**Objectives of This Session:**

Q. **What are the objectives of this session on tight gas reservoirs?**

A. **Exploration and development strategies for low permeability gas reservoirs — technical challenges and solutions:**
   - Low permeability gas resource assessment.
   - Identification of sweet spots and fracture prediction.
   - Identifying risks and rewards.
   - Drilling, fracturing, underbalanced drilling, horizontal wells, etc.
   - Production technologies and future outlook.
   - Case studies.

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*Exploration is really the essence of the human spirit.*

Frank Borman (Astronaut) (1928-)

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From: Rushing, J.A. (private communication).
Reservoir Characterization: Integration Approach

Q. Process for characterizing low permeability gas reservoir models?
A. A comprehensive process must include all data possible, as well as the integration of expertise for interpretation and analysis.

You cannot build character and courage by taking away a man's initiative and independence.
Abraham Lincoln (1809-1865)

Reservoir Interpretation: Performance Analysis

Q. What technology is best for reserves estimation (decline curve analysis, rate transient analysis, pressure transient analysis)?
A. MULTIPLE analyses must be used. A "model-based" analysis/forecast is strongly encouraged — a reservoir model must be used in the analysis, interpretation, forecast of production performance.

To succeed in life, you need two things: ignorance and confidence.
Mark Twain (1835-1910)
Factors Influencing Reservoir Performance:

**Q. What are the factors which influence reservoir performance in tight gas reservoir systems?**

**A. The primary factors include:**
- Reservoir permeability (and geologic distribution of permeability).
- Reservoir pressure and temperature.
- Well completions — hydraulic fracturing, horizontal wells, etc.
- Geomechanical effects (including abnormal (high/low) pressure).
- Water saturation and vaporized water component.

*For most tight gas reservoirs, the reserves are proportional to the length of the hydraulic fracture created to stimulate the well.*

Various Industry Personnel (consensus statement)

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Inversion of Reservoir Performance:

**Q. What is inversion?**

**A. You know the output(s), and you want to estimate the underlying model and/or properties of the model:**

\[
\text{Data} = \text{Physics(Reservoir)} + \text{Error}
\]

\[
\text{Inversion (Interpretation)}
\]

\[
\text{Reservoir} = \text{Physics}^{-1}(\text{Data}) + \text{Uncertainty} + \text{Bias}
\]

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I do not have much patience with a thing of beauty that must be explained to be understood.

Charlie Chaplin (1889-1977)
Hydraulic Fracture Stimulation of Tight Gas Reservoirs:

**Q. Can we "map" the path of a hydraulic fracture in a tight gas reservoir?**

**A. Sort of — microseismic imaging has become popular, but it is an expensive operation, and the interpretation is more art than science.**

It is odd how learned persons fail to see that new terms and definitions are apt to mean new doubts and litigation.

Frederick Pollock (English Judge) (1845-1937)

**Q. Do we understand fracture geometry?**

**A. Not really ...**

It is better to have enough ideas for some of them to be wrong than to be always right by having no ideas at all.

Edward de Bono (English Psychologist) (1933)
Appendix: Energy Issues (for reference)

**Energy Summary Data:** (EIA 2002 data and some 2003 estimates — http://www.eia.doe.gov/emeu/cabs/)

<table>
<thead>
<tr>
<th>Country</th>
<th>CH Reserves (B STB)</th>
<th>CH Production (MMSTB/D)</th>
<th>CH Consumption (MMSTB/D)</th>
<th>Net CH Imports (MMSTB/D)</th>
<th>CH Wells Drilled in 2002/total wells</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>18.3</td>
<td>3.39</td>
<td>5.26</td>
<td>1.87</td>
<td>&gt; 70,000² (total)</td>
</tr>
<tr>
<td>United States</td>
<td>22.4</td>
<td>5.7 (8.8³)</td>
<td>19.9</td>
<td>11.2</td>
<td>4964/531,610²</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Country</th>
<th>Conventional Gas Reserves (tcf)</th>
<th>Gas Production (tcf/EYr)</th>
<th>Gas Consumption (tcf/EYr)</th>
<th>Gas Imports (tcf/EYr)</th>
<th>Gas Wells Drilled in 2002/total wells</th>
<th>Unconventional Gas Reserves (tcf)</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>53.3</td>
<td>1.07</td>
<td>1.07</td>
<td>—</td>
<td>—</td>
<td>1060²</td>
</tr>
<tr>
<td>United States</td>
<td>183</td>
<td>19.4</td>
<td>22.3</td>
<td>4.0</td>
<td>1594/7358,76²</td>
<td>1685⁵/1200⁶</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Country</th>
<th>Coal Reserves (B sl t mt)</th>
<th>Coal Production (B sl t mt/EYr)</th>
<th>Coal Consumption (B sl t mt/EYr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>126.2</td>
<td>1.49</td>
<td>1.38</td>
</tr>
<tr>
<td>United States</td>
<td>275.1</td>
<td>1.13</td>
<td>1.06</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Country</th>
<th>Electric Generation Capacity (Gigawatts)</th>
<th>Electricty Generation (B Kilowatt-hr)</th>
<th>Thermal Electricity Generation (Percent)</th>
<th>Nuclear Electricity Generation (Percent)</th>
<th>Hydroelectric Electricity Generation (Percent)</th>
<th>&quot;Renewable&quot; Electricity Generation (Percent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>318</td>
<td>1420</td>
<td>74.5</td>
<td>0.6</td>
<td>24.9</td>
<td>—</td>
</tr>
<tr>
<td>United States</td>
<td>813</td>
<td>3889</td>
<td>74</td>
<td>12</td>
<td>12</td>
<td>2</td>
</tr>
</tbody>
</table>

*Notes: ¹Includes "refinery gains", ²Oil and Gas J. (24 Dec. 2001), ³IPAA Research and Information webpage, (http://www.ipaa.org/info/InYourState/), ⁴Coalbed Methane (Central Coal Mining Research Institute (China)), ⁵Coalbed Methane — Past, Present, and Future (EIA: http://www.eia.doe.gov/petroleum/gas/natural_gas/analysis_publications/maps/maps.htm#Top), ⁶Tight Gas Sands (http://www.mines.edu/research/pgs/).*
Appendix: Energy Issues (for reference)

Oil Production History for the United States — 1949-2002
Petroleum Production History for China — 1980-2002
Data from US DOE EIA (http://www.eia.doe.gov)

Legend: US Oil Variables
- US Oil Consumption (MSTB/D)
- US Oil Production (Total) (MSTB/D)
- US Oil Production (Crude Oil) (MSTB/D)
- US Oil Imports (MSTB/D)
- US Oil Production (Plant Liquids) (MSTB/D)

Legend: China Oil Variables
- China Oil Consumption (MSTB/D)
- China Oil Production (MSTB/D)
- China Oil Imports (MSTB/D)

Note: Differences in US Oil Production, Consumption, and Imports is cited as "refinery gain" by DOE-EIA.

Appendix: Energy Issues (for reference)

Oil Production History for China — 1980-2002
Data from US DOS-EIA (http://www.eia.doe.gov)

Legend: China Oil Variables
- China Oil Consumption (MSTB/D)
- China Oil Production (MSTB/D)
- China Oil Imports (MSTB/D)

Note: China oil consumption increasing at ~ 260,000 STBD/yr.
China oil production increasing at ~ 46,000 STBD/yr.
China oil imports increasing at ~ 260,000 STBD/yr.
Appendix: Energy Issues (for reference)
Appendix: Energy Issues (for reference)

Energy Consumption History for the United States — Marchetti-Nakicenovic Fraction Function
(International Institute for Applied Systems Analysis (cited in Oil and Gas Journal 26 January 2004))
Data from US DOE-EIA (http://www.cia.doc.gov)