A Global Perspective for IOR and Primary in Unconventional Tight Oil and Gas Reservoirs

Richard Baker May-13
Conclusions

1. There has been tremendous growth in tight oil and gas rates and reserves.

2. Despite the rapid oil rate well counts and wells drill in major plays are constant.

3. It is extremely difficult to forecast the future oil production because the classic “S” shaped growth curve and the Resource pyramid.

4. It is my opinion that growth in tight oil will level off
   - Constant well counts (constant production profiles)
   - Decreasing liquids from gas (CGR ↓ )
Conclusions

5. Most of these shale plays are not really shales rather they are very low permeability plays (0.01 to 0.1 mD)

6. Estimates of recoverable oil in volumetric basis are too high.

7. Pay Cut offs are way too pessimistic
General Observations

- Reservoir permeability is often higher than air permeability (small fractures contributing) inflow tests and pressure transient analysis.
- Most of the times we have more hydraulically induced fractures than we need.
  - No strong correlation between
    - number of induced fractures and IP or reserves
    - number of induced fractures and IP or reserves
    - but near wellbore permeability is huge variable
- This may only be true for tight oil (true shale gas???)
Presentation Flow

Big picture (countries)

Medium size picture (basins)

Small picture (wells)

Summary
Making Forecast using historical data

- Forecasting like this is a bit like only looking at the rudder and determining where the boat goes
  - Wind + waves
Beware of all forecasts with developing plays/technology

• Most shale oil and shale gas wells have only few years production
• Most shale plays are developed in sweet spots first
• Shale plays are large areally and only portions of fields have been developed
• Technology advancements will impact plays

U.S. Shale Gas and Shale Oil Plays Review of Emerging Resources: July 2011

CAUTION STATEMENT
USA AND CANADIAN OIL RATE TRENDS
USA Oil and Liquids forecast from IEA July 2011

U.S. oil output set to boom
By Simone Sebastian
Updated 12:10 a.m., Tuesday, February 21, 2012

The United States' rapidly declining crude oil supply has made a stunning about-face, shredding federal projections and putting energy independence in sight of some analyst forecasts.

After declining to levels not seen since the 1940s, U.S. crude production began rising again in 2009. Drilling rigs have rushed into the nation's oil fields, suggesting that a surge in domestic crude is on the horizon.

"The growth that we've seen in shale, that's one of the biggest changes that's contributing to our outlook," said Dana Van-Wagener, a research analyst for the agency. "It's evolving so quickly. We weren't anticipating enough growth."

USA Oil + Liquids Production

US Total Oil Production
Crude Oil, NGPL, and Other
Natural Gas Plant Liquids

U.S. Oil Production Jan 1994 - Jan 2013
Thousands of Barrels/day
USA Oil + Liquids Production

US EIA website

U.S. Oil Production Jan 1994 - Jan 2013

Oil+ liq. 11.8 MM bbl/d

Oil+ liq. 8.5 MM bbl/d

Initially liquids from gas wells
Now growth from oil wells

Thousands of Barrels/day


USA Total Oil Production
Crude Oil, NGPL, and Other
Natural Gas Plant Liquids
CAN Historical Oil Production

Canadian Oil Production vs Time (from 1994 to 2013)

- Mining: 756000 bbl/day (2010)
- In-Situ stm: 704000 bbl/day (2010)

Source: Geoscout
All wells Canada

Ends in 2012

all wells in canada from 2000 Jan to 2012 Dec

Series1
Canadian Oil Production from Hz with 5 or more fractures….includes SAGD
(medium size picture)

BASIN ANALYSIS
Figure 1. Map of U.S. shale gas and shale oil plays (as of May 9, 2011)

Source U.S. Energy Information Administration based on data from various published studies.
Update: May 9, 2011
## Summary of Liquids Production (oil + ngl) vs. Year

<table>
<thead>
<tr>
<th>Sum of Annual Liquid</th>
<th>BAKKEN</th>
<th>BARNETT</th>
<th>EAGLE FORD</th>
<th>HAYNESVILLE</th>
<th>MARCELLUS/SH/</th>
<th>NIOBRARA</th>
<th>WOODFORD</th>
<th>Grand Total</th>
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<tbody>
<tr>
<td><strong>Row Labels</strong></td>
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<td></td>
<td></td>
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<td>2005</td>
<td>7,368,710</td>
<td>86,401</td>
<td>7,455,111</td>
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<td>7,455,111</td>
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<td>2006</td>
<td>13,951,603</td>
<td>98,416</td>
<td>14,070,307</td>
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<td>2007</td>
<td>19,183,264</td>
<td>63,122</td>
<td>11,558,193</td>
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<td>19,345,940</td>
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<td>2008</td>
<td>36,316,578</td>
<td>89,034</td>
<td>144,348,002</td>
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<td>36,697,002</td>
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<td>2009</td>
<td>57,047,968</td>
<td>160,498</td>
<td>237,092,309</td>
<td></td>
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<td></td>
<td></td>
<td>237,092,309</td>
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<td>2010</td>
<td>90,898,597</td>
<td>1,029,022</td>
<td>334,521,010</td>
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<tr>
<td>2011</td>
<td>127,302,933</td>
<td>48,851</td>
<td>931,469,052</td>
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<td>931,469,052</td>
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<td>2012</td>
<td>206,717,003</td>
<td>53,450</td>
<td>1,668,710,133</td>
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<td>1,668,710,133</td>
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<td>2013</td>
<td>241,033,131</td>
<td>62,971</td>
<td>48,936,723,010</td>
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<td>48,936,723,010</td>
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<tr>
<td><strong>Grand Total</strong></td>
<td>592,989,787</td>
<td>176,433,420</td>
<td>3,328,855,055</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3,328,855,055</td>
</tr>
</tbody>
</table>

\[
\frac{206 \text{ MMbbl}}{355 \text{ MMbbl}} = 58% \\
\frac{136 \text{ MMbbl}}{355 \text{ MMbbl}} = 38% \\
\frac{10 \text{ MMbbl}}{355 \text{ MMbbl}} = 3% 
\]

Source: USA EIA
U.S. Shale Basins – 862 Tcf & 24 BBO TRR (TRR - Technically Recoverable Resources by EIA)

23 Significant Shale Basins in U.S. - over 55,000 producing wells
Bakken Shale Production

Source: Baker Hughes
✓ Rising oil
✓ Decreasing gas
Note rapid decline in production

✓ Decreasing oil
✓ Decreasing gas
Rig Count (~drilled wells)

Jan. 2012

Jan. 2013
## Major Shale Oil Play Data Comparison

<table>
<thead>
<tr>
<th>PLAY</th>
<th>BAKKEN</th>
<th>EAGLE FORD</th>
<th>NIOBRARA</th>
<th>UTICA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth, ft</td>
<td>8,500 – 10,400</td>
<td>4,000 – 12,000</td>
<td>3,000 – 14,000</td>
<td>2,000 – 14,000</td>
</tr>
<tr>
<td>Thickness, ft</td>
<td>8 - 14</td>
<td>300 - 475</td>
<td>50 - 300</td>
<td>70 - 500</td>
</tr>
<tr>
<td>Permeability, md</td>
<td>0.05 md @ Middle Bakken</td>
<td>Up to 0.13 md</td>
<td>0.1 - 1 md</td>
<td>0.0003 md</td>
</tr>
<tr>
<td>IP Rate, BOPD</td>
<td>200 – 1,800</td>
<td>250 – 1,500</td>
<td>+/- 600</td>
<td>1,000 Bopd + 6 MMcfd</td>
</tr>
<tr>
<td>Avg Lateral, ft</td>
<td>10,000+</td>
<td>5,000 – 7,000</td>
<td>3,300 – 10,000</td>
<td>5,500 – 7,500</td>
</tr>
<tr>
<td>Resources, BBO</td>
<td>4.5 (est to 20)</td>
<td>3.5</td>
<td>1.5</td>
<td>3.0 (est to 5.5)</td>
</tr>
</tbody>
</table>

**Niobrara and Utica very “early” data**

Resources = Technically Recoverable (TRR) Source: EIA
Definitions of Low Permeability vs. Shale Permeability

Unconventional Reservoirs
- Tight Gas or Tight Oil Sandstone
- Shale

Conventional Reservoirs
- Conventional Oil or Gas Reservoirs
- Limestone
- *Natural Gas from Coal

Permeability (mD)
- Extremely Tight: 0.0001
- Very Tight: 0.001
- Tight: 0.01
- Low: 0.1
- Moderate: 1.0
- High: 10.0
- 100.0

Quality of Reservoir
- Poor
- Good

Granite
Sidewalk Cement
Volcanic Pumice

*Natural Gas from Coal reservoirs are classified as unconventional due to type of gas storage

Modified from US Department of Energy

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Major Shale Oil Play Data Comparison

ARE THESE REALLY LOW PERMEABILITY “SHALE” … I WOULD CALL THEM VERY LOW PERM.


<table>
<thead>
<tr>
<th>Permeability Classification</th>
<th>Permeability (mD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very low</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Low</td>
<td>0.01 – 1</td>
</tr>
<tr>
<td>Average</td>
<td>1 – 100</td>
</tr>
<tr>
<td>High</td>
<td>100 – 10000</td>
</tr>
<tr>
<td>Very high</td>
<td>&gt; 10000</td>
</tr>
</tbody>
</table>

Resources = Technically Recoverable (TRR) Source: EIA

Niobrara and Utica very “early” data

Resources, BBO

Niobrara and Utica very “early” data

- Bakken
  - Depth, ft: 8,500 – 10,400
  - Thickness, ft: 8 - 14
  - Permeability, md: 0.05 md @ Middle Bakken, Up to 0.13 md
  - IP Rate, BOPD: 200 – 1,800
  - Avg Lateral, ft: 10,000+

- Eagle Ford
  - Depth, ft: 4,000 – 12,000
  - Thickness, ft: 300 – 475
  - Permeability, md: 0.1 – 1 md
  - IP Rate, BOPD: 250 – 1,500
  - Avg Lateral, ft: 5,000 – 7,000

- Niobrara
  - Depth, ft: 3,000 – 14,000
  - Thickness, ft: 50 – 300
  - Permeability, md: 0.0003 md
  - IP Rate, BOPD: +/− 600
  - Avg Lateral, ft: 3,300 – 10,000

- Utica
  - Depth, ft: 2,000 – 14,000
  - Thickness, ft: 70 – 500
  - Permeability, md: 0.0003 md
  - IP Rate, BOPD: 1,000 Bopd + 6 MMcfd
  - Avg Lateral, ft: 5,500 – 7,500
Initial rates show large scatter but similar decline trend

Total trend 81 wells
USA BAKKEN OIL RATE

~Arithmetic average~200bbl/d
ABCs of Reservoir and Well Dynamics: Controlling Factors

First year production

- Completion
- Fractures
- Near wellbore permeability

- Pressure support
- Drive mechanism
- Far field permeability
ABCs of Reservoir and Well Dynamics: Controlling Factors

Decline rate is steep ~65%/yr in first year, generally caused by:
- Transient effects
- Pressure depletion
- Increasing gas saturation

Secondary recovery will become critical to maintain a higher plateau oil rate
- Lack of drive energy

First year production
Checks and Balances

Use available data in many ways:

- **Model Building**
  - Image logs
  - Fracture reports
  - Shale petrophysics
  - Mechanical properties
  - Formation structure
  - Well geometry
  - Fluid characterization

- **Model Validation**
  - Microseismic
  - Tracer surveys
  - Production logging
  - Minifrac
  - Transient tests
  - Production rates and pressures
Finite difference numerical options

- Can capture most flow dynamics
- Need to be oriented along principle stresses

a. Tartan Grid (SPE 125530)
b. Variable Frac Conductivity (SPE 135262)
c. Affected Rock Volume Modeling (SPE 138134)
d. Shale Engineering (SPE 146912*)
Advanced Reservoir Engineering for Shales

**In-Place Description**

**Shale Engineering**

**Cash flows**

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**Shale Engineering Modeling**

- Based on geo-mechanics
  - Flow Physics
  - Pressure-dependent properties
  - Matches observed performance
  - Interprets and implements micro-seismic

- Optimizes well design and field development
- Provides early predictions of long term production behavior

Based on: CSUG/SPE 146912
What are the lessons learned from Fracture Diagnostics and Reservoir Simulation

• Permeability is controlling factor
  – Primary
  – waterflood
• In lower permeability formations natural fractures increase permeability
• Pay cut offs are way too high
• Reservoir drive energy is late stage controlling factor
With new technology

HISTORIC GROWTH CURVES
Historic Growth Curves (organic growth)
Historic Growth Curves (organic growth)

- Rapid growth
- Best fields being exploited
- Few operators + not much experience
- Only so many good fields/infrastructure/political limitations
- Reservoir depletion

Time or date
Thermal EOR Production Data (mainly California)


Rapid growth
Best fields being exploited
Limitations on number good fields/infrastructure
Reservoir depletion
Few operators + not much experience
Historic Growth Curves (organic growth)

- Rapid growth
- Best fields being exploited
- Only so many good fields/infrastructure/political limitations
- Few operators + not much experience

LET’S FOCUS HERE
Note Oil rate Growth in West Texas ‘‘s’’ shaped curve in 1950’s
Oil Production from Saskatchewan’s Horizontal Wells PTAC Report 2006

Growth has been achieved by using horizontal wells

Flat plateau; decreasing costs + more poor res. quality

130 Mstb/d
Alberta Tar Sands

750 MSTB/d
Not including Cold Lake + >150
Approximately ~900 MSTB per day

Note Field Pilots, note growth oil rate
Most growth in CO$_2$ occurred in a low price environment…

J. Shaw EOR Presentation April 7, 2006 (Calgary EOR Forum) and WTRG Economics
There is always a much larger lower quality resources compared to high quality resources.
USA Oil + Liquids Production
US EIA website plus RB view

U.S. Oil Production Jan 1994 - Jan 2013

Why constant well Count + infrastructure

- US Total Oil Production
- Crude Oil, NGPL, and Other
- Natural Gas Plant Liquids
Conclusions

The future forecast is sensitive to:

- Oil price and
- Technology
- Pressure support

*Not in that order*

The future of tight oil forecast is a function of IP, decline rate and plateau oil rate of *individual wells*

- Geology
- Completion, well length
- OOIP

**Shale Oil Development Requires Large Number of Wells**
US Tight/Shale Oil Basins

An overview

Fabián Vera (FVR)
Reservoir Engineer | Unconventional Resources Team
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