The Peak in World Oil Supply

Dr. Peter R. A. Wells

September 2008
Acknowledgements

- **Data Sources**
  - IHS – crude oil field data (except USA)
  - International Oil Scouts Association (USA)
  - Our own database and analyses for oil fields (Iran, Iraq, Saudi Arabia)
  - IEA, EIA, BP, UK DTI, NPD, government agencies in Australia, Canada, USA (MMS, states of California, Oklahoma, Texas, Ohio, Louisiana etc)
  - Permission to publish analysis derived from the IHS database
Is growth in oil consumption sustainable?

Data from BP Statistical Review of World Energy, EIA, IEA and CERA
Are Asian aspirations realisable?

Data from BP Statistical Review of World Energy and UN
What do we mean by “Oil” or “liquids”?

- **Crude oil**: including condensate produced with crude oil at the separator
- **Natural gas liquids (NGLs)**: natural gas plant liquids (NGPLs) produced from associated and non-associated gas fields and condensate produced from non-associated gas fields
- **Tar sands**: Syncrude/bitumen extracted from tar sands
- **GTL and CTL**: Liquids produced in gas-to-liquids and coal-to-liquids plants
- **Liquid biofuels**: ethanol, biodiesel etc.
- **Shale oil**: oil extracted from oil shale
- **Other hydrocarbon liquids**: orimulsion, MTBE etc.
- **Refinery Gains**: Net liquid gains in refining crude oil due mainly to hydrogenation
Components of supply

Historical production data from our own database derived from EIA, IEA, BP Statistical Review of World Energy and national publicly available databases

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Components of crude oil

Historical production data from our own database derived from EIA, IEA, BP Statistical Review of World Energy and national publicly available databases

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World liquids supply model

Produced to maximum with no long term spare capacity

Spare capacity

Spare capacity production

We need forecasts for each of these components with uncertainties

OPEC crude oil

Non-OPEC liquids

Swing producers

Demand

capacity

Non-OPEC crude oil

NGLs (Kuwait, Saudi Arabia)

Refinery gains

Can. Tar sands

GTL

CTL

Biofuels

Shale oil

NGLs*

Refinery gains

Produced to maximum with no long term spare capacity

We need forecasts for each of these components with uncertainties

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Not just oil in the ground ... 

Recoverable reserves at the marginal cost of supply in 2007: ~3,000 billion barrels

Oil-in-place, 2007: ~8,000 to 9,000 billion barrels

"costs" – capital, operating costs, fiscal regime etc.

Canadian tar sands ~$60/b
Political/economic issues and interactions

- **OPEC**
- **Non-OPEC**
- **Unconventionals**

*Unconventional liquids: NGLs, Gas-to-Liquids, Coal-to-Liquids, Canadian tar sands, biofuels, oil shale*

Spare Capacity

Excess spare capacity weakens oil price and can reduce supply at the margin

Insufficient spare capacity leads to high oil prices and demand destruction

Balance is affected by long lead times in supply projects 5-15 years and, ultimately, the finite nature of supply

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Price floor set by the needs of the Saudi Arabian budget
Components of future crude oil production
(billion barrels)

- Remaining discovered IHS+ databases: 1,111 billion barrels
- Tar sands: 445 billion barrels
- Future exploration: ?
- Enhanced oil recovery: ?
- Produced to end 2007: 864 billion barrels
Future Exploration Success

**USGS/CERA**
- 3 x Saudi Arabia??
- 45% of past discoveries??
- 150 years to 2,000 bln b, but only 30 years to 900 billion b??
- Requires discovery rate of 36 bln b/year – Only achieved 12 bln b/year between 1995 and 2007

**Neftex**
- 1 x Saudi Arabia
- 15% of past discoveries
- Requires discovery rate of 13 bln b/year (2008 to 2020) declining to 5 bln b/year in 2030
Future exploration success - based on USGS/CERA view

Raw field reserves data and exploration success history for OPEC, FSU and rest of non-OPEC from IHS and for USA from the International Oil Scouts Association

Forecast exploration success from our Monte Carlo simulator

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World – future exploration success – our view

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Improved Oil Recovery (IOR)

Enhanced Oil Recovery

- Additional reserves extracted
- Technologies: Miscible non hydrocarbon gas (CO₂, N₂) floods, thermal, chemical

AIM is to raise and extend production BY increasing reserves

“Field Upgrades”

- Oil pulled forward from the tail – “accelerated” no reserves added
- Technologies: Horizontal wells, multilateral wells, MRC wells, smart wells, smart fields, gas lift, pumps, fracturing

AIM is to recover more of the oil profitably - MAY increase reserves
Major New Technologies take time

• Horizontal wells were first drilled in 1929
• Early 1980s, USSR developed drilling technologies for long radius wells making them widely applicable
• In 2000, 24,000 horizontal wells were drilled
• Technology took ~15-20 years to become widespread
• If it is not under development today, it will not have much impact until after 2025
USA experience with Enhanced Oil Recovery (EOR)

- Thermal (steam injection)
- Miscible non-hydrocarbon gas injection (CO₂, N₂ injection)
- Chemical floods
USA experience of EOR – specific to field, reservoir, oil type, location

- **Thermal/Steam**: Heavy oils in good reservoirs above 900 metres depth – thermal methods such as steam injection can increase reserves considerably (add up to 40% of OIIP to recovery) (California, Oman, some Persian Gulf fields, Venezuela (not tar sands))

- **CO₂**: Light to medium oils in poor reservoirs (few fractures) – miscible non-hydrocarbon gas injection (CO₂, N₂) can add 8-17% of OIIP to recovery to reserves (Permian Basin USA, some Persian Gulf oil fields)

- **No Gains**: Light-medium oils in good quality reservoirs achieve high recovery rates (>65%) from water or hydrocarbon gas injection – EOR cannot add much to recovery and reserves (North Sea, West African and Gulf of Mexico fields)
Global EOR potential (existing fields) dominated by OPEC….

- CO₂ EOR potential 160-350 billion barrels
- Thermal EOR potential 60-120 billion barrels

EOR potential 220 – 340 - 470 billion barrels

(CERA: 592 billion barrels)
World (potential) crude oil volumes...

(billion barrels)

- 1,111 Remaining discovered IHS+ databases
- 290 Future exploration
- 445 Tar sands
- 220-470 Enhanced oil recovery
- 864 Produced to end 2007

TOTAL conventional crude oil, 2,600
Simulation Model approach to crude oil forecasting

- If a field has not been discovered it cannot be produced or enhanced – model starts with the discovery history (proven + probable (2P) reserves and date of discovery)

- Model is built up using individual fields –
  - Real discovered fields in the IHS or other databases discovered to the end of 2007 (10s of thousands)
  - Modelled yet-to-be-discovered fields based on forecast exploration success after 2007 (10s of thousands)

- Preserves the granularity of individual oil fields throughout the forecast and continuity of methodology
Simulation Model approach to crude oil forecasting

Past discoveries

Future discoveries

<table>
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<tr>
<th>Country</th>
<th>Field</th>
<th>Date discovery</th>
<th>2P reserves</th>
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<tbody>
<tr>
<td>A</td>
<td>1</td>
<td>1890</td>
<td>500</td>
</tr>
<tr>
<td>B</td>
<td>2</td>
<td>1910</td>
<td>45</td>
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<th>Country</th>
<th>Field</th>
<th>Date discovery</th>
<th>2P reserves</th>
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</thead>
<tbody>
<tr>
<td>A</td>
<td>1</td>
<td>2008</td>
<td>900</td>
</tr>
<tr>
<td>B</td>
<td>2</td>
<td>2009</td>
<td>320</td>
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Field size

Probability distributions for time between discovery and production

Field size

Probability distributions for shape of production profile

+ ……10s of thousands of fields

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Neftex
Simulation Model approach to crude oil forecasting

- A simulation model provides a direct link between exploration success/Enhanced Oil Recovery (EOR) and production on the scale of individual oil fields.
- Uncertainties in input are properly carried through and expressed as uncertainties in the forecast.
- If a calibrated simulation model can replicate historical production closely then we can have confidence in its forecasts (history match).
- To test the model, we have history matched:
  - USA
  - Non OPEC less USA, less FSU (ROW)
  - FSU
USA Exploration Success History

Derived from raw data for the USA provided by the International Oil Scouts Association

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History matching - USA

- Derived from raw data for the USA provided by the International Oil Scouts Association
- Actual production profile from our own database

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Non-OPEC – Exploration Success

Raw field reserves data and exploration success history for FSU and non-OPEC less FSU and USA from IHS

Raw field reserves and exploration success history for the USA from the International Oil Scouts Association

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History Matching – Non-OPEC

Raw field reserves data and exploration success history from IHS and International Oil Scouts Association
Actual production profile from our own database
Forecast model profile from the Monte Carlo Simulation

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Most non-OPEC, non FSU oil fields are offshore – rapid declines...EOR??

Derived from raw data provided by IHS
Yet-to-find (billion barrels)

<table>
<thead>
<tr>
<th></th>
<th>P95</th>
<th>Mean</th>
<th>P5</th>
</tr>
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<tbody>
<tr>
<td>Our</td>
<td>60</td>
<td>157</td>
<td>270</td>
</tr>
</tbody>
</table>

90% confidence band

Forecast from our Monte Carlo Simulator

Raw field reserves data and exploration success history for FSU and rest of non-OPEC from IHS and for USA from the International Oil Scouts Association

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Non-OPEC – at peak! – after 2008, demand growth must be met by increased capacity in OPEC or unconventional liquids

Produced to end 2007: 625 billion barrels
Future production: 530 billion barrels

Raw field reserves data and exploration success history for FSU and rest of non-OPEC from IHS and for USA from the International Oil Scouts Association
Forecast from Monte Carlo simulator
Raw field reserves data and exploration success history for FSU and rest of non-OPEC from IHS and for USA from the International Oil Scouts Association

Forecast from Monte Carlo simulator
OPEC’s Dilemma ....
How much new capacity and by when?

Demand (~87)

Crude oil

Spare capacity
(1.5)

ref. gain (0.9)

OPEC (32.0)

Non-OPEC (55.3)

NGLs

Can. Tar sands (1.6)

Biofuels (1.3)

CTL, GTL, ref. gain etc (1.6)

Crude oil

41.9

10.2

31.0

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<table>
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<tr>
<th>Issues and constraints in capacity expansion – decision making is slow</th>
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<tr>
<td><strong>-ve</strong></td>
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<tr>
<td>National heritage</td>
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<tr>
<td>Timing of investment</td>
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<tr>
<td>High prices – why expand to reduce prices?</td>
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<tr>
<td>Politics – Iran, Iraq, Venezuela, Nigeria, Kuwait</td>
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<tr>
<td>Capability and openness</td>
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<tr>
<td>Old fields/reserves</td>
</tr>
</tbody>
</table>
OPEC – our forecast of exploration success

(billion barrels)
P95  mean  P5
86    96    120
(2008 to 2050)

Raw historical data from IHS
Forecasts by Neftex

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The large OPEC fields are mature (fields >2 billion barrels reserves)

Includes data provided by Petroconsultants S.A. (data copyright 2008 Petroconsultants S.A.)
OPEC – issue is not reserves but maximum sustainable rate and pace of getting there

Maximum production capacity determined by maximum production from primary and secondary recovery from existing producing fields

EOR, development of discovered fields and exploration extend plateau

(EXCEPTIONS:- Nigeria, Libya, Algeria)
Saudi Arabia – Forecast Production Capacity

- Ghawar
- Abu Sa’fah
- Berri EOR
- Manifa
- Safaniya
- Shaybah EOR
- Other fields including Divided Zone

Ghawar EOR
- Abu Sa’fah EOR
- Khurais complex
- Marjan
- Safaniya EOR
- Zuluf

Abqaiq
- Berri
- Khursaniyah cluster
- Qatif
- Shaybah
- Khafji

Total remaining: 278 billion barrels

Production to end 2007
115 billion barrels

Raw historical data and most primary and secondary recovery reserves from IHS and forecast from Neftex

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Iran – forecast production capacity

Production to end 2007
61 billion barrels

Total remaining:
90 billion barrels

Raw historical data and most primary and secondary recovery reserves for conventional crude from Khazar Associates
Forecasts by Neftex

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Ahwaz
Marun
Gachsaran
Agha Jari

Undeveloped discoveries
Azadegan
Iraq – Forecast Production Capacity

Total remaining: 177 billion barrels

Production to end 2007
31 billion barrels

Raw historical data and most primary and secondary recovery reserves from and forecast from Neftex

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Venezuela – forecast production capacity

- **Orinoco tar sands**
- **Discovered and yet-to-find fields**
- **Other existing fields**
- **Lagunillas, Tia Juana, Bachaquero, Cabimas**

**Total remaining:** 322 billion barrels

**Production to end 2007:** 58 billion barrels

Raw historical data and most primary and secondary recovery reserves for conventional crude from IHS
Orinoco tar sands from project data
Forecasts by Neftex
Includes data provided by Petroconsultants S.A. (data copyright 2008 Petroconsultants S.A.)
OPEC - Enhanced Oil Recovery forecast

Forecasts by Neftex

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OPEC – Forecast Production Capacity

Raw historical data and most primary and secondary recovery reserves from IHS and forecast from Neftex
Includes data provided by Petroconsultants S.A. (data copyright 2008 Petroconsultants S.A.)
Challenges for OPEC

• Balance creation of capacity to “guesstimate” of future call on OPEC

• Call on OPEC is the difference between two large unknowns – non-OPEC liquids (from crude oil to biofuels) and demand

• Extensive investment of capital and expertise will be required just to maintain current production capacity

• Additional capital to create new capacity is available but decision making is necessarily cautious

• Major potential for new capacity is in four countries:
  – **Saudi Arabia** (potential 2-3 million b/d) – underway but technical risks
  – **Iran** (1-2 million b/d) - stymied by politics
  – **Iraq** (4-5 million b/d) - major political/security risks
  – **Venezuela** tar sands (>2 million b/d) – resource nationalism
High Impact potential new production capacity is also high risk

Impact on capacity, million b/d

Qatar

Kuwait

Iran

Venezuela

Iraq

UAE

Libya

Angola

Nigeria

Saudi Arabia

Algeria

Ecuador

Political risks and constraints

Nigeria – IOCs active

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About or below ground risks?

<table>
<thead>
<tr>
<th>Geological constraints</th>
<th>Political constraints</th>
</tr>
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<tbody>
<tr>
<td>&quot;Below ground&quot;</td>
<td>low</td>
</tr>
<tr>
<td>High</td>
<td>USA, ROW, Qatar, Libya, Angola</td>
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Natural Gas Liquids (NGLs)

Historical data from our own database based on EIA, IEA, BP Statistical Review of World Energy and national databases

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“Non-crude oil” liquids

- Oil shale
- Other liquids
- Biofuels
- Coal-to-Liquids
- Gas-to-Liquids
- Canadian tar sands
- NGLs

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Peak liquids production: 98-105 million b/d
Between: 2017 and 2023

CERA Asian Phoenix (2006) 121 million b/d
IEA Ref. Case (2007) 116 million b/d
World liquids supply base case – 121-116 million b/d in 2030?

- CERA Asian Phoenix (2006) 121 million b/d
Hard to make up for 40 years of declining exploration success

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Forecast exploration success from our Monte Carlo simulator

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OPEC - Crude Oil

Change in production

Change in capacity

World crude oil peaks

Real oil price, dated Brent, $/b

year-on-year change, b/d

Non OPEC
Saudi Arabia
Iraq
Rest of OPEC
Oil price


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Liquids balance

Change in production

Change in capacity

World liquids peaks

year-on-year change, b/d

Real oil price, dated Brent, $/b

World crude oil

NGLs

Canadian tar sands

Biofuels

Other unconventional

Oil price

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Nefte
Mitigation? – the upper limit to OPEC production capacity constrains scope for a demand-led “rescue”

Low demand case – annual increment 850,000 b/d

Deferred OPEC production
Mitigation - Substitution within the crude oil system

- Liquid fuels are uniquely efficient for transportation – high energy per volume
- 75% of crude oil consumed in the USA is used for transportation (motor gasoline, jet fuel and diesel)
  - 25% is 5 million b/d!
- Only ~60% crude oil worldwide used for transportation
  - 40% is 25 million b/d - mainly heavy end of the barrel used for space heating, industry and power generation
- Scope for substituting gas and nuclear in power generation and natural gas liquids in industrial uses
- Major investment in refining and refining technology and access to cheap, clean hydrogen – nuclear power for hydrogen and process energy

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Mitigation - substitutions... electricity replaces gasoline (plug ins, hydrogen fuel cells) – nuclear!

- Solar-wind-tidal
- hydrogen
- plug-ins
- hybrids

- diesel
- Sugar cane ethanol
- Clean coal power

- Gas from Russia
- Gas-to-liquids
- Canadian tar sands
- Coal-to-liquids
- EU biodiesel
- Corn ethanol

Global Warming

Security of Supply

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Mitigation - Natural gas will outlast liquids

...Compressed natural gas (CNG)
Back up slides
Shale Oil

- Environment (GHG, land)
- Infrastructure
- Capital cost
- Gas, water resources
- Unproven technology

Forecast range
- Rand
- US DOE/DOD
- Time-Shifted Canadian Tar Sands
- EIA
- Base Case Forecast

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Coal-to-Liquids

Attractive option for countries with large cheap coal reserves and high imports of conventional crude oil – India, China, USA

Competitive with conventional oil products at >$40/b
Gas-to-liquids

Not for stranded gas without major technology breakthroughs due to high cost and need for economies of scale

Limited by high supply cost and competition with more profitable export alternatives for gas - LNG