Unconventional Gas Resources to Reserves –
A Predictive Approach

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Unconventional Resources • Enhanced Recovery • Carbon Sequestration
Abstract

Estimating potential hydrocarbon recoveries from greenfield (but resource-rich) unconventional gas plays is a challenge. While analogs are routinely employed for this purpose, there is no shortage of examples of how frontier tight sand, coalbed methane and organic shale plays have required new operating practices that can run contrary to historical (analog) experience. An analytic approach is presented to account for whatever limited geologic and reservoir information might be available for a new resource play, and based upon sound engineering principles, make predictions of potential gas recoveries, their variability, and identify areas of uncertainty. The methodology involves selecting the potential ranges (and distributions where appropriate) of reservoir parameters across a particular acreage position, such as depth and pressure, formation thickness, porosity, fluid saturations, permeability, relative permeability, etc. Where no data exists, analogs and experience must still be employed. Single-well probabilistic reservoir simulation forecasting is then performed using Monte Carlo methods to establish a distribution of potential well recoveries, which are in turn used for field development planning and economic analysis. Factors having the greatest impact on well recoveries and economics can be identified via statistical analysis of the results, thus focusing field data collection efforts on issues with the greatest potential for uncertainty reduction.
“The only way to convert resources to reserves is to drill and produce commercial wells.”

- Anonymous
Resource Classification System and Project Maturity Sub-Classes


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CBM Reserves Assignment Methodology

Drilling Spacing Unit (DSU) { 1 well = 9 proved + 16 probable + 24 possible + 120 contingent }

Commercially Producing Well (Different scheme if a data well)


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Example Application

**Assumptions**
- 100,000 acres
- 160 acre DSU
- 625 DSU total

**Graph Details**
- **Number of Commercially Producing Wells**
- **# DSU’s**
- Lines represent different categories:
  - 1P
  - 2P
  - 3P
  - Contingent
  - Prospective

**Legend**
- Unconventional Resources • Enhanced Recovery • Carbon Sequestration
Objective of Presentation

• How does an operator assess “likely” reserves and commerciality in the early stages of play development?
• At the point in time when a resource assessment has been performed, and (limited) well/production data available.
• i.e., “The production forecasting challenge.”
A Few Premises

• Unconventional gas plays are statistical – many wells drilled with a manufacturing mentality yielding a distribution of outcomes.

• “Best” drilling, completion, stimulation & production practices evolve over time.
  – i.e., early production results are likely understated.
The Statistical Nature of Unconventional Gas – A Coalbed Methane Example

By Basin

By Field in a Basin

By Well in a Field

Evolution of “Best” Practices - The Barnett Shale


The Production Forecasting Approach

- Unconventional gas reservoir simulation
  - to account for complex reservoir behavior
- Monte-Carlo simulation
  - to account for statistical variability of reservoir properties
- Plus...
  - experience
  - analogy
  - skepticism
  - etc.
Modeling Permeability Variability Using Geostatistics

Spherical Variogram Model

\[ \gamma(h) = \begin{cases} 1.5 \left( \frac{h}{1,200} \right) - 0.5 \left( \frac{h}{1,200} \right)^3, & \text{if } h \leq 1,200 \\ 1, & \text{otherwise} \end{cases} \]

- Sill
- Range = 1,200 m
- Minor range = 600 m
- Anisotropy Coefficient = 1/2
- Major Direction of Continuity: Rotated Y axis (N60E)
- Minor Direction of Continuity: Rotated X axis (E60S)
- Azimuth = 60°
Permeability – Porosity Relationships

\[
\frac{k}{k_0} = \left(\frac{\phi}{\phi_0}\right)^3
\]

\[
\phi = A^{\frac{3}{2}} k
\]

\[
\phi = A^{\frac{3}{2}} k + \epsilon
\]

\(\epsilon\) is an added random error!

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The Importance of Accounting for Permeability/Porosity Heterogeneity

Permeability heterogeneously distributed
Permeability homogeneously distributed

Porosity heterogeneously distributed
Porosity homogeneously distributed

Lognormal Distribution
Mean = 100 mD

Normal Distribution
Mean = 0.05

Truncated!
Relative Permeability

\[ K_{rw} = K_{rw \ max} \left( \frac{Sw - Swr}{1 - Swr - Sgr} \right)^m \]

\[ K_{rg} = K_{rg \ max} \left( \frac{1 - Sw - Sgr}{1 - Swr - Sgr} \right)^n \]

Uniform(0.2, 0.5)

CoreyCstKrg

CoreyExpKrg

Krwmax=0.9

Krgmax=0.7

n=1.5

m=4.5

Swr=0.1

Sgr=0.2

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Building the Model

• Single – well
• Multiple layer (can use clustering methods to establish layering scheme)
• Probablistic distributions of reservoir properties
Establishing Layering Scheme Using Clustering

Clustering methods are applied to selected well logs and core data for lithology interpretation, and reservoir quality (RQ) characterization.

A data-driven software (GAMLS) permits clustering using mixed variables, and probabilistic assignment of samples to each multi-dimensional cluster.

At each depth, clustering analysis provides rock types with different RQ, and estimates of an analyzed reservoir parameter.

Logs Track: Density (red) & GR (blue)

Colorful Track: Probabilistic representation of clusters

Different tones of . . .
- gray: possible shale
- green: possible siltstone
- yellow: possible sandstone

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Establishing Probabilistic Variables

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>Distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial Water Saturation</td>
<td>fraction</td>
<td>T(0.7, 1,1)</td>
</tr>
<tr>
<td>Average Permeability</td>
<td>md</td>
<td>L(5,2)</td>
</tr>
<tr>
<td>Permeability Anisotropy Factor</td>
<td>dimensionless</td>
<td>T(1,2,5)</td>
</tr>
<tr>
<td>Fracture Porosity</td>
<td>fraction</td>
<td>N(0.005, 0.002)</td>
</tr>
<tr>
<td>Sorption Time</td>
<td>days</td>
<td>T(30, 300, 3000)</td>
</tr>
<tr>
<td>Fracture Spacing</td>
<td>inches</td>
<td>T(12, 36, 120)</td>
</tr>
<tr>
<td>Langmuir Volume</td>
<td>cuft/cuft</td>
<td>T(3.82, 6.82, 9.82)</td>
</tr>
<tr>
<td>Langmuir Pressure</td>
<td>psi</td>
<td>T(300, 354, 400)</td>
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<tr>
<td>Water Density</td>
<td>lb/ft</td>
<td>T(43.2, 50.42, 57.63)</td>
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<tr>
<td>Skin Factor</td>
<td>dimensionless</td>
<td>T(-4, 0, -2)</td>
</tr>
<tr>
<td>Desorption Pressure Function</td>
<td>dimensionless</td>
<td>T(0.7, 1,1)</td>
</tr>
<tr>
<td>Irreducible Water Saturation</td>
<td>fraction</td>
<td>T(0.1, 0.2, 0.3)</td>
</tr>
<tr>
<td>Maximum gas relative permeability</td>
<td>dimensionless</td>
<td>T(0.5, 0.75, 1)</td>
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<tr>
<td>Corey gas exponent</td>
<td>dimensionless</td>
<td>T(1, 2, 3)</td>
</tr>
<tr>
<td>Corey water exponent</td>
<td>dimensionless</td>
<td>T(1, 2, 3)</td>
</tr>
<tr>
<td>Azimuth</td>
<td>degrees</td>
<td>U(-90, 90)</td>
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<tr>
<td>Nugget Effect</td>
<td>dimensionless</td>
<td>U(0,1)</td>
</tr>
<tr>
<td>Range</td>
<td>mts</td>
<td>U(800, 2000)</td>
</tr>
<tr>
<td>Anisotropy Coefficient</td>
<td>dimensionless</td>
<td>U(0.001, 1.0)</td>
</tr>
</tbody>
</table>

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Sample Outcome

Each case has unique production profile!

Cumulative Gas, MMcf

Frequency

0 120 240 360 480 600 720 840 960 1080 1200

Cumulative Percentage

0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%

Dry Holes

Average= 513 MMcf

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Understanding Critical Success Factors

Cumulative Total Gas

Avg Permeability
Por Frac
KrgExp
Sorption Time
Pd_Pi
Lang Vol
Water Density
Frac Spacing
KrgMax
KrwExp
Skin Prod
Irred Water Sat
Initial Water Sat
Perm Anisotrophy Fac
Lang Press

Important
Questionable
Important

Rank Correlation

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Field Development Planning*

- Set constraints (e.g., drilling rate, max gas production, etc.)

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Final Remarks

- Integrated reservoir and Monte Carlo simulation approach replicates statistical nature of unconventional gas plays while honoring physical nature of complex reservoir system.
- Results provide a range of outcomes that can be used for more realistic development planning and economic analysis.
- Sensitivity analysis can be used to focus data collection efforts where they can have the greatest impact on uncertainty reduction.
- Accounting for permeability and porosity variability has important implications for production forecasting.
For More Information...

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