Oil Depletion Revisited

Why the peak is probably near

by John Attarian

The explosion in oil prices in 2004 has prompted renewed attention to the possibility of a peak and decline in world annual oil production (or, properly, extraction),[1] making this an appropriate time to revisit the issue. Evidence is accumulating that world annual oil extraction is indeed approaching a peak, and that the peak will probably occur before this decade is out.

The Growing Trend to Peak

Historical data on oil extraction at the U.S. Energy Information Administration, BP (British Petroleum), and ASPO (Association for the Study of Peak Oil & Gas) websites reveal a strong trend toward global peak. As we have gone forward in time, more and more oil-producing countries have passed through their peaks and gone into decline. One country (Austria) peaked during the 1950s, four (including the United States) peaked in the 1960s, 11 in the 1970s, 19 in the 1980s, 25 in the 1990s, and apparently another six in 2001 alone, for a total of 66 out of 92 oil-producing countries.[2]

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1956-2004

The oil producing countries which really matter are the 48 major producers tracked by BP, which account for over 98 percent of the world*s annual oil extraction. These countries are listed in Table 1, in descending order of their 2003 output, with the dates of their extraction peaks and annual extraction data for selected years in 1993-2003.[3] Extraction figures for peaks which occurred in this period are in boldface, and outputs which are smaller than those of the immediately previous year are in italics – simple visual aids which throw into high relief how widespread depletion has become among major producers.

Table 2 highlights the peaking and declining trends among the major producers.[4] Whereas only 17 major producers were past peak as of 1993, 31 – almost twice as many – were past peak as of 2003. That the lion*s share of the countries extracting almost all the world*s oil are past peak, and that the number of major countries past peak is rising rapidly, are strong indicators that a world peak is nigh. Moreover, whereas a decade ago output was increasing in a lopsided majority of major producers, in recent years more and more have seen their output declining. Indeed, in 2001 and 2002 the major producers with declining output outnumbered those with increasing output, and in 2003 the number with output increasing barely exceeded the number of decliners.

Also, notice from Table 1 that whereas in 1993 63.1 percent of the world*s oil was produced by countries which were past their peaks, in 2003 72.9 percent was from countries which had passed their peaks and whose output was, despite any surge that year, trending downward. Obviously the world is leaning on something which is starting to collapse.

It is with sadness and regret that we publish this article prepared by the late ***John Attarian, Ph.D.*** *who died December 31, 2004. With a doctorate in economics from the University of Michigan (1984), John had been a professional writer since 1990 on such topics as Social Security, general entitlements, the budget deficit, the culture war, the crisis in education, the impact of immigration, and the future of petroleum-based economies. He is the author of* Economism and the National Prospect *(American Immigration Control Foundation) and* Social Security: False Consciousness and Crisis *(Transaction),* Immigration: Wrong Answer for Social Security *(American Immigration Control Press), and many other essays and book reviews.*

TABLE 1: ANNUAL OIL EXTRACTION BY MAJOR PRODUCING COUNTRIES, 1993-2003, SELECTED YEARS (thousands of barrels/day)

Country (peak date)	1993	1995	1997	1999	2000	2001	2002	2003
Saudi Arabia (1980)	8,962	9,032	9,361	*8,694*	9,297	*8,992*	*8,664*	9,817
Russia (1987)	7,173	*6,288*	6,227	6,178	6,536	7,056	7,698	8,543
United States (1970)	*8,583*	*8,322*	*8,269*	*7,731*	7,733	*7,669*	*7,626*	*7,454*
Iran (1974)	3,712	3,744	3,776	*3,603*	3,818	*3,734*	*3,420*	3,852
Mexico	3,312	*3,065*	3,410	*3,343*	3,450	3,560	3,585	3,789
China	2,888	2,989	3,211	3,213	3,252	3,306	3,346	3,396
Norway (2001)	2,377	2,903	3,280	*3,139*	3,343	**3,416**	*3,329*	*3,260*
Venezuela (1970)	2,592	2,959	3,321	*3,248*	3,321	*3,233*	*3,218*	*2,987*
Canada	2,184	2,402	2,588	*2,604*	2,721	*2,712*	2,838	2,986
Arab Emirates (1991)	2,443	2,410	2,483	*2,302*	2,499	*2,430*	*2,159*	2,520
Great Britain (1999)	2,119	2,749	*2,702*	**2,893**	*2,657*	*2,476*	*2,463*	*2,225*
Kuwait (1999)	1,945	2,130	2,137	*2,000*	2,105	*2,069*	*1,871*	2,238
Nigeria (1979)	1,985	1,998	2,303	*2,028*	2,104	2,199	*2,013*	2,185
Algeria	1,329	1,327	1,421	1,515	1,578	*1,562*	1,681	1,857
Brazil	664	718	868	1,133	1,268	1,337	1,499	1,552
Libya (1970)	1,402	1,439	1,489	*1,425*	1,475	*1,425*	*1,376*	1,488
Iraq (1979)	455	530	1,166	2,541	2,583	*2,371*	*2,030*	*1,344*
Indonesia (1977)	1,588	*1,578*	*1,557*	*1,408*	1,456	*1,389*	*1,288*	*1,179*
Kazakhstan	490	434	536	631	744	836	1,018	1,106
Qatar	460	461	719	797	855	*854*	*783*	917
Angola	504	633	741	745	746	*742*	905	*885*
Malaysia	662	724	764	*791*	791	*786*	828	875
Oman (2001)	785	868	909	911	959	**961**	*900*	*823*
Argentina (1998)	630	758	877	*847*	*819*	829	*808*	*793*
India (1995)	620	**804**	800	*788*	*780*	780	794	*793*
Egypt (1993)	**941**	924	*873*	*827*	*781*	*758*	*753*	*750*
Australia (2000)	572	*583*	669	625	**809**	*733*	*731*	*624*
Syria (1995)	566	**596**	*577*	579	*550*	583	*572*	594
Colombia (1999)	458	591	667	**838**	*711*	*627*	*601*	*564*
Yemen (2001)	209	351	375	405	450	**471**	*462*	*454*
Ecuador	353	395	397	*382*	409	416	*410*	427
Vietnam	128	155	205	296	328	350	354	372
Denmark	170	188	233	301	364	*347*	372	*368*
Azerbaijan	209	*185*	185	278	281	300	311	313
Sudan	2	2	9	63	174	211	233	255
Equatorial Guinea	5	7	60	100	113	181	237	249
Congo (1999)	185	180	225	**293**	*275*	*271*	*259*	*243*
Gabon (1996)	305	356	364	340	*327*	*301*	*295*	*240*
Thailand	92	*84*	108	143	144	162	182	217
Brunei (1979)	175	*175*	*163*	182	193	203	210	214
Turkmenistan	92	*84*	108	143	144	162	182	210
Uzbekistan (1998)	94	172	182	191	*177*	*171*	*171*	*166*
Trinidad (1978)	134	142	*135*	141	*138*	*135*	155	163
Romania (1976)	144	145	*141*	*133*	*131*	*130*	*127*	*123*
Italy (1997)	89	101	**114**	*98*	*88*	*79*	106	107
Peru (1980)	127	*123*	*120*	*110*	*104*	*98*	*98*	*92*
Cameroon (1985)	130	*106*	124	*95*	*88*	*80*	*72*	*68*
Tunisia (1980)	99	*90*	*81*	84	*78*	*71*	73	*66*
Total, 48 majors	64,958	67,003	71,038	71,142	73,767	73,576	73,115	75,763
Total, post-peak	41,649	42,135	45,467	45,573	50,824	50,892	54,342	55,989
Total, world	66,006	68,008	72,024	72,063	74,669	74,487	74,065	76,777

Source: BP Statistical Review of World Energy 2004

Rampant Depletion Among Major Producers

Moreover, depletion is becoming not only widespread but substantial among the major producers, as we see in Table 3, which shows changes in annual extraction from the previous year in the 1993-2003 period for each of the 48 major producing countries, with declines in italics.[5] Notice that several major producers – for example, the United States, Venezuela, Great Britain, Indonesia, Egypt, and Colombia – have seen their output declining for several years in a row. Others such as Libya and the United Arab Emirates have a long downward trend punctuated by shorter, hiccup-like increases. Others, however, such as Canada, Mexico, Brazil, Algeria, Sudan, and Equatorial Guinea, are still expanding strongly.

From Table 4, which aggregates the data in Table 3 (plus those for a few omitted years early in the period), giving the total annual output of major producers, the aggregates of the individual countries* output increases and decreases, and the net change in total major producer output, we see that in 1993-1998 the total net change in major producers* output (Column 4) was positive every year, and averaged 1,289 thousands of barrels a day (kb/d).[6] That is, declines in output from some major producers were substantially exceeded by increases among others (Column 3). By contrast, beginning with 1999, the aggregate decline in major producers* output averaged 1,590 kb/d – almost 1.6 *million*. (And this *omits* Iraq*s large decline in 2003, obviously a special case due to wartime disruption.) Although this was of course offset by increases elsewhere, the net change in major producers* output was actually negative in some years – that is, aggregate decline exceeded aggregate increase – and averaged just 802 kb/d in 1999-2003. Moreover, major producers* total output fluctuated after 1998. All this indicates that world oil extraction, after rising steadily, has reached a bumpy plateau.

Table 2. Analysis of Major Oil Producing Countries, 1993-2003

YEAR	Countries w/ Output Declining	Countries w/ Output Increasing	Countries Past Peak	Countries Peaking in Year
1993	18	30	17	1
1994	11	37	18	0
1995	14	34	18	2
1996	14	34	20	1
1997	11	37	21	1
1998	20	28	22	2
1999	23	25	24	3
2000	16	32	27	1
2001	29	19	28	3
2002	27	21	31	0
2003	22	26	31	0

Comparing these output dynamics with the price of oil is highly instructive. In the years when increases substantially exceeded decreases and total output consistently rose, prices were much lower than in 1999-2003, when even as the oil price began exploding, the declining countries sometimes outnumbered the advancing ones, aggregate depletion was much larger and sometimes exceeded aggregate output increase, and total output fluctuated. This, surely, is a sign that economic forces such as price and demand are not the sole factors determining oil extraction, and that geological reality – i.e., resource finitude and depletion – is starting to take over.

TABLE 3: ANNUAL CHANGES IN OIL EXTRACTION BY MAJOR PRODUCING COUNTRIES, 1993-2003, SELECTED YEARS (thousands of barrels/day)

Country (peak date)	1993	1995	1997	1999	2000	2001	2002	2003
Saudi Arabia (1980)	-136	+9	+181	-676	+603	-305	-328	+1,153
Russia (1987)	-865	-131	+113	+9	+358	+520	+642	+845
United States (1970)	-285	-67	-26	-280	+2	-64	-43	-172
Iran (1974)	+189	+14	+17	-252	+215	-84-	-314	+432
Mexico	+12	-77	+133	-156	+107	+110	+25	+204
China	+47	+59	+41	+1	+39	+54	+40	+50
Norway (2001)	+159	+210	+47	0	+204	+73	-87	-69
Venezuela (1970)	+93	+207	+184	-262	+73	-88	-15	-231
Canada	+122	+126	+108	-68	+117	-9	+126	+148
Arab Emirates (1991)	-67	-72	+4	-256	+197	-69	-271	+361
Great Britain (1999)	+138	+74	-33	+100	-236	-181	-13	-218
Kuwait (1999)	+868	+45	+8	-176	+105	-36	-198	+367
Nigeria (1979)	+35	+10	+165	-135	+76	+95	-186	+172
Algeria	+6	+3	+35	+54	+63	-16	+119	+176
Brazil	+12	+25	+61	+130	+135	+69	+162	+53
Libya (1970)	-71	+8	+37	-55	+50	-50	-49	+112
Iraq (1979)	-76	+25	+586	+415	+42	-212	-341	-686*
Indonesia (1977)	+9	-11	-23	-112	+48	-67	-101	-109
Kazakhstan	-59	+4	+62	+94	+113	+92	+182	+88
Qatar	-35	+10	+151	+50	+58	-1	-71	+134
Angola	-46	+76	+25	+14	+1	-4	+163	-20
Malaysia	-8	+50	+28	-24	0	-5	+42	+47
Oman (2001)	+37	+49	+12	+6	+48	+2	-61	-77
Argentina (1998)	+43	+63	+54	-43	-28	+10	-21	-15
India (1995)	-23	+96	+22	-3	-8	0	+14	-1
Egypt (1993)	+35	+3	-21	-30	-46	-23	-5	-3
Australia (2000)	-37	-31	+50	-19	+184	-76	-2	-107
Syria (1995)	+52	+33	-9	+3	-29	+33	-11	+22
Colombia (1999)	+16	+131	+32	+63	-127	-84	-26	-37
Yemen (2001)	+25	+5	+18	+25	+45	+21	-9	-8
Ecuador	+25	+7	+4	-2	+27	+7	-6	+17
Vietnam	+17	+11	+26	+51	+32	+22	+4	+18
Denmark	+11	+1	+26	+66	+63	-17	+25	-4
Azerbaijan	-17	-8	+2	+48	+3	+19	+11	+2
Sudan	+2	0	+4	+51	+111	+37	+22	+22
Equatorial Guinea	+3	+2	+43	+17	+13	+68	+56	+12
Congo (1999)	+18	-5	+25	+29	-18	-4	-12	-16
Gabon (1996)	+16	+19	-1	+3	-13	-26	-6	-55
Thailand	+4	0	+19	+11	+32	+10	+17	+26
Brunei (1979)	-7	-4	-2	+25	+11	+10	+7	+4
Turkmenistan	-17	-3	+18	+14	+1	+18	+20	+28
Uzbekistan (1998)	+15	+48	+8	0	-14	-6	0	-5
Trinidad (1978)	-10	+1	-6	+7	-3	-3	+20	+8
Romania (1976)	+2	0	-1	-4	-2	-1	-3	-4
Italy (1997)	+3	+7	+10	-12	-8	-9	+27	+1
Peru (1980)	+10	-5	-1	-9	-6	-6	0	-6
Cameroon (1985)	-4	-9	+14	-10	-7	-8	-8	-4
Tunisia (1980)	-11	-3	-8	+1	-6	-7	+2	-7

Source: Table 1

*Iraq decline in 2003 omitted from totals as a special case.

TABLE 4: TOTAL OUTPUT OF MAJOR PRODUCERS AND CHANGES FROM PREVIOUS YEAR (thousands of barrels/day) AND SPOT CRUDE PRICE, 1993-2003

Year	(1) Total Output of Major Producers	Changes from Previous Year (2) Aggregate of Output Decreases	(3) Aggregate of Output Increases	(2) + (3) = (4) Total Net Change	Spot Crude Price** (dollars/barrel)
1993	64,958	-1,774	+2,2024	+250	16.95
1994	65,998	-1,087	+2,127	+1,040	16.00
1995	67,003	-426	+1,431	+1,005	17.20
1996	68,796	-303	+2,096	+1,793	20.63
1997	71,038	-131	+2,373	+2,242	19.32
1998	72,439	-785	+2,186	+1,401	12.99
1999	71,142	-2,584	+1,287	-1,297	18.13
2000	73,767	-551	+3,176	+2,625	28.37
2001	73,576	-1,461	+1,269	-192	24.35
2002	73,115	-2,187	+1,726	-461	24.99
2003	75,763	-1,168*	+4,502	+3,334*	28.83

*Iraq 2003 decline omitted due to wartime disruption.
**Price is average of spot crude prices for Dubai, Brent, Nigerian Forcados, and W. Texas Intermediate.
Source: BP Statistical Review of World Energy 2004

Heavy Dependence on Aging Giant Fields

Another important element in the case for an imminent oil peak is that the world's oil supply leans heavily on a small number of very large oil fields, and that many of them are faltering. Drawing on months of research, Houston-based energy investment banker Matthew Simmons has shown that 116 oilfields – just three percent of the world's roughly 4,000 producing fields – are so-called "giant" fields extracting 100,000 barrels or more per day, and that in 2000 these giants supplied 47.6 percent of the world crude oil output. The fourteen largest giants, each producing 500,000 or more barrels daily, supplied 20 percent of the world's crude oil, and the four largest – in descending order: Ghawar (Saudi Arabia), Cantarell (Mexico), Burgan (Kuwait) and Daqing (China) – furnished about 12 percent. Persian Gulf nations obtain the overwhelming majority of their oil from giant fields. In 2000, giants accounted for 92 percent of Saudi Arabia*s oil, 51 percent of Iran*s, 96 percent of Iraq*s, 95 percent of the United Arab Emirates*, and 89 percent of Kuwait*s. Altogether, 36 giant fields in the Persian Gulf supplied about 83 percent of the region*s crude oil and 23.7 percent of the world*s.[7]

Most of the world*s giants are decades old, and the largest, producing the most oil, are usually the oldest, since larger fields tend to be found first. After being drained for decades, many giants are getting tired. Output in several has declined, and many are losing pressure in their reservoirs, making oil extraction harder and costlier (in energy terms as well as dollar terms).

Many are now producing mostly water, either because underground water is seeping into them, or because the concerns developing them are employing an extraction technique known as waterflooding: injecting water into the reservoir to maintain pressure and force more oil toward the wellbores (drilled well shafts) so it can be extracted. This is necessary, because only a fraction of the original oil in place in a field is recoverable. As the field ages and reservoir pressure drops, "primary recovery" (using natural pressure or pumps) no longer works, and producers turn to "secondary recovery" – injecting water (waterflooding) or natural gas. Beyond these is "tertiary recovery" or "enhanced recovery," in which steam, solvent, liquid gas (e.g., butane or propane), carbon dioxide, or even fire is put into the reservoir. Other improved recovery methods, which became prominent in recent years, are directional and horizontal drilling: well shafts are drilled at an angle from the vertical, or even horizontally, underground. All these techniques can substantially raise the share of oil recovered and are widely used in America, where they account for over 60 percent of daily output.[8]

Unfortunately, a high "water cut" (share of water in the extracted liquid), whether due to natural causes or secondary recovery, is often a serious problem. Unless a sufficiently high oil price and a sufficiently large daily oil flow make it economical to keep a watery field going, when the water cut is very high, further extraction is often pointless. Moreover, a watery field has high production costs. Water is heavy and costly to pump out, and once extracted must be separated from the oil and disposed of – either reinjected if being used for water flood, or dumped into special disposal wells drilled to hold it. This extra work implies very low net energy yields for very watery fields.[9]

Space permits only a survey of some of the biggest giants, but even this is disquieting. Discovered in 1948 and operating since 1951 (fifty-three years!), Saudi Arabia*s Ghawar field, the world*s largest, produces about 4,500 kb/d, over half of Saudi Arabia*s daily output, and about *5.5* percent of world output. To maintain pressure in Ghawar*s reservoir, the Saudis must inject seven million barrels of seawater daily. The water cut is at least 30 percent, some sources put it at 55 percent, and it may be even higher. A Saudi presentation in London in February 2004 indicates that Ghawar*s total output may be around 80 billion barrels (Gb) by 2010, and that by that time water cut will be 80 percent. According to an engineer who has worked at Ghawar, output peaked in 1998, and the field is depleting by 1.1-1.5 percent a year, while water cut is now about 60 percent and rising by three percentage points yearly. By about 2017, output may be down to about 1.9 million barrels a day, with maybe 900 kb/d of it from enhanced recovery – very worthwhile, but far less than Ghawar*s current yield.[10] Given Ghawar*s importance for world supply, if Ghawar really is in trouble, world oil peak is likely.

Saudi Arabia*s seven other major fields are also extremely old: Abqaiq (discovered in 1940), Safaniyah (1951), Bern (1964), Zuluf (1965), Marjan (1967), and Shayba (1975). All of Saudi Arabia*s five largest fields, which have produced over 90 percent of its oil, rely on water flood to maintain pressure. According to Simmons, Abqaiq peaked in 1973 with oil output exceeding one million barrels a day (mb/d) and Bern peaked in 1979 at 900 kb/d.[11]

Indeed, Simmons created an uproar this year when he publicly questioned Saudi Arabia*s ability to sustain high output levels indefinitely. [See the sidebar on page 146 referring to Simmons' newest book.] He cited substantial water cut at Ghawar and Saudi Arabia*s dependence on a few very large, old fields for almost all its output. Moreover, he added, in 1975 the American geologists who were then running Aramco, Saudi*s national oil company, estimated Ghawar*s total reserves at 60 Gb, whereas the Saudis now claim 55 Gb already produced plus 125 Gb remaining reserves. If the old estimates are right, which they may well be, Simmons argues, then major declines in Saudi output are likely soon, perhaps in the next six months to three years. Aramco has, understandably, dismissed these claims, and even maintains that Saudi Arabia could produce as much as 15 mb/d for fifty years. However, Sadad al-Husseinyi, until recently Aramco*s head of exploration and production, warns that such high levels of output may be sustainable for only a few years and that Saudi Arabia*s "excess capacity is no longer there." And oil economist Mamdouh Salameh, a consultant to the World Bank, points out that Saudi Arabia now drills only horizontal wells, adding about 200 horizontal wells a year, giving the appearance of a country "working hard just to maintain production," rather than one which is capable of "simply opening the tap when more production is needed."[12] It looks like Simmons is on to something.

Mexico*s Cantarell field, the world*s second largest, found in 1976, started producing in 1979. By 1996 Cantarell was declining due to pressure loss. The state-owned oil company, Petróleos Mexicanos (Pemex), decided to boost extraction by injecting nitrogen, and by 2002 output was at 1,851 kb/d, more than double 1995*s 906 kb/d. Pemex has disclosed that it had expected Cantarell*s output to start declining in 2003, and now expects it to begin dropping in 2006, by 14 percent a year, perhaps as much as a million barrels a day by 2008.[13] The exponential function implies that five years decline at 14 percent will cut Cantarell*s annual output in half.

China depends heavily on four aging giants – Daqing, Shengli. Liaohe, and Xinjiang. These accounted for 2,055 kb/d in 2000, or about 63 percent of China*s total crude oil extraction that year, and 1,975 kb/d, or about 58 percent of the total, in 2003. Discovered in 1961 and producing since 1964, Shengli has a 90 percent water cut and has been producing about 519 kb/d of oil for the past few years. Daqing, the world*s fourth largest field, was found in 1959, began producing in 1963, and was producing a million barrels a day by 1976. Its annual extraction fell from 1,133.9 kb/d in 1998 to 985.3 kb/d in 2003, while the share of its output from enhanced recovery rose from 13.7 percent to 25.1 percent, and its water cut is high and rising, from 86.2 percent in 2000 to 88.4 percent 2003: signs that the field is faltering. Liaohe*s water cut is over 72 percent, and Xinjiang*s rose from 68.5 percent in 2000 to 71.4 percent in 2003.[14] Clearly, China*s giants are going downhill.

Some 59 percent of Venezuela*s output in 2000 was from giant fields. Venezuela contains four of the world*s oldest giants – Laqunillas, its largest, found in 1925; Bachaquero, found in 1930; Tia Juana, discovered in 1962; and Cabimas, found in 1917 – which together produced over 850,000 barrels a day in 2000, almost a third of total output. In 1971 they yielded over two million barrels a day, so these four fields are declining. In 1999, a Venezuelan oil executive observed that Venezuela must increase extraction by 800,000 barrels a day merely to maintain it at 2.75-2.8 mb/d.[15]

Indeed, decline is widespread among the largest giants. Simmons*s giant fields study reveals that of the world*s 20 largest fields, each producing 300 kb/d or more in 2000, 11 were past peak as of that year. There may have been more, because Simmons did not have peak output estimates available for ten of them. These 20 giants extracted 16,526 kb/d, or about 24 percent of world crude oil extraction in 2000; those past peak extracted 11 ,578 kb/d, or 70 percent of these giants* output, and 16.9 percent of world supply. Of the world*s fourteen largest, nine were past peak.[16]

Since 2000, three more major producing countries have peaked (Table 2), and the magnitude and incidence of depletion among major producers has exploded (Table 4). Given these developments, and the prominent role giants play in supply, it is virtually certain that more giant fields have peaked and gone into decline. Put another way, the keystone of the oil supply arch is beginning to crumble.

The Recent Extraction Surge is Unsustainable

In response, an optimist may cite the big output surge among major producers in 2003 and 2004. But these gains are almost certainly unsustainable. First, 2003*s increase of +3,334 kb/d is concentrated in a few large producers which are both past peak and dependent on elderly giants. From Table 3, most of it (+3,158 kb/cl) was in just five such countries: Saudi Arabia (+1,153 kb/d), Russia (+845 kb/d), Iran (+432 kb/d), the United Arab Emirates (+361 kb/d), and Kuwait (+367 kb/d).

As for the sixth largest contributor, Mexico (+204 kb/d), virtually every Mexican field other than Cantarell is already past peak; aggregate decline in 2002 from 2001 output levels was -188 kb/d. Cantarell*s 2002 output was 2,152 kb/d, up 178 kb/d from 2001*s 1,986 kb/d, but Mexico*s total output grew in 2002 by just 50 kb/d, from 3,127 kb/d to 3,177 kb/d. This means that 128 kb/d (72 percent) of Cantarell*s output growth was merely offsetting declines elsewhere.[17] Barring great investment to find and develop offshore oil, once Cantarell starts declining it will drag Mexico*s output down with it. It is likely, then, that Mexico will peak in 2005 or 2006.

Second, the same is true of the 2004 output surge. According to the Energy Information Administration (EIA), during the first eight months of 2004, 19 major producers had a total crude oil output increase of +3,233 kb/d, and other countries had an increase of +539 kb/d, for a total of +3,772 kb/d. This was offset by total declines in 11 major producers of -680 kb/d – which, being in the teeth of an 80 percent increase in oil prices in one year, is powerful evidence of depletion among major producers – for a net increase in world crude extraction of +3,092 kb/d. Here again, most of it (+2,474 kb/d) was from a few large producers: Russia (+709 kb/d), Iraq (+691 kb/d), Nigeria (+295 kb/d), Venezuela (+205 kb/d), Iran (+201 kb/d), Norway (+187 kb/d), and Kuwait (+186 kb/d).[18] Every last one is past peak; all but Nigeria depend heavily on old giant fields.

Third, many major contributors to the output surge are members of the Organization of Petroleum Exporting Countries (OPEC), and continued large increases from OPEC are uncertain. Conventional wisdom has it that OPEC has spare capacity of 1-2 million barrels a day, mostly in Saudi Arabia, but in recent months OPEC has intermittently signaled that it is at full stretch. On August 3, OPEC*s president, Indonesia*s oil minister Purnomo

Yusgiantoro, said that “There is no more supply.” The next day he reversed himself and said that not only did OPEC have spare capacity of 1-1.5 mb/d, but members plan to raise capacity further by another million barrels a day. Just a few days later, however, Venezuela*s Energy Minister, Rafael Ramirez, said that OPEC was producing at capacity, and could not immediately respond to higher demand. On September 22, Yusgiantoro told reporters that “1 called on non-OPEC producers to [boost output to help supply” – something which would have been unnecessary if OPEC had abundant spare capacity. That OPEC was essentially maxed out in the late summer and early fall was confirmed by the International Energy Agency*s October *Monthly Oil Market Report*, which noted that OPEC*s crude extraction rose 710 kb/d from its August level to 29.9 mb/d, and that 540 kb/d of this increase came from Iraq as it recovered from wartime disruption. Not counting Iraq, OPEC extracted 27.58 mb/d, versus sustainable capacity (i.e., production levels which can be reached in thirty days and maintained for ninety days) of 27.94 mb/d, leaving spare capacity of just 410 kb/d. With Iraq added, OPEC*s total spare capacity in September was just 580 kb/d. The IEA added that “OPEC may still be able to call on an additional 1.5-2.0 mb/d of surge capacity over and above strictly sustainable levels.”[19] If what Matthew Simmons has revealed about giant fields, especially Ghawar, is true, this claim is dubious, which means that sustaining the extraction surge will be difficult at best.

Fourth, Russia is a main driver of the 2003-2004 output surge, but whether Russia*s output will keep growing this briskly is problematic. The energy analysis firm Wood Mackenzie forecasts that – given enough extraction and transportation investment – output could reach 12 mb/d by 2010. Russia apparently does have abundant oil, perhaps as much as 100-120 Gb, perhaps 60-70 Gb of it proved reserves, mostly in Western Siberia.[20]

There are, however, serious difficulties. Russia is a mature region, and for most of the 20th Century was governed by the Soviets, who stressed maximizing short-term output to the detriment of reservoir management, drilling too many wells and flooding fields with water. Consequently, Russian fields are plagued with declining oil flows per well, falling reservoir pressure, and high water cuts and operating costs. Soviet reservoir mismanagement badly damaged several fields, including the Siberian giant Samotlor, which once yielded over 3,500 kb/d but as of 2001 produced just 319 kb/d. As of 2000, according to a study by Aton Capital Group, a Russian investment bank, Russia*s average daily well flow was just 55 barrels, and average water cut was 82 percent. Among major Russian oil companies, LUKoil, for example, had an oil flow per well of 64 barrels, and a 77 percent water cut; Yukos had a flow of 80 barrels per well and a 77 percent water cut; TNK a 70 barrel flow per well and a 91 percent water cut. Samotlor*s water cut in 2000 was 94 percent. Moreover, Russian average reserve recovery rates have fallen from almost 50 percent in 1965 to 35 percent in 2000.[21]

> *“...Russian fields are plagued with declining oil flows per well, falling reservoir pressure, and high water cuts and operating costs. Soviet reservoir mismanagement badly damaged several fields...”*

Recent developments have been mixed. Water cuts at some fields were higher by end-2002; Samotlor*s hit 94.2 percent. Russia*s oil companies are working hard, however, to improve output per well and reduce water cut by decommissioning some old, watery fields, enhancing recovery at others, and drilling new wells, which have higher well flows and low water cuts. LUKoil trimmed overall water cut from 76.9 percent in 2001 to 76.6 percent in 2003. Likewise, Sibneft raised its average daily flow at active production wells from 88 barrels in 2000 to 140 in 2002, and reduced water cut from 66.8percent to 61.1 percent. These encouraging results have, of course, required large investments in production technology.[22]

This is the crux of the matter. Wood Mackenzie*s 12 mb/d peak in 2010 assumes that all needed investment will be forthcoming. This means estimated capital expenditure of about $11-$13 billion a year in 2005-2013 for exploration and production, and total capital expenditure of $214 billion ($180 billion in 2003 dollars) in 2003-2020.

Analysis of Russian firms* financial statements and published plans indicates that in the near term actual capital spending could be $4-6 billion less per year than the amount needed to push extraction to this level. Wood Mackenzie*s more realistic "base case" forecast, factoring in constraints on investment and other limitations, sees output peaking at 10.4 mb/d in 2010. This is quite near the 10.0 mb/d projected by ASPO, a supposedly pessimistic group. And it entails a projected increase from 2004*s projected 9.2 mb/d of +1.2 rnb/d over six years, which implies slower annual increases than those seen recently (see Table 3).[23]

Recently, prominent Russian officials have said that output will grow more slowly or even drop. Sergei Oganesyan, chairman of Russia*s Federal Energy Agency, said in October that daily output could hit about 10 million barrels in a year or two, "But I think that*s the maximum possible for at least a decade." On November 9, Yuri Shafranik, head of the Russian Union of Oil and Gas Producers, said that Russia was now at maximum possible output, that only further oil price increases could increase it, and that since these are unlikely, production "will be automatically limited in two years* time." And LUKoil has announced an output target for 2005 implying just four percent growth from 2004 levels, far below growth in recent years.[24]

It seems most likely, then, that Russian output will indeed grow for a few years, although more slowly, but then level off or perhaps decline. This implies that Russia will have trouble replacing output declines elsewhere, let alone keeping world output growing.

Fifth, attempts to rapidly boost output risk damaging reservoirs and reducing or even terminating future extraction. There are, alas, several precedents of reservoir damage through aggressive secondary and tertiary recovery. Beside the Soviet-era damage to Russian fields, recovery enhancement through horizontal drilling damaged the Yibal giant field in Oman. Yibal began producing in 1968, and Petroleum Development Oman kept output high for years with water injection. In 1994, PDO opted for horizontal drilling. With some 500 horizontal wells drilled, Yibal*s output peaked at 225-250 kb/d in 1997, then collapsed to about 80 kb/d of oil and 700 kb/d of water in 2003. Yibal now apparently produces just 40-50 kb/d.[25] So insofar as the output surge is due to aggressive attempts to get more from old fields, it may be self-limiting.

Sixth, more major producers may have peaked in the past two years or will peak soon. From Table 1, Denmark may have peaked in 2002, although caution is in order: only continued subsequent decline in output can confirm a peak. The EIA*s crude oil data reveal that Brazil*s output went from 1,455 kb/d in 2002 to 1,550 kb/d in 2003 and (so far) 1,470 kb/d in 2004, indicating possible peak in 2003 – though, again, only time will tell. Mexico is likely to peak in a year or two. China*s State Information Center predicts that China*s crude output will peak in 2015 at 200 million tons, or 1466 Gb, or 4,106 kb/d.[26] Given that China*s giants, which supply the majority of her output, are watering out, this date may be optimistic. As more major producers peak and decline, the likelihood of sustaining increased production is whittled away, making world peak more likely.

Finally, because several years elapse between finding fields and getting them into production, any output increase in the near future must come from oil already known to exist – which takes us to the vexing issue of proved reserves, i.e., oil which can be extracted from known reservoirs under current economic and technological conditions. Some companies* reserve claims may be questionable. Shell Oil, for example, reduced its reserves four times in 2004, for a total reduction of 4.47 Gb.[27]

Great controversy surrounds reserve claims by OPEC members. After OPEC decided in the 1980s to base production quotas partly on reserves, many members abruptly increased their reserves substantially. As of the end of 2003, OPEC members claimed a total of 882 Gb in proved reserves (up from 475.3 Gb at end-1983), with, for example, Saudi Arabia reporting proved reserves of 262.7 Gb (up from 168.8 Gb at end-1983), Iran 130.7 Gb (versus 55.3 in 1983), and the United Arab Emirates (U.A.E.) 97.8 Gb (versus 32.3 in 1983). Some oil analysts, such as ASPO*s founder, geologist Colin Campbell, dismiss the increases as politically driven. Recently, oil economist Mamdouh Salameh, a consultant to the World Bank, took a hard look at the matter. Based on his own calculations from OPEC discovery, extraction and consumption data, he argued that a "more reasonable estimate" would be not the 819 Gb claimed at end-2002 but 519 Gb, 300 Gb less. Salarneh*s revised end-2002 proved reserves for Saudi Arabia, Iran, and the U.A.E. were 181.85, 63.69, and 37.36 Gb, respectively. The 519 Gb figure, he noted, cuts ultimate world reserves from

TABLE 5: REGULAR OIL AVERAGE ANNUAL DISCOVERY, EXTRACTION,AND DIFFERENCE, 1931-2002, BY DECADE (Gb)			
Period	Average annual discovery	Average annual extraction	Difference
1931-1940	15.6	1.8	+13.8
1941-1950	20.6	2.8	+17.8
1951-1960	32.2	5.7	+26.5
1961-1970	46.1	11.6	+34.5
1971-1980	31.8	20.1	+11.7
1981-1990	16.7	19.4	-2.7
1991-2000	12.2	21.9	-9.7
2001-2002	8.3	22.6	-14.3

Source: ASPO

2,100 to 1,800 Gb.[28]

If OPEC*s reserves are indeed substantially lower than their official claims, then there will be a considerably smaller amount of recoverable oil to draw upon, meaning that the output surge will be hard to maintain. Moreover, a smaller recoverable oil endowment obviously implies an earlier peak than a larger one. Energy analyst Richard Duncan recently generated oil peak forecasts with different estimated ultimate recoveries (EURs), and found that an EUR of 2 trillion barrels generates a peak in 2007, while a 3.3 trillion barrel EUR yields peak in 2010.[29]

Oil Discovery Collapsed As Consumption Exploded

But won*t the oil price runup provoke a flood of oil discovery, and won*t this prevent peak and decline? Not necessarily. Whether or not more oil will be found depends, ultimately, on whether or not it exists, which is a matter of geology, not economics. Arguing that if price gets high enough there will be massive oil discovery is like telling drought-stricken farmers that when the price of water gets high enough, it will rain. Oh? It will rain if the physical conditions are right for it, and not otherwise. So it is with finding oil. High prices induce exploration. They do not guarantee discovery.

Moreover, in recent decades oil discovery has collapsed, while extraction has kept rising to meet rising oil demand. For most of the 20th Century, oil discovery far exceeded extraction. Table 5 presents the discovery and extraction trends for what ASPO defines as "regular oil." Note that in the 1931-1970 period, humanity found from four to almost nine times as much regular oil as it extracted. Since then, the relationship between the trends has reversed; in 2001-2002 extraction averaged 22.6 Gb a year, while discovery averaged just 8.3 Gb, for a deficit of -14.3 Gb; we were extracting almost three times as much as we were finding.[30]

Regular oil discovery peaked in 1965. Beginning in 1984, extraction has exceeded discovery by a growing margin. There *was* a discovery hiccup in 1998-2000, but even this did not suffice to replace extraction, and was in any case modest compared to discovery in earlier decades. Then the decline resumed (Table 6).[31] The long discovery collapse is a strong sign that there isn*t much oil left to be found; if there is, we*d be finding far more than we are.

ASPO defines "regular oil" as oil other than oil from coal and bitumen, shale oil, heavy oil (e.g., oil from tarsands), deepwater oil, oil from polar locations, and natural gas liquids (e.g., propane, butane, and ethane extracted with natural gas and recovered in natural gas processing plants). Regular oil, then, roughly corresponds to conventional crude. The overwhelming majority of oil is regular oil. For example, of 26.87 Gb of oil extracted in 2000, regular oil accounted for 23.22 Gb (86.4 percent), heavy oil 0.51 Gb (I .9 percent), deepwater oil 0.5 Gb (1 .9 percent), polar oil 0.37 Gb (1 .4 percent), and natural gas liquids 2.3 Gb (8.6 percent).[32]

The centrality of regular oil to oil supply is crucial. Since most oil is regular oil, if regular oil discovery is collapsing, so, necessarily, is oil discovery as a whole. Moreover, as Colin Campbell has pointed out, and as common sense would indicate, oil must be found before it can be extracted, and therefore the discovery trend must be more or less repeated, after some years* lag, by the extraction trend. It necessarily follows that a decline in regular oil extraction is just a matter of time. Since the other kinds of oil, which are more difficult and costly to extract, are such small slivers of the total, even their

"An equally crucial development is that demand for oil is both huge and soaring, driven by explosive growth in Asia"

TABLE 6: REGULAR OIL ANNUAL DISCOVERY, EXTRACTION, AND DIFFERENCE, 1961-1970 AND 1981-2002 (Gb)

A. The [illegible] Years (1961-1970)

Year	Discovery	Extraction	Diff'ce.	Year	Discovery	Extraction	Diff'ce.
1961	50.19	8.01	+42.18	1966	36.89	11.73	+25.16
1962	49.33	8.68	+38.95	1967	33.81	12.62	+21.19
1963	55.21	9.31	+45.90	1968	32.91	13.76	+19.15
1964	55.54	10.13	+45.41	1969	37.25	14.93	+22.52
1965	56.83	10.80	+46.03	1970	34.86	16.15	+18.71

B. The Growing Discovery Deficit (1981-2002)

Year	Discovery	Extraction	Diff'ce.	Year	Discovery	Extraction	Diff'ce.
1981	20.74	19.49	+1.25	1992	15.21	20.90	-5.69
1982	18.53	18.41	+0.12	1993	8.23	20.88	-12.65
1983	19.27	18.34	+0.93	1994	6.81	21.12	-14.31
1984	16.94	18.68	-1.74	1995	8.33	21.57	-13.24
1985	14.69	18.55	-3.86	1996	8.39	22.08	-13.69
1986	14.56	19.40	-4.84	1997	9.24	22.81	-13.57
1987	14.76	19.39	-4.63	1998	10.84	23.05	12.21
1988	17.49	20.02	-2.53	1999	14.83	22.44	-7.61
1989	16.70	20.94	-4.24	2000	15.00	23.22	-8.22
1990	20.17	21.11	-0.94	2001	11.96	23.09	-11.13
1991	18.21	20.95	-2.74	2002	7.56	22.07	-14.51

Source: ASPO

greatly expanded development is unlikely to replace even, say, half the extraction of regular oil. A decline in regular oil extraction, then, means a decline in total oil extraction. Greater non-regular oil extraction can mitigate the decline, but not cancel it out.

The combination of improved exploration technology and a finite Earth also militates against a new discovery flood. The more places which have already been explored, the fewer unexplored places remain – and with better exploration we are less and less likely to miss good fields. As the Wood Mackenzie firm rightly observed, "as [technology] has accelerated hydrocarbons discovery, it has also added to the future problem. There is no escaping the fact that oil and gas are finite resources: the more that have been found the less that remain to be found."[33]

What*s more, few recent finds have been giants, and these are much smaller than those found earlier. In 2000, giants found before 1950 had an average production of 557 kb/d per field, whereas those found in the 1990s had average output per field of 126 kb/d. The largest giant found in the last thirty years, the Caspian region*s Kashagan (1999), has proven reserves of 7-9 billion barrels and is projected to yield 100 kb/d by 2005.[34] This is welcome, but modest compared to, say, Cantarell, Shengli, or even Samotlor.

In recent years, about two-thirds of total discoveries have been in deep water, a sign that less and less regular oil remains to be found. Last year, according to IHS Energy*s 2004 report on 10-year petroleum trends, some 13.9 Gb were discovered worldwide, which replaced only 50 percent of production. As Tables 5 and 6 show, this is well within the declining discovery trend. Discovery replaced liquids extraction for only three non-OPEC countries in both 1994-2003 and 1999-2003: Brazil, Kazakhstan, and Angola. These are mere middleweight major producers, with average 2003 output of 1,181 kb/d, slightly below the 1,578.4 kb/d average for the 48 majors (see Table 1). None of 2003*s discoveries was a giant; the largest were between 500 million and one billion barrels.[35]

Given all this, it is likely that discovery will keep falling. Unfortunately, as Simmons points out, as the aging giants decline, it will take "an exponential number of new small fields" to replace them. "Since almost all smaller fields tend to peak fast and then decline at rapid rates, this creates a treadmill of new fields required that few energy analysts ever envisioned."[36] That is, the oil industry will have to work harder and harder just to maintain extraction at current levels. The declining discovery trend necessarily means that future production will fall below current levels.

An equally crucial development is that demand for oil is both huge and soaring, driven by explosive growth in Asia. In 1993, according to BP, world oil consumption was 66.7 mb/d (24.3 Gb); by 2003 it had reached 78.1 mb/d (28.5 Gb). In that period America's consumption, the world*s largest, rose from 17.2 rnb/d to 20.1 mb/d, while China*s more than doubled, from 2.9 mb/d to almost 6 mb/d, making China the world*s second largest oil consumer. India is now the sixth largest; its consumption rose from 1.3 mb/d to 2.4 rnb/d. Importantly, demand growth is accelerating. Per BP data, from 1993 to 2003 annual consumption grew an average of 1.1 nib/d. The International Energy Agency puts demand this year at 82.4 mb/d (30.1 Gb), up 2.7 mb/d (3.4 percent) from its 2003 figure. and forecasts 83.85 mb/d (30.6 Gb) for 2005, up *1.5* mb/d (1.8 percent) from 2004. Demand is likely to keep surging. Indeed, the World Markets Research Centre points out that if demand keeps rising at 1.8 percent a year, supply must rise to about 100 mb/d by 20l5.[37] Where will all this additional oil come from?

Taken together with a declining discovery trend, exploding demand means that the extraction-discovery gap will keep growing. This means that rapidly rising demand must be met mainly by accelerating drainage of fields which are already producing, driving them toward earlier peaks and faster depletion, while less and less new oil, from smaller and harder to extract sources, comes on stream to compensate. Now, common sense would suggest that the more rapidly the abundant, easily-accessed share of a finite resource is removed, the sooner extraction will start dropping, because what*s left is both present in smaller lots and harder to get. This implies that the combination of ac-celerating demand growth and declining discovery will push extraction into peaking sooner rather than later.

New Oil Frontiers Can't Replace Old Ones

But what about emerging producers in Asia and Africa, and deepwater fields? Returning to Table 1, we see that African and Asian producers such as Angola, Malaysia, Equatorial Guinea, Vietnam, Sudan, and Thailand have outputs far smaller than those in the Persian Gulf; so far only Angola and Malaysia have come close to extracting a million barrels a day. Obviously, these small fry cannot offset the fading of the Persian Gulf*s giants. Indeed, some of them, such as Congo (Brazzaville) and Gabon, have already peaked and are declining rapidly. As for future extraction, as of end-2003, Africa*s proved reserves were 101.8 Gb, and Asia Pacific reserves were 47.7 Gb.[38] Salameh*s *conservative* estimate of Saudi Arabia*s reserves is 181.85 Gb. These two regions combined have substantially less.

The story is similar for deepwater oil – oil under the sea floor, in at least 500 meters of water. For one thing, deepwater wells peak and decline just like their landlubber cousins, and apparently very quickly. A report on Gulf of Mexico deepwater oil by the Department of the Interior*s Minerals Management Service shows that newer wells in the Gulf have much higher outputs than older ones, but their extraction almost invariably shoots up at first, peaks very early, and then falls off rapidly, in fact faster than the older wells.[39]

Also, deepwater poses extreme challenges. It involves drilling in water which may be a mile or more deep, to total depths of up to 30,000 feet or more. Developing deepwater oil takes incredibly advanced technology, sometimes including equipment that rests on the ocean floor itself. A deepwater well can easily cost $50 million or more. Moreover, deepwater operations in the Gulf are vulnerable to disruption by hurricanes. ColinCampbell*s observation is apt: "no one would be looking for oil far offshore beneath 6,000 feet of water if there was anything else left that was easier.[40]

Finally, and most importantly, deepwater's potential is limited. Deepwater oil exists in only a few locations. As Merrill Lynch oil analyst Ivan Sandrea points out, most deepwater discovery and extraction is occurring in four provinces: Angola, Nigeria, Brazil, and the Gulf of Mexico. Total deepwater discovery in these "Big Four" areas was 47 Gb as of end-2002. Cumulative extraction from the Big Four was about 4.4 Gb as of end-2003, and in that year global deepwater extraction accounted for 3.6 percent of total world oil production. Moreover, discovery in the Big Four may have already peaked at 5.8 Gb in 1996, with Brazil*s discovery peaking in 1987, the Gulf*s in 1999, Angola*s in 1998, and Nigeria*s in 1996. Sandrea projects that Big Four deepwater extraction could peak in 2010-2013. A more optimistic study by the Wood Mackenzie and Fugro-Robertson firms puts deepwater extraction so far at 6 Gb, remaining proved deepwater reserves at 44 Gb, and yet-to-find deepwater oil at 114 Gb. Even so, the total, 164 Gb, is less than Salameh*s estimate for Saudi Arabia*s reserves alone. And the study*s production forecast graph shows each of the Big Four peaking in 2008-20l0.[41]

Combining Asian and African proved reserves and the Wood Mackenzie/Fugro-Robertson proved deepwater reserves gives 193.5 Gb, not much above Salameh*s estimate for Saudi Arabia, and far less than his 519 Gb for OPEC*s total reserves. Development of these new frontiers will help, of course. But on current evidence, they cannot replace declines elsewhere.

The Upshot: Imminent Peak Likely

Some analysts have predicted that world oil extraction will peak in this decade. In 1999 Walter Youngquist and Richard Duncan, using production data from the 42 largest producing countries, estimated that peak would occur in 2007. A. M. Samsam Bakhtiari, of the National Iranian Oil Company, says peak is likely by 2006 or 2007, and will occur no later than 2008. ASPO projects regular oil peaking in 2005, and all oil peaking in 2006.[42]

Given all the foregoing evidence, these forecasts seem quite believable. To recapitulate: Depletion has become substantial and widespread among major producers, most of whom are past peak. Many of the giant fields supplying almost half our oil are showing signs of age and exhaustion. The recent production surge leans heavily on just a few post-peak producers, who themselves lean heavily on elderly giant fields. Several more major producing countries are likely to peak soon. Russia is a mature producer with serious problems, making sustained Russian output growth problematic. Discovery has collapsed while extraction is driven upward by exploding demand, implying earlier exhaustion of existing fields. Emerging producers and deepwater oil are not adequate to replace declining Persian Gulf producers.

It is quite likely, then, that oil extraction will indeed peak by 2010. Given all the factors involved, dating it precisely is somewhat risky. Recently extraction hit a bumpy plateau, and "peak" may turn out to be the highest bump in a plateau which could continue, say, three to five years. And only after recording several years of decline will we know that we have gone through the peak.

Peak does *not* mean that "we are about to run out of oil." Extraction will continue for decades post-peak. What it does mean is that post-peak extraction will be dominated by physical limits and will therefore necessarily keep falling. After peak, instead of supply adjusting upward to meet demand, as it has so far, demand will have to adjust – *downward* – to meet supply.

Our Vulnerability is Great

This means that we face serious difficulties. We are very dependent on oil, and ill-prepared to cope with its peak and decline. Oil is the world*s single largest energy source, supplying 37 percent of the world*s primary energy production as of 2000, and almost all of that oil is regular oil – the kind we aren*t finding very much of any more. Fossil fuels provide the overwhelming majority of the world*s energy, 85.3 percent in 2000. Most of the decline in crude oil*s share from 1970 was offset by increases in the shares of natural gas and natural gas liquids. The decline in fossil fuels* share was largely made up by increases in energy from nuclear power and hydroelectricity. Even so, nuclear power furnished just 6.4 percent of primary energy in 2000, and hydroelectric dams 6.9 percent. All other sources, including all renewables (wind, solar, etc.), accounted for just 1.3 percent of energy output in 2000 (see Table 7).[43]

"It is quite likely, then, that oil extraction will indeed peak by 2010. ...After peak, instead of supply adjusting upward to meet demand, demand will have to adjust downward to meet supply."

America is in the same predicament. Since we import much energy, it is appropriate to look at the sources of the energy we consume rather than those of the energy we generate. In 2000, America consumed 98.94 quadrillion British thermal units (Quads) of energy. Fossil fuels provided 85.0 Quads (85.8 percent), with 38.4 Quads (38.8 percent), the largest single share of America*s energy use, coming from oil. Natural gas accounted for 23.95 Quads (24.2 percent), and coal another 22.58 Quads (22.8 percent). Nuclear power furnished 7.86 Quads (7.9 percent); hydroelectric dams, 2.81 Quads (2.8 percent); waste, wood, and alcohol, 2.91

Quads (2.9 percent); geothermal energy, 0.32 Quads (0.3 percent); solar, 0.066 Quads (0.07 percent); and wind, 0.057 Quads (0.06 percent).[44]

The implications are grim. We are overwhel-mingly dependent on finite and rapidly depleting fossil fuels, especially oil, and will continue to be for decades, and a collapse in the oil supply means the collapse of our way of life, because the bleak truth is that other energy sources are not remotely capable of replacing oil. There are only so many places where building dams makes sense, and most are in use. Uranium, like the fossil fuels, is a finite mineral resource, and a scarce one at that. Chapter 15 of Garrett Hardin*s *Living Within Limits* is a sobering survey of the difficulties with nuclear power. (Also, nuclear plants will be prime targets for terrorists.) Leaning on wood, waste, and alcohol would deforest America and exhaust millions of acres of topsoil growing corn for ethanol.

As for solar and wind, everybody*s favorite, environmentally-friendly alternatives, even enormous crash programs to develop them cannot possibly replace oil, let alone all fossil fuels. A little simple arithmetic suffices to drive the point home. Subtracting 0.123 Quads (energy consumption from wind plus solar) from 38.40 Quads (energy consumption from oil) leaves 38.277 Quads. Dividing this by 0.123 Quads, we get 311.20. That is, the amount by which U.S. consumption of energy from oil *exceeded* consumption of wind and solar energy was *311.20 times as large* as our consumption of wind and solar energy. To convert this to a percentage figure, we multiply by 100, and learn that fully replacing oil as an energy source would require a 31,120 percent increase in the amount of energy obtained from wind and solar. Totally replacing America*s fossil fuel energy consumption with wind and solar is even more daunting: 85.0 Quads0 versus 0.123 Quads. It works out to a 69,006 percent increase.

Perhaps we can pull it off, but it means building tens of thousands of windmills and thousands of square miles of solar collectors, which would take decades and cost trillions. But where will the energy needed to build and install all these windmills, solar panels, and other necessary hardware come from? Fossil fuels, of course. There is nowhere else to go for the huge energy inputs needed to reconfigure our energy sector. And these fuels will be increasingly scarce and expensive.

An obvious implication of these figures is that biomass, wind and solar energy cannot possibly support anything remotely like today*s populations at anything like modern living standards. Biomass, wind and solar can support only much smaller populations, living far more modestly than we do now. That, in fact, is exactly what these energy sources did for millennia. Modern industrial civilization and affluence require gargantuan quantities of cheap and utterly reliable energy. The Industrial Revolution could not have occurred without coal. Only fossil fuels make our way of life possible. Does anyone really believe that an automobile plant, a foundry, a steel mill, a sewage treatment plant, or a large modern hospital can run on wind or solar power? Or that a city the size of Detroit or Los Angeles could get its electricity from

TABLE 7: WORLD PRIMARY ENERGY PRODUCTION BY SOURCE, 1970-2000, SELECTED YEARS, QUADRILLION BTU
(percentage shares of total in parentheses)

Year	Coal	Natural Gas	Crude Oil	Natural Gas Liquids	All Fossil Fuels	Nuclear	Hydro-electric	Other	Total
1970	62.96 (29.2)	37.09 (17.2)	97.09 (45.1)	3.61 (1.7)	22.75 (93.2)	0.90 (0.4)	12.15 (5.6)	1.59 (0.7)	215.39 (100.0)
1975	66.20 (26.5)	45.67 (18.3)	113.08 (45.3)	4.12 (1.7)	229.07 (91.7)	3.85 (1.5)	15.03 (6.0)	1.74 (0.7)	249.69 (100.0)
1980	72.72 (25.1)	54.73 (18.9)	128.12 (44.3)	5.10 (1.8)	260.67 (90.1)	7.58 (2.6)	18.06 (6.2)	2.95 (1.0)	289.26 (100.0)
1985	84.09 (27.2)	64.22 (20.8)	115.40 (37.3)	5.82 (1.9)	269.53 (87.2)	15.30 (5.0)	20.56 (6.7)	3.67 (1.2)	309.05 (100.0)
1990	93.17 (26.5)	75.87 (21.5)	129.50 (36.8)	6.85 (1.9)	305.39 (86.7)	20.31 (5.8)	22.56 (6.4)	3.95 (1.1)	352.22 (100.0)
1995	90.59 (24.8)	80.24 (21.9)	133.32 (36.4)	8.16 (2.2)	312.31 (85.4)	23.21 (6.30	25.61 (7.0)	4.77 (1.3)	365.91 (100.0)
2000	91.7 (23.0)	91.02 (23.0)	146.50 (37.0)	9.36 (2.4)	338.05 (85.3)	25.51 (6.4)	27.25 (6.9)	5.29 (1.3)	396.11 (100.0)

Source: Energy Information Administration

burning wood?

Any feasible mix of future energy sources, then, will necessarily be dominated by hydrocarbons, and as they become scarcer life is going to get harder. Which takes us to our final point: the consequences of peak are almost too terrible to think about. Since everything we do, produce, and consume uses energy, scarcer oil will mean higher energy costs and therefore higher prices for everything. We will likely face an energy famine, which means severe economic contraction: lower employment and output. Smaller and poorer economies will have a harder time supporting every human endeavor, such as supporting aging populations and providing health care. As alluded to earlier, shifting to alternative energies will be harder and costlier, and perhaps impossible.

Declining availability of oil will collide with population growth, so less and less oil will be available per person. The Census Bureau projects that world population will reach 6.81 billion in 2010, 8.11 billion in 2030, and 9.05 billion by 2050. Meanwhile, ASPO projects that regular oil extraction will plummet from 21.35 Gb in 2010 to just 7.33 Gb by 2050, and that extraction of all oil will fall from 28.74 Gb to 11.54. Per capita oil supply will collapse accordingly. Table 8 gives historical and projected data for population, oil extraction, and per capita oil supply. Whereas in 2000 enough oil was extracted for each person to have 4.41 barrels, there will 1.28 barrels per person – only 29 percent as much – in 2050. Note that per-capita oil supply peaked around I980.[45]

In 1950 most of humanity, including the relatively comfortable West, was much poorer than it is now. Oil*s most likely replacements are coal and natural gas, which are finite and depleting. Non-fossil fuel sources can replace only a slice of the energy from oil. The necessary implication of oil peak and decline plus continued population growth, then, is that the people living in 2050, especially in the oil-guzzling West, will be much poorer than those alive now.

Worse outcomes are possible. Some energy experts, such as Campbell and Richard Heinberg, hint that the peak and decline of oil will precipitate a human die-off. Others, such as Jay Hanson (see www.dieoff.com)

TABLE 8: HISTORICAL (1950-2000) AND PROJECTED (2010-2050) ANNUAL OIL PRODUCTION, WORLD POPULATION, AND BARRELS OIL PER CAPITA					
Year	(1) Regular Oil Extraction, Gb	(2) All Liquids Extraction, Gb	(3) World Population, billions	(1)/(3) = (4) Barrels Regular Oil per Capita	(2)/(3) = (5) Barrels All Liquids per Capita
1950	3.76	3.96	2.56	1.46	1.55
1960	7.51	7.95	3.04	2.47	2.62
1970	16.15	17.12	3.71	4.35	4.61
1980	20.90	22.82	4.45	4.69	5.13
1990	21.11	23.78	5.28	3.99	4.50
2000	23.22	26.87	6.09	3.81	4.41
2010	21.35	28.74	6.81	3.14	4.22
2020	15.72	23.49	7.51	2.09	3.13
2030	11.92	19.30	8.11	1.47	2.38
2040	9.05	15.36	8.62	1.04	1.78
2050	7.33	11.54	9.05	0.81	1.28

Sources: ASPO, Census Bureau

regard a die-off as inevitable. We should not dismiss the possibility out of hand. It has happened before.

Of course, there could be pleasant surprises. We might find more large giant fields. But given resource finitude, these will just postpone the inevitable. We might see breakthroughs in developing other energy sources or technologies. But we probably won*t unless we accept the reality of oil peak and make a bigger effort to cope with it than we are making now.

NOTES

1. “Extraction” is correct, because humans do not produce oil, they extract it from the earth. Nevertheless, extraction is almost universally called “production” We shall use the two terms interchangeably.

2. Sources consulted: ASPO, Production by Country & Peak Date, spreadsheet, July 2003; U.S. Department of Energy, Energy Information Administration thereafter, U.S., DOE, EIAI Table 2.2, World Crude Oil Production, 1980-Present, at www.eia.doe. gov/pub/international/iealf/table22; U.S., DOE, El A, Table G. I, World Production of Crude Oil, Natural Gas Plant Liquids, and Other Liquids, 1980-present, at Ibid.; BP, Statistical Review of World Energy full report workbook 2004, table, Oil Production (thousand barrels daily), *1965-2003*, at www. bp.com/statisticalreview2004. The various sources define oil differently: BP includes natural gas liquids; EIA*s “crude” includes oil from shale and tar sands, whereas ASPO*s “regular” excludes it, this made remarkably little difference for which countries peaked when, since the overwhelming majority of oil being produced is crude oil. The two most comparable seemed to be ASPO*s “regular” and EIA*s “crude,” therefore ASPO is the source for countries peaking in the l950s and l960s, and EIA is the source for all others.

3. Table 1 source: BP, *BP Statistical Review of World Energy 2004,* p. 6, Table: Oil Production (thousand barrels daily), 1993-2003.

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5. Table 3 sources: Table I and its sources. Annual change calculations mine.

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