A Future for Fossil Fuels?

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http://pesd.stanford.edu/
Electrification of the U.S. Economy

World Oil Prices

chart of crude oil prices since 1861
US dollars per barrel

World events

- Russian oil exports begin
  - Pennsylvanian oil boom
- Sumatra production begins
  - Discovery of Spindletop, Texas
- Fears of shortage in USA
- Growth of Venezuelan production
- East Texas field discovered
- Loss of Iranian supplies
- Iranian revolution
- Netback pricing introduced
  - Iraq invaded Kuwait
  - Yom Kippur war

bp statistical review of world energy 2002

1861-1944 US average.
1945-1985 Arabian Light posted at Ras Tanura.
1986-2001 Brent spot.

$ money of the day  $ 2001
Proved Oil Reserves, 2004 (R/P ratio)

Source: BP Statistical Review of World Energy. 2005
FUTURE OIL RESOURCES AND COUNTRY OIL CONSUMPTION
(September, 2005)

Future Oil (MMBO)
USGS - 2000 data
(without USA)

- < 20 MMBO
- 20 - 200 MMBO
- 200 - 2000 MMBO
- 2000 - 3000 MMBO
- 3000+ MMBO

Country by Oil Consumption
(Thousand Barrels/Day)
EIA - 2003 data

Future Oil = Remaining Reserves + Undiscovered Resources

Source: USGS

Energy Information Administration (EIA) WEB site (2003 data)
Hubbert’s Peak: United States

Est. World Oil Production 1850-2020

Lower Curve assumes 1.8 trillion barrels
Upper curve assumes 2.1 trillion barrels

World Oil Consumption and Production

World Oil Consumption and Production:

Historical and Selected Projections

- ASPO (capacity)
- ASPO: Association for the Study of Peak Oil (2005)
- EIA: Energy Information Administration (2005)
- IEA: International Energy Agency (WEO, 2005)

Total World Consumption (BP)

Total Developing Country Consumption (BP; EIA projections to 2025 extrapolated to 2030)

ASPO: Association for the Study of Peak Oil (2005)
EIA: Energy Information Administration (2005)
IEA: International Energy Agency (WEO, 2005)
Shares Of Liquid Reserves ordered by controlling firm (2003)

Figure 2. Data Source: Energy Intelligence (2005)
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Colors represent ownership of the oil and gas companies:
- Red: 90%-100% owned by state
- Orange: Up to 35% owned by state
- Blue: Not owned by state

#### Combined Oil and Natural Gas Reserves (in billions of barrels of oil equivalent)

<table>
<thead>
<tr>
<th>COMPANY</th>
<th>HOME COUNTRY</th>
<th>OUTPUT, MILLIONS OF BARRELS PER DAY</th>
<th>COMBINED OIL AND NATURAL GAS RESERVES, IN BILLIONS OF BARRELS OF OIL EQUIVALENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saudi Aramco</td>
<td>Saudi Arabia</td>
<td>10.3</td>
<td>302.5</td>
</tr>
<tr>
<td>National Iranian Oil Co.</td>
<td>Iran</td>
<td>5.3</td>
<td>301.7</td>
</tr>
<tr>
<td>Gazprom</td>
<td>Russia</td>
<td>10.0</td>
<td>198.3</td>
</tr>
<tr>
<td>Iraq National Oil Council</td>
<td>Iraq</td>
<td>1.4</td>
<td>135.6</td>
</tr>
<tr>
<td>Qatargas</td>
<td>Qatar</td>
<td>n/a</td>
<td>133.4</td>
</tr>
<tr>
<td>Kuwait Petroleum Co.</td>
<td>Kuwait</td>
<td>2.4</td>
<td>109.4</td>
</tr>
<tr>
<td>Petróleos de Venezuela</td>
<td>Venezuela</td>
<td>3.2</td>
<td>105.5</td>
</tr>
<tr>
<td>Adnoc</td>
<td>U.A.E.</td>
<td>2.0</td>
<td>80.1</td>
</tr>
<tr>
<td>Nigerian National Petroleum Co.</td>
<td>Nigeria</td>
<td>2.3</td>
<td>40.9</td>
</tr>
<tr>
<td>Sonatrach</td>
<td>Algeria</td>
<td>3.2</td>
<td>38.4</td>
</tr>
<tr>
<td>LHY NOC</td>
<td>Libya</td>
<td>n/a</td>
<td>31.3</td>
</tr>
<tr>
<td>Rosneft</td>
<td>Russia</td>
<td>n/a</td>
<td>28.1</td>
</tr>
<tr>
<td>Petronas</td>
<td>Malaysia</td>
<td>1.5</td>
<td>25.6</td>
</tr>
<tr>
<td>Exxon Mobil</td>
<td>U.S.</td>
<td>4.4</td>
<td>23.1 (14th)</td>
</tr>
<tr>
<td>Pertamina</td>
<td>Indonesia</td>
<td>1.6</td>
<td>21.6</td>
</tr>
<tr>
<td>Lukoil</td>
<td>Russia</td>
<td>1.7</td>
<td>20.6</td>
</tr>
<tr>
<td>BP</td>
<td>U.K.</td>
<td>3.7</td>
<td>19.1</td>
</tr>
<tr>
<td>PetroChina</td>
<td>China</td>
<td>4.3</td>
<td>18.8</td>
</tr>
<tr>
<td>Royal Dutch/Shell</td>
<td>U.K. and Netherlands</td>
<td>4.0</td>
<td>15.7</td>
</tr>
<tr>
<td>Yanes</td>
<td>Russia</td>
<td>1.7</td>
<td>12.7</td>
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<tr>
<td>Chevron</td>
<td>U.S.</td>
<td>2.6</td>
<td>12.4</td>
</tr>
<tr>
<td>Petrobras</td>
<td>Brazil</td>
<td>2.1</td>
<td>11.9</td>
</tr>
<tr>
<td>Total</td>
<td>France</td>
<td>2.6</td>
<td>11.5</td>
</tr>
<tr>
<td>SiburKhimgas</td>
<td>Russia</td>
<td>1.3</td>
<td>9.0</td>
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</tbody>
</table>

Figures are for 2009, the latest year available.
Oil Production: Worldwide and OPEC

[Graph showing oil production from 1965 to 2003, with separate lines for world production and OPEC production.]

- World Production
- OPEC Production

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Sources of Increased Demand

Growth in World Oil Demand

Source: EIA Short Term Energy Outlook, February 2006
Alcohol Production from Sugar Cane
(thousands of barrels of oil equivalent per day)

Source: MME Energy Balance
Brazil’s Oil Production & Consumption over time

Source: BP 2004
Electrification of the U.S. Economy

US Gas Prices Linked to Oil Products

Source: US EIA, energycentral.com
Gas Resources and Potential Demand

White: where the lights are on, satellite imagery
Blue → Red: Gas resources, with increasing size (USGS)
North American Natural Gas Production & Consumption 1980 – 2025

- North America Consumption (DOE/EIA)
- North American Production (DOE/EIA)
- Consumption Projection (Deutche Bank, Sieminski)
LNG Transport
Trinidad’s Atlantic LNG Cargoes Already Follow US-Spain Price Differential

Volume

USA
Spain

1,000 cubic meters LNG

$/MMBtu

Henry Hub - Spain Price Differential

Source: Gas Strategies Consulting Ltd.
US LNG Import Capacity Utilization

Source: US EIA
European Gas Imports: Russia & Algeria

- % Algerian gas
- % Russian gas

Countries: Austria, Bulgaria, Czech Republic, Finland, France, Germany, Hungary, Italy, Poland, Romania, Slovakia, Spain, Turkey, Others, All Europe.
US Combined Cycle Capacity Factors: Impact of Overbuilding and High Fuel Prices

Heat Rates Span Wide Range
2004 (1st 6 months) - Btu/kWh
< 7,000 to >9,000
U.S CC average: 8,400

A Coal Mine in Wyoming
The Navajo power plant, Page, AZ
Growth in Electricity from Coal: United States

**Figure 5. Electricity generation by fuel, 1980-2030**

(billion kilowatthours)

<table>
<thead>
<tr>
<th>Year</th>
<th>Natural gas</th>
<th>Nuclear</th>
<th>Renewables</th>
<th>Petroleum</th>
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</thead>
<tbody>
<tr>
<td>1980</td>
<td>1,000</td>
<td>500</td>
<td>100</td>
<td>200</td>
</tr>
<tr>
<td>1995</td>
<td>1,500</td>
<td>700</td>
<td>150</td>
<td>250</td>
</tr>
<tr>
<td>2004</td>
<td>2,000</td>
<td>900</td>
<td>200</td>
<td>300</td>
</tr>
<tr>
<td>2015</td>
<td>2,500</td>
<td>1,100</td>
<td>250</td>
<td>350</td>
</tr>
<tr>
<td>2030</td>
<td>3,000</td>
<td>1,300</td>
<td>300</td>
<td>400</td>
</tr>
</tbody>
</table>

Source: U.S. EIA Annual Energy Outlook 2006
Nuclear Power: A Fresh Start?

Cattenom, France
Tokyo Electricity Demand & Solar Supply Potential

Additional source: Arnulf Gruebler
Exergy Flow of Planet Earth (TW)

Current Global Exergy Usage Rate ~ 15 TW (0.5 ZJ per year)

(1 ZJ = 10^{21} J)

80900/15 = 5393

U.S. Wind Plant Capacity Factors, 2004

Variations of the Earth’s surface temperature for...

- The past 140 years (global)
- The past 1000 years (Northern Hemisphere)
Trends in Fossil Carbon Emissions (Trajectories and Kyoto Commitments)
Trends in Fossil Carbon Emissions
(Trajectories and Kyoto Commitments)
“Carbon Intensity” of the U.S. Economy (1800-1999)

Intensity: grams C per 1990 USD(mer)
Carbon Intensity of Major Economies

Integrated Gasification Combined Cycle (IGCC)

Wabash River Integrated Gasification Combined-Cycle Plant
Coal: Production & Consumption: 1949-2004

Source: EIA