Characterizing Tight Gas Resources in Western Canada

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Let It Flow
Flow of Ideas, Hydrocarbons and Business

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Calgary, Alberta
Western Canada Tight Gas Resource Characterization Project

Natural Resources Canada - GSC

Devon Canada Corporation
Husky Oil Operations Ltd.
Imperial Oil Limited
Petrel Robertson Consulting Ltd.
Talisman Energy Inc.
TransCanada Pipelines Limited

NEB, CGPC, BCMEMPR, EUB, Sask IR, ARI, USGS, EIA
Outline

• Project introduction
• Tight gas definition
• Characterization by play
• Resource estimation
• Supply potential and technology
Unconventional gas is largest source in the US

Natural Gas Production by Source, 1990-2030

trillion cubic feet

EIA AEO 2007

Largest single source of supply since 2000
Tight formation gas is largest unconventional type

Unconventional Natural Gas Production by Type 1990-2030

History Projections

Tight sands
Coalbed methane
Gas shales

Largest single source of supply since 2005
Tight gas in Western Canada

Tight gas is an expression widely used by:

- Publicly-traded firms to describe plays and activity in financial disclosure
- Technical associations, professionals and academics
- Journalists in trade publications
- Government agencies (rarely)

According to these sources:

- Tight gas is developed and producing in Western Canada
- The undeveloped resource base is believed to be large
- Supply from tight gas will increase as industry learns to develop and apply appropriate technology

High expectations
Tight gas not reported in Canada

- Tight formation gas is not defined and distinguished from “conventional”
- Current tight gas production and size of future opportunity remain uncertain
- Geographic and stratigraphic distribution and reservoir characterization of tight gas plays not available in public reports
- Tight gas resource potential not included in CGPC, federal or provincial agency estimates
- Supply potential and opportunities to increase tight gas supply not founded on consistent definition, play characterization and resource estimates

GIP estimates up to 1500 Tcf in the early 1980s
Is the resource really there?
What’s in a name?

<table>
<thead>
<tr>
<th>CONVENTIONAL</th>
<th>UNCONVENTIONAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Discrete gas pools in ocean of water</td>
<td>1. Pervasive gas saturated accumulations</td>
</tr>
<tr>
<td>2. Only high quality reservoir accumulates gas in place</td>
<td>2. Very large gas in place in reservoir of all qualities</td>
</tr>
<tr>
<td>3. Discovery is uncertain, recovery is certain</td>
<td>3. Discovery is certain, recovery is uncertain</td>
</tr>
<tr>
<td>4. Discovery process is efficient</td>
<td>4. Recovery is inefficient but improves with technology</td>
</tr>
<tr>
<td>5. R&amp;D to increase success</td>
<td>5. R&amp;D to improve recovery and characterization</td>
</tr>
<tr>
<td>6. Remaining resource, in small undiscovered pools, is small</td>
<td>6. Remaining resource in lower quality reservoirs is large</td>
</tr>
<tr>
<td>7. Official view of WCSB remaining resources</td>
<td>7. US and industry view of WCSB remaining resources</td>
</tr>
</tbody>
</table>

“Glass is mostly empty”

“Glass is mostly full”

Models define how we evaluate potential
Gas Production Profiles

**US Lower 48**
- Conventional gas in decline
- Tight gas in lower 48 over 30% of 2005 total
- CBM and shale gas significant

**Western Canada**
- CBM growing rapidly
- Tight gas not reported
  - estimate over 30% of 2005 total
- Conventional gas in decline

Better understanding of tight gas is important
Project Objectives

1. Communicate clearly the tight gas opportunity by establishing a **workable definition** for tight gas accepted by stakeholders

2. **Characterize** the tight gas opportunities into play types and analyze their supply trends

3. **Estimate** remaining tight gas resource potential and model its future conversion into supply.

4. Summarize resource and **supply potential** and **identify technology** and opportunities to maximize development of tight gas in Western Canada.
Gas Resource definition issues

Accumulation Type
- Small trap in large aquifer
- Large trap ‘continuous’

Reservoir Quality
- Excellent
- Very Poor

Conventional Gas
Tight Formation Gas
Coalbed Methane
Shale Gas
Gas Hydrates
Other

What are the dimensions?
What are the limits?
Continuous accumulation
Free gas produced by gas expansion
Clastic and carbonate reservoirs
Reservoir quality continuum
Technology application
Economics

Workable
Gas Accumulation Types

Low K reservoirs contain GIP only in Continuous
### Reservoir quality: The 0.1 mD Myth

#### Tight Formation Designation
- US tax credit program for wells drilled 1977 to 1992
- Area-average in-situ formation permeability < 0.1 mD
- Historical tight gas designation generalized to basin-formation and field-formation – includes areas previously excluded
- New plays included based on USGS continuous accumulation criteria – not screened by permeability criteria

- In-situ permeability is difficult to measure and average
- Average permeability is only one of several factors that determine flow rate, ultimate recovery and economics

**US tight gas plays include all reservoir qualities**
Reservoir quality: The 0.1 mD Myth

- Rate-depth limits classified formations with low productivity for their depth as tight formation gas
- Shallow biogenic gas

US tight gas plays include all reservoir qualities
Definition Workshop Outcomes

**Definition**: All gas resources occurring as free gas in the pores of clastic and carbonate reservoirs in regionally-pervasive continuous gas accumulations will be defined as tight gas resources. *Adopted working definition.*

Characterize the resource potential of **the complete spectrum of reservoir qualities** within these gas accumulations.

**Regionally-pervasive gas accumulations** be classified as tight gas areas and reviewed in the following priority:

- Deep Basin trap *Primary characterization focus*
  - Shallow biogenic gas *Low priority*
  - Jean Marie Fm, B.C. *Low priority*
  - Additional accumulations *Low priority*
Plays and Characterization

Production by Tight Gas Region

Three major tight gas regions – all on growth trends
Jean Marie
Cum production: 1.3 tcf (raw)
4.5% of rate additions 03-05
2.5% of production 03-05

Milk River – Med Hat – 2WS
Cum production: 14 tcf (raw)
11% of rate additions 03-05
10% of production 03-05

Deep Basin tight gas
Cum production: 17 tcf (raw)
21.5% of rate additions 03-05
15% of production 03-05
# Deep Basin Play Definitions

<table>
<thead>
<tr>
<th>Geologic Age &amp; Interval</th>
<th>Deep Basin Play, this study</th>
<th>CGPC Play</th>
<th>Undiscovered Mktb Potential, Bcf</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tertiary &amp; Upper Cretaceous</td>
<td>Younger</td>
<td>Various</td>
<td></td>
</tr>
<tr>
<td>Cardium</td>
<td>Cardium Gas</td>
<td>B065P Cardium, includes oil</td>
<td>1,237</td>
</tr>
<tr>
<td>Dunvegan</td>
<td>Dunvegan Gas</td>
<td>B083P Dunvegan, includes oil</td>
<td>2,623</td>
</tr>
<tr>
<td>Lower Cretaceous</td>
<td>Viking interval</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cadotte &amp; Viking Gas</td>
<td>C113R</td>
<td>Paddy/Cadotte and Viking Deep Basin</td>
<td>1,865</td>
</tr>
<tr>
<td>Viking Oil</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bow Island</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Upper Mannville</td>
<td>Spirit River</td>
<td>C113R</td>
<td>4,998</td>
</tr>
<tr>
<td>Upper Mannville South</td>
<td></td>
<td>Spirit River and Upper Mannville Deep Basin</td>
<td></td>
</tr>
<tr>
<td>Bluesky &amp; Glauconitic</td>
<td>C143R Bluesky Deep Basin</td>
<td>853</td>
<td></td>
</tr>
<tr>
<td>Lower Mannville</td>
<td>Gething</td>
<td>C163R</td>
<td>6,274</td>
</tr>
<tr>
<td>Ellerslie</td>
<td></td>
<td>Gething Deep Basin</td>
<td></td>
</tr>
<tr>
<td>Lower Mannville South</td>
<td>C173R</td>
<td>C1omin/Nikanassin Deep Basin</td>
<td>2,790</td>
</tr>
<tr>
<td>Nikanassin</td>
<td>Nikanassin</td>
<td>C1omin/Nikanassin Deep Basin</td>
<td></td>
</tr>
<tr>
<td>various</td>
<td>Multiplay</td>
<td>Included in all of above plays</td>
<td></td>
</tr>
<tr>
<td>Triassic+</td>
<td>various</td>
<td>Older</td>
<td>Various</td>
</tr>
</tbody>
</table>
Play Definition Process

• CGPC Lower Cretaceous resource plays
  – Anomalous pressure area generalized by CGPC from Rakhit to classify pools
• Cardium and Dunvegan where commingled with L. Cret
• Adjust boundaries and subdivide, considering
  – Alternative Deep Basin definitions
  – Distribution of gas, oil and water production
  – Stratigraphic nomenclature and mappability
  – Alignment with EUB and BCMEMPR play boundaries
  – Eastern limit of significant faulting in Lower Cretaceous
• Sources
  – Petrel Robertson tight gas report, Deep Basin memoir, published papers
  – Oil and gas pool data (g/w contacts, pressure - elev)
  – Maps of reservoirs and seals controlling fluids
Play Definition Issues

- Some areas of the CGPC resource plays are not pervasively gas charged
  - Viking Oil, Upper Mannville South and Ellerslie plays have a higher probability of oil and water
  - Characterization for gaswells
  - Estimate resources for non-associated gas

- Multiplay producers
  - Increasing commingling with regulatory changes
  - Commingled production from zones in different plays
  - Dominant producing play cannot be identified
  - Multizone pools and metering units (MUs)
    - Wild River + Wapiti + Cecilia + Elmworth > 185 MMcfd

- Commingling zones affects play characterization
Play Definition and Boundaries

Viking Interval Plays
Rate Added per Township, MMcfd
Events Onstream 1990 to 2005

Rate Added per Township, MMcfd
- 16 to 27 (7)
- 8 to 16 (20)
- 4 to 8 (35)
- 2 to 4 (53)
- 1 to 2 (50)
- 0.5 to 1 (50)
- 0 to 0.25 (62)

Multiple Play Producers
Rate Added per Township, MMcfd
Events Onstream 1990 to 2005

Rate Added per Township, MMcfd
- 32 to 92 (1)
- 16 to 32 (2)
- 8 to 16 (7)
- 4 to 8 (16)
- 2 to 4 (39)
- 1 to 2 (49)
- 0.5 to 1 (50)
- 0.25 to 0.5 (46)
- 0 to 0.25 (62)

Edges compiled from multiple sources
Commimgled producers analyzed by well, not play
Deep Basin Play Outlines

Maximum extent ~ 40,000 sq. miles
Raw Gas Production by Play

Deep Basin production growing to over 15% of WCSB
Rate Additions by Deep Basin Play

Deep Basin plays growing source since 2002
Growth plays in recent years
Deep Basin Play Production Summary

<table>
<thead>
<tr>
<th>Producing Play</th>
<th>Gas Events On-stream 1990 to 2005</th>
<th>Rate added, MMcfd</th>
<th>Extrapolated Recovery, Bcf</th>
<th>Single zone wells 1990 to 2005</th>
<th>Average Rate added per well, Mcfd</th>
<th>Average Extrapolated recovery per well, Bcf</th>
<th>Average Feet Drilled</th>
<th>Average Decline Rate, % per year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cardium Gas</td>
<td>867</td>
<td>461</td>
<td>809</td>
<td>775</td>
<td>559</td>
<td>0.980</td>
<td>8,160</td>
<td>20.8%</td>
</tr>
<tr>
<td>Dunvegan Gas</td>
<td>193</td>
<td>187</td>
<td>446</td>
<td>161</td>
<td>930</td>
<td>2.250</td>
<td>7,520</td>
<td>15.3%</td>
</tr>
<tr>
<td>Cadotte &amp; Viking Gas</td>
<td>609</td>
<td>541</td>
<td>870</td>
<td>405</td>
<td>977</td>
<td>1.620</td>
<td>7,983</td>
<td>22.7%</td>
</tr>
<tr>
<td>Viking Oil</td>
<td>668</td>
<td>213</td>
<td>367</td>
<td>473</td>
<td>331</td>
<td>0.610</td>
<td>5,901</td>
<td>21.1%</td>
</tr>
<tr>
<td>Bow Island</td>
<td>274</td>
<td>69</td>
<td>108</td>
<td>160</td>
<td>243</td>
<td>0.410</td>
<td>4,001</td>
<td>23.2%</td>
</tr>
<tr>
<td>Spirit River</td>
<td>892</td>
<td>1,137</td>
<td>1,580</td>
<td>557</td>
<td>1,406</td>
<td>2.100</td>
<td>8,004</td>
<td>26.3%</td>
</tr>
<tr>
<td>Upper Mannville S.</td>
<td>486</td>
<td>397</td>
<td>659</td>
<td>321</td>
<td>929</td>
<td>1.650</td>
<td>6,725</td>
<td>22.0%</td>
</tr>
<tr>
<td>Bluesky &amp; Glauconitic</td>
<td>1,077</td>
<td>765</td>
<td>1,712</td>
<td>821</td>
<td>737</td>
<td>1.710</td>
<td>7,551</td>
<td>16.3%</td>
</tr>
<tr>
<td>Gething</td>
<td>1,143</td>
<td>824</td>
<td>1,428</td>
<td>880</td>
<td>741</td>
<td>1.360</td>
<td>7,985</td>
<td>21.0%</td>
</tr>
<tr>
<td>Ellerslie</td>
<td>1,216</td>
<td>783</td>
<td>1,303</td>
<td>888</td>
<td>700</td>
<td>1.180</td>
<td>7,584</td>
<td>21.9%</td>
</tr>
<tr>
<td>Lower Mannville S.</td>
<td>204</td>
<td>113</td>
<td>211</td>
<td>179</td>
<td>572</td>
<td>1.070</td>
<td>8,129</td>
<td>19.6%</td>
</tr>
<tr>
<td>Cadomin</td>
<td>868</td>
<td>774</td>
<td>888</td>
<td>692</td>
<td>938</td>
<td>1.020</td>
<td>9,652</td>
<td>31.8%</td>
</tr>
<tr>
<td>Nikanassin</td>
<td>19</td>
<td>12</td>
<td>19</td>
<td>10</td>
<td>683</td>
<td>0.730</td>
<td>11,006</td>
<td>23.4%</td>
</tr>
<tr>
<td>Multiplay</td>
<td>969</td>
<td>530</td>
<td>730</td>
<td>517</td>
<td>627</td>
<td>0.870</td>
<td>8,895</td>
<td>26.5%</td>
</tr>
<tr>
<td>Total</td>
<td>9,485</td>
<td>6,806</td>
<td>11,129</td>
<td>6839</td>
<td>763</td>
<td>1.292</td>
<td>7,840</td>
<td>22.3%</td>
</tr>
</tbody>
</table>

Rate added and extrapolated recovery are net after surface loss.

Deep Basin plays added >14% of new supply 1990-2005
Cadomin Single Zone Wells

$q_i$ vs well TVD where analysis type is decline

Rate - Depth Limits for US Tight Formation Gas

Evaluating use to distinguish “tight” gas
Resource Estimation Methods

- Discovery process / Arps-Roberts / TPDM / Petrimes
  - Discrete pools in play where discovery history exists
  - Where are the pool boundaries in a continuous gas accumulation?
  - Could method be applied with appropriate framing?

- GIP volumetric from petrophysics and mapping
  - Subsurface basin study from logs, measuring and mapping structure, isopach, gross and net sand, porosity, saturations, pressure, permeability
  - Output is interpreted subsurface grid models of GIP for further technology and economic modeling
  - Data generation beyond scope of current project

- Cellular methods
  - Extrapolate resources from drilled and evaluated cells (tracts) to undrilled cells based on well recovery, success rate, etc.

Applying cellular method similar to USGS & ARI
Recoverable resources = area * EUR/well * success rate
Aggregate production profiles for characterization
Model production profiles for EUR extrapolation by play
Cumulative Frequency of Well EUR by Connection Period
Spirit River Play wells only with 0.25 Bcf EUR cutoff

<table>
<thead>
<tr>
<th>EUR, Bcf per Well</th>
<th>Mean</th>
<th>Median</th>
<th>Mean, P30-60</th>
<th>Wells</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre 1986 Connections</td>
<td>16.4</td>
<td>12.2</td>
<td>13.8</td>
<td>99</td>
</tr>
<tr>
<td>1985-1994 Connections</td>
<td>7.0</td>
<td>4.4</td>
<td>5.5</td>
<td>119</td>
</tr>
<tr>
<td>1995-1998 Connections</td>
<td>3.9</td>
<td>1.8</td>
<td>2.3</td>
<td>93</td>
</tr>
<tr>
<td>1999-2001 Connections</td>
<td>2.2</td>
<td>1.3</td>
<td>1.5</td>
<td>114</td>
</tr>
<tr>
<td>2002-2004 Connections</td>
<td>2.2</td>
<td>1.5</td>
<td>1.7</td>
<td>148</td>
</tr>
<tr>
<td>2005 Connections</td>
<td>1.6</td>
<td>1.1</td>
<td>1.2</td>
<td>78</td>
</tr>
</tbody>
</table>

EUR per well trends for resource estimation
Cumulative frequency of Well EUR by Well Type
Cadomin Play wells only in the Cutbank-Sinclair area

Horizontals improving EUR per well, accelerating rate
Supply Potential and Technology

• Supply evaluation at well level, not individual play
  – Commingling is norm for future

• Opportunities and challenges to tight gas
  – Economic
  – Fiscal terms
  – Regulatory

• Technology to reduce risk and increase output
  – Sweet spot detection
  – Permeability measurement
  – Drainage optimization
  – Drilling cost reduction

• Innovation will increase recovery - examples
Conclusions

• Regionally pervasive gas accumulations host tight gas resources, regardless of the reservoir quality
  – The 0.1 mD cutoff is a myth

• Production from tight gas areas comprises over 30% of current WCSB production

• Tight gas production is growing while production from conventional sources decline

• Deep Basin trap remains the largest current source of tight gas in the WCSB

• Single play characteristics must be integrated to evaluate supply from commingled stacked plays

• GIP resource estimates by play will be needed.

• Targeted public research on tight gas is needed.

Impact on supply will be evolution, not revolution
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