Dr. Richard Duncan has done extensive modeling of the Global Hubbert Peak using Stella®. Based on his investigations, he has proposed The Olduvai Theory of Industrial Civilization. Following are links to several of Richard Duncan's papers and letters.

- In a letter to President Clinton, Dr. Duncan describes a critical issue that emerged at the May 8-11, 1997 Princeton Space Studies Institute (SSI) conference regarding the Looming Alliance of Muslim Petroleum Exporting Countries ("AMPEC")
- **World Petroleum** “The World Petroleum Life-Cycle: Encircling the Production Peak.”
- **Mexico's Petroleum Exports**: Safe Collateral for a $50 Billion Loan?

Dr. Duncan offers to all interested parties his Heuristic / Numeric model, running under Stella® which is available from High Performance Systems, Inc. You may obtain a full operating copy of Stella, or rely on their economical Run-Time module which allows you to view and change Dr. Duncan's model to produce plots, but does not allow you to save your changes.

Stella templates of Dr. Duncan's models are available for the world and countries combined in regional models for:

- Africa
- Asia / Pacific)
- Europe
- the Former Soviet Union
- the Middle East
- North America
- South and Central America

These regional models are combined to create an integrated model of the seven regions of the World. The world model also characterizes The Looming Alliance of Muslim Petroleum Exporting Countries ("AMPEC").

To obtain copies of these templates:

- for the Mac
- for the PC
The Olduvai Theory of Industrial Civilization

1. Pre-Industrial Phase [c. 3,000,000 BC to 1765]
   - A = Tool making begins (c. 3,000,000 BC)
   - B = Fire use begins (c. 1,000,000 BC)
   - C = Neolithic Agricultural Revolution (c. 8,000 BC)
   - D = Watt's steam engine, 1765
   - Interval D-E is a transition period.

2. Industrial Phase [1930 to 2025, estimated]
   - E = Industrial Civilization is defined to begin in 1930 when the leading-edge value of energy-use per person reached 37% of its peak value.
   - F = Peak of Industrial Civilization, c. 1978: confirmed by historic data published by BP, IEA, USCB, UN, etc.
   - G = World average energy-use per person continues to fall, 1996
   - H = Industrial Civilization is defined to end when energy-use per person shrinks to 37% of its peak value, forecast to occur by 2025. Life-expectancy (X) is estimated to be less than 100 years.
   - Interval H-I is a transition period.

3. Post-Industrial Phase [c. 2100 and beyond]
   - J, K, and L = Recurring future attempts at industrialization fail.
May 13, 1997

President William J. Clinton

The White House
1600 Pennsylvania Avenue NW
Washington, DC 20500

Dear President Clinton:

Re. US National Security Threatened by a New Alliance of Muslim Petroleum Exporting Countries ("AMPEC")

As you know, we Americans now import more than 50% of the petroleum we use. In fact, in 1995 18% of our imports came from the Muslim Middle East alone, and 27% from all the Muslim exporting countries.

Moreover, in 1995 40% of Europe’s petroleum imports came from the Middle East, and 58% from the Muslim exporting countries. In Japan, 77% came from the Middle East, and 92% from the Muslim exporting countries.

The percentage of World petroleum exports from Muslim countries will, willy-nilly, continue to increase until (perhaps by 2010) the Muslim countries will control nearly 100% of the World’s petroleum exports. This situation was revealed in my study, “The World Petroleum Life-Cycle: Encircling the Production Peak,” presented on 9 May 1997 at Princeton University. See especially Figures 2-4 (to be published in the 1997 Space Studies Institute Conference Proceedings - Attachment #1).

Significantly, after reading my SSI paper — a French petroleum geologist called and requested a forecast of the year that the petroleum production of the World’s 19 Muslim countries will exceed the production of all 181 non-Muslim countries. Per my forecast, this ‘cross-over’ will occur in 1999 (Attachment #2).

At Princeton, I gave the following “Thought Experiment”:

What if tomorrow Palestinian leader Yasir Arafat met with representatives from each of the 19 Muslim petroleum exporting countries and proposed an entirely new organization called the “Alliance of Muslim Petroleum Exporting Nations” — “AMPEC” for short?

This proposal alone could cause World stock markets to fall 50% in one day. And crucially, it could ignite both (1) a World Petroleum War, and (2) a World Holy War (called a “Jihad” by Muslims). I view an “AMPEC shock” as looming likely because powerful Muslim forces are pushing Mr. Arafat (and others) further every day.

Please be advised.

Sincerely,

Richard C. Duncan Ph.D., Director
INSTITUTE on ENERGY and MAN

Attachments (2)
Duncan Model of OPEC/Non-OPEC and Muslim/Non-Muslim Oil Production or the looming Alliance of Muslim Petroleum Exporting Countries (“AMPEC”)

OPEC/Non-OPEC
The next cross-over time (when OPEC oil extraction rate will exceed non-OPEC rate) is predicted to be in the year 2006.

Muslim/Non-Muslim
However, the next cross-over time for the Muslim countries will occur much sooner -- predicted to occur in 1998.

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Richard C. Duncan Ph.D., Director

http://www.hubbertpeak.com/duncan/ampec.htm (1 of 2)
After being awarded a Ph.D at Oxford in 1957, Dr Campbell joined the oil industry as an exploration geologist. His career took him to Borneo, Trinidad, Colombia, Australia, Papua New Guinea, the USA, Ecuador, United Kingdom, Ireland, and Norway.

He is now an associate of PetroPlan, advising governments and industry. He has published extensively, and his recent articles have stimulated lively debate. His views are provocative yet carry the weight of a wide international experience.

2000 March 23

**Evolution of Oil Assessments**

"Assessing the world's endowment of oil would not be a particularly difficult task were it not for the atrociously unreliable database on what has been found so far.... Critics relish pointing out how the assessment has evolved over time, taking it as evidence that depletion studies are meaningless. A good response would be to quote the famous economist, Maynard Keynes, who on being accused of inconsistency replied. 'When I have new information, I change my conclusions. What do you do? Sir.'"

The table in this report plots the essential statistics of successive assessments of conventional oil by Dr. Campbell and his associates since 1989.

2000 March 20

**The Myth of Spare Capacity**

from the Oil and Gas Journal, March 20, 2000.

"The fundamental driver of the 20th Century's economic prosperity has been an abundant supply of cheap oil.... Middle East share ... is now about 30%. Unlike in the 1970s, this time it is set to continue to rise.... Share will likely reach 35% by 2002 and 50% by 2009. By then, the Middle East too will be close to its depletion midpoint, and unable to sustain production much longer irrespective of investment or desire."

2000 January

**Letter to the Editor, Foreign Affairs**

Comments on the article "The Shocks of a World of Cheap Oil" by Jaffe and Manning in the January-February issue.

"What needs to be challenged ... is the assumption that oil prices will [remain] low, for which hardly any cogent argument or firm data are
1999 July

The Imminent Peak of World Oil Production
A Presentation to a House of Commons All-Party Committee, July 7th 1999

"The title of my talk is The Imminent Peak of World Oil Production. I would like to provide the evidence. It is of course a very large subject. There are colossal economic and political consequences. Indeed the very future of our subspecies – Hydrocarbon Man – is at stake. But I think that you are better qualified than I to assess these matters. I will therefore concentrate on the technical assessment."

1998 March

A Guide to Determining the World's Endowment and Depletion of Oil
© C.J.Campbell, March, 1998

"This is a simple guide to help you determine the world's endowment and depletion of oil. Why would you need to know? For as long as you can remember, you were able to drive to the nearest filling station and fill your tank.... lingering in the back of everyone's mind is the vague knowledge that oil is after all a finite resource that one day must run out...."

For this year's data, see Global Conventional Oil Endowment 1998.

1998

Global Conventional Oil Endowment [table]
© C.J.Campbell, 1998

This extensive table lists the global conventional oil endowment by country.

1998 March

Hear an interview with Dr. Campbell on National Public Radio
March 21, 1998 using Real Audio [click on "Oil Production"]:

"Oil Production: Scott [Simon] talks with oil industry expert Colin Campbell about Mr. Campbell's assertion that oil production will decline within the next decade... and that our current great oil prices are soon to be history. (5:00)"

1997

The Coming Oil Crisis
© C.J.Campbell, 1997
Dr. Campbell has released *The Coming Oil Crisis*, published by Petroconsultants, in association with Multi-Science Publishing Co. Ltd. It is a provocative, readable, well illustrated and thoroughly researched assessment of future world oil supply. The 210-page paperback discusses how much conventional oil remains to be produced, and its depletion pattern. It explains how to properly interpret published numbers, many of which are spurious or distorted by vested interests.

The book is non-technical, readable and realistic. It combines technical knowledge with a thorough grasp of the political and economic factors central to oil. It is above all a timely book, providing critical reading for management and government, bankers and investors, as well as being excellent academic material for a range of subjects including economics, environment, resources, geography, political and social studies and petroleum studies.

1996 January

**The Twenty First Century**

**The World's Endowment of Conventional Oil and its Depletion**

© C.J.Campbell, January, 1996

"No one should imagine that this is a simple subject. Public data are unreliable, and comment is often ill-informed or biased.... The world has now been very thoroughly explored so that nearly all of the oil provinces have been found...."
Assessing the world's endowment of oil would not be a particularly difficult task were it not for the atrociously unreliable database on what has been found so far. The analyst has therefore to spend much time and effort defining the data and removing the worst anomalies before addressing the nature of depletion. Critics relish pointing out how the assessment has evolved over time, taking it as evidence that depletion studies are meaningless. A good response would be to quote the famous economist, Maynard Keynes, who on being accused of inconsistency replied. "When I have new information, I change my conclusions. What do you do? Sir."

The following table plots the essential statistics of successive assessments of conventional oil:

They are not however strictly comparable because:

- the definition of conventional oil has evolved, now excluding tar sand/ heavy oil, deepwater and polar oil
- the scenario of the impact of Middle East control on price, demand and eventually production has evolved.

The early estimates were based on public domain data, before the degree of misreporting by industry and governments was appreciated.

It has been stressed that all numbers, which are quoted as computed, are to be generously rounded. No one should imagine that this is an exact science.

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Produced + Reserves = Discovered
Reserves + Yet-to-Find = Yet-to-Produce
Produced + Yet-to-Produce = Ultimate
Click here to see a plot of all variables

References

#1 Noroil, v.17/12 Dec 1989
#2 Golden Century of Oil
#3 Petrole et Technique, Oct 1993
#4 Energy Exploration & Exploitation, 13/1. 1995
#6 Oil & Gas Journal, April 7th 1997
#7 Scientific American v 278/3. 1998
#8 The National Interest, Spring 1998
#9 World's Non-conventional Oil & Gas, Pet. Economist
#10 Petroleum Expl. Soc. of Gt. Britain
#11 Geopolics of Energy, Jan. 1999
#12 Tomorrow's Oil, v 2/2 Feb.2000

Last Updated on 3/23/2000
The fundamental driver of the 20th Century's economic prosperity has been an abundant supply of cheap oil. At first, it came largely from the United States as it opened up its great territories with dynamic capitalism and technological prowess. But its discovery peaked around 1930, and inevitably led to a corresponding peak in production some forty years later. The focus of supply shifted to the Middle East, as its vast resources were tapped by the international companies. They however soon lost their control in a series of expropriations as the host governments sought a greater share of the proceeds. In 1973, some Middle East governments used their control of oil as a weapon in their conflict with Israel, giving rise to the First Oil Shock that rocked the world.

The international companies had however largely anticipated these pressures, and before the shock had successfully diversified their supply from new productive provinces in Alaska, the North Sea, Africa and elsewhere. These deposits were more difficult and costly to exploit, but production was rapidly stepped up when control of the traditional sources was lost. In part that was made possible by great technological advances in everything from seismic surveys to drilling. Geochemistry and better geological understanding made it possible to identify the productive trends, once the essential data had been gathered.

The industry found and produced the expensive and difficult oil from the new provinces at the maximum rate possible, leaving the control of the abundant, cheap and easy oil in the hands of the Middle East OPEC countries. The latter were accordingly forced into a swing role, making up the difference between world demand and what the other countries could produce. It should surprise no one that such an arrangement led to price volatility.

But these new provinces faced the same depletion pattern as had already been demonstrated in the United States. The larger fields, which are found and exploited first, gave a natural discovery peak. Advances in technology and operating efficiency also reduced the time-lag from discovery to the corresponding production peaks. Whereas it took the United States forty years, the North Sea, which is now at peak, did it in only twenty-six.

As discovery in accessible areas dwindled to about one-quarter of consumption, the industry, which fully appreciated this obvious link between discovery and production, turned its attention to the last remaining frontier, namely the deepwater. It is also subject to depletion with an even shorter time-lag between the peaks of discovery and production. Although much of the ocean is deep, only a few areas have the essential geology, giving a potential of not more than about 85 Gb (billion barrels) - enough to supply the world for less than four years. It is no panacea.

A combination of circumstances led to a dramatic fall in the price of oil in 1998. They included unseasonably warm weather; an Asian recession that reduced the demand for swing Middle East production; the collapse of the ruble, encouraging exports; and further turns in the UN-Iraq imbroglio. The market itself, which now included hedge funds and derivative merchants, had no alternative but to over-react because of its transparent short-term nature. The major companies, plainly seeing that
exploration could not underpin their future, took the opportunity of the price crisis to merge, successfully concealing their real predicament from the stockmarket. Budgets were slashed, and a climate of uncertainty led to an improvident draw on stocks. Everyone hung on the pronouncements of OPEC, imagining that it held the key.

Norway and Mexico offered to cut production to help support price. The OPEC countries themselves did everything possible to foster the notion that they could flood the world with cheap oil at the flick of a switch. It was a strategy aimed to inhibit investments in gas, non-conventional oil, renewable energy or energy saving that they feared might undermine the market for their oil, on which they utterly depend.

But it was a short-lived crisis, and before long the underlying resource and depletion pressures manifested themselves. Now, prices have rebounded with a staggering 300% increase in twelve months. Many of the famous oil analysts, who were predicting that oil prices would stay low forever, are changing their chameleon skins, as they watch prices soar through $30/b and break the chartists' barriers. With baited breath, they hang on the next word from OPEC. The US Secretary of Energy travels the world speaking of diversity of supply as he talks in vain to countries with little to offer in the face of depletion. Norway's role as the world's second largest exporter is critical, but it transpires that not a single well was closed by government edict. It is easy for the Norwegians to support price as they watch their old giant fields fall off plateau despite every heroic effort. Mexico has now confessed to the previous exaggeration of its reserves, which in 1999 fell, following an external audit, from 49 Gb to a more realistic 28 Gb. Meanwhile it is forced to undertake a mammoth nitrogen injection scheme to try to pump up the ageing Cantarell Field. It does not sound as if the Mexicans have much option but to watch their production fall.

The Middle East fields too are getting old, and in some cases, very old. Development drilling has continued unabated despite the fall in production. Venezuela's new production comes largely from infill drilling in old heavy oil fields, which is dependent on the amount of effort and investment. It does not sound as if it has many shut-in wells either. Its oilmen now speak of reduced capacity.

Logic suggests a future something like this:

1. OPEC makes some conciliatory noises about raising quotas in response to US pressure, wishing to maintain the illusion that its members can meet demand at will.

2. Norway and Mexico continue to support OPEC within the framework of such conciliatory words, making a virtue of necessity.

3. The market takes the hint and marks down the price of oil in an action that feeds on itself as the new flavour of the month permeates the ranks of speculators, hedge funds and derivative specialists searching for a quick buck. Refiners hold back from filling their tanks. Prices collapse to the low $20's, even perhaps plummeting briefly into the 'teens. People relax in the belief that the wolf has headed back into the forests. The famous flat-earth economists again cheer that market forces reign supreme.

4. But then a few weeks later, people begin to notice that fewer tankers are arriving. Norway says that storms have had an impact; Venezuela speaks of floods; Mexico claims restructuring; Saddam says he needs a spare part; King Fahd leads a delegation of puzzled Senators into the desert to show that all the wells are fully open.

5. The penny finally drops that there is no instant spare capacity in the sense of shut-in wells. The men at their screens start marking up prices.

6. A new upward momentum drives prices through the $40 barrier. When Air Force One makes a new panic tour to Norway, Mexico and the Middle East, it meets ashen faced oilmen saying that...
they have been working night and day to meet their quotas, but were unable to do so.

- The world, including OPEC, gradually appreciates that it faces a losing battle in trying to offset the depletion of the large, old, low-cost fields.

Of course, the Middle East can raise its production, since its depletion rate is so low, but it will be a long haul to bring in the ever smaller fields, which are all that remain, and exploit small extensions and secondary reservoirs in known fields. It is not a matter of simply opening a valve.

Middle East share of the world's supply of conventional oil was 38% in 1973 at the time of the First Oil Shock, but had fallen to 18% by 1985 as the new provinces flooded the world with flush production from giant fields. It is now about 30%. Unlike in the 1970s, this time it is set to continue to rise as, there are no new major provinces in sight. Share will likely reach 35% by 2002 and 50% by 2009. By then, the Middle East too will be close to its depletion midpoint, and unable to sustain production much longer irrespective of investment or desire.

It will be a hot summer. Strident politicians will accuse the oil companies or the Muslims of gouging the consumer, their minds having been further concentrated by a related collapse of an already grossly overheated stockmarket. No doubt, there will be calls to send in the Marines. But it is an election year, and the Presidential candidates will relish the agony of the dying days of the old administration. Democratic politicians cannot in practice plan for the future, but they can certainly win votes by reacting to crises. So, the hope is that the new President will look reality in the face and tell the people what he saw. If he does so, he will explain that we are not about to run out of oil, but that conventional oil will peak around 2005 and all oil, five years later. Once the people realise that they are not being gouged by anyone, they will face up to their predicament with courage and fortitude. They will be surprised at the number of solutions, some improving the quality of life, but finding oil that is not there to be found will not be one of them.

2000 March 7
8th January, 2000

The Editor
Foreign Affairs
58, East 68th Street,
New York, NY 10021

Dear Sir:

I would like to comment on the article "The Shocks of a World of Cheap Oil" by Jaffe and Manning in the January-February issue. One can of course agree with its main theme that a prolonged period of low oil prices would wreak havoc with the social, political and economic structure of those countries that depend heavily upon oil revenue. Nor can one do other than applaud the recommendation that the United States or NATO should avoid further ill-considered military engagements overseas.

What needs to be challenged, however, is the assumption that oil prices will be low, for which hardly any cogent argument or firm data are offered. I will examine this aspect of the paper.

1. The paper tries to justify an abundant oil supply on the alleged flaws in past oil resource estimates, casting derision on the Club of Rome's Limits to Growth report, which is misrepresented. In fact, it correctly stated that the known reserves of petroleum in 1972 were 455 Gb (billion barrels), a number which is incidentally wrongly quoted as 550 Gb by the authors. They fail to grasp that the term Reserves refers to prudent estimates of what remained to be produced from known fields at that time and did not include the amounts left to discover in new fields. The Limits to Growth report did, however, consider a case of the ultimate recovery being five times larger than the then reserves, namely 2275 Gb. This is close to the mean of consistent world estimates of conventional oil over the past thirty years, being confirmed recently by the US Geological Survey and International Energy Agency. The paper is not therefore justified in deriding the Limits to Growth report on this score.

It goes on to state that the world consumed 600 Gb between 1970 and 1990, again demonstrating a casual approach to oil statistics: the actual amount was 374 Gb.

2. The paper states bluntly that the world faces a glut of oil, not a pending shortage, without offering a shred of evidence or supporting data. It states that OPEC is currently holding 5 Mb/d off the market as if it were an established fact. How many wells are actually shut in? and where are they?

3. It refers to the impressive advances in technology, but misunderstands the import. Advances in geochemistry now make it possible to identify and map the oil generating trends once the essential data have been gathered, explaining the occurrences of oil and why the intervening tracts are barren. Advances in seismic technology, together with colossal computing power, now make it possible to see the smallest trap, even in some cases the oil itself. Accordingly, oilmen now have a much better knowledge of where oil occurs and where it does not, and are hence able to make more accurate estimates of the endowment in Nature.

The reality is that discovery peaked in the 1960s, despite all the technology, a worldwide search and a deliberate effort to find the largest remaining fields. The world now finds one barrel of conventional oil for every four it consumes, and there is no evidence that the downward trend can be reversed. Few would dispute that oil has to be found before it can be produced, or that peak discovery has to be followed by peak production. The authors ignore the critical evidence of discovery trends, which in
turn point to a global peak of production in the next few years. About half the yet-to-produce (reserves plus yet-to-find) lies in just five Middle East countries whose share of world supply is inexorably rising, as the International Energy Agency confirms.

4. The paper claims that market forces have released new oil supplies after the hegemony of the major companies, causing a fall in price. The market, with its derivatives component, does indeed set price on the marginal barrel based on sentiment and very short-term pressures, making no charge for depletion. A free oil market has always over-reacted and has a minimal impact on overall supply because most oil comes from the large old low-cost fields. It is not a good way to deal with a depleting resource as important as oil. Some measure of external control has always been required, whether exercised by Rockefeller, the Texas Railroad Commission, the major companies or OPEC.

5. The authors think that oil supply is controlled by politics not geology. Oil and politics are indeed never far apart, and politics can affect the rate of extraction to a degree. In Britain, Mrs Thatcher created an environment of hyper-activity during which most of the country’s oil was found. But if they brought her back, there is nothing even she could do to arrest the pending consequential steep decline in production imposed by Nature and the immutable physics of the reservoir.

6. The paper claims that America has ample supplies in the Western Hemisphere and Atlantic Basin to meet its future needs. It is not specific as to where this oil is, and fails to point out some important limitations. Mexico this year reduced its reserves from the previously exaggerated number of 44 Gb to 28 Gb following an external audit. Of Venezuela's 73 Gb reported reserves only about 29 are conventional oil: the rest being Heavy and Extra-Heavy oil, which is expensive and, above all, slow to produce. Some promising deepwater finds have indeed been made off Brasil and in the Gulf of Mexico, together offering promise of some 30-40 Gb, but the economics of deepwater operations demand high flow rates and rapid depletion. Nor can America rely on North Sea supply because production is at peak. Norway is currently the world's second largest exporter but its oil production is set to decline at about 6% a year as its old giant fields come off their designed production plateaux, despite heroic technological efforts.

Besides, the other inhabitants of the Western Hemisphere have their demands on oil too. Most countries in Latin America are already net importers.

The only way by which America, whose own production peaked in the early 1970s, can meet its future needs from local sources would be to reduce those needs.

7. The authors rightly draw attention to the disappointments of the Caspian, and speak of the growing dependence of Europe, India, China and Japan on Middle East oil. Do they admit that these regions are subject to resource constraints in their otherwise Cornucopian world?

One is left wondering what their motive was in writing such a misleading piece and how it came to be published. Was it perhaps intended to undermine the confidence of the Middle East in its control of world oil supply and price, or to remind us obliquely of the prospect of American military intervention? If the Middle East were forced to make the colossal investments needed to ramp up its production, global peak would be higher and the subsequent decline steeper, making a bad situation worse.

yours sincerely,

C. J. Campbell
The title of my talk is *The Imminent Peak of World Oil Production*. I would like to provide the evidence. It is of course a very large subject. There are colossal economic and political consequences. Indeed the very future of our subspecies – *Hydrocarbon Man* – is at stake. But I think that you are better qualified than I to assess these matters. I will therefore concentrate on the technical assessment.

My qualifications for taking up your time are that I have spent the last 45 years studying the subject both directly and indirectly. I have evaluated hundreds of oil prospects around the world. I have drilled many dry holes and even made a few discoveries. I have observed the oil industry from many angles, including its senior management. I have published two books and several papers on oil depletion.

I will start by giving you a short explanation of petroleum geology.

If you go to the coast near the village of Kimmeridge in Dorset, you will find a black clay which smells petroliferous and sometimes even catches fire. It was deposited 140 million years ago near the end of the Jurassic Period.

Chemical analysis shows that it contains up to 10% organic material, which itself contains various compounds characteristic of plankton and algae.

It is a truly remarkable clay, only about 100 metres thick, which was responsible for almost all the oil in the North Sea. It was deposited under unique conditions not found before or since in NW Europe over 600 million years of recorded history.

Geochemical and geological advances over the past 20 years have made it possible to understand the origin of hydrocarbon source rocks such as this Kimmeridge Clay. It was deposited in warm sunlit waters that allowed prolific blooms of algae. The Jurassic was a period of global warming. Britain was then closer to the tropics than now, due to plate tectonic movements.

Normally, the remains of the algae are destroyed as they sink to the seabed. But great rifts, analogous with the Red Sea, were developing in what is now the North Sea as the North Atlantic began to open. Stagnant conditions developed in the depths of these rifts, which preserved the organic material. Furthermore, relatively little other sediment was being washed in, so that the organic material was concentrated.
Let’s now look at samples from this same Kimmeridge Clay taken from a borehole in the eastern side of the North Sea. We will notice a difference. The organic material now contains admixtures of other organic substances that have the isotopic signature of plants. The area was closer to the Jurassic coast and more vegetal material was being washed in.

Tests in the laboratory show that if you heat the algal material you get oil, whereas if you heat the other stuff with plant remains you get gas. Furthermore, if you heat the oily rock too much it breaks down into gas.

Let’s now track the later history of this Kimmeridge Clay in the North Sea. The rifts were covered by several thousand metres of younger sediment which were laid down in a broad basin.

As the Kimmerdige Clay was buried, it became heated by the Earth’s heat flow. At a certain point, chemical reactions occurred similar to those observed in the laboratory. They led to the conversion of the organic material into oil and gas.

The conversion involved expansion so that the each droplet of oil and gas was born under a very high pressure. The pressure increased as the rocks continued to subside. Finally the droplets burst and the oil and gas forced its way upwards to zones of lesser pressure. It was an episodic movement. It occurred only briefly in geological time when the temperature and pressure thresholds were passed. In the North Sea, oil generation commenced when the source rock was buried to about 2000 m.

We now have to study where it moved to. The subsidence I have described was periodically interrupted by earth movements, even volcanic activity. The basin was folded and faulted into complex structures. They can now all be mapped in extreme detail thanks to advances in seismic surveying. It is as if we had a very high quality X-Ray of the earth, showing every feature in three dimensions.

We have to unravel geological conditions of great complexity. I will simplify to consider three different situations.

**Oil Migration**

- First, let’s consider the case where the source-rock is buried under a thick sequence of uniform clay. The oil and gas will move upwards along the hair line fractures until pressure equilibrium is reached. The result is an un-exploitable disseminated deposit.
- Second, let’s look at the case where the oil, as it moves upwards, encounters a porous sandstone, rising to the surface at the edge of the basin. The pores in this carrier bed contain water. The oil is lighter than the water, and floats upwards to the surface where it escapes and is lost.
- Lastly, we come to the third case where the carrier bed has been folded or faulted. The oil floats upwards, but this time it cannot escape, being trapped in the highest part of the structures. Such traps form oilfields.
- But we are not quite home yet, because the trap has to be sealed by the rocks above it. Such seals are never perfect so that the oil and gas leak over time.

**A very rare combination**

This slide is an illustrative map of an oil province. It explains why oilfields depend on a very rare combination of circumstances. There are many structures shown as white blobs. The yellow belt shows where there is a reservoir. The purple belt shows where there are generating source rocks. Only structures where the essential ingredients coincide can contain oil. It is of course still more complex...
than this.

I think I can summarise the position into a few key points.

- We now have a comprehensive understanding of petroleum systems. It has become relatively easy to identify and map them, once the critical information has been gathered from seismic surveys and exploration boreholes.
- The prolific generation of oil and gas was a very rare event in both time and place in the geological past. Furthermore, much that was formed was lost by leakage. As I said, in the North Sea, we rely on one unique event 140 million years ago.
- The world has now been very thoroughly explored with the benefits of this new understanding and the high resolution seismic surveys. About 90% of the world’s oil endowment lies in just 30 major petroleum systems.

![North Sea Generating Map](image)

This shows where oil was generated in the North Sea. It was generated in the coloured areas and nowhere else. Similar maps are now available for virtually the entire world. All such provinces have been subject to at least some exploration. All the promising areas have been thoroughly explored. There are good reasons why other areas receive little attention. There are of course details to fill in, but the general picture has become very clear. Some oil economists claim that if all the basins of the world were drilled as intensively as Texas, they would yield a huge amount of new oil. They are utterly mistaken for well understood scientific reasons.

Now, I would like to go to Norway and explain the pattern of discovery there. I choose Norway, because the Norwegians publish reliable information.

![Norway Hyperbolic](image)

This plots cumulative discovery against cumulative wildcats. These are the exploration wells that either do or don’t find new fields. By plotting discovery against wildcats we overcome the distortions from external factors such as government policy. The large fields were found first and discovery follows a hyperbolic model fairly closely. Exploration will end when the discovery curve becomes almost flat. This plot suggests that Norway’s total is just under 28 Gb.

![Parabolic Fractal](image)

This is a plot of the size distribution of the fields. We can see the close correlation with the theoretical parabolic fractal distribution. It gives a slightly lower total of 26 Gb

These models – and there are other statistical techniques – suggest that the total of Norway’s known basins is between 26 and 28 Gb. But I think that some of the more recent fields will prove a little bigger than currently estimated. I accordingly use judgment to slightly modify the theory, giving Norway an Ultimate Recovery of 29 Gb. Note how critical it is to have good data of past discovery both by quantity and date.

Similar plots have been made for every productive area.

It is also interesting to plot a company’s record

![Shell](image)
This shows Shell’s record. It has drilled about 3600 wildcats since 1885, finding 60 Gb oil. The fit with the hyperbolic model is remarkable. It suggests that if Shell drilled as many wildcats again, it would find only about 16 Gb. The falling discovery is despite a large budget, the best available technology and a deliberate policy to find the largest fields. The short explanation is that there has been progressively less left to find.

Amoco

We might look at another company, Amoco. It was much less successful because it was late into the international arena. It found about 15 Gb with 900 wildcats, but hardly anything with the last 600. It is no surprise that it was forced to sell out to BP.

The point is that all discovery curves are flattening.

The growing gap

Looking at the world as a whole, we see this growing deficit. Discovery peaked in the 1960s with a 60 Gb surplus. But that has given way to a deficit of almost 20 Gb. We now find one barrel for every four we consume.

The general situation seems so obvious. Surely everyone can see it staring them in the face. How can any thinking person not be aware of it? How can governments be oblivious of the realities of discovery and their implications? How is it possible, given the critical importance of oil to our entire economy.

There are several possible explanations, including denial, but one of the main reasons relates to the reporting of reserves. It is a huge subject, but I will try to reduce it to three cardinal issues

Explanations of confusion

- First, we need to distinguish all the many different categories of oil and assess their endowment in nature, their characteristics and above all depletion profile. Obviously, a Middle East well flowing at 20 000 b/d is very different from extracting a few barrels a day from a tar deposit. Deepwater and polar oil is different from oil in Texas. We need to know how each category can contribute to peak.
- Second, we need to define the probability ranking of our estimates so as to get the best estimates of what a field will actually deliver, such that statistically any revisions will be neutral.
- Thirdly, we have to backdate any reserve revisions to the discovery of the fields containing them.

Unfortunately the public database is extremely unreliable. I might here refer to BP’s Statistical Review which many people consider a valid source of information given its reputable author. It is in fact exceedingly unreliable. It simply reproduces data from a trade journal and does not reveal the Company’s own considerable knowledge. It is very unfortunate that a company of this standing should put out such misleading information. I don’t know why it does so.

There are several reasons why the public database is so unreliable and misleading.

- First, companies systematically under-report the size of discoveries for a host of good regulatory and commercial reasons. They refer to what they call Proved reserves which are much less than what the field will eventually deliver. They treat reserves as an inventory to be
booked as suits their commercial and financial needs.

- Second is the unreliable reporting by the major OPEC countries. This table shows two obvious flaws. First is the huge increase in the late 1980s, underlined in red. The sudden increase resulted from the so-called quota wars: quota being partly based on reserves. The second is shown in green. It is absolutely implausible that reserves should have remained so constant subsequently given the high production rates. Incidentally, 60 countries reported unchanged numbers last year. No right thinking person could accept such a data-set, yet it is embodied unnoticed in the public database.

But there is a third less obvious, yet much more important, factor. Clearly, nothing happened in the reservoir in these countries in the late 1980s. The reserve revisions — whatever the right reserve number is — should be backdated to the discovery of the fields containing them. They had been found up to 50 years before. Backdating has a huge impact on the discovery plot.

Popular image

This illustrates the popular image of growing discovery, based for example on BP’s public numbers. It fails to backdate revisions and has misled many analysts. They see reserves growing which they attribute to technology. In reality the growth was just in the reporting.

Real Discovery

This shows the true position with more realistic numbers properly backdated. It shows that discovery is flattening not growing.

It is fashionable to accuse oil companies of conspiracy, but I think the deception has more to do with differing mind-sets and objectives than conspiracy. Oil companies are in business to make money not plan the world’s future.

Backdating is obvious to an explorer. But the engineers who develop the fields over a long period of time soon forget the original discovery and report the revisions when they occur having no particular reason to backdate. The management takes the revisions as best suits their commercial image. Reserve growth makes a much better story than a dwindling asset, which is the reality.

Mostly, this lax reporting does not matter. But if we want to use the record of the past to extrapolate future discovery, we need to insert the right amounts and the right dates.

I should say something about getting more oil out the reservoir. You will hear a great deal about that. Now that falling discovery is widely recognized, hopes are pinned on getting more out of what has already been found.

I am sorry to say that reports of improved recovery are largely an illusion reflecting the reporting procedure rather than any particular technological achievement.

Prudhoe Bay

I might illustrate this by Prudhoe Bay. It is by no means exceptional. This plots annual production against cumulative production to show the end point. The operator internally estimated its reserves in 1977 at 12.5 Gb. But for a host of good commercial and regulatory reasons reported 9 Gb. The
depletion curve has been as straight as an arrow since 1991. It shows that the field will barely make the original estimate, despite all the considerable technology that has been applied. Yet many analysts are misled by the rise in the official numbers from 9 to 12.5 Gb.

Of course it is possible to go back to an old field developed long ago with poor technology and extract a little more oil from it by a range of well known methods, such as steam injection. But this is a phenomenon of the dying days of old onshore fields of the United States, Soviet Union and Venezuela. Most modern fields are developed efficiently from the beginning. In any event the addition contributes little in global terms and has no impact on peak.

Technology serves mainly to hold production rate as high as possible for as long as possible. That obviously makes the most profit. But it adds little to the reserves themselves and clearly accelerates the rate of depletion. The high depletion rate of Norway shows how efficient they have been at extending plateau production. The decline slope now becomes a cliff.

I hope I have explained why it is so difficult to obtain valid numbers and dates. It is hugely complex subject.

**Essential Parameters**

If we hired a detective to somehow penetrate the smokescreen, I think he would come up with numbers like this for what we can call "narrowly defined conventional oil". This is the stuff that has provided most oil to-date. It will also continue to dominate supply until long past peak. It excludes oil from

- coal and shale;
- heavy oil and tar,
- deepwater and polar areas,
- synthetic oil and
- natural gas liquids.

The contribution of these non conventional categories has to be added to get total supply, but their impact on peak is small.

The bottom line is that there is a rounded one trillion barrels left to produce.

**Distribution**

It is most unevenly distributed with about half lying in just five Middle East countries, due to that region’s unique geology, including particularly the widespread occurrence of salt which seals the reservoirs, preventing the escape of oil.

No one can dispute that you have to find oil before you can produce it. The curve of discovery clearly has eventually to control the curve of production that follows it after a time lag.

**Discovery curve**

Experience has shown that the exploration of a new province follows a standard pattern. It starts with the learning period. Boreholes have to be drilled and seismic shot to find out if the new area has the necessary geology. If it does not, it will never deliver no matter how much investment and technology is thrown at it.
But if it does have the ingredients, the larger fields are found first. They are too large to miss. These large fields give a natural peak.

This natural discovery curve has to be reflected in the production curve that follows. Production, like discovery, starts and ends at zero, and reaches a peak around the midpoint of depletion when half is gone.

The US-48 is a good example. Discovery peaked in the 1930s and production in 1971, despite ample technology, money and incentive. In the North Sea, peak discovery around 1980 is now being followed by peak production. It should surprise no one.

We can use this general curve to model depletion in most countries, adjusting for any special circumstances.

But it is not quite a simple as that because we have to recognize the swing role of the Middle East countries around global peak. They have large reserves and a low depletion rate. So they can make up the difference between world demand and what the other countries can deliver within their resource base.

Swing share was 38% at the time of the first oil shock in 1973. It fell to 18% by 1985 as flush production from new provinces, such as the North Sea, that had already been found before the shock, was dumped onto the market. I say dumped because had the major companies not lost control through expropriation, they would probably have managed things better.

Since then, share has been rising to around 30% to-day. This time it is set to continue to rise because there are no new provinces ready to deliver flush production, save perhaps the Caspian and that seems to be turning sour.

This allows us to develop some scenarios about future production. I will describe in a moment what seems a reasonable base case.

But before coming to that, I should say something about the International Energy Agency. It was established in the aftermath of the oil shocks of the 1970s, under a treaty signed by most OECD governments. It has a mandate to study oil supply and alert the OECD governments to dangers to supply. Note that the governments are treaty-bound to react and coordinate their response.

It is naturally a highly political institution. But nevertheless it did succeed this year to deliver a coded message. I am glad to say that the media is decrypting the message, as I gather the IEA intended.

I would say that this message from the IEA, the highest world authority on the subject, is dynamite. I am sorry to say that the European Commission remains in blissful ignorance; and I don’t have any confidence in the DTI either.

I will now explain what I think is a reasonable scenario

1) Oil demand will grow at 1.5% a year – slightly below the IEA estimate of 1.8% – until Swing
Share reaches about 35% in 2001.

2) The Middle East countries will then have the confidence to impose much higher prices, realising that they have no competition. They may even get such confidence sooner.

For example, they might read an official report showing that Norway’s production is set to halve by 2006. Norway is the world’s second largest exporter. The impact on Swing Share is obvious.

3) I think prices may briefly soar to very high levels due to the working of the market that sets prices on the marginal barrel. I believe that the market itself may be manipulated by hedge funds and similar insiders, who are in a position to talk price up and down. They must have made huge fortunes when prices recently rose 80% over a few weeks. Most forecasts now predict falling stocks by the last quarter as the insiders talk price up again.

4) I think that a price shock around 2001, if not before, from Middle East control is inevitable and will probably trigger a stockmarket crash.

5) I think that demand does become elastic above about $30/b, reacting to normal market forces, so higher prices may curb demand.

6) Nevertheless, I think it will be a time of great political and economic tension as Europe, America and Japan vie for access to Middle East oil. More missiles can be expected. The third world will be badly hit, being unable to afford imports. Agriculture is very dependent on oil.

7) But I expect that somehow a plateau of production, however volatile, will unfold around $30 a barrel. But the end of the plateau will soon come into sight.

8) It may have a fundamental impact on investment. Up til now, the investment community has believed in perpetual growth on which cycles are superimposed. The bottom of each cycle has been higher than its predecessor making capital appreciation the primary goal of investment. But the tensions of the oil shock and related events, including the colossal financial transfers to the Middle East, may create a new view.

After the many years of growth we may then experience a new downward trend, however cyclic. Share prices may sink to more realistic levels as the main focus will be on yield not growth. Capital will be destroyed.

9) The plateau has to come to an end by around 2008 when Swing Share will have passed 50% and the Swing countries in the Middle East will be approaching their depletion midpoint too. Production will then start its inevitable long term decline at about 3% a year. Increasing shortages will develop, and agriculture and transport will be seriously affected. The global market will come to an end because of high transport costs.

That is a scenario. There are of course many alternatives, but the range of possibility is limited given the resource constraints. These constraints are facts not scenarios. If by some miracle we could add 500 Gb of reserves – more than half as much as produced so far – it would delay peak by only ten years.

One indisputable fact stands out. Discovery peaked 30 years ago. It takes no feat of intellect to conclude that we now face the corresponding peak of production.
All hydrocarbons

But there are solutions. Gas and non-conventional oil production can be stepped up giving an overall peak around 2015. Gas will be useful but needs special management because it depletes very differently from oil on account of its greater mobility. The controlled plateau ends abruptly. The open market is not designed to deal with depletion.

Nuclear energy and coal production can be stepped up. The environmental hazards can presumably be solved by technology if efforts are made.

Renewable energy and above all energy savings can make really important contributions.

One problem is that all of these things take time to implement. Nothing is likely to be done without proper fiscal or price incentives.

I think it is absurd that the management of the depletion of the world’s supply of its most important fuel should be left to a few feudal families controlling the Middle East. The consuming governments should recognize where their interests lie.

They could for example ameliorate the tensions by introducing a Depletion Protocol such as I proposed last year.

But it is easier for them to react to a crisis than anticipate one. My hope therefore is that this talk will have helped you understand the nature of what is about to strike even if in practice you are unable to prepare.

Summary

I close with a simple diagram. Think of it as two tanks. The top contains what is Yet-to-Find and it is flowing into the second tank at a falling rate of about 6 Gb/a. The second tank contains what it left from past discovery. This tank is being drained at about 23 Gb/a rising : much faster than it is being filled. We take out four barrels for every one we put in.
The Imminent Peak of World Oil Production

By

C.J. Campbell
The stagnant trough

Conditions for prolific hydrocarbon generation

1. Algal flowering for oil; Plants for gas
2. A reducing environment
3. Critical balance of sediment influx
to preserve and concentrate
Oil Migration

1. Dissipated

2. Escape

3. Oilfield
THE VERY RARE COMBINATION

Reservoir Trend

Source Trend
North Sea oil generating trends
Causes of Confusion

Many vested interests

- Categories of oil and gas
  - Many different species - each with its own endowment and depletion rate
  - Peak driven by easy, cheap and fast to produce
- Nature of Reserve Estimates
  - Need best estimate not lowest
- Backdate revisions to discovery
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P50 Estimates by Petroconsultants

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"Technology marches onward"
PRUDHOE BAY FIELD

Operator in 1977 estimated 12.5 Gb but reported 9 Gb
### Parameters

**Conventional oil only (excl NGL)**

1. Produced 816 Gb
2. Reserves 821 Gb
3. Ultimate 1800 Gb
   - Discovered (1+2) 1637 Gb
   - Yet-to-Find (3-2-1) 163 Gb
   - Yet-to-Produce (3-1) 984 Gb

### RATES

- Consuming (rising) 23 Gb/a
- Finding (falling) ~6
- Depleting 2.2% /a
The IEA coded message

Why business will NOT be as usual

- Demand rises at 1.8% to 112 Mb/d by 2020
- Under a scenario with prices rising to $25

- How is the demand met?
  - NGL
  - Unconventional
  - Processing gains
  - Middle East (now 18 Mb/d)
  - Non Middle East
  - "Unidentified Unconventional"

- Reality
  - Oil not $25 when Middle East supplies 62%
  - "Unidentified Unconventional" not there
A proposed protocol

To lessen tension: buy time

- Countries not to produce above depletion rate
- Countries not to import infringements
- Important exemptions
  - Gas & gas-liquids
  - Non-conventional
  - New and small producers
- Countries to open reserves to audit
### The road to ruin

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<th>Yet-to-Find</th>
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**Reserves from the past**

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**Half in 5 M East countries**

**Consumption Rate rising**

23 Gb/a

One in : four out
1. INTRODUCTION

This is a simple guide to help you determine the world's endowment and depletion of oil. Why would you need to know? For as long as you can remember, you were able to drive to the nearest filling station and fill your tank. Briefly in the 1970s, there were shortages when certain Arab countries imposed an embargo on exports as a weapon in the Yom Kippur War with Israel, but it was a passing incident, now long forgotten. Well, not quite forgotten, for lingering in the back of everyone's mind is the vague knowledge that oil is after all a finite resource that one day must run out. At the time of the oil shocks there was all sorts of Doomsday talk, but it proved misplaced as we have had plenty of oil for the past twenty years, and there are still many reports that this happy state will continue. Will it?

Think for a moment: what if? Oil may not run out for a long time, but can we rely on cheap oil such as we have known? Is it cheap? I hear you say. Well, the answer is that although oil prices are well above average producing cost, yielding profit to the companies and huge revenues to the producing and consuming states, it is very cheap in relation to its replacement cost. In fact it is almost infinitely cheap. We are now finding less than six billion barrels a year but using 23: if we lived like that in our personal lives we would be facing bankruptcy. Discovery peaked in the 1960s and it should surprise no one that thirty years on we face the corresponding peak in production. The sad truth is that we have to find it before we can produce it. So a great discontinuity is approaching.

It is hard to think of any aspect of our modern life that is not vitally dependent on cheap oil-based energy: driving to work; the tractor in the field; the ships on the sea; the airliners overhead; not to mention the military with its thirst for oil. It is the same whether we depend on a rural bus in central India or a commuter train into Manhattan. We all use oil and have come to depend on it. If it were suddenly to cost double, we would certainly notice; and the new economy that would inevitably result would surely affect our lives in many important ways. It is not impossible that the new ways would be better, but different to be sure. It certainly would be a discontinuity.

Should we seriously expect such an upheaval? Well, yes. If we look back we see that history is full of them both local and regional. For centuries in western Norway, they lived by catching herrings, and in due course learnt to preserve them by canning. King Oscar sardines were famous the world over. Nobody much noticed the arrival of the domestic refrigerator at the end of the war, but within a few years it had almost ruined the fish canning business. Frozen fish was easier, and for the canners it certainly was a terminal discontinuity. Who would have imagined the once all-powerful Soviet Union would so suddenly implode from internal tensions; and what a discontinuity that proved to be for the world's arms manufacturers, who figuratively had to turn to making plough shares that were much less profitable. It appears that economists dedicate themselves to studying the trends and patterns of trade in the periods of calm between the discontinuities but don't often successfully predict the arrival of a discontinuity. It is unfortunate because it is the discontinuities rather than the intervening calms that shape our destiny. In any event, we can say that those who fail to react to a discontinuity will suffer; those who react survive; but those who anticipate prosper.
So why should I, as a humble individual, care about such things, you may wonder? Surely there are better qualified institutions, world authorities and governments who are aware of the situation and getting prepared? Unfortunately, there are not. Oil and oil price are hot potatoes. The politicians don’t get votes for preparing for a crisis; only for solving one when it comes as a perceived Act of God. Furthermore, there are many vested interests with motives to conceal, confuse or be economical with the truth. Besides oil is a very slippery substance that is not easy to understand or measure.

So if you want to be counted amongst those who prosper from the coming discontinuity, you have no alternative but to figure it out for yourself. If it were easy you would have no advantage. No one can fully evaluate the situation and know exactly what to do, but if you are marginally better prepared than the uninformed you may still enjoy a great advantage.

So this is a step-by-step guide to help you through the maze.

2. WHAT IS OIL ANYWAY?

In the summer of 1987 the tourist industry on the Adriatic coast of Italy faced disaster. The beaches were clogged with an evil smelling glutinous material; and the fishermen reported that the same stuff was clogging their nets and killing the fish. What had happened was that exceptional weather conditions in the near tide-less and current-free Adriatic had led to a huge proliferation of algae. These soft bodied microorganisms were extracting the oxygen from the sea and poisoning all life. The crisis lasted a few weeks before the weather changed. The glutinous masses sank to the seabed and things returned to normal.

This material is the origin of oil in a long and complex process. Simply stated, the process involves the following steps. First there have to be the climatic and physical conditions for prolific algal growth to take place. Second, the organic debris that falls to the sea (or lake) bed has to be preserved from oxidation by bottom-dwelling organisms or current action. Third, it has to be concentrated to provide the quantities needed to charge an oilfield. Lastly, it has to be buried by younger sediments over geological time so that it becomes heated sufficiently to be converted into petroleum. Algal material is the main source of oil, but sometimes there are admixtures of other organic debris, including vegetal remains that are gas prone.

3. WHERE AND WHEN WERE CONDITIONS FOR OIL FORMATION FOUND

In the same way as the Italian experience of 1987 was a very unusual event, so the conditions that led to the deposition and preservation of prolific oil source-rocks were extremely rare in the geological record both in time and place. Most source-rocks were laid down in tropical regions, some of which were later moved to higher latitudes by the plate tectonic movements of the continents. Periods of global warming may have helped. The late Jurassic, 150 million years ago, was one such period, responsible for the main oil source-rocks in the Middle East, North Sea and parts of Siberia. Another occurred in the mid Cretaceous, 90 million years ago, and was responsible for the oil in northern South America. Much of the oil in the United States comes from older sources, such as the Permian, 230 million years ago.

Conditions for the preservation of oil were equally rare. The main requirement was stagnant water to prevent the organic material being oxidized. The North Sea for example was a stagnant rift during the Jurassic, something like the present Red Sea, that was opening as the North American continent split apart from the European landmass and began to drift westward. The Middle East region was an extensive marine carbonate platform with internal stagnant sink holes and lagoons ideal for preserving the organic material. Sometimes lakes were satisfactory environments, as along the west coast of Africa before the Atlantic opened.
In global terms, the bulk of the oil occurs in a geological province known as the Tethys, a zone of rifting between the southern and northern continents, of which the Mediterranean and Gulf of Mexico are relics. Segments of what were previously in this zone were subsequently moved northward, explaining the paucity of oil in the southern hemisphere.

The world has now been so extensively explored that all the large oil provinces have been found, and the scope for finding an entirely new one of any size is now greatly reduced if not entirely removed. The question of source-rock is critical and explains the easily made observation that oil fields are clustered together in clearly defined geological trends, separated by huge areas that are entirely barren of oil.

Although the early explorers had a general idea that oil came from dark-looking shales, it is only in the last twenty years that advances in geochemistry have made it possible to clearly identify where and when it was generated. This knowledge made the world a much smaller place, emphasising the very finite nature of the resource.

References:


Campbell C.J. 1997, The Coming Oil Crisis, Multi-Science Publishing & Petroconsultants

Campbell C.J.,1998, Running out of gas: this time the wolf is coming; National Interest 51 spring

4. MIGRATION AND TRAPPING THE OIL

Once the organic material was buried to a depth of 2000-3000 m depending on the geothermal gradient, it was heated sufficiently of chemical reactions to transform it into oil and gas. The reactions involved expansion which together with the difference in density between the oil and the water preserved within the rocks led to the onset of migration. The oil and gas gradually moved upwards through the pore space in the rocks or along fractures until it encountered a porous and permeable interval, such as a sandstone layer, along which it could more easily flow.

The sediments in the oil basins have been generally folded and faulted by earth movements. The oil migrates upwards along the porous conduits until it is trapped at the top of a fold, against a fault or where the bed carrying it pinches out. Geologists and geophysicists can map these structures and determine if they are closed and sealed, such as to form prospects for drilling. Sealing is an important factor, because over long periods of geological time, oil and gas tends to dissipate and leak from the traps that once held it. Salt deposits form the most effective seals, and their widespread presence in the Middle East and for example the Permian Basin of Texas contributes to the prolific production of these areas. Oil and gas may migrate vertically to be trapped above where it was formed, or it may migrate laterally depending on the geological circumstances. In some areas, large quantities have migrated to shallow depths around the margins of the basins, where the deposits have been attacked by bacteria that leave behind bitumen and heavy sticky oil. If the oil source-rocks or traps are buried too deeply, the high temperatures crack the oil to gas. Finding more oil is not simply a case of drilling deeper.

This short description is sufficient to explain how oil and gas are formed and how once formed they migrate, much to be lost, but some to be trapped in accumulations large enough to be exploited.

Probably only about one percent of the oil generated has collected in accumulations large enough to be produced. The older the oil, the greater the risks of it being lost. Each individual field has its unique characteristics reflecting the long and varied geological circumstances to which it has been exposed. The oil itself varies greatly in composition and physical property for the same reason. This diversity explains some of the confusion surrounding how much there is.

Reference
Bjørlykke K., 1995; *From black shale to black gold*; Science Spectra 2, 1995 44-49

5. CONVENTIONAL AND NON-CONVENTIONAL OIL AND GAS

The family of hydrocarbons is a large one, and each member has its own endowment in nature, its own characteristics and above all its own depletion profile. Ideally we should identify each of these species and consider its contribution, although in practice that is not easily done on public domain data.

It is common to distinguish two broad categories of oil and gas: conventional and non-conventional (also called unconventional), although there are no standard definitions. Generally speaking, conventional oil refers to those categories which have yielded most production to-date and will continue to dominate supply until well past peak. Much flows freely from giant fields, found long ago.

The production of conventional oil rises fairly rapidly to a peak and then declines exponentially, whereas the production of non-conventional oil rises only slowly to a long low plateau before eventually also declining.

Non-conventional oil, including particularly the heavy oils and tar of Venezuela and Canada will become increasingly important in the future but it will be no substitute for the oil we have known. Most of it will be available only at great cost, including environmental cost, and at comparatively low rates of production. We are not running out of oil - only cheap oil.

To summarise, we may recognise five categories of petroleum

5.1. Conventional Oil

As makes up almost all oil produced so far, being economic to produce under current or foreseen economic and technological conditions;

5.2. Non-conventional Oil (also known as unconventional)

a) Oil from tar sands

b) Heavy and extra heavy oil

c) Oil from enhanced recovery whereby the characteristics of the oil in the reservoir are changed by steam injection or in other ways

d) Oil very hostile environments in deep water or polar regions

e) Oil is accumulations too small to represent viable exploration objectives

f) Oil from infill drilling, reaching pockets in inhomogeneous reservoirs that have been bypassed or partly bypassed in the primary drainage

g) Oil extracted from immature source-rocks ("oil shales")
5.3. Natural Gas Liquids (NGL):

Liquids derived from gas either condensing naturally at the surface (Condensate) or produced by processing. These substances are often reported with conventional oil confusing the analysis as they belong to the gas domain.

5.4. Conventional Gas

a) "Wet" gas, being the gas associated with an oil accumulation, commonly forming a gas-cap, overlying the oil in the trap.

b) "Dry" gas, being gas unrelated to oil, coming from a different gas-prone source-rock.

5.5. Non-Conventional Gas

a) Gas from coalbeds (coal-bed methane)

b) Gas from tight reservoirs

c) Gas held in solution in brines

d) Mantle gas (if any) from deep in the Earth's crust

e) Hydrates (if any): gas in ice-like solid concretions in oceans and polar regions.

Some authorities define non-conventional petroleum as that which is not yet exploitable in economic or technical terms, which means that the goal posts continually move, making it impossible to quantify the amounts. It is much better to define the terms on physical characteristics, recognizing that some non-conventional (about 2 Mb/d) is already in production.

Reference


6. CONVENTIONAL OIL

Conventional oil is quite cheap to produce. About half of what remains lies in just five countries around the Persian Gulf where actual production costs are less than about $5/b and likely to remain so for a long time to come. Of course, it is difficult to know what the actual cost is because it depends on accounting practices, which differ from country to country and between enterprises. Even the expensive North Sea and Alaskan oil probably does not cost more than about $12/b, and there is no particular reason why it should get significantly more expensive. The difference between the cost of producing oil and buying it in the market is of course the substantial amounts of tax levied by producing and consuming governments.

Cost is not therefore a serious constraint. What will determine the price is the scarcity of the resource itself, which prompts us to ask how much there is and how available it is. The question we should NOT ask is how long it will last. That depends on how quickly the old fields decline and how demand behaves. A tank may hold 100 gallons, which if it tipped over empties in a second, but if it springs no more than a tiny leak might take several days to empty. Oil does not lie in a huge underground cavern, which could be drained quickly, but is disseminated in the minute pore space of the reservoir where it is partly held in place by capillary pressure. Production in all oilfields declines during the latter half of their lives as the physical constraints of the reservoir impose increasing restrictions to the flow of oil to the wellbores. We will return to this all important question of depletion, but first let us determine
7. DETERMINING RESERVES

No one can directly measure the amount of oil in a reservoir in an oilfield far underground, which will be known absolutely on the day when the field is finally abandoned. At that point cumulative production, namely the total produced, will equal what are termed the initial (or original) reserves and also the ultimate recovery. Prior to that date, it is necessary to use geological and engineering data to estimate the size of the field. Estimates are naturally subject to change with more knowledge and in some cases new technology. Furthermore, estimates vary depending on who makes them, for what purpose, and under what definitions. It is not an exact science, and there are no hard and fast rules for how reserves should be reported. Much of the confusion over the size of the world's endowment of oil relates to differences in the reporting procedure and the definitions, stated or implied.

When the explorer identifies a prospect before drilling, he maps the size of the trap usually with the help of seismic surveys that provide something akin to an X-ray of the geological formations underground. He then uses regional knowledge to make some assumption about the likely reservoir, and calculates the pore volume occupied by oil, which will give him a value for what is known as oil-in-place. To this he applies a recovery factor, say 40%, and another factor to adjust the volumes for surface temperature and pressure to arrive at what he estimates to be the amount recoverable, namely the Reserves. These factors are influenced by the gravity of the oil: the heavier the oil, the lower the recovery. If the amount is judged to be viable after taking into account the development costs, the wildcat well will be drilled on the prospect.

If it is successful, a new estimate of its reserves will be made based on the information from the initial well, which might be above or below the first estimate. In practice, it is normally below the first estimate, which is often somewhat exaggerated by the explorers to encourage their backers to take the risk. Once the discovery is made engineers take over. They want to be quite sure that they have the reserves to justify the huge investments that follow. It is natural that they should prefer a conservative number.

The traditional practice is to recognize three categories of reserves: Proved for what is sure; and Probable and Possible for less or unsure additions as the terms imply. For financial purposes, only the Proved category counts, and in the United States, SEC regulations require that it be confined to the drainage area of a producing well, normally 40 acres. It is not surprising that Proved Reserves tend to grow over time, which is called Reserve Growth. There is thus a sort of U-curve of reserve reporting: the number starts high before drilling, falls to a low on discovery and then gradually recovers as the field is produced to come somewhere close to the original number. Furthermore, the techniques for estimating change over time. At first the estimates relate to the mapped volumes of the reservoir, but later production performance from the wells themselves can be used to plot the decline and so extrapolate to the ultimate recovery. Computer based simulations and material balance calculations are further tools. What we are after are median probability reserves (P50) namely the best estimate of what will actually be produced taking into account the impact of the application of known and foreseen technology.

8. THE ILLUSION OF RESERVE GROWTH AND IMPROVED RECOVERY

One hears a lot about increased recovery as a means by which to add more oil supply.

As touched on above, the reported reserves of a large offshore field at the point of development may be as little as half those estimated prior to drilling the wildcat responsible for its discovery. It is no surprise that in such cases the reported reserves grow over time as the field approaches exhaustion.
when by definition its reserves will match a P50 probability ranking.

This apparent growth has confused many analysts who are in position to observe only the changing national reserve numbers and are distant from the actual business. They commonly attribute the increase to technological advances and management skills, and they are certainly encouraged so to do by many vested interests. In reality, the increase is little more than a move from a conservative to a realistic estimate. That said, it is of course true that knowledge and experience of the reservoir and its management improve over time along with continuing advances in technology, so that some dynamic increase may also be involved. Such anticipated progress is however incorporated into the P50 estimates. It is not easy to make accurate P50 estimates, but it is obvious that statistically they will show neutral revisions with as many down as up. Systematic upward revision speaks of initial under-reporting. Figure 1 shows the decline of production in the giant Prudhoe Bay Field. It has been at a constant rate since 1990, demonstrating the minimal impact of new technology. The Ultimately recovery of about 12 Gb is probably little different now from when it was first calculated by the operator twenty years ago.

A secondary related issue is the notion that technology leads to an increase in the recovery factor over time. It is said that average recoveries were once about 30% but have now risen to 50% thanks to technology. This does not bear close examination either. First, the early 30% number was little more than a rule of thumb, because few fields had then been abandoned so that no one knew what they would deliver, and second, the tools available to map the oil-in-place, on which the recovery factors are based, were less sophisticated than now. In fact, recovery factor is a consideration only at the exploration and development planning phase. Later, recovery is based on the performance of the wells themselves, and no one knows or cares what percentage that might be of a notional amount of oil-in-place, which cannot in any event be measured accurately because much of it remains forever in the ground. Recovery factor is primarily related to the quality of the oil and the reservoir, and has little to do with technology. Naturally, if a conservative early estimate of oil-in-place is compared with what the wells are actually found to deliver late in the field’s life there will be an apparent improvement.

Governments normally collect data on reserves without stating the probability ranking, which they publish for various purposes, but in recent years these reports have become increasingly unreliable in many countries. Certain countries overstate; some understate; and others simply do not update their reports to account for production which inevitably eats into reserves unless matched by new discovery. For most purposes, the validity of the reserves of a country are not a particularly vital issue, with most eyes being primarily interested in short-term production. But knowledge of the reserves is a critical part of determining the future trends, and is indispensable to a study of this sort. We need to know how much oil has been found and when, if we are to have a sound basis for projecting the future availability.

The issue of dating reserve revisions is even more important than the size of the revisions. Clearly if the revisions simply reflect a move from a cautious to a realistic estimate the revision has to be backdated to the discovery of the fields, since nothing was dynamically added. Proper backdating is essential to determining the real discovery trend.

9. DATA BASE

What information is there and how can we use it? If the numbers are not reliable can we nevertheless interpret them usefully? The following are the main sources of information.

9.1. Petroconsultants in Geneva
This company maintains the most authoritative database on production and reserves as well as important drilling statistics for the world outside the United States and Canada, but it is available only on subscription. It also publishes reports on future supply and depletion built on its database and unrivalled knowledge. It is extensively used by the oil companies who contribute their knowledge to it. Access is however costly reflecting the large investments involved, which puts this database out of range for most individuals or scholars.

9.2. The Oil and Gas Journal

This journal has published for many years reserves and production by country normally in one of the last issues in the year. It is one of the most widely used sources of information, and particularly useful because of the long history of consistent reporting. As a trade journal it cannot however interpret the validity of the data provided to it.

9.3. World Oil

This journal likewise has published similar data over the years, usually in an August issue. In many cases, its numbers are the same as those in the Oil and Gas Journal although there are also significant differences.

9.4. BP

This major oil company publishes the same type of data in its annual Statistical Review of World Energy, but the reserve data are simply reproduced from the Oil and Gas Journal and do not reflect the company's own assessment.

9.5. US Geological Survey

This government department publishes useful data at three year intervals at World Petroleum Congresses, but it is important to understand that it has its own reserve definitions that need to be decoded before the material can be used profitably.

10. WHAT INFORMATION DO WE NEED?

We need to know how much conventional oil there is, and we need to know the rate at which it is being produced, found and depleted.

There are three key elements on quantities

a). Cumulative Production : how much has been produced by the reference date
b). Reserves : how much remains to produce from known fields on the reference date
c). Ultimate Recovery : how much will have been produced when production ends.

Remembering always to identify the category of oil concerned of which Conventional oil is the most important. From these three elements, three further parameters can be derived:

d) Discovered-to-date (a + b)
e) Yet-to-find (c- d)
f) Yet-to- Produce (c - a) or (b + e)

In terms of timing we need to know:

g) Production Rate : annual production
h) Depletion Rate: annual production as a percentage of the Yet-to-Produce (f)

i) Discovery Rate: how much is found in new discoveries each year (excluding reserve revision)

j) Drilling Rate: how many exploration wells are drilled each year

Most of these elements, save Drilling and Discovery Rates, can be input from the indicated public domain information with such interpretation and adjustment as the analyst feels confident in making. For Drilling and Discovery Rates it is necessary to turn to Petroconsultants.

11. CRITICAL ELEMENTS

We will now discuss each of these important elements and give some numbers for consideration. It is useful to secure the historical trends back to, say, 1930 with the earlier statistics being lumped together as a single pre-1930 total, as will be seen later.

11.1. CUMULATIVE PRODUCTION (PRODUCED-TO-DATE)

In principle, this is a straightforward concept: how much has been produced. However it is important to check the treatment of statistics of countries whose frontiers have changed, and to consider war-loss as in Kuwait, where about 2 billion barrels are thought to have been lost. It should in principle be treated as production, although not very useful production, because it eats into the reserves and ultimate endowment. Information on the former Communist countries is unreliable, and naturally the early production was not always properly recorded. Probably many countries are not correctly reporting their current production either. It is also important to try to determine if Natural Gas Liquids (NGL) are included or excluded in the statistics, particularly in the case of the United States.

Reference


A practical way to proceed is to take the figure of 698.6 Gb for end 1992, as reported by Masters of the authoritative US Geological Survey, which is itself probably derived from Petroconsultants material and then subtract annual production data from the Oil and Gas Journal back to 1930, lumping the balance into a single number for pre-1930. It also needs to be updated in the same way for the years since 1992.

Reference


Campbell has already done this in:

Reference


A good number for end 1997 is **795 Gb** (billion barrels), excluding Alaska being treated as non-conventional see Figure 2.

We will need Cumulative Production by country and year when we come to analyse the depletion of
oil. Production inexorably eats into reserves: don't forget it!

11.2 RESERVES

There is nothing straightforward about the subject of reserves. It is a mess. Nothing can be accepted at face value because different definitions are used and in recent years governments have been providing unreliable information. There is nothing absolute about reserves. As discussed earlier, the term reserves means the amounts to be recovered from known fields at the reference date, which is only a fraction of the oil-in-place in such fields.

Then there is the whole issue of reserve revision, as already discussed. For most purposes it does not matter whether the revision is taken on a current bases or backdated as if known at the time of the discovery. For our purpose it is critically important to backdate so as to obtain a valid picture of the discovery pattern as a basis for predicting future discovery. Failure to backdate is the cause of many misconceptions in the public domain.

To make any real inroad into this issue, it is necessary to access the Petroconsultants database that lists reserves by field, properly backdated. In the absence of that information, we may nevertheless still make some useful progress by interpreting the public domain information, using for example the Oil and Gas Journal data.

Political Reserves

Before going further, it is worth commenting on the most blatant distortions, as already discussed by Campbell in

References:


What seems to have happened is that the eastern division of the state oil company in Venezuela decided in 1987 to add 20 Gb of heavy oil reserves, which had been discovered long before, on the strength of a pilot project even though no large scale development was in place. We treat such reserves as non-conventional. In any event it had the, not necessarily intended, consequence of increasing Venezuela's OPEC quota, and prompted the main Middle East producers to retaliate with huge arbitrary increases, adding overnight some 200 Gb. At the same time it has to be remembered that their reserve numbers had been understated previously by the companies prior to their expropriation. The important point is that nothing happened in terms of technology or knowledge of the reservoir in 1987: such reserve revision as was technically valid should have been backdated to the fields concerned which were discovered more than 30 years before in most cases (see Figure 3). Mexico has also confessed to exaggerating by the inclusion on non-conventional oil in the Chicontepec Field. Numbers for the FSU and China are unreliable, as are those from the increasing number of countries — 63 in 1997 — that report the same number year after year, which is clearly implausible.

There is no easy way to unravel these difficulties. Campbell has used a practical short cut of applying a factor to convert the reported Oil and Gas Journal (after adjustment by subtracting the amount produced during periods of unchanged reporting) to Median Probability (P50) reserves. In principle, such reserves take into account any technically justified revision. Other factors could be applied by analysts with different understandings or knowledge. It is also possible to use arbitrary alternatives to
test the sensitivities.

On this basis, world reserves are assessed for end 1997 at 823 Gb, which is about 200 Gb less than the 1020 Gb reported in the Oil and Gas Journal and other such sources. It is distributed as shown in Figure 2.

11.3. DISCOVERED-TO-DATE

The sum of the Cumulative Production and the Reserves gives the total discovered to date, namely 1618 Gb. Again, we need to access Petroconsultants' material to determine when and where it was found. A useful clue is however provided by the published listings of giant fields, namely those with in excess of 500 Mb of initial reserves (i.e. ultimate recovery) in the following references

References

Nehring R, 1978, *Giant oil fields and world oil resources*; CIA report R-2284-CIA


The definition of giant fields is also not without its difficulties. Some single fields are divided for arbitrary reasons, such for example if they cross a national or concessional boundary. In other cases, fields are combined for administrative or other reasons. It does not matter for most purposes, but for us it is important because we want to analyze the field size distribution, as discussed later.

The published data suggests that 60-70% of the world's known oil occurs in little over 300 giant fields. The discovery of such fields peaked in the 1960s. Most are found early in the exploration of a new area, simply because they are too large to miss. No particularly advanced technology is required. Few have been found in the past decade and very few remain to be discovered in the future, unless some entirely new province is unearthed, which is now very unlikely (save for the Caspian), as the world has been so thoroughly explored.

Figure 4 shows the plot of giant fields and Figure 5 shows the distribution of discovered oil. About 40% is in just five countries around the Persian Gulf.

11.4. YET-TO-FIND

In earlier years, the world was a large place and the possibilities for finding oil in the numerous sedimentary basins that make up the continents, especially the margins, and the continental shelves, seemed almost infinite. Several earlier studies took the rock-volume of these huge tracts as a basis for estimating how much oil there was. But in the 1980s came the geochemical breakthrough, already described, which made it possible to determine exactly where oil was generated and when it migrated. Only structures in communication with such generating belts are potential traps for oil. The world became a much smaller place with this new knowledge. It means in effect that most of what will be found lies in ever smaller accumulations in the already known oil producing basins.

While we can estimate the Yet-to-Find directly, it is better for the purposes of the depletion model to derive it indirectly by subtracting the *Discovered-to-Date* from the *Ultimate*, first because some of the
techniques relate to the total distribution; and second because it is better to keep the \textit{Ultimate} as a constant, until it needs to be revised significantly, instead of having to adjust it every time a small discovery is made anywhere in the world.

Published estimates of the Yet-to-Find apparently range widely, but in most cases the range reflects the use of different definitions, which have to be closely examined before the numbers can be properly understood. For example, Masters, speaks of a range of range from 292 to 1005 Gb, quoting a Mean value of 470 Gb, but close reading of the text reveals that these are based on notional geological criteria, ignoring economics, the timing or the number of wells required to find them. They evidently include what are here treated as \textit{non-conventional} reserves. Only the low end of this range deserves serious consideration for these reasons and when a find rate of less than 6 Gb/a is taken into account. Campbell in his latest assessment gives 182 Gb as yet to find, which considering the present falling discovery trend of 6 Gb/y probably means that it will take something like 50 years to find. \textbf{Figure 2} shows the distribution based on this estimate. Almost half lies in the Middle East Gulf, the FSU and China, where exploration is unlikely to be a high priority for a long time to come.

No one should dismiss the technological achievements: they will be needed to the full to find what remains which occurs in ever smaller and more difficult circumstances. And no one should be misled into thinking that technology can find what is not there to be found.

11.5. YET-TO-PRODUCE

The bottom line is how much oil remains to produce. It is equivalent either to the sum of the \textit{Discovered-to-Date} and the \textit{Yet-to-Find} or in other terms, the \textit{Ultimate} less the \textit{Produced-to-Date} (\textit{Cumulative Production}). It stands at 1006 Gb (or a rounded one trillion barrels) As shown in \textbf{Figure 2}, about half lies in the five countries around the Persian Gulf. Other input estimates will give other results, but the important point is to recognize the framework and methodology, including in particular the discovery rate. It will be found that there are serious constraints to much higher numbers, although such are often quoted.

11.6. ULTIMATE

The Ultimate Recovery, or \textit{Ultimate}, of a field is its \textit{Cumulative Production} when production ends, which is the same as its \textit{Initial} or \textit{Original Reserves} before production began, provided that reserve revisions are backdated. It may be determined initially by mapping the volumes of the reservoir or later by projecting the performance of the wells when they are in decline. It is the same for a basin, country, region and eventually the world as a whole, always remembering to define the category of oil being considered, here conventional oil only. It is an important cornerstone of the study. The number is in principle a constant, whereas production, reserves and discovery change every day, although it is naturally subject to periodic revision, either up or down, depending on the evolving knowledge of the endowment.

There are several ways in which to determine an \textit{Ultimate} value.

\textit{1. Old-fashioned Judgment}

Experienced explorers with access to the worldwide files of an oil company can may reasonable estimates based on their knowledge of the underlying geology in relation to the maturity of exploration.

\textit{2. Record}
Something is to be learned by studying the trend or scatter of published estimates. As shown in Figure 6, the range is narrowing. But again it is necessary to check carefully into the definitions. For example, the recent estimate of Masters of 2300 Gb could be restated as about 1800 when it is realized that his Reserves are High Case (10% probability of occurrence) and only the low end of his Undiscovered is realistic in terms of discovery and drilling rate projections.

3. Creaming Curve
Plotting cumulative discovery against time or against wildcat wells gives a hyperbolic pattern, because the larger fields tend to be found first, and the asymptote approximates with the Ultimate subject to a cutoff for uneconomic small fields.

4. Parabolic Fractal
Plotting size against rank of fields in a natural domain plots as a parabola on a log-log format. Once a segment of the distribution is complete or nearly so, namely when no more large fields are found after a reasonable period of time, it defines the parameters of the parabola and hence the ultimate distribution, including the fields yet to find. It works best for a single petroleum system, but can give useful results for larger groupings, such as giant fields or continents that become natural domains in their own right.

References


Laherrère J.H., 1994, Study charts US reserves yet to be discovered; American Oil & Gas Reporter 37/9 99-104.

Laherrère J.H., 1994, Nouvelle approche des reserves ultimate - application aux reserves de gaz des Etas-Unis; Petrole et Technique, Paris 392. 29-33

5. Bell-curves
Much can be learnt by plotting cumulative discovery by size class and by relating discovery peaks with their corresponding subsequent production peaks. Declining discovery is reflected in declining production after a time-lag, and that can be extrapolated to exhaustion, which corresponds with the Ultimate. It is an evolution of the well known Hubbert curve.

The three latter methods rely on data which is available only in the Petroconsultants database, and those working in the public domain are forced to rely on considering the record of published material or of trying arbitrary numbers to achieve a plot of sensitivities to alternative assumptions. The lowest estimate in recent years is Campbell at 1650 Gb, since increased to 1800 Gb, which is about the same as Masters’ US Geological Survey estimate, once its definitions have been decoded. Estimates of more than 2000 Gb almost certainly include much non-conventional oil. Some oil companies, and for example Townes, the former President of the American Association of Petroleum Geologists, take the scatter rather than the trend of the same published estimates to propose numbers as high as 2500-3000 Gb, but they may have motives other than objectivity.

Reference

Townes H.L.,1993, The hydrocarbon era, world population growth and oil use - a continuing geological challenge; Amer. Assoc. Petrol. Geol. 77/5, 723-730.]

The reason for the fall in the published estimates since the high of 3550 Gb in 1969 is the radical fall in giant discovery and the disappointments from many offshore areas, whose potential was over-rated when the offshore was first opened. In reality the range of opinion is not that great.

In addition to these six elements that relate to quantity, it is necessary to consider three more that take into account timing. It is not enough to know how much oil remains to produce but we need to know when it can become available given the physical constraints of the reservoir.

11.7. DEPLETION RATE

Depletion Rate is defined as annual production as a percentage of the amount Yet-to-Produce at the end of the preceding year. It tends to increase in a country until the midpoint of depletion, when it stabilises and equates to the Decline Rate, the percentage change in production from one year to the next. The reason is that in practice it is mainly controlled by the large early fields, which are already in decline, giving a composite Depletion Rate, which effectively masks the impact of any late stage small discoveries.

Figure 5 shows the trend of discovery, with reserves properly backdated. The inflection to falling discovery in the mid 1960s, despite the high levels of subsequent drilling and the technological advances, is highly significant. Extrapolating this curve is a cogent argument in support of the proposed Ultimate.

11.8. DISCOVERY RATE

Discovery Rate is the amount found each year in genuine new field wildcats, that is to say, exploration wells drilled on prospects that if successful will yield entirely new fields. This information is really only available from Petroconsultants on a global basis, see Figure 7. You may be tempted to try to derive it by comparing successive year end reserve reports after adding the intervening production. This does not work because the reserve reports commonly include reserve revisions, that are not discoveries, as is especially the case in the United States.

Reference

Cope G., 1998, Have all the elephants been found?; Petroleum Review 52/163 Feb.

11.9 DRILLING RATE

It is important to consider the number of new field wildcats drilled each year, to plot the trend of such drilling and to determine the discovery rate per well. Extrapolation of these factors imposes a serious constraint on the estimate of the Yet-to-Find. It is effectively available only from Petroconsultants on a global basis.

This concludes the list of the elements we need to have in building a depletion model.

12. DEPLETION MODEL.

Now is the time to try to use the data we have collected to build a depletion model recognizing that production from all oilfields declines during the latter half of their lives. The reason is that as each wellbore drains its catchment area, it has to draw oil from farther and farther away. The oil has to make its way through a network of minute pore spaces and constrictions and overcome the capillary pressures. Furthermore the drive mechanism in the form of expanding gas or encroaching water under a hydrostatic head may lose some of its effect as depletion proceeds. Normally an individual well's production profile is asymmetrical, rising rapidly to a peak and then declining exponentially. But the
profile of a field depends on the rate at which new wells are added. There is a law of statistics that explains why a composite profile of asymmetric profiles tends to become symmetrical. The profile of a country is much the same. It depends on the rate at which new fields are added: it being normal for the larger ones to be found first.

Both theoretically and empirically there seems to be a good case for building a model in which the production peaks at the midpoint of depletion, namely when half the Ultimate has been produced. So, why don't you try to construct one for the country in which you live as a test case. You will have to research the input data described above, paying particular attention to trying to understand exactly how the official data are defined, as already discussed. You want to aim at securing Median Probability reserves, which may be termed Proved & Probable. You probably won't find much published on the undiscovered potential, so you can either use the estimates in Figure 2 or use your own judgment. Perhaps you can find a knowledgeable explorer who can give the benefit of his experience, perhaps in some local professional society.

You will need a personal computer and a spreadsheet. We may look at the profile of a hypothetical mature country, which is well past its assessed midpoint of depletion, see Figure 8. The practical steps in filling out the spreadsheet formulae are as follows:

| CUM PROD C2  | @Sum(C12..C78) |
| RESERVES   C3  | INPUT or +I6+(I6*I8) |
| DISCOVERED  C4  | +C2+C3 |
| YET-TO-FIND C5  | +C7-C4 |
| YET-TO-PRODUCE C6  | +C7-C2 |
| ULTIMATE  C7  | INPUT |
| CUM PROD 2050 C8  | @Sum(C12.C133) |
| MIDPOINT E3  | C7/2 |
| DATE E4  | By examination |
| YEARS E5  | +EF-1995 |
| GIANTS E7  | @SUM(F13..F78) |
| % E8  | +E7/C4 |
| LAST E9  | By examination |
| PROD Peak G3  | By examination |
| 3YR TREND G4  | (B78-B75)/B75/3 |
| DISC-PROD G5  | +G3-I3 |
| DEP RATE G7  | +E78 |
| Midpoint G8  | By examination |
This is an example of a country past its midpoint, but you may face a country that is not yet at midpoint. In this case you either input future production if known from forecast developments until midpoint is reached, or make an arbitrary assumption such as a 5% annual increase to midpoint. As shown in Figure 9, most countries, except the five Middle East producers are past or close to midpoint, and an arbitrary assumption of a 5% increase to midpoint is not material to the model.

If you have come this far CONGRATULATIONS! You have assessed your first country. You may now like to make a Line-Bar graph plotting production over time, and inserting the giant fields as bars. If you look at the following reference you will see all countries covered in a similar way

Reference:


and if you want an updated much more sophisticated version with all discoveries, not only the giant fields and also critical well data and projections, you could consult

Reference


13. BUILDING THE WORLD PICTURE

Having done one country, you can do all the rest in the same way, but it is convenient to divide up the world into a number of regions such as Latin America, Africa etc. and then consolidate the data from each country into regional totals. Two groups of countries have to be treated differently:

13.1 "Other and Unforeseen". It is convenient to consider in the above fashion only countries in production and having an *Ultimate* of greater than 500 Mb as described above. Other less important countries and those not yet in production can be lumped together as a group. It is helpful here to add a certain assumed *Ultimate* for them and the "unforeseen" so as to bring the total of the other regions up to a rounded world *Ultimate*. In this way, say, about 50 Gb can be held back for unforeseen discoveries or reserve revisions anywhere. By doing so, the world *Ultimate* remains constant, not having to be adjusted for every minor change in individual countries. Campbell in the most recent assessment proposes a world *Ultimate* of 1800 Gb.

13.2 The other issue is the identification of what we may call swing countries. The most uneven distribution of the amount of *Yet-to-Produce* oil means that some countries are at a much earlier stage of depletion than others. So they are able to maintain or even increase their production when the others are already in decline. Thus the swing countries can make up the difference between world demand under alternative scenarios and what the other countries can provide because of their resource limitations. There are several options for how to identify the swing countries. Probably the simplest and best is to limit it to the five countries around the Persian Gulf which together own half of what remains and are geographically in the same area. They are Abu Dhabi, Iran, Iraq, Kuwait and Saudi Arabia (also including the small Neutral Zone because it is owned by Kuwait and Saudi Arabia). Although there are many serious conflicts between these countries they do have much in common, not least their religion, and apart from Iran, a shared heritage in having been part of the Ottoman Empire prior to the First World War. Other options would be to consider OPEC as a swing producer, which would make sense if it did represent the larger exporters and if it did act as the swing producer it seeks to be. In resource terms its members differ from each other widely. A third option would be to expand the Persian Gulf group to include, say, Venezuela, Mexico, Libya and Nigeria.

14. CALCULATING THE SWING SHARE

Once the swing group has been identified, steps can be made to calculate its production and share under alternative world demand scenarios. Many different scenarios could be investigated such as:

14.1 *Low Case* : world production stays flat until the world midpoint is reached and then declines at the then depletion rate

14.2 *High Case* : world production increases at 3% a year until the Swing Share reaches a certain percentage, say 40%, when higher prices may be assumed to lead to a plateau of production until the share has reached 50% by which time these country too will be close their midpoint

14.3 *Base Case* : as the High Case, save that world demand grows at a slower rate, say 2% per year, and the plateau sets in sooner, say when swing share passes 30%.
Once the scenario has been selected the total swing production and share can be readily calculated and then reallocated back to each swing country individually, always recognizing that each country will be forced into decline at its midpoint, with the balance then being taken up by the other swing countries not yet at midpoint.

**Figure 10** illustrates such a model. It will be noted that the several production scenarios converge over time because more today means less tomorrow given a finite total. **Figure 11** shows the relationship between swing share and oil price.

### 15. POLITICAL FACTORS

The scenarios in Section 14 are driven mainly by resource constraints, although the swing share is expected to a critical factor around peak.

Many short term political scenarios affecting the issue can be considered: some advancing the onset of decline, others delaying it. Such factors apply however only over the next 10-15 years after which decline will be imposed by immutable resource constraints.

It is obvious that the Middle East swing countries are in a parlous political condition, and the future developments there are hard to predict. Oil price is critical to these countries as oil contributes the bulk of their revenue. This is not the place to review the issue in detail but some general comments can be made.

1. A decline in oil price would further undermine the stability of particularly Iran and Saudi Arabia.

2. Iraq in the aftermath of the Gulf War, which some commentators hint may have been contrived, is acting as a swing producer of last recourse. The embargo will have to be lifted in due course, and may lead to a temporary drop in oil price, which may concentrate the minds of other producers to cooperate sufficiently to restrict production to control price. Once they perceive the control they have they may continue to exert it and force prices to high levels. It may not be necessary to wait for the 30% threshold foreseen in the scenarios. The wisdom of antagonizing the principal producers in the Gulf by aggressive military postures may be questioned.

3. The oil industry in all the swing countries, save Abu Dhabi and the Neutral Zone, is in state hands, and the state has many demands on oil revenues, so that there is limited incentive to make investments in maintaining current production, still less increasing it, in a low price environment. At the same time the dependency on oil revenue makes it difficult for the countries to permit prices to fall for long

4. Rising prices could well feed on themselves in these circumstances, giving the participants more resources with which to play the market.

5. Demand in the former Soviet Union has fallen drastically in recent years. If the economy bottomed out or improved, it would put pressure on exports, strengthening the Swing producers' hand.

6. Production in Norway, which is now one of the world's largest exporters, will have peaked around 2000, and its decline will strengthen the Swing control.

7. A temporary interruption to production in places like, Nigeria, Mexico, Venezuela, Libya due
to political events would likely be sufficient to trigger a price leap.

16. CONCLUSIONS

The world is not running out of oil: only cheap oil. The resource constraints are however serious and not widely understood. A doubling of oil price by about 2000 is not only on the cards, but highly probable given the growing control of world supply by a few countries. The next oil price shock will be due to circumstances very different from those that gave the shocks of the 1970s when prolific new production from alternative sources was in sight. This time it is not. Production costs will remain similar to those of today because most of the oil comes from old giant fields which are cheap to produce. So, the price of oil is mainly determined by tax, levied either by the producing or consuming governments.

Given the pending resource driven decline in production, the world has every incentive to curb further increases in demand and take active steps to prepare for the day not more than a few years off when cheap oil, such as has driven the 20th Century's economy, is no longer available.

17. WHAT CAN I DO ABOUT IT?

One great contribution would be to try to improve knowledge of how much oil has been found already which is critical to assessing how much remains to be found. So, if you can find out about the reserves of oilfields in your country or neighbourhood and feed in the information, we can build up a file of compelling evidence.

In your own lives you have many opportunities to start thinking of how you would personally react to a doubling of oil prices. There are many beneficial steps you could begin to take. The most beneficial would probably be a new mind-set to consider these issues.
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<th>Dubai</th>
<th>Iran</th>
<th>Iraq</th>
<th>Kuwait</th>
<th>Neutral Zone</th>
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<td>5.0</td>
<td>259.0</td>
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</table>
| 1997 | 92.2     | 4.0   | 93.0 | 112.5 | 94.0 | 5.0          | 259.0        | 71.7      

**P50 Estimates by Petroconsultants**

|     | 1996 | 57.7 | 1.0  | 64.7 | 77.4 | 52.0 | 8.2  | 222.6 | 27.4 |

Figure 3. Anomalous discontinuities in red. Venezuela’s increase was due to the inclusion of heavy...
Orinoco oil, to be properly classified as non-conventional. It prompted a reaction by other OPEC countries in the "quota wars". Iraq’s 1983 increase was the late reporting of the East Baghdad Field found in the 1978. Unchanged reports are implausible, irrespective of the amount. Petroconsultants estimate is based on the sum of individual fields.
GIANT FIELDS

Initial reserves by discovery year

>500 Mb Fields.
Reserve revisions backdated.
WORLD
Discovery by year

1930 includes pre-1930

All discovery Gb

Discovery in Giant Fields Gb

All Fields

Giants

Depletion Midpoint
Years to or from

ME.Other
East
W.Europe
Africa
L.America
N.America
Eurasia
ME Gulf

-30 -25 -20 -15 -10 -5 0 5 10 15 20
Years
## Global Conventional Oil Endowment 1998

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<th>Production</th>
<th>Reserves</th>
<th>Discovered</th>
<th>Peak</th>
<th>Pk/</th>
<th>% Dep</th>
<th>MP Dep</th>
<th>Peak Prod</th>
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Ref. date end 1998  Gb (billion barrels)  

[http://www.hubbertpeak.com/campbell/endowment.htm](http://www.hubbertpeak.com/campbell/endowment.htm)
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Last Updated on 2/21/2000

By RBS
No one should imagine that this is a simple subject. Public data are unreliable, and comment is often ill-informed or biased. There are many arguments and counter arguments which need to be understood fully as the study evolves. There is important reading to be done, for which selected references at the end of the report may be a starting point.

That said, we will nevertheless try to reduce the subject to its bare essentials, using graphics to make the main points. [Note: Graphs can be seen full size by clicking on the image with the right mouse button and selecting "view."]

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  - Discovered-to-date (1561 Gb)
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- Depletion Model
- Future Scenarios
- Political Factors
- Conclusions
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Frame Version
Complete Version (no breaks between sections)

1998 June 8
Some key background

1. Origins

Petroleum is derived from organic material under conditions that were met only rarely in the Earth's long history and then only in a few places. Oil comes primarily from algal material, and gas comes from vegetal remains. Such organic debris settled to the floor of the lake or sea in which it lived, and in most cases was oxidized by bottom dwelling organisms or currents, but in certain stagnant environments has been preserved and buried beneath other sediments. On deeper burial, it was heated by the Earth's heat flow, and chemical reactions converted it into petroleum. Oil on very deep burial is cracked into gas. Once formed oil and gas migrate upwards through minute fractures and pores in the rocks, until they find a porous and permeable layer through which they can move. They then flow through this conduit until they are trapped in a fold, against a fault or where the conduit pinches out. Much is dissipated or held in the many constrictions encountered during its migration, so that only about one percent of what was formed is trapped in accumulations large enough to be exploited.

2. Trends

The world has now been very thoroughly explored so that nearly all of the oil provinces have been found. Oilfields are clustered together in discrete trends where the remarkable and very exceptional geological conditions needed for generation and entrapment were met. They are separated by huge barren tracts that are barren for reasons that are well understood. For obvious reasons, the more prolific trends were found first, as were the larger fields within them. Most of what remains to be found will come from ever smaller fields in mature areas.

3. Technology

Much of the world's oil was found long ago with fairly primitive technology. There have been considerable technological advances such as the semisubmersible rig that opened the offshore to routine drilling. Modern seismic surveys can map the oil zones with a very high resolution, and geochemistry can explain where and when the oil moved. These tools are sufficient to efficiently find and produce the world's endowment of conventional oil, as discussed below. Further technological advances can be expected and will be needed to find and develop ever smaller accumulations that have progressively less impact on world supply. This year's Buick is better than last year's model, but that was still good enough for most purposes. So there is no technological solution to the impending shortfall: it is not a technological problem.

4. Conventional and Non-conventional Oil

Much of the confusion about the world's endowment of oil stems from a failure to distinguish these two categories. Almost all the oil produced so far can be classed as conventional as will the bulk of what will be produced over the next twenty years or so. But when that supply dwindles, attention will turn to what may be termed non-conventional oil made up of:

1. oil from tar sands and oil shales
2. heavy oil
3. enhanced recovery by changing the characteristics of the oil in the reservoir by steam injection or in other ways
4. oil (if any) in very hostile environments - polar regions or very deep water
5. oil from infill drilling to reach pockets bye-passed in the primary depletion of a field
6. oil in accumulations too small to be viable exploration targets

The important distinction is that the unfettered production of conventional oil rises rapidly to a peak and then declines exponentially; whereas the production of non-conventional oil rises only slowly to a long low plateau, before in turn declining. The resources of heavy oil and tar sands are considerable, but the constraint to production is cost and the sheer scale of the undertaking. Non-conventional production is unlikely to make an impact until the tail end of conventional depletion and then only in a high or very high price environment. It is no substitute for conventional oil as has fueled the Twentieth Century economy.

5. Recovery Factor

Oil occurs in the pore space of the reservoir rock where it is subject to capillary pressures. Production falls when the wells have to draw on oil farther and farther from the wellbore. Eventually a point is reached when no more can be produced. The percentage recoverable ranges from about 20 to 60% depending primarily on the gravity of the oil. Recovery factors depend on the amount of oil-in-place which is often not exactly known. It is often claimed that technology can improve recovery. In fact, the apparent improvements may reflect initial underestimate or underestimation of the amount of oil-in-place rather than any technological breakthrough.

Next section, Data Bases

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Data Bases

The following are the main sources of information:

1. Petroconsultants in Geneva

   This company maintains the most authoritative database on production and reserves as well as important drilling statistics for the world outside the United States and Canada, but it is available only on subscription. It also publishes reports on future supply and depletion built on its database and unrivaled knowledge. It is extensively used by the oil companies who contribute their knowledge to it. Access is however costly reflecting the large investments involved, which puts it out of range for most individuals or scholars.

2. The Oil and Gas Journal

   This journal has published for many years reserves and production by country normally in one of the last issues of the year. It is one of the most widely used sources of information, and particularly useful because of the long history of consistent reporting. As a trade journal it cannot however interpret the validity of the data provided to it.

3. World Oil

   This journal likewise has published similar data over the years, usually in an August issue. In many cases, its numbers are the same as those in the Oil and Gas Journal, although there are also significant differences.

4. BP

   This major oil company publishes the same type of data in its annual Statistical Review of World Energy, but the reserve data are simply reproduced from the Oil and Gas Journal and do not reflect the company's own assessment.

5. US Geological Survey

   This government department publishes useful data at three year intervals at World Petroleum Congresses, but it is important to understand that it has its own reserve definitions that need to be decoded before the material can be used profitably.

Next section, Elements

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Elements

Certain key elements have to be taken into account in estimating the world's endowment of conventional oil. The references should be consulted for a discussion on how these elements are defined, which is particularly important in connection with reserves. Here, it will be sufficient to illustrate them graphically, considering the world's regions and the fifteen most amply endowed countries. The numbers are taken from Campbell (1996), except were indicated otherwise and are quoted in billion barrels (Gb). In all cases they refer to conventional oil only as of the end of 1995. Although quoted as exact numbers as computed, they should of course be generously rounded. The regions for this purpose are defined as follows:

- Middle East (Other): Turkey to Oman and Yemen outside M.E.(Gulf)
- East: Pakistan to Viet Nam and Australasia
- W.Europe: Norway to Italy
- Africa
- Latin America: South America and Mexico
- North America: USA and Canada
- Eurasia: FSU, China and Eastern Europe
- Middle East (Gulf): Abu Dhabi, Iran, Iraq, Kuwait, Neutral Zone, Saudi Arabia
- Other: countries with <500 Mb Ultimate or not in production; and unforeseen discovery and revisions anywhere.

Next section, Produced-to-date (761 Gb)
Produced-to-date (761 Gb)

The concept of Produced-to-date or cumulative Production is straightforward - how much has been produced. It is however necessary to watch out for territorial changes and the treatment of war loss, as in Kuwait (2.5 Gb), which in principle should be regarded as production, although in this case is ignored as being small in relation to the uncertainty of the reserves. North America and the Middle East Gulf have produced the most, at just under 190 Gb, with Eurasia in third place. In terms of individual countries, the United States heads the list (171 Gb), followed by the FSU (125 Gb) and, far behind in third place, Saudi Arabia with 74 Gb. This illustrates the maturity of the United States, which for many years in the past was the world's most important producer.

Next section, Reserves (800 Gb)
Reserves (800 Gb)

The term Reserves means the amounts yet to produce from known discoveries as of the reference date, but the numbers are confused by differing definitions and other distortions (see references). Many published numbers are unreliable. Here, we refer to what are termed "Median Probability Reserves (or P50 Reserves)", which means that the risks that the actual number will turn out higher or lower than the estimate are equally matched. Most published reserves are described as Proved, but are often far from that.

The Middle East (Gulf) has more than half the world's reserves with 439 Gb, followed far behind by Eurasia with 114 Gb, and trailed by Latin America (74 Gb). In terms of individual countries, Saudi Arabia heads the list with 189 Gb, followed by the FSU with 84 Gb. Several other countries with comparable amounts come next in line: Iraq (68 Gb); Abu Dhabi (62 Gb); Kuwait (60 Gb) and Iran (53 Gb). Figure 4 illustrates the wide range in the published estimates.

Next section, Discovered-to-date (1561 Gb)
Discovered-to-date (1561 Gb)

The Discovered-to-date is the sum of the Cumulative Production and the Reserves.

The Middle East Gulf is in first place with 626 Gb, followed by Eurasia (267 Gb) and North America (225 Gb). In terms of individual countries, Saudi Arabia is again at the head of the list with 264 Gb, followed by the FSU (209 Gb) and USA (200 Gb).

About 63% occurs in just over 300 giant fields, namely those with more than 500 Mb of ultimate recovery. The discovery of giants fields peaked in the 1960s as shown in Figure 7. This is a very critical statistic with serious implications for the future. The discovery of giant fields has fallen dramatically in recent years and few, if any, remain to be found. Most giant fields are found early in the exploration process, being too large to miss. Most were found without the benefit of advanced technology.

Next section, Undiscovered (189 Gb)
Figure 7

GIANT FIELD INITIAL RESERVES
by discovery date

Includes pre-1930
Undiscovered (189 Gb)

The Undiscovered, or Yet-to-find, is the Ultimate (see below) less the Discovered. The Middle East (Gulf) has the greatest potential with 61 Gb, followed by Eurasia with 28 Gb. North and Latin America with respectively 13 Gb and 13.5 Gb are in near equal third place. In addition, some 50 Gb is attributed to unforeseen discoveries or reserve revisions anywhere. In terms of individual countries, the FSU (21 Gb), Iraq (19 Gb), Iran (17 Gb) and Saudi Arabia (16 Gb) seem to have the greatest promise. Discovery rates are falling, currently standing at about 7 Gb a year. Drilling rates and the amount discovered per well are also falling. There may be some improvement in success ratio as exploration turns to lower risk mature areas, but the amounts found are expected to continue to decline. Most of what remains will likely be found within 10-20 years in most countries outside the Middle East Gulf and the FSU where exploration may continue to be a low priority for some years to come.

Next section, Remaining (989 Gb)
Remaining (989 Gb)

The Remaining is the Ultimate less the Produced, or in other terms the Reserves plus the Undiscovered. It is the bottom line, namely how much is left to produce, and is the statistic we need to run the depletion model. The region with the most is of course the Middle East Gulf with 499 Gb, which is about half the total. It is followed by Eurasia with 142 Gb and then Latin America with 88 Gb. By individual country, Saudi Arabia comes first with 206 Gb, followed by the FSU (105 Gb) and Iraq (88 Gb). So far as the western world is concerned, the two leading countries are the USA with 39 Gb and Venezuela with 38 Gb. It is evident that about 70% of the world's remaining oil lies in countries that are not really part of the open market and in which the oil industry is exclusively in state hands.

Next section, Ultimate (1750 Gb)
Ultimate (1750 Gb)

The Ultimate is Cumulative Production when production ends. It is very important to recognize that there is an ultimate, even if the number cannot be determined exactly. The number proposed here is a rounded 1750 Gb which can be used to drive the depletion model for the next ten or twenty years through peak production into decline. It refers, like all the other numbers to conventional oil only. It may well be due for some upward revision in the far future in a high or very high price environment when some of what is here treated as non-conventional becomes conventional. The 1750 Gb is in fact approximately the same as the 2300 Gb proposed by the US Geological Survey, if that is redefined to take into account only Median Probability Reserves and the low end of the range of Undiscovered which is all that meets relevant time and economic constraints. It also is suggested by the trend of published estimates. Those desiring a higher number often show the same plot but take the scatter rather than the trend. Here weight is given to the trend because the more recent estimates have the advantage of modern technology and a colossal database from worldwide drilling. Care must however be taken in checking the definitions applied. Some of the higher reported numbers include what is here treated as non-conventional oil. Another very compelling argument comes from the plot given in Figure 15, showing discovery with reserve revision backdated to the discovery date. It shows a marked inflection to falling discovery in the 1960s. Extrapolating the subsequent curve gives a very clear intimation of future discovery and hence the Ultimate. If indeed the reserve estimates of particularly the Middle East prove to be higher than here assessed, it would mean that the inflection would be even more pronounced, reducing further the recent
trend. It is accordingly difficult to argue convincingly for an Ultimate much higher than that proposed, given especially the fact that virtually the entire world has been explored sufficiently to indicate the existence of the major provinces. Only a new province with a crop of giant fields could have any global impact.

The Middle East Gulf Region has the largest endowment with 687 Gb, followed by Eurasia with 295 Gb and North America with 238 Gb. Saudi Arabia (280 Gb), the FSU (230 Gb) and the United States (210 Gb) are the three most richly endowed countries.

Next section, Depletion Model
Depletion Model

We have now developed an assessment of how much conventional oil there is and how much remains to produce, the Remaining. Oil does not occur in some vast underground cavern from which it could be quickly pumped, but it is held in the minute pore space of the reservoir rocks, in the same way as rising damp can flow through the walls of old stone buildings. It is easy to understand therefore why wells begin to decline as they have to draw on oil farther and farther from the wellbore. The production of an oilfield rises rapidly as new wells are added but then when all the wells are in place declines exponentially at a composite depletion rate. Depletion Rate is a given year's production as a percentage of the remaining reserves at the end of the preceding year. So it is with a geological basin: production rises as new fields are found, and it is normal for the larger ones to be found first. Their depletion rate tends to mask the effects of small late stage additions. Lastly, it is the same for a country, with the larger basins usually being developed first. The natural pattern can of course be modified if production is deliberately held to a certain limit. Thus production of an offshore field may be held at a plateau constrained by the number of wells and the optimal off-take in relation to investments. Likewise, a country may arbitrarily manipulate production to maintain price in a practice known as prorationing, as practiced for example by the Texas Railroad Commission, and less successfully by OPEC with its quotas. In any event, the production of any field starts at zero, rises to a peak (or plateau if artificially constrained) and then falls to zero. The profile of individual fields is normally asymmetrical, being skewed to the left, but a country's peak tends to be symmetrical because it is made up of a progression of individual field profiles. It follows then that peak production will more or less coincide with the midpoint of depletion, except where there are artificial constraints, and even then the midpoint of depletion will roughly coincide with the midpoint of the constrained period. Depletion rate rises during the early production of a field (or country's production) as new wells or fields are added, but tends to stabilize at the midpoint, such that production declines exponentially thereafter, ultimately due to the immutable physics of the reservoir. The midpoint of depletion comes when half the Ultimate has been produced. Since we have now estimated the Ultimate for each country, we are in a position to estimate when peak production will come and plot the subsequent decline. It means that we can divide the world's producing countries into three categories

1. Post-Midpoint Countries

Production is declining exponentially in these countries. Strictly speaking it would be best to plot the depletion from midpoint at the midpoint depletion rate, and treat any departures from this notional curve as anomalies that eventually even out, because more production early has to be matched by less production later, given the fixed Ultimate. But in practice one can as well take the current depletion rate to keep it simple, because in most cases the current rate differs only slightly from the midpoint rate. Doing so also makes the short term prognosis a little

![Depletion MIDpoint Chart](http://www.hubbertpeak.com/campbell/camdepl.htm)
2. Pre-Midpoint Countries

A few countries, save those in the Middle East Gulf region, are still a year or two away from midpoint. If actual near term production forecasts are known, they can be fed in, but otherwise it will suffice to apply an arbitrary increase of, say, 5%, because it applies only for a few years. Once they reach midpoint, they decline exponentially at the midpoint depletion rate.

3. Swing Producers

As outlined above, about half the Remaining lies in the five countries of the Middle East (Gulf) Region, which are at a very early stage of their depletion. These countries are therefore natural candidates to perform a swing role, making up the difference between world demand under alternative scenarios and what the other countries can produce under the model. It is role that they can perform for about 15 years until they themselves also reach their midpoint. It would also be an option to include certain other countries, such as Venezuela or Mexico, in the swing category, but on balance it seems better to restrict the swing role to the Middle East Gulf.
Future Scenarios

Many different scenarios could be considered, but for illustrative purposes we are content with four, see Figure 18.

1. High Case
   Demand increases at 3% a year until production reaches the world midpoint, when resource constraints cause it to decline at the then depletion rate.

2. Low Case
   Demand is flat, and production stays level until the world midpoint, when it declines.

3. Base Case
   Demand rises at 1.5% a year until production reaches the world midpoint when it declines.

4. Swing Case
   As the Base Case, save that price rises, when the swing share exceeds 30%, curb further demand increases, leading to a production plateau that lasts, not until the world midpoint, but until the swing producers reach their midpoint.

It happens that in the Base Case, the swing share rises to 30% only a year before the world midpoint. It points to a radical rise in price, due to the increasing control of the market exercised by these countries. The share under the Swing Case rises to almost 60% by the time the swing producers are forced into decline.

Next section, Political Factors
Political Factors

This model is built on resource criteria, which show that a few Middle East countries will have a critical control of the world supply within a few years. Exactly what constitutes effective control is hard to say, but the threshold for the last oil shocks was 30%, which seems a reasonable approximation. How these countries elect to use their control and what political pressures are brought to bear cannot of course be predicted from resource considerations.

Some key elements can however be identified

1. The pivotal role of Iraq

No one quite knows the origins of the Gulf War, although some hints are given by Schweizer in his book Victory. The net consequence, however, has been the removal of 2-3 Mb/d from the market under the embargo, which OPEC failed to achieve by its quota system. This has been sufficient to maintain oil prices at a moderate level, which in turn has contributed to the survival of the Saudi, Iranian and a few other regimes that depend heavily on oil revenues. The embargo can also be relaxed if prices rise in a manner unacceptable to those enforcing the embargo. In effect, it makes Iraq the swing producer of last recourse. It is however a function that can be applied for only a few years, as Iraq's oil will be needed in full from about 2000 to meet the requirements of the demand scenarios.

2. Financing the Swing Share

Doubts have been expressed as to the willingness of the swing countries to invest in adding the capacity needed for them to discharge their swing role, given that the oil industry is almost exclusively in State hands and given that the State has many other demands on its precious oil revenues. While prices are low, they are ironically forced to produce to the maximum to meet their pressing demands for revenue, but once prices rise they will have greater room to maneuver. The investment could be forthcoming if they were willing to open their doors wide to the international oil companies, but that may be unacceptable in political terms, especially if rising prices reduce the need.

3. Short term exports from Norway and the FSU

Norway, which has about half the North Sea's remaining oil, exports a large proportion of its production because of its small population. Production will peak in 1999 under the model and then decline at a high depletion rate of about 8%, as is typical of offshore production. FSU exports have also been relatively strong because falling production has been exceeded by falling domestic demand. Any economic improvement there could radically change this situation. Both of these factors may serve to greatly increase the Swing control by about 2000.

4. Instability, market and limited capacity

The price of oil is today set by a very efficient forward market that is more a reflection of present trends than speculation or judgment about the future. There is today very little immediately available spare capacity anywhere. It follows that relatively minor interruptions in supply, or even threats of same, in any one of a number of countries subject to political or industrial strife can have a radical impact on the price of oil. Once prices rise for what ever short term reason, the trend may feed on itself as the suppliers have greater ability to curb production without crippling their revenue stream. There are currently question marks about the nature of the Saudi succession as well as Iranian intentions in arming islands in the Gulf of Hormuz. A spark once kindled could easy lead to a bush fire.
Conclusions

Predicting the future is a dubious undertaking. The oil database in the public domain is weak, and there are many uncertainties. That said, compelling evidence points to a pending oil supply shortfall, possibly before 2000, which could trigger a third and permanent radical rise in oil prices. There is a certain skepticism because people have cried wolf before, but this time the situation is totally different from that which allowed the oil shocks of the 1970s. Then, the swing control was being undermined by flush production coming on stream from new provinces in the North Sea, Alaska and elsewhere that had already been found. This time none are even in sight and very possibly do not exist. We face a different world. The basic situation is clear, although there is plenty of room for debate about the size of the numbers and depletion scenarios. Those who investigate sensitivities will soon find that there is not in fact much room for radically different interpretations. Every effort should be made to improve knowledge of what has been found so far to secure a better basis for projecting future discovery and production. It is not so much a technical issue as a political one to open the files and see what is really in them.

Bibliography

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Bibliography of Hubbert Peak Documents

Selected References Provided by Dr. Colin Campbell

- Bookout J.F., 1989, Two centuries of fossil fuel energy; Episodes 12/4
- British Petroleum Co., BP Statistical Review of World Energy; Published annually by BP, London.
- -----------, 1993, The Depletion of the world's oil; Petrole et technique. No.383. 5-12 Paris
- -----------, 1994, World oil - Reserves, production, politics and prices; Proc. 1993 NPF Conference, Stavanger, Norway Quantification and prediction of hydrocarbon resources. in press
- -----------, 1994, The imminent end of cheap oil-based energy; SunWorld 18/4 17-19
- -----------, 1995, Taking stock; SunWorld 19/1 16-19
- -----------, 1995, The Coming Crisis; SunWorld 19/2 16-19
- -----------, 1995, The next oil price shock: the world's remaining oil and its depletion; Energy Expl. & Exploit., 13/1 19-46
- -----------, 1995, Proving the unprovable; Petroleum Economist, May 1995
- Carmalt S.W. and B.St.John, 1986, Giant oil and gas fields; in Future petroleum provinces of the world; Amer. Assoc.Petrol. Geol. Mem.40
- Davies P., 1994, Oil supply and demand in the 1990s; World Petrol. Congr. Topic 16
- -----------, 1980, Oil and gas supply modeling; in Gass S.I., ed. proceedings of symposium, U.S.Dept. of Commerce June 18-20,1980
- 1980, World's prospective petroleum areas; Oil & Gas Journ. April 28
- 1984, Oil discovery indices and projected discoveries; Oil & Gas Journ. 11/19/84
- 1985, Potential of world's significant oil provinces; Oil & Gas Journ. 18/11/85
- 1886, Oil discovery index rates and projected discoveries of the free world; in Oil &
- 1987, Permanent oil shock; AAPG 71/5
- 1988, Future crude oil supply and prices; Oil & Gas Journ. July 25 111-112
- 1995, Future world oil supplies: there is a finite limit; World Oil Oct. 1995
- 1991, Data on field size useful to supply planners; Oil & Gas Journ. April 29 1991
- Klemme H.D., 1983, Field size distribution related to basin characteristics; Oil & Gas Journ.
  Dec. 25. 1983 169-176
- & Ulmishek G.F., 1991, Effective petroleum source rocks of the world: stratigraphic,
  distribution and controlling depositions factors; Amer. Assoc. Petrol. Geol 75/12, 1908-185
- Knott D., 1996, Reserves debate; Oil & Gas Journ. Jan 29. 40
  new approach based on distribution of ultimate resources; Rept. Petroconsultants S.A., Geneva
- 1994, Published figures and political reserves; World Oil, Jan 1994 p. 33.
- 1994, Study charts US reserves yet to be discovered; American Oil & Gas Reporter
  37/9 99-104.
- 1994, New parabolic fractal tells how much oil yet to find: draft paper
- 1995, World oil reserves: which number to believe?; OPEC bull. Feb draft. [256]
  Final
- Masters C.D., 1987, Global oil assessments and the search for non-OPEC oil; OPEC Review,
  Summer 1987, 153-169
- 1991, World resources of crude oil and natural gas; Review and Forecast Paper,
  potential; Science 253.
  Assoc. Petrol. Geol. 77/3 452-453 (with other relevant references).
- 1994 Bibliography of the world energy resources program; USGS Open File 94-556
- Phipps S.C., 1993, Declining oil giants, significant contributors to U.S. production; Oil &
- Riva J.P., 1991, Dominant Middle East oil reserves critically important to world supply; Oil &
  Gas Journ., Sept 23 1991
- 1992, Petroleum in the Muslim Republics of the Commonwealth of Independent

States: more oil for opec; US Congressional Research Report 92-684 SPR


- ------------, 1993, Large oil resource awaits exploitation in former Soviet Union's Muslim republics; Oil & Gas Journ., Jan 4 1993


- Simmons M.R., 1990, Our upcoming domestic embargo; Panel discussion, Alaska

- ------------, 1994, It's not like '86; World Oil Feb. 1994

- ------------, 1995, Strong market indicators; World Oil, Feb 1995


- Yamani A.Z., 1995, Oil's global role -the outlook to 2005; MEES 38/33

No one should imagine that this is a simple subject. Public data are unreliable, and comment is often ill-informed or biased. There are many arguments and counter arguments which need to be understood fully as the study evolves. There is important reading to be done, for which selected references at the end of the report may be a starting point.

That said, we will nevertheless try to reduce the subject to its bare essentials, using graphics to make the main points.

Some key background

1. Origins

Petroleum is derived from organic material under conditions that were met only rarely in the Earth's long history and then only in a few places. Oil comes primarily from algal material, and gas comes from vegetal remains. Such organic debris settled to the floor of the lake or sea in which it lived, and in most cases was oxidized by bottom dwelling organisms or currents, but in certain stagnant environments has been preserved and buried beneath other sediments. On deeper burial, it was heated by the Earth's heat flow, and chemical reactions converted it into petroleum. Oil on very deep burial is cracked into gas. Once formed oil and gas migrate upwards through minute fractures and pores in the rocks, until they find a porous and permeable layer through which they can move. They then flow through this conduit until they are trapped in a fold, against a fault or where the conduit pinches out. Much is dissipated or held in the many constrictions encountered during its migration, so that only about one percent of what was formed is trapped in accumulations large enough to be exploited.

2. Trends

The world has now been very thoroughly explored so that nearly all of the oil provinces have been found. Oilfields are clustered together in discrete trends where the remarkable and very exceptional geological conditions needed for generation and entrapment were met. They are separated by huge barren tracts that are barren for reasons that are well understood.
obvious reasons, the more prolific trends were found first, as were the larger fields within them. Most of what remains to be found will come from ever smaller fields in mature areas.

3. Technology

Much of the world's oil was found long ago with fairly primitive technology. There have been considerable technological advances such as the semisubmersible rig that opened the offshore to routine drilling. Modern seismic surveys can map the oil zones with a very high resolution, and geochemistry can explain where and when the oil moved. These tools are sufficient to efficiently find and produce the world's endowment of conventional oil, as discussed below. Further technological advances can be expected and will be needed to find and develop ever smaller accumulations that have progressively less impact on world supply. This year's Buick is better than last year's model, but that was still good enough for most purposes. So there is no technological solution to the impending shortfall: it is not a technological problem.

4. Conventional and Non-conventional Oil

Much of the confusion about the world's endowment of oil stems from a failure to distinguish these two categories. Almost all the oil produced so far can be classed as conventional as will the bulk of what will be produced over the next twenty years or so. But when that supply dwindles, attention will turn to what may be termed non-conventional oil made up of:

1. oil from tar sands and oil shales
2. heavy oil
3. enhanced recovery by changing the characteristics of the oil in the reservoir by steam injection or in other ways
4. oil (if any) in very hostile environments - polar regions or very deep water
5. oil from infill drilling to reach pockets by-passed in the primary depletion of a field
6. oil in accumulations too small to be viable exploration targets

The important distinction is that the unfettered production of conventional oil rises rapidly to a peak and then declines exponentially; whereas the production of non-conventional oil rises only slowly to a long low plateau, before in turn declining. The resources of heavy oil and tar sands are considerable, but the constraint to production is cost and the sheer scale of the undertaking. Non-conventional production is unlikely to make an impact until the tail end of conventional depletion and then only in a high or very high price environment. It is no substitute for conventional oil as has fueled the Twentieth Century economy.

5. Recovery Factor

Oil occurs in the pore space of the reservoir rock where it is subject to capillary pressures. Production falls when the wells have to draw on oil farther and farther from the wellbore. Eventually a point is reached when no
more can be produced. The percentage recoverable ranges from about 20 to 60% depending primarily on the gravity of the oil. Recovery factors depend on the amount of oil-in-place which is often not exactly known. It is often claimed that technology can improve recovery. In fact, the apparent improvements may reflect initial underestimate or understatement of the amount of oil-in-place rather than any technological breakthrough.

Next section, Data Bases

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The Twenty First Century
The World's Endowment of
Conventional Oil and its Depletion

by C.J.Campbell
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Data Bases

The following are the main sources of information:

1. Petroconsultants in Geneva

This company maintains the most authoritative database on production and reserves as well as important drilling statistics for the world outside the United States and Canada, but it is available only on subscription. It also publishes reports on future supply and depletion built on its database and unrivaled knowledge. It is extensively used by the oil companies who contribute their knowledge to it. Access is however costly reflecting the large investments.
involved, which puts it out of range for most individuals or scholars.

2. The Oil and Gas Journal

This journal has published for many years reserves and production by country normally in one of the last issues of the year. It is one of the most widely used sources of information, and particularly useful because of the long history of consistent reporting. As a trade journal it cannot however interpret the validity of the data provided to it.

3. World Oil

This journal likewise has published similar data over the years, usually in an August issue. In many cases, its numbers are the same as those in the Oil and Gas Journal, although there are also significant differences.

4. BP

This major oil company publishes the same type of data in its annual Statistical Review of World Energy, but the reserve data are simply reproduced from the Oil and Gas Journal and do not reflect the company's own assessment.

5. US Geological Survey

This government department publishes useful data at three year intervals at World Petroleum Congresses, but it is important to understand that it has its own reserve definitions that need to be decoded before the material can be used profitably.

Elements

Certain key elements have to be taken into account in estimating the world's endowment of conventional oil. The references should be consulted for a discussion on how these elements are defined, which is particularly important in connection with reserves. Here, it will be sufficient to illustrate them graphically, considering the world's regions and the fifteen most amply endowed countries. The numbers are taken from Campbell (1996), except were indicated otherwise and are quoted in billion barrels (Gb). In all cases they refer to conventional oil only as of the end of 1995. Although quoted as exact numbers as computed, they should of course be generously rounded. The regions for this purpose are defined as follows:

- Middle East (Other): Turkey to Oman and Yemen outside M.E.(Gulf)
- East: Pakistan to Viet Nam and Australasia
- W.Europe: Norway to Italy
- Africa
- Latin America: South America and Mexico
- North America: USA and Canada
- Eurasia: FSU, China and Eastern Europe
- Middle East (Gulf): Abu Dhabi, Iran, Iraq, Kuwait, Neutral Zone, Saudi Arabia
- Other: countries with <500 Mb Ultimate or not in production; and unforeseen discovery and revisions anywhere.
Produced-to-date (761 Gb)

The concept of Produced-to-date or cumulative Production is straightforward - how much has been produced. It is however necessary to watch out for territorial changes and the treatment of war loss, as in Kuwait (2.5 Gb), which in principle should be regarded as production, although in this case is ignored as being small in relation to the uncertainty of the reserves. North America and the Middle East Gulf have produced the most, at just under 190 Gb, with Eurasia in third place. In terms of individual countries, the United States heads the list (171 Gb), followed by the FSU (125 Gb) and, far behind in third place, Saudi Arabia with 74 Gb. This illustrates the maturity of the United States, which for many years in the past was the world's most important producer.

Reserves (800 Gb)

The term Reserves means the amounts yet to produce from known discoveries as of the reference date, but the numbers are confused by differing definitions and other distortions (see references). Many published numbers are unreliable. Here, we refer to what are termed "Median Probability Reserves (or P50 Reserves)", which means that the risks that the actual number will turn out higher or lower than the estimate are equally matched. Most
published reserves are described as Proved, but are often far from that.

The Middle East (Gulf) has more than half the world's reserves with 439 Gb, followed far behind by Eurasia with 114 Gb, and trailed by Latin America (74 Gb). In terms of individual countries, Saudi Arabia heads the list with 189 Gb, followed by the FSU with 84 Gb. Several other countries with comparable amounts come next in line: Iraq (68 Gb); Abu Dhabi (62 Gb); Kuwait (60 Gb) and Iran (53 Gb). Figure 4 illustrates the wide range in the published estimates.

**Figure 3**

![P50 RESERVES - 1995](chart)

**Figure 4**

![RESERVES Major countries](chart)

**Discovered-to-date (1561 Gb)**

The Discovered-to-date is the sum of the Cumulative Production and the Reserves.

The Middle East Gulf is in first place with 626 Gb, followed by Eurasia (267 Gb) and North America (225 Gb). In terms of individual countries, Saudi Arabia is again at the head of the list with 264 Gb, followed by the FSU (209 Gb) and USA (200 Gb).
About 63% occurs in just over 300 giant fields, namely those with more than 500 Mb of ultimate recovery. The discovery of giants fields peaked in the 1960s as shown in Figure 7. This is a very critical statistic with serious implications for the future. The discovery of giant fields has fallen dramatically in recent years and few, if any, remain to be found. Most giant fields are found early in the exploration process, being too large to miss. Most were found without the benefit of advanced technology.
Undiscovered (189 Gb)

The Undiscovered, or Yet-to-find, is the Ultimate (see below) less the Discovered. The Middle East (Gulf) has the greatest potential with 61 Gb, followed by Eurasia with 28 Gb. North and Latin America with respectively 13 Gb and 13.5 Gb are in near equal third place. In addition, some 50 Gb is attributed to unforeseen discoveries or reserve revisions anywhere. In terms of individual countries, the FSU (21 Gb), Iraq (19 Gb), Iran (17 Gb) and Saudi Arabia (16 Gb) seem to have the greatest promise. Discovery rates are falling, currently standing at about 7 Gb a year. Drilling rates and the amount discovered per well are also falling. There may be some improvement in success ratio as exploration turns to lower risk mature areas, but the amounts found are expected to continue to decline. Most of what remains will likely be found within 10-20 years in most countries outside the Middle East Gulf and the FSU where exploration may continue to be a low priority for some years to come.

Remaining (989 Gb)

The Remaining is the Ultimate less the Produced, or in other terms the Reserves plus the Undiscovered. It is the bottom line, namely how much is left to produce, and is the statistic we need to run the depletion model. The region with the most is of course the Middle East Gulf with 499 Gb, which is about half the total. It is followed by Eurasia with 142 Gb and then Latin America with 88 Gb. By individual country, Saudi Arabia comes first with 206 Gb, followed by the FSU (105 Gb) and Iraq (88 Gb). So far as the western world is concerned, the two leading countries are the USA with 39 Gb and Venezuela with 38 Gb. It is evident that about 70% of the world's remaining oil lies in countries that are not really part of the open market and in which the oil industry is exclusively in state hands.
Ultimate (1750 Gb)

The Ultimate is Cumulative Production when production ends. It is very important to recognize that there is an ultimate, even if the number cannot be determined exactly. The number proposed here is a rounded 1750 Gb which can be used to drive the depletion model for the next ten or twenty years through peak production into decline. It refers, like all the other numbers to conventional oil only. It may well be due for some upward revision in the far future in a high or very high price environment when some of what is here treated as non-conventional becomes conventional. The 1750 Gb is in fact approximately the same as the 2300 Gb proposed by the US Geological Survey, if that is redefined to take into account only Median Probability Reserves and the low end of the range of Undiscovered which is all that meets relevant time and economic constraints. It also is suggested by the trend of published estimates. Those desiring a higher number often show the same plot but take the scatter rather than the trend. Here weight is given to the trend because the more recent estimates have the advantage of modern technology and a
A colossal database from worldwide drilling. Care must however be taken in checking the definitions applied. Some of the higher reported numbers include what is here treated as non-conventional oil. Another very compelling argument comes from the plot given in Figure 15, showing discovery with reserve revision backdated to the discovery date. It shows a marked inflection to falling discovery in the 1960s. Extrapolating the subsequent curve gives a very clear intimation of future discovery and hence the Ultimate. If indeed the reserve estimates of particularly the Middle East prove to be higher than here assessed, it would mean that the inflection would be even more pronounced, reducing further the recent trend. It is accordingly difficult to argue convincingly for an Ultimate much higher than that proposed, given especially the fact that virtually the entire world has been explored sufficiently to indicate the existence of the major provinces. Only a new province with a crop of giant fields could have any global impact.

The Middle East Gulf Region has the largest endowment with 687 Gb, followed by Eurasia with 295 Gb and North America with 238 Gb. Saudi Arabia (280 Gb), the FSU (230 Gb) and the United States (210 Gb) are the three most richly endowed countries.
Depletion Model

We have now developed an assessment of how much conventional oil there is and how much remains to produce, the Remaining. Oil does not occur in some vast underground cavern from which it could be quickly pumped, but it is held in the minute pore space of the reservoir rocks, in the same way as rising damp can flow through the walls of old stone buildings. It is easy to understand therefore why wells begin to decline as they have to draw on oil farther and farther from the wellbore. The production of an oilfield rises rapidly as new wells are added but then when all the wells are in place declines exponentially at a composite depletion rate. Depletion Rate is a given year's production as a percentage of the remaining reserves at the end of the preceding year. So it is with a geological basin: production rises as new fields are found, and it is normal for the larger ones to be found first. Their depletion rate tends to mask the effects of small late stage additions. Lastly, it is the same for a country, with the larger basins usually being developed first. The natural pattern can of course be modified if production is deliberately held to a certain limit. Thus production of an offshore field may be held at a plateau constrained by the number of wells and the optimal off-take in relation to investments. Likewise, a country may arbitrarily manipulate production to maintain price in a practice known as prorationing, as practiced for example by the Texas Railroad Commission, and less successfully by OPEC with its quotas. In any event, the production of any field starts at zero, rises to a peak (or plateau if artificially constrained) and then falls to zero. The profile of individual fields is normally asymmetrical, being skewed to the left, but a country's peak tends to be symmetrical because it is made up of a progression of individual field profiles. It follows then that peak production will more or less coincide with the midpoint of depletion, except where there are artificial constraints, and even then the midpoint of depletion will roughly coincide with the midpoint of the constrained period.

Depletion rate rises during the early production of a field (or country's production) as new wells or fields are added, but tends to stabilize at the midpoint, such that production declines exponentially thereafter, ultimately due to the immutable physics of the reservoir. The midpoint of depletion comes when half the Ultimate has been produced. Since we have now estimated the Ultimate for each country, we are in a position to estimate when peak production will come and plot the subsequent decline. It means that we can divide the world's producing countries into three categories...
1. Post-Midpoint Countries

Production is declining exponentially in these countries. Strictly speaking it would be best to plot the depletion from midpoint at the midpoint depletion rate, and treat any departures from this notional curve as anomalies that eventually even out, because more production early has to be matched by less production later, given the fixed Ultimate. But in practice one can as well take the current depletion rate to keep it simple, because in most cases the current rate differs only slightly from the midpoint rate. Doing so also makes the short term prognosis a little more realistic.

2. Pre-Midpoint Countries

A few countries, save those in the Middle East Gulf region, are still a year or two away from midpoint. If actual near term production forecasts are known, they can be fed in, but otherwise it will suffice to apply an arbitrary increase of, say, 5%, because it applies only for a few years. Once they reach midpoint, they decline exponentially at the midpoint depletion rate.

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Some key elements can however be identified

1. The pivotal role of Iraq

No one quite knows the origins of the Gulf War, although some hints are given by Schweizer in his book Victory. The net consequence, however, has been the removal of 2-3 Mb/d from the...
market under the embargo, which OPEC failed to achieve by its quota system. This has been sufficient to maintain oil prices at a moderate level, which in turn has contributed to the survival of the Saudi, Iranian and a few other regimes that depend heavily on oil revenues. The embargo can also be relaxed if prices rise in a manner unacceptable to those enforcing the embargo. In effect, it makes Iraq the swing producer of last recourse. It is however a function that can be applied for only a few years, as Iraq's oil will be needed in full from about 2000 to meet the requirements of the demand scenarios.

2. Finishing the Swing Share

Doubts have been expressed as to the willingness of the swing countries to invest in adding the capacity needed for them to discharge their swing role, given that the oil industry is almost exclusively in State hands and given that the State has many other demands on its precious oil revenues. While prices are low, they are ironically forced to produce to the maximum to meet their pressing demands for revenue, but once prices rise they will have greater room to maneuver. The investment could be forthcoming if they were willing to open their doors wide to the international oil companies, but that may be unacceptable in political terms, especially if rising prices reduce the need.

3. Short term exports from Norway and the FSU

Norway, which has about half the North Sea's remaining oil, exports a large proportion of its production because of its small population. Production will peak in 1999 under the model and then decline at a high depletion rate of about 8%, as is typical of offshore production. FSU exports have also been relatively strong because falling production has been exceeded by falling domestic demand. Any economic improvement there could radically change this situation. Both of these factors may serve to greatly increase the Swing control by about 2000.

4. Instability, market and limited capacity

The price of oil is today set by a very efficient forward market that is more a reflection of present trends than speculation or judgment about the future. There is today very little immediately available spare capacity anywhere. It follows that relatively minor interruptions in supply, or even threats of same, in any one of a number of countries subject to political or industrial strife can have a radical impact on the price of oil. Once prices rise for what ever short term reason, the trend may feed on itself as the suppliers have greater ability to curb production without crippling their revenue stream. There are currently question marks about the nature of the Saudi succession as well as Iranian intentions in arming islands in the Gulf of Hormuz. A spark once kindled could easy lead to a bush fire.

Conclusions

Predicting the future is a dubious undertaking. The oil database in the public domain is weak, and there are many uncertainties. That said, compelling evidence points to a pending oil supply shortfall, possibly before 2000, which could trigger a third and permanent radical rise in oil prices. There is a certain skepticism because people have cried wolf before, but this time the situation is totally different from that which allowed the oil shocks of the 1970s. Then, the swing control was being undermined by flush production coming on stream from new provinces in the North Sea, Alaska and elsewhere that had already been found. This time none are even in sight and very possibly do not exist. We face a different world. The basic situation is clear, although there is plenty of room for debate about the size of the numbers and depletion scenarios. Those who investigate sensitivities will soon find that
there is not in fact much room for radically different interpretations. Every effort should be made to improve knowledge of what has been found so far to secure a better basis for projecting future discovery and production. It is not so much a technical issue as a political one to open the files and see what is really in them.

Bibliography
March 21, 1998

WEEKEND EDITION - SATURDAY (entire program)

Requires the RealAudio Player

CLINTON LEGAL STRATEGY -- NPR's Mara Liasson reports the President's lawyers have made one last attempt to have the Paula Jones sexual harassment case thrown out. (4:30)

ACCUSER CREDIBILITY -- Scott talks with Andrea Sankar, an anthropology professor and Leonie Huddy, a political science professor, about how the public determines the credibility of the women who have accused President Clinton of sexual harassment -- it all goes back to Anita Hill. (7:00)

KOSOVO DEVELOPMENTS -- NPR's Tom Gjelten talks with Scott about the latest developments on the problems in Kosovo. (4:20)

POPE IN NIGERIA -- NPR's Jennifer Ludden reports on the Pope's trip to Nigeria (3:50)

CRANE SONG -- Producer of the radio feature "Pulse of the Planet," Jim Metzner, introduces the sounds of the migrating Great Sandhill Cranes. (5:30)

JAYWALKING -- Scott speaks with Jean Godden, columnist for the Seattle Times, about a new initiative in Seattle which punishes jaywalkers with a stiff fine. (3:00)

VIRGINIA ANTHEM -- Scott speaks with former Virginia legislator Tom Moncieur about his state's search for a new song. (6:00) This item is unavailable due to copyright issues.

MISSISSIPPI SOVEREIGNTY COMMISSION -- Scott speaks with David Ingerbretson, Director of the American Civil Liberties Union of Mississippi, and Rita Bender, who was a civil rights worker in Mississippi during the 1960s and is the widow of David Schwerner, who along with two other civil rights workers was murdered in that state in 1964, about the long-sought release this week of the secret files of the pro-segregation Mississippi Sovereignty Commission. (11:30)

WEEK-IN-REVIEW -- Dan Schorr reviews the week's news. (9:00)

GREAT LAKES -- Scott tells us what he really thinks about elevating Lake Champlain to Great Lake status under law. (3:00)

GEORGIA TORNADOS -- Melissa Grey of Peach State Public Radio reports on the tornados that swept through Georgia yesterday, killing twelve people. (2:30)
**OIL PRODUCTION** -- Scott talks with oil industry expert Colin Campbell about Mr. Campbell's assertion that oil production will decline within the next decade -- and that our current great oil prices are soon to be history. (5:00)

**FROM DINOSAURS TO BIRDS** -- NPR's David Baron reports on the debate among dinosaur experts surrounding the theory that dinosaurs evolved into birds. (6:30)

**OBSERVATION SKILLS** -- Scott talks with Yale Medical School Professor Irwin Braverman about a new informal program he has developed to help medical students sharpen their observation skills. In the program students diagnose paintings instead of patients. (3:00)

**LETTERS** -- Scott reads letters from listeners. (2:00)

**PRIMARY COLORS** -- Scott speaks with Weekend Edition's entertainment critic Elvis Mitchell about the movie "Primary Colors." (6:00)

**HOPE** -- NPR's Susan Stamberg visits Bill Clinton's hometown to find out what folks are thinking about the President these days. (8:30).

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Mexico's Petroleum Exports: Safe Collateral for a $50 Billion Loan?

Richard C. Duncan, Ph.D.
Institute on Energy and Man

[note: graphics under construction]

It is illusory, and would be harmful, to pretend that petroleum produced and exported in large quantities could become the factotum of Mexico's economy or the panacea for Mexico's economic ills. Mexico does not wish ever to be forced to export such an indispensable energy and chemical resource.

Antonio J. Bermúdez, 1963
Director General
Petroleos Mexicanos, 1947-58

1. INTRODUCTION

In the mid-1990s, Mexico found it increasingly difficult to attract foreign capital, especially into its energy sector. Then, within a week in December 1994, the Mexican peso fell by 35 to 40%. The Mexican central banks' international reserves, which had stood at $29 billion, plunged to $5 billion. In an effort to stave off a collapse of the Mexican economy, on 31 January 1995 the President of the United States, by executive order, signed a $50 billion "Emergency Stabilization Package" loan to the Mexican government. The collateral for the loan was Mexico's pledge of revenues from its future petroleum exports. (PE, 1995b)

This study uses Mexican petroleum production data and a robust geophysical approach to answer the question, Are Mexico's oil exports safe collateral for the 1995 $50 billion Emergency Stabilization Package (ESP) loan? This question is answered in the context of Mexico's capacity to simultaneously repay the ESP loan, and meet the requirements of the 1993 North American Free Trade Agreement (NAFTA), and complete its plan for industrial development.

2. MEXICAN PETROLEUM PRODUCTION: 1901-1994

The creation of Pemex in 1938 helped establish firm respect for state sovereignty both at home and abroad. Thus, Mexicans believe that what happens to Pemex will directly affect the national dignity, economic independence, and state sovereignty of their country.

David Ronfeldt, 1980

A history of Mexican petroleum production is illustrated in Figure 1. Production began in 1901, and, spurred by a strong demand for oil by the allies during World War I, it peaked sharply in 1921 to mark Mexico's "first oil boom" Although the 1921 peak is small compared to recent rates, from 1918 to 1928 Mexico ranked second only to the United States in world oil production. (Powell, 1956; Bermúdez, 1963)

Figure 1

View image (typically right mouse button)
to see graphs full size
In the early years, the Mexican oil industry was dominated by American and British companies. However, in the 1930s with national feelings rising and oil production falling, and open conflict between the foreign oil companies on one side and the Mexican government and labor on the other, the days of outside domination were numbered. On March 18, 1938, the Mexican government expropriated all foreign oil assets and, by June 7, 1938, the petroleum industry was nationalized in the shape of Petróleos Mexicanos, or "Pemex" for short. (Bermúdez, 1963)

Mexican oil production stagnated from 1938 until the mid-1940s (Figure 1). Then from 1944 to 1973 production increased at a vigorous average rate of 15% per year (i.e., from 0.11 to 0.55 million barrels per day). After the discovery of large new fields in the 1960s and the sharp jump in world oil prices in 1973, Mexico's "second oil boom" took off. From 1973 through 1982 oil production increased by a whopping average of 50% per year (i.e., from 0.55 to 3.0 million barrels per day). However, from 1982 through 1994 production slowed dramatically (Figure 1) with an average growth rate of only 1% per year (i.e., from 3.0 to 3.3 million barrels per day).

[Note 2: In this report, the words petroleum and oil are used synonymously to mean crude oil and natural gas liquids, "NGLs" - the liquid content of natural gas wherever this is recovered separately.]

The next section focuses on oil production, consumption and "surplus."

3. MEXICAN OIL PRODUCTION IN THE WORLD CONTEXT

Mexico's oil reserves will match those of Saudi Arabia.

Jose López Portillo, 1978
President of Mexico, 1976-82
(in Metz, 1978)

An analysis not dissimilar from that of Venezuela can be applied to Mexico, where newly discovered reserves of oil are, as usual, much exaggerated.

Aubrey Jones, 1981

President Portillo's prediction that Mexico's oil reserves would match those of Saudi Arabia was (and is) flatly wrong. "Oil in place is an abstraction. For Mexico during L-pez Portillo's time, it stood as the foundation of Mexico's line of credit with international bankers." (Baker, 1984) Others too were skeptical.

Is Mexico a new Saudi Arabia? ... By its official estimates, ... Mexico has about 60.10 billion barrels of proven reserves; Saudi Arabia ... has nearly three times that amount or 163.35 billion barrels ... Moreover, Saudi Arabia's production costs are in the neighborhood of thirty-five to fifty cents per barrel, a fraction of the Mexican figures. ... Mexico's large, fast-growing population now consumes six out of ten barrels produced in the country ... In contrast, Saudi Arabia, with fewer than eight million people ... can export almost all of its output. (Grayson, 1980)

But the exaggerated predictions of Mexican petroleum reserves (e.g., described as "an oil bonanza," "prolific wells," "unlimited quantities," and "a veritable sea of oil") were taken seriously by some high American officials on energy. For instance, early in 1979 U. S. Energy Secretary James Schlesinger affirmed, "The Mexican oil reserves prospectively are as great as those of Saudi Arabia." (Gentleman,
[Note 3: A word of caution before we proceed. There exists a pervasive confusion about the difference between oil resources and oil reserves. Suffice it is to say that (1) reserves are but a small fraction of resources, and (2) the word reserves itself is clouded by an infinite regress of artificial categories such as, "proved," "probable," "possible," "potential," "economic" and "sub-economic." Geologist C. J. Campbell (1991) added yet two more categories, "political" and "suspect." Not to be outdone, a former Mexican Minister of Natural Resources leaped to heavenly heights with "theological" reserves. (Williams, 1979) "We have in the word reserves a chaos of meaninglessness." (North, 1985) In short, most estimates of Mexican oil reserves are not useful for serious study.]

Historic data shows that the Mexican oil industry is now mature. No unexplored frontiers remain. No "major" fields lie cooly awaiting discovery. The last major Mexican oil field was discovered in 1978. (Campbell, 1991; 1995b) ("Major" means an ultimate recovery of 500 million barrels or more.) Fortunately, however, estimates of Mexican reserves are irrelevant to this study, because ample historic data is now available to confidently predict the life-cycle of Mexican petroleum production.

Figure 2 compares Mexican oil production with that of the United States, Texas and Saudi Arabia. Several features are noteworthy. First, the data confirms that Mexico is not "another Saudi Arabia." For instance, Saudi Arabian oil production reached a remarkable 10.0 million barrels per day (in 1980) compared to Mexico's maximum (to date) of 3.3 million barrels per day (in 1994).

Second, comparing Mexican oil production to that of the United States (Figure 2), even with the addition of Alaskan oil and the remarkable advances in exploratory and production (OE & PO) technologies, from 1970 through 1994 total United States oil production decreased by 25.7% (i.e., from 11.3 to 8.4 million barrels per day) and Lower-48 production decreased by a dizzying 45.0% (i.e., from 9.4 to 5.2 million barrels per day). (API, 1994; BP, 1995) The decline is an example of the Theory of Depletion Dominance: "During the down-side of the life cycle of petroleum production, resource depletion dominates both price and technology." (Duncan, 1995a) In fact, resource depletion is already tightening its jugular grip as Mexican petroleum production nears its all-time peak, discussed later in this report.

Third, the history of Texas oil production sheds light on the future of Mexican oil production (Figure 2). Texas production started in 1889 and peaked in 1972 at 3.6 million barrels a day: i.e., 83 years from start to peak. Moreover, despite heroic efforts to the contrary, Texas oil production has obstinately declined since the peak. (API, 1994; Duncan, 1995a) In comparison, Mexican oil production started in 1901 and reached its greatest rate in 1994 at 3.3 million barrels per day: i.e., 93 years from start to present. Although details differ, in Sections 6 and 7, I show that Mexican oil production is now near its peak, and likely to fall even faster than that of Texas.

Figure 3, a column chart, compares Mexico's cumulative oil production with that of the United States, Saudi Arabia, and Texas. The height of each column represents the cumulative oil production for each nation from the start of production to year-end 1994, abbreviated "Q1994": United States = 191.4; Saudi Arabia = 66.2; Texas = 62.7; Mexico = 23.9 billion barrels. In percentages, the cumulative oil production of Mexico stands at 38% that of Texas, 36% that of Saudi Arabia, and a scant 12% that of the United States.

Recall that Mexico's oil exports are collateral for the 1995 ESP loan. Mexico's potential for petroleum
exports is determined by its "surplus" production. (Surplus oil is defined as total production minus domestic consumption.) Figure 4 plots Mexico's total oil production, domestic consumption, and its surplus for the period 1970 through 1994. The data shows that Mexico's oil surplus grew rapidly from 1974 to 1982, but decreased by 10.6% from 1984 through 1994 (i.e., from 1.795 to 1.605 million barrels per day, a decline in surplus of 190,000 barrels per day).

The following section describes and develops the Hubbert simulation model.

4. KING HUBBERT'S MODEL: THE ENERGY DEPLETION ARCH

Hubbert was for many years with the Shell Oil Company. In 1958 he predicted with uncanny accuracy the course of discovery and production of [United States] petroleum.

*Philip H. Ableson, 1975*

Several decades ago, distinguished geologist and geophysicist M. King Hubbert developed a technique for predicting the production life-cycle of nonrenewable energy resources, such as crude oil and natural gas (Hubbert, 1949; 1956; 1969). By design, King Hubbert wisely avoided the use of energy "reserves." However, his method is critically dependent on exploration and production data. The Hubbert model, as it is called, is based on a simple law of resource geology.

The complete cycle of production of any nonrenewable resource, in any one region or in the entire world, must begin with production rising from zero towards a maximum; there may be several maxima separated by temporary declines; but eventually the cycle is completed by a long-continued decline back to zero via the negative exponential. (North, 1985)

Petroleum expert F. K. North continues,

Hubbert's forecasts for the ultimate oil and gas production of the continental USA survived the passage of time so much better than other forecasts that his methodology was accorded almost magical capabilities by some. In fact, its utility is strictly limited, though if used within its limits the results to which it leads are crucially important. The method obviously makes no pretense of application to unexplored or little-explored areas which provide no historical data to extrapolate. It cannot be used with any reliability until the rate of additions to reserves (dQD/dt) has clearly entered the negative slope. ... In those regions, if in few others, use of the Hubbert technique is likely to yield trustworthy assessments. (ibid.)

[Note 4: In the equations and charts that follow, I have dropped the subscript "D" that appears in F. K. North's notation (above), because the subscript introduces a level of detail that is not needed in this discussion.]

The applicability of the Hubbert model to a specific oil-bearing region thus boils down to two factors: (1) the stage of development, and (2) the availability of historic data. No one describes the petroleum life-cycle better than geologist and oil field developer Rick Bass. First, the up-side of the curve.
Geologists, if they work on a new basin long enough, and if the basin holds enough oil and gas, get to see the basin "mature." ... What they mean is that there is now enough information on it, enough control - seismic lines shot, wells drilled - for them to have a very good handle on it. They mean the basin is in the peak of its years, exploration- and development-wise. ... When a basin is "young," there isn't enough information. ... Paradoxically, up to a certain point, the more oil and gas fields found, the easier it becomes to find others. You would think that every time one was discovered, it would make it that much harder to find another - that there'd be one less around. But before you reach a saturation point, it doesn't work that way at all. Because that's the single best way to discover oil: to figure out how it is trapped, under what conditions, nearby, and then look for another area that has similar conditions. ... There are a few golden years in the maturation of any successful basin where, truly, if the homework has been done and all the facts studied and learned, it is . . . easier. (Bass, 1989)

Next, petroleum geologist Rick Bass describes the down-side of the curve.

After a while, of course, the saturation point is reached; it gets harder to find new fields. Because finally a large percentage of the fields have been found. It is so like middle age that it is depressing. Basically, one day you just notice - though it may have been going on for quite some time before you admit it - that you are not finding oil wells as frequently, or with the success rate that you once were. It's not an immediate thing, but it's part of the phase too, part of the cycle. "Overmature" is the term for it. (ibid.)

The model consists of two equally important parts: the Hubbert equation, and the boundary conditions. The foregoing qualitative descriptions by Messrs. Bass and North are translated into the quantitative Hubbert model as follows.

[Note 5: I develop the Hubbert equation in two steps. The resulting Hubbert equation is given by Equation (2) below.]

I. The Hubbert Equation: During the young years of exploration in an oil-bearing region, the characteristic rate of discovery is exponential growth. In this young phase (see Bass above), oil production is approximated by the equation,

\[ \frac{dQ}{dt} = a*Q \]

where \( \frac{dQ}{dt} \) is the rate of oil production, say, in millions of barrels per day, and \( Q_{inf} \) is the cumulative production of oil, in billions of barrels. The term "a*Q" represents exponential growth. It is like compound interest paid on a bank account: "The rich get richer ... ." Or like a bunch of amorous rabbits multiplying their numbers. Taken alone, Equation (1) means that an oil-bearing region would remain eternally young and oil production would grow faster-and-faster, forever. Unreal. Impossible.

Inevitably, of course, "middle age" sets in (Bass again). The oil-bearing region becomes "mature." Worse yet, after "a few golden years," the region becomes "overmature." Depletion dominates. The process of slowdown and decline is modeled by adding a negative term, \(-b*Q^2\), to Equation (1). Doing this, we get,

\[ \frac{dQ}{dt} = a*Q - b*Q^2 \]

Equation (2), above, is the Hubbert equation, but (I re-emphasize) it is only half of the Hubbert model.

II. The Boundary Conditions: The boundary conditions ("BCs") are the initial and final states of the system. They are ironclad, inescapable. They lock-in a unique solution. As stated above by F. K. North, energy production, \( \frac{dQ}{dt} \), must be zero before production begins (i.e., at \( Q = 0 \)) and eventually
it must return to zero (i.e., at \( Q = Q[\text{inf}] \).) Substituting the boundary conditions into Equation (2), we get,

\[
[\text{Equation}] \quad (3)
\]

Equation (3) is the Hubbert model. The "Energy Depletion Arch." Just as the positive term, \( a*Q \), dominates on the up-slope, the negative term (or the "senility gene," so to speak), \(-\left(\frac{a}{Q[\text{inf}]}\right)Q^2\), dominates on the down-slope, during the "overmature" or "old-age" phase of the oil production life-cycle.

[Note 6: Suggestion. Verify that the boundary conditions are satisfied by the Hubbert model: i.e., substitute separately \( Q = 0 \), and \( Q = Q[\text{inf}] \) into Equation (3) and confirm that \( \frac{dQ}{dt} \) equals zero in each case.]

A graph with \( Q \) on the x-axis and \( \frac{dQ}{dt} \) on the y-axis produces a parabolic arch, one like the majestic Gateway Arch in St. Louis. Mentally translating Equation (3) onto an x-y plot, imagine one "foot" of the arch planted at the origin (i.e., at \( Q = 0, \frac{dQ}{dt} = 0 \)) and the other planted at \( Q = Q[\text{inf}], \frac{dQ}{dt} = 0 \). But because countless graphs of the Hubbert arch appear in the literature (e.g., Hubbert, 1982; Duncan, 1995a), I will not repeat it here. For now however, have a look at Figure 7, Section 6, where the "Energy Depletion Arch" for Mexico is graphed.

[Note 7: Boundary conditions are extremely important in modeling because (1) they eliminate most candidate models, and (2) they lock the model-of-choice into a specific solution. For a familiar example, consider the fine sport of baseball. When the batter hits a ball into the air, the fielder "knows," (1) that the trajectory will be a parabola, and (2) that the ball will come down. Woe be unto the fielder who chooses an ellipse or hyperbola. Getting back to energy, I leave it to you, the reader, to describe the model and boundary conditions that you (subconsciously) apply every time you fill your automobile's tank with petrol.]

[Note 8: The main goal of science is to predict, not explain. Thus, there is no need to have any philosophical worries about what the Hubbert model means, i.e., Equation (3). At the very least, the Hubbert model is a mathematical construction that is too fruitful to embellish or abandon.]

In the next Section, I determine the values of "\( a \)" and "\( Q[\text{inf}] \)" for the Mexican model.

5. REGRESSION ANALYSIS: SPECIFYING THE MEXICAN MODEL

The need for anticipating petroleum-industry development does not derive solely from the immediate function which that industry provides, but also from the depletion character of its operations. Oil and gas are wasting assets; that is, once placed in production, their outputs are subject to inevitable and sometimes rapid decline to exhaustion.

Antonio J. Bermúdez, 1963

Figure 5 below displays Mexican oil production on the y-axis, and cumulative oil depletion, \( Q \), on the x-axis. Although the general profile of the data is similar to that in Figure 1, the change to cumulative oil depletion in Figure 5 emphasizes the causal relationship between oil production and resource depletion. The causality is simple. For every barrel of oil extracted from the earth, the amount of producible oil that remains underground (i.e., the reserve) is depleted by exactly the same amount. As the reserve goes to zero, production goes to zero, inexorably.

\[
\text{Figure xxx}
\]

[Note 9: Crude oil is not "produced" in the dictionary meaning that it is made or manufactured. Rather, it is extracted from the earth. Therefore, it would be more accurate to label the y-axis of the graphs, "Extraction, \( \frac{dQ}{dt} \)," and the x-axis "Cumulative Depletion, \( Q \)," as I have done in Figure 5. However, to avoid confusion, I will defer to the common...]

To apply the Hubbert model to Mexico, specific values for "a" and "Q[inf]" must be determined. The process is known as "parameterization." The method employs a statistical technique called linear regression. First, I divide Equation (3) through by Q to obtain the linear regression equation. The result is,

\[ \text{Equation (4)} \]

Note 10: Equation (4) above is a linear equation. It is related to, but different from, the Hubbert model, as given previously by Equation (3). As such, Equation (4) is called an "auxiliary" equation. Bottom Line: It is the auxiliary equation that is fit to the data (e.g., Figure 6, below), not the Hubbert model.

Second, I use Microsoft Excel (an application program) to determine the values of "a" and "Q[inf]". Figure 6 displays the ratio of the Mexican annual oil production to the cumulative oil production, i.e., \((DQ/DT)/Q\) data, on the y-axis, and the cumulative oil production, Q, on the x-axis. It also shows the best-fit regression line, i.e., \((dQ/dt)/Q\), Equation (4), superimposed on the historic data, for comparison.

In Figure 6, the interception of the regression line and the y-axis estimates the value of "a" to be 0.133 per year. Similarly, the interception of the regression line and the x-axis estimates Q[inf] to be 35.4 billion barrels. Note also in Figure 6, that the historic data displays a definite downward trend and, of course, the regression line reflects that trend by its negative slope.

Looking again at Figure 6, the negative slope of the regression line, i.e., Equation (4), means simply that, "The faster Mexico extracts oil out of the ground, the sooner production goes to zero." Or in more picturesque language,

The fat and easy areas have been discovered. We, the world - not just the United States but the petroleum strongholds such as Mexico, the USSR, and the Middle East - are pulling out of the ground twice the amount we are finding. Each year. (Bass, 1989)

The ensuing section examines the future of the Mexican oil industry.

6. THE DOWN-SIDE OF MEXICAN OIL: SLOPE OR CLIFF?
It is supposed that the foreign currency from petroleum exports would allow Mexico's financial problems to be overcome. This position is unsound from Mexico's standpoint. There is no doubt that Mexico is a country rich in petroleum, and that its subsoil contains great volumes of still undiscovered and unexploited oil and gas. But the country is not so rich in petroleum as some suppose - at least not rich enough to throw an abundance of oil on glutted world markets.

Antonio J. Bermúdez, 1963

The values of the parameters for the Hubbert model, as configured for Mexico previously in Section 5, are, "$a" = 0.364 per day, and "$Q[inf]" = 35.4 billion barrels. Substituting these values in Equation (3), gives,

\[
\text{(5)}
\]

[Note 14: Compared to the value of "a" given previously (i.e., in Section 5) ¥ In Equation (5) above, I have multiplied "a" by (1,000/365) to convert production from billions of barrels per year to millions of barrels per day.]

Equation (5) is the theoretical model for Mexican oil production. The resulting curve - a parabola - is plotted in Figure 7 (shaded circles). Selected years are highlighted: e.g., 1989 (the theoretical peak), 1994 (for comparison with the 1994 data point), and 2000 and 2010 (i.e., the predicted production rates, 4 and 14 years hence). The historic data (X-shaded squares) is superimposed for comparison.

One: When will Mexican oil production start to fall? In December 1994, while the beleaguered Mexican government faced bankruptcy, I analyzed the Mexican oil industry and predicted that production would peak in 1995 or 1996. On 31 January 1995, I summarized my findings in a letter to President Clinton.

My calculations show that Mexican oil production is now near its all-time peak and poised for a steep and obstinate fall, much like the decline (since 1972) in Texas oil production. In fact, I predict that Mexican oil production will start to fall sharply in less than two years, i.e., before January 31, 1997. (Duncan, 1995b)

My conclusions were (and are) based on (1) the unequivocal negative slope of the regression line (Figure 6, this report), (2) the fact that Mexican oil production has long since passed its theoretical peak (i.e., 1989, Figure 7), and (3) the theoretical production curve is already in sharp decline (as shown in Figures 7 and 9).

The President’s response was disquietingly visionary.
My plan to aid Mexico's economy in the face of that nation's financial crisis, which I announced under executive authority, will avert further disruptions in world markets, stabilize the peso, renew confidence in the Mexican economy, and protect American jobs dependent upon exports. The plan will also reduce immigration pressure on the border.

The peso crisis presented us with a situation where decisive action by the United States could prevent a far greater crisis down the line. Recognizing the need for immediate action, we quickly put together a sound financial package that secures collateral from Mexico and places specific restrictions on Mexico's financial practices, which will safeguard U.S. interests. We also worked to gain support from global organizations, such as the International Monetary Fund and the Bank of International Settlements. Allies in the hemisphere, including Canada, Brazil, and Argentina, also made important contributions. Initial reaction of the markets to this U.S.-led effort has been positive.

Our nation's security depends on our continued world leadership -- and only the United States can take this leadership role. In moving decisively, we have acted in the world's interest and in our best interest and that of the millions of Americans whose livelihoods are tied to Mexico's well-being.

America's economic security is inextricably linked with Mexico's. By putting Mexico back on track, we have secured American jobs, preserved American exports, and safeguarded America's borders. (Bill Clinton, 27 February 1995, personal communication)

**Two: How fast will Mexican oil production decline?** The Hubbert model predicts that, for example, from 1996 to 2010 Mexican oil production will decline at average rate of 4.9% per year (as shown in Figure 7). Petroleum consultant C. J. Campbell describes the Mexican petroleum predicament as typical in the Western World.

Depletion rates for most countries outside the Middle East lie between 3% and 8%, with a few above 10%. The profile is primarily driven by the early large fields which are already in terminal decline and are not being replaced. (PE, 1995a)

**Three: What will be the ultimate magnitude of Mexican oil production, Q[inf]?** Recall that the value of Q[inf] is an estimate, but (and this is important) the estimate becomes ever more accurate as additional production data becomes available: i.e., as Qi -> Q[inf]. My calculations, and those of other analysts, show that Mexican production is fast approaching Q[inf]. For example, Table 1 gives two forecasts for the Mexican petroleum industry (i.e., Duncan, this study; and Campbell in PE, 1995a).

<table>
<thead>
<tr>
<th>Table 1. The Down-Side of Mexican Oil: Two Estimates</th>
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<td>[Values of Q are in billions of barrels.]</td>
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<tr>
<td></td>
</tr>
<tr>
<td><strong>Peak Year (prediction)</strong></td>
</tr>
<tr>
<td>Duncan</td>
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<tr>
<td>(this study)</td>
</tr>
<tr>
<td>1996</td>
</tr>
<tr>
<td>Q-ultimate (estimate)</td>
</tr>
<tr>
<td>35.4</td>
</tr>
<tr>
<td>Q end-94 (data source)</td>
</tr>
<tr>
<td>23.9</td>
</tr>
<tr>
<td>Amount remaining</td>
</tr>
<tr>
<td>11.5</td>
</tr>
<tr>
<td>Percent produced</td>
</tr>
<tr>
<td>67.5%</td>
</tr>
<tr>
<td>Percent remaining</td>
</tr>
<tr>
<td>32.5%</td>
</tr>
<tr>
<td>Depletion rate (prediction)</td>
</tr>
<tr>
<td>4.9%</td>
</tr>
</tbody>
</table>
Note especially the two **bold** rows in Table 1. Both studies predict that the peak of Mexican oil production is imminent, i.e., 1996 and 1998, respectively. Both likewise predict steep rates of decline, i.e., 4.9% and 3.1% per year, respectively. Because the down-slopes will be socially, politically, and economically devastating in either case, the difference of 1.8% does not alter the conclusions of this study.

[Note 15: Table 1 gives estimates of Mexico’s Q-ultimate equal to 35.4 and 52.0 billion barrels. Of course there are other estimates, ranging from 48.5 all the way up to 700 billion barrels. (Grayson, 1980; Metz, 1978) Take your pick.]

In Figure 8, I have sketched a hypothetical trajectory for the down-side of Mexican oil production. Note that the trajectory is consistent with the historic data (Figure 1) because it starts at the 1994 data point (i.e., \( Q^{1994} = 23.9 \) billion barrels, and \( \frac{dQ}{dt} = 3.3 \) million barrels/day), and it ends at my estimate of \( Q^{[inf]} = 35.4 \) billion barrels and \( \frac{dQ}{dt} = 0 \).

**Figure xxx**

graph

Our main concern here is, Will the down-side of Mexican oil production be gentle or steep, a slope or a cliff? Although the fine details are not predictable, there are telling clues. If the range of estimates of Q-ultimate in Table 1 is correct (i.e., if \( 35.4 < Q < 52.0 \) billion barrels), then sometime between 1 January 1996 and 31 December 1998, Mexican oil production will, so to speak, tumble headlong over a sheer cliff.

It will be very interesting to see how we handle it. (Bass, 1989)

The following section shows the life-cycle of Mexican oil production, in years.

### 7. THE LIFE-CYCLE OF MEXICAN OIL PRODUCTION: 1950-2030

The rebirth of the Mexican petroleum industry concerns not only the destiny of Pemex, but of all Mexico, because if Pemex fails, the nation will fail.

*Díaz Serrano, c. 1976*

**Director General, Pemex**

*(in Williams, 1979)*

I believe the next 10 to 15 years are our last chance. Failure to provide young people with a stake in the system may have serious consequences for a regime whose commitment to "revolutionary" goals often seems more rhetorical than real. [If Mexico does not succeed] social tensions will grow difficult. There will be invasions of property, insecurity in the cities, new political leaders.

*Victor Urquidi, c. 1979*

**President, Colegio de México**

*(in Grayson, 1980)*

More than fifteen years have passed since the warnings of Messrs. Serrano and Urquidi. In preparation for such contingencies, the U.S. Immigration and Naturalization Service (INS) developed a scenario for field exercises held along the U.S.-Mexican border in 1995. It reads,

Suddenly, a vast flood of illegal immigrants - Mexicans driven to desperation by some unspeakable and unspecified social catastrophe - surges across the Southwest border, inundating entire communities as it washes north into the American heartland. (Dillon, 1995)
Fortunately, we are no longer dependent on scenarios and vague warnings. We can now use historic petroleum production data (Figure 1) and the time-dependent Hubbert model configured for Mexico [i.e., Equation (6), discussed below], to reliably predict the future of Pemex petroleum production, and, if Mr. Serrano is correct, the future of Mexico itself.

The Hubbert model, configured for Mexico in the Q-domain by Equation (5), can be transformed into the time-domain by separating the variables and integrating. The result is Q(t), the cumulative production of oil as a function of time, t. Then, by differentiating Q(t) once with respect to time, we get the equation for oil production, dQ/dt, in the time domain. The result is,

\[\text{Equation} \quad (6)\]

Equation (6) is the time-dependent counterpart of Equation (3). As before, dQ/dt is the production rate of oil, e.g., in millions of barrels per day. The values of "a" and "Q[inf]" are given in Section 6. Time "t" means "year minus regression start year" [i.e., \(t = (\text{year} - 1981)\)]. To simplify the notation, Ns is defined as \(\frac{(Q[\text{inf}] - Q_s)/Q[\text{inf}]}{\text{where } Q_s \text{ is the cumulative production at the regression start year (i.e., Q1981, Figure 6)}.\]

For those who wish, details of the Hubbert model are discussed in Hubbert (1971; 1981; 1982), Smith, et al. (1992), and Duncan (1994a; 1994b; 1994c; 1995a). What matters here is that Equation (6) represents the time-dependent life-cycle of Mexican oil production.

Figure 9 shows the theoretical life-cycle of Mexican oil production in the time-domain, i.e., a plot of Equation (6) for the years 1950 to 2030. The historic data is superimposed on the theoretical curve for comparison.

Considering the consequences of collapse (e.g., "If Pemex fails, Mexico will fail," and "America's economic security is inextricably linked with Mexico's," and "No one can estimate how far the contagion might spread."), the down-slope of Mexican oil production is stark, to say the least. Equation (6), graphed in Figure 9, indicates that Mexican oil production is now at or near its all-time peak -- tottering at the brink of a precipitous cliff. Twelve years ago, this possibility (including what are now called "maquiladora" industries) was foreseen by political scientist Judith Gentleman.

Unfortunately, the past always constitutes a preface to the future, and in Mexico's case, it does not make for pleasant reading. ... Rather than constituting a harbinger of a new level of material well being for the mass of the population, the development of Mexico's petroleum resource signaled the opening of a new era of dependence for the nation. ... The opening of the floodgates for a new period of direct foreign investment fashioned from the demand profiles of foreign economies will mean the further elaboration in Mexico of a productive structure that neither provides a satisfactory level of employment nor produces goods that are compatible with the needs of the mass of population. (Gentleman, 1984)

Equally prescient, but decades earlier, natural resource expert Harrison Brown warned that the United States was slouching toward an ill-conceived, unworkable NAFTA-like involvement with Mexico. His afta' NAFTA scenario follows.
True federation between countries of high population growth potentials and those of low is extremely difficult to imagine if abolition of economic barriers is to be an integral feature of federation. For example, a federation between the United States and Mexico at the present time could have disastrous consequences. Although the standards of living in Mexico would probably be improved by such a move, at least temporarily, the standard of living in the United States would almost certainly be lowered, and, far more important, the sudden incorporation in our society of a major group possessed of high [population] growth potential would lead to an accelerated rate of population increase, together with the numerous difficulties associated with an accelerated rate of increase. (Brown, 1954)

The ensuing section discusses the 1995 Emergency Stabilization Package (ESP) loan in the context of Mexico's plan for industrialization and its obligations to the NAFTA.

8. MEXICO'S PLAN FOR UNATTAINABLE DEVELOPMENT

The United states can find an inexpensive solution to the problem now, or an expensive one later. No one can estimate how far the contagion might spread, or how many jobs might be lost. Mexican default is extremely unlikely.

Robert E. Rubin, 1995
U.S. Secretary of the Treasury
(in Sanger, 1995a; 1955b)

Unless decisive political leadership is shown now, this ancient Aztec nation could find itself in the mid-twenty first century with the same deformed economy, but it may have exhausted the abundant oil reserves with which to pursue the equalitarian ideals of the 1910 upheaval.

A North American Analyst
(in Williams, 1979)

The Republic of Mexico - historic, independent, and proud - faces several major problems simultaneously. The triad includes, (1) its ambitious plan for industrial development, (2) the requirements of the NAFTA, and (3) its external debt - with the focus here on the 1995 $50 billion Emergency Stabilization Package (ESP) loan.

1. Industrial Development: The most fundamental requirement for "sustainable" development (of Mexico, or any country) is that its economic infrastructure - i.e., agriculture, transportation, commerce, and industry - must be based on renewable and permanent primary sources of energy, e.g., photovoltaic and nuclear fusion power, should either become practical. (Duncan, 1993a; 1993b)

If Mexico is to avoid serious and substantial problems in the future, its government will soon, in this decade, have to take steps to restrain domestic energy demand, and to begin developing alternative energy sources. ... Mexico will need to develop substitutes for oil, especially in the generation of electricity. Currently, 90 percent of its electrical production relies on oil and gas. (Ronfeldt, 1980)

However, in the 16 years since the Ronfeldt document appeared, Mexico's dependence on nonrenewable energy has gone from bad to disaster. In fact, the Mexican economy is among the most unsustainable in the world. Mexico is now dependent on fossil fuels for more than ninety-six percent of its primary energy supply. Specifically, the tally for year-end 1994 is; oil = 71.3%, natural gas = 21.7%, and coal = 3.7% for a total fossil-fuel dependence of 96.8%. (BP, 1995) Therefore, if Mr. Ronfeldt is correct, Mexico's plan to use fossil fuels as the basis for industrial development is
unrealistic. Unattainable.

2. NAFTA Requirements: As I understand them, the NAFTA requirements (both written and "understood") include,

- Reduce tariffs and trade restrictions between the U.S., Mexico, and Canada.
- Control inflation and steady the peso.
- Strengthen and regulate the banking system.
- Improve the wages and safety for Mexican workers.
- Reduce the (long-standing) maldistribution of wealth.
- Improve Mexico's democratic and legal institutions.
- Reduce corruption in the government and the police system.
- Stop drug trafficking within, and shipment across, Mexican borders.
- Cooperate with the U.S. to "control" illegal immigration.
- Reform Mexico's electoral and political systems.
- Implement land reform in rural areas (e.g., in the State of Chiapas)
- Improve public health care, housing, water supplies, and sanitation.
- Restore and protect the natural environment. [See Note 16.]

[Note 16: Mexico's major environmental problems include: Untreated sewage and industrial effluents polluting rivers in urban areas; deforestation; widespread erosion; desertification; serious air pollution in the national capital and urban centers along the U.S.-Mexican border. (EIA, 1995)]

There is no doubt that each of the foregoing NAFTA requirements, taken alone, could be achieved to North American standards. But taken together, and given the present discordant state of the Mexican government and the distressed state of the economy, the reality is that the NAFTA requirements (even in part) are unachievable in the foreseeable future.

3. The ESP Loan: Theoretically, i.e., taken alone, out of context, Mexico could use the revenues from its oil exports to repay the full amount of the 1995 $50 billion Emergency Stabilization Package (ESP) loan. But that is not the problem.

The real problem facing Mexico, taken simultaneously, in context, is to repay the 1995 ESP loan, and meet the requirements of the 1993 NAFTA, and complete its plan for industrial development. To accomplish this, Mexico would have to quintuple (i.e., increase by five times) its oil exports over the next decade (i.e., by 2005, it would have to increase its oil exports from the present 1.6 million barrels per day to some 7.5 million barrels per day, roughly the 1995 export level of Saudi Arabia). Quintupling its oil exports is not feasible for several reasons: financial, political, engineering, geological, and moral.

3.1 Financial: To quintuple oil exports by 2005, Pemex would have to spend billions of dollars each year on oil exploration, development and capital infrastructure. But Pemex is now financially strapped. "Between 1995 and 2000, Pemex requires more than $20 billion in investment [just] to maintain current production." (Grayson, 1995) Moreover, it makes no sense for Pemex to invest a lot of up-front capital that, in a glutted market, would only reduce the price of its oil exports.

3.2 Political: Conceivably, Mexico could privatize its entire oil industry, and thereby obtain a large injection of foreign capital to repay the ESP loan. But at best, this would only be a temporary fix because the government would lose control of its Cash Cow, Pemex. Further, Article 27 of the Mexican Constitution forbids foreign ownership of crude oil reserves, and transportation and
production facilities.

3.3 Engineering: Even if 100% financing were assured and engineering design started today, it would take more than 10 years to construct the physical infrastructure necessary to quintuple Mexican oil exports. But by that time, Mexican oil production will already be in abrupt decline. (Campbell, 1991; PE, 1995b; Duncan, this study)

3.4 Geological: Oil production at most Mexican wells is severely "rate limited." Thus, even if Mexico solved problems 1-3 above, its rate of oil production would not significantly increase, and the ultimate recovery, \( Q \), would, in fact, decrease.

Oil and gas cannot be extracted efficiently from natural reservoirs excepting at relatively low rates. ...From 1911 to 1925 ... there were well fields in which salt water broke through the oil after only a few months of uncontrolled production. Had these fields been exploited with the proper technique and the application of proper conservation measures, they would have remained productive for anywhere from ten to fifty years. (Bermúdez, 1963)

3.5 Moral: David E. Sanger covers the moral issue.

If all goes well, American taxpayers could even profit from the [ESP] strategy, because Mexico is paying hefty fees for the loan guarantees. The United States is also insisting on first rights to Mexico's oil export earnings in case of default, an annual income flow of roughly $7 billion.

Many people say, however, that it would be impossible for the United States to demand those oil profits if Mexico falls into deeper crisis and its unemployment rate soars. (Sanger, 1995b)

The main goal of this study, you will recall, is to answer the question, Is the revenue from Mexico's petroleum exports safe collateral for the 1995 $50 billion Emergency Stabilization Package (ESP) loan? The answer is no. Specifically, if the Mexican government meets the requirements of the North American Free Trade Agreement (NAFTA), then it must default the Emergency Stabilization Package (ESP) loan, and vice versa.

However, if President Clinton (1995) and Secretary Rubin (in Sanger, 1995a; 1995b) are correct, then the ESP-NAFTA problem is much worse. Historic data shows that the remaining amount of Mexico's producible oil is small and rapidly depleting (Figures 6-9, Sections 5-7). This means that Mexico's present plan for industrial development, because it is uniquely dependent on petroleum, is bound to fail. [See Note 17.]

[Note 17: This does not mean that Mexico can never develop. It only means that Mexican development, should it occur, must rely on renewable and permanent sources of energy, not petroleum.]

9. SUMMARY AND CONCLUSIONS

Summary: On January 31, 1995 the President of United States signed a $50 billion Emergency Stabilization Package (ESP) loan to bailout the near bankrupt Mexican government. In case of default, the United States has first rights to revenues from Mexico's oil exports. This study uses a robust method to answer the question, Are Mexico's petroleum exports safe collateral for the 1995 $50 billion Emergency Stabilization Package (ESP) loan? (Section 1)

Mexican oil production grew rapidly from 1973 to 1982, but stagnated from 1982 through 1994 (Section 2, Figure 1). For comparison, Mexico's cumulative oil production through 1994 was only
38% that of the adjacent State of Texas, and Texas production is now in sharp decline (Section 3, Figures 2 and 3). Moreover, Mexico's oil surplus increased rapidly from 1974 to 1982, but decreased by 10.6% from 1984 through 1994 (Figure 4).

The Hubbert model (i.e., the method used in this study) is described and configured for Mexico (Sections 4 and 5, Figures 5 and 6). The ultimate production of Mexican oil is estimated to be 35.4 billion barrels, an amount that is only 55% that of Texas, and a minuscule 13% that of Saudi Arabia. Although for the past four years (through 1994), Mexican oil production has increased slightly, this study predicts that it will reach its all-time peak in 1995 or 1996, and thereafter decline at about 4.9% per year (Section 6, Figures 7 and 8, and Table 1).

The theoretical life-cycle of Mexican oil production is graphed for the years 1950-2030 (Section 7, Figure 9). The question of repayment of the 1995 ESP loan is discussed within the context of three major problems that simultaneously confront Mexico: industrial development, NAFTA requirements, and external debt (Section 8).

**Conclusions:** Mexico's petroleum production is now near its all-time peak. Decline is imminent. Mexican oil production will follow a down-slope trajectory similar to that of its U.S. neighbor, Texas. More to the point of this study, Mexico's oil exports are falling and, overall, they will continue to fall. As a result, the Mexican government will be forced to default or renege on, or abandon, one or more of its major commitments, respectively, (1) the 1995 $50 billion Emergency Stabilization Package (ESP) loan, or (2) the 1993 North American Free Trade Agreement (NAFTA), or (3) its plan for industrial development. The contagion will spread far, wide, and deep.

**REFERENCES**


Mexico's Petroleum Exports: Safe Collateral for a $50 Billion Loan?


U.S. Mail Distribution: Hard copies are available by either of following procedures. (1) Send an e-mail letter to duncanrc@halcyon.com with the title, "Mexico's Petroleum Exports: Safe Collateral for a $50 Billion Loan?" Or (2) Send a regular letter to the Institute on Energy and Man; 3821 NE 45th, #37; Seattle, WA 98105. In either case, be sure to include the title of the paper and your U.S. (or international) mailing address.


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This Website is divided into two main sections.  

You can view Dr. Duncan's paper "The Heuristic Oil Forecasting Method - User's Guide and Forecast #4" by clicking on the Paper button at left.  

You can read a description of Dr. Duncan's World Oil Forecasting Program, and download his forecast models by clicking the Models button.  

Dr. Duncan welcomes your feedback. Click the Contact button to send your ideas, data or questions directly to Dr. Duncan.  

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Abstract of Paper

The Heuristic Oil Forecasting Method is a unique and entirely new approach to predict oil production. First World oil production is broken out into the top 42 oil-producing nations that account for more than 98% of World's oil. Then a separate forecast is made for each nation. Finally these forecasts are aggregated to get the forecasts for regions, categories, and the World.

The goals of this paper are (1) to provide a brief User’s Guide to the models, and (2) to summarize the main conclusions of the latest in a series of World oil forecasts (i.e. #4).

The User’s Guide appears in sections 2-7. The main conclusions of Forecast #4 are found in sections 8-10 and summarized as follows. North America's oil production peaked in 1985 and from 1985 to 1998 it fell by 7.4% — an average decline of 0.59 %/year during 13 years. Moreover, North American production is forecast to fall a further 84.0% from 1998 to 2040 — an average decline of 3.3 %/year during these 42 years. The peak of World oil production is forecast to occur in 2005, and by 2040 production falls by 53% — an average decline of 2.1 %/year during 35 years. OPEC oil production is forecast to exceed non-OPEC production in 2007, and by 2040 the OPEC nations will produce 75% of the World’s oil. The Muslim nations' oil production is forecast to exceed the non-Muslim nations' oil production in 2001, and by 2040 these Muslim nations will produce 73.0% of the World's oil. The likelihood of a "World Petroleum War" ("Jihad") appears to be growing. President Clinton was advised of this situation in a letter dated May 13, 1997.
1. INTRODUCTION

The Heuristic Oil Forecasting Method is a 100% new approach for predicting national, regional, categorical, and World oil production. It was developed over a period of seven years (1) to supersede the obsolete hand-drafting and outmoded curve-fitting techniques, and (2) to meet a rigorous set of Design Specifications. Albeit new to oil forecasting, this approach is widely used in systems engineering.

As of this writing, the Method has been used to make four World oil forecasts. The papers that describe Forecasts #1, 2 & 3 were written for a general audience and thus avoided technical details about the models and how to use them. In contrast, this paper is written for both audiences. Sections 1 and 8-10 give a general overview of the models and a summary of the latest predictions (i.e. Forecast #4). Sections 2-7 give the technical details, including the model diagrams and equations. Several examples and numerous graphs...
show how the Method was used to forecast oil production for three nations, one region, several categories, and the World.

The Method disaggregates World oil production into the top 42 oil-producing nations of the World (together producing over 98% of the World's oil). Each nation is modeled separately and independently. The time span of major interest is the 80-year period from 1960 to 2040. The 42 national forecasts are then aggregated into 7 geographic regions (e.g. North America) and 6 categories (e.g. OPEC and non-OPEC nations) to generate their respective forecasts. Finally, the oil forecasts for all 42 nations are summed to get the World oil forecast. The Method is both User-intensive and time consuming. Namely: (1) It requires the User's knowledge, judgement and input for every forecast. (2) Forecast #4 required 2.5 man-months of work. However, after four years of experience, it is my preferred approach to oil forecasting - by far.

The equations for the models are written in Stella® (i.e. a special modeling and simulation applications program). The symbols, syntax, and semantics for the equations are similar to those used in e.g. Basic, Fortran, and Excel®. Stella (run-time) is available free by downloading the Demonstration Package from http://www.hps-inc.com/. The oil-forecasting models are available free at http://www.halcyon.com/duncanrc/.

NB: Only the North America, Middle East, and World sectors (i.e. models) are needed for the examples discussed in this paper.

2. GLOSSARY [return to table of contents]

'Heuristic' (H) means "using or obtained by informal methods or reasoning from experience, often because no precise algorithm is known or is relevant. It involves trial and error, as in iteration." "M" means minimum. 'Oil' means crude oil and natural gas liquids. 'P' and 'dQ/dt' mean production. 'Q' and 'Q(t)' mean cumulative production. 'EUR' means expected ultimate recovery. 'R' means oil reserves. 'PR' means 'proved reserves' [fictional, of course, but conceptually useful]. 'YtfR' means yet-to-find reserves [ditto]. In equation form: EUR = Q1998 + R, where R = PR + YtfR. 'G' means billion (109). 'b' means barrels. 'User' means the author or forecaster. 'NB' means "note carefully".

Note on oil production and oil reserves: The oil production data up through 1959 were obtained from BP Amoco (1965-1999), Campbell (1991), Bermúdez, (1963, for Mexico), and FLPH (1959, for Romania). However, the production data from 1960 to 1998 were obtained exclusively from the BP Amoco Statistical Review of World Energy. I am confident that the BP Amoco oil production data are satisfactory for our work. As was mentioned, however, 'proved reserves' are fictional (i.e. they vary widely and are highly contentious). Happily however, that is of no consequence to our Method because we integrate the oil production profile for each nation (i.e. the production data plus our own forecast) to predict each nation's expected ultimate recovery (EUR) and reserves (R). Then we sum them all up to get our own estimate for the World's EUR and R. Bottom Line: 'Proved reserves' (PR) and 'Yet-to-find reserves' (YtfR) are conceptually important and very useful in our discussions. That said, the PR and YtfR (as published in various databases) play no role whatsoever in our final oil forecasts.

3. DESIGN SPECIFICATIONS [return to table of contents]

The Heuristic Oil Forecasting Method evolved over a period of seven years as follows. From 1993 to 1995 I studied the strengths and weaknesses of several 'graphical' and 'curve-fitting' techniques for oil forecasting. Guided by what I learned, in 1996 I devised the first version of the Method and used it to construct Forecast #1 (Duncan, 1997a). That early version was later used to construct Forecasts #2 and 3 in 1997 and 1998 (Duncan & Youngquist, 1999; ibid., 2001). Then by early 2000 I had streamlined the Method and used it to complete Forecast #4, discussed in this paper. The Method was built to satisfy the following Design
Specifications.

**Specific:**

1. The Method must be based on historic oil production data, recent oil production trends, and heuristics including a range of independent estimates of each nation's oil reserves. The data and reserve estimates must be freely available to the public.

2. It must not use Gauss distributions, Hubbert curves, parabolas, logistic derivatives, etc. "Curve-fitting" is not acceptable.

3. It must meet the zero-peak-zero boundary conditions in both the time-domain and in the Q-domain. "Close enough" is not acceptable.

4. It must generate realistic production curves. Smooth and symmetric curves - and 'Matterhorn peaks' - are unrealistic, thus unacceptable.

5. Oil production forecasts must come first. Then cumulative production is calculated by integration. In math-speak: Production is the independent variable.

6. It must predict the EUR and R for each nation by integrating the oil production profile from the beginning to the end of production (i.e. data and forecast).

7. It must handle both symmetric and asymmetric production data with equal ease, no matter how asymmetric the data.

8. It must handle nations with large oil reserves and nations with small oil reserves with equal ease, no matter how large the reserves.

9. Each forecast must predict a value for World oil reserves that is within the range of current estimates of World oil reserves (e.g. from 1,100 to 2,300 Gb for Forecast #4).

10. The Method must facilitate the use of heuristic knowledge by (1) graphical and numerical I/O tools, (2) mathematical functions, and (3) run-time options.

11. It must break out the total World oil production by the top oil-producing nations and treat each nation according to its unique geology, reserve estimates, geography, social structure, etc.

12. The World is organized into nations, i.e. the UN, OPEC, OECD, EU, WTO, etc. Oil basins must be parceled to nations.

13. It must use state-of-the-art-modeling software to facilitate the forecasts. Pencil-and-paper sketches and spreadsheet techniques are not acceptable.

14. It must predict a specific peak year (such as 2005). Wide ranging forecasts such as 'plateau peaks' (e.g. "somewhere between 2005 and 2020") are not acceptable.

15. The last year of the production data must connect directly to the first year of the production forecast. Production gaps (i.e. discontinuities) are not acceptable.

16. The ongoing series of forecasts must be tracked on a 'phase diagram' to verify that the series is (1) endogenously consistent, and (2) converging on the World peak.

**General:**

17. The oil production forecast for each nation will usually continue the most recent production trend for at least a few years into the future.
18. The User-computer iterations for each nation must continue until the User is satisfied with (1) the shape of the nation's forecasted oil production curve, and (2) the magnitude of the nation's forecasted oil reserves.

19. The Method must be able to answer new questions about (1) any of the top 42 oil-producing nations in less than 15 minutes, (2) any combination of the top 42 nations in less than 30 minutes, and (3) World oil production in less than 45 minutes.

4. CANADA OIL FORECAST [return to table of contents]

In this section we show how the Heuristic Forecasting Method was used to predict Canada's oil production. The Method requires close interaction between the User (e.g. the author, geologist, forecaster) and the computer. The computer provides the memory, speed, and I/O devices. Moreover, it executes Stella for running the models, assisting the forecasts, and displaying the curves. The User, in turn, provides heuristic (i.e. non-quantifiable) information such as knowledge, field experience, and judgement.

Figures 1-A and 1-B depict the completed Canada model, including the final values of the parameters and the oil forecasts. Figure 1-A shows the 'Construction Layer' including (1) the M-forecast part of the model (upper-left), and (2) the H-forecast part (upper-right). Figure 1-B shows the 'Equations View' of the model. The numbers in Figure 1-A correspond to the equations in Figure 1-B (i.e. #1-16). Later we will detail and discuss how the forecasts were constructed. But first we'll introduce the symbols and equations that will be used in our discussions.

Canada Oil Model: Figure 1, Minimum-Forecast Part

Data Input:

Eqn. #5, INIT Q_M_Cn: Cumulative oil production as of 1 Jan. 1960. See Eqn. #2.

Eqn. #6, MinFcst_Cn: ‘Data_Cn’ contains the production data. See Eqn #16.


Eqn. #16, Data_Cn: Canada production data from 1960 to 1998. See Fig. 2.

Construction of the Minimum Forecast:

Eqn. #9, OneMnsSM_Cn: A multiplier that begins at 1 and then goes to zero.

Eqn. #13, SMTH_Cn: User selects two integers (e.g. 40 & 5) to shape the M-forecast.

Eqn. #14, STEP_1999: A unit step function that fires (i.e. begins) in 1 Jan. 1999.

Eqn. #15, YrPrEnds_Cn: User assumes that Canada production will end in 2058.
Program Output:
Eqn. #4, Q_M_Cn(t): M-cumulative production from 1960 to 2040. By integration.
Eqn. #6, MinFcst_Cn: M-production from 1960 to 2040. See curve 2, Fig. 3.
Eqn. #8, EUR_M_Cn: Minimum EUR = 61.7 Gb. See Numeric Display, Fig. 1-A.
Eqn. #12, Reserves_M_Cn: M-reserves = 36.3 Gb. See Numeric Display, Fig. 1-A.

Canada Oil Model: Figure 1, Heuristic-Forecast Part

Data Input:
Eqn. #10, Q_1999_Cn: Same as the M-part (previous).

Construction of the Heuristic Forecast:
Eqn. #3, HrstFcst_Cn: User-constructs the H-forecast from 1999 to 2040.
Eqn.#15, YrPrEnds_Cn: Same as the M-part (previous).

Program Output:
Eqn. #1, Q_H_Cn(t): H-cumulative production from 1960 to 2040. By integration.
Eqn. #3, HrstFcst_Cn: H-production from 1960 to 2040. See curve 3, Fig. 4.
Eqn. #7, EUR_H_Cn: Heuristic EUR = 64.8 Gb. See Numeric Display, Fig. 1-A.
Eqn. #11, Reserves_H_Cn: H-reserves = 39.5 Gb. See Numeric Display, Fig. 1-A.

The most important output from the Canada model is the oil production profile from 1960 to 2040 (see Figure 5). We will proceed step-by-step to Figure 5.

Canada Oil Production Graphs: Figures 2 to 6

Figures 2-6 and the discussions help to explain how I (the User) constructed the M- and H-forecasts for Canada. These figures show 'Years' (from 1960 to 2040) on the x-axis and 'Production' (in Gb/year) on the y-axis. The x-axis in Figure 2 is divided into two time domains. The first time domain (labeled 'History') depicts the Canadian oil production data from 1960 to 1998. The second time domain (labeled 'Future') is where we will construct the M- and H-forecasts from 1999 to 2040.

Figure 2. Canada Oil Production Data: 1960-1998
Figure 2 shows Canada's oil production from 1960 to 1998. The upward trend-line (dashed) shows that oil production from 1982 to 1998 grew at a strong average rate of 3.2% per year. (You can verify this growth rate from the data in Eqn. #16, Fig. 1-B.) The area that is shaded by down-sloping lines represents Canada's cumulative oil production up to the end of 1998 (i.e. Q1998 = 25.4 Gb). Further, our database (BP Amoco, 1999) gives Canada's (PR)/P ratio = 7.0 years [i.e. 7.0 years = (6.8 Gb)/(0.975 Gb/year)]. Thus, at a bare minimum, the crosshatched area in Figure 2 represents Canada's production during the 7 years from 1998 to 2005. But recall that Reserves = (Proved Reserves) + (Yet-to-find Reserves), so we must extend the crosshatched area to include the 'Yet-to-find Reserves'. To accomplish this we proceed to Figure 3 below.

Figure 3 depicts two curves. Curve 1 has been discussed. Curve 2 consists of the production data from 1960 to 1998 and the M-forecast from 1999 to 2040. The integer smoothing parameters in the SMTHN function (Eqn. #13, Fig. 1-B) are the key to constructing the M-forecast. I selected the parameters 40 and 5 to get the results that I wanted: (1) the shape of the M-forecast, and (2) the magnitude of the M-reserves. I was trying for about 35 Gb of M-reserves. And, as I recall, it took about 7 or 8 runs to obtain the value of 36.3 Gb (see Eqn. #12, Numeric Display, Fig. 1-A) and the shape of the M-forecast (curve 2, Fig. 3).

Figure 3. Canada Oil Production Data and Minimum Forecast

The Minimum forecast is optimistic about Canada's Yet-to-find-Reserves (YtfR) as verified by simple arithmetic. Viz. We know that YtfR = EUR - Q1998 - PR. Thus, YtfR = 61.7 - 25.36 - 6.8 = 29.5 Gb, i.e. over four times Canada's 6.8 Gb of 'proved reserves'.

Now that we have the M-forecast, an amalgam of reserve estimates, the heuristic information, et cetera, we proceed to construct the H-forecast, shown in Figure 4.

Figure 4. Canada Data, Minimum Forecast and Heuristic Forecast

Figure 4 shows three curves. Curves 1 and 2 have been discussed. Curve 3 is made up of the production data from 1960 to 1998 and the User-constructed H-forecast from 1999 to 2040. Construction was facilitated by the Graphical Function (Eqn. #3, Fig. 1-B). I used this handy 'tool' to make a series of cut-and-try iterations to get the desired (1) shape of the H-forecast, and (2) magnitude of the H-reserves. It is very useful (and fun) to watch the test curve 'plot out' on a graph during each test run. Then instantly the value of the H-reserves pops up on a Numeric Display. I was trying for about 40 Gb of H-reserves. It took about 5 or 6 runs to get 39.5 Gb (see Eqn. #11, Numeric Display, Fig. 1-A). In other words, I played the shape of my H-forecast against the value of the computer-calculated H-reserves until I got the results I wanted.

Note that the H-forecast for Canada's yet-to-find reserves (YtfR) is very optimistic. Specifically, YtfR = 64.8 - 25.4 - 6.8 = 32.6 Gb, i.e. nearly five times Canada's 6.8 Gb of 'proved reserves'. Thus, I hope this example makes it clear that 'proved reserves' (whatever their fictional magnitudes) do not matter one whit to our forecasts. But again, 'proved reserves' are still conceptually very important.

Observe in Figure 4 that the shape of the H-forecast was 'guided' by the upward production trend and the M-curve. Moreover, it was also guided by my knowledge of several independent estimates of Canada's oil reserves, oil geology, hydrocarbon quality, etc. Having served as 'guides' for the H-forecast, curves 1 and 2 (Figure 4) are discarded and the H-forecast becomes our 'best prediction', as shown in Figure 5.

Figure 5. Canada Oil Production: 1960 to 2040

Figure 5 depicts Canada oil production from 1960 to 2040. This curve is our final prediction for Forecast #4. Canada's production peak is forecast to occur in 2010 at 1.07 Gb/year. At the end of 1998, Canada's cumulative production (Q1998) = 25.4 Gb, its reserves (R) = 39.5 Gb, and its expected ultimate recovery (EUR) = 64.8 Gb. We verify these numbers as follows: EUR = 64.8 = Q1998 + R = 25.4 + 39.5 = 64.8 Gb.

You may recall that Canadian oil production was assumed to end in year 2058 (Eqn. #15, Fig. 1-B). Question: "OK. But what does the curve look like between year 2040 and year 2058?" Response: "Our Method forecasts the area under the curve from 2040 to 2058, but not its shape. All we know is that
production goes from 0.44 Gb in 2040 to 0.00 Gb in 2058."  (You can confirm these values from the data in Eqns. #3 & 15, Fig. 1-B.) The cumulative production from 2040 to 2058 is calculated as the area of a right triangle equal to "one-half the base times the height" (see Eqn. #7, Fig. 1-B). However, we can only guess at the shape of Canada's production curve from 2040 to 2058, as sketched by the dashed curve in Figure 6 (i.e. see 'A more realistic trajectory').

Figure 6. Canada Oil Production Extended from 2040 to 2058

You will recall that in this section we used the Heuristic Oil Forecasting Method to predict the oil production for Canada, a nation whose most recent production trend was strongly upward. In Section 5 (below) we will see how the Method must be modified to forecast the production of a nation whose most recent production trend was strongly downward.

5. UNITED STATES OIL FORECAST

In contrast to Canada's steep upward production trend (discussed above), the United States' oil production has been on a steep downward trend since 1985. Therefore the technique for constructing the M-forecast for the US must be modified. Figure 7-A shows the Construction Layer and Figure 1-B shows the Equations View of the US model.

Figure 7-A. United States Oil Model: Construction Layer

Figure 7-B. United States Oil Model: Equations View

United States Oil Model: Figure 7, Minimum-Forecast Part:

Data Input


Eqn. #6, MinFcst_US: Graphic Function with historic data from 1960 to 1998.


Eqn. #13, Data_US: User-entered data from 1960 to 1998. See curve 1, Fig. 8.

Construction of the Minimum Forecast:

Eqn. #6, MinFcst_US: User-constructed M-forecast from 1999 to 2040.

Eqn. #12, YrPrEnds_US: User assumes US production will end in 2060.

Program Output:

Eqn. #4, Q_M_US(t): M-cumulative production from 1960 to 2040. By integration.

Eqn. #6, MinFcst_US: M-production from 1960 to 2040. See curve 2, Fig. 9.

Eqn. #8, EUR_M_US: Minimum EUR = 248.4 Gb. See Numeric Display, Fig. 7-A.

Eqn. #11, Reserves_M_US: M-oil reserves = 45.1 Gb. See Numeric Display, Fig. 7-A.
United States Oil Model: Figure 7, Heuristic-Forecast Part

The US heuristic forecast was constructed by exactly the same technique as that used for the Canadian heuristic forecast (see Figure 1, Section 4). Therefore we proceed directly to the graphs for US oil production.

US Oil Production: Figures 8 to 11

Figure 8 for the United States is similar to Figure 2 for Canada. But - in contrast to Canada's strong upward production trend - the US oil production shows a strong downward trend from 1985 to 1998, as readily seen in Figure 8.

Figure 8. United States Oil Production Data: 1960-1998

US production grew exponentially from 1859 until its peak in 1970. Then from 1970 to 1985 overall production declined, despite the substantial addition of Alaskan oil. Next, during the 18 years from 1985 to 1998, US production decreased at an average rate of 2.1%/year (see 'Downward Trend', Figure 8). Due to the recent downward trend and its waning reserves, we conclude that overall US oil production will continue to fall indefinitely. In other words - despite having the world's best technology - US oil extraction is now limited by the depletion of its oil fields. Figure 9 shows the US production data from 1960 to 1998 and the M-forecast from 1999 to 2040.

Figure 9. US Production Data and Minimum Forecast

Guided by the downward trend of US production and heuristic information, I made several test runs to construct the M-forecast; see curve 2, Figure 9. The heuristics included several different estimates of US oil reserves, the declining oil discoveries, the advent of new technologies, and the potentials in the Arctic shelf and the Gulf of Mexico. Observe that the US M-forecast declines more rapidly than did the actual US production from 1985 to 1998. Thus, even though the M-forecast may be pessimistic, it does establish a (very useful) lower bound for future US oil production.

Next, armed with the M-forecast, the downward production trend and the above-mentioned heuristics, we proceed to construct the H-forecast for US oil production by reasoning as follows. The US sedimentary basins are well explored and overall US oil production has fallen during the past 30 years. Thus it is likely that both US oil reserves and production will continue to fall (see Design Specification 17). With that knowledge, it took only a few iterations to get (1) the shape of the H-forecast, and (2) the magnitude of the H-reserves that I wanted, i.e. that I judged to be reasonable. See curve 3, Figure 10 at the top of the next page.

The complete profile of US oil production from 1960 to 2040 (i.e. our final forecast) is shown as the single curve in Figure 11.

Figure 10. US Data, Minimum Forecast and Heuristic Forecast

Next we tally up the production forecasts for the United States, Canada and Mexico to get the production...
forecast for North America.

6. NORTH AMERICA OIL FORECAST [return to table of contents]

The North America Region comprises the United States, Canada and Mexico. Forecasts for the US and Canada have been discussed. Mexico is not discussed because the technique used for Mexico is identical to that used for Canada. North America oil production spans 201 years (i.e. from Titusville, Pennsylvania in 1859 to the assumed end of US oil production in 2060). In this section we sum the US, Canada, and Mexico forecasts to get the North America forecast. Figure 12-A shows the Construction Layer and Figure 12-B shows Equations View of the North America model.

Figure 12-A. North America Oil Model: Construction Layer

Figure 12-B. North America Oil Model: Equations View

North America Oil Production Model

NA Model Input (see the right-hand side of Eqns. #1-4, Fig. 12-B):
Eqn. #1, Data_US, Data_Cn & Data_Mx: Oil production data from 1960 to 1998.
Eqn. #2, EUR_H_US, EUR_H_Cn & EUR_H_Mx: The EUR value for each nation.
Eqn. #3, HrstFcst_US, HrstFcst_Cn & HrstFcst_Mx: Production (curves 1, 2 & 3, Fig. 13).
Eqn. #4, Q_H_US, Q_H_Cn & Q_H_Mx: Cumulative prod. (curves 1, 2 & 3, Fig 14).

NA Model Output (see the left-hand side of Eqns. #1-4, Fig. 12-B):
Eqn. #1, Data_NA: Oil production data for NA from 1960 to 1998.
Eqn. #2, EUR_NA: EUR for NA (see Numeric Display = 380.4 Gb, Fig. 12-A).
Eqn. #3, P_NA: Oil production for NA, 1960 to 2040 (curve 4, Fig. 13).
Eqn. #4, Q_NA: Cumulative oil production for NA, 1960 to 2040 (curve 4, Fig. 14).

North America Oil Production: Figures 13 to 15

North America oil production, cumulative production, and production versus cumulative production are shown in Figures 13-15, respectively. We begin with NA oil production, Figure 13.

Figure 13. North America Oil Production: 1960-2040

Figure 13 shows US, Canada and Mexico oil production (curves 1, 2 & 3) and the total NA oil production (curve 4). Observe in Figure 13 that NA oil production peaked in 1985 at 5.59 Gb and then decreased to 5.17 Gb in 1998 - an average decline of 0.59 %/year during these 13 years. The proximate cause is easy, Namely: The increasing production of Canada and Mexico combined from 1985 to 1998 failed to make up for the decreasing US production during the same period.

By integrating the production curves for the US, Canada, Mexico and then summing them up we get the
cumulative production for North America from 1960 to 2040, i.e. \( Q(t) = \int (dQ/dt) dt \). The resulting curves are shown in Figure 14.

**Figure 14. North America Cumulative Oil Production: 1960-2040**

Figure 14 reveals that the inflection point for NA cumulative oil production occurred in 1985, coinciding (as it must) with the 1985 peak of NA oil production (Figure 13). Moreover, US oil production was assumed to end in 2060, the last of the three NA nations to cease production. Thus, North America’s cumulative oil production (also) reaches its terminal value in the year 2060 with exactly 380.4 Gb (i.e. NA’s EUR, Eqn. #2, Numeric Display, Fig. 12-A). This once again confirms that our Method satisfies the zero-peak-zero boundary conditions in the time-domain (per Design Specification 3).

NB: There are no asymptotic curves in our Method. Said differently: (1) All oil production curves start and end at exactly zero. (2) All cumulative oil production curves start at zero and end exactly at the respective EUR.

Next we verify that our Method also satisfies the zero-peak-zero boundary conditions in the Q-domain (per Design Specification 3). By eliminating time (i.e. 'years') from Figures 13 and 14, we can display cumulative production (Q) on the x-axis and production (P or dQ/dt) on the y-axis, as shown in Figure 15.

**Figure 15. North America Oil Production versus Cumulative Production**

The graph in Figure 15 is called a 'phase diagram' (or 'scatter diagram' in the Stella lexicon). Phase diagrams are very useful for gaining insight oil modeling and forecasting. For example, Figure 15 shows that the boundary conditions in the Q-domain are satisfied in our Method - namely \( P = 0.0 \) when \( Q = 0.0 \) and again when \( Q = EUR = 380.4 \) Gb (as required by Design Specification 3). Observe that the NA peak production rate equals 5.59 Gb/year when \( Q_{1985} = 190.4 \) Gb, in agreement with the curves in Figures 13 and 14. Moreover, \( (Q_{1985})/(EUR) = (190.4)/(380.4) = 50.1\% \), i.e. the results of Forecast #4 are in close agreement with the 'Peak Rule' that states, "The peak of oil production usually occurs when about half the feasible oil in a region (or basin) has been extracted." NB: Despite its success with North America (above), we will soon see that the 'Peak Rule' should be used with caution.

In the next Section we demonstrate that our Method is easy to use and works equally well for a nation that has a highly asymmetric oil production profile.

7. IRAN OIL FORECAST [return to table of contents]

The Heuristic Oil Forecasting Method for Iran is similar to that for Canada because the most recent production trends of both of these nations are strongly upwards (i.e. compare Figure 17 for Iran [below] with Figure 2 for Canada [previous]). Moreover, experience indicates that our Method is just as easy - and perhaps just as accurate - for Iran as it is for Canada. (That's why I chose this example. Read on.)

Figure 16-A shows the Construction Layer and Figure 16-B shows the Equations View of the Iran model.

**Figure 16-A. Iran Oil Model: Construction Layer**

**Figure 16-B. Iran Oil Model: Equations View**

The procedures for the M- and H-forecasts for Iran are, you will recall, the same as for Canada. Thus we go directly to the Iran oil production graphs.

**Iran Oil Production: Figures 17 to 22**

Albeit Iran and Canada each had strong upward production trends during recent years, there are still two important differences. First, Iran's (PR)/P ratio is more than 9 times that of Canada. Second, although...
Canada's historic oil production data is quite regular, Iran's data is highly irregular, as seen in Figure 17.

**Figure 17. Iran Production Data and (PR)/P Ratio: 1960-2063**

Iran's 'proved reserves' (PR) equal 89.7 Gb and its (PR)/P ratio equals 64.7 years [i.e. 64.7 years = (89.7 Gb)/(1.39 Gb/year), neglect rounding]. Thus the crosshatched area in Figure 17 represents Iran's 'proved reserves' of 89.7 Gb, extending from the 1998 to nearly 2063. Moreover, note that Iran's production strongly increased from 0.752 Gb in 1986 to 1.39 Gb in 1998 (see Eqn. #16, Fig. 16-B). This amounts to an average increase of 5.0 %/year during those 12 years. Therefore - knowing Iran's production trend (i.e. strongly upward) and its large 'proved reserves' (i.e. vast) - it took me only a few iterations to select the smoothing parameters and the year that production ends (see Eqns. #13 & 15, Fig. 16-B).

Observe also that the M-reserves of 90.2 Gb (Eqn. 12, Fig. 16-A) are slightly larger than the 89.7 Gb of 'proved reserves' in our database (BP Amoco, 1999). Thus the results were just what I wanted. The completed M-forecast appears as curve 2 in Figure 18 at the top of the following page.

**Figure 18. Iran Oil Production Data and Minimum Forecast**

Next, we construct the Heuristic forecast, as graphed in Figure 19.

**Figure 19. Iran Oil Data, Minimum Forecast and Heuristic Forecast**

The H-forecast in Figure 19 was constructed by cut-and-try iterations using Stella's (elegant) Graphical Function (Eqn. #3, Fig. 16-B). It took some 5 or 6 iterations to obtain (1) the shape of the H-forecast, and (2) the magnitude of the H-reserves that I wanted. (These decisions are the User's judgements, i.e. heuristics.) Note that Iran's H-reserves are calculated to be 108.9 Gb on the Numeric Display, Eqn. #11, Figure 16-A. This means that Iran's Yet-to-find Reserves (YtfR) are 19.2 Gb (i.e. 19.2 = R - PR = 108.9 - 89.7). Our H-forecast appears as a single curve in Figure 20.

**Figure 20. Iran Oil Production: 1960 to 2040**

The H-forecast in Figure 20 is our 'best forecast'. Thus the 'H-' prefix has been dropped from the figures and discussion. Two production peaks are shown. Iran's historic peak occurred in 1974 at 2.21 Gb. A secondary peak is forecast to occur in 2011 at 2.04 Gb; its magnitude is 90% of the historic peak.

The next two graphs reveal some subtle details about Iran's oil-production profile, especially its two peaks. Figure 21 shows Iran's cumulative production.

**Figure 21. Iran Cumulative Oil Production: 1960-2040**

Figure 21 (above) shows Iran's cumulative oil production (Q(t)) from 1960 to 2040. Recall that Figure 20 (previous) shows Iran's production (i.e. P = dQ/dt) from 1960 to 2040. Thus we have a one-to-one correspondence between dQ/dt and Q(t). So let's eliminate time (i.e. years), and simply graph Q(t) on the x-axis and dQ/dt on the y-axis. This gives the phase diagram shown in Figure 22.

**Figure 22. Iran Oil Production vs. Cumulative Production**

Observe in Figure 22 that P = 0.0 when Q = 0.0, and again when Q = EUR = 159.1 Gb. Thus Iran's oil production curve satisfies the boundary conditions in the Q-domain (see Design Specification 3). Yet another use of the phase diagram of Figure 22 is to test the 'Peak Rule' that states, "Oil production peaks when cumulative production reaches about half of the expected ultimate recovery." Test: Observe that Iran's first production peak occurred in 1974 when Q = 19.2 Gb which is only 12.1% of Iran's EUR (i.e. 12.1% = (19.2 Gb)/(159.1 Gb). This is a far cry from the 50% called for by the 'Peak Rule'. Bottom Line: The 'Peak Rule' only holds rigorously when the phase diagram of P versus Q plots out to a perfect parabola. (However, a near perfect parabola is good enough for me.)
Although it fails badly for Iran (above), I expect that the 'Peak Rule' will hold up remarkably well for the all-time peak of World oil production, as demonstrated in the next Section where we summarize the main results of Forecast #4.

8. OVERVIEW OF WORLD OIL FORECAST #4 [return to table of contents]

It appears that commercial oil production actually began in Baku, Azerbaijan in about 1850. However, the earliest data that I can find are for the oil production near Bucharest in 1857 (FLPH, 1959). Further, I assume that the last nation to produce oil on this planet will be Saudi Arabia, with its production ending in 2110. Thus in this Forecast #4, the World oil interval began in Romania in 1857 and it will end in the Middle East in 2110, a mere pip of 253 years in the vast sweep of geologic time.

We have seen how our Method uses historic oil production data, heuristic knowledge, mathematical functions, special I/O devices, and extensive User-computer interaction to construct oil-production forecasts for the United States, Canada and Iran. The Method was likewise applied to the other 39 top oil-producing nations. Then the 42 national forecasts were summed, as needed, to get the oil production forecasts for e.g. North America, the OPEC and non-OPEC nations, and the World. (You may recall that our Method is time consuming. Namely: It took a total of 2.5 man-months of work to do Forecast #4.) Figure 23 gives some of the important results.

Figure 23 shows World oil production data from 1960 to 1998 and our forecasts from 1999 to 2040. Observe that from 1960 to 1973 World oil production (curve 1) grew at a strong average rate of 7.0 %/year. But, dollars to dimes, 1973 marks the end of the halcyon interval of oil production on this planet. Next, the overall rate of growth of World production was near zero from 1973 to 1983. However it picked up from 1983 to 1998, growing at an average rate of 1.7 %/year during this 15-year period. Forecast #4 predicts that the rate of production will accelerate from 1998 to year 2001 and then quickly decelerate to zero in 2005, thus marking the all-time peak of World oil production. From its peak in 2005 to year 2040 World oil production is forecast to fall by 53 % - an average decline of 2.1 %/year during these 35 years (see Forecast #4, Table 1, later). "Computer simulations show that the peak of World oil production is not a moving target. In fact, it is probably fixed by the most recent production trends of the 42 nations that we model" (Duncan & Youngquist, 2001).

Perhaps even more important than the World oil peak will be the OPEC/non-OPEC crossover event predicted to occur in 2007. This event (or even its anticipation) could divide the World into two camps: one with surplus oil, the other with none. Forecast #4 presents the following scenario. (1) Beginning in 2007 the OPEC nations will control nearly 100% of the World's oil exports. (2) The certainty of OPEC dominance is confirmed by every estimate of the World's 'proved oil reserves' that I've ever seen. For instance, our database puts OPEC's 'proved reserves' at 76% of the World total. (3) The nearing OPEC/non-OPEC crossover event is clearly evident from the historic production trends alone (i.e. no forecasting is needed). For instance, Figure 23 shows that OPEC production grew at a strong average rate of 4.54 %/year from 1985 to 1998. In contrast, non-OPEC production grew at sluggish 0.30 %/year during this same period. (4) The US Secretary of Energy in March 2000 made emergency trips to Riyadh, Kuwait City and Abu Dhabi. Then he followed up by calling OPEC members directly during their meeting in Vienna to 'lobby' for increased oil production. The de facto US Energy Policy, as I see it, amounts to little more that "Oil Brinkmanship".

I lived and worked in the Eastern (oil) Province of Saudi Arabia for seven years. There's no doubt that the leaders of oil-exporting nations know that their oil reserves - a one-time inheritance from Mother Nature - are an increasingly valuable commodity. Moreover, they realize that it would be a bad investment to sink large amounts of up-front capital into new production, only to have it drive down prices. Rather, in seems prudent that the OPEC nations just stand aside and let the forces of supply-demand achieve their goals for them. And why not? After all, the oil-importing nations have just as much control over the supply-demand equation as...
do the OPEC nations.

Marianne Kah, chief economist at Conoco, summed up the situation. "Many of the OPEC members are at their full production capacity right now. It's going to be very difficult for OPEC to agree to increase production." (Le Min & Wisenthal, 2000)

Table 1 summarizes World oil production from 1960 to 1998 and our latest predictions from 1999 to 2040.

Table 1. World Oil Forecast #4: Summary

Table 1 summarizes the data and predictions of Forecast #4 for the seven regions of the World, and for the World itself. Notice that two of the regions passed their peaks long ago: North America in 1985 and the Former Soviet Union in 1987. Four regions are predicted to peak in quick succession: Europe in 2001, Asia Pacific in 2003, Africa in 2004, and South & Central America in 2006. The last region to peak is, of course, the Middle East in 2011. Ominously, Asia Pacific has over 60% of the World's population, but only a scant 6.6% of the World's 'proved reserves'. In contrast, the oil-producing nations of Middle East have only 4% of the World's population, but own 54.9% of the World's 'proved reserves' (see Famighetti, 2000 for population; see BP Amoco, 1999 for oil). Our study puts the World's oil reserves at the end of 1998 at 1,340 Gb (i.e. 1,340 \times 2,213 \times 872; see Design Specification 9).

Regarding the 'Peak Rule': Forecast #4 predicts that the peak of World oil production will occur in 2005 when the World cumulative production reaches 1,087 Gb. Further, the World EUR is predicted to be 2,169 Gb (Table 1). Thus, Forecast #4 predicts that the peak of World oil production will occur when cumulative production reaches 50.1% of the World EUR [i.e. 50.1% = (1,087)/(2,169)]. This result came as a surprise to me because some nations deviate sharply from the 'Peak Rule' (e.g. see Fig. 22 for Iran). But by summing up all the 42 national oil-production curves, the World production curve smooths out and gives a near balance between pre-peak and post-peak production, viz. a near perfect parabola in the Q-domain.

Conclusion: The peak of World oil production is likely to occur near the midpoint of World cumulative oil production.

I believe two other crossover events will be significant. The first - the Middle East/non-Middle East crossover event - has been widely discussed. The second - the Muslim/non-Muslim crossover event - is taboo. It would be irresponsible for me to suppress the following information because the Muslim nations of the World are now united as never before on some difficult regional and global issues.

The Middle East region includes nine oil-producing nations in-and-near the Arabian Peninsula: Iran, Iraq, Kuwait, Oman, Qatar, Saudi Arabia, Syria, United Arab Emirates, and Yemen. Forecast #4 predicts the Middle East/non-Middle East oil production crossover event will occur in 2023 and by 2040 these nine nations will produce 63.6% of the World's oil [63.6% = (9.1)/(14.3); see Table 1].

The Muslim oil-producing nations include all the nations in-and-near the Arabian Peninsula, four North African nations, Indonesia, and the Caspian-area nations, plus a portion of the West African oil-producing nations. Forecast #4 predicts that the Muslim/non-Muslim oil production crossover event will occur in 2001. Thereafter the Muslim nation's oil production will increase to 55.6% of the World total in 2010; to 61.0% in 2020; 67.5% in 2030; and 73.0% in 2040.

Scenario 2005:

Windy politician, "Why didn't you warn us?"

Energy forecaster, "I did." (See 'Letter to President Clinton')

Next we map our route to the peak of World oil production.
9. MAPPING OUR ROUTE TO THE PEAK [return to table of contents]

We previously used phase diagrams to learn more about oil-production profiles and to verify the zero-peak-zero boundary conditions (see Figs. 15 & 22). In this section we demonstrate yet another application - namely, how we map our route to the peak of World oil production. In brief, we use a phase diagram to verify that our ongoing series of oil forecasts (1) are endogenously consistent, and (2) are actually converging on the World oil peak. Figure 24 shows the 'route' we have followed from Forecast #1 (done in 1996) to Forecast #4 (done in 1999 and summarized in this paper).

Figure 24. Mapping Our Route to the World Oil Peak

Observe in Figure 24 that we began our 'trek to the summit' with Forecast #1, i.e. marked 'START' in the lower-left hand part of the graph. Forecast #1 was done (i.e. completed) in 1996 and predicted that the World peak would occur in 2005 at magnitude 29.0 Gb (Duncan, 1997a). Forecast #2 was done in 1997 and predicted the peak in 2007 at 30.6 Gb (Duncan & Youngquist, 1999). Forecast #3 was done in 1998 and predicted the peak in 2006 at 31.6 Gb (ibid., 2001). Forecast #4 was done in 1999 and predicted the World peak in 2005 at 30.4 Gb (see Figure 23 and Table 1, this paper). No doubt our predictions will bounce around from one forecast to the next, but our ongoing series of forecasts will surely lead to the peak of World oil production.

Now that we have reached the Forecast #4 milestone (Figure 24), it is time to ask "Where next, Colonel Drake?" Our response is "We really don't know, but it seems unlikely that the all-time World oil peak will occur right in the midst of the four points shown in Figure 24. Nor, we surmise, is it likely to occur very far beyond the year 2007. Meanwhile, we'll continue to record our progress on a phase diagram map, as we ascend to the summit of World oil production."

10. SUMMARY AND CONCLUSIONS [return to table of contents]

The Heuristic Oil Forecasting Method is a completely new approach to predict the oil production for nations, geographic regions, special categories, and the World. It evolved over a period of seven years (1) to supersede obsolete pencil-and-paper sketches and outmoded curve-fitting techniques, and (2) to meet a set of rigorous Design Specifications. The Method breaks out World oil production into the top 42 oil-producing nations, accounting for more than 98% of World production in 1998. Then the User separately forecasts the oil production for each of the 42 nations. Next the expected ultimate recovery (EUR) and the oil reserves (R) are calculated by integrating each nation's oil production curve (i.e. its complete life cycle of oil production from start to end). The national forecasts are then summed, as needed, to get the forecasts for the regions and categories, and the World.

This paper includes a brief User's Guide to our Method and models. Sections 4 and 5 detail and discuss the Canada and US oil models and how to use them. A series of graphs depict (1) the historic oil production data, (2) the 'Minimum' forecast, and (3) the 'Heuristic' forecast for each nation. NB: Our Method is 'tailored' for each nation's unique characteristics. For example, Canada's recent production trend was strongly upward. In contrast, the United States' recent production trend was strongly downward. These different situations show how our Method is modified for nations with an increasing production trend vis-à-vis those with a decreasing trend.

Section 6 adds up (i.e. sums) the oil production forecasts for the US, Canada and Mexico to get the oil production forecast for North America. The most important finding in Section 6 is that North America's oil production peaked in 1985 and from 1985 to 1998 it fell by 7.4% - an average decline of 0.59 %/year during 13 years. North America's oil production is forecast to fall a further 84.0% from 1998 to 2040 - an average decline of 3.3 %/year during these 42 years.
The Iran oil model (discussed in Section 7) contrasts sharply with the US and Canada models. Namely: Iran (1) has vast 'proved oil reserves', (2) its production is constrained by an OPEC 'quota', and (3) it has a bimodal peak. Nonetheless: Experience shows that our Method is just as easy to use - and perhaps just as accurate - for Iran as it is for e.g. the US and Canada. A phase diagram shows that Iran's oil production peaked in 1974 when its cumulative production was only [sic] 12.1% of its EUR - a far cry from the 50% called for by the 'Peak Rule'. Moreover, Iran's secondary peak occurs in 2011, and from 2011 to 2040 production falls by 40.5% - an average decline of 1.8 %/year during these 29 years.

Our long-term plan is to continue the ongoing series of annual forecasts that will inevitably reveal all of the critical events in the life cycle of World oil production. Figure 23 shows two of these events. (1) The peak of World oil production is forecast to occur in 2005, and by 2040 production falls by 53% - an average decline of 2.1 %/year during 35 years. (2) The OPEC/non-OPEC crossover event occurs in 2007, and by 2040 the OPEC nations will produce 75% of the World's oil. NB: Both the OPEC and non-OPEC nations will be in steep decline after the OPEC peak in 2011.

Two more critical events are also predicted. Viz. (3) The Middle East/non-Middle East crossover event is forecast to occur in 2023, and by 2040 the Middle East nations will produce 64.1% of the World's oil. (4) The Muslim/non-Muslim oil production crossover event is forecast to occur in [sic] 2001, and by 2040 these Muslim nations will produce 73.0% of the World's oil. President Clinton was advised of this situation in a letter dated May 13, 1997 (see 'Letter', below).

Table 1 summarizes the oil production history and our forecasts for the seven regions of the World, and for the World itself. Note that (1) the seven regional peaks range from 1985 [North America] to 2011 [Middle East], (2) 40% of the World's total EUR has been produced, and (3) the World's oil reserves stand at 1,300 billion barrels. Forecasts #1-4 put the World peak in the tight range of 2005 to 2007.

Ongoing application of the Heuristic Oil Forecasting Method will, I believe, reveal all of the important events in the remaining life cycle of oil production on this planet. Oil forecasting is, of course, a risky business and - as we all know - the data will be the final arbiter.

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LETTER TO PRESIDENT CLINTON (Duncan, 1997b) [return to table of contents]

President William J. Clinton May 13, 1997 The White House 1600 Pennsylvania Avenue NW Washington, DC 20500

Dear President Clinton:

Re. US National Security Threatened by a New Alliance of Muslim Petroleum Exporting Countries ("AMPEC")

As you know, America now imports more than 50% of its petroleum. … The percentage of World petroleum exports from Muslim countries will, willy-nilly, continue to increase until (perhaps by 2010) the Muslim countries will control nearly 100% of the World's petroleum exports. This situation was revealed in my study … presented on 9 May 1997 at Princeton University. … Per my forecast, the Muslim crossover point will occur in 1999.

At Princeton, I gave the following "Thought Experiment":

What if tomorrow Palestinian leader Yasir Arafat met with representatives from each of the 19 Muslim petroleum exporting countries and proposed an entirely new organization called the "Alliance of Muslim Petroleum Exporting Countries" - "AMPEC" for short?

This proposal alone could cause World stock markets to fall 50% in one day. And crucially, it could ignite both (1) a World Petroleum War, and (2) a World Holy War (called a "Jihad" by Muslims). I view an "AMPEC
shock” as likely because powerful Muslim forces are pushing Mr. Arafat (and others) further every day.

Please be advised. Sincerely,

Richard C. Duncan, Ph.D. Institute on Energy and Man

The President did not reply. This subject is updated in a new paper (see Duncan, 2000).

REFERENCES [return to table of contents]


We assume that the peak of World oil production will be a watershed in human history. Our goal is to predict the year that production will reach its all-time peak. The World Oil Forecasting Program is designed to accomplish that goal. Our strategy is to build up a series of forecasts which, taken together, will inevitably converge on the peak. This website contains the latest models and forecasts in this ongoing project.

The Program, our research tool, depicts the historic production and predicted future production for the world's 42 top oil-producing nations, grouped in 7 Regions. Plus a World Summary. All compliments of the Institute On Energy and Man, a non-profit research organization in Seattle, USA.

You can use the World Oil Forecasting Program in two ways. First, you can simply observe and study the "base-line" forecasts, as contained in the downloaded files. Second, you can make your own forecasts and print out your own graphs and tables. The Program includes a step-by-step instructions file.
Send your comments and/or forecasts to:

Richard C. Duncan, Ph.D.
Institute on Energy and Man*
duncanrc@halcyon.com

For more information and relevant data, visit these sites:

Site for oil production data: BP Review

*The Institute was founded in 1992 to study the feedback dynamics of energy use and industrial civilization.