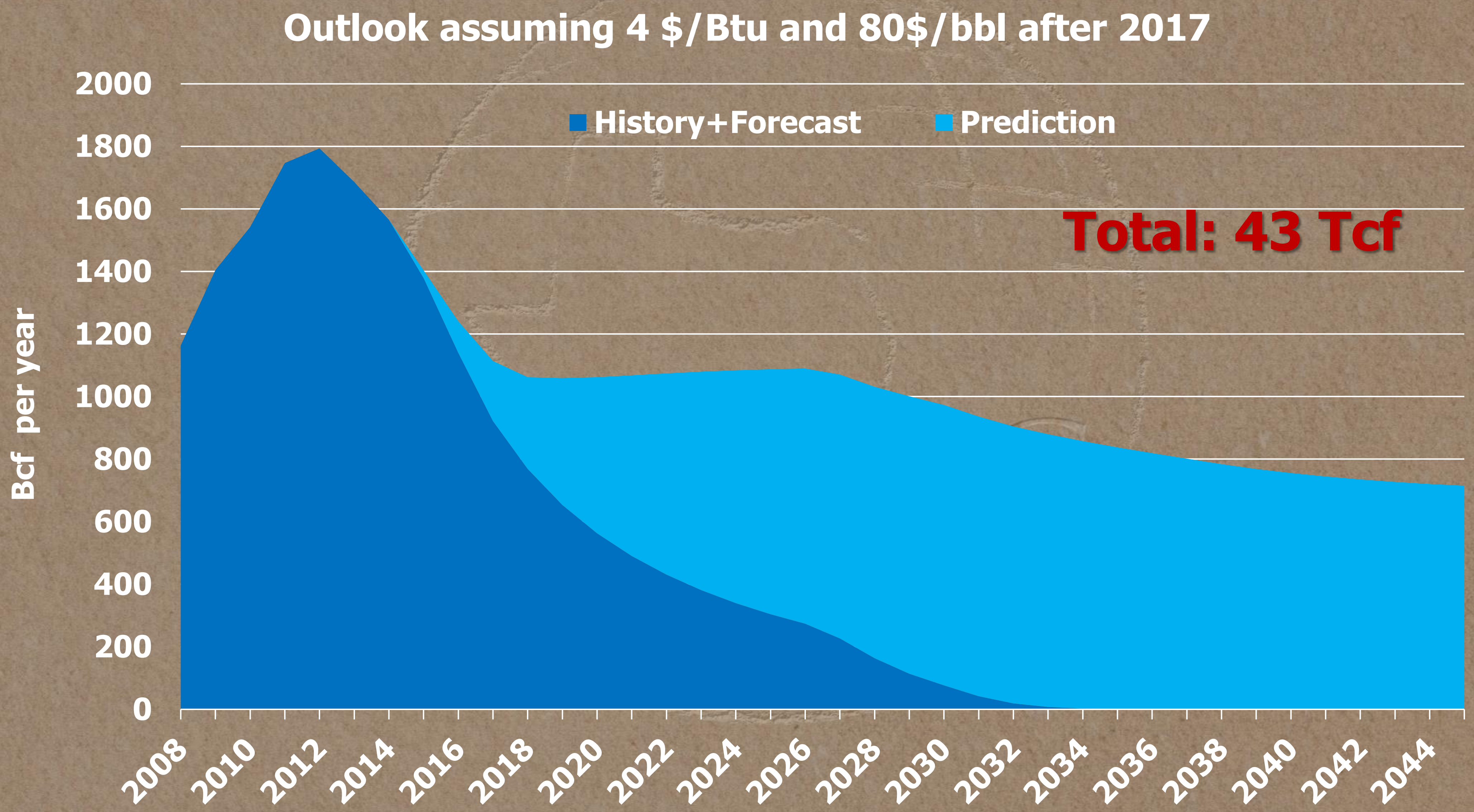
- Energy prices (natural gas, gas liquids, and oil),
- Drilling and Completion Cost (change with prices, technology, efficiency),
- Regulation (fiscal environment, drilling and production constraints),

- Expected well production given expectations about completions,
- Uncertainty

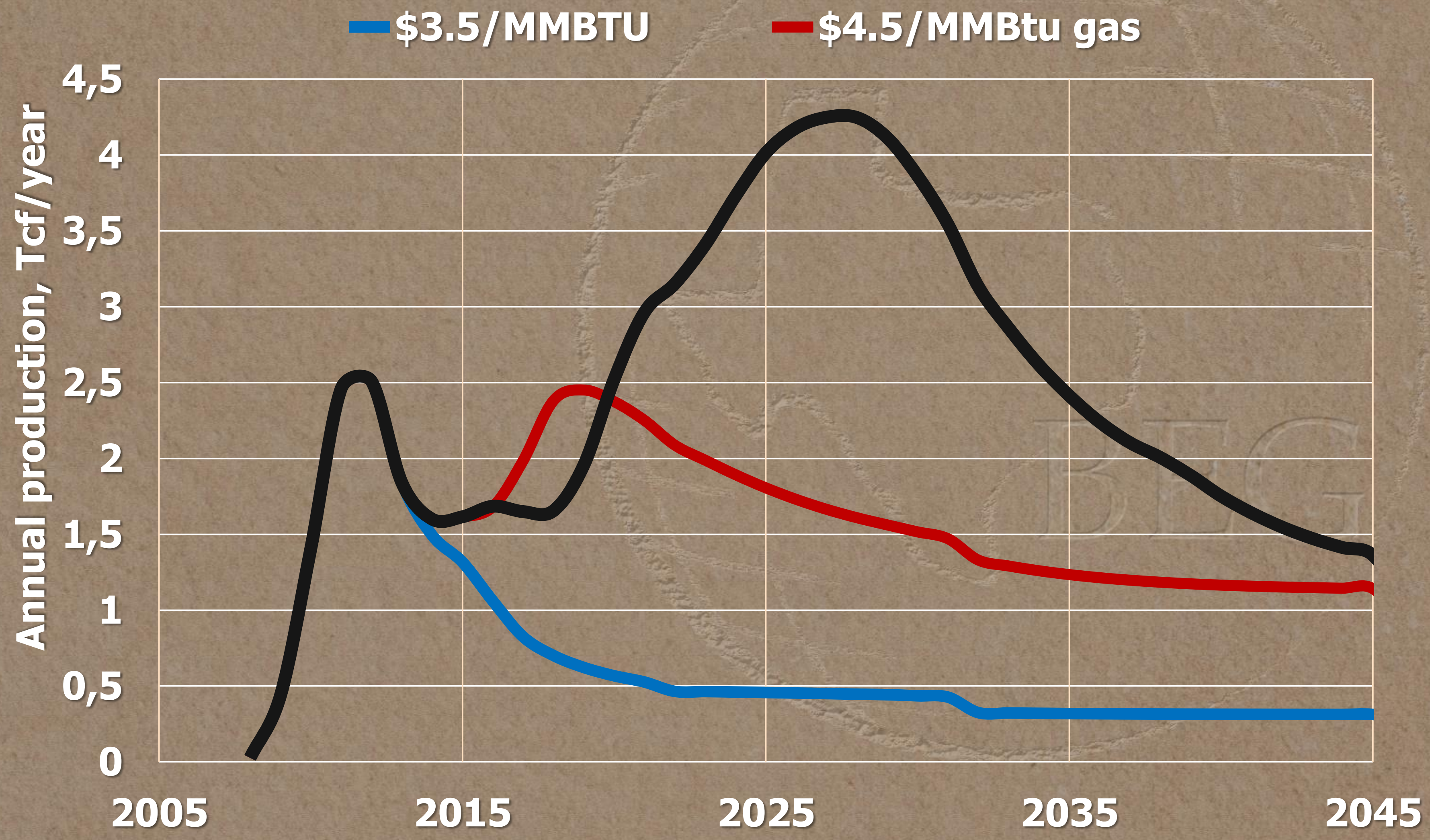
Base case Scenario



Assuming Increasing energy prices



Production Projections



	Tcf	New wells
$3	26	7,000
$4	62	11,300
EIA	95	20,000

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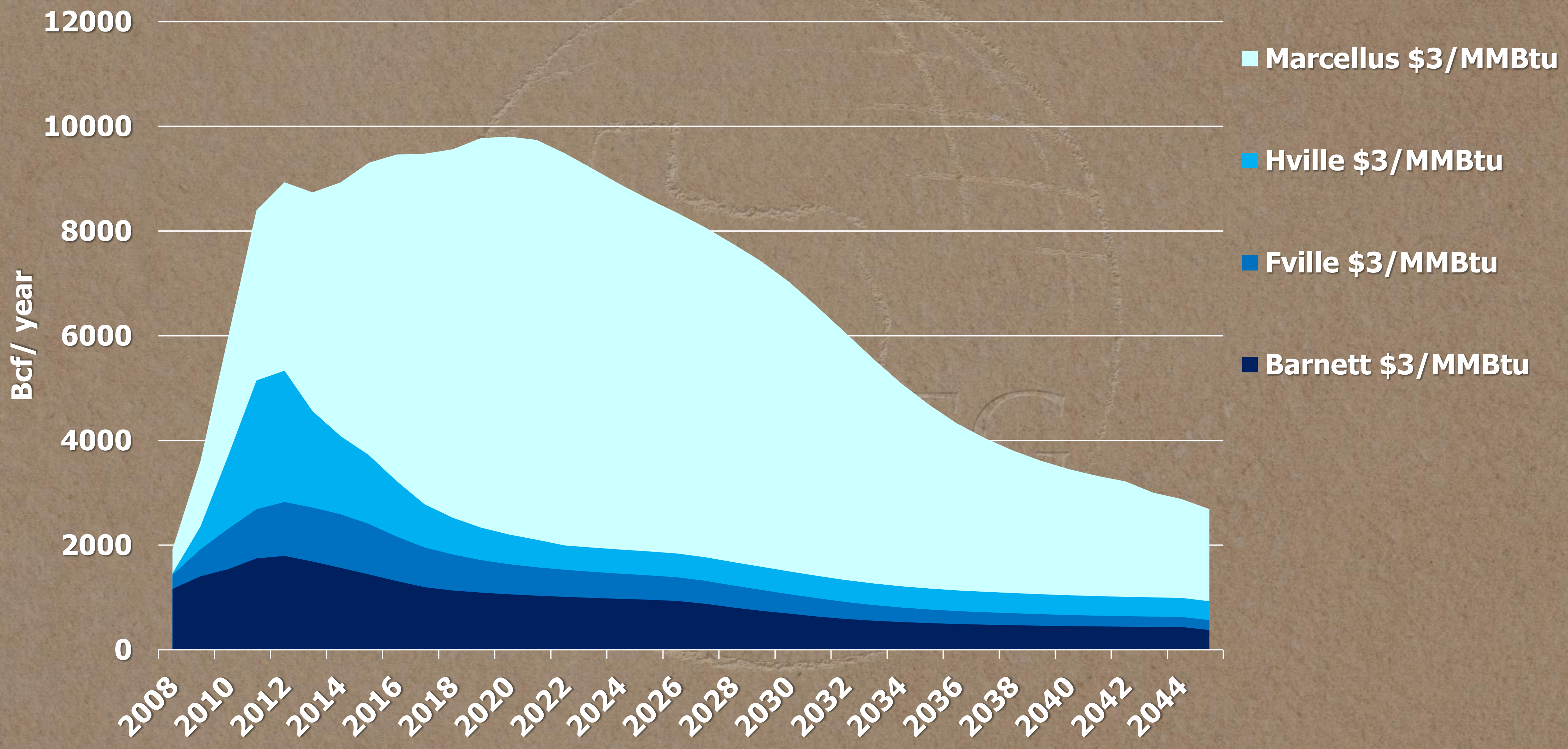
Projections for Different Prices



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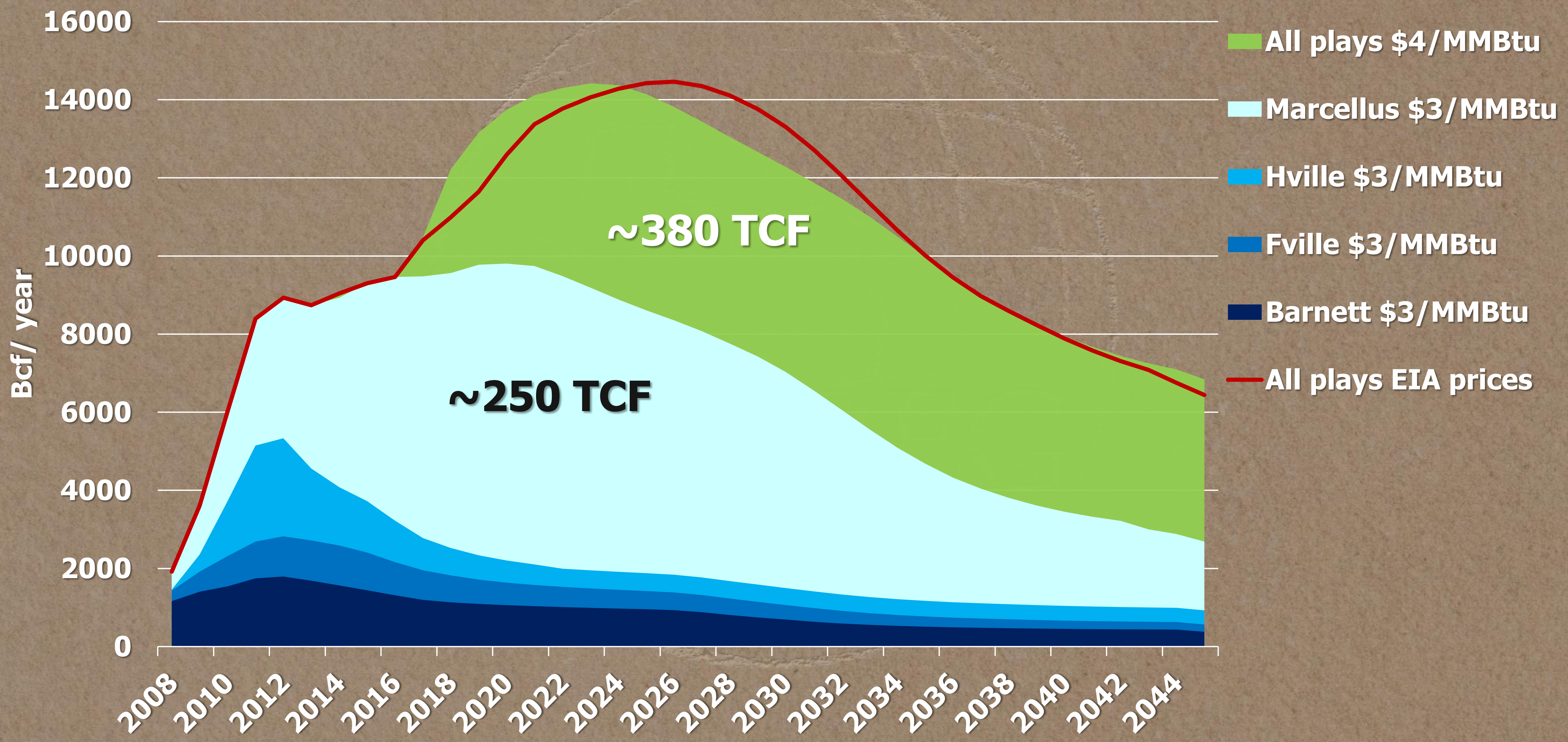
Projections for Different Prices



Summary

- Geologic and reservoir characteristics vary dramatically but 3D look helps us to understand the variability
- Technology plays an important role in the basin dynamics and future production outlook, and so dynamic rigorous study is essential
- Shale plays will continue their development even in the current price environment, supporting the U.S. natural gas and oil consumption
- Environmental implications and infrastructure development are important and may constrain the development in the future, but preemptive actions can help