Evaluation of Shale Reserves and Resources in US Acquisitions

Dwayne Purvis, P.E.
with Dr. Curtis Whitson

SPE Calgary, International Business Development:
January 28th, 2016
There were two times for making big money, one in the up-building of a country and the other in its destruction. Slow money on the up-building, fast money in the crack-up.

Rhett Butler

George Mitchell
Trevor Rees-Jones
Harold Hamm
Hollis Sullivan
Floyd Wilson

Aubrey McClendon
Tom Ward
David Arrington
Hunter Enis
Larry Brogden
The Barnett Gold Rush

Before 2003

Before 2007
Lease bonus vs time

Johnson County Lease Bonus vs. Time

Strategic Exits in 2007
Shell in Parker and Erath Counties
“Shell just couldn’t crack the north Texas field.” (Dallas Morning News November 7, 2007)
DTE
Sold area in “expanded core”, kept “expansion area” “to focus on core utility business”

Final Bonus Bubble
Bonuses spike to $25,000 /acre
Crash to $2,000 /acre
## Example Revisions

<table>
<thead>
<tr>
<th>Company</th>
<th>Impairments in 2012</th>
<th>Plays</th>
<th>Commentary</th>
</tr>
</thead>
<tbody>
<tr>
<td>BHP Billiton</td>
<td>$2.8 billion</td>
<td>Haynesville, Fayetteville</td>
<td>as much about lower production levels as about gas prices –analyst</td>
</tr>
<tr>
<td>Royal Dutch Shell</td>
<td>$2.4 billion</td>
<td>US, liquid-rich shales</td>
<td>assets proved “disappointing” -Shell exec</td>
</tr>
<tr>
<td>BG Group</td>
<td>$1.8 billion</td>
<td>Haynesville, Marcellus</td>
<td>“The impairment is against the backdrop of lower forward gas market prices, lower production expectations based on well performance and the continued low rig count.” - BG</td>
</tr>
<tr>
<td>BP</td>
<td>$1.1 billion</td>
<td>Fayetteville, Woodford</td>
<td>“due to reserve revisions” - BP</td>
</tr>
<tr>
<td>Encana</td>
<td>$1.7 billion</td>
<td>Haynesville, Marcellus</td>
<td>“primarily resulted from the decline in the 12-month average trailing natural gas prices” -Encana</td>
</tr>
<tr>
<td>EXCO</td>
<td>$276 million</td>
<td>Haynesville, Eagle Ford</td>
<td></td>
</tr>
</tbody>
</table>
Everything is the same, early Barnett

Horizontal wells 2004 and before, Prac IP (mcfpd)
Reserve Determination Methods, Early Shale

- More data
- More physics
- More predictive
- More difficult

Frequency

- Analogy
- Decline Curve
- Volumetrics
- Material Balance
- Rate Transient
- Simulation
## Uncertainty in Early Time Forecasts

### Table: Gas Production Forecasting

<table>
<thead>
<tr>
<th>Year</th>
<th>Initial Decline</th>
<th>Hyperbolic Exponent</th>
<th>EUR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>75</td>
<td>0.7</td>
<td>1.4 Bcf</td>
</tr>
<tr>
<td>Mid</td>
<td>96</td>
<td>1.3</td>
<td>2.4 Bcf</td>
</tr>
<tr>
<td>High</td>
<td>99</td>
<td>1.7</td>
<td>2.9 Bcf</td>
</tr>
</tbody>
</table>

![Graph showing gas production over time with three scenarios: Low, Mid, and High.](image)

SPE 144357
Uncertainty in Early Time Forecasts

<table>
<thead>
<tr>
<th></th>
<th>Initial Decline</th>
<th>Hyperbolic Exponent</th>
<th>EUR</th>
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<tbody>
<tr>
<td>Low</td>
<td>65</td>
<td>0.7</td>
<td>1.3 Bcf</td>
</tr>
<tr>
<td>Mid</td>
<td>88</td>
<td>1.3</td>
<td>2.2 Bcf</td>
</tr>
<tr>
<td>High</td>
<td>97</td>
<td>2.0</td>
<td>3.0 Bcf</td>
</tr>
</tbody>
</table>

SPE 144357
Average Well, Without Forecasts

Di 70%
Bfactor 1.4
EUR 2.5 Bcf*

*Note that it could also be fit with b=2.4 and much higher EUR
Average Well, With Forecasts

Di 92%
Bfactor 1.3
EUR 2.0 Bcf
Johnson County Today, 24 Month Cum
<table>
<thead>
<tr>
<th>P90/P10 Ratio</th>
<th>Recommended Sample Size &amp; Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>15 - Not likely to be seen</td>
</tr>
<tr>
<td>3</td>
<td>35</td>
</tr>
<tr>
<td>4</td>
<td>60</td>
</tr>
<tr>
<td>5</td>
<td>75</td>
</tr>
<tr>
<td>6</td>
<td>100</td>
</tr>
<tr>
<td>8</td>
<td>130</td>
</tr>
<tr>
<td>10</td>
<td>170 - Possible issue with data quality or analogy</td>
</tr>
</tbody>
</table>

**Fig 4.15 – Ratio of P\textsubscript{90} to P\textsuperscript{\text} versus Well Count**

*SPEE Monograph 3: Guidelines for the Practical Evaluation of Undeveloped Reserves in Resource Plays, Chapter 3, @Copyright 2010 by the Society of Petroleum Evaluation Engineers*
US Gas Rig Count and Gas Prices

Peak in October 2011
Reserve Determination Methods, Mid Shale

More data
More physics
More predictive
More difficult

Frequency

Analogy  Decline Curve  Volumetrics  Material Balance  Rate Transient  Simulation
Volumetrics in Shales

\[ EUR = \frac{1}{FVF} \times BRV \times (\phi_{eff} (1 - S_w)) \times RF \]

Bulk Rock Volume: Lateral, Vertical Limits?

Analogy (predicated on reserve analyses with unknown/inconsistent inputs), Wide normalized uncertainty

<table>
<thead>
<tr>
<th>Oil</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Poor</td>
<td>2%</td>
</tr>
<tr>
<td>Less Favorable</td>
<td>3%</td>
</tr>
<tr>
<td>Average</td>
<td>4-5%</td>
</tr>
<tr>
<td>Favorable</td>
<td>6%</td>
</tr>
<tr>
<td>Exceptional</td>
<td>8%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Volatile Oil, Liquid-Rich?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poor</td>
</tr>
<tr>
<td>Less Favorable</td>
</tr>
<tr>
<td>Average</td>
</tr>
<tr>
<td>Favorable</td>
</tr>
<tr>
<td>Exceptional</td>
</tr>
</tbody>
</table>

EIA/ARI World Shale Gas and Shale Oil Resource Assessment, 2013
Volumetrics in Shales

\[ EUR = \frac{1}{FVF} \cdot BRV \cdot (\phi_{eff}(1 - S_w)) \cdot RF \]
Rate Transient Analysis

AKA. . .
Model-based analysis
Time-Rate-Pressure analysis
Modern Decline Analysis
Advanced Production Decline

Models such as. . .
• Fetkovich
• Agarwal-Gardner
• Blasingame
• Flowing Material Balance
• Normalized Pressure Integral
• Wattenbarger
Rate Transient Procedure

1. Identify Flow Regimes
   - log-log rate vs time
   - log-log material balance time

2. Straight-Line Analyses
   - SQRT of time or superposition time
   - Cartesian rate vs MB time

3. Type-Curve Analysis
   - (Pre-calculated analytical solutions to simplified assumptions)

4. Validation with Simulation
Reserve Determination Methods, State of the Art

- More data
- More physics
- More predictive
- More difficult

Diagram showing frequency of methods: Analogy, Decline Curve, Volumetrics, Material Balance, Rate Transient, Simulation.
Methusaleh - Shale Gas Well

Barnett Shale
- 2003: 100 wells
- 2004: 300 wells
- 2005: 1500 wells

Fayetteville 2005
Haynesville 2008
Noah - Shale Oil Well

<table>
<thead>
<tr>
<th>Year</th>
<th>Bakken Wells</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005</td>
<td>30 wells</td>
</tr>
<tr>
<td>2006</td>
<td>70 wells</td>
</tr>
<tr>
<td>2007</td>
<td>200 wells</td>
</tr>
<tr>
<td>2008</td>
<td>440 wells</td>
</tr>
</tbody>
</table>

Eagle Ford 2010
Oldest Shale Wells

12 of 50 years

2003

10 of 50 years

2005

2003

2053

2005

2055
Evolution of Decline Methods

<table>
<thead>
<tr>
<th>Model Type</th>
<th>Derivatives</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exponential</td>
<td>Constant 1st Derivative*</td>
</tr>
<tr>
<td>Hyperbolic</td>
<td>Constant 2nd Derivative</td>
</tr>
<tr>
<td>(Fetkovich)</td>
<td>Two segments of above</td>
</tr>
<tr>
<td>Stretched Exponential &amp; Duong</td>
<td>Constant 3rd Derivative</td>
</tr>
<tr>
<td></td>
<td>Declining b-factor</td>
</tr>
<tr>
<td>Extended SEDM &amp; Modified Duong</td>
<td>Adds a segment of late life</td>
</tr>
<tr>
<td></td>
<td>hyperbolic</td>
</tr>
</tbody>
</table>

Recently introduced Linear Transient Hyperbolic, and Extended Exponential models are not discussed here.
Fetkovich General Decline Type Curve

Infinte-Acting Transient: Essentially the inverse of dimensionless pressure
\[ q_{D}(t_{D}) \approx \frac{1}{p_{D}(t_{D})} \]

\[ \frac{1}{\sqrt{t_{D}}} \ldots \frac{1}{\ln(t_{D})} \]
Linear \ldots Radial

Boundary-Dominated: (Arps) Derived from Material Balance Equation and Pseudosteady State Rate Equation

SPE 4629, SPE 13169
Decline Periods in Gas Shales

- Linear Flow, $b \approx 2$
  - ends $\sim 10$ to $\sim 36$ mos

- Transition
  - $\sim 1$ log cycle

- "Boundary Dominated"

- 2nd Linear?
  - Decades to centuries

- "Noise"
  - up to 6 mos

Based on 2015 webinars by Dr. John Lee and Dr. Tom Blasingame
## Comparison Table

<table>
<thead>
<tr>
<th>Model</th>
<th>Original Source</th>
<th>Reasonable Forecasts?</th>
<th>&lt; 1yr</th>
<th>Early / Transient</th>
<th>Late / “BDF”</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arps, Modified</td>
<td>Arps 1945, SPE 945228 Long, SPE 16237</td>
<td>maybe</td>
<td>no</td>
<td>no</td>
<td>yes</td>
</tr>
<tr>
<td>Stretched Exponential (SEM, SEDM, SEPD)</td>
<td>Valko 2009, SPE 119369</td>
<td>maybe</td>
<td>no</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>Power Law Exponential &amp; Extended PLE (PLE)</td>
<td>Ilk Rushing Blasingame 2008, SPE 116731 Ilk Blasingame 2011, SPE 1405556</td>
<td>maybe</td>
<td>no</td>
<td>yes</td>
<td>no (yes with extension)</td>
</tr>
<tr>
<td>Duong &amp; Modified Duong</td>
<td>Duong 2010, SPE 137748 Duong 2011, SPE 171610</td>
<td>maybe</td>
<td>yes</td>
<td>yes</td>
<td>no (yes with modification)</td>
</tr>
<tr>
<td>Linear</td>
<td>Anderson 2010, SPE 131787</td>
<td>maybe</td>
<td>maybe</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>Transient Hyperbolic</td>
<td>Fulford Blasingame 2013, SPE 167242</td>
<td>??</td>
<td>??</td>
<td>??</td>
<td>??</td>
</tr>
<tr>
<td>Extended Exponential</td>
<td>Zhang et al. (Ryder Scott) 2015, SPE 175016</td>
<td>??</td>
<td>??</td>
<td>??</td>
<td>??</td>
</tr>
</tbody>
</table>

Based on 2015 webinars by Dr. John Lee and Dr. Tom Blasingame
Since you must use Arps. . .

- Common geologic areas
  - Rock and fluids
  - 50 to 100 forecastable wells

- Forecast individual wells
  - Oldest wells first
  - Ignore wells with <12 months (some say 24 to 36)
  - Prefer to fit later time and with lower b-factors
  - Iterate for consistency

- Averaging
  - Normalize for lateral length, perhaps other drivers
  - Average with forecasts

*If you can, get decline curve params from higher quality analysis like simulation.*
Machine Learning: The Next Step?

Spread of Uncertainty

- MBBL/month
- Blind Test
- P10
- P50
- P90
- Standard Fit
Understanding via Simulation

More physics such as

- pressure-dependent permeability (fracture and matrix)
- two and three phases, variable relative permeability curves
- variable fracture geometries
- variable rock properties
- desorption
- Fickian flow
Understanding via Simulation

- **ET**
  - Area 1: Fracture permeability and spacing
  - Effective lateral length
  - Duration controlled by Area 1 volume

- **MT**
  - Area 1 primary: Fracture permeability, Width of Area 1

- **LT**
  - Matrix Permeability and Porosity
  - Area 1 Secondary: Matrix Porosity, Formation Thickness

SPE 144357, Figure 1

“Area 1” is stimulated area.
What to Simulate, What a Waste

Pressure Distribution — 8 Years

Courtesy of Dr. Tom Blasingame
"Since all models are wrong the scientist cannot obtain a "correct" one by excessive elaboration. On the contrary following William of Occam he should seek an economical description of natural phenomena."

George Box, mathematician

"A general rule that should be, but seldom' is, followed is "select the least complicated model and grossest reservoir description that' will allow the desired estimation of reservoir performance".

Dr. Keith Coats, pioneer of reservoir simulation
What to Simulate, 2

Flowback History

Production History

SPE 171591, Figure 18

SPE 144357, Figure 9
Guidance

Test impact of each variable at the beginning.

Match from earliest time to latest, from closest to wellbore to farthest.


Perhaps create several matches.

Simulate more than one well.

Compare matches across wells simulated.

SPE 144357, Figure 1
“Area 1” is stimulated area.
Eight history-matches with different baseline assumptions. (Secondary phase forecasts differed much more.)
Simulation Uncertainty Compared to Arps

Unconstrained Arps forecast would significantly overcall 30 yr reserves.
And it’s not just me. . .
Original and Updated Matches

![Graph showing Bottomhole Pressure and Water Rate over time](image)

- **Bottomhole Pressure (psia)**
- **Time (days)**

**Legend:**
- Observed -before model
- Observed -after model
- Model -900 days
- Model -1400 days

Courtesy of PETSTREAMZ
Original and Updated Matches

- Observed
- Model -1400 days
- Model -900 days

Cumulative Gas (bcf)

Years

0 5 10 15 20 25 30
Obligatory Slide on the Importance of Shale

U.S. crude oil production

- **Reference**
  - U.S. maximum production level of 9.8 million barrels per day in 1970

- **High Oil and Gas Resource**

- **Low Oil Price**

Source: EIA, Annual Energy Outlook 2015

U.S. dry natural gas production

- **Shale gas and tight oil plays**
- **Other lower 48 onshore**
- **Tight gas**
- **Coalbed methane**
- **Lower 48 offshore**
- **Alaska**

Projections

Source: EIA, Annual Energy Outlook 2015 Reference case
Thank You!

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www.dpurvisPE.com

www.petrostreamz.com