THE WORLD PETROLEUM LIFE-CYCLE
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Abstract

The world oil production peak, we assume, will be a turning point in human history. Our goal is to predict the world peak. To accomplish this goal, we have developed (to our knowledge) a unique new procedure based on oil production data, data analysis, conventional formulas, and heuristic knowledge. It comprises (1) a program, and (2) a method.

The program uses the historic oil production data and predicts by statistical and heuristic techniques future production for the world's 42 top oil-producing nations (each modeled separately), grouped into 7 regions, and the world. The method is to build up a series of forecasts which, taken together, will inevitably converge on the peak. This paper presents the third in this series of forecasts -- designated 'Issue #3.'

The peak production year and the expected ultimate recovery for each nation, seven regions, and the world are given in Table 1. Figure 1 graphs the world oil production life-cycle with the peak in 2006. Table 2 gives similar information for each region. Figures 2-8 graph the life-cycle for each region with peaks from 1985 for North America to 2011 for the Middle East.

Middle East & non-Middle East and OPEC & non-OPEC categories are compared in Table 3. Figure 9 graphs the Middle East & non-Middle East. Figure 10 graphs OPEC & non-OPEC.

Figures 11 and 12 depict by simulation whether or not new oil discoveries can delay the world peak. If so, by how much? Figure 13 is a 'phase diagram' that maps, as it were, our crooked route to the world oil summit. All tables and figures are discussed in the text.

We believe that a 'base-camp' and a series of higher camps must be established before finally ascending to the summit. 'Encircling' we call it, as illustrated by the three forecasts we've made so far. Specifically, the 1996 Issue #1 put the peak in 2005; Issue #2 put it in 2007; Issue #3 (this paper) put the peak in 2006. Of course the peak could occur before 2005 or after 2007. Perhaps 10 camps will be required. Maybe more.

En route to the summit, four predictions that we have made have since proved consistent with trends and events: Asian economic crisis, non-OPEC peak year, world peak inertia, and Caspian dry holes.

All the models are available free on the Internet at http://www.halcyon.com/duncanrc/

Looking ahead: The new forecasting method, we believe, can successfully predict the production life-cycle of any of the fossil fuels, including oil, gas, and coal.

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1. Introduction

The world oil production peak, we assume, will be a turning point in human history. Our major goal is to forecast the all-time world oil peak, not by one heroic effort, but rather by a series of smaller efforts -- much like an experienced team of mountaineers would climb the world's tallest peak.

The main goals of this paper are sevenfold:
(1) Introduce a unique new 'tool' to forecast petroleum production, so-named the 'World Oil Forecasting Program' ('Program') and demonstrate its predicting power, versatility, and utility.
(2) Use it to predict the peak year for each of the world's top 42 oil-nations.
(3) Use it to predict the peak year for each of the world's seven regions.
(4) Use it to predict the peak year for world oil production.
(5) Use it to predict the production peaks and cross-over points of (a) the Middle East and non-Middle East, and (b) OPEC and non-OPEC.
(6) Use it to answer the questions: Can we delay the world oil peak? If so, by how much? What is the relationship between new production and peak delay?
(7) Describe how the 'World Oil Forecasting Method' ('Method') uses the Program to produce a series of forecasts which, taken together, will inevitably converge on the world peak. Show how a 'phase-diagram' ensures the consistency and convergence of our Method.

Some definitions will be useful. 'Petroleum' and 'oil' are used synonymously to include crude oil, shale oil, oil sands and natural gas liquids (NGLs). EUR means expected ultimate recovery. 'Qi' means cumulative production to year i. 'RR' means remaining reserves. 'G' means billion (10^9). 'b' means barrels.

2. This Study

Presently the world's favorable petroleum geology is unequally divided up among some 182 nations, of which the top 42 produce more than 98% of the world's oil; the next 70 nations less than 2%; the remaining 70, none. The top 42 producers are detailed in Table 1. The historic production data is from the BP Statistical Review of World Energy (1961-1998). The forecasts were generated by the World Oil Forecasting Program, described later. The numbers in Table 1 are the bedrock of our study.
Table 1. Petroleum Production Summary: Nations and World. Columns, 1-to-r:
Nation’s number and name. Production peak years, some firmly established; others forecast, for 42 nations representing more than 98% of total world oil production. Peak production rate, 1997 rate, and forecast 2040 rate Cumulative production through 1997, forecast cumulative production through 2040, and expected ultimate recovery (EUR). Percent fall from peak to 2040. Remaining reserves. Far right column: The telling ratio of the remaining reserves of each nation to the remaining reserves of all 42 nations. Saudi Arabia alone controls 16.3% of the world’s future oil supply. Notes: SI units are used in this study where ‘G’ means billion ($10^9$), and ‘b’ means barrels. '*' Designates OPEC member. '+' Indicates that relevant figures are increased by 2% top account for nations omitted from this list.
Table I Discussion: Columns A and B give each nation's number and name. The bold horizontal lines divide the nations into 7 regions (discussed later). Column C gives each nation's peak year; some are well established, others forecast. Fourteen of the 42 nations (33%) have passed their peaks. Most notable are the USA in 1970 and the FSU in 1987. In some cases, of course, future production may rise to surpass the old peaks; examples are the UK and Syria. However, the downward slide is likely permanent for several nations; examples are the USA, Libya, and Romania. Note too that 28 of the 42 nations (67%) have not yet reached their peaks. No doubt the last nations to peak will be in the Middle East, e.g. Iraq 2010, Saudi Arabia 2011, UAE 2017, and Kuwait 2018.

Column D gives each nation's peak production rate. Increasingly it appears that the FSU will retain the all-time production record at 4.62 Gb/year. However, Saudi Arabia is may soon exceed the USA for second place. At the other extreme, Tunisia is forecast to peak at 0.04 Gb/year, less than 1% of the FSU's towering peak.

Column E lists the 1997 production rate for each nation. Note that in 1997 the top four nations together (Saudi Arabia, USA, FSU, and Iran) produced over 40% of the world's oil. In contrast, the bottom four nations (Peru, Italy, Tunisia, and Papua New Guinea) managed only a meager 0.05%. Column F forecasts the national production rates for 2040.

Column G records each nation's cumulative production through 1997 (Q1997). Motto: "The faster you pump, the sooner you peak." For example, the USA in 1997 led cumulative production with 200.4 Gb, and it was also first to peak in 1970 (tied with Libya). Column H forecasts the cumulative production through year 2040 (Q2040). Column I forecasts each nation's expected ultimate recovery (EUR).

Columns J through L provide an overview of future trends. Column J predicts the percent decline in production for each nation from its peak to year 2040. Note that the maximum decline is Mexico's 92%; the minimum decline is Kuwait's 44%. But by 2040 all nations will be in steep decline. Column K forecasts the remaining reserves (RR) for each nation (RR = EUR – Q1997). Saudi Arabia owns the lion's share of reserves at 189.4 Gb. In contrast, Papua New Guinea is running dry with a scant 0.8 Gb.

Column L, far right, gives the revealing ratio of each nation's remaining reserves to the 42 nation's remaining reserves. These ratios are useful indicators of each nation's importance to the future oil supply. But caution is needed. Example: In column L, the USA's ratio is 6.1% (= 70.8/1160). Kuwait ratio is 6.3% (= 73.6/1160), close to that of the USA. However, direct comparison of the ratios is complex because, for instance, the USA has null surplus oil for export but vast military power. Just the opposite, Kuwait has vast surplus oil for export but null military power. Nonetheless, the ratios in column L are telling. And it is no surprise that Saudi Arabia's oil reserves at 16.3% rank first in the world.

With the data and forecasts of the world's top 42 oil producers handy in Table 1, we now transform some of the numbers into an eye-friendly overview in Figure 1 following.
Figure 1. World, OPEC, and non-OPEC Oil Production Life Cycles. Oil production curves for years 1960-2040 are graphed. Years 1960-1997 are historic data. Years 1998-2040 are forecast by use of the World Oil Forecasting Program. World production peaks in 2006, key to this study (curve 1, a.k.a. the ‘base-line’ curve), OPEC and non-OPEC production are shown (curves 2 and 3) for comparison to the world curve. The cross-over point when OPEC production exceeds non-OPEC production is 2007 (discussed later in Section 4 and detailed in Figure 10).

Figure 1 shows three oil production curves ranging from 1960 to 2040. Historic production data is plotted from 1960 through 1997, and forecast values from 1998 through 2040. Curve 1 shows that production of the 42 top nations was 26.0 Gb/year in 1997 and it is forecast to peak in 2006 at 31.0 Gb/year, thereafter decreasing to 11.5 Gb/year in 2040, a fall of 63% in 43 years. OPEC and non-OPEC oil production (curves 2 and 3) are also shown for comparison to world production. They will be discussed in a later section.

We have grouped the world's oil-producing nations into seven oil-producing regions.

3. Seven Oil Regions

The top 42 oil-producing nations are grouped into seven geographical regions to get a better, more general picture of the world oil situation. The regions are: 1 North America, 2 South & Central America, 3 Europe, 4 Former Soviet Union, 5 Middle East, 6 Africa, and 7 Asia Pacific. The historic production data, production forecasts, and key indicators for each region are summarized in Table 2.
**Table 2. Seven Oil Regions.** Columns, 1-to-r: Region number and name. Peak year (data or forecast), and peak rate. Production in 1997, forecast in 2040. Cumulative production through 1997 ($Q_{1997}$), forecast cumulative production through 2040 ($Q_{2040}$), and expected ultimate recovery (EUR). Production decline from peak to 2040. Remaining reserves (RR). Far right column: The revealing ratio of the remaining reserves for each region to the remaining reserves for all 42 nations. NB: The Middle East now controls 46% of the world's future oil supply. (The bold horizontal lines in Table 1 identify the nations in each of the 7 regions.)

<table>
<thead>
<tr>
<th>Region</th>
<th>Year</th>
<th>Peak</th>
<th>1997</th>
<th>2040</th>
<th>1997</th>
<th>2040</th>
<th>EUR</th>
<th>Pk Yr</th>
<th>Rem</th>
<th>RR,42N</th>
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<tr>
<td>North America</td>
<td>1985</td>
<td>5.6</td>
<td>5.2</td>
<td>0.9</td>
<td>250.4</td>
<td>384</td>
<td>392</td>
<td>-84%</td>
<td>142</td>
<td>12%</td>
</tr>
<tr>
<td>So. &amp; Cent. America</td>
<td>2005</td>
<td>2.7</td>
<td>2.3</td>
<td>1.2</td>
<td>74.2</td>
<td>167</td>
<td>178</td>
<td>-56%</td>
<td>104</td>
<td>9%</td>
</tr>
<tr>
<td>Europe</td>
<td>2000</td>
<td>2.4</td>
<td>2.4</td>
<td>0.4</td>
<td>32.7</td>
<td>95</td>
<td>98</td>
<td>-83%</td>
<td>65</td>
<td>6%</td>
</tr>
<tr>
<td>Former Soviet Union</td>
<td>1987</td>
<td>4.6</td>
<td>2.7</td>
<td>1.4</td>
<td>133.4</td>
<td>248</td>
<td>265</td>
<td>-70%</td>
<td>131</td>
<td>11%</td>
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<td>Middle East</td>
<td>2011</td>
<td>12.1</td>
<td>7.9</td>
<td>5.8</td>
<td>218.7</td>
<td>664</td>
<td>747</td>
<td>-52%</td>
<td>528</td>
<td>46%</td>
</tr>
<tr>
<td>Africa</td>
<td>2004</td>
<td>3.3</td>
<td>2.8</td>
<td>0.9</td>
<td>68.4</td>
<td>161</td>
<td>165</td>
<td>-73%</td>
<td>97</td>
<td>8%</td>
</tr>
<tr>
<td>Asia Pacific</td>
<td>2002</td>
<td>2.9</td>
<td>2.7</td>
<td>0.9</td>
<td>58.4</td>
<td>145</td>
<td>150</td>
<td>-69%</td>
<td>92</td>
<td>8%</td>
</tr>
<tr>
<td>42 Nations</td>
<td>2006</td>
<td>31.0</td>
<td>26.0</td>
<td>11.5</td>
<td>836.0</td>
<td>1865</td>
<td>1996</td>
<td>-63%</td>
<td>1160</td>
<td>100%</td>
</tr>
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</table>

**Table 2 Discussion:** Columns A and B give each region's number and name. Column C gives the region's peak year (some historic, others forecast). North America was first to peak in 1985, followed by the FSU in 1987. Then four regions peak in quick succession: Europe 2000, Asia Pacific 2002, Africa 2004, and South & Central America 2005. Last to peak is (you guessed it!) the oil colossus Middle East in 2011.

Column D gives the magnitude of each region's oil peak. The Middle East towers at 12.1 Gb/year, compared to Europe's modest 2.4 Gb/year. Column E records the 1997 oil production rates, wherein the Middle East ranks first at 7.9 Gb/year. Column F forecasts the 2040 production rate for each region. The Middle East by 2040, with over 50% of the world's production, is likely to be the world's only oil-exporting region.

Column G records each region's cumulative production through 1997 ($Q_{1997}$). North America is still leading, but the Middle East is closing in fast. Column H forecasts cumulative production through 2040 ($Q_{2040}$) when the Middle East will have exploited 664 Gb of its original endowment, or nearly twice that of ‘second place’ North America. Column I forecasts the expected ultimate recovery (EUR) for each region. The Middle East has a fat 747 Gb. Europe a lean 98 Gb.

Columns J through L give an overview of future oil trends. Column J forecasts each region's decline in production from its peak to year 2040. North America falls 84%. The Middle East 52%. The average is 63%. Column K gives each region's remaining reserves (RR). At the start of 1998 the Middle East had a hefty 528 Gb remaining. Europe a slim 65 Gb. Column L gives the telling ratio of the remaining reserves for each region to the remaining reserves for all 7 regions. At present the Middle East has 46% of the world's remaining reserves. And with only 4% of the world's population, the Middle East has even a much larger percentage of the world's remaining oil surplus (e.g. perhaps 70-80%), potentially available for future international export.

The world's seven oil-producing regions are graphed in Figures 2-8 following.
**Figure 2. North America Oil Production.** This includes Canada, United States, and Mexico. United States passed its peak in 1970, but the later development of the offshore Mexican fields along with Canadian exploration successes moved the regional peak to 1985. This region, dominated by the United States, reached its peak the earliest of the seven regions. The United States was the first nation to substantially exploit its oil resources, and reach its production peak. This early exploited abundant and cheap oil helped to rapidly propel the United States to its high 'oil standard' of living enjoyed today, but maintained now only by increasing oil imports.

**Figure 3. South and Central America Oil Production.** This includes all countries south of Mexico. We forecast that the recent growth trend will continue to the all-time peak in 2005, due to recent successes and developments along the eastern margin of the Andean fold belt, the privatization and increased activity in the Argentine oil industry, and more aggressive development programs in Venezuela, which country now accounts for over 53% (Table 1) of this region's production.
**Figure 4. Europe Oil Production.** This region's production is now chiefly from the North Sea, where Norway and United Kingdom (Great Britain) are dominant. Other European oil production is minor. The curve reflects a steady, orderly growth, and then a decline, with the regional peak at 2000. Decision by the Norwegian Government to limit production in order to flatten and lengthen their production peak, may move the 2000 peak to slightly later. Countering this move however, United Kingdom production declined during 1996 and 1997.

**Figure 5. Former Soviet Union (FSU) Oil Production.** Since the break-up of the USSR, this region now has diverse political and economic agendas. The previous production peak reached by the unified USSR in 1987 seems unlikely to be surpassed. The Russian oil fields are in an aging phase. Further, the now independent republics are not coordinated in their efforts to secure needed financing and technology for oil development, and will not achieve a unified peak production time. We do project a secondary peak in the year 2009, but it will be much lower than the earlier 1987 USSR peak.
**Figure 6. Middle East Oil Production.** This region holds the bulk (46%, Table 2) of the world's remaining oil reserves. Because of political and religious considerations, and the production quota system which is met with intermittent and uneven success, production here is the most difficult of the seven regions to forecast. However, the practical political necessity for these governments to continue to finance their variety of social programs, combined with the rapidly growing population, suggest that future production will continue to approach the classic bell-shaped curve of a finite resource. Even allowing for some intermittent production distortions, such as the United Nation's oil sale curtailment imposed on Iraq, the curve seems established long enough to be projected with some confidence to 2040. It is clear this region will be the last to reach peak production; our forecast is 2011. And by the year 2020, when oil prices are likely to be much higher relative to today's prices, this region will have the bulk of the world's remaining oil reserves -- a large international economic and political advantage.

**Figure 7. Africa Oil Production.** Order of importance in this region is Nigeria, Libya, Algeria, Egypt, and Angola. Other production is minor. This rank of importance is not likely to change, except that Angola could move up ahead of Egypt. Therefore, the production curve data controls already in place probable will not be significantly altered. With the peak year forecast at 2004, the curve is already well established.
Figure 8. Asia Pacific Oil Production. This region includes China, Indonesia, India, Australia, and Malaysia as the principal oil producers. It produces about 10% of present world oil supplies (Table 2). But with some 60% of the world's population, it has been endowed with only 8% of the world's remaining oil reserves (Table 2). If Asian nations become more motorized, as is their plan, their oil demands will add significant strain to the world's production capacity. China is seeking joint ventures with Caspian Sea area oil operations, and has already bought into some U.S. oil production in the Gulf of Mexico.

4. Geographic and Organizational Comparisons

The world's oil-producing nations can be categorized in several ways. Here we choose two: (1) geographic: Middle East and non-Middle East, and (2) organizational: OPEC and non-OPEC. These categories, and their potential importance, have been widely discussed since the so-called 'Arab oil embargo' in 1973. Table 3 gives details.

Table 3. Geographic and Organizational Comparisons. Columns, 1-to-r: Category number and name. Cross-over year when categories 1a and 2a begin production dominance. Forecast peak year, forecast peak rate. Production in 1997, forecast in 2040. Cumulative production in 1997 (Q_{1997}), forecast cumulative production in 2040 (Q_{2040}), and expected ultimate recovery (EUR). Production decline from peak to 2040. Remaining reserves (RR). Far right column: The important ratio of the remaining reserves for each category to the remaining reserves for all 42 nations [(RR,C)/(RR,42N)]. Worth note is that virtually all 'swing producers' are in the Middle East and OPEC (i.e. categories 1a and 2a). Swing producers have production capacity to spare beyond their domestic needs, i.e. oil available for international export. This vast capacity for oil export represents more than just chemical energy; it is potential international political and economic power.
Figure 9. Middle East and non-Middle East Comparison. The Middle East includes nine Persian Gulf nations (#17-25, Table 1). Middle East production peaks in 2011 (curve 1). Non-Middle East production peaks in 2003 (curve 2). Middle East production exceeds non-Middle East production in 2025 (i.e. the Middle East cross-over point). Thereafter the Middle East dominates world oil production. In the global context, the Middle East nations, with only 4% of the world’s population, own 46% of the world’s oil reserves (Table 3, far right column). In contrast, the non-Middle East nations, with 96% of the world’s population, own only 54% divided unevenly among them (Table 3, far right column). Moreover, the Middle East production itself is dominated by the Big Five: Iran, Iraq, Kuwait, Saudi Arabia, and United Arab Emirates which together own 94% of the Middle East’s oil reserves. The Earth is well explored so this geographical disparity is not likely to change. However, by 2025 both Middle East and non-Middle East oil production will be in steep decline. Thus it is hard to predict what the global impact of the Middle East’s oil reserves might be, but it could be significant indeed.

Question 1: How about the Middle East’s oil exports? Response 1: The Middle East’s oil production could soon be overshadowed by its oil exports because most of the world’s ‘swing producers’ are located there. In fact, Middle East exports averaged 43.4% of the world’s export trade from 1982 through 1997. And despite OPEC production ‘quotas’ and U. N. export sanctions against Iraq, by 1997 Middle East exports had increased to 45.3% of the world total. Moreover, their installed plant has surplus capacity to immediately increase their exports far above 50% of the world total.

Question 2: So who imports the Middle East’s oil? Response 2: The Middle East exported 6.6 billion barrels (Gb) in 1997. Of that total, the USA imported 9.6%, Europe 20.8%, Japan 24.2%, other Asia Pacific nations 32.8%, and Asia Pacific total (including Japan) 57.0%. (BP, 1998)

Question 3: The Middle East in 1971 reached 32% of the world’s oil production. When will this happen again? Response 3: It’s forecast to occur again in 1999 (Figure 9).

Next OPEC and non-OPEC comparisons are shown in Figure 10 following.
Eleven nations are OPEC members: six in the Middle East, three in Africa, one each in South America and Asia Pacific (asterisks, Table 1). Middle East nations now control 76% of OPEC's remaining reserves, African nations 11%, Venezuela 10%, and Indonesia a scant 3%. OPEC production peaks in 2009 (curve 1). Non-OPEC production peaks in 2003 (curve 2). OPEC production exceeds non-OPEC production in 2007 (the OPEC cross-over point) and thereafter OPEC dominates world production. By 2007 almost all OPEC production will be in the Persian Gulf area. Some nations may drop out of OPEC when their domestic demand exceeds production, with no surplus to export. OPEC itself could disintegrate and dissolve. On the other hand, OPEC could soon become a wider, more effective organization by adding new members such as Mexico and Norway. This uncertainty makes it hard to predict OPEC's future, but its potential influence on future world oil prices is significant, to say the least.

**Question 4:** OPEC in 1971 reached 50% of the world's oil production. When will this happen again? **Response 4:** It's forecast to occur again in 2007 (the OPEC cross-over point, Figures 1 & 10).

Next we test the possibility of delaying the world oil peak.

**5. Can We Delay the World Oil Peak?**

Optimists see at least several decades more of unfettered world oil production—but a growing number of realists conclude that world oil production is nearing its all-time peak, perhaps within 10 years. The optimists, mostly economists, believe that new oil discoveries and enhanced recovery from old fields will delay the world peak beyond 2040. The opposition, mostly geologists, argue otherwise. (Kerr, 1998)

In this section we use the World Oil Forecasting Program to answer the questions: Can we delay the world oil peak? If so, by how much? This is done by two simulation tests; each test builds on the 'base-line' world oil production profile (e.g. curve 1, Figure 1). Then discrete increments of new production are added to the baseline production curve to delay the world peak (i.e. postpone it) by 1 year, 2 years, ..., n years, .... The increments of new production consist of so-called 'Norway Equivalents' (abbreviated 'NE'). Each NE is defined as a symmetrical production curve with EUR = 42.4 Gb (i.e. see Norway's EUR, Table 1).
PEAK DELAY SIMULATION: TEST SERIES #1. Given the base-line world oil production profile from 1960 to 2040, by simulation we bring four discrete increments of new production on-stream on 1 January 1998. Note that the on-stream date is exactly 8 years before the base-line world oil peak in 2006. The results of Test Series #1 are graphed in Figure 11.

Figure 11. Peak Delay Simulation: Test Series #1: The ‘base-line’ world oil curve is our reference (curve 1, peak 2006). Curves 2-5 are peak delay tests which add increments of new production to the base-line curve. The increments come on-stream on 1 January 1998, 8 years before the 2006 base-line peak. New production is measured in ‘Norway Equivalents’, or ‘NE’, defined as a symmetrical production curve with EUR = 42.4 Gb (Table 1). Curve 2 shows that an increment of 3.5 NE delays the world peak by 1 year, from 2006 to 2007. Curve 3 shows that 7.0 NE delays the peak by 2 years, from 2006 to 2008. Curve 4 shows that 8.2 NE delays the peak by 3 years, from 2006 to 2009. Now a shock! Curve 5 shows that 8.8 NE delays the peak by 16 years, from 2006 to 2022. Summary: Curves 2 and 3 each give a peak delay of 2.5 days per Gb of new production. Curve 4 gives 3.1 days delay per Gb. Curve 5 gives 15.7 days delay per Gb. Clearly the peak delay is a highly nonlinear function of new production.

Curve 1: This is the base-line world oil production curve with peak in 2006. Four discrete increments of new production are then added to the base-line curve.
Curve 2: By cut-and-try, 3.5 NE (i.e. 3.5*42.4 Gb = 150 Gb) of new production were required to delay the peak by 1 year, i.e. from 2006 to 2007. This gives to 2.5 days delay per Gb of new production.
Curve 3: Similarly, 7.0 NE of new production were required to delay the peak by 2 years, i.e. from 2006 to 2008. This (again) gives 2.5 days delay per Gb. Curve 4: Continuing the tests, 8.2 NE of new production were required to delay the peak by 3 years, i.e. from 2006 to 2009. This gives 3.1 days delay per Gb.
Curve 5: Now the big surprise! It took 8.8 NE to delay the peak by 16 years, i.e. from 2006 to 2022. In other words, curve 5 required only 0.6 Gb more new production than did curve 4, but this relatively small increase delayed the world base-line peak by 15.7 days per Gb. Note well that no intermediate peak occurred between the peak of curve 4 (2009) and the peak of curve 5 (2022). A quantum leap, so to speak.

Summary: Test Series #1. Relative to the 2006 base-line peak, curves 2 and 3 each give a peak delay of 2.5 days per Gb of new production. Curve 4 gives 3.1 days delay per Gb. Curve 5 gives 15.7 days delay per Gb. Test Series #1 (above) demonstrates that the peak delay is a highly nonlinear function of new production.
**PEAK DELAY SIMULATION:** TEST SERIES #2: Starting again with the world base-line curve, we add the same increments of new production as previously, except this time they come on-stream on 1 January 2015, 8 years after the baseline world peak in 2006. The results of Test Series #2 are graphed in Figure 12.

Figure 12. Peak Delay Simulation: Test Series #2: The base-line world oil curve is again our reference (curve 1, peak 2006). Curves 2-5 result from the same four increments of new production used in Test Series #1, except that here in Test Series #2 the new increments are brought on-stream on 1 January 2015, 8 years after the base-line world peak in 2006. As seen in Figure 12 above, none of the four increments of new production cause any delay whatsoever to the base-line world oil peak in 2006 because the amounts of new production are 'too little, too late' to compensate for the rapidly falling base-line production. For instance, even the huge increment of 370 Gb of new production (curve 5 above) does not stop the overall fall in world oil production. Summary: Even if large amounts of new oil production are brought on-stream after the 2006 base-line world oil peak, they are not likely to reverse the downward trend in production, to say nothing of creating a later and higher peak.

Curve 1: The base-line world oil production curve with peak in 2006.
Curves 2-5: We add the same four increments of new production as in Test Series #1, except here in Test Series #2 the increments come on-stream on 1 January 2015, 8 years after the world base-line peak in 2006. Clearly seen in Figure 12, the base-line world oil peak in 2006 remains the all-time world oil peak, unchallenged by any of the four increments of new production (curves 2-5).

Summary: Test Series #2. None of the four increments of new production (ranging from 150 to 370 Gb) brought on-stream 8 years after the base-line peak cause any delay whatsoever in the 2006 base-line world oil peak. In other words, the four heroic amounts of new production are simply 'too little, too late' to compensate for the rapidly falling base-line world oil production.

**SUMMARY:** PEAK DELAY TESTS #1 AND #2. The world oil peak delay time per Gb increment of new production is neither constant nor linear. Rather it is a highly nonlinear function of four factors: (1) shape of the base-line production curve, (2) the shape of the added new production curve, (3) the area under the new production curve, i.e. the total new EUR, and (4) the date the new production is brought on-stream. The average delay for Test Series #1 is 6.0 days per Gb of new production brought on-stream 8 years before the base-line peak. The average for Test Series #2 is 0.0 (zero!) days per Gb increment brought on-stream 8 years after the base-line peak. The average delay for Test Series #1 and #2 combined is 3.0 days per Gb of new production.
CONCLUSION: The headline of this section asked, "Can we delay the world peak?" Our response is, "Yes, new production brought on-stream well before the 2006 base-line peak can delay it, but only by a few days per Gb of new production. However, even large increments of new production brought on-stream after the peak are not likely to have any effect whatsoever on delaying the base-line world oil peak. Although we can't precisely predict when the peak will occur, we are assured that it is not a 'moving target'. In fact the world peak is probably fixed by the most recent production trends of the top 42 oil-producing nations included in this study (Table 1)."

6. The World Oil Forecasting Method

Webster's dictionary defines method as, "a way of doing anything; mode; procedure; process; especially, a regular, orderly, definite procedure or way of teaching, investigating, etc." Our Method amounts to an ongoing series of 'squeeze plays' that constrains our forecasts and increases their certainty. Each new forecast starts with the latest oil production data and then goes through three regular, orderly, definite steps to produce 42 national oil forecasts, 7 regional forecasts, and a world forecast. These steps are repeated until the world oil peak is identified and verified. It may take ten years or longer, but inevitably it gets the right answer.

Step 1: This step constrains (restricts) each nation's future oil production between a minimum curve and a maximum curve, i.e. lower and upper bounds. To accomplish this, each nation is modeled separately by a 'numeric-heuristic' model, 'N-H' for short.

First the numeric (N) part: Each nation's oil production data is analyzed by a special numeric technique to establish a lower boundary forecast ('LB-forecast') for its future oil production. (Duncan, 1996)

Second the heuristic (H) part: Heuristic means, "a method of solving a problem for which no algorithm exists. It involves trial and error, as in iteration." From a search of the petroleum literature, we use the maximum estimated ultimate recovery (EUR, the estimates vary widely) together with a computer tool called a 'graphical input device' to construct an upper boundary forecast, ('UB-forecast') for each nation'.

We next use our heuristic knowledge and the LB- and UB-forecasts to construct the heuristic forecast ('H-forecast') for each nation. The H-forecast always (1) is constrained by (i.e. constructed to lie between) the LB-forecast and the UB-forecast, and (2) extends each nation's most recent production trend for at least a few years into the future. Thus the oil production data are seamlessly joined with the H-forecast to give the oil production lifecycle for each nation from 1960 to 2040. (Both the LB- and the UB-forecasts are then discarded.) Finally the 42 national life-cycles are summed (as needed) to get the world oil production life-cycle (Figure 1), the seven regional life-cycles (Figures 2-8), the Middle East and non-Middle East life-cycles (Figure 9), and the OPEC and non-OPEC life-cycles (Figure 10). (Duncan 1997; Duncan & Youngquist 1998)

Step 2: Although the world's oil discovery peak occurred in the 1960's, some new fields are still being discovered and oil technology advances. So the question arises anew each year, "Can new oil discoveries and enhanced oil recovery from old fields delay the world peak?" Our response is, "Yes, but not by much," as was demonstrated in the previous section. Thus the world oil peak, we believe, is constrained to occur within approximately the next 10 years.
Step 3: We check to see that our series of forecasts (each produced with the simulation Program) are consistent and are also converging on a specific peak year, even though we don’t yet know what that year will be. ‘Encircling’ we call it. Of course encircling does not mean an exact Euclidean circle, but it does mean that we can map our route by a series points (forecasts) connected by lines (arrows) depicting our progress towards the world peak. Like mountaineering, however, our route to the world oil production peak may be subject to some irregularities along the way. To facilitate our climb we ‘map’ our route anew each year by a ‘phase diagram’, Figure 13.

Figure 13. Encircling the World Petroleum Peak. The ‘phase diagram’ depicts on the x-axis the range of likely peak years, 2004 through 2008. The y-axis depicts the range of likely peak rates, 28 to 32 Gb per year. For our example, assume that the actual peak will be in 2006 and that three years of falling production will be necessary to verify the peak. START at the first point in the lower left corner of the diagram: Issue #1 of the World Oil Forecasting Program, ‘WOFP’. That study was done in 1996 and predicted the peak in 2005 at a rate of 29.0 Gb/year. The Issue #2 study (rightmost point) was done in 1997 and predicted the peak in 2007 at 30.6 Gb/year. The Issue #3 study (topmost point, this paper) was done in 1998 and predicted the peak in 2006 at 31.6 Gb/year. Issue #4 was done in 1999 and predicted the peak in 2005 at 29.8 Gb/year. The studies continue from Issue #5 through Issue #11; all predict the world peak in 2006, but with different rates of production. Then the actual production rates fall from 2007 through 2009 (i.e. during Issues #12-14). Thus after three downward years, the production data verifies that the world oil peak occurred in 2006. STOP. Note that (in this hypothetical example) it took 14 forecasts, 14 issues, 14 years to finish the job.

As was mentioned, a phase diagram is very useful to ensure the consistency and convergence of the forecasts. Just follow the arrows closely in Figure 13 and you’ll see how it works. Of course the example is over-simplified. So expect that the actual phase diagram, when completed several years hence, will look somewhat more complex than the example given above.

Following, we review our progress during the past three years.
7. Progress En Route

Here we extend the analogue of oil forecasting and mountain climbing to include verification along the way that our predictions seem to be leading toward the world oil peak. We consider four predictions that were made in Issues #1 and #2 of the World Oil Forecasting Program and continued in Issue #3. These predictions are now verified or at least consistent with recent trends and supported by published data.

**Prediction 1 -- Asian Economic Crisis:** Issue #1 of the Program was presented at Princeton University on 9 May 1997, a full 6 months before the Asian economy began to melt. It warned that the Asia Pacific region had 60% of the world's population, but less than 8% of the world's oil reserves. Our conclusion: "Asian Tigers? In terms of oil resources, the so-called 'Asian Tigers' -- such as China, India and Indonesia are just pussy-cats in disguise." (Duncan 1997, p. 268)

Our warning about Asia Pacific's lack of resources was repeated in Issue #2. "Compounding world energy demands will be the increasingly industrialized nations (particularly SE Asia, China, and India) wanting more energy per capita. China, Southeast Asia, and India now with some 60% of the world population are getting motorized wheels. If China used oil on a per capita basis as does the United States, China alone would account for approximately 14 million barrels a day more than the present entire world oil production." (Duncan & Youngquist 1998, p. 5)

This caveat was again repeated in Issue #3, "Asia Pacific includes China, Indonesia, India, Australia, and Malaysia as the principal oil producers. It produces about 10% of present world oil supplies (Table 2). But with some 60% of the world's population, it has been endowed with only 8% of the world's remaining oil reserves (Table 2). If Asian nations become more motorized, as is their plan, their oil demands will add significant strain to the world's production capacity. China is seeking joint ventures with Caspian Sea area oil operations, and has already bought into some U.S. oil production in the Gulf of Mexico." (this paper, p. 9)


**Prediction 2 -- Non-OPEC Peak:** Issue #1 of the Program predicted the non-OPEC peak in 2003. (Duncan 1997, p. 270) Issue #2 predicted it in 2001. (Duncan & Youngquist, p. 22b) Issue #3 predicted it (also) in 2003. (this paper, p. 9-10)

"A recent analysis by the Centre for Global Energy Studies (CGES), London, using a technique called logistic curve analysis, created one scenario in which, even if non-OPEC countries discovered a further 500 billion barrels of oil, non-OPEC production would peak in about 2002 at 50 million barrels per day and decline more rapidly than under conventional analysis." (Knott 1998)

We are in full agreement with the CGES about the nearing non-OPEC peak.

**Prediction 3 -- World Peak Delay:** Issues #1 through #3 of the Program predicted the world peak in the tight range of 2005 to 2007. However, Issue #3, Section 5 entitled "Can We Delay the World Oil Peak?" further investigated this contentious issue by a series of eight peak delay tests. We concluded, "Yes, new production brought on-stream well before the 2006 baseline peak can delay it, but only by a few days per billion barrels (Gb) of new production. However, even large increments of new production
brought on-stream after the peak are not likely to have any effect whatsoever on delaying the base-line world oil peak. Although we can't precisely predict when the peak will occur, we are assured that it's not a 'moving target'. In fact the world peak is probably fixed by the most recent production trends of the top 42 oil-producing nations included in this study (Table 1).” (this paper, p. 14)

CGES also investigated the possibility of delaying (i.e. postponing) the world oil peak. "CGES starts its review with the comforting thought that oil production was once expected to peak in the late 1980s, but that has been successively pushed back into the first decade of the next century. However, CGES concludes that the peak may not be pushed back much further." (Knott 1998)

We are in full agreement with the CGES about the inertia of the world oil peak.

Prediction 4 -- Caspian "Bonanza" Modest: Although in our Program the Caspian Sea republics are included in the Former Soviet Union (FSU), their contribution to future FSU oil production is still clearly marked. Specifically: Issue #1 predicted the FSU expected ultimate recovery (EUR) at 305 billion barrels (Gb). (Duncan 1997, p. 268-269) However in 1997, one of us (Youngquist) cautioned that the conventional Caspian oil forecasts were probably much exaggerated, so in Issue #2 we reduced the FSU forecast EUR to 264 Gb. (Duncan & Youngquist 1998, p. 22a) In Issue #3 it is 265 Gb. (this paper, p. 5)

A recent Wall Street Journal article (October 12, 1998) updated the oil prospects in the Caspian area. "A growing number of wells are coming up dry in the Caspian Sea, raising questions about the reserves in a region that some have promoted as a potential Middle East of the next millennium .... In the six years since this chunk of the former Soviet frontier opened to outside investment, major oil companies have spent billions of dollars drilling for oil, and haven't yet hit a new discovery significant enough to repay the investment .... In a report last year, the U.S. State Department estimated that the Caspian region's possible oil reserves could reach 178 billion barrels, ... [But] several independent consulting firms now place total probable reserves in the Caspian region at about one-tenth the original U.S. government estimates .... at between 15 billion and 31 billion barrels of crude, ... That would be a good strike, but even at the high end of that range, the Caspian would contribute about 3% of the world's oil supply. By contrast, the Middle East holds about 60% of the world's known reserves." (Cooper & Pope 1998)
8. Summary and Conclusions

The main goal of this paper is to predict the world oil production peak. To accomplish this goal we use a unique new procedure based on oil production data, data analysis, conventional formulas, and heuristic knowledge. It comprises (1) the World Oil Forecasting Program, and (2) the World Oil Forecasting Method.

The Program analyzes the historic oil production data and predicts by statistical and heuristic techniques future production from 1998 to 2040 for the world's 42 top oil-producing nations, seven regions, and the world. The Method is to build up a series of forecasts which, taken together, will inevitably converge on the peak. This paper presents the third in this series of forecasts, or simply 'Issue #3.'

Table 1 gives the peak production year, expected ultimate recovery, remaining reserves, decline from the peak to 2040, percent of the world's remaining reserves, et cetera, for each nation and for the world. Table 2 gives similar information for each of the seven regions. Figure 1 graphs the world oil production life-cycle from 1960 to 2040 with the peak in 2006. Figures 2 - 8 graph the oil life-cycle and peak year for each region: North America 1985, Former Soviet Union 1987, Europe 2000, Asia Pacific 2002, Africa 2004, South & Central America 2005, and Middle East 2011.

Table 3 compares the Middle East and non-Middle East oil production, and the OPEC & non-OPEC oil production. Figure 9 shows that the non-Middle East peaks in 2003, the Middle East peaks in 2011, and then after 2025 the Middle East dominates world oil production. Figure 10 shows that non-OPEC peaks in 2003, then OPEC dominates world production after 2007, but soon OPEC itself peaks in 2009.

Simulation is used to answer the contentious and important question, "Can new oil production delay the world oil peak?" Our answer is, "Yes, new production brought on-stream well before the 2006 base-line peak can delay it, but only by a few days per billion barrels of new production. However, even large increments of new production brought on-stream after the peak are not likely to have any effect whatsoever on delaying the base-line world oil peak. Although we can't precisely predict when the peak will occur, we are assured that it is not a 'moving target'. In fact we believe the world oil peak is fixed by the most recent production trends of the top 42 oil-producing nations included in this study." Not to be missed are Figures 11 & 12. We hope this simulation technique will be a useful addition to oil forecasting.

A base-camp and a series of higher camps will be necessary before finally ascending to the summit. 'Encircling' we call it, as illustrated by the three forecasts we've made so far. Specifically, Issue #1 put the peak in 2005; Issue #2 put it in 2007; Issue #3 (this paper) put it in 2006. Figure 13 is a 'phase diagram' that assures the consistency and convergence of our ongoing forecasts. Each forecast (Issue) is shown as a point, and arrows connect successive points. The arrows map our crooked and tedious, but inevitably successful, route from Issue #1 to the world oil summit. This is our Method.

En route to the summit, four of our predictions have since been verified or at least they have proved consistent with recent trends and events: the Asian economic crisis, the nearing non-OPEC peak, the inertia of the world oil peak, and the six-year string of dry holes in the Caspian Sea.
BIBLIOGRAPHY

What is the life cycle of a petroleum project based on this description? To begin with, as indicated in earlier columns, the project’s life cycle is integral to the accurate calculation of government take. Indeed, government revenue varies over the life cycle of the project, along with production costs, prices, cash flow, and profitability. At this stage: “development planning commences using site-specific geo-technical and environmental impact assessment” (World Bank, page 3). In practice, this phase requires that the necessary production and transportation facilities are established at the operations site. At the fifth stage production commences and hydrocarbons recovery begins. Many organizations have attempted to develop an accurate well-to-pump life cycle model of petroleum products in order to inform decision makers of the consequences of its use. Our paper studies five of these models, demonstrating the differences in their predictions and attempting to evaluate their data quality. Paper presented at the world clean energy conference, Geneva. Brandão M, Heath G, Cooper J (2012) What can meta-analyses tell us about the reliability of life cycle assessment for decision support? J Ind Ecol 16:S3–S7. doi: 10.1111/j.1530-9290.2012.00477.x. Article Google Scholar. Petroleum makes our lives easy in many ways. In many countries, including the U.S., the oil industry provides millions jobs, from surveyors and platform workers to geologists and engineers. The United States consumes more oil than any other country. Carbon Cycle. There are major disadvantages to extracting fossil fuels, and extracting petroleum is a controversial industry. Carbon, an essential element on Earth, makes up about 85% of the hydrocarbons in petroleum. Carbon constantly cycles between the water, land, and atmosphere. Peak Oil Oil is a non-renewable resource, and the world’s oil reserves will not always be enough to provide for the world’s demand for petroleum. Peak oil is the point when the oil industry is extracting the maximum possible amount of petroleum. Life Cycle Associates has examined the environmental impacts for a wide range of petroleum production processes. We developed a model for thermally enhanced oil recovery (TEOR), which was used to estimate the energy intensity and greenhouse gas emissions associated with TEOR for the CA LCFS petroleum baseline (see report). Petroleum is produced from crude oil, a complex mixture of hydrocarbons, various organic compounds and associated impurities. The crude product exists as deposits in the earth’s crust, and the composition varies by geographic location and deposit formation contributors. Its physical consistency varies from a free flowing liquid to nearly solid. Crude oil is extracted from geological deposits by a number of different techniques.