U.S. Shale-Gas Reserves and Production Forecast: A Bottom-Up Approach

Funded by Alfred P. Sloan Foundation

Scott Tinker, John R. Browning, Svetlana Ikonnikova, Gürcan Gülen, Tad Patzek, Eric Potter, William Fisher, Qilong Fu, Susan Horvath, Frank Male, Ken Medlock, Forrest Roberts, Katie Smye
Workflow

Log and seismic data

Production history data and directional surveys

Geologic Analysis:
Structure, porosity, net pay-zone maps

Decline Analysis:
Production rate estimate, EURs

Well Spacing:
Well Recovery, Drainage Areas, Infill drilling locations (by tier)
=> Technically Recoverable Resources

Panel Data Analysis:
Validate Decline Curve; Test Geologic and Other parameters; Describe “typical well”

Well Economics:
Attrition rate, Breakeven prices, Representative well profiles (by tier)

Production Outlook:
Pace of drilling and ultimate recovery w.r.t. Prices, Technology, and Time
**Geological Approach**

- Utilize gamma ray, density, and neutron porosity logs to pick pay-zone
- Calibrate density porosity using core data
- Map pay-zone thickness and porosity (cf. Ver Hoeve et al. 2010), and depth across the field
- Calculate original free gas-in-place and compare to production to determine main drivers
- Look at other geologic drivers/barriers, e.g. natural fractures, swelling clays.

\[
OGIP^{free} = 43560 \cdot 10^{-9} \cdot (1 - S_W) \cdot \phi \cdot H \cdot \frac{640}{B_g}
\]

assumed 0.25

includes depth-specific reservoir pressure and temperature
Barnett Shale

Modified from Montgomery et al. (2005)
Barnett Shale

Phi * H

OGIP$^{\text{free}}$

For complete Barnett geologic analysis see Fu et al. (AAPG Bulletin in press)
Barnett Productivity Tiers

Sources
County and State Vector Data were acquired from the Texas Natural Resources Information System (TNRIS); USGS Quadrangle Index (1964) was adapted from TNRIS. Available online: http://www.tnris.org/get-data/?quicktabs_maps_data=1Map/quicktabs_maps_data. Well data provided by H3 and DrillingInfo, well raster logs provided by MJ Systems.

30-year production projection (Bcf), based on the average 4,000 ft. horizontal well.
The graph illustrates production rates for different tiers of production, with distinct lines representing various tiers and unconventional layering in colors.

- **Fayetteville 1**
- **Fayetteville 2**
- **Fayetteville 3**
- **Fayetteville 4**
- **Fayetteville 5**
- **Fayetteville 6**
- **Barnett 1**
- **Barnett 2**
- **Barnett 3**
- **Barnett 4**
- **Barnett 5**
- **Barnett 6**
- **Barnett 7**
- **Barnett 8**
- **Barnett 9**
- **Barnett 10**

### Notes

- We derive the decline function based on physical properties confirming that well production can be described with linear transient flow.
- We estimate ultimate recovery (EUR) for every existing wells and derive EUR of future wells.
## Expected production and Average well

<table>
<thead>
<tr>
<th></th>
<th>Barnett Average EUR (Bcf) 4,000 ft well</th>
<th>Fayetteville Average EUR (Bcf) 4,400 ft well</th>
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<tbody>
<tr>
<td>Tier 1</td>
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<td>Tier 2</td>
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<tr>
<td>Tier 10</td>
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</tbody>
</table>
Drainage Areas and Drilling Patterns

Barnett:
- Smaller leases
- Multiple operators
- Wide range of completion types
Barnett Shale: Base Case

Base Case @ $4 HH
45 Tcf Cumulative Production
Barnett Production by Tier – $4 HH
Summary

- Multidisciplinary study by geologists, engineers, and economists, linking geologic mapping, production analysis, well economics, and development forecasting.
- Development of a physics-based decline curve that accounts for interfracture interference later in well life.
- Well-by-well analysis of production and calculation of individual well EUR for all wells.
- Improved granularity for reserve forecasting and economics through productivity tiers.
- Calculation of OGIPfree and TRR for each square mile.
- Quantification of well-drainage volumes and recovery factors.
- Detailed modeling of future drilling through 2030 and production through 2050, factoring in production histories, well economics, pace of development, and many other drivers of well performance.
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