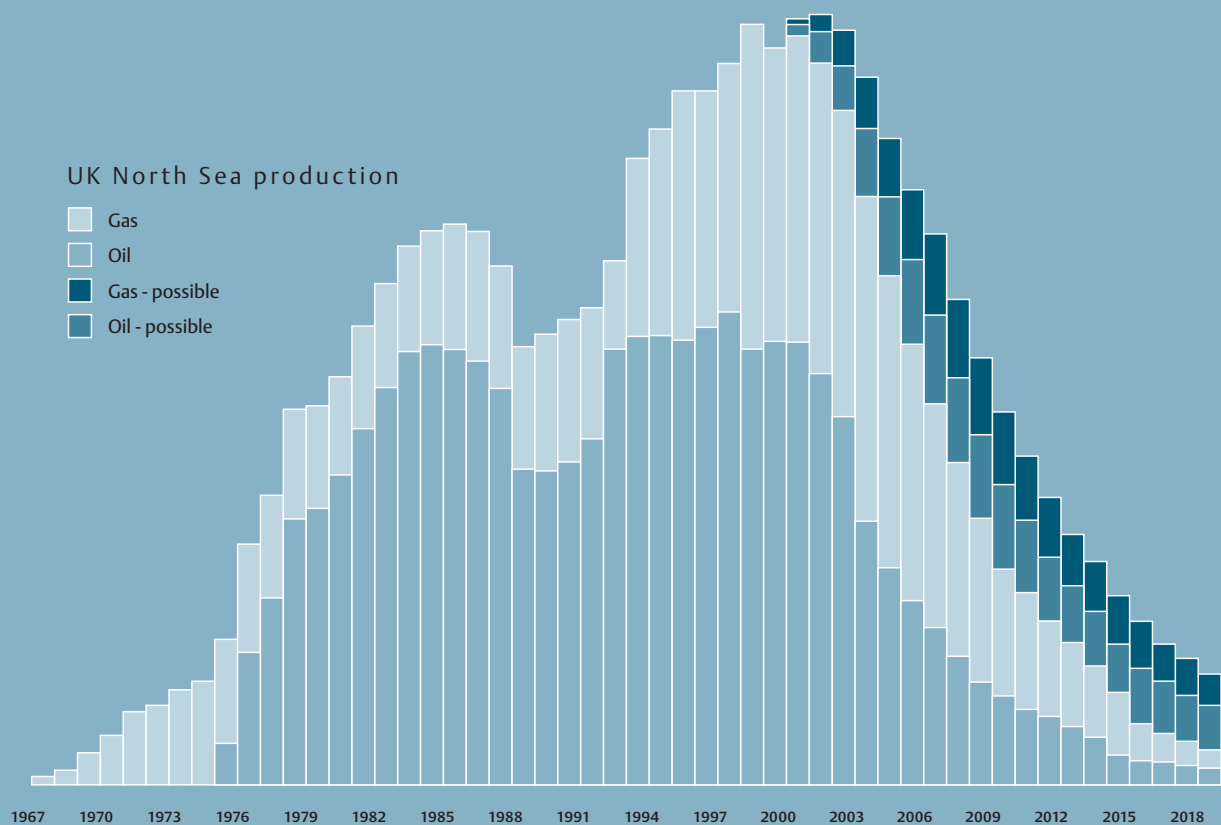


Oil-based Technology and Economy

Prospects for the Future



A short introduction to basic issues and a review of oil depletion projections derived from different theories and methods

Units used:

Oil:

1 barrel of oil = 1 bo = 159 litres

1 Mb = 1 million barrel of oil

1 Gb = 1 billion barrel of oil = 1,000 million barrel of oil

1 Tb = 1 trillion barrel of oil = 1,000 billion barrel of oil

1 bn bbl = 1 Gb

1 b/d = 1 barrel per day

Gas:

1 m³ of gas = 1 cubic metre of gas

1 billion m³ of gas = 1,000 million m³ of gas

Energy:

1 J = 1 Joule

1 W = 1 Watt = 1 J/sec

1 MJ = 1 million J

1 GJ = 1,000 MJ

1 TJ = 1,000 GJ

1 Wh = 3600 J

1 MWh = 1 million Wh

1 GWh = 1,000 MWh

1 TWh = 1,000 GWh

1 MW = 1,000 W

1 GW = 1,000 MW

Front page graph:

UK North Sea Production. Production from already discovered fields.

Reproduced from the CD "*Promote the United Kingdom 2003*"

issued by the UK Department of Trade and Industry.

Reproduced with permission from the UK Department of Trade and Industry.

Oil-based Technology and Economy Prospects for the Future

A short introduction to basic issues and a review of oil depletion
projections derived from different theories and methods

**The Danish Board of Technology
Teknologirådet
and
The Society of Danish Engineers
Ingeniørforeningen i Danmark**

March 2004

Title:

Oil-based Technology and Economy - Prospects for the Future

A short introduction to basic issues and a review of oil depletion projections derived from different theories and methods

Author: Klaus Illum

Copyright 2004:

The Danish Board of Technology (Teknologirådet)

The Society of Danish Engineers (Ingeniørforeningen i Danmark)

The author

All rights reserved

ISBN 87-90221- 86-9

ISSN 1395-7392

Published by:

The Danish Board of Technology

Antonigade 4

DK-1106 Copenhagen K

Phone: +45 33 32 05 03

e-mail: tekno@tekno.dk

www.tekno.dk

In December 2003 a preliminary edition of this review was distributed to the participants in the conference:

Oil Demand, Production and Cost - Prospects for the Future

Copenhagen December 10th 2003

www.ida.dk/oilconference

jointly organized and held by The Danish Board of Technology and The Society of Danish Engineers.

Throughout the present edition this conference is referred to as:

The Copenhagen conference 2003

Speakers at the conference:

Dr. Ali Morteza Samsam Bakhtiari, Senior Expert in Corporate Planning, Directorate of the Iranian National Oil Company (NIOC), Iran

Dr. Colin J. Campbell, Petroleum Consultant, Ireland. Founder and chairman of the Association for the Study of Peak Oil (ASPO)

Dr. Donald L. Gautier, Petroleum Geologist, US Geological Survey, Menlo Park California, USA

Mr. Francis Harper, Exploration Consultant. Former Manager, Reserves and Resources at BP, UK

Mr. Jean H. Laherrère, France. Former President of the Exploration Commission of the Comité des Techniciens of the Union Française de l'Industrie Pétrolière

Mr. Christopher Skrebowski, Editor of Petroleum Review, UK

Mr. Peter Stewart, Crude Oil Manager Europe, Platts Global Energy, McGraw-Hill Companies, London

Foreword

Oil depletion has been a non-issue in energy policy casting and macro-economic forecasting. However, in 2003 the issue surfaced in the periodicals of the professional community of oil geologists and oil economists, notably in a series of articles in the *Oil & Gas Journal*, July - August 2003. Recently, there has also been an increase in the number of articles on the issue in newspapers and magazines.

Recognising the world economy's technological dependence on oil and, hence, the serious consequences of a decline in oil production for which the world community is technologically unprepared, *The Danish Board of Technology* and *The Society of Danish Engineers* wish to draw attention to the issue. In pursuance of this objective, our two institutions jointly commissioned this review and organised the conference *Oil Demand, Production and Cost - Prospects for the Future*, held in Copenhagen on December 10th 2003.

The aim of the review is to outline the characteristics of the cheap-oil economy and provide an overview of different scenarios for the future development in demand and supply presented by various experienced researchers and institutions who base their analyses on different methodologies.

The review has been prepared by Klaus Illum in collaboration with a workgroup set up to organise the conference and to form a forum for the critical discussion and revision of the review drafts. The members of the workgroup participated in their individual capacity and do not necessarily represent the views of their company or institution. The members of the workgroup were:

Dr. Flemming Getreuer Christiansen, Geological Survey of Denmark and Greenland (GEUS)

Dr. Jerome Dean Davis, Roskilde University (RUC)

Mr. Tage Dræbye, Dræbye Consulting and Management

Dr. Poul Dyhr-Mikkelsen, Danfoss AS

Mr. David Gibson, The General Worker's Union in Denmark (SID)

Dr. Klaus Illum, ECO Consult

Dr. Poul Erik Morthorst, Risø National Laboratory

Dr. Jan Reffstrup, DONG AS (Danish Oil and Natural Gas)

Project managers:

Mrs. Gy Larsen, The Danish Board of Technology

Mr. Bjarke Fønnesbech Jensen, The Society of Danish Engineers

A draft of the review, approved by the workgroup, was critically reviewed by:

Dr. Ali Morteza Samsam Bakhtiari

Dr. Colin J. Campbell

Dr. Donald L. Gautier

Mr. Francis Harper

Mr. Jean Laherrère

The critical comments and corrections received from these prominent experts were indispensable for the preparation of the review and we sincerely acknowledge their contributions.

Dr. P. Criqui, who is a key researcher in the research group behind the *World energy, technology and climate policy outlook 2030* report (WETO, 2003) published by the EU Commission, DG Research (Directorate Energy), has kindly submitted his comments on the draft sections in which the WETO report is discussed. We sincerely thank him for his valuable comments.

We also extend our thanks to the members of the workgroup for their valuable contributions.

A preliminary edition of the review was presented at the Copenhagen conference mentioned above. In the present edition, the Summary has been extended and additions have been made to some other sections. Some additions refer to the presentations at the conference, others to articles published shortly before or after the conference.

The comments and corrigenda to the draft of the review which were submitted by the reviewers and the members of the workgroup are sincerely acknowledged and they have to the best of the author's ability been taken into account. However, any errors or misinterpretations which may be found in this edition remain the sole responsibility of the author.

March 2004

Torben Klein
President of the Danish Board of Technology

Per Ole Front
President of the Society of Danish Engineers

Contents

Preface	1
Summary	5
Depletion scenarios	7
The economy and the geological reality of oil supply	13
Oil and natural gas. Energy costs of oil production	15
Oil consumption and climate change	16
The need for international regulation	16
Transportation	18
1. The Cheap-oil Era	19
1.1 The oil-world	21
1.2 Towards the end of the windfall energy economy	22
1.3 The aging resource base	26
2. Oil - the Unique Liquid Fuel	29
2.1 Conventional oil	30
2.1.1 Liquid fossil oil deposits	30
2.1.2 Natural gas liquids (NGL)	33
2.2 Non-conventional fossil oil	33
2.2.1 Heavy oil, extra heavy oil, and tar sand	33
2.2.2 Oil Shale	34
2.2.3 Synthetic oil from coal and natural gas	34
2.3 Oil from biomass	35
2.4 The terms ‘Reserves’ and ‘Resources’	35
3. Demand and Supply	39
3.1 The IEA World Energy Outlook 2002 and World Energy Investment Outlook 2003	40
3.2 World energy, technology and climate policy outlook 2030 (WETO) ..	48
3.3 The higher the rise the steeper the fall	50
3.4 Options for the reduction of the demand for conventional oil	51
3.4.1 Oil demand determinants	52
3.4.2 Ways and means to restrain the demand for conventional oil	53
1) Reduction of inefficient, unnecessary, wasteful or extravagant use of oil	53
2) Reduction of the demand for oil by the replacement of oil-based technologies	53
3) The substitution of non-conventional fossil oil and oil from biomass for conventional oil	55

4. Conventional Oil Reserve Assessments	57
4.1 Reserve development	58
4.2 Future discoveries and enhanced recovery techniques	59
4.3 Ultimate reserve estimates	63
4.3.1 Laherrère's estimates	64
4.3.2 Campbell's estimates	67
4.3.3 USGS's probabilistic assessments	69
4.3.4 The WETO POLES model	72
5. Oil Demand and Reserve Depletion Scenarios	77
5.1 Demand and supply	78
5.2 Hubbert depletion scenarios	79
5.3 Campbell's depletion scenario	81
5.4 EIA's R/P based depletion scenarios	83
5.5 OILPROSPECTS scenarios	87
6. On the Economy of Oil	95
6.1 On the economy of the cheap-oil technology complex	95
6.1.1 Motorcars	95
6.1.2 Speed	97
6.1.3 Trucking	97
6.2 On the new economy of oil supply	97
6.3 Administering a market with low marginal production costs	100
6.4 Market experiments with the global economy	102

Preface



The cheap-oil era is a short anomaly in the Earth's history.

In the 20th century the production of liquid and gaseous hydrocarbons from fossil reservoirs - oil and natural gas - rose towards a peak.

In the 21st century production will be declining.

In the course of a century, technologies based on oil as a unique, easily handled fuel have shaped the world, its human habitats, its transportation infrastructures, its agriculture. The time available to find substitutes for fossil oil and the technologies depending on it is much shorter.¹

From 1900 onward, people have been “crying wolf” when they had done their R/P arithmetic on conventional oil reserves (R) and annual oil production (P) and found that the ratio was only 10 years or so. However, as reserves grew at a faster rate than production, the ratio kept growing, being now about 40 years. So far, so good. Today no one disagrees that the wolf is out there but differences in analyses and opinions as to when it will attack the sheep still prevail. An R/P ratio of 40 years does not mean that production can be sustained at the present level for 40 years. Production will peak and begin declining long before the last barrel has been produced. The question is, when is the peak likely to occur and how steep is the decline likely to be ?

In recent years several experienced oil geologists and some economists have sought to draw attention to their analyses of the prospects for the future supply of cheap, conventional oil, which - according to their findings - is likely to peak within the next ten or fifteen years. If demand continues to grow until the production peak occurs, the following irrevocable decline in production will have grave social and economic consequences.

Other researchers, notably researchers in the United States Geological Survey (USGS), which is the governmental body responsible for oil and gas research in the US, and the US Energy Information Administration (EIA) refute the validity of these analyses, claiming that the predictions of an imminent peak in conventional oil production are unrealistic. Also the OECD's Paris-based International Energy Agency (IEA) states in its *World Energy Outlook 2002* that supply can meet demand at least until 2030, provided that very

¹ The graph above is copied from Kenneth S. Deffeyes: *Hubbert's Peak - The Impending World Oil Shortage*. Princeton University Press, 2001. (page 6)

large investments in exploration and the development of production capacity and pipelines are made. Similar projections are presented by the European Commission in the report *World energy, technology and climate policy outlook 2030* (WETO, 2003). However, the IEA explicitly states its concerns regarding the strenuous actions to be taken by governments in order to increase production at such a rate that economic development in the OECD countries as well as in the transition economies and the developing countries can be sustained.

Any prediction of future demand and production is counterfactual and, therefore, uncertain. However, the functioning of modern societies is so heavily dependent on oil-based technologies and, therefore, on the supply of oil that governments must gain qualified information about the past and the probable future development in reserves and production capacities in order to assess the number of years that may be made available for the substitution of oil-based technologies before the decline in the supply of oil sets in.

This review draws attention to the technological and economic characteristics of the brief singular era in the history of the Earth in which cheap conventional oil has been available in abundant amounts and presents the perspectives for the prospective ending of this era as assessed by various researchers who base their analyses on different methods.

It is recognised that the assessments to be made should not concern the total geological depositions of oil and other fossil hydrocarbons from which oil can be extracted or synthesised. Assessments of these abundant amounts are practically irrelevant for the assessment of supplies in the next decades. The assessments to be made concern the volume of the reserves and the production capacities which can be made available in a foreseeable future at competitive costs and without unacceptable environmental impacts. Also, governments should assess the compatibility of the global oil consumption rate with climate change mitigation policies.

No conclusions are drawn in this review. However, it is found that the evidence provided from public domain sources, upon which this review is based, warrants the scrupulous and politically unbiased assessment of the opportunities to balance global oil demand and oil production capacity in the next decades and the consequences of a decline in oil production capacity for the economies in the affluent countries and the economic development in the poor regions.

If the time-horizon for the impending peak in the production of cheap conventional oil is as short as one or two decades or less, the problems involved in handling the situation are of a specific, practical nature. Therefore, economic policies should not rely on general, theoretical assumptions that technological progress will ensure sufficient supplies of oil or substitutes for oil. Engineers and oil geologists should assess the investments in new, more energy-efficient end-use techniques and new discovery and recovery techniques needed to ensure that demand peaks before a decline in supply sets in. And economists should make governments aware of the national and international economic consequences of a peak in oil supply for which governments, industries and consumers are unprepared and spell out economic policy conditions required for the implementation of the investments needed in end-use and supply industries in order to mitigate the consequences before the peak occurs.

The low cost of conventional oil has allowed the development within a few decades of a world economy which is based on extravagant and wasteful use of this unique, most valuable fuel and thus depletes its precious resource base much faster than long-term economic considerations would justify.

In each chapter of this review the factual evidence referred to is presented in the form of quotations from articles found in professional journals; conference proceedings; books written by prominent authors in the field of oil geology and oil economy; and reports published by authoritative institutions. This evidence constitutes the basic substance of the review. It is the subject matter of the interpretations and discussions offered.

Future oil supply is a controversial subject. The professional discussion is very heated. Not only the media but also professional journals have set up a verbal boxing ring where the so-called "pessimists" fight the so-called "optimists" - notions which suggest that professional judgement in this field is based on subjective sentiments rather than objective assessments based on well-documented evidence, theories and methods. This should be disquieting as the subject matter is of crucial importance to the world economy. Disagreement between professional analysts is no excuse for responsible politicians not to examine the evidence available and take a stand.

The verbal boxing ring is good entertainment in the media. However, the truth does not reveal itself when a contender takes the count. Irrespective of human controversies, the truth relentlessly reveals itself as time goes by. And whether we like it or not, it is biassed towards the realities of this world. Regarding oil production, scrupulous research and analysis of the geological, technological, economic, and political evidence available is the only way to trace it. No one knows what the future will bring. But men and women are born to use their intellect to look ahead and pass warnings from the crow's nest to the helmsman - so as to avoid the fate of the Titanic.

From the author's presentation of this review at the
Copenhagen conference 2003

"Is the future going to be a rerun of the past ? I don't think so. "

"We'll see an exchange of the cheap and easy with the expensive and slow."

Francis Harper at the Copenhagen conference 2003

The conventional wisdom of the prevailing economic theories relies on the axiom that worldwide economic growth of a nature which implies continued growth in the production and consumption of energy-consuming hardware can continue for an indefinite length of time. That market forces will ensure that new resources and new technologies will always be at hand when access to the resources upon which our societies depend becomes restrained and present technologies therefore become obsolete.

History shows that man has hitherto succeeded in making life easier by means of new energy sources and technologies. From manpower to horsepower. From horsepower to coal-fired steam engines. From steam engines to oil-engines. Thus economic development has, so to speak, been a ride downhill with the wind behind us. However, there is nothing in sight which is so easy and cheap to get, handle, store, and to use in cars, buses, trucks, tractors, ships, and aeroplanes as oil from oil wells.

Therefore, unless something unknown today turns up or our oil-based consumer culture takes a turn towards less oil-dependent activities, we face an arduous ride uphill against a headwind when one day the supplies of cheap conventional oil become restricted.

History may reveal that the prevailing axiom of sustainable economic growth is a theoretical derivative of the cheap-oil era. In contradistinction to economic theory, oil geologists have voiced concerns about future oil supply.

Summary

The evidence presented in this review shows that forecasts made by governmental and international institutions differ markedly from the results of analyses made by individual, independent researchers and some analysts representing the oil industry. The oil industry's analysts point to ever greater costs of matching growing demand with supply from an aging resource base.

Depending mainly on developments in the Middle East and the development of the world economy in the coming years, production may peak within one or two decades. It is a question of geology, technology, economy, and the policies conducted by various nations. The trouble is that no realistic technological, economic and political strategies for the warding off of the impacts of a decline in conventional oil supply are in sight.

In Chapter 1, the preamble to the review of oil depletion projections, attention is drawn to the unique properties of the technologies and the economy of the historically singular cheap-oil era. Full appreciation of these properties is essential for the comprehension of the wide range of technical and economic problems to be encountered in the transition to the post-cheap-oil era.

Drawing on elementary oil and gas geology textbooks and other publications for non-specialists, Chapter 2 gives a concise introduction to the terms and concepts of the oil industry and, concurrently, a few quotations and figures which serve to outline the current status of the industry.

Few governments have taken warnings of an impending peak in oil production into account in their energy security policies. In accordance with the scenarios for the development in the world's energy supply until 2030, presented in the International Energy Agency's *World Energy Outlook 2002* (WEO 2002) and the EU commission's *World energy, technology and climate policy outlook 2030* (WETO, 2003), governments are investing in more motorways, bridges and airports so as to facilitate continued growth in traffic volumes, without taking into account that the cheap-oil era may end well before these investments are paid back. The development in demand and supply in the WEO and the WETO scenarios is described in Chapter 3. The development trends in these scenarios are derived from theoretical, macroeconomic growth models. The underlying growth theory implies the following hypothetical assumptions:

- C the disparities in living standards between affluent countries with a high per capita energy consumption and poor countries with a population 5 - 6 times bigger and a low per capita consumption will not further destabilise international political and economic relations so as to influence economic growth in the affluent countries;
- C economic growth will not for any period of time be disrupted because of shortages in energy supply, in particular oil and gas supply. The market will ensure that the oil and gas industry provides sufficient production capacity to meet the growing demand;
- C a growth in annual CO₂ emission by 70-100 % will not influence the global climate to such an extent that climate change will have a significant negative influence on the global economy.

Regarding the hypothesis that there will be no shortage in oil supply, publicly available empirical evidence provided by oil geologists and the oil industry is reviewed in Chapters 4 and 5.

Finally, in Chapter 6 some aspects of the particular properties of the oil economy and the economic conditions for a transition from the present cheap-oil technological complex with its aging resource base to a much more energy-efficient technological complex are touched on.

Considering the publicly available empirical evidence concerning the development in oil production capacities, the validity of the hypotheses that the market will ensure sufficient supplies of cheap oil is disputable. Assessments made by the oil industry itself and its financial analysts point to increasing costs of sustaining the present production capacity and developing the additional capacity needed to meet a growing demand (Chapter 5 (box) and section 6.2). Cost assessments for the investments needed run as high as \$100 billion per year in the period 2003-2010 but currently the industry invests considerably less, assessing project profitability on the basis of a normalised crude oil price of less than \$20 per barrel. Apparently, the anticipation of a future oil price at this level is reasoned by an expected surge in the Iraqi oil production capacity, possibly combined with the belief that demand growth will be slow in the coming years due to a low economic growth rate in the OECD countries.

However, even if the industry's anticipations of future oil prices were adjusted upwards, possibly because the surge in Iraqi capacity is deferred and the Middle East is further destabilised while economic growth is regained elsewhere - however unlikely such a combination of events may seem - it is uncertain whether increased investments will continue to bring about new reserves sufficient to compensate for the decline in production from aging oil fields. Empirical evidence provided by independent, experienced oil geologists indicate declining reserves and production irrespective of increased efforts by the industry to replenish reserves and increase the production capacity.

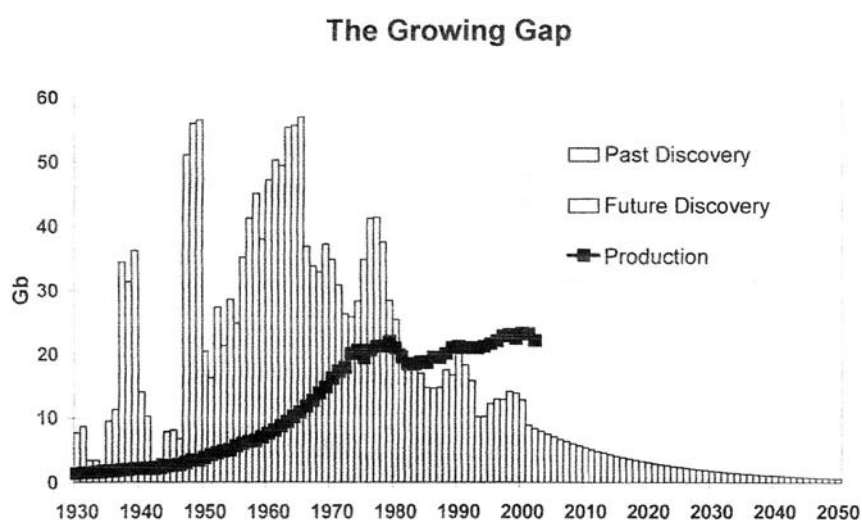


Figure 1. Discovery and production history and extrapolated future discovery. Colin J. Campbell, ASPO Newsletters, www.asponews.org See also section 4.2, fig. 4.3 and 4.4.

The crux of the matter is that most of the existing oil reserves are in oil fields found more than 20 years ago and that since 1980 annual consumption has exceeded annual new

discoveries, see fig.1. A growth in oil consumption by 1.6% per year, as assumed in IEA's *World Energy Outlook 2002*, means that the total global consumption from 2000 to 2030 years will exceed the total consumption in the 20th century by more than 20%. This implies that production capacity (conventional+non-conventional) must be increased by 60% by 2030.

Enhanced recovery techniques (see section 4.2) and reserve revisions, based on the improved geological mapping of existing fields, will increase reserves in some fields. There is, however, no evidence that such techniques will bring about additional reserves at such a rate that the gap between annual consumption and annual reserve additions will be significantly reduced. On the contrary, the US oil production history shows that after the peak in 1970 reserves and production have been irrevocably declining (see section 5.4, fig. 5.7) although enhanced recovery techniques have been applied since the 1980s.

Depletion scenarios

When new reserves are no longer added at the rate at which existing reserves are depleted, production must peak sooner or later. Based on different assumptions as to ultimate reserves, future growth in demand, and decline rates after the peak, the Energy Information Agency (EIA) of the US Department of Energy has computed a series of scenarios for the future development in conventional oil production (section 5.4). Two of these scenarios are shown in fig. 2. In the one scenario it is assumed that an exponential growth in demand by 2% per year can be sustained until production peaks in 2016. In the other, this demand growth is sustained until 2037, whereupon production drops almost vertically.

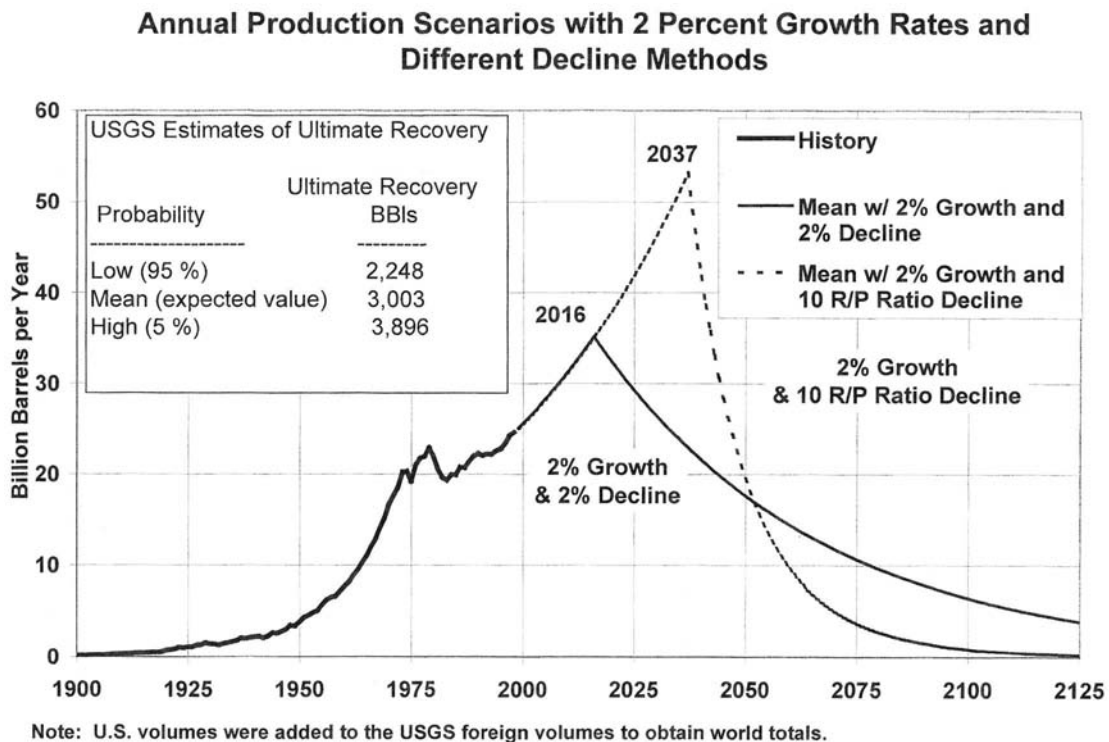


Figure 2. US Department of Energy, Energy Information Administration (EIA), 2000. See also section 5.4, fig. 5.6.

Such scenarios, which - apart perhaps from the ultimate reserves assumed² - cannot be ruled out as unrealistic, depict a most unfortunate development path: The world economy becomes more and more dependent on conventional oil until the growing demand can no longer be sustained. This implies that conventional oil remains cheap until the peak occurs and that, therefore, few investments in oil-saving measures and alternative energy sources are made. Thus, the oil-based economy will be entirely unprepared for the abrupt shift from growth to decline in the production of conventional oil. The longer production can cover demand, the more the economy becomes dependent on conventional oil, and the steeper the fall will be.

A detailed country-by-country analysis of reserves and production capacities (section 4.3.2) results in the scenario forecast shown in fig. 3. Assuming a demand growth of about 1.2% per year in the next years, the peak in oil production occurs in 2010. Thereupon production declines at a rate of about 2% per year. Although the demand growth rate is lower than in fig. 2, the peak occurs earlier. This is because ultimate conventional reserves, in accordance with fig. 1, are estimated at 1,900 Gb as against 3,000 Gb in fig. 2.

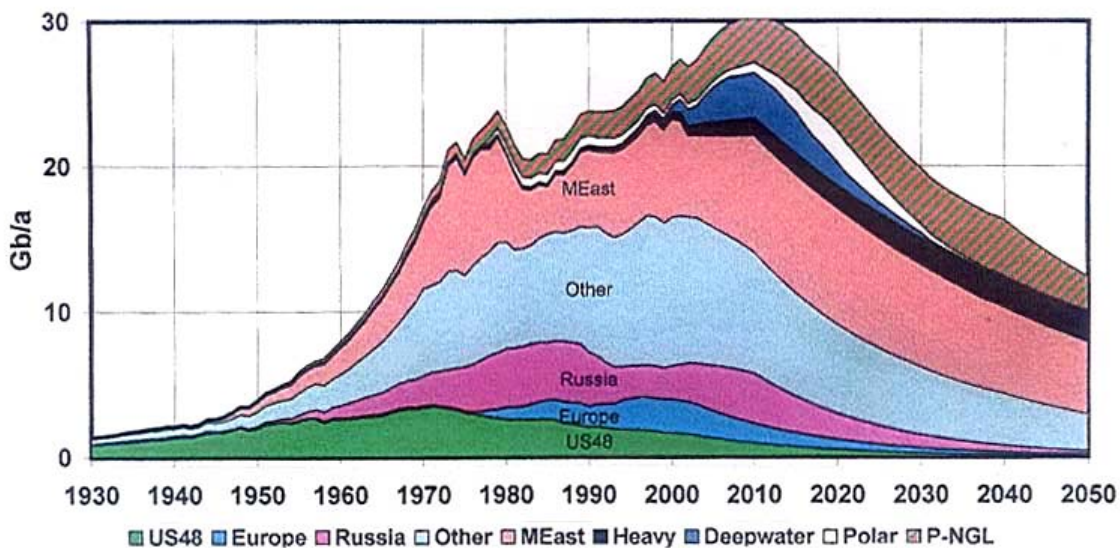


Figure 3. Oil depletion scenario based on detailed country-by-country analyses of reserves and production capacities for ultimate conventional reserves of 1,900 Gb. Colin J. Campbell, 2003.

Campbell's analysis is partly based on M. King Hubbert's hypothesis that oil production in a particular province will peak when about 50% of the recoverable oil has been produced (see section 5.2). This hypothesis has been contested by several authors. However, other

² It should be noted that ultimate reserves of 3000 Gb (billion barrels, BBls) are assumed in these scenarios. To obtain this quantity, new reserves amounting to 80% of the accumulated reserve additions until 2000, shown in fig. 1, must be added in the next decades. Considering the reserve addition record for the last 20 years, shown in fig. 1, this implies a dramatic increase in the rate of reserve additions in the next decades.

analyses which do not presuppose the validity of Hubbert's hypothesis also show a peak occurring when about 50% of the estimated ultimately recoverable resources has been produced. For example, when a not outrageous decline rate of 2% is assumed, as in fig. 2, above, which is derived from a very simplified model (see section 5.4).

By means of another model, which takes several production determinants into account, see fig. 4, the relationship between peak-time and a): ultimate recovery (or ultimate reserves), including future reserve growth, and b): production efficiency has been studied, see fig. 5. It appears from fig. 5 that at a consumption growth rate of 1.6% p.a., an increase in ultimate recovery from 2400 Gb to 3100 Gb postpones the peak by less than 8 years, depending on the growth in production efficiency. Also in these cases the peak occurs when about 50% of the ultimate reserves have been produced.

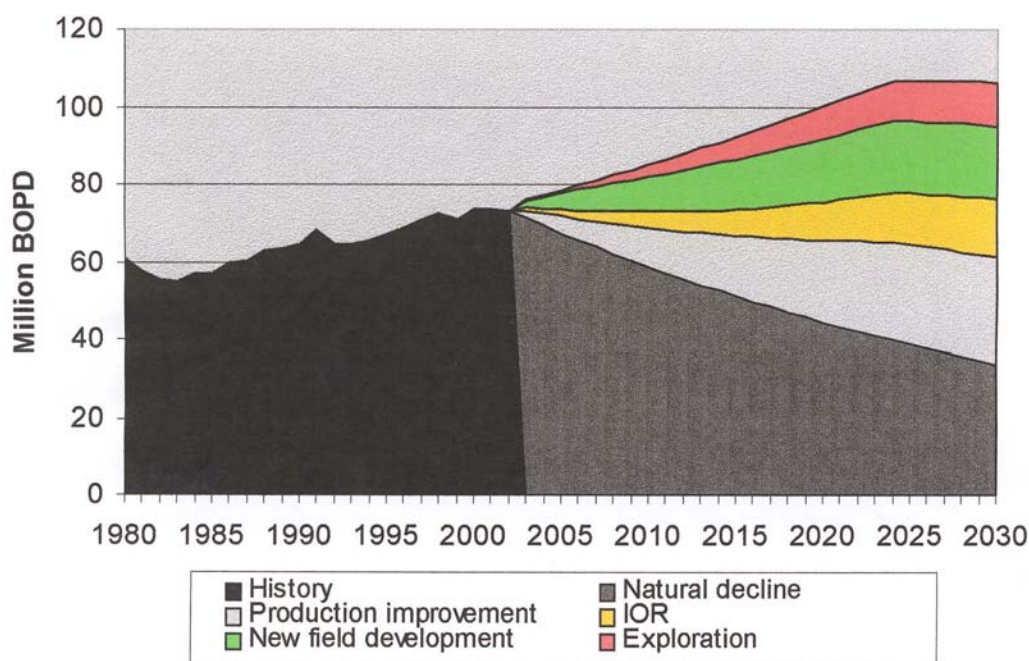


Figure 4. This graph was presented at the World Petroleum Congress Regional Meeting, Doha, Qatar, by Leif Magne Meling, Statoil, in December 2003.

IOR: Improved Oil Recovery

Production improvement: Due to increased production efficiency (PE), which is a measure of the yearly ratio of liquids produced to remaining developed reserves, i.e. the decline rate of exponential-decline-rate-analysis, or the inverse of the reserves-to-annual production ratio R/P (Meling, 2003). An example of an exponential-decline-rate curve ($R/P=10$, $PE=1/10$) is shown in Fig. 2, above.

In the depletion scenario shown in fig. 6, which is computed by means of the OILPROSPECTS model (see section 5.5) using IEA data (see section 3.1), the peak occurs when about 60% of the ultimate conventional reserves have been produced. However, in this case the addition of non-conventional oil production postpones the peak.

Thus, it appears that various models, which do not intrinsically assume the validity of Hubbert's hypothesis, do confirm the basic validity of Hubbert's hypothesis although the shape of the production curve may not be as smooth as Hubbert's canonical curve.

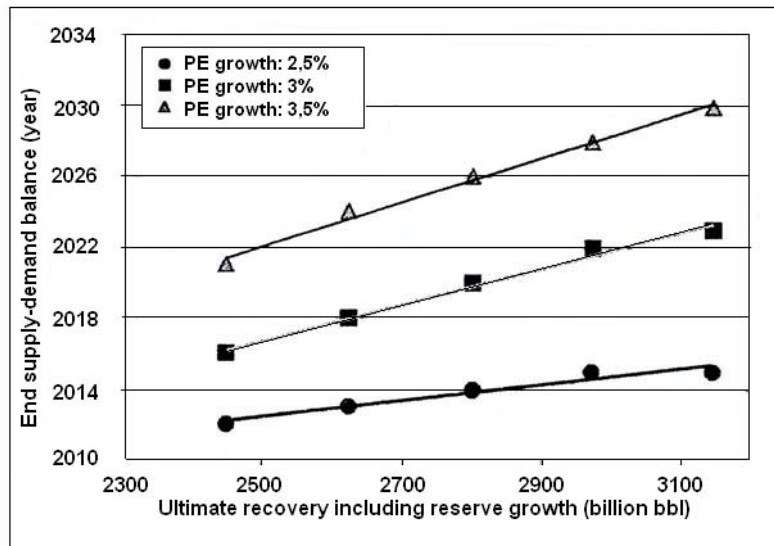


Figure 5. Relationship between reserve growth, production efficiency (PE, see fig. 4), and end-supply demand (i.e. the time when production can no longer meet demand) at a demand growth rate of 1.6%. Source: see fig. 4. The author deems a 3.5% PE growth very optimistic compared with historical data.

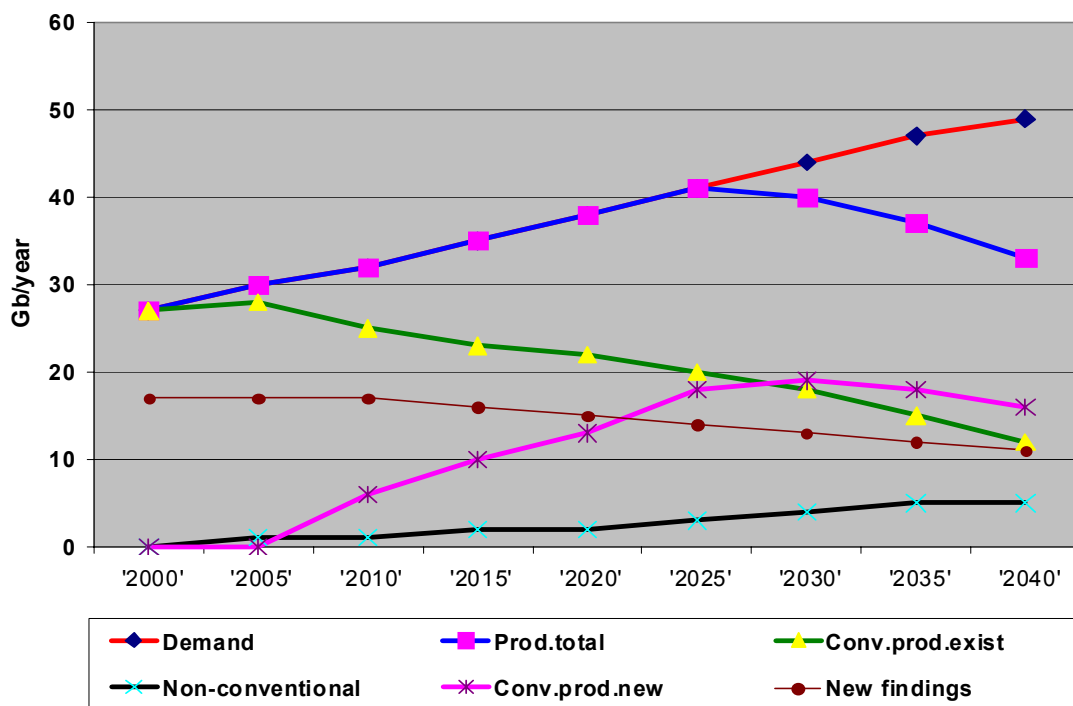


Figure 6. Production balanced against demand, using IEA *World Energy Outlook 2002* data and *World Energy Investment Outlook 2003* assumptions regarding new findings (see section 3.1). It should be noted that the assumption that new findings will amount to 17 Gb/year in the coming years is in contrast to the empirical evidence that new findings in the period 1993 - 2002 averaged only 10 Gb/year.

If instead it is assumed that new findings in the next decades amount to 10 Gb/year, then production will reach a plateau of about 34 Gb/year in 2015 - 2025, whereupon the decline will set in.

From this evidence it appears that depending on future demand, the assumed ultimate reserves and production efficiency, conventional oil production is likely to peak between

2010 Fig. 3, Campbell, ultimate conventional reserves 2,400 Gb (incl. deepwater and polar fields, and natural gas liquids), plus non-conventional oil 300 Gb (see section 5.3)

and

2025 Fig. 5, ultimate conventional reserves 3100 Gb; PE growth >3% p.a
Fig. 6, ultimate conventional reserves 2600 Gb, plus non-conventional oil 350 Gb (see section 3.1); a steep increase in new findings to 17 Gb/year as against 10 Gb/year in 1993- 2003 is assumed.

However, even under the assumption that the world's endowment of accessible oil is sufficient and that it is technically possible to increase reserves and production capacity at such a rate that the peak can be postponed until 2025, there is no guarantee that the oil industry will make the investments needed to increase production at a sufficient rate.

And, more importantly, this is not to be desired under all circumstances. It must be kept in mind that the postponement of the peak by the continued increase in production to meet continued growth in demand is not something to be desired. On the contrary, growing demand means that the global economy becomes ever more addicted to oil - until oil production can no longer meet demand. What is to be desired is that oil demand peaks before production capacity peaks.

It should be noted that if the peak is postponed by means of increased production efficiency (fig. 7), the decline after the peak becomes steeper, as illustrated in fig. 2.

Moreover, to the extent that the peak in total oil production is postponed by the additional production of synthetic oil from tar sand and natural gas, a reduction in total hydrocarbon production by the amount of gas used by the oil industry must be taken into account, see below.

This evidence does not confirm the International Energy Agency's (IEA) statement in *World Energy Outlook 2002* that "Resources of conventional oil and NGLs are adequate to meet the projected increase in demand to 2030, although new discoveries will be needed to renew reserves." (see section 3.1). Even if the IEA's assumption (see below) that 470 Gb of new reserves will be added to the reserve base before 2030 should hold, production may not meet demand after 2025 (see fig.6).

In contrast to the scenarios shown above, the forecasts presented in the International Energy Agency's *World Energy Outlook 2002* and *World Energy Investment Outlook 2003* (see section 3.1) and in the US Department of Energy, Energy Information Administration's (EIA) *International Energy Outlook 2003* (see section 5.4) do not proclaim any levelling out or decline in global oil production. On the contrary, relying on the USGS probabilistic reserves assessments (see section 4.3.3), they proclaim continued growth in oil production in the OPEC countries and the FSU as well as in the rest of the world, see fig. 7.

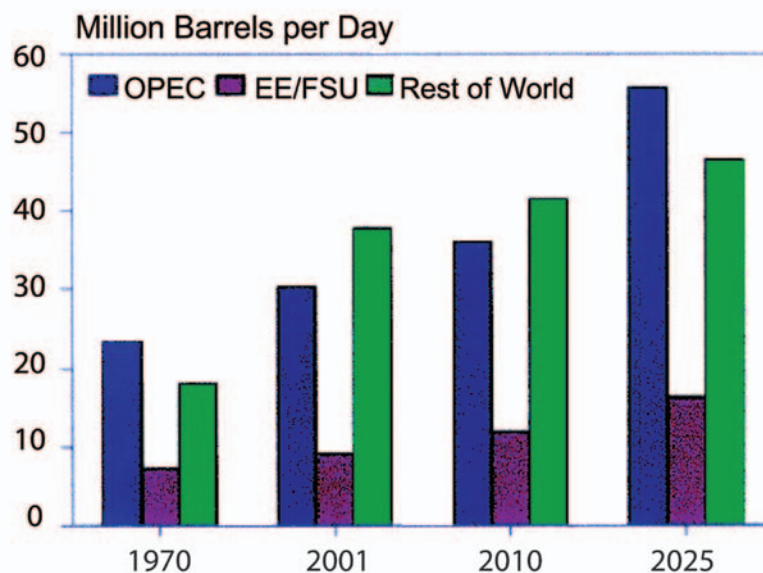


Figure 7 US Department of Energy, Energy Information Agency. International Energy Agency (EIA). *International Energy Outlook 2003*. World Oil Production in the Reference Case by Region. DOE/EIA-0129 (2001) (Washington, DC, February 2003). www.eia.doe.gov/iea.

The reason for this fundamental difference in forecasts presented to the public and the political decision-makers is that the IEA and the EIA (and also the EU in the WETO report, see section 4.3.4) presuppose that at a demand growth rate of 1.6 -1.8 % p.a. production will grow at the same rate as demand, because improved oil recovery by means of advanced technology in existing fields and the discovery of undiscovered fields will ensure that sufficient production capacity will be available at all times in the scenario period. This presupposition is based on the assumption that future production capacity is determined only by the investments made in the application of advanced technology and the discovery of new fields and that the oil industry will make sure that such investments are made in time to ensure that sufficient production capacity will be available at all times. At least until 2030 when, according to IEA, the reserve to production ratio will be reduced to 20 years, which means that a steep decline in production will set in (see section 3.1).

However, as mentioned in section 5.1, any conventional oil production scenario is subject to the following constraints:

- C The area covered by the production curve (past and future production) equals the ultimate reserves as estimated for the scenario in question.
- C Cumulative production must follow cumulative discovery with a certain time lag. Depending on demand and/or production restrictions the time lag may vary over time.
- C Annual global production should equal annual global demand.

Moreover, in a major oil province with many fields and wells, production does not suddenly plunge from a peak to a very low level. Rather, it follows a decline curve with a shape like a Hubbert curve, see section 5.2, unless production from a giant field such as the Saudi Arabian Ghawar field suddenly plunges because the water level reaches horizontal wells (see section 6.2).

Therefore, total production in the world's existing fields will follow a decline curve subject to the constraint that the area below the curve equals remaining reserves in these fields (see fig. 6). Concurrently, production in new fields is added at a rate determined by the annual discovery rate and the need to balance production and demand.

Taking these constraints into account, it appears that a production growth rate of 1.6 - 1.8% p.a. in the next three decades would require new discoveries and reserve growth in existing fields of magnitudes which are inconsistent with the assumptions made in scenarios in which such a production growth takes place. Moreover, the empirical evidence from the previous decades does not render new discoveries and reserve growth of such magnitudes credible.

The economy and the geological reality of oil supply

The IEA report *World Energy Investment Outlook, 2003* (WEIO 2003) was published in November 2003. The report says:

“A little over \$3 trillion will be needed in the oil sector through to 2030. Investment needs will average \$103 billion per year, but will increase steadily through the period as demand increases. Annual capital spending will rise from \$92 billion in the current decade to \$114 billion in the last decade of the projection period.”

(op.cit. p. 103. For a further discussion of the IEA projections, see section 3.1.)

According to these figures, the cost of sustaining an exponential growth of 1.6% per year in the supply of a resource which is of vital importance to the world economy is relatively low. On the average, it amounts to about \$14/year per capita in a world population of 7 billion people.

However, as pointed out by Christopher Skrebowski³, the oil industry *“is all about profits....It is not there to guarantee supply”*. Hence, the question is whether the crude oil price in the coming years will remain high enough to make investments in sufficient new production capacity sufficiently lucrative for the oil industry. In 2003, the industry was investing less than required, using a normalised oil price of only \$ 18-20 in determining whether to pursue new projects, see section 6.2. A steady oil price of \$ 30-35 may not significantly dampen down the growth in world economy and it may induce the oil industry to squeeze more oil out of the crust of the Earth. Until geological reality makes the marginal costs of squeezing out another barrel prohibitive.

³In his speech at the Copenhagen conference 2003. Christopher Skrebowski is editor of *Petroleum Review*, Energy Institute, London.

In any case, if the old oil fields in the Middle East begin to run empty before hitherto expected, then no amount of money will bring about enough conventional oil from other fields to prevent a plunge in global production. Matthew R. Simmons (see section 1.3), A.M. Samsam Bakhtiari (see section 6.2), Colin J. Campbell (see section 4.3.2), and others have drawn attention to the fact that the reserves and resources in the old oil fields in the Middle East may be grossly overestimated. And Jean Laherrère has pointed out the danger that Saudi Arabia's giant Ghawar field could suffer a fate that is worse than the fate of the Omani fields (see section 6.2).

For political reasons, OPEC countries revised their reserves upwards in the late 1980s, when their production quotas became related to their reserves. A recent case of such an upward revision was reported in *Oil & Gas Journal*, December 22, 2003, p. 43-44:

"The update [in Iran] listed developed and undeveloped fields. It showed upward revisions for 16 reservoirs in 14 land and offshore fields.The net of revisions totalled a positive 14.2 billion bbl.

Iran also revised upwards its estimates of reserves from improved recovery from 25 onshore and 9 offshore reservoirs. The net of those revisions is a positive 30.3 billion bbl. [From 80 billion bbl in 1999 to 126 billion bbl in 2003, including Natural Gas Liquids].....

Iran did not cite reasons for these revisions, such as reservoir performance, development drillings, or injection projects.

.....

With restoration of Iraqi production capacity, Iran has political reason to increase its reserves estimate.

....

The prospect of Iraq's raising production significantly beyond 3.7 million b/d gives Iran a motivation to disclose reserves able to sustain comparable increases."

What really remains in the Middle East remains to be seen. However, as long as the world economy becomes ever more dependent on oil-fueled technology, it becomes ever more dependent on the Middle East production capacity (see section 3.1, table 3.2 and map 3.1). When the decline in this capacity sets in, a decline which may appear to be a matter of geological reality rather than economic profitability, it is doubtful whether at that time alternative sources will be ready to replace it.

Prosperous years for the oil industry:

"Profits will continue because oil and gas supplies will be low, with US demand rising faster than production - and total world demand increasing by about 1 million barrel/day/year [0.365 Gb/year] and because the Organization of Oil Exporting Countries will continue to maintain the price of oil at \$25-28/barrel for an OPEC crude basket.

'We are drilling deeper and we are looking for much smaller reserves - one twentieth or one thirtieth the size of reserves 50 years ago', said Marshal Adkins, managing director and head of energy research at Raymond James & Associates Inc. Although the number of drilling rigs has tripled, he said, oil and gas production in the US continues to fall dramatically.

.....

'I think that the next few years (2003-06) will be very good years for the energy business,' said Adkins."

Oil and natural gas. Energy costs of oil production

Natural gas can replace oil in boilers and vehicles and be cracked into carbon and hydrogen for use in fuel cells, which can replace internal combustion engines. However, long-distance transport (in gas pipelines or in liquified-gas vessels, see section 3.1, Map 2) as well as the distribution and storage of gas is more expensive and energy consuming than the transport and storage of oil. And although natural gas production - conventional plus non-conventional - may continue to grow for several decades, a redoubling of the gas production over the next 30 years will not compensate for the decline in oil production shown in fig. 3 - see fig. 8.

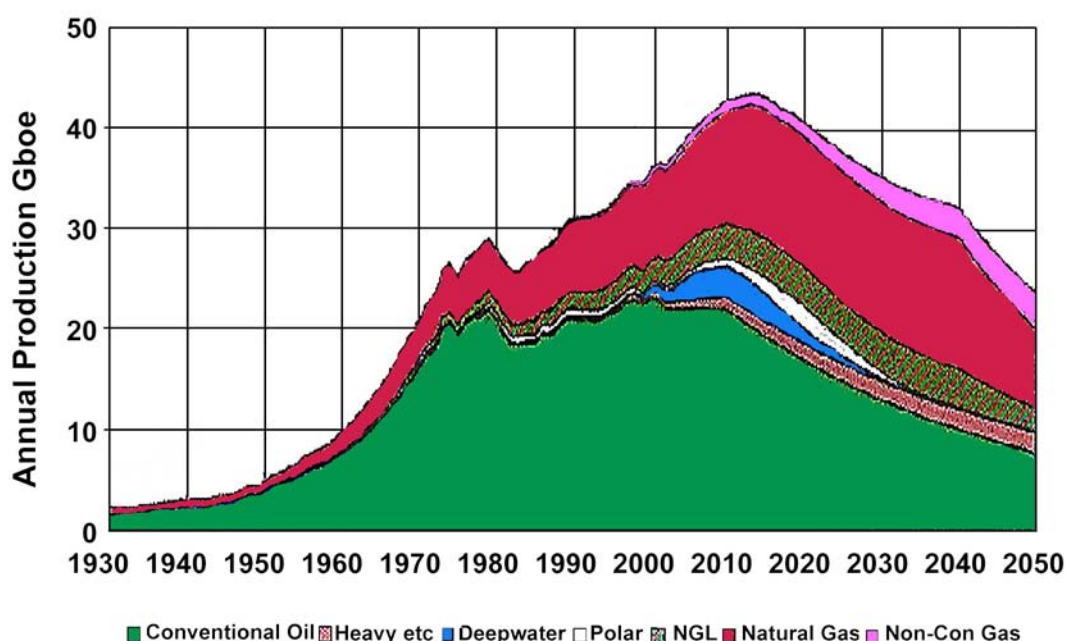


Figure 8. All hydrocarbons. Natural gas and non-conventional natural gas superimposed on the graph in fig. 3. Colin J. Campbell, 2003.

There are several links between oil supply and natural gas supply. The production of natural gas contributes to oil supply, partly in the form of condensate from wellheads, partly as Natural Gas Plant Liquids (NGPL) produced in variable amounts in gas processing plants (see section 2.1.2). The more gas from the wellheads, the more oil in the form of condensate. The more oil in the form of NGPL, the less gas for the market.

Moreover, the production of synthetic oil from tar sand takes large amounts of gas. Most of the reported increase in oil reserves since 1995 - from 1,000 Gb in 1995 to 1,265 GB in 2004 (Oil&Gas Journal, Dec. 22, 2003) - stems from the inclusion of synthetic oil from Canadian tar sand (174 Gb) in the reserve account. To produce 174 Gb of oil from tar sand could take about 5,500 billion cubic metres of gas or 80% of the present gas reserves in the USA and Canada (see section 2.2.1). Likewise, the production of 1 Gb of synthetic oil from natural gas (the Gas-to-Liquid process GTL) takes about 190 billion cubic metres of gas (see section 2.2.3). Thus, if 10% of the present global oil consumption (28 Gb/year) were

to be covered by GTL, it would take about 18% of the present global gas production (2,900 billion cubic metres).

Thus the production of NGPL and synthetic oil has a significant influence on the gas reserves available for use outside the oil industry itself. Moreover, the CO₂ emission to be assigned to the consumption of a barrel of synthetic oil is considerably higher than the emission to be assigned to a barrel of conventional oil.

Oil consumption and climate change

Presently the combustion of oil accounts for about 40% of the anthropogenic CO₂ emission caused by the combustion of fossil fuels. If in future a substantial portion of a growing oil demand is to be covered by non-conventional oil production (synthetic oil from tar sand, oil shale, natural gas (GTL), and possibly even coal) the specific CO₂ emission (kg CO₂ per kg oil combusted) to be assigned to the combustion of oil in vehicles, houses, industries, power stations, etc. will increase significantly. Also for this reason continued growth in oil consumption will render climate change mitigation policies fruitless.

The need for international regulation

The shift from growth to decline in the production of cheap conventional oil entails a host of environmental, economic, political, and technological problems to be solved within a short period of time. Just to wait and see which solutions may turn up is to wait to see the uncertain outcome of a hazardous experiment.

Instead the international community could seek to reach a fair and just agreement on the international regulation of oil demand and supply so as to prevent demand from surpassing production capacity. Such an agreement should comprise technological energy efficiency and emission standards for vehicles and other oil-consuming hardware to be implemented within a certain period of time; production and consumption quotas for each country; and realistic long-term strategies for the technological transition to the post-cheap-oil era.

Colin J. Campbell has proposed that the countries of the world should be called upon to sign a global oil depletion protocol⁴ with two requirements:

- a) Producing countries shall not produce oil in excess of their current depletion rate; namely annual production as a percentage of estimated future production. This would be no particular burden as few countries can do so anyway.*
- b) Importing countries shall reduce their imports to match the world depletion rate, currently running at about 2.2% a year.*

The consequence would be that world oil prices would remain in reasonable relationship with actual production costs. Profiteering would be avoided, as would the

⁴ Colin J. Campbell has presented the protocol proposal at several international conferences in 2003, including the Copenhagen conference 2003.

damaging consequences of massive financial transfers to the Middle East. The importing countries could manage their allocation as suited their inclination, auctioning it to the highest bidder, taxing it to cut demand, perhaps making parallel reductions in other taxes, rationing it, or finding a happy compromise.

Such an arrangement would encourage the avoidance of waste, which is now running at a monumental scale, and it would stimulate a turn to renewable energies, including nuclear energy if the safety and environmental hazards can be reduced.

The determination of the depletion rate itself calls for much transparency in reserve reporting and better technical audit.⁵

There can be no doubt that considering the national interests involved, it will be as difficult to reach international agreement on a protocol of this nature as it has been to make progress towards the ratification of the Kyoto protocol in a sufficient number of countries to put it into force. However, if the consumption and production of oil is determined by unregulated market conditions and the policies of individual states, the distorting effects of oil shortage on the global economy cannot be foreseen.

The higher the rise - the steeper the fall

Continued growth in the global supply of cheap conventional oil means that while cheap conventional oil reserves are being depleted, the world economy is becoming technologically ever more dependent on oil. Continued growth in the supply of cheap conventional oil also implies that no competitive alternatives to conventional oil are introduced on the market on a large scale - otherwise the growth in supply would cease as demand went down.

As long as supply can meet demand, the market price of crude conventional oil may remain low. The supply of conventional oil may, therefore, continue to grow until production can no longer meet demand. Thus production capacity may peak while demand is still growing. Whereupon the oil price may surge in a seller's market with no swing producers to balance supply and demand. As illustrated by scenarios presented by the United States Energy Information Agency (EIA), the peak situation may become more catastrophic the longer the peak is postponed (fig. 5.5). See section 3.3.

In short, if a growing world economy is fuelled by ever-growing supplies of cheap conventional oil, the economy will become technologically ever more dependent on cheap oil. Hence, when the peak occurs, sooner or later, the economy will be technologically unprepared for the decline in the supply of its most vital resource.

Therefore, the rule of the game must be to ensure that the demand for oil peaks before the oil production capacity peaks.

⁵ Quotation from Colin .J. Campbell: *The Meaning of Oil Depletion*. The Association for the Study of Peak Oil (ASPO), 2003.

Transportation

The global oil consumption for transportation (land, air and sea) presently accounts for 48% of the total crude oil and NGL consumption or about 13 Gb/year. In the IEA *World Energy Outlook 2002* reference scenario, consumption grows by 70% over the next 25 years, assuming a value of about 24 Gb/year in 2030 (a little less than the present total oil consumption).

In addition to the investments needed in the oil industry to achieve the growth in oil supply - estimated at \$3 trillion through to 2030 (IEA, see p. 13 above) - the cost of building and maintaining fleets of cars, trucks, aeroplanes, ships, etc. capable of consuming 24 Gb/year and the construction of the physical infrastructures needed to accommodate such fleets (roads, highways, bridges, airports, harbours, etc.) will be in the order of magnitude of \$10 trillion.

However, in the IEA reference scenario the growth in oil reserves falls below the growth in consumption. This “...implies a decline in the global proven reserves to production ratio from around 40 years at present to under 20 years in 2030” (see section 3.3).

It does seem contradictory to economic rationality to continue to make investments with long pay-back times in long-lasting infrastructures so as to facilitate a growth in oil-based means of transportation which rapidly depletes the very resource-base of these infrastructures and means of transportation.

It would seem a more rational approach to invest a growing portion of these trillions of dollars in more energy-efficient means of transportation and not-oil-based transportation infrastructures. This could reduce the growth in consumption so that the peak in consumption occurs before the peak in production. The market penetration of more energy-efficient oil-driven cars would mitigate the growth in oil consumption as would the introduction of hydrogen-fuelled fuel cell powered electric cars. But continued growth in the number of cars still requires comprehensive infrastructure investments, and the development of a hydrogen-supply infrastructure will be very costly (see section 3.4.2, 2)). Moreover, car traffic congestion in urban areas is a growing problem.

In contrast to oil-based infrastructures, the infrastructures needed for electrically powered means of transportation (trains, trams, trolley buses) will not become obsolete because of the depletion of one particular resource. Electric power can be generated from many different non-renewable and renewable resources. Also for other reasons electrically powered transportation infrastructures are preferable to fuel-based infrastructures: They are less polluting, less noisy, and faster in urban areas.

The Rapid Urban Flexible (RUF) system⁶, which combines the electric car and the electric minibus with a fast collective rail transport system, is gaining growing interest in several countries. Traffic planners in India are planning a 180 km monorail network in Calcutta, a system which may be constructed as a RUF network. Electric transportation networks of this kind could help to rehabilitate urban environments.

⁶ RUF has been developed in Denmark by Palle R. Jensen. See www.ruf.dk.

1. The Cheap-oil Era

The second half of the 20th century bears no resemblance to any earlier period in the history of the Earth. Never before did its population grow from two to six billion. Never before was it a regular experience for millions of people to watch from above the myriads of motorcars and trucks circulating on motorways around a city when their plane approached the destination of their holiday or business trip. Never before were so many new urban areas, roads, motorways and airports built. Never before did agricultural and industrial production and international trade grow exponentially to the levels of the present economy. And never before did man have the power to exhaust the fish stocks in the seas and to change the climate.

Obviously, this explosive economic growth, which in all respects has changed the world, was based on abundant supplies of cheap fossil fuels. Coal, mainly for electric power generation, oil and gas mainly for industries and for the heating of buildings, and petrol and diesel for the millions of internal combustion engines in cars, trucks, buses, air planes, tractors, ferries, cargo ships and fishing boats. Had oil not been found in abundant amounts in the 1950s and 1960s, the basic infrastructures of the industrialised societies - the physical structures and transportation networks of the cities, the industrial production networks, the mechanised agricultural production, etc. - would not have been as they are today. Also, the migration of millions of people from rural areas to the megalopolises in the third world was conditioned by oil for the transportation of food and other basic necessities to these huge, overcrowded habitats.

Although there are, naturally, limits to growth on a finite planet, the predominant economic growth theories of this singular historic era are based on the axiom that economic growth will not be constrained by limitations in the supply of the fossil fuel resources upon which the economy is based, in particular the supply of oil. It is recognised that continued growth in the global oil demand will result in accelerated depletion of the so-called conventional oil reserves, i.e. oil which can easily and cheaply be extracted from oil wells. But economists assume that the market will ensure the smooth transition to so-called non-conventional sources (oil sands and oil shale, conversion of natural gas (gas-to-liquids)) and other chemical energy carriers (natural gas, hydrogen) without major unfortunate consequences neither for the affluent societies nor for the poor. Thus, in its *World Energy Outlook 2002* the International Energy Agency (IEA) does not foresee any shortage of liquid fuels before 2030. The report states that “*Resources of conventional crude oil and NGLs are adequate to meet the projected increase in demand to 2030, although new discoveries will be needed to renew reserves. The importance of non-conventional sources of oil, such as oil sands and gas-to-liquids, is nonetheless expected to grow, especially after 2020*” (op.cit. p. 97).

However, considering the fact that our present economy in all respects depends on the physical power and mobility provided by petrol and diesel engines and that hundreds of millions of people have no immediate alternative to oil for heating their houses, it is hazardous to rely unconditionally on the validity of a continued-growth axiom for which there is no empirical evidence. In this singular historic period of transition from growth to decline in conventional oil reserves, the particular geological, economic, demographic and

political circumstances which determine the balance between demand and supply of liquid hydrocarbon fuels must be examined with scrutiny.

In its *World Energy Outlook 2002* the IEA forecasts an increase in oil demand from 26 billion barrels in 2000 to 44 billion barrels in 2030, of which only 8 % will be covered by non-conventional oil. This means that the global economy becomes increasingly dependent on continued supplies of cheap conventional oil - while at the same time the reserves of this cheap conventional oil are depleted at such a rate that a steep decline in the production is likely to occur if not years before then shortly after 2030. Under these circumstances it is questionable whether liquid fuel production from non-conventional sources can be brought on-stream quickly enough to make up for the decline in conventional oil production.

Regarding demography, wealth distribution and oil demand, the IEA assumes that a global economy in which the inequalities between the affluent minority and the poor majority are perpetuated can be sustained. Today the 1.1 billion people living in the affluent OECD countries consume 16 billion barrels of oil per year whereas the 4.9 billion living in poorer countries consume 10 billion barrels. In other words, the per capita consumption is 7 times higher in the OECD countries than in the rest of the world. In the IEA scenario, this ratio will be only modestly reduced in the coming decades, the average per capita consumption being 5.7 times higher in the OECD countries than in the rest of the World by 2030 (see section 3.1, table 3.1). Thus, as long as oil consumption is an indicator of material wealth, the assertion that there will be no oil shortage in the next decades implies that poor peoples remain poor. Should, for instance, the economy of China continue to grow so that the Chinese per capita demand for oil grows to just 50 % of the OECD level by 2030, instead of the 17 % assumed in the IEA scenario, then the additional demand in that country alone would amount to 9 billion barrels or a 20 % increase in global demand by 2030.

Another fundamental issue concerning the global economy is climate change. The rationale of the Kyoto agreement on greenhouse gas reductions is to reduce the risks of economic calamities caused by climate change. Therefore, the aim of the agreement is to initiate the transition to technologies which do not or to a much lesser extent depend on fossil fuels. However, if oil consumption continues to grow, the CO₂ emission reductions required to prevent climate change cannot be achieved, in particular because the CO₂ emission per barrel of non-conventional oil is significantly higher than the emission per barrel of conventional oil. Consequently, unless they are prepared to reduce their oil consumption, the Kyoto signatories are engaging their countries in a futile, expensive exercise. On the other hand, if they do reduce their oil consumption, the lower demand may keep the price of oil relatively low for a longer period of time. Thus significant CO₂ reductions may be attained at low or zero costs for the oil importing countries.

These immediate reflections on the depletion and replacement of oil, on global policies concerning the distribution of material wealth, and on economic costs of environmental deterioration reveal the complexities, contradictions and inconsistencies encountered in the process of technological and economic transition from the short era of cheap oil into a future where the physical power provided by oil will be too expensive to compete with other power sources - because of the oil price and because of environmental costs.

In order to comprehend in full the implications of this transition process, the following further reflections on the technological and economic characteristics of the system to be transformed may be of relevance.

1.1 The oil-world

Technologies and natural resources are complementary. Coal was needed to fuel the steam engine and the steam engine was needed to mine and transport coal. Coal and the steam engine replaced watermills, windmills, horse-drawn coaches, sail ships and human labour, thus creating the industrial infrastructures which in turn enabled man to develop the technologies needed to exploit another natural resource: crude oil. Yet, had easily accessible cheap oil not become available from the oil wells in Pennsylvania and Texas in the late 19th century, the internal combustion engine would not within a couple of decades have been developed to propel the cars, trucks, ships and aeroplanes, which are basic constituents of the present oil-based societies' technological infrastructure. As it happened, cheap oil and the internal combustion engine gave rise to an ever-growing demand for cheap oil and engines.

The oil-engine technologies themselves were needed to find and develop new oil fields which ensured that the demand they created was covered by abundant supplies of cheap oil. Also they were needed to find and develop natural gas fields. The world-wide oil prospecting, the drilling, the pumping, and the transport of oil and gas from the wells could not have taken place without the oil-engines which propelled the aeroplanes, helicopters, the on-site equipment, the trucks, and the cranes for the laying down of pipelines. Also, the construction of huge dam walls for hydropower stations in remote areas could not have been accomplished without oil-engines. Moreover, without oil-engine propelled aeroplanes the first nuclear bombs would have remained destructive only to those who made them, and without the production of nuclear warheads the development of a nuclear power industry would hardly have been economically feasible. Coal still covers 25 % of the world's primary energy supply - primarily for electric power generation - but without oil it could not be so easily mined and transported. It should also be recalled that in many towns in the US and Europe the first electric power stations were oil-powered.

Thus, the transition to oil had many more technological ramifications than the transition to coal which preceded it and laid the grounds for it. Ample power from oil-engines, which start at the push of a button, has become available at any place at any time at very low costs. It is Prometheus unbound.

World War II was the first great war in which the mobility of troops, armoury and bombs was provided almost entirely by the oil-fuelled internal combustion engine: in trucks, jeeps, armoured cars, tanks, warships and, most prominently, the fighter and bomber planes. However, while suffering from the attacks by oil-driven war machines, Europe's civilians were able to survive without oil. Agriculture was still predominantly horse-powered and the supply of food did not depend on long-distance transportation of feedstock and agricultural products. Today, half a century later, the situation is different. Without oil the entire economy will immediately come to a standstill. Even a modest

reduction in supply will make the economies of the rich countries tremble and a substantial increase in the price of oil will have a heavy impact on the economies in the rich as well as the poor countries.

The transition to the coal-steam engine era made life easier for those who enjoyed the goods of industrial production and travelled comfortably in the railway coaches and on board the steamships. However, life became less easy for those who mined the coal, those who shovelled it into the furnaces, and those who carried it on their backs into the stores. With oil its all different. It flows by itself - or assisted by pressure generated by oil-engines - from the wells through pipelines to refineries or tankers which, propelled by oil-engines, transport it to any destination. It is easily distributed and easily stored. It is readily available as petrol, diesel and fuel-oil everywhere.

1.2 Towards the end of the windfall energy economy

In the short era of cheap oil, all the techniques and technological infrastructures upon which the functioning of present societies is based have been designed so as to balance investment and maintenance costs against low costs of oil consumption. When oil prices rise, this balance shifts in favour of other techniques and infrastructures, meaning that not just some but practically all techniques and infrastructures must be renewed and restructured.

At the beginning of the 19th century no one could foresee that the coal-based industrialisation was to bring about the technologies needed to utilise the then unknown oil resources. And in the second half of the century, when the Diesel and the Otto engine were invented, no one knew how much oil could be found to run these engines. It could have been much less than the approximately 1.7 trillion barrels found so far. And this planet's total endowment of recoverable conventional oil and natural gas liquids could have been much in excess of the 2.3 trillion barrels which it seems likely to obtain at relatively low costs. As it is, the world's conventional oil endowment is a windfall energy asset which is hastily being used - without specific plans for the replacement of oil-based technologies being developed.

Because of low recovery costs, the conventional oil resources have been depleted at a much faster rate than necessary to provide the goods and services obtained. Had the oil price been substantially higher, more energy efficient technologies would have been developed and less wasteful local production would have had competitive advantages against goods produced far away. Cars would have done more kilometres per litre and buildings would have been designed to sustain a comfortable indoor climate at lower oil or gas expenses; railways would have been modernised instead of closed down; energy-saving recycling would have played a bigger role in industries; and less feedstock and food would have travelled thousands of miles before being consumed.

Thus, in the short era of cheap oil, all the techniques and technological infrastructures upon which the functioning of present societies is based have been designed so as to balance investment and maintenance costs against low costs of oil consumption. When oil prices rise, this balance shifts in favour of other techniques and infrastructures, meaning

that not just some but practically all techniques and infrastructures must be renewed and restructured. The question is whether this transition will take place smoothly as oil prices rise slowly, allowing the market economy to accommodate to the new conditions. Or whether more abrupt oil price upswings will cause a self-perpetuating economic recession which will inhibit technological renewal and restructuring.

No economic theory can give a credible answer to this question, simply because there is no empirical evidence upon which the assessment of the validity of economic theorems concerning this singular era in the history of economic development can be based. Therefore, attempts to answer the question must be based on specific analyses of the actual circumstances, based on the best available data on conventional oil reserves; present and potential future production capacities in the different oil provinces; and alternative demand forecasts, resulting from different assumptions as to future technological, social and economic development.

In his book *Undiscovered Petroleum and Mineral Resources. Assessment and Controversy*⁷, from 1997, Lawrence J. Drew of the United States Geological Survey (USGS, Virginia) describes the controversy which erupted in the early 1960's between the geophysicist and social development analyst M. King Hubbert and the oil geologist and mineral resources analyst V.E. McKelvey, both geologists at the US Geological Survey. Hubbert and McKelvey disagreed not only on US resource data but also on assessment methods (see section 5.2).

Hubbert's approach was based on a general life-cycle concept of the exploitation of finite natural resources within a certain geographical region: First discovery; then growing production until a peak is reached; and subsequently irrevocable decline. The cycle appears as a bell-shaped curve, a Hubbert-curve, covering an area equal to the reserves ultimately recovered (see fig. 5.2, section 5.2). Based on recordings of past discovery and production and his estimate that ultimate reserves in the US amount to 200 Gb, Hubbert predicted in 1956 that US oil production would peak in 1970. Which indeed it did.

Instead, McKelvey advocated a volumetric method for the assessment of undiscovered resources based on geological data for the provinces in which there is a potential to find oil or other minerals. Using this method, he estimated ultimate US conventional oil reserves at 590 Gb - almost three times larger than Hubbert's assessment.

However, both were concerned about the prospects for the future. In his article *Mineral Resource Estimates and Public Policy*⁸ (1971) McKelvey expresses his expectations that technological progress will make much larger resources available just as technological progress in other fields has substantially increased efficiency. But he also observes that:

"...many others do not share these views, and it seems likely that soon there will be a demand for a confrontation with the full-speed-ahead [economic growth] philosophy that will have to be answered by a deep review of resource adequacy.

⁷ Lawrence J. Drew (USGS, Virginia): *Undiscovered Petroleum and Mineral Resources. Assessment and Controversy*. Plenum Press, 1997.

⁸ V.E. McKelvey: *Mineral Resource Estimates and Public Policy*. American Scientist, vol. 60, 1971.

I myself think that such a review is necessary, simply because the stakes have become so high. Our own population, to say nothing of the world's, is already too large to exist without industrialized, high energy- and mineral-consuming agriculture, transportation, and manufacturing.

If our supply of critical materials is enough to meet our needs for only a few decades, a mere tapering off in the rate of increase of their use, or even a modest cutback, would stretch out the supplies for only a trivial period. If resource adequacy cannot be assured into the far-distant future, a major reorientation of our philosophy, goals, and way of life will be necessary.

And if we do need to revert to a low resource-consuming economy, we will have to begin the process as quickly as possible to avoid chaos and catastrophe.”

And in 1976 M. King Hubbert (1903-1989) concluded his paper *Exponential Growth as a Transient Phenomenon in Human History*⁹ with the following observations:

“It appears therefore that one of the foremost problems confronting humanity today is how to make the transition from the precarious state that we are now in to this optimum future state by a least catastrophic progression. Our principal impediments at present are neither lack of energy or material resources nor of essential physical and biological knowledge. Our principal constraints are cultural. During the last two centuries we have known nothing but exponential growth and in parallel we have evolved what amounts to an exponential-growth culture, a culture so heavily dependent upon the continuance of exponential growth for its stability that it is incapable of reckoning with problems of nongrowth.

Since the problems confronting us are not intrinsically insoluble, it behooves us, while there is yet time, to begin a serious examination of the nature of our cultural constraints and of the cultural adjustments necessary to permit us to deal effectively with the problems rapidly arising. Provided this can be done before unmanageable crises arise, there is promise that we could be on the threshold of achieving one of the greatest intellectual and cultural advances in human history.”

Twelve years later, in 1988, Dr. Hubbert said in an interview:

“Our window of opportunity is slowly closing ... at the same time, it probably requires a spiral of adversity. In other words, things have to get worse before they can get better. The most important thing is to get a clear picture of the situation we're in, and the outlook for the future - exhaustion of oil and gas, that kind of thing - and an appraisal of where we are and what the time scale is. And the time scale is not centuries, it is decades.”

Since then exponential growth has continued for another 15 years and the world economy has year by year become more and more dependent on oil and natural gas. At the same time, experienced oil and gas geologists have presented quite a ‘clear picture of the situation we're in’ and assessed ‘what the time scale is’. On the basis of increasingly detailed mappings of the Earth's geological formations and meticulous recordings of the

⁹ M. King Hubbert: *Exponential Growth as a Transient Phenomenon in Human History*, 1974. www.hubbertpeak.com/hubbert/wwf1976. Presented before the World Wildlife Fund, Fourth International Congress, The Fragile Earth, San Fransisco, 1976.

findings of new oil and gas fields and the development in reserves, they have recorded the history of the exploration and discovery of oil and gas reserves and the subsequent depletion of these reserves. Naturally, these recordings do not provide accurate data on the development in reserves and production - the ultimate yield from any particular oil field can only be assessed to a certain degree of accuracy and in many cases production potential forecasts depend on assumptions regarding future investments in oil rigs, recovery techniques, pipelines, refineries, etc. However, they constitute the only empirical evidence for the appraisal of the prospects for the future.

Others, whom Peter J. McCabe of the US Geological Survey refer to as cornucopians¹⁰, repudiate the relevance of this pragmatic appraisal of the actual circumstances, which they refer to as Neo-Malthusian. They argue that reserves are not fixed but determined by

“the mix of knowledge, technology and investment that sustains the process of exploration and production sufficiently to meet short- and medium-term demand expectations. Reserves depend on the interaction of this process, government policies and, finally, the price people are willing to pay for oil products. Since we cannot know future technology or prices, we cannot quantify future reserves. This should not be a concern, since it is these processes that are important. Ultimately, as [Morris A.] Adelman commented, ‘oil resources are unknown, unknowable and unimportant’

“¹¹

The cornucopians subscribe to the frequently cited saying that “the stone age did not end because of lack of stones. Likewise, the oil age will not end because of lack of oil”. History shows that technologies come and go. As conventional oil becomes too expensive or more convenient fuels and technologies become available, it will be replaced by non-conventional oil, other liquid fuels, electric power or whatever new technologies may turn up. However, few would miss the difference between on the one hand the shift, taking place over hundreds of years, from axes and spearheads made of stone to more effective tools and weapons made out of bronze, and, on the other, the transition to be accomplished over a few decades of an eight billion people world economy based on cheap-oil-technologies to an economy based on other not yet developed technologies.

Yet, the stone age offers an analogy to modern times: Flintstone well suited for tool-making was mined from underground veins. As the miners did not know the extension of the veins of relatively easily mined good quality flintstone, one could imagine that they kept producing the stones at low costs in increasing quantities until one day they suddenly, without warning, came to the end of the veins. Unprepared, because their economists foresaw continued growth in the cheap-flintstone economy, the tribe faced a sudden economic recession as it took time and big investments to open other less easily accessible veins. Likewise, cheap conventional oil may cover a rising demand for another decade or two before a sudden decline in the production occurs.

¹⁰ Peter J. McCabe: *Energy Resources - Cornucopia or Empty Barrel ?* AAPG Bulletin V.82, No.11 (November 1998)

¹¹ John Mitchell et al.: *The New Economy of Oil. Impacts on Business, Geopolitics and Society.* Earthscan Publications Ltd, London (2001). Op.cit. p. 46-47.

As Peter J. McCabe states:

“... in the long run the supply of fossil fuel is finite, and prices inevitably will rise unless alternate energy sources substitute for fossil energy supplies; however, there appears to be little reason to suspect that long-term price trends will rise significantly over the next few decades.”¹⁰

It is questionable whether under these circumstances the transition to an economy based on other technologies and fuels will begin early enough to be accomplished smoothly. Growing consumption of cheap oil means increased use of oil-based technologies so that while the conventional reserves are being depleted the economy becomes increasingly dependent on supplies from these reserves.

1.3 The aging resource base

In an article in *World Energy*, 2002, Harry J. Longwell, Director and Executive Vice President of ExxonMobil Corporation, assesses the need for additional oil and gas production:

“The catch is that while demand increases, existing production declines. To put a number on it, we expect that by 2010 about half the daily volume needed to meet projected demand is not on production today - and that’s the challenge facing producers.

This means industry may need to add some 80 million oil-equivalent barrels per day to production by 2010 to meet projected demand. The cost of doing so could reach \$ 1 trillion, or about \$ 100 billion a year. That’s substantially more than the industry is spending today.”¹²

Several experienced oil geologists have expressed their concern that considering the evidence provided by reserve additions during the past decade, even such large investments may not bring about the increase in production capacity needed to meet demand. Also Matthew R. Simmons¹³ has drawn attention to reserve assessment and forecast uncertainties because of a general lack of data on the largest oilfields. In a recent paper¹⁴ he presents a study of oil production in the world’s “giant oilfields”, i.e. fields producing more than 100,000 barrels a day.

¹² Harry J. Longwell: *The Future of the Oil and Gas Industry: Past Approaches, New Challenges*, World Energy, Vol. 5, No. 3, 2002.

www.worldenergysource.com/articles/pdf/longwell_WE_v5n3.pdf

¹³ Matthew R. Simmons is Chairman and Executive Officer of Simmons&Company International, a specialised energy investment banking firm with offices in the USA and Europe. The firm enjoys a leading role as one of the largest energy investment banking groups in the world.

¹⁴ Matthew R. Simmons: *The World’s Giant Oil Fields*. Hubbert Center Newsletter #2002/1. M. King Hubbert Center, Colorado School of Mines. January 2002.

Matthew R. Simmons finds that

“The world’s 120 largest oilfields produce close to 33 million barrels a day, almost 50% of the world’s crude oil supply. The 62 smallest of these “giant fields” account for 12% of the world’s daily oil supply. In contrast, the fourteen largest account for over 20%. The average age of these 14 largest fields is 43.5 years.

Thirty-six giant oilfields that were all discovered more than 40 years ago still collectively produce close to 16 million barrels a day. In contrast, twelve giant oilfields found in the past decade together now produce less than one tenth of this, or 1.5 million barrels a day, 2% of the world’s supply. The world clearly has bifurcated oil supply in terms of both age of our important oilfields and the number of key fields propping up our production base. Another 20 to 25 new giant fields have been discovered but are still being developed. However, no new field whose development program is now underway is projected to have daily production in excess of 250,000 barrels. In sharp contrast, the world’s 19 largest “old giant fields” still produce on average more than 500,000 barrels per day, in spite of an average age of almost 70 years !”

and notes that

“Sooner or later, most of the world’s current population of giant oil fields will all be in decline. If the world’s future supply needs to result from new fields that are getting progressively smaller, it could require more than 3,000 new oilfields to be found and developed over the next ten years, compared to slightly more than over 400 named new oilfields that were discovered in the past decade.

Until there is far better transparency on the world’s giant oilfield production data and decline rates, the world can only guess at its future oil supply. There is an urgent need for better data on all these key fields.”

And he issues a serious warning:

“Proper OPEC oil data would likely shatter the current myth that plentiful quantities of cheap oil are abundant throughout the Middle East.”

These analyses are in contrast to the International Energy Agency’s oil production forecasts. On the basis of the US Geological Survey’s probabilistic conventional oil reserve assessments (see section 4.3.3), the IEA assumes that investments in exploration and development of about \$75 billion/year will ensure continued exponential growth in conventional oil production to a level of 40 Gb/year in 2030 as against 27 Gb/year in 2000.¹⁵ This means that more than 1,000 Gb will be produced in the period 2000 - 2030, i.e. 40% more than the total global oil production in the 20th century. It also means that the world economy in 2030 will to a much larger extent than today be technologically dependent on oil. Therefore, to avoid serious economic problems, oil production must be sustained at a level of at least 40 Gb/year for a considerable period of time after 2030, assuming that a continued increase in demand, partly to satisfy needs in the developing countries, will be covered mainly by non-conventional oil.

For a further discussion of the IEA projections, see section 3.1.

¹⁵ *World Energy Outlook 2002*, International Energy Agency, 2002, p. 96-97, and *World Energy Investment Outlook, 2003*. International Energy Agency, November 2003, p. 103.

2. Oil - the Unique Liquid Fuel

Hydrocarbon molecules are chains of carbon atoms each of which has one or more hydrogen atoms attached to it. The simplest (CH₄, methane) have only one carbon atom with four hydrogen atoms attached. Crude oil and the liquid oil product made from it in refineries consist mainly of hydrocarbons with 5 - 15 carbon atoms. 'Crude oil ' covers a spectrum of different liquids as the density, viscosity, sulphur content, and the specific heat of combustion varies from one oilfield to another.

No other fuel produced in nature or found in the crust of this planet is so easy to recover, transport and store as the crude oil found in oilfields and the oil products made from it: fuel oil, diesel, petrol, aircraft fuel, etc. Oil has the highest energy intensity (MJ per litre) and can easily be pumped from oil wells into pipelines, tankers, refineries, trucks, and storage tanks at buildings and airports and in vehicles, ships and airplanes. Therefore, coal-fired steam engines in steamships and railway engines were during the first 60 years of the 20th century replaced by diesel engines. Coal-fired boilers in industries and buildings were replaced by oil-fired boilers. In agriculture, horses were replaced by tractors and on the roads horse carriages were replaced by cars and trucks. And in many countries electric power generation became mainly oil-based.

However,

“Very likely, future oil production is going to be more valuable as a petrochemical feedstock than it is for fuel.”

Kenneth S. Deffeyes: *Hubbert's Peak. The Impending World Oil Shortage*. Princeton University Press, 2001. op.cit. p. 127

When oil prices went up in 1973 and 1980, many oil-fired power stations and some industries shifted back to coal, but oil remains the fuel upon which transportation technologies and agricultural production technologies are based and millions of industries and hundreds of millions of buildings still depend on oil for production and heating. Thus basic technologies and infrastructures depend on this unique liquid fuel. And its replacement by other energy sources and energy carriers entails the shift to other not yet developed technologies.

Today circa 86% of the oil used is produced from oil wells, including off-shore and deepwater wells. Circa 10% is condensates from natural gas production and circa 4% is extracted from tar sands and extra heavy oil deposits. In future, oil of fossil origin may also be synthesised from natural gas (gas to liquids, GTL) and coal. As a supplement, bio-diesel can be extracted from oil seeds and alcohol fermented from carbohydrate-rich crops (sugar canes, grain, etc.).

For technological and economic reasons, a distinction is made between *conventional* and *non-conventional* fossil oil¹⁶. Conventional oil is the cheaply recoverable oil produced in the well-known (conventional) manner from liquid, fossil reservoirs (oil wells) and oil recovered as natural gas liquids (NGL)¹⁷. So far conventional fossil oil has covered the bulk of the demand. The production of non-conventional fossil oil - i.e. heavy and extra heavy oil, oil from tar sands, oil derived from oil shale, and synthetic oil made on the basis of coal or natural gas - requires other techniques and is more costly in terms of money, energy consumption in the production process, and environmental impacts. Oil production from biomass, which is also non-conventional, requires yet other techniques and has other economic costs and environmental implications.

Therefore, the coming peak and the subsequent decline in conventional oil production marks a shift in the technology and economy of energy supply, even if non-conventional fossil oil production is allowed to make up for the decline in conventional oil production. However, as long as conventional oil can be produced in sufficient amounts at low costs it will continue to dominate the market, thus delaying the development of facilities for the production of non-conventional fossil oil as well as oil from biomass.

2.1 Conventional oil

2.1.1 Liquid fossil oil deposits

Popular, non-technical and well-illustrated explanations of the geology of the formation of oil and gas fields and the methods applied in the exploration of these fields are given in:
C.J. Campbell: *The Coming Oil Crisis*. Multi-Science Publishing Company & Petroconsultants S.A., 1997.
Kenneth S. Deffeyes: *Hubbert's Peak. The Impending Oil Shortage*. Princeton University Press, 2001.
Norman J. Hyne: *Nontechnical Guide to Petroleum Geology, Exploration, Drilling and Production*. Pennwell Books, 1995.

The source of fossil oil and natural gas is organic matter (from algae, plants and animals) mixed with sand and mud in sediments deposited in river beds and estuaries and on sea bottoms within a short epoch of the Earth's history:

¹⁶ Colin J. Campbell now prefers the term *regular oil* instead of *conventional oil*, see section 5.3, fig. 5.4.

¹⁷ The boundary between conventional and non-conventional fossil oil is drawn differently by different authors. In Colin J. Campbell: *The Coming Oil Crisis* (1997), oil in very hostile environment (polar and deepwater), oil in very small accumulations, and oil from enhanced recovery is included in non-conventional oil. In *Reserven, Ressourcen und Verfügbarkeit von Energierohstoffen 2002*, Bundesanstalt für Geowissenschaften und Rohstoffe, Geozentrum Hannover, conventional oil is defined as oil with a density of 0.8-0.934 g/cm³, including also natural gas liquids.

These sedimentary source rocks are very rare organic rich clays deposited under exceptional conditions of extreme global warming. The bulk of the world's oil comes from just two short epochs 90 and 145 million years ago when the algal growth proliferated. The organic material was preserved only in special geotectonic settings, mainly in rifts of stagnant water low in oxygen. These rifts were later filled up by sands and clays, washed in by rivers and currents. (Colin J. Campbell)

The source rocks were in the course of time buried under other sediments of eroded rocks, chalk deposits, salt horsts, lava, and rock displaced by tectonic movements. As a source rock is covered deeper and deeper, its temperature increases. When it is covered to a depth of more than 2,000 metres and less than 5,500 metres its temperature is in the interval 65° C to 150° C - the so-called *oil window* - where the formation of oil can take place. At lower depths the temperature is too low. At the higher temperatures at greater depths the organic matter was transformed into natural gas.

The chemical processes in which oil is formed are complex and slow. As oil drops are formed they slowly migrate upwards because their density is lighter than the water filling the pores of the source rock. If gas is formed in deeper layers of the source rock, it likewise migrates upwards. Thus most of the oil and gas eventually escapes or is decomposed at the surface of overlying water-saturated rocks. Only at places where the oil and/or gas migrating upwards was trapped under a dome or in a fault trap of impenetrable rock did it form an oil or gas field (fig. 2.1).

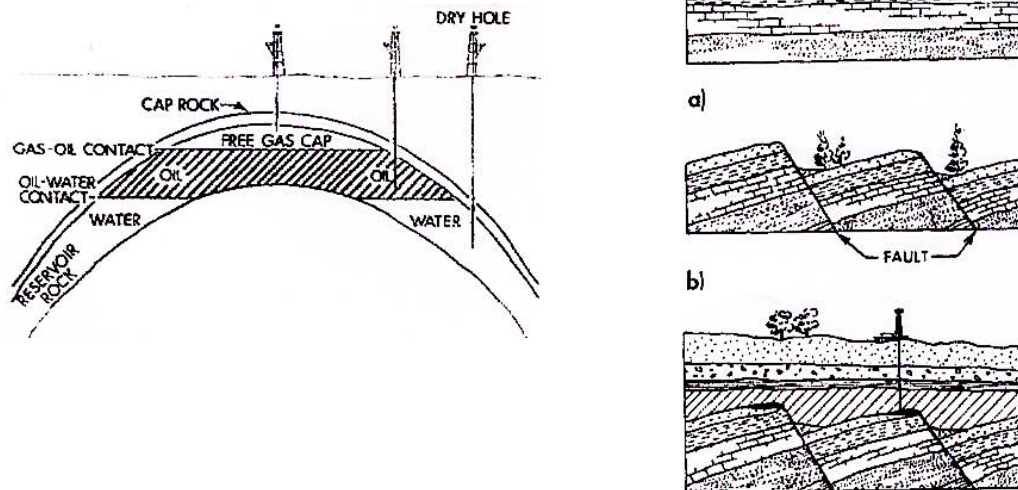


Figure 2.1 Oil and gas trap in a dome or anticline (left). Formation of a tilted fault block trap (right). Norman J. Hyne: *Nontechnical Guide to Petroleum Geology, Exploration, Drilling and Production*. PenWell Publishing Company, Oklahoma 1995.

This knowledge about the particular geological circumstances under which oil and gas was formed and deposited in fields in the crust of the Earth enables geologists to point out geological formations where there is a chance of finding oil or gas. By means of 3-dimensional seismic mapping they can locate areas where source rocks are found at the proper depth under cap rocks which may have prevented the oil and/or gas to escape.

Walter Ziegler, Oil geologist and explorer, on the search for oil and gas basins:

“Each successful basin has its source system, by which I mean not only the rock itself, but the timing of generation and migration. It is a thermokinetic process whereby the rocks give up their oil and gas on critical exposure to heat. In addition, the preservation of the oil and gas formed is vitally important: all oilfields leak over time. So we had to search for structures that had been charged in the relatively recent geological past.”

“It was my good fortune to live during an epoch when petroleum geology became a science, subject to rigorous scientific discipline. It is well capable of answering questions about the availability of hydrocarbon resources on which the modern economy depends. Our studies have confirmed beyond any doubt that the globe has a decidedly final potential for oil exploration. The implications are colossal.”

Excerpts from C.J. Campbell: *The Coming Oil Crisis*, p. 25-26.

By 2002, 74 380 new field wildcats had been drilled in provinces outside the USA and Canada. The average success ratio was 30%, increasing to 40% over the last 10 years because of improved discovery methods and techniques. Thus, more than 20 000 fields or field extensions were discovered, bringing about an estimated 1,700 Gb of recoverable reserves.¹⁸

However, the reserves found per 10 000 wildcats drilled have been steadily declining from about 600 Gb found by drilling the first 10 000 wildcats to about 100 Gb found by drilling the last 10 000. Moreover, the success rates, measured as the findings per 1 000 wildcats, are very different for the different regions. In the Middle East, more than 400 Gb were found by the drilling of about 3 000 wildcats. In Europe, by contrast, it took the drilling about 20 000 wildcats to find less than 100 Gb. In the US a large number of wildcats were drilled by prospectors in the early oilrush, everyone hoping to find an oilfield in his backyard. Hence, the success rate appears to be very low: more than 300 000 wildcats were drilled to find about 200 Gb.

These statistics are reflected in fig. 4.3. The biggest discoveries were made in the period from 1930 to 1980. Since then, average annual discovery has been declining in spite of improved discovery methods and techniques.

¹⁸ Jean Laherrère: *Future of Oil Supplies*. Presentation at the Seminar Centre of Energy Conservation, Zürich, May 7th 2003.

2.1.2 Natural gas liquids (NGL)

When natural gas from fields with a high temperature and pressure is cooled and decompressed, some hydrocarbons contained in the gas condensate at the wellhead into oil of a composition resembling low-octane petrol. Other liquids (Natural Gas Plant Liquids (NGPL)) are produced in the gas processing plants. Natural Gas Liquids (NGL) comprise condensate and NGPL. They can be mixed with crude oil and thus contribute to the conventional oil production. (In the US, one quarter of the oil production is NGPL¹⁹). They can, however, also be cracked into gas and thus increase the gas production. Thus, the NGL contribution to the conventional oil production depends partly on the production of natural gas and partly on the ratios of oil prices to the gas prices at the different production sites.

2.2 Non-conventional fossil oil

2.2.1 Heavy oil, extra heavy oil, and tar sand

“Saudi Arabia’s oil is so easily reached that it takes little more than a pipe stuck in the ground to set it gushing out. To get Shell’s tar sand project [in Alberta, Canada] off the ground, by contrast, required well over 10,000 employees and a huge industrial operation

Shell’s project is already an incredibly complex operation at its current output of below 200,000 barrels a day. But that is a drop in the bucket compared with Saudi Arabia’s daily production of about 8 million barrels.”

Quotation from the article *There’s oil in them tar sands*,
The Economist June 28th-July 4th 2003.

Oil which has migrated over long distances from the source rock to shallow depths has been exposed to bacteria. The bacteria have removed the light molecular components and thus degraded the lighter oil into heavier substances: heavy oil, bitumen, tar or asphalt. Heavy oil and extra heavy oil is by some authors defined as oil with a density of 0.934 - 1.0 g/cm³ and > 1.0 g/cm³ respectively. Heavy oil can be pumped to the surface while extra heavy oil, which is heavier than water, requires special recovery techniques: steam injection or the injection of a solvent which liquefies the oil. Bitumen is oil with a viscosity higher than 10,000 mPa.

Tar sand is a sandstone which contains very heavy oil (bitumen). Tar sand deposits near the surface are mined with huge 400-tonne payload shovels (4-metre tall tyres) and dumped into a hot-water mixer where the sand (84 - 92 % by volume) sinks to the bottom. From deeper deposits in-situ mining methods are applied. The bitumen is extracted by the injection of steam into vertical and horizontal multi-directional wells to create a fluid mix of hot water and bitumen. After recovery, the bitumen is treated with steam to crack it into crude oil.

¹⁹ Jean Laherrère, personal communication.

Large extra heavy oil and tar sand deposits are found in Alberta, Canada, and in the Orinoco Belt in Venezuela.

The production of synthetic oil from extra heavy oil and tar sand has a significant influence on the oil and/or gas reserves available for use outside the oil industry itself. In addition to electricity consumption and oil consumption in shovels and trucks and in refinery processes, it takes about 35 cubic metres of gas to produce 1 barrel of bitumen from tar sand by the in-situ steam injection recovery method (below 50 metres of overburden) and to hydrogenate the bitumen into crude oil. Somewhat less where surface mining is feasible. As about 80% of the oil will have to be recovered by the in-situ method, the production of 174 Gb will take about 5,500 billion cubic metres of gas. This corresponds to most of the present gas reserves in the USA and Canada (7,000 billion cubic metres). Some of this gas can be replaced by oil, but then the oil reserves must be reduced correspondingly.²⁰

Thus, for tar sand the energy used in the mining and the subsequent refinery processes equals 25 - 30% of the energy gained in the oil produced. Moreover, large amounts of water is used in the mining process and large amounts of hazardous waste has to be deposited.

2.2.2 Oil Shale

Oil shales are oil source rocks (clay, fine grained-sand, calcite, etc.) containing organic material - mainly from algae - which were not buried deep enough for the temperature be high enough for the conversion into oil or gas to take place. At the lower temperatures the organic material was converted into kerogen²¹. When heated to about 350° C, kerogen breaks down into recoverable gaseous and liquid substances resembling petroleum. Oil shale rock is mined in open pits, then crushed and heated. The volume of the waste products is bigger than the volume of the oil shale mined and the production processes require substantial amounts of energy. Large deposits of oil shale are found in the United States, Brazil, Russia, and Australia.

2.2.3 Synthetic oil from coal and natural gas

Oil can be synthesised from coal and from natural gas. Based on carbon from coal²², synthetic oil was produced in Germany during World War II and in South Africa during

²⁰ John Busby: Oilsands Production. ASPO Newsletter No. 37, December 2004.

www.asponews.org and

Rohstoffwirtschaftliche Länderstudien, Heft XXVIII: Reserven, Ressourcen und Verfügbarkeit von Energierohstoffen

Bundesanstalt für Geowissenschaften und Rohstoffe, Hannover. 2003

²¹ Kerogen is a complex mixture of large molecules containing mainly hydrogen and carbon but also nitrogen, oxygen, and sulphur.

²² In the so-called Bergius process, developed in Germany during World War I, oil is formed in a process where coal and hydrogen react at a temperature of about 500° C and a pressure of several hundred bar. Per tonne of coal, about 160 litres of petrol, 190 litres of diesel, and 130 litres of fuel oil can be produced.

the trade boycott. Presently, the possibility of producing oil from natural gas (gas to liquid, GTL) at remote sites with no gas-pipeline connections (such as Eastern Siberia) is being considered. However, the energy consumption in the synthesising processes is very high. In the GTL process about 45% of the gas used is used to fuel the process itself²³. Thus, to gain 1 GJ in the form of oil about 1.54 GJ in the form of gas is used.

2.3 Oil from biomass

Oil from biomass can supplement fossil oil. In Denmark, about 1,000 litres (34 GJ) of bio-diesel can be produced from the rape grown on one hectare. Thus, to cover Denmark's present annual oil consumption for road transport (160 PJ/year) by bio-diesel, crops suitable for bio-diesel production must be grown on an area of about 47,000 square kilometres or about 1.6 times Denmark's cultivated area. Hence, oil consumption must be substantially reduced if oil from biomass is to cover a major portion of the oil consumption.

Alcohol (ethanol) can be produced from crops such as sugar cane, grain, and elephant grass. Depending on the crop, the soil and the climate, the yield amounts to 60 - 100 GJ per hectare, i.e. 2 - 3 times more than the bio-diesel yield. Alcohol can be added to petrol and thus substitute oil. Also, engines can be designed to run entirely on alcohol.

2.4 The terms 'Reserves' and 'Resources'

A coal deposit covers a wide area having huge 'resources' but only at places with thick seams or ease of access do the 'resources' become 'reserves' to be mined. It is largely a matter of concentration. Thus, if prices rise or costs fall then lower concentrations become viable 'reserves'. It is the same with mineral mining.

Oil is different because it is a liquid which collected in certain places. It is either there in profitable abundance or it is not there at all. The oil-water contact in the reservoir is abrupt. So it is not a matter of concentration. The notion of huge 'resources' being converted to 'reserves' as needed is deeply embedded in economic thinking, but it does not apply to conventional oil. But, of course, the tar sands behave like coal.

Colin J. Campbell

In the oil business terminology, the term *reserves* denotes proven or proven+probable quantities of oil which are deemed economically profitable to produce at the expected future oil prices, implying that the oil can be recovered by means of known technologies. In addition to reserves, *resources* comprise quantities known or assumed to exist but, for technical or economic reasons, not presently recoverable, and additional amounts deemed likely to be found in promising geological structures. Thus, when new recovery techniques are developed, new oil fields are found or the oil price goes up, some resource quantities

²³International Energy Agency, *World Energy Outlook 2002*. p. 112

may become reserves.²⁴ The term *undiscovered resources* refers to quantities which are supposed to exist and which may possibly become reserves.

Clearly, reserve and - especially - resource assessments are uncertain. Even at the time when production from a new oil field begins, it is uncertain how much oil will be recovered before the field is finally closed. Estimated reserves in big oil fields tend to grow when more production wells are drilled. For small fields the tendency is the opposite²⁵.

If reported reserve assessments were based strictly on geological surveys, field pressures, viscosities, well flows, and other physical data, the uncertainties would be due to incomplete geological and physical data. However, for various political and financial reasons governments and oil companies may be obliged to or tend to publish reserve volumes which are bigger or smaller than the volumes found by an objective assessment based on the best available geological and physical data²⁶. Moreover, some countries omit to publish regular revisions of reserves. For such reasons, public domain data are less reliable than the data kept in the industry's own databases.

Because most of the present reserves are in thoroughly explored fields discovered more than 20 years ago, there are reasons to assume that the assessment of present reserves, based on the industry's data, are quite accurate.

For a particular oil province or region, the *ultimate conventional oil reserve* is the total potential production from the opening of the first well until the last well is finally closed. In other words, the ultimate reserve equals:

$$\text{past production} + \text{present reserves} + \text{future reserve additions}$$

The ultimate reserve for a province or region equals the area under the curve showing annual production as a function of time (the integral of the production function). The production peak is the maximum value on this curve. Knowing past production year by year, the curve can be drawn up to the present time. Any extrapolation of the curve into the future must cover an area equal to the ultimate reserve minus past production. This restriction is an important necessary condition to be met by any prediction of the peak value and the time when the peak is likely to occur. Therefore, the ultimate reserve is an essential parameter in any production peak assessment.

Apart from reserve growth due to enhanced recovery techniques, conventional resources become reserves only when new fields are found and developed. In contrast, to turn non-conventional oil resources such as tar sand and oil shale oil into reserves, no new deposits need to be found. The known deposits, constituting the resources, are very large.

²⁴ In this section *conventional oil* should be interpreted as oil from oil fields, excluding natural gas liquids (NGL).

²⁵ Colin J. Campbell: Presentation at the Public Hearing on Oil Supply, Copenhagen October 30 2002

²⁶ In the US, oil companies must comply with the SEC (Securities and Exchange Commission) rules, requiring that only proved reserves are reported. In the rest of the world, reported reserves normally comprise proven+probable reserves.

To turn them into reserves, only government acceptance of the environmental impacts caused by the production and large investments in mining and processing plants are required. However, when the more easily accessible layers have been mined, the production costs in terms of money and energy of producing a barrel of oil from these resources grow steeply.

3. Demand and Supply

At a Global Harvard Business School Conference in Berlin 1999: “*A World Without Walls: The Challenges of a Global Economy*”, James Wolfenson, head of the World Bank, in a keynote opening address focused on “...the acute need for the affluent population of the globe to never forget the less fortunate parts of the world. As he eloquently stated, there are only 1.2 billion people now living in the highly developed countries of the world. 250 million are in the United States, 500 million living in the expanded Europe and 350 million in Canada, Mexico and the Pacific Rim countries of the OECD. For this group, affluence is not only on the rise, it has never been better.

But Mr. Wolfenson then warned of the risks inherent by overlooking the 4.8 billion people living in the less developed or transition economies of the world. An astonishing 2 billion of these people live on less than \$2 a day ! One billion live on less than \$1 a day ! Mr. Wolfenson warned that it is not reasonable to even think that we can maintain this great gap between the well to do and the impoverished for another 50 years.”

“In three decades [1970-2000] the rich/poor gap has widened from 35/65 to 20/80.”

Quotations from: *Revisiting The Limits to Growth: Could The Club of Rome Have Been Correct, After All?* An Energy White Paper by Matthew R. Simmons, October 2000.

www.sco-intl.com/domino/html/research.nsf

No countries plan for a decline in global oil production in the next decades. On the contrary, in its annual *World Energy Outlook* reports the International Energy Agency (IEA) presents scenarios for the future development of the global economy based on continued growth in fossil fuel consumption in general and oil consumption in particular. In these scenarios the per capita energy consumption remains much higher in the OECD countries than in the developing countries (9 times higher in 2000, 6 times higher in 2030) and the OECD countries become more and more dependent on oil and gas imports from the Middle East, Africa, and the FSU.

In a recent report *World energy, technology and climate policy outlook 2030 (WETO)* the EU Commission presents similar scenarios, based on macroeconomic modelling under certain assumptions regarding growth in population, economic growth, future costs of different energy technologies, etc.

The IEA scenarios as well as the WETO scenarios are essentially business-as-usual scenarios with no resource restrictions and no restrictions regarding climate change mitigation. However, comparing the scenarios, it appears that the different modelling methods and hypotheses applied result in considerable differences in future demand and supply in the different regions of the world.

As mentioned in the last section of this chapter, curbing inefficient, unnecessary, wasteful or extravagant use of oil is the only way to attain substantial reductions in conventional oil demand which does not involve high economic costs, environmental hazards, and the depletion of other resources.

3.1 The IEA World Energy Outlook 2002 and World Energy Investment Outlook 2003

The IEA begins the Executive Summary of its *World Energy Outlook 2002* (WEO 2002) with the following statement:

“This edition of the World Energy Outlook, which sets out the IEA’s latest energy projections to 2030, depicts a future in which energy use continues to grow inexorably, fossil fuels continue to dominate the energy mix and developing countries fast approach OECD countries as the largest consumers of commercial energy. The Earth’s energy resources are undoubtedly adequate to meet rising demand for at least the next three decades. But the projections in this Outlook raise serious concerns about the security of energy supplies, investment in energy infrastructure, the threat of environmental damage caused by energy production and use and the unequal access of the world’s population to modern energy.

Governments will have to take strenuous action in many areas of energy use and supply if these concerns are to be met. The core projections presented here are derived from a Reference Scenario that takes into account only those government policies and measures that had been adopted by mid-2002. A separate Alternative Policy Scenario assesses the impact of a range of new energy and environmental policies that OECD countries are considering adopting as well as a faster deployment of new energy technologies. Both scenarios confirm the extent of the policy challenges facing governments around the world.” (op. cit. WEO 2002, p. 25)

From table 3.1 and 3.2 and map 3.1 and 3.2 below it appears that there are good reasons why the IEA forecasts raise serious concerns and induce the strong appeal to governments:

- C The disproportionate difference between the per capita energy consumption in the affluent countries and the developing countries is only modestly reduced from 8.6:1 to 6.3:1 over the next three decades. Such a scenario should cause serious concerns. The WEO 2000 predicted a higher growth rate and higher total consumption in the developing countries and a lower growth rate and lower total consumption in the OECD countries than the WEO 2002, see table 3.1.²⁷
- C The global CO₂ emission rate continues to grow, from 22.6 billion tonnes in 2000 to 38.2 billion tonnes in 2030. Should this in actual fact happen, the Kyoto Protocol efforts are futile.
- C In 2030, 77 % of the world’s population, living in oil-importing countries, will depend on the Middle East for 72 % of their oil imports (see table 3.2). Moreover, export of natural gas - mostly liquified - from the Middle East to Europe, the USA and the Far East will surge from 23 billion cubic metres in 2000 to 365 cubic metres in 2030 and gas exports from the FSU to Europe will grow from 112 billion cubic metres in 2000 to 244

²⁷ Regarding oil demand, the report says: *“This years WEO [2002] projects a lower growth rate in world oil demand over the next twenty years than was anticipated in WEO 2000. This difference is mainly due to downward revisions to historical data and slower growth rate than expected.”* (op.cit. WEO 2002, p. 91)

in 2030. In IEA's somewhat euphemistical words: "*These developments will push supply security back to the top of the energy policy agenda*" (op. cit. WEO 2002, p. 57).

- C Considerable investments²⁸ - most in the Middle East and other developing countries - must be made to increase global oil production from 27 Gb in 2000 to 44 Gb in 2030. The IEA observes that "*Mobilising this investment in a timely fashion will require the lowering of regulatory and market barriers*" (op. cit. WEO 2002, p. 57). Considering the extent to which OECD countries, China, India and other newly industrialised countries depend on oil imports from the countries where these investments are to be made (see table 3.2), it seems likely, however, that the importing countries will not entirely rely on market forces to ensure that investments are made in time.
- C It is a priority for the oil importing countries to keep the oil price low. The IEA expects that an increase in the production of conventional oil from 26.7 Gb in 2000 to 40.2 in 2030 can be obtained at an oil price well below 30 \$/barrel (see table 3.3), assuming that the investments required will be profitable at these prices. If the investments required are made and do bring about the foreseen increase in conventional oil production, then conventional oil production may peak before or shortly after 2030 and thereupon decline steeply. If the conventional oil prices are kept low until then, it is questionable whether sufficient investments in non-conventional oil capacity and alternative liquid fuel sources will be made in time to avoid a sudden oil shortage.
- C In the alternative scenario mentioned in the Executive Summary (see quotation above), fossil fuel saving policies (energy savings; renewable energy sources; energy savings in the transport sector; etc.) under consideration in the OECD countries are taken into account. These savings reduce the CO₂ emission from the OECD countries by 16 % and the global emission by 7 % by 2030 (see table 3.1). OECD oil demand in 2030 is reduced by 8 %. Thus, the fossil fuel saving policies presently considered will not significantly change the global energy and environment outlook.

Thus the IEA's serious concerns about

- C unequal access of the world's population to modern energy
- C environmental damage caused by energy consumption
- C security of energy supply
- C investments in energy infrastructure

and its appeal to governments to take strenuous action are well reasoned.

Regarding total demand, supply, and reserves, the WEO 2002 projections are shown in tables 3.4 and 3.5. Total demand and production of conventional oil is projected to grow exponentially (average growth rate 1.33%) from 27 Gb (74 Mb/day) in 2000 to 40 Gb (110 Mb/day) in 2030. Thus, total production from 2000 to 2030 amounts to 1,000 Gb or 40% more than the total production in the 20th century.

²⁸ The IEA report *World Energy Investment Outlook, 2003*, November 2003, says:
"*A little over \$3 trillion will be needed in the oil sector through to 2030. Investment needs will average \$103 billion per year, but will increase steadily through the period as demand increases. Annual capital spending will rise from \$92 billion in the current decade to \$114 billion in the last decade of the projection period.*" (op.cit. p. 103)

The WEO 2002 says that “Resources of conventional oil and NGLs are adequate to meet the projected increase in demand to 2030, although new discoveries will be needed to renew reserves. The importance of non-conventional sources of oil, such as oil sands and gas-to-liquids, is nonetheless expected to grow, especially after 2020.” (op. cit. p.97). The World Energy Investment Outlook 2003 (WEIO 2003) quantifies the new discoveries needed: “Some 470 billion barrels of [conventional] oil will have to be found in the next three decades, to replace reserves in existing producing fields and to meet growth in demand” (op.cit. p. 107)

Thus, by 2030 50% of the undiscovered resources, namely 470 Gb or 16 Gb/year on average, should be discovered and added to the 959 Gb of reserves remaining in 2000 (see table 3.4), giving a reserve base of 1,430 Gb. However, WEO 2002 does not show how production can be balanced against demand in the next decades under these assumptions.

Assume that new findings and reserve additions by means of enhanced recovery techniques add new reserves to the reserve base at a rate of 17 Gb/year until 2010, thereupon declining slowly to 13 Gb/year in 2030 (see fig. 3.1) - even though annual reserve additions currently average only about 10 Gb/year. Assume also that production from these new reserves come on-stream as needed to balance production and demand as production from existing fields declines while non-conventional oil production increases as shown in fig. 3.1 and table 3.5. Then, if demand grows as assumed in WEO 2002, production may be balanced against demand as shown in fig. 3.1. However, the reserve data used in fig. 3.1 (table 3.4) are from 1996. Therefore, the production peak should occur earlier than 2025.

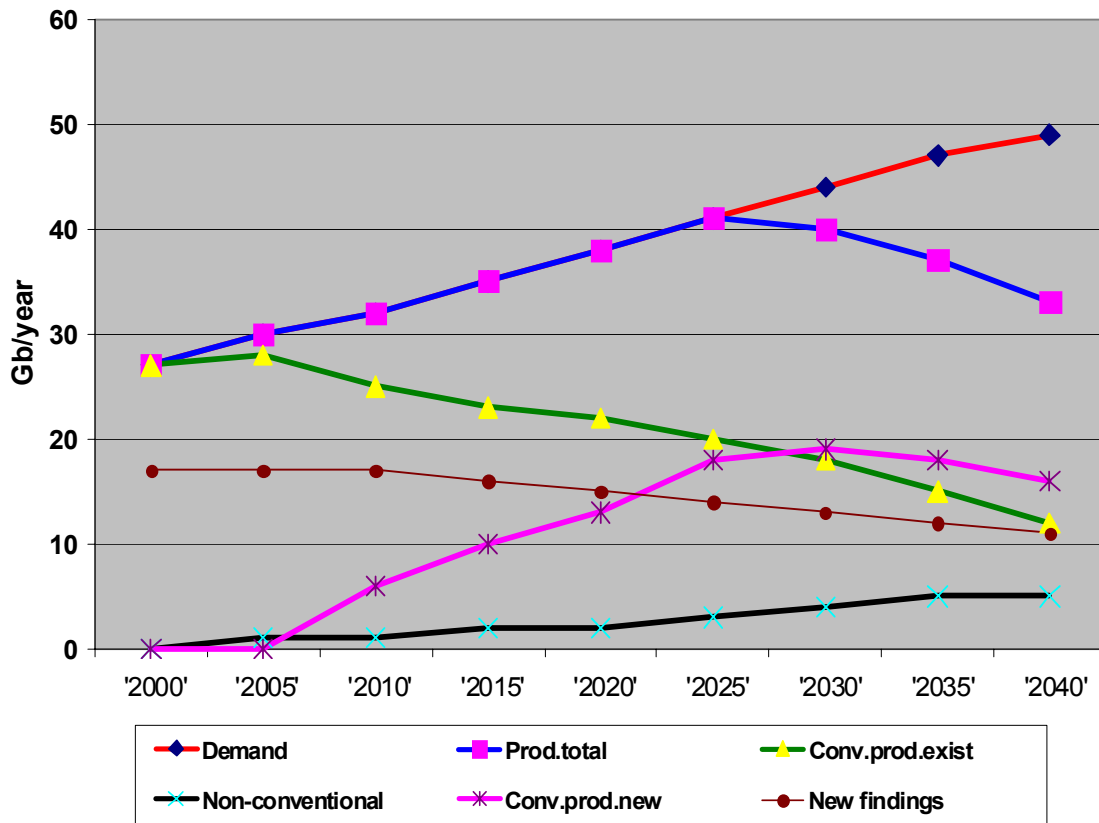


Figure 3.1 Balancing production against demand using WEO 2002 data (see below).

The scenario shown in fig. 3.1 is computed by the OILPROSPECTS program, described in Chapter 5 section 5.5 below.

Scenario data:

The scenario is based on the following production and reserve data, aggregated from table 3.4 and 3.5:

	Conventional oil			Production Mb/day in 2000
	Produced Gb	Reserves Gb	Yet-to-find Gb	
Middle.East	181	512	269	20.4
FSU	101	157	140	7.8
Latin.America	70	61	102	8.0
Africa	40	60	62	5.1
North.America	171	32	83	7.7
Europe	23	29	30	5.9
Asia	39	35	27	3.3
Other	91	73	220	15.7
Total	716	959	933	74.0

In this table, 'conventional oil' includes crude oil and NLGs irrespective of place of origin (i.e. deep water and polar is included).

Non-conventional oil production (see table 3.5)

	Mb/day					
	2000	2005	2010	2020	2030	2075
	1.1	2.0	3.0	6.0	10.0	10.0

Total conventional production to date (2000) = 716 Gb
 Existing conventional reserves (2000) = 959 Gb
 Undiscovered conventional reserves (2000) = 933 Gb
 Ultimate conventional reserves = 2608 Gb

Non-conventional oil produced before 2000 = 85 Gb
 Non-conventional oil produced 2000-2075 = 347 Gb

Total production of liquids until 2075 = 3040 Gb

In fig. 3.1 'New findings' include reserve additions from new fields and reserve additions obtained by enhanced recovery techniques. The area below the 'Conv.prod.exist' curve (production from existing conventional reserves), extended to infinity, equals existing conventional reserves (959 Gb). Likewise, the area below the 'Conv.prod.new' curve (production from new conventional reserves) equals the area below the 'New findings' curve (933 Gb). For each of the regions shown in the data table above, production from existing reserves (2000) is assumed to peak when 60% of the region's ultimate reserves have been produced.

The figure shows that even if 470 Gb are added to the conventional oil reserve base before 2030 ('New findings'), as assumed in WEO 2002, it may only be possible to balance production against demand until 2025. This is because the production from new reserves ('Conv.prod.new') needed to satisfy demand surpasses 'New findings' from 2022 onwards. Thus, as the 'New' reserves are depleted production from these reserves begins to decline. The increase in non-conventional production assumed in WEO 2002 is not sufficient to offset this decline.

Should production from existing reserves decline less steeply, the industry may defer its investments in the discovery and development of new reserves. In that case, total production may still peak by 2025 but then decline more steeply for some years.

Table 3.1

IEA, World Energy Outlook 2000/2002, Global Development Scenarios 2000 - 2030					
Population, billions		2000	2010	2020	2030
Developing countries		4.9	5.6	6.3	7.0
Transition economies		0.35	0.34	0.33	0.33
OECD countries		1.1	1.15	1.2	1.22
Total		6.4	7.1	7.8	8.6
Energy consumption per capita, kg oil equivalent/year					
Reference scenario		2000	2010	2020	2030
Developing countries	WEO 2000	660	805	980	
	WEO 2002	560	670	800	925
Transition economies	WEO 2000	2990	3505	4365	
	WEO 2002	2925	3590	4160	4580
OECD countries	WEO 2000	4500	4800	4900	
	WEO 2002	4800	5200	5500	5800
Oil consumption per capita, kg oil/year					
Reference scenario		2000	2010	2020	2030
Developing countries	WEO 2000	285	345	410	
	WEO 2002	220	263	310	355
Transition economies	WEO 2000	690	835	1100	
	WEO 2002	635	765	920	1055
OECD countries	WEO 2000	1820	1930	1975	
	WEO 2002	1970	2080	2170	2275
CO₂ emission, billion tonnes/year					
Reference scenario WEO 2002		2000	2010	2020	2030
Developing countries		7.8	10.6	14.0	18.1
Transition economies		2.5	3.0	3.4	3.6
Other		12.4	13.8	15.3	16.4
Total		22.6	27.5	32.7	38.2
<i>The Alternative Policy Scenario (Energy savings in the OECD) Total</i>		22.6	27.1	31.3	35.6

Table 3.2

IEA, World Energy Outlook 2002. Oil demand and production 2030				
Conventional oil: 40.2 Gb Non-conventional oil: 3.6 Gb				
Gb	Demand	Production	Net import	Net export
OECD, US and Canada	10.0	4.2	5.8	
OECD, Europe	6.0	0.9	5.1	
OECD, Pacific	3.8	0.2	3.6	
China	4.4	0.8	3.6	
India	2.0	0.1	1.9	
Other East and South Asia	4.1	0.9	3.2	
Importing countries, total	30.3	7.0	23.3	
Russia	1.6	3.5		1.9
Other transition economies	1.0	2.0		1.0
Mexico and Latin America	4.7	5.5		0.8
Africa	2.0	5.0		3.0
Middle East	2.8	19.5		16.7
Exporting countries, total	12.0	35.5		23.3
Processing gains		1.1		
Bunkers and stock change	1.5			
Total	43.7	43.7		

Table 3.3

IEA, World Energy Outlook 2002. Oil prices (in year 2000 dollars)				
	2000	2010	2020	2030
IEA crude oil imports, \$/barrel	28	21	25	29

Oil Reserves, Resources and Production by Country

Rank	Country	Remaining reserves (billion barrels)	Undiscovered resources (billion barrels)	Total production to date (billion barrels)	2001 production (mb/d)
1	Saudi Arabia	221	136	73	8.5
2	Russia	137	115	97	7.0
3	Iraq	78	51	22	2.4
4	Iran	76	67	34	3.8
5	UAE	59	10	16	2.5
6	Kuwait	55	4	26	1.8
7	United States	32	83	171	7.7
8	Venezuela	30	24	46	3.0
9	Libya	25	9	14	1.4
10	China	25	17	24	3.3
11	Mexico	22	23	22	3.6
12	Nigeria	20	43	16	2.2
13	Kazakhstan	20	25	4	0.8
14	Norway	16	23	9	3.4
15	Algeria	15	10	10	1.5
16	Qatar	15	5	5	0.8
17	United Kingdom	13	7	14	2.5
18	Indonesia	10	10	15	1.4
19	Brazil	9	55	2	1.4
20	Neutral zone*	8	0	5	0.6
	Others	73	220	91	16.2
Total		959	939	718	75.8

* Kuwait/Saudi Arabia.

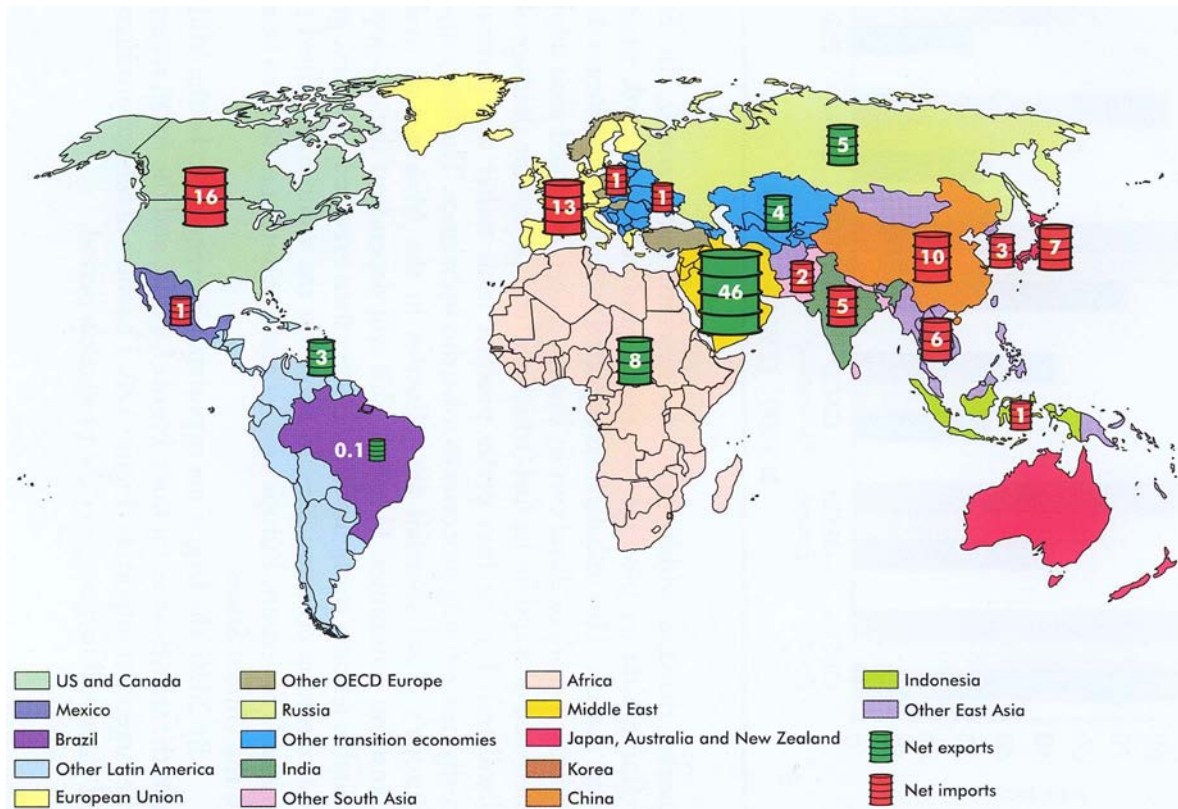
Note: Estimates include crude oil and NGLs; reserves are effective 1/1/96; resources, effective 1/1/2000, are mean estimates. See footnote 2 for definitions of reserves and resources.

Sources: United States Geological Survey (2000); IEA databases.

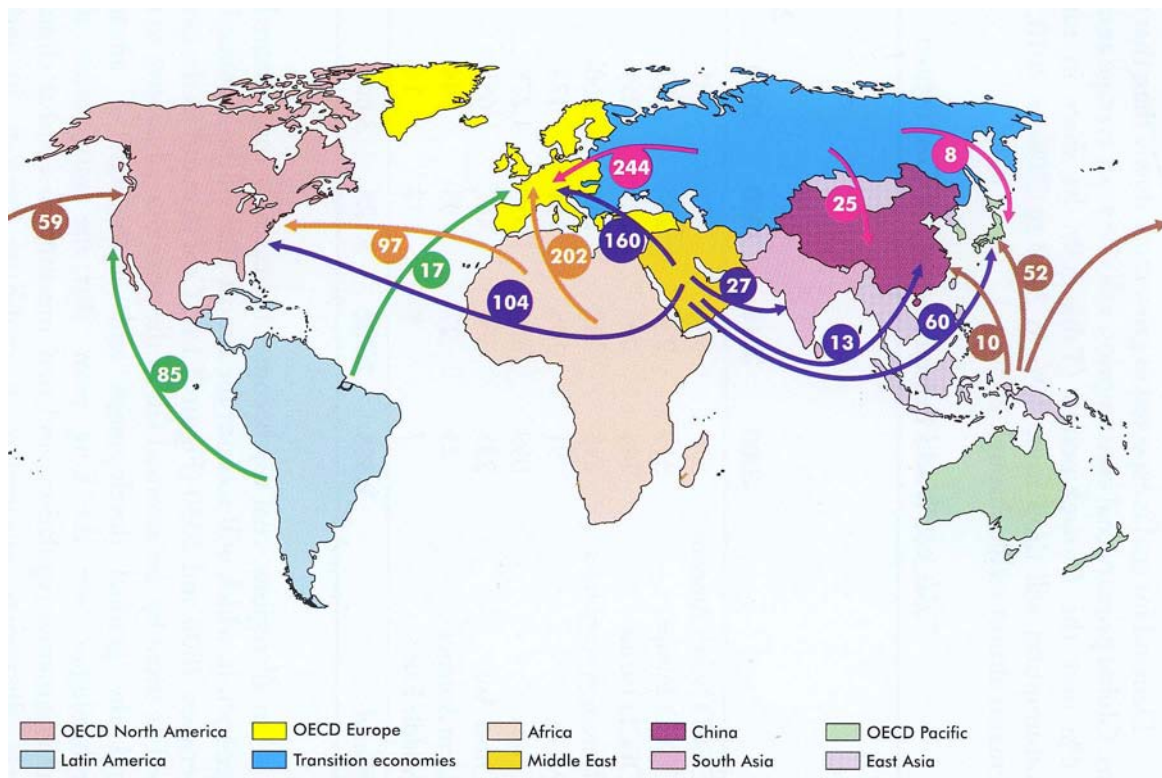
Table 3.4 Data from IEA *World Energy Outlook 2002*, p. 97

IEA World Energy Outlook 2002. Supply for forecast				
Gb/year	2000	2010	2020	2030
Conventional oil, OPEC	10.5	13.1	18.3	23.7
Conventional oil, non-OPEC	16.4	18.3	17.6	16.5
Non-conventional oil	0.4	1.1	2.0	3.6
Total supply	27.4	32.4	37.9	43.8

Table 3.5 Summarised data from IEA *World Energy Outlook 2002*, p. 96



Map 3.1. Projected net inter-regional oil trade, 2030 (million barrels/day). IEA, World Energy Outlook 2002.



Map 3.2. Projected net inter-regional gas trade flows, 2030 (billion cubic metres/year). IEA, World Energy Outlook 2002.

3.2 World energy, technology and climate policy outlook 2030 (WETO)

“World energy consumption is projected to increase at about 1.8%/year between 2000 and 2030. This growth is driven by economic and population growth (of respectively 3.1% and 1%/year on average), whose impacts are nevertheless moderated by a decrease in energy intensity of 1.2%/year, due to the combined effects of structural changes in the economy, of technological progress and of energy price increases.”

“Industrialised countries experience a slowdown in their energy demand growth (0.4%/year in the EU). Conversely, the energy demand of developing countries is growing rapidly. In 2030, some 55% of the world energy demand is expected to come from developing countries, compared to 40% now.”

“The world energy system will continue to be dominated by fossil fuels.....Oil remains the main source of energy...”

“....world CO₂ emissions are expected to grow rapidly....”

Excerpts from WETO, Key conclusions.

The WETO report from the European Commission²⁹ presents a reference scenario and a carbon abatement scenario for the development until 2030. These scenarios resemble the scenarios presented in the IEA *World Energy Outlook 2002*. In the WETO reference scenario the growth in global fossil fuel consumption is a little higher than in the IEA reference scenario and the growth in coal consumption is bigger while the growth in oil consumption is smaller. Therefore, global CO₂ emission grows by 100%, from 22.6 billion tonnes in 2000 to 44.5 billion tonnes in 2030 in the WETO reference scenario, as against a 70% growth in the IEA reference scenario. In the carbon abatement scenario, the growth in CO₂ emission equals the growth in the IEA alternative policy scenario, namely 58%.

There are, however, major differences in regional demand and supply between the WETO and the IEA scenarios. The growth in energy consumption in Europe and North America in the WETO scenario is only about half the growth in the IEA scenario so that the per capita consumption in these regions is almost unchanged while the per capita consumption in the developing countries in 2030 is about 30% higher than in the IEA scenario.

There are also major differences regarding regional energy supplies between the WETO and the IEA scenarios, see for instance table 3.6. While the IEA foresees that North

²⁹ WETO: *World energy, technology and climate policy outlook 2030*. European Commission, Directorate-General for Research. Community Research, 2003. (EUR 20366). <http://europa.eu.int/comm/research/>

America in 2030 will import 345 billion m3 from the Middle East, Africa, South America and Indonesia (see Map 3.2 above), this region will import only 73 billion m3 from Latin America and 1 billion m3 from Africa and the Middle East in the WETO scenario.

Differences of this magnitude indicate that different world sectoral models for the computation of global demand and production give significantly different results, in these cases partly because of different assumptions as to the values of exogenous parameters. Considering the long-term planning and investments needed to facilitate the global gas trade shown in Map 3.2 and the implications for the global economy, it is important for many countries to assess which of the two scenarios is most likely to materialize.

Likewise, the future oil trade depicted in Map 3.1 should be compared with the trade occurring in the WETO scenarios. However, the WETO report does not give figures for oil trade between regions.

Gas demand and supply, North America	Demand	Demand	Production	Import	Import %
	2000	2030			
WETO	662	940	866	74	8
IEA	788	1305	960	345	26

Table 3.6 Gas demand and supply (billion m3) in North America in the WETO and the IEA reference scenarios. Gas to be shipped between the continents in the form of Liquefied Natural Gas (LNG).

WETO, table 5.2, p. 93.

IEA WEO 2002, tables 3.7 and 3.8.

(Corresponding figures for oil are not found in the WETO report)

3.3 *The higher the rise the steeper the fall*

Implicitly, the IEA *World Energy Investment Outlook 2003* (WEIO 2003) indicates that continued growth in oil consumption will lead to a most unfortunate situation for the world economy. The report says that even if new findings through to 2030 amount to some 470 Gb, a continued consumption growth of 1.6% p.a. “...implies a decline in the global proven reserves to production ratio from around 40 years at present to under 20 years in 2030”³⁰ (p. 107-108). This means that in such a scenario the consumption rate grows by 63% from the present 27 Gb/year to about 44 Gb/year in 2030, while remaining reserves are being depleted. When the R/P ratio is as low as 20 years, a steep decline in production will be imminent. At that time the world economy will be much more dependent on oil than it is today and it will be technologically unprepared for the steep decline in supply:

It will take about one billion motorcars, and hundreds of thousands of tractors, aeroplanes, motor yachts, oil boilers, etc.etc. to consume 44 Gb/year in 2030.

At a decline rate in oil supply corresponding to an R/P ratio of 20 years there will be little time available for the replacement of all these piston engines and turbo engines and all the technological infrastructures upon which they depend (from oil wells to pipelines, tankers, refineries, and filling stations) and which depend on them (urban infrastructures, regional and international transportation of persons and goods along roads and motorways and through airports and harbours) by something else.

And the enormous new investments needed to accomplish a transition to other infrastructures and technologies will have to be made at a time of economic recession because of a steeply surging oil price. Indeed a grim outlook.

WEIO 2003 vividly describes the investments to be made in the coming years in order to reach such an unfortunate peak - or rather a cliff - in 2030 or shortly thereafter:

“In total, more than 200 mb/d of new production capacity will have to be added during the next three decades. [The present capacity is about 75 mb/d.] This will be required mainly to replace progressive declines in production capacity from wells already in production or that come onstream during the projection period, as well as to meet demand growth. Replacement capacity of 175 mb/d will be more than five times larger than the 33 mb/d of capacity additions required to meet demand growth. Of this replacement capacity, 37 mb/d will be needed simply to maintain capacity related to the increase in demand over the projection period. The rest will be needed to maintain current capacity.”

IEA, *World Energy Investment Outlook 2003*
Op.cit. p. 109-110

Should the oil industry be reluctant to make these investments or should the geological reality not allow for such a steep increase in production capacity, then the peak will occur earlier at a lower consumption level. This would probably be less unfortunate for mankind and its environment.

³⁰In 2003 reserves were 1040 Gb (Oil&Gas Journal, excluding Canadian tar sand) and production about 27 Gb/year, giving a reserves to production ratio of R/P= 1040/27 years = 38 years.

3.4 Options for the reduction of the demand for conventional oil

The objective of a rational energy policy strategy must be to ensure that the demand for conventional oil peaks before the peak in conventional oil production occurs.

The least-cost solution is to reduce inefficient, unnecessary, wasteful or extravagant use of oil.

Other options are an upswing in the production of non-conventional fossil oil and oil from biomass and the switching to other fuels and other energy sources. However - any of these options have their limitations because of limited resources, economic costs, or environmental hazards.

In the 20th century exponential economic growth to an unprecedented level of material wealth which took place in industrialised, capitalistic countries. This growth was based on transportation technologies, construction technologies, and agricultural production technologies whose proliferation depended on access to cheap oil³¹ in abundant amounts. Therefore, economic growth has been strongly correlated with growth in the consumption of oil, and it still is.

Had the large but limited conventional oil reserves been used with forethought as a precious, non-renewable endowment to mankind, consumption would have been much smaller and the time allowed for the transition to other energy sources would have been much longer. However, the way the market economy works, the consumption of a cheap commodity, be it oil or fresh water for drinking or irrigation, is practically unrestricted until the sources of cheap supplies begin to dry out. When this happens for conventional oil, the transition to other energy sources and technologies will be costly because it involves not only the development of other more expensive energy sources but also the development and implementation of more energy-efficient technologies and infrastructures so as to reduce the amounts of energy needed.

Clearly, a reduction in the demand for *conventional* oil or at least in the demand growth rate can be achieved only by

C reducing oil demand, and/or

C increasing the production of non-conventional fossil oil and oil from biomass.

³¹ From the end of World War II until 1973 the price of crude oil declined slightly, averaging approximately 10 USD/barrel. After the OPEC price hikes in 1973 and 1980, it has since 1985 fluctuated between 26 and 13 USD/barrel, averaging approximately 17 USD/barrel. At a crude oil price of 25 USD/barrel, the total costs of refined oil products consumed in the OECD countries amount to only about 2% of the present total GDP in these countries.

3.4.1 Oil demand determinants

Oil demand is determined by

- C *Quantitative factors*: The number of oil-engines and oil boilers in use (in cars, buses, trucks, tractors, ships, aeroplanes, power stations, boiler stations and individual boilers, etc.)
- C *Technological efficiencies*, measured as average specific oil consumption (litres per kilometre) for vehicles, ships and aeroplanes, and the efficiencies (MJ power or heat per MJ oil consumed) of power stations and boilers.
- C *Behavioural consumption factors*: The average usage (kilometres per year) of vehicles, ships and aeroplanes, and the consumption of power and heat (GJ per year) produced in oil-fired power stations and boilers.

Assuming that technological efficiencies are not worsening but rather improving, an increase in oil consumption means

- *growth in quantitative factors*: people and companies invest in additional oil-fuelled machinery, and/or
- *increases in behavioural consumption factors*: people and goods travel longer distances and consume more power and heat.

For national and local governments it means additional investments in infrastructures needed to facilitate the increased use of oil-fuelled machinery: roads, parking lots, bridges, airports, etc. Moreover, increased oil consumption requires additional investments in tankers, pipelines, and refineries.

Thus, increased oil consumption means widespread investments in oil-based machinery and infrastructures which make the economy more and more technologically dependent on oil. In view of an impending peak in conventional oil production this is a dangerous road to follow. Because conventional oil is likely to remain the cheaper fuel alternative until the peak occurs and the decline in production sets in, market incentives will hardly correct the course of technological development and consumer preferences so as to ensure the smooth transition to new technologies. In the absence of goal-directed energy policy measures, the development and marketing of other energy sources and technologies which can substitute oil and oil-based technologies may be postponed, leaving our societies unprepared for the decline in conventional oil production.

The objective of a rational energy policy strategy must be to avoid this danger, i.e. to ensure that the demand for conventional oil peaks before the peak in conventional oil production occurs. In a market economy, such a strategy implies the introduction of economic incentives, regulatory measures, and public information campaigns aimed at reducing the demand for oil and, to the extent that it is deemed environmentally acceptable, to induce the industry to develop the production of non-conventional oil.

3.4.2 Ways and means to restrain the demand for conventional oil

Ways and means to restrain the demand for conventional oil can be divided into three main categories:

1) *Reduction of inefficient, unnecessary, wasteful or extravagant use of oil by*

- improving technological efficiencies.
- reducing behavioural consumption factors.

Public awareness of the need to curb demand could create political consensus on the gradual introduction of economic incentives and regulatory measures which partly substitute taxation of consumption for taxation of income. If over a period of time heavy taxes were levied on cars doing less than 20 kilometres per litre of petrol in 2010, 30 kilometres per litre in 2020, and/or heavier taxes were levied on oil and other energy consumption, oil consumption in the affluent countries could be substantially reduced at zero social costs and without any noteworthy losses of comfort. Moreover, environmental benefits of reduced emissions of CO₂ and air polluting gases could be gained at zero costs for the consumer (see section 6.1.1).

2) *Reduction of the demand for oil by the replacement of oil-based technologies by technologies based on other fuels or electricity.*

Oil-based technologies can be replaced by other technologies. However, because no other fuel is so easy to transport and store and because oil-engines are cheap as compared to other energy converters, the substitutes are much more costly.

Mechanical shaft power from oil-fuelled internal combustion engines can be replaced by electric power from fuel cells, batteries, or power lines. Vehicles driven by fuel cells fuelled with hydrogen³², natural gas or methanol (synthesised from natural gas) are being developed by the automobile industry. Cars powered by batteries or by batteries in combination with internal combustion engines or fuel cells (hybrid propulsion units) are also being developed. Large fuel cells can also replace internal combustion engines in ships. However, as long as oil is cheap and fuel cells and batteries expensive, consumers and industries have little incentive to replace oil-fuelled combustion engines by the new electrochemical energy converters. Moreover, technological infrastructures for the production and distribution of hydrogen must be in place before hydrogen-fuelled vehicles can replace a significant number of oil-fuelled vehicles. Hence, a concerted, long-term investment strategy is a precondition for a shift to hydrogen-fuelled vehicles.

Natural gas

Where natural gas can be made available, gas can be substituted for oil in oil-fired power stations, heating stations, industries, and individual boilers. To reduce fuel consumption for low-temperature heating, heat from boilers can be replaced by heat from the cooling circuits in power generating units (i.e. cogeneration in steam turbine and gas engine power plants or fuel cell plants). Moreover, compressed natural gas in voluminous storage tanks can replace oil in vehicles driven by ordinary piston engines

³² Hydrogen from electrolytic converters, powered from the electric grid, or from natural gas, biomass, or waste. See also the section *Nuclear power*, below.

and natural gas can be converted to methanol or hydrogen for fuel cells replacing oil-engines.

However, substantial reductions in oil demand by the substitution of natural gas for oil require large investments in gas pipelines and LNG tankers for the transportation of gas from the major fields in the Middle East, North Africa, and Siberia to the major consumers in the United States, Europe, and the Far East (see Map 3.2). Because increased gas consumption shortens the time until the production of natural gas peaks, these investments only serve to postpone the development of sustainable solutions one or two decades and the payback time for these investments may be relatively short.

Coal

At the cost of increased CO₂ emission, coal can be substituted for oil in power stations and some industries. However, as oil consumption in power stations account for less than 10% of the world's oil consumption and the transport of coal to many of these stations will be costly, the reduction in oil consumption attainable by substituting coal for oil is limited.

Nuclear power

Electricity from nuclear power stations can replace any other energy supply. However, in the foreseeable future nuclear power can in practise only provide a modest reduction in oil demand.

Oil consumption in vehicles can be replaced by hydrogen produced in electrolytic converters by electric power from nuclear power stations. Assume, for instance,

- that hydrogen-fuelled fuel cells in vehicles can obtain an efficiency (kilometres per MJ of fuel) twice the average efficiency of petrol and diesel engines and
- that the world's oil consumption for transport were to be reduced by 30% of the present consumption by the replacement of petrol and diesel engines by such fuel cells

Then the construction of about 550 nuclear power stations each of a capacity of 1000 MW would be needed.

Were 30% of the present oil consumption in industrial boilers and households also to be replaced by electric power from nuclear power stations, using efficient electric heat pumps for low-temperature heating, about 250 nuclear power stations of 1000 MW would be needed.

If also 30% of the oil consumption in oil-fired power stations were to be replaced by nuclear power generation, about 150 nuclear power stations of 1000 MW would be needed.

In total, about 950 nuclear power stations of 1000 MW would be needed to substitute nuclear power for 30% of the present oil consumption, using efficient technologies for the utilisation of the electric power generated in these plants. The total additional capacity of 950 GW to be commissioned corresponds to 270% of the existing nuclear capacity of 360 GW worldwide.

In its *World Energy Outlook 2002*, the International Energy Agency assumes a growth in oil demand of 1.6% per year until 2030. Were this growth to be avoided by the substitution of nuclear power for oil, new nuclear power stations of 1000 MW would have to be commissioned at a rate of one station per week in the coming years, increasing to one station every 5 days in 2030.

Renewable energy sources

Sustainable substitutes for oil are electric power from wind turbines, wave and tidal turbines, photovoltaic panels, and thermal solar power plants and hydrogen produced by power from these sources. However, to facilitate the more than marginal substitution of renewable energy sources for fossil fuels, the technological infrastructures of local, regional and national energy systems have to be reconstructed.

In contrast to the existing fossil fuel-based energy systems, in which the regulation of power and heat generation on an hourly, diurnal, annual basis can be easily handled, energy systems in which these fluctuating energy sources play a major role must have energy storage facilities and advanced regulation systems to balance the production of and the demand for electric power and heat at all times. Moreover, hydrogen should be produced at rates determined by storage capacities and demand.

The construction of such integrated energy systems (integration of the generation of electric power and heat and the production of hydrogen) requires long-term planning which transcends the boundaries between fuel markets, electricity markets and heat markets and also international boundaries.

3) *The substitution of non-conventional fossil oil and oil from biomass for conventional oil*

“Because of oil price fluctuations and terrorist threats, the issue of energy security is back on the agenda with renewed focus on non-conventional resources (NCO) , says Robert Priddle, executive director of the International Energy Agency.”

“Priddle said that it is important to evaluate whether NCO can meet the environmental and cost challenges of development.”

“Fatih Birol, IEA’s chief economist and head of its economic analysis division, said that development of NCO reserves could be crucial to meeting supply needs over the longer term. IEA forecasts over the next 30 years are based on the assumption that countries would not radically change current energy policies. That means that oil will remain the dominant energy source and meet about 40% of world energy needs, Birol said.”

Quotations from the article:

IEA Chief: Worldwide energy security favors non-conventional oil.
Oil & Gas Journal/Dec. 9, 2002.

As long as the demand for oil remains high, only the increased production of non-conventional fossil oil can make up for a decline in the production of conventional oil, apart from limited contributions from sustainable production of oil from biomass (see section 2.3). The economic costs of non-conventional oil production from the more easily accessible sediment rocks may not be prohibitive and apart from the development of mining facilities and refineries and the laying out of new pipelines, the shift to non-conventional fossil oil has no technological implications. However, if the price of conventional oil remains low until the production peaks, so that conventional oil remains the most competitive alternative, it is questionable whether a sufficient non-conventional

production capacity will be in place in time to make up for the decline in conventional oil production.

In any case, the environmental impacts of non-conventional oil production will call for production restrictions. The local and regional impacts of the water consumption in the recovery processes and the amounts of hazardous waste produced call for national regulations. Moreover, the CO₂ emission caused by the use of fossil fuels in the production processes, be it oil from tar sand or oil shale or synthetic oil, calls for international regulations.

In contrast to non-conventional fossil oil, oil and alcohol from biomass can be produced and combusted in a closed carbon-cycle, i.e. with no net CO₂ emission, provided that the crops used for the production are grown in biologically sustainable production cycles without the use of artificial fertilisers. However, at the present global oil consumption rate of about 27 Gb/year, oil and alcohol from biomass could cover only a small percentage of the present demand. To replace 27 Gb/year of fossil oil by oil and alcohol from biomass, about one fifth of the Earth's land area - i.e. most of the cultivated area - would have to be allocated to crops for oil and alcohol production. Hence, only when oil consumption has been substantially reduced, can oil and alcohol from biomass cover a significant part of the consumption.

Nevertheless, farmers around the world could incorporate the production of sufficient amounts of bio-diesel, ethanol and biogas to fuel their tractors and other machinery in ecologically sustainable farming cycles. This might be possible because the residues (straw etc.) from the production of these fuels can be used for animal feedstock and/or the fuels can be produced on the basis of residues from crops for alimentation or animal feedstock and, in the case of biogas, from plant residues and animal manure. It would be a most important achievement if the basis of the food chain of all human societies in this manner became independent of petroleum supplies.

4. Conventional Oil Reserve Assessments

It is not easy for laymen nor learned:

IHS Energy has not followed Oil&Gas Journal in booking large volumes for Canada tar sand. I think their volumes here are more akin to proved reserves (thus guaranteeing future growth) rather than proved+probable (2P) reserves which are their usual criterion (and I would regard the OGJ number as much higher than 2P). IHS have confirmed to me that their number for Canada tar sands is restricted to developed projects which, combined with historical cumulative production, comprises about 10 Gb of the total Canada resource quoted by IHS Energy.

In 2003, IHS increased their end 2001 reserves by about 61 Gb, somewhat higher than the historical average but not substantially so. Increases occurred in each region but were dominated by Venezuela (I assume the Orinoco heavy but can't confirm) and Qatar, where a dramatic upward revision of the gas reserves in the North field pulled up the condensate reserves by about 17 Gb alone.

Personal communication with an analyst from the oil industry, 2004

Reserve reporting is an intricate business involving not only geological, geophysical and technical surveys and assessments but also regulations, political interests, and the oil companies' vested interests. In some countries regulations are imposed in order to prevent companies from overreporting the reserves, thereby misleading the stock market. However, overreporting may take place. In the mid-1980's the OPEC member countries' regulation of production quotas in proportion to national reserves was an incentive to overestimate national reserves. On the other hand, royalties and taxation may influence oil companies' reporting policies.³³

At the time when an exploitable reservoir is found and the first wells have been drilled it is uncertain how much will eventually be produced, although modern 3-dimensional seismic surveys have reduced the uncertainties. Therefore, in the reporting of global, regional or national reserves or the reserve estimates for a particular oil province, a distinction is made between:

- C Proved reserves: Reserves judged to have a high (90- 95%) probability of occurrence.
- C Probable reserves: Less sure reserves that are likely to occur but fail to qualify as Proved reserves.

³³ A discussion of reserve reporting issues is presented in *Jean Laherrère: Is USGS 2000 Assessments reliable ?*. Published on the cyberconference of the WEC on May 19, 2000. www.dieoff.off/page195.htm.

Proved+Probable reserves (2P) as reported should be close to the C Median probability (P50) reserves. The probability that the actual recovery turns out to be higher than the P50 estimate equals the probability that it turns out to be less.³⁴

4.1 Reserve development

Naturally, when a new reserve is first reported, the amount reported differs from the amount that will actually be produced in the lifetime of the field. For large fields, the first reported public domain data for newly found reserves tend to underestimate the amounts found. Therefore, in the course of time the data are adjusted upwards. For small fields, the tendency is the opposite: the first reported public domain data tend to overestimate the amounts actually found.

The historical development in global conventional oil reserves - i.e. new volumes added when new fields are discovered, plus/minus current changes in reserve estimates for existing fields, minus consumption - are reported in two different ways, see fig. 4.1.

The lower curves in fig. 4.1 show current reserve estimates reported in various publications. The trend is continued reserve growth, although in the later years there is an apparent tendency of a flattening out or decline.

The upper curve show backdated reserve data, 'backdating' meaning that when the original reserves in a field are revised, the revised number is registered as the reserve actually added at the time when the field was discovered.

The lower curves data may be highly inaccurate. Yet, in principle, for each year the difference between the upper curve and the lower curves show the reserves added at later revisions of the original reserve estimates. For example, in the year 1970 reserves were estimated at about 550 Gb. However, in the following years it appeared that the reserves existing in 1970 were in fact much bigger, namely about 1,100 Gb.

Whether reserves will continue to grow or are already declining is a question of whether future reserve revisions and/or the finding of new oil fields will result in reserve additions in excess of future consumption. In other words, whether or not the backdated curve when revised in 2010 will be lifted enough to meet again the curve showing the current reserve assessment - or whether the current assessment curve will be declining over the next decade. See fig. 4.2.

Most of the known oil fields were discovered before 1980. Reported discoveries in the 1990's were only about 10 Gb per year (see fig. 4.3) as against an annual consumption of about 25 Gb per year. The 15 Gb per year deficit corresponds to the decline in reserves from 2000 to 2010 shown by the backdated curve in fig. 4.1. Thus, reserve growth during the next decade requires that on the average more than 25 Gb are added every year by revisions of existing reserves and by new discoveries as against the 10 Gb per year added in the 1990's.

³⁴ A discussion of reserve assessments is given in *Jean Laherrère: Modelling future liquids production from extrapolation of the past and from ultimates*. Paper presented at the International Workshop on Oil Depletion, Uppsala University, Sweden. May 23-24th 2002.

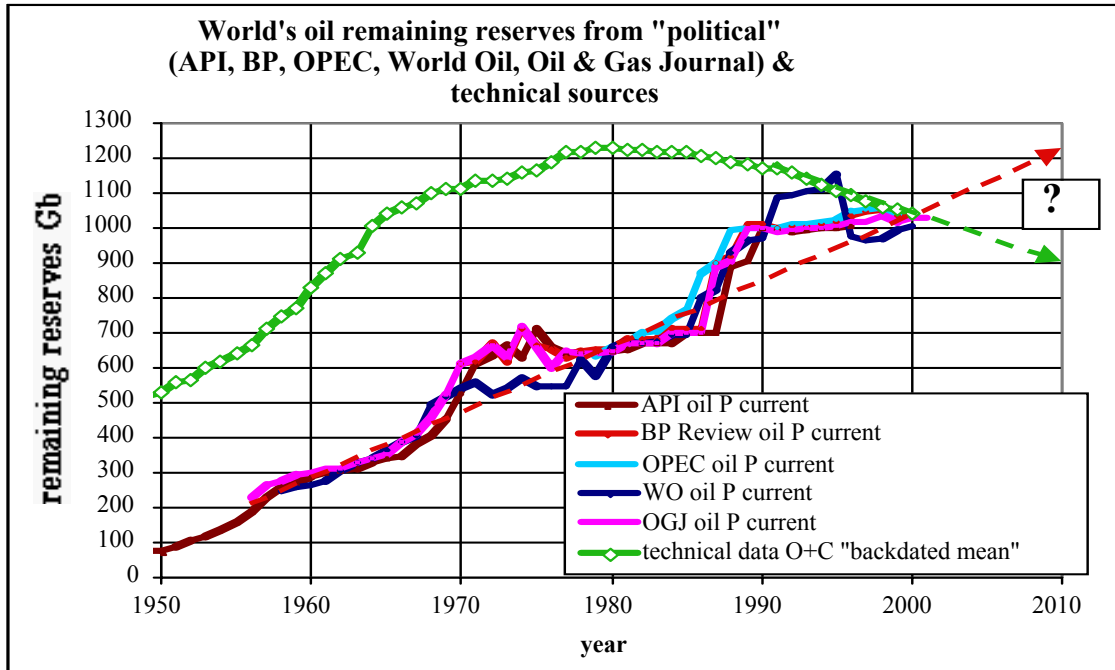


Figure 4.1. Backdated technical data (Conventional Oil+Condensate) as against “political” (public domain) revisions taken on a current basis.(Condensate: see section 2.1.2)³⁵

At closer inspection, fig. 4.1 shows an abrupt increase in current reserves by the mid-1980's - mainly due to upwards revisions of OPEC countries' reserves by about 290 Gb at the time when production quotas proportional to reserves were introduced - followed by a leveling out in the 1990's.

4.2 Future discoveries and enhanced recovery techniques

Since the 1970's discoveries have been declining. In 1982, M.King Hubbert observed that

*“During the last decade we have seen very large increases in the monetary price of oil. This has stimulated an accelerated program of exploratory drilling and a slightly increased rate of discovery, but the discoveries per foot of exploratory drilling have continuously declined from an initial rate of about 200 barrels per foot to a present rate of only 8 barrels per foot.”*³⁶

If the average annual discovery rate of about 10 Gb/year obtained in the last years (see figure 4.3) can be sustained, additional reserves amounting to about 200 Gb could be discovered in the next two decades.

³⁵ Jean Laherrère: *Modelling future liquids production from extrapolation of the past and from ultimates.* Paper presented at the International Workshop on Oil Depletion, Uppsala University, Sweden. May 23-24th 2002.

³⁶ http://www.hubbertpeak.com/hubbert/to_nissen.htm

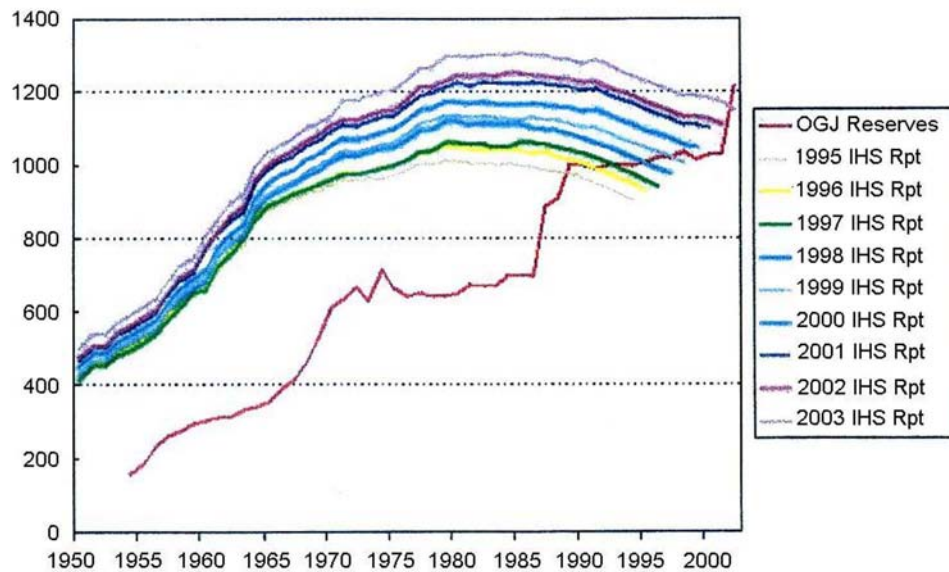


Figure 4.2. Currently reported remaining reserves (Oil&Gas Journal, OGJ) and currently backdated reserves (IHS Energy). The steep increase in remaining reserves in the late 1980's is mainly due to sudden upward revisions of the OPEC countries' reserves at the time when there was a political incentive to make such revisions because the countries' production quota became related to their reserves. The steep increase in 2003 is mainly due to the inclusion of oil from Canadian tar sand in the OGJ's reserve account. The decline in the backdated IHS curves from about 1985 show that since 1985 consumption has exceeded new discoveries. Therefore, the plateau in remaining reserves in the 1990's is partly due to upwards reserve revisions of existing fields as shown by the upwards shifts in the backdated IHS curves. Source: Francis Harper, Exploration Consultant. Former Manager, Reserves and Resources, BP. Presentation at the Copenhagen conference 2003.

Offshore deepwater discoveries (at depths of more than 500 metres) seem promising. According to Francis Harper (see figure 4.3 reference) deepwater oil reserves reported in 1999 amounted to 25 Gb. A Newsletter from World Environment News³⁷ reports global oil and gas deepwater discoveries of 60 Gb - mostly in waters in the Gulf of Mexico and off Brazil and West Africa - and the possible presence of another 40 Gb. Oil is estimated to comprise two thirds of these amounts.

On the continents, the Caspian oil provinces have given rise to great expectations. However, early estimates that the Caspian provinces could hold as much as 200 Gb were soon reduced to about 100 Gb and proven reserves may set at only 17 - 33 Gb³⁸. As some of these discoveries were made before 1999, they are included in figure 4.3. Hence, if new discoveries amounting in the range of 200 Gb are to be found in the next two decades, other large reserves than the hitherto reported deepwater and Caspian reserves must be discovered before then.

³⁷ <http://www.planetark.org> October 10 2002.

³⁸ ASPO Newsletter No 18, June 2002. Press report, Boston April 10 2002.

The African oil states of the sub-Saharan African region (Nigeria, Equatorial Guinea, Angola, Sudan) in which the US is now strongly engaged, could become the second largest oil exporting region after the Middle East³⁹. The South China Sea, where exploration has been delayed because of disputes about exploitation rights between China, Vietnam, and the Philippines, may hold considerable reserves. However, no major oil company has pushed to gain exploration rights.

Enhanced recovery techniques have increased and will continue to increase reserves. By means of such techniques the pressure driving the oil in the reservoir rock towards the wells is increased and/or the viscosity of the oil is reduced.

The forces which drive the oil from the reservoir rocks into the wells are

C the pressure of water below the oil reservoir, and/or

C in cases where natural gas has accumulated above the oil reservoir, the gas pressure, and/or

C the expansion of gas bubbles separating from the oil as the oil flows to the well.⁴⁰

More oil can be recovered (become reserves) by

C the injection of :

- steam, CO₂ (possibly dissolved in water) or nitrogen into the reservoir rock;
- water into the aquifer below the oil-water contact; or
- gas into the gas cap above the gas-oil contact, so as to increase the pressure that drives the oil towards the wells.

C the injection of chemicals which reduce the viscosity of the oil, thus increasing the speed of the flow towards the wells.

Moreover, enhanced recovery can be achieved by

C horizontal drilling, which enlarges the volume of reservoir rock from which oil can be recovered.

The use of these techniques has been profitable since the 1980's. However, enhanced recovery by means of CO₂ injection - a means of CO₂ sequestration - requires that CO₂ is separated from the flue gas from power stations or industrial plants and transported to the injection wells through pipelines. For instance, in a paper *A CO₂ Infrastructure for the North Sea* by Hugh Sharman⁴¹ it is proposed that pipelines for the transportation of CO₂ to mature oil fields in the North Sea are laid out from the UK and Denmark.

According to Francis Harper (see figure 4.3 reference), the recovery factor for the world's oilfields - in many of which enhanced recovery techniques are already used - range from 1% to over 90% with a likely average close to 35% (1998). A 10% increase in the average recovery factor would add about 500 Gb to the world's reserve endowment. However, on the basis of some rough calculations, Harper finds that "*it is hard to escape the general conclusion that annual growth in average oil recovery is a small fraction of 1%. A 10% gain is certainly achievable but it may take a lot of time or a significant increase in technological capability to realize the prize.*"

³⁹ Jean-Christophe Servant: *The new Gulf oil states*. Le Monde Diplomatique, January 2003.

⁴⁰ As described in more detail in Kenneth S. Deffeyes: *Hubbert's Peak. The Impending World Oil Shortage*. Princeton University Press, 2001. Chapter 5.

⁴¹ Hugh Sharman et. al.: *A CO₂ Infrastructure for the North Sea*.
<http://ior.rml.co.uk/issue4/co2/inco2/summary.htm>

In his presentation at the Copenhagen conference 2003 Francis Harper showed that the global average recovery factor is now 30% as against 35% five years ago, probably because a larger number of fields with low recovery factors have been included in the statistics. As total remaining oil-in-place in the world's discovered fields may be 6000 Gb, an increase in the average recovery factor (by volume) of 1% may add 60 Gb to recoverable oil. This is probably more than the reserves in the North Sea, the largest oil province discovered since the 1960's. However, to achieve a 1% increase for the world will be very hard indeed, said Harper. He expects an increase averaging 1/6% per year - maximum 1/4% - and pointed out that significant increases in recovery factors are very costly and only apply to big old fields.

“Many authors claim that technological progress increases the recovery factor and that the [average] recovery factor of presently 30% can be increased to 45%, but such claims cannot be justified on statistical global data nor individual fields. For the world outside US+Canada reported recovery factors (from about 4000 fields over 10 Mb representing 1300 Gb or 70% of total world discovery) varies from 3% to 80% as the most important factor is the geology of the reservoir. 3% occurs in fractured tight reservoirs when 80% can be achieved for very porous reefs. The second factor is the status of the fluid: one-phase oil, oil with dissolved gas drive, oil with gas cap, and oil with aquifer.”

Jean Laherrère: Future of oil supplies. Seminar Centre on Energy Conservation, Zürich, May 7 2003.

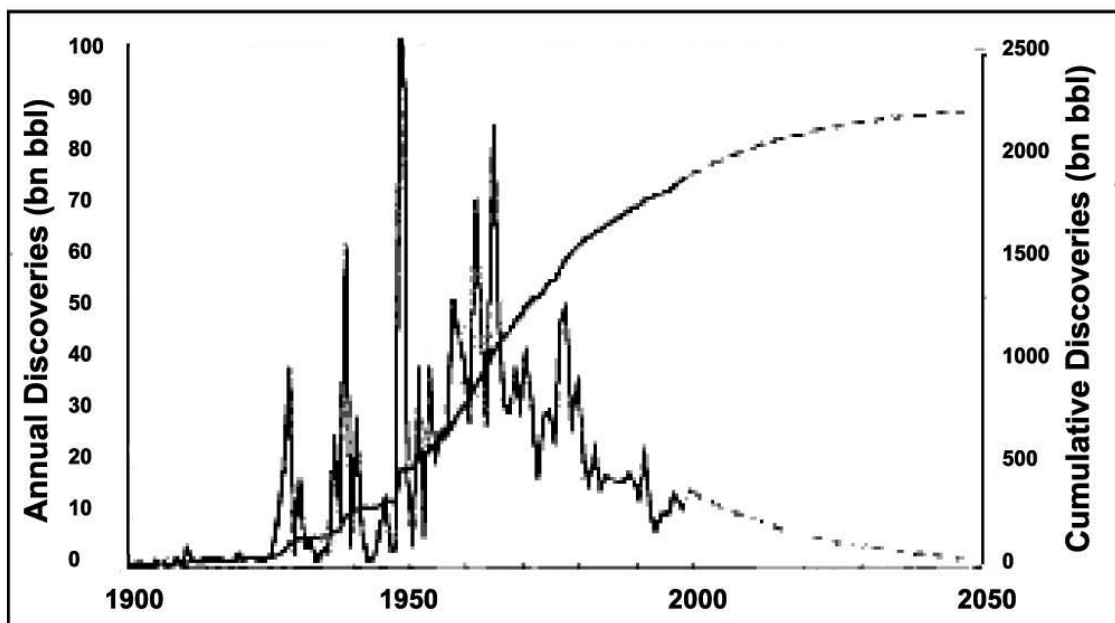


Figure 4.3. Global discovery of petroleum liquids (conventional crude oil+NGLs; revisions backdated to original field discovery date) and one possible extrapolation to an asymptote at 2,250 Gb. (bn bbl=Gb)

Source: Francis Harper (Exploration Consultant. Former Manager, Reserves and Resources, BP), *Ultimate Hydrocarbon Resources in the 21st century*. AAPG Conference “Oil & Gas in the 21st Century”, September 1999, UK. Here copied from the website <http://www.oildepletion.org>, edited by Dr. Roger W. Bentley, University of Reading, UK.

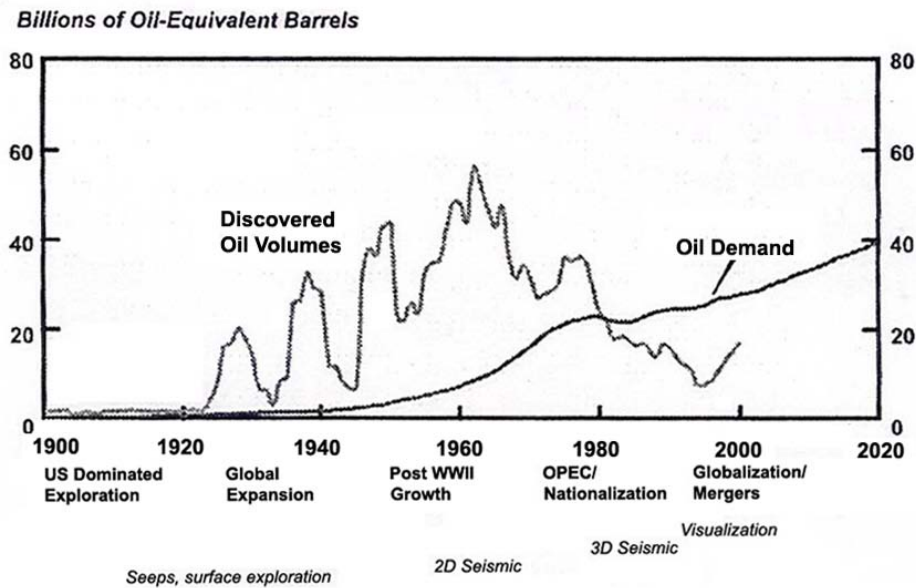


Figure 4.4 This graph is shown in Director and Executive Vice President of ExxonMobil Corporation Harry J. Longwell's article: *The Future of the Oil and Gas Industry. Past Approaches, New Challenges*, World Energy, Vol.5 No.3 2002. Apparently, the introduction of 3D seismic exploration techniques in the 1980's did not reverse the decline in discoveries. The shown increase in discoveries beginning in the 1990's, when computer visualisation of deep structures was introduced, indicating that discoveries reached almost 20 Gb in 2000, is not in accordance with the trend shown in fig. 4.3. In recent years reported discoveries have averaged circa 12 Gb per year.

4.3 Ultimate reserve estimates

The ultimate reserves of an oil province is the total amount of oil produced in the province from the opening of the first well to the closing of the last. Thus, at a certain time, *remaining reserves equals ultimate reserves minus past production*.

Any scenario for future production must meet the condition that the area covered by the production curve (production versus time) equals the remaining reserves. Moreover, the time when the production peak is likely to occur is related to the ratio of past production to ultimate reserves. Therefore, the assessment of ultimate reserves is important for the prediction of production potentials in the next decades.

Several different methods are being used to assess ultimate reserves. Jean Laherrère uses a logistic extrapolation method, based on the empirical evidence gained from historical recordings (fig. 4.5 and 4.6) or creaming curves with cumulative discoveries versus the number of New Field Wildcats (fig. 4.8). Colin J. Campbell estimates reserves in known fields and reserve additions from new fields on a country by country basis.

The United States Geological Survey (USGS) does not estimate ultimate reserves. It estimates probability distributions for undiscovered recoverable resources in the world's oil provinces which may become reserves before 2025.

It should be kept in mind that regarding the assessment of future production capacities, *ultimate reserves* means the total production of conventional oil from the time when the recording of production began until production has declined to an insignificant level.

4.3.1 Laherrère's estimates

In broad principle, the method is illustrated by fig. 4.3. The curve showing cumulative discoveries is extrapolated to a maximum of about 2,250 Gb, which is the estimated ultimate reserve value found in the case shown.

Based on the industry's technical databases, Jean Laherrère has carried out detailed analyses of reported reserve and production values for the world's many oil provinces. Some of his main results are shown in fig. 4.5, 4.6 and 4.7.⁴² In these figures, discoveries correspond to backdated so-called P50 data.

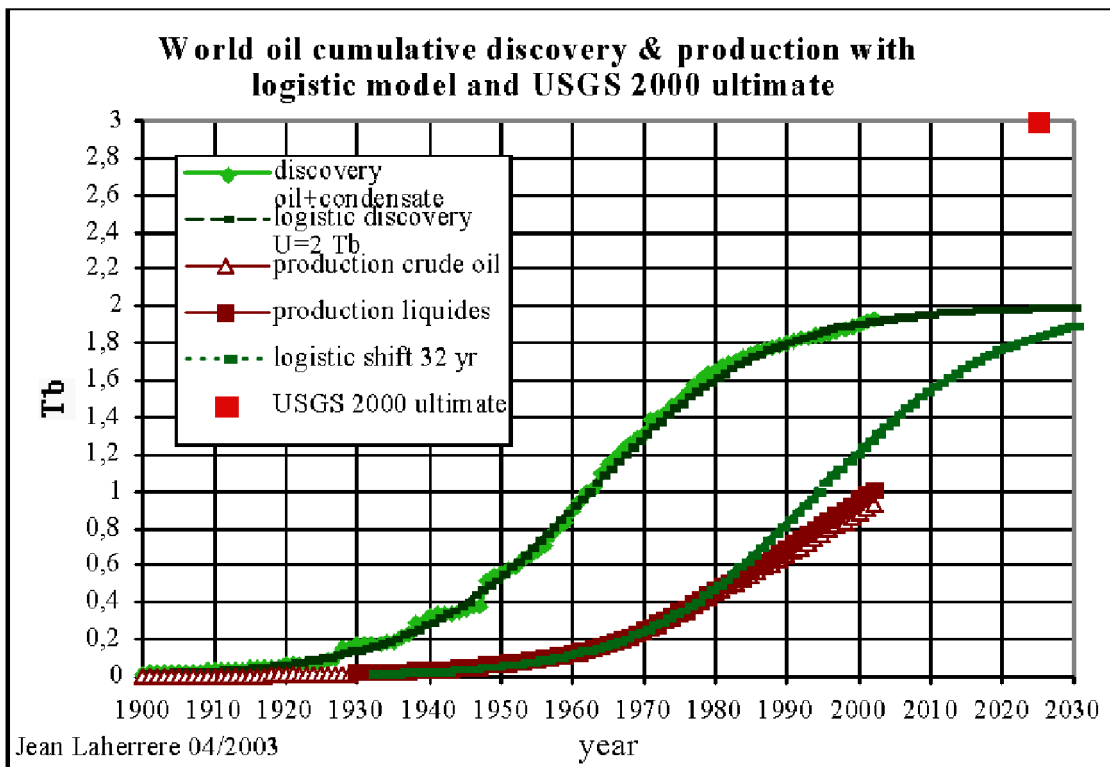


Figure 4.5 World oil + condensate discovery (FSU corrected and excluding extra-heavy oils) with logistic model which fits production after a shift of 32 years.⁴³

The USGS 2000 [see section 4.2.2 below] estimate of the conventional oil+NGL to be discovered in 2025 being 3 Tb (in fact the published value is more accurate being 3,012 Gb) is plotted on this graph and looks very hard to fit with the past discovery.

[Tb= 1,000 Gb. Condensate: condensates from gas wells, not including Natural Gas Plant Liquids (NGPL), see section 2.1.2 above]

Cumulative production lags behind cumulative discovery. Fig. 4.5 shows a time lag of 32 years until 1980 when OPEC countries reduced production as demand decreased because of the increase in the oil price. Had cumulative production followed the logistic curve, almost all of the ultimate reserves of about 2,000 Gb (2 Tb) would have been produced by 2030.

⁴² Figure 4.5, 4.6, 4.7 and 4.8 and figure texts are copied from:
Jean Laherrère: *Future of oil supplies*. Seminar Centre on Energy Conservation, Zürich, May 7 2003.

⁴³ The logistic model shown in fig. 4.5 was first used by M. King Hubbert when in 1956 he predicted that oil production in the US would peak in 1970, estimating ultimate US reserves at 200 Gb. Production did peak in 1970.

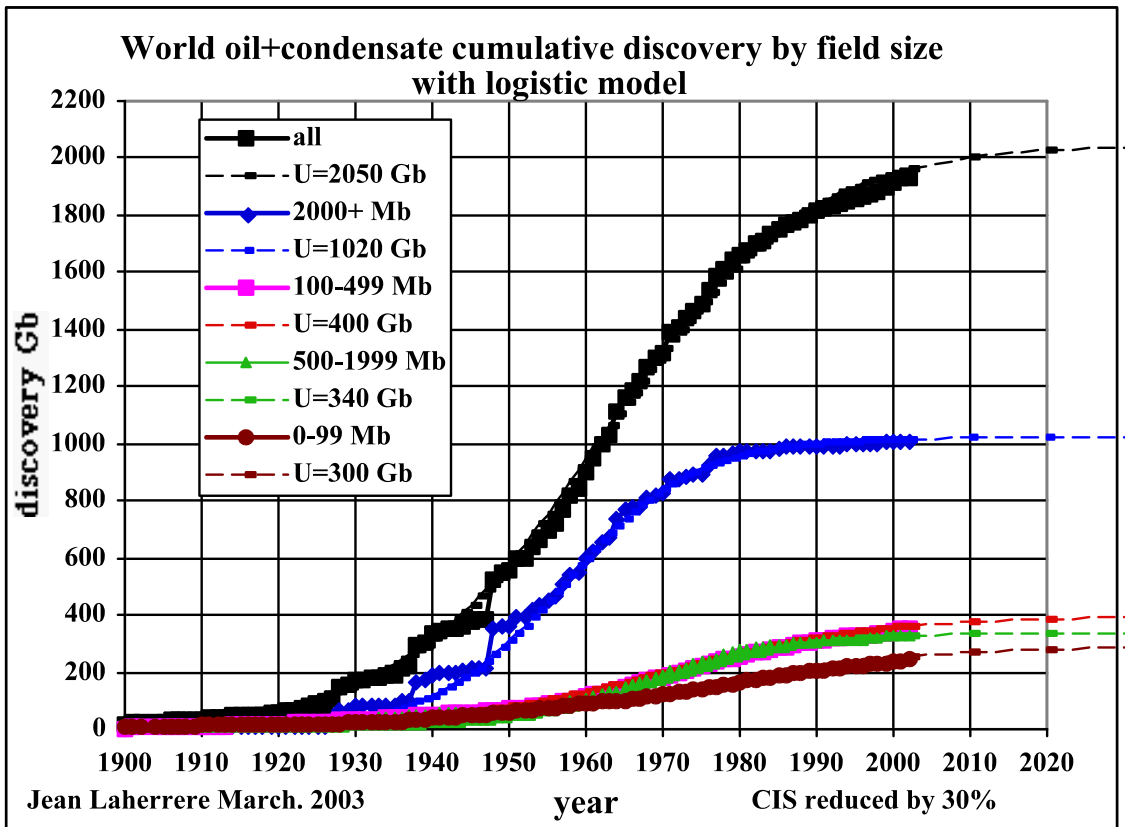


Figure 4.6. World oil+condensate cumulative discovery by field size with logistic model.

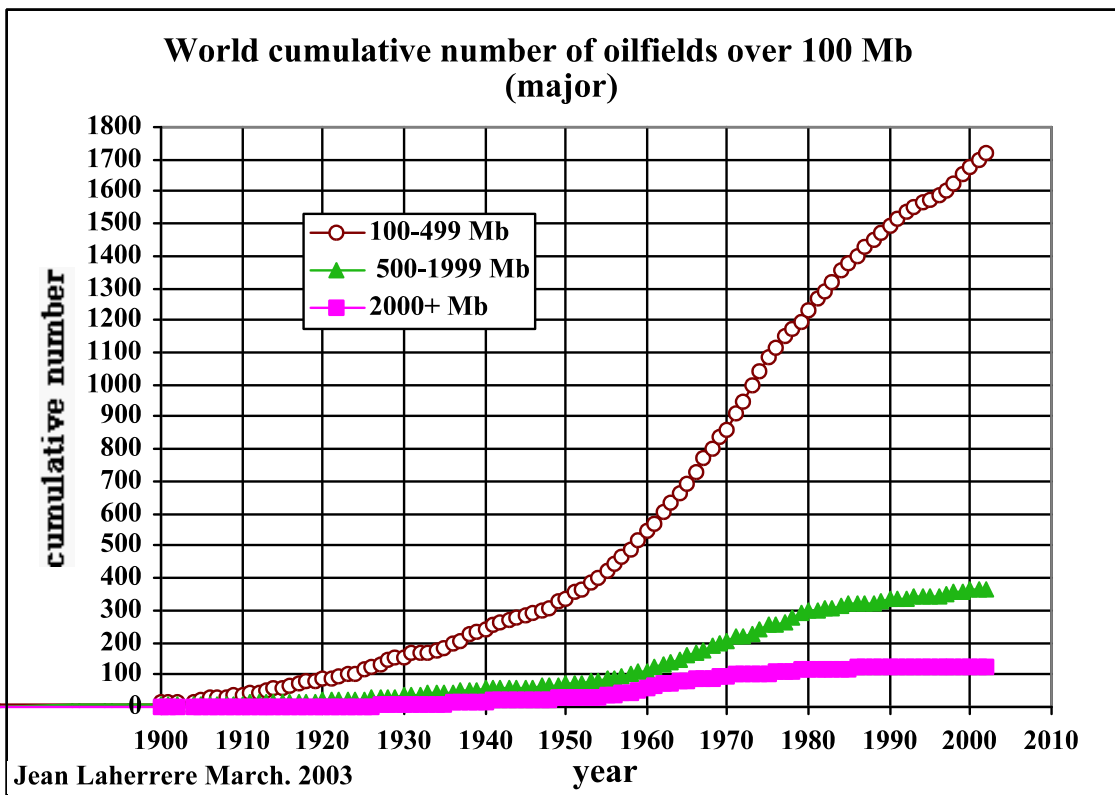


Figure 4.7. World cumulative number of fields over 100 Mb (major) The extrapolation of the annual/cumulative versus cumulative production (or discovery) can deliver the ultimate when the annual curve follows a derivative of the logistic curve
For the US, the extrapolation of the production gives an ultimate of 220 Gb.

In accordance with fig. 4.3 and fig. 4.4, fig. 4.6 shows that before 1980 most of the discovered volumes were in giant fields larger than 2 Gb (= 2000 Mb) while after 1980 the discovered volumes were much smaller and found in smaller fields, about 30% being smaller than 0.01 Gb. Thus, comparing fig. 4.6 and 4.7, it appears that

- C about half the oil discovered so far has been found in fewer than 150 giant fields,
- C the other half has been found in about 2 000 smaller fields, and
- C most of the discoveries made after 1980 were in small fields.

In the different regions, a shift in the cumulative discovery trend - a new cycle - occurs when new major discoveries are made. For example, new discoveries in East Sahara and in deep water west of Africa gave rise to the new cycle shown in fig. 4.8, increasing the ultimate reserve estimate for Africa from 210 Gb (1991 estimate) to 270 Gb (2002 estimate). This reserve growth, corresponding to about 2 years of the present global consumption, is included in the figures shown in fig. 4.5 and 4.6.

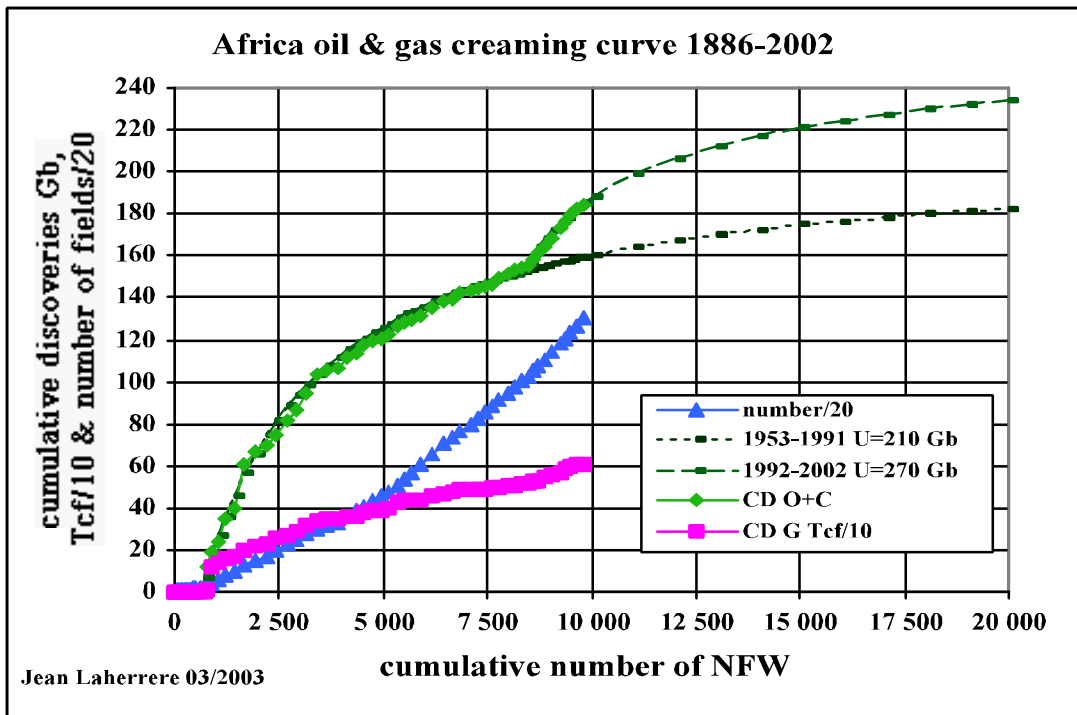


Figure 4.8. Africa discovery: creaming curve.
 [NFW: New Field Wildcats (exploratory drillings). CD: Cumulative Discoveries.
 O: oil. C: Condensate. G: Gas]

Laherrère estimates on the basis of the empirical evidence summarized in figs. 4.5-4.7, his creaming curves, and his logistic modelling, that ultimate reserves of conventional crude oil + condensate (NGL) amounts to 2,000 Gb plus or minus 20% (or plus 20% and minus 10%)⁴⁴.

⁴⁴ Jean Laherrère: *Modelling future liquids production from extrapolation of the past and from ultimates*. Paper presented at the International Workshop on Oil Depletion, Uppsala, Sweden, May 23-24th, 2002.

4.3.2 Campbell's estimates

Colin J. Campbell has adjusted public domain reserve data (from *World Oil* and the *Oil&Gas Journal*) for 64 oil producing countries and estimated future reserve additions from new fields, using available data from the industry's databases, see table 4.1.

Adding up, he finds :

Conventional crude oil+condensate:	
	Gb
Past production (2002)	873
Known reserves (2002)	884
New fields	144
<hr/>	
Ultimate global reserve	1900

This estimate is at the lower end of the interval estimated by Jean Laherrère.

As Campbell has emphasized in his speeches and papers, we know that all the numbers are imprecise. However, when for each country the best available data are used for the scrupulous, professional estimation of ultimate reserves, then the relative deviation (in %) of the estimated total from the value actually to materialize is likely to be smaller than the relative deviations of the particular country-values - assuming the same (Gaussian) probability distribution for each country estimate.

Hence, the questioning of the total is the questioning of the particular country-values. In other words, any assertion that the total is likely to be too high or too low should be supported by the indication of the particular country-values deemed too high or too low.

Campbell uses the industry's data to adjust the reserves reported in the public domain (in the journals *World Oil* and *Oil&Gas Journal*) and to estimate the portion of the actual reserves reported in the public domain. For Russia, for instance (second line in table 4.1), he adjusts the public domain reserve estimates downwards by 4.83 Gb (about 10%) and estimates that only 67% of the actual reserves has been reported in the public domain. Adding past production (121 Gb) and future production from new fields (estimated at 12.9 Gb), he estimates Russia's ultimate reserves to be 200 Gb.

Assertions that these values are unrealistic should be supported by the specification of the numbers claimed to be more realistic and the indication of plausible reasons why the numbers should be changed. For example, if future reserve growth in existing fields in Russia is deemed to add a substantial amount to Campbell's reserve estimate, the technological, geological and economic prerequisites for such additional growth should be indicated for the major oil provinces and the annual growth rates to be expected in the next decades should be specified.

Thus, table 4.1 provides a useful framework for the objective, well-reasoned assessment of the global conventional reserves likely to be accessible within the next decades and the rates at which these reserves can be produced. Additional reserves may become accessible in the more distant future but this is of no consequence for the assessment of the time when an impending peak is likely to occur.

In section 5.5 below, possible effects of modifications of Campbell's estimates with respect to the time of the peak in oil supply and the subsequent decline are examined.

4.3.3 USGS's probabilistic assessments

The U.S. Geological Survey presents resource estimates in terms of probability distributions computed by means of the Crystal Ball Monte Carlo simulation program:

“EMCEE and Emc2 are Monte Carlo simulation programs for assessing undiscovered oil and gas resources. EMCEE allows a variety of distribution types for input, while Emc2 works with a specific set of distributions. They run as spreadsheet workbooks in Microsoft Excel. EMCEE and Emc2 require Crystal Ball, a Monte Carlo simulation program from Decisioneering, Inc. that runs in Microsoft Excel.

EMCEE and Emc2 forecast undiscovered resources by simulating the sizes and numbers of undiscovered fields. The user provides distributions for several variables. The program samples from these distributions and calculates a forecast of undiscovered resources. This procedure is iterated a specified number of times and the distributions are presented in both tabular and graphical formats.”

“Both EMCEE and Emc2 forecast undiscovered resources for oil fields and gas fields separately. The user provides distributions for the number of undiscovered fields and for the sizes of those fields”

“Resource estimates were made for parts of 128 geologic provinces in 96 countries and 2 jointly held areas exclusive of the United States”.

Quotations from the U.S. Geological Survey Digital Data Series 60:
Ronald R. Charpentier and Timothy R. Klett: *Monte Carlo Simulation Method.*, and
Thomas S. Ahlbrandt: *Introduction.*

While Laherrère and Campbell estimate *ultimate reserves* on the basis of the empirical evidence provided by historical data, the USGS estimates *undiscovered resources* which have the potential to be added to existing reserves before 2025 as well as *reserve growth in existing fields* which have the potential to materialize before 2025. The estimates are made on the basis of probability distributions specified by the user of the Monte Carlo simulation program. Laherrère and Campbell's results should be interpreted as reserves likely to materialize within a longer time span (see 4.3, first paragraph), while the USGS assessments should be interpreted as probabilities that certain volumes of oil having been captured in reservoir rocks will become reserves before 2025.

The USGS results of ultimate reserve probability calculations, based on individual probability assessments for 128 geologic provinces in 96 countries, are summarized in table 4.2.

USGS. World Petroleum Assessment 2000	Conventional oil. Billion barrels			
	P95	P50	P5	Mean
World, excluding United States				
Undiscovered	334	607	1107	649
Reserve growth	192	612	1031	612
Existing reserves (1996)				859
Cumulative production (1996)				539
Total				2659
United States				
Undiscovered	66		104	83
Reserve growth				76
Existing reserves (1996)				32
Cumulative production (1996)				171
Total				362
World total	2248		3896	3003

Table 4.2 U.S. Geological Survey's probability assessments of new reserves which have the potential to be added to existing reserves before 2025.

Px: x % probability that at least the shown undiscovered reserves exist and that at least the shown reserve growth will materialise before 2025.

Mean: the mean value of the probability distribution.

USGS. World Petroleum Assessment 2000	Conventional oil. Billion barrels Undiscovered reserves			
	P95	P50	P5	Mean
Middle East and North Africa	73	216	432	230
East Greenland	0		112	47
Iraq	14	45	84	

Table 4.3 U.S. Geological Survey's probability assessments for undiscovered reserves in three regions. In the East Greenland province there may be nothing, but the USGS finds that there is a 5% probability (P5) that there is 112 Gb, i.e. 80% more than the North Sea reserves (Norway, UK, Denmark, totalling about 62 Gb in 2000).

The US is the most mature of the world's major oil regions. Most of the discoveries were made before 1940 and most of the oil discovered has already been produced. Therefore, the relative deviation (P5 - P95)/Mean for undiscovered reserves is much lower for the US than for the world outside the US. Also, because the P95 and P5 values for the world's individual regions are not additive, the relative deviations are higher for the individual regions outside the US than for the world outside the US as a whole, see for example table 4.3.

Regarding reserve growth, Laherrère and Campbell have drawn attention to the different reserve definitions used in the US and the rest of the world and the probable consequences the different definitions may have for the USGS assessments. *“The US practice has to comply with the SEC (Securities and Exchange Commission) rules, which recognise only Proven Reserves, omitting Probable Reserves, whereas in the rest of the world Proven and Probable Reserves are recognised”*⁴⁵ Thus, as the reported reserves for the world outside the US include Probable Reserves it should be expected that future reserve growth is relatively smaller than in the US, where the basis for the growth assessment is lower because Probable Reserves are not included.

In any case, the assessments must be interpreted within the framework of probability theory, which refers to events or samples drawn from an event space specified in terms of probabilities assigned to the particular events. For example, one can imagine a bottle-filling machine filling different volumes at random into an array of bottles, the volume in each bottle being larger than or equal to zero and less than or equal to 100 ml. On the basis of a long series of samples or, alternatively, knowledge about the functioning of the machine, a probability P_x may be assigned to the event that a bottle chosen at random contains more than x ml.

Regarding the amounts of oil “bottled” in a certain province, the “bottle-filling machine” is the complex of biological, chemical and geological processes which have taken place over the last 150 million years or so and which may have resulted in a certain amount of oil still being trapped in reservoir rocks. As the processes cannot be repeated, the assignment of a probability to a certain outcome (event) must be based on knowledge about “the functioning of the machine”, i.e. the particular conditions under which the formation and subsequent trapping of oil may have taken place. Moreover, as the probability assignments concern only quantities which have the potentials to become reserves before 2025, also knowledge about or assumptions as to exploration activities and the results of these activities within this period of time must be taken into account.

In the USGS survey, such knowledge about geological conditions and exploration activities was represented by groups of experts appointed for the different provinces. For each province, the group specified probability distributions for the amount of oil trapped in the province, assigning probabilities to the different possible outcomes of the particular complex of chemical and geological processes which have taken place in the province over many millions of years and which are unknown with respect to several decisive parameters. The specified probability distributions were entered into the Monte Carlo

⁴⁵ Jean Laherrère: *Future of Oil Supply*. Paper presented at Seminar Centre of Energy Conversion. Zürich, May 2003.

simulation program and probability distributions for the different regions and for the world outside the US were computed by multiplying the geological probabilities by *accessibility probabilities*, i.e. probabilities that at least part of the oil to which a geological probability is assigned will be politically and technologically open to exploitation. In view of the results computed, the estimation process was iterated a number of times.

Considering the unquantifiable uncertainties pertaining to the probability distributions thus specified for each of the 128 geological provinces, the uncertainties of the results summarized in table 4.2 cannot be estimated.

The International Energy Agency (IEA)⁴⁶, the US Energy Information Administration (EIA)⁴⁷, and the European Commission⁴⁸ base their supply security assessments on the probabilities presented by the USGS. However, the extent to which IEA's investment estimates regarding exploration and development until 2030 are related to the USGS probability assessments is not evident.

4.3.4 The WETO POLES model

“The modelling of oil and gas reserves and production is carried out in three stages in the POLES model.

First, the model simulates the level of oil and gas resources discovered each year (cumulated discoveries) as a function of Ultimate Recoverable Reserves and of the cumulative drilling effort. URR are not fixed as considered usually: they are the product of the oil and gas in place for a base year (from USGS estimates) and of a recovery ratio that increases with the price and an autonomous technological trend. The drilling effort is also a function of the price and a trend.

Second, the reserves are equal to the difference between the cumulative discoveries and this cumulative production for the previous period.

Finally, the model calculates production. For oil, it results from applying a Reserve on Production ratio in the “price taker” regions, while the “swing producers” balance between the oil demand and supply. For gas, it is derived from the simulated demand”.

WETO: *World energy, technology and climate policy outlook 2030.* European Commission, Directorate-General for Research. Community Research, 2003. (EUR 20366). <http://europa.eu.int/comm/research/>
Op. cit. p. 39, box 4.

⁴⁶ IEA, *World Energy Outlook 2002* and *World Energy Investment Outlook 2003*

⁴⁷ EIA: *Long Term World Oil Supply*. www.eia.doe.gov

⁴⁸ WETO: *World energy, technology and climate policy outlook 2030.* European Commission, Directorate-General for Research. Community Research, 2003. (EUR 20366). <http://europa.eu.int/comm/research/>

In the WETO report it is concluded that

“Sufficient oil reserves exist worldwide to satisfy the projected demand during the next decades. However the decline in conventional oil reserves may constitute a preoccupying signal beyond 2030. It is only partially compensated by an increase in the reserves of non-conventional oil. The reserves of natural gas are abundant and expected to increase by around 10%.” (op.cit.p.3, Key Messages)

Although oil production is not determined by reserves but by production capacity, which depends on reserves and for each oil field begins to decline when a certain portion of the reserve has been produced, the message conveyed by this conclusion is that conventional oil production can cover most of the oil demand until and beyond 2030, even if the demand grows by 70% from 75 Gb in 2000 to 120 Gb in 2030.

The hypothesis upon which this conclusion is based is that reserve growth and new discoveries in the next decades are functions of the oil price and a technological trend, representing enhanced recovery technology (see box above)⁴⁹. Ultimate Recoverable Reserves (URR) are assumed to grow to 4,500 Gb in 2030 due to an increase in recovery rates from 30-40 % in 2000 to 50-70% in 2030, depending on the region (p. 38):

“As the production level is increasing during the projection period, the world Reserve to Production [R/P] ratio decreases from 40 years to 18 years: in the model simulation this is the key driving force explaining the increase in oil price from the end of the current decade onwards.” (op.cit. p.38)

World oil price	USD per barrel			
	2000	2010	2020	2030
WETO (1)	26.5	23.8	28.7	34.9
US-DOE (1)		21.6	22.8	
IEA (2)	28	21	25	29

(1): WETO p. 121 (2): IEA, World Energy Outlook 2002, p. 48

Table 4.4 Oil price forecasts. The WETO prices are computed on the basis of the development in the global R/P ratio, adopting the theoretical assumption that this ratio is the key driving force for the price development. Yet, although the IEA oil prices are considerably lower than the WETO prices from 2010 onwards, global oil production assumes the same value (120 million barrel per day or 44 Gb per year) in 2030 in the IEA reference scenario and in the WETO reference scenario. This implies that the models used to compute the two scenarios have inherently different properties.

⁴⁹ In the WETO model the assumed growth in recovery rates varies between 0.3% and 0.5% per year depending on the initial recovery rates in the different regions (additional information submitted by Dr. P. Criqui, see footnote on the opposite page). Francis Harper of BP estimates that an increase in the global average recovery rate of 1/6 % = 0.17% (maximum 1/4% = 0.25%) or about half the WETO estimates may be achieved at high costs (see section 4.2)

In essence, the key message is that assuming the hypothesis that Ultimate Recoverable Resources grow as a function of an unspecified technology trend and the oil price, which is a function of the current R/P ratio, a growth in oil demand by 1.6 % per year (from 27 Gb per year in 2000 to 44 Gb per year in 2030) can be sustained at the oil prices shown in table 4.4 (WETO).

According to the *BP Statistical Review of World Energy 2003*, the global R/P ratio declined from 43 years in 1992 to 41 years in 2002. As the WETO oil price is a declining function of the R/P ratio, the drop in the price from 2000 to 2010 (table 4.4) should imply a growth in the R/P ratio, i.e. a reversal of the trend in the past 10 years. However, at closer inspection⁵⁰ it appears that the initial oil price in the WETO scenario computation is not the price in 2000 but the lower price in 2001 (\$ 22.5/barrel). This choice of the price for a particular year instead of a price derived from a price trend seems to be inconsistent with the statement in the WETO report that “...*the price movements mainly depend on the variation of the Reserve on Production (R/P) ratio, which constitutes a long-term indicator of the balance between demand and supply*” (p. 21).

Moreover, as pointed out by Christopher Skrebowski⁵¹, the oil industry “*is all about profits....It is not there to guarantee supply*”. In recent years the oil companies have established a normalized oil price of \$ 18 - 20/bbl in determining whether they will pursue new projects⁵² although the market price has been around \$ 27/bbl. Thus, empirical evidence does not support the WETO hypothesis that reserve growth and new discoveries is a function of the oil price and a technological trend in recovery growth.

Although the enhanced recovery techniques mentioned in section 4.2 above have been applied in the US since the 1980's, the continual decline in production since the peak in 1970 has not been reversed, see fig. 5.7 below. The high oil price at the beginning of the 1980's (up from \$ 25 /barrel in 1979 to \$ 38 /barrel in 1980 and then declining to \$ 30 /barrel in 1983) was accompanied by a small growth in reserves and production (see fig. 5.7). However, from 1985 onwards the decline in US production has continued even though increasing dependency on oil imports has been a serious concern for the US administrations. Moreover, because reported reserves in the US are proved reserves while most other countries report proved+probable reserves, the reserve growth in the US should be higher than in the rest of the world.

Thus, the history of US oil production does not render evidence to the hypothesis that enhanced recovery techniques will substantially increase reserves and production in the next decades with the R/P ratio as the ‘key driving force’. (The US R/P ratio was practically constant in the 1980's when the decline in reserves was arrested). Nor does the evidence so far gained from the North Sea oilfields support this hypothesis:

⁵⁰ Additional data provided by Dr. P. Criqui, WETO researcher in a note to The Danish Board of Technology, December 2003.

⁵¹ In his speech at the Copenhagen conference 2003. Christopher Skrebowski is editor of Petroleum Review, Energy Institute, London.

⁵² Merryll Lynch Global Securities Research & Economics Group, 2003. (See section 6.2)

“Experience in North America and the North Sea shows that advanced technology can help arrest declines in production. But there is growing evidence that decline rates are becoming steeper in some regions.” (IEA World Energy Outlook 2002. op.cit. p. 100)

“North Sea production is already in decline and this is unlikely to change.” (ibid. p. 98)

The WETO report does not refer to other empirical evidence which supports its hypotheses.

In his presentation at the Copenhagen conference 2003, Francis Harper showed that the estimated recovery factors for the BP oil fields varied considerably from one field to another, in some cases being negative from one year to the next. And he pointed out that recovery factor growth only applies to big old fields. Among the BP fields the highest recovery factor has been achieved in Prudhoe Bay, see fig. 4.9, the average being about 50%, which is considerably higher than the present world average of about 30%. Harper said that he expects growth rates to be lower in future than in the past. And he pointed out that in cases like Prudhoe Bay *“if you stop spending money, production plummets”*.

The increase in the recovery factor which may be achieved by investing a certain amount of money differs widely from one oil field to another and is generally small in smaller new oil fields. Also for this reason, it is unlikely that the WETO hypothesis, namely that the global average recovery factor (by volume or by field) is a simple mathematical function of the market price of crude oil and the R/P ratio, reflects the geological and economic realities. In particular when Peter Stewart’s observations regarding the benchmark setting of the crude oil price are taken into account (see section 6.3).

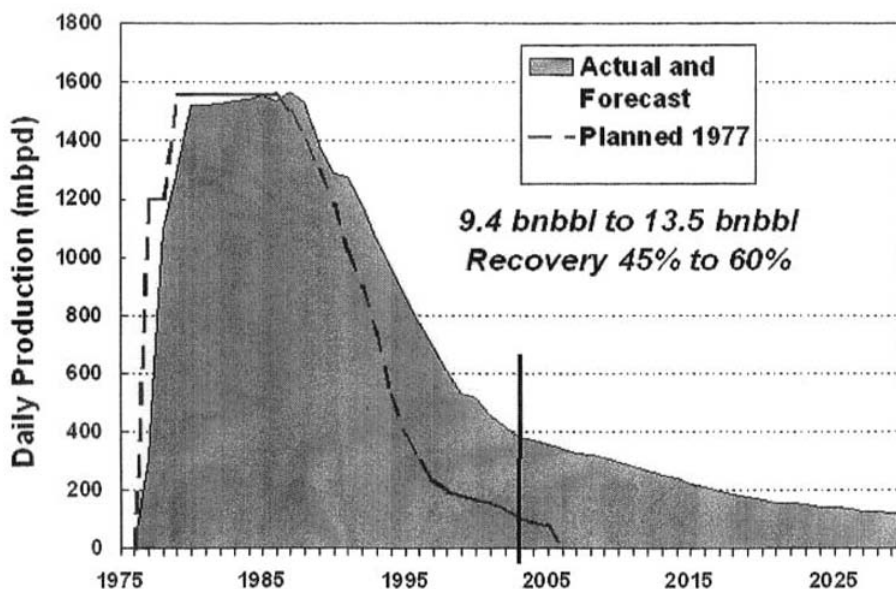


Figure 4.9 Production in Prudhoe Bay, Alaska. The increase in the recovery factor did not significantly change production around the peak. It made the decline less steep, as ultimate recovery was increased. From Francis Harper’s presentation at the Copenhagen conference 2003.

5. Oil Demand and Reserve Depletion Scenarios

“The catch is that while demand increases, existing production declines. To put a number on it, we expect that by 2010 about half the daily volume needed to meet projected demand is not on production today - and that’s the challenge facing producers.

This means that industry may need to add some 80 million oil-equivalent barrels per day to production by 2010 to meet projected demand. The cost of doing so could reach \$ 1 trillion, or about \$ 100 billion a year. That’s substantially more than industry is spending today.”

Harry J. Longwell, Director and Executive Vice President of Exxon Mobil Corporation in his article:

The Future of the Oil and Gas Industry: Past Approaches, New Challenges. World Energy, Vol.5 No. 3, 2002.

Oil demand is determined by the dependence of the economy on oil-based technologies: oil-driven vehicles, aeroplanes, ships, agricultural machinery, industrial processes, power stations, oil-fired boilers in buildings and district heating stations. In areas where natural gas distribution networks exist, natural gas can be substituted for oil in boilers and power stations at moderate investment costs and in some areas solid biomass fuels or coal may partly substitute oil in boilers. However, in many areas there are no immediately available substitutes for oil in stationary units and nowhere are infrastructures in place for the distribution of other fuels than oil for vehicles. Moreover, it takes time to replace the growing number of cars (presently about 400 million worldwide, expected to grow to about 900 million in 2030⁵³) and the millions of trucks and other oil-powered vehicles by new vehicles which can run on other fuels than oil.

Hence, a smooth technological transition to an economy less dependent on oil implies the initiation of technological shifts well ahead of the peak in oil production. If oil-based technologies remain the cheapest alternatives until the production peak occurs, the continued increase in demand will shorten the time until the peak occurs and make the gap between demand and production wider and the decline in production steeper. The world economy will become technologically more and more dependent on oil as the cheap-oil era comes to an end. This unfortunate development appears in all the different scenarios published by energy agencies and the industry. Only the estimated time and height of the peak and the subsequent decline rate differs from one scenario to another.

In the 1970's and 1980's, when OPEC curtailed production and introduced production quotas for its member states, oil demand in the USA and Europe was reduced by shifting from oil to coal or natural gas in many power stations and industries and to natural gas or electricity for room heating in many buildings. Thus global oil demand plunged by about

⁵³European Commission: *World energy, technology and climate policy outlook 2030* (WETO), 2003

2% per year from 1979 to 1985, then resuming growth at a rate averaging about 1.2 % from 1985 to 2001 - the growth rate being strongly correlated to the global economic growth rate⁵⁴. At the same time new non-OPEC oil fields were opened, the North Sea being the biggest new oil province, reaching almost 25% of the total OPEC production by the year 2000.

Today the scope for shifting from oil to coal or natural gas is much smaller. Moreover, demand has grown by about 20% since 1975, the North Sea production is in decline, and the US production has dropped by about 30% since its peak in 1970. Hence, the options for counteracting in the short term an unexpected decline in supply are much more limited today than they were in the 1970's and 1980's. Therefore, the prospects for future demand and supply should be examined closely and presented to the public in an intelligible form with references to the methods and data upon which the forecasts are based. A subjective distinction between 'optimists' and 'pessimists' is not helpful for the objective discussion.

5.1 Demand and supply

The logical catch is that if a gap between demand and production occurs, it is because no economically competitive and environmentally acceptable alternatives to conventional oil are in place. If economically competitive alternatives are in place, then there will be no gap.

Any conventional oil production scenario is subject to the following constraints:

- C The area covered by the production curve (past and future production) equals the ultimate reserves as estimated for the scenario in question.
- C Cumulative production must follow cumulative discovery with a certain time lag. Depending on demand and/or production restrictions the time lag may vary over time, see for example fig. 4.5.
- C Annual global production should equal annual global demand.

Under these objective constraints, scenarios for the future development are prepared under the axiomatic assumption that economic growth at a rate averaging at least 2% p.a. will continue worldwide, unrestricted by eventual constraints in the supply of oil and natural gas. The reason for this is not that there is empirical evidence that such growth is sustainable. The reason is that without such an economic growth axiom the future becomes incalculable, because nobody can foresee the disruptive consequences that zero or negative economic growth over a longer period of time will have in the capitalistic market economy. If economic growth remains technologically dependent on growth in conventional oil supply until global conventional oil production peaks, then the development following the peak is unpredictable.

It follows that a continuous economic growth scenario implies that the peak in conventional oil production occurs because of a decline in demand and that the subsequent decline in conventional oil production is determined by the decline in demand, not by a decline in production capacity.

⁵⁴ IEA. World Energy Outlook 2002.

In spite of this condition, scenarios for the future production of conventional oil are, generally, based on the implicit assumption that production is primarily related to production capacity, deviations of demand from production capacity (e.g. figs. 4.5 and 5.3) being considered anomalies.

5.2 Hubbert depletion scenarios

“My analyses are based upon the simple fundamental geologic fact that initially there was only a fixed and finite amount of oil in the ground, and that, as exploitation proceeds, the amount of oil remaining diminishes monotonically. We do not know how much oil was present originally or what fraction of this will ultimately be recovered. These are among the quantities that we are trying to estimate.”

“If oil had the price of pharmaceuticals and could be sold in unlimited quantity, we probably would get all out except the smell. However, there is a different and more fundamental price that is independent of the monetary price. That is the energy cost of exploration and production.”

Quotations from M. King Hubbert’s response to remarks by David Nissen, Exxon, 1982.
www.hubbertpeak.com/hubbert/to_nissen.htm

In essence, the message conveyed by M. King Hubbert’s extensive studies of growth and decline phenomena on this planet, exemplified by population growth in its biological systems - including homo sapiens - and the industrial extraction of minerals and fossil fuels, is shown in fig. 5.1. Regarding biological and physical resources, exponential growth can continue only for a limited period of time. Renewable resources, i.e. those regenerated by solar radiation in annual biological, hydrological and aerodynamic cycles, have upper limits, theoretically determined by the difference in entropy between the insolation and the heat radiation from the Earth to the universe, but in practice set by biological, technological and economic constraints. The production of exhaustible resources, such as conventional oil, will peak at a time determined by the marginal costs of producing another tonne or barrel by means of available technologies, as well as by the production capacity which is available or can be made available early enough to postpone the peak. Regarding oil, these economic conditions are mainly determined by the resources discovered, the amounts already produced, and the time and money it takes to add resources to the reserve base.

In 1956 Hubbert made his famous prediction that oil production in the US lower 48 states would peak around 1970, which indeed it did, see section 5.4, fig. 5.7. His prediction was based on the assumption that annual oil production in a region comprising a large number of oil provinces follows a bell-shaped curve, a Hubbert-curve, symmetrical with respect to the peak and covering an area equal to the ultimate reserves. It follows that the peak occurs when 50% of the ultimate reserves have been produced. Later he drew a

Hubbert-curve for world crude oil production, assuming ultimate reserves to be 2,000 Gb, see fig. 5.2.

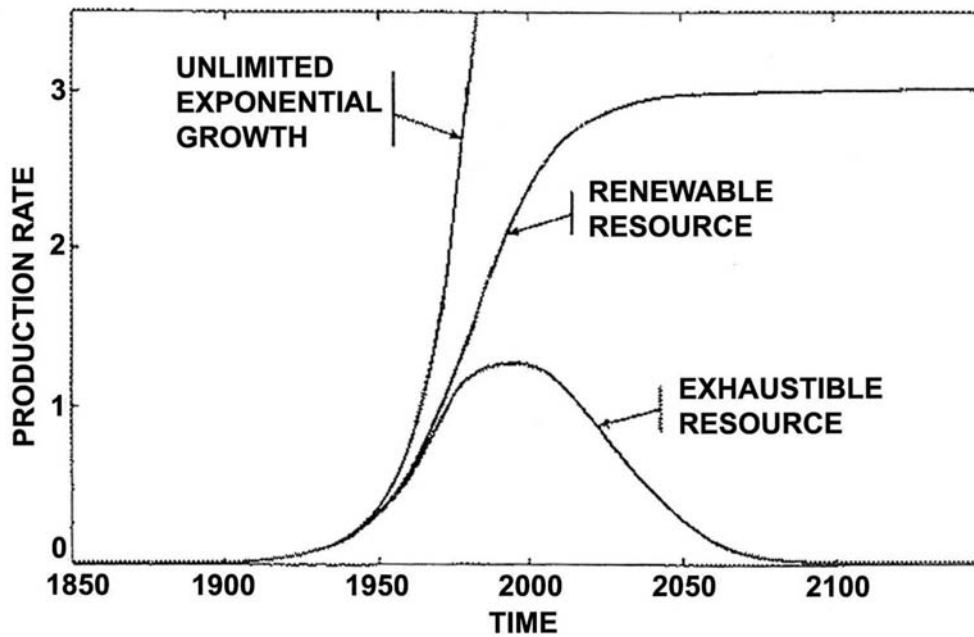


Figure 5.1 Three types of growth. (From M. King Hubbert: *Exponential Growth as a Transient Phenomenon in Human History*, 1974. www.hubbertpeak.com/hubbert/wwf1976)

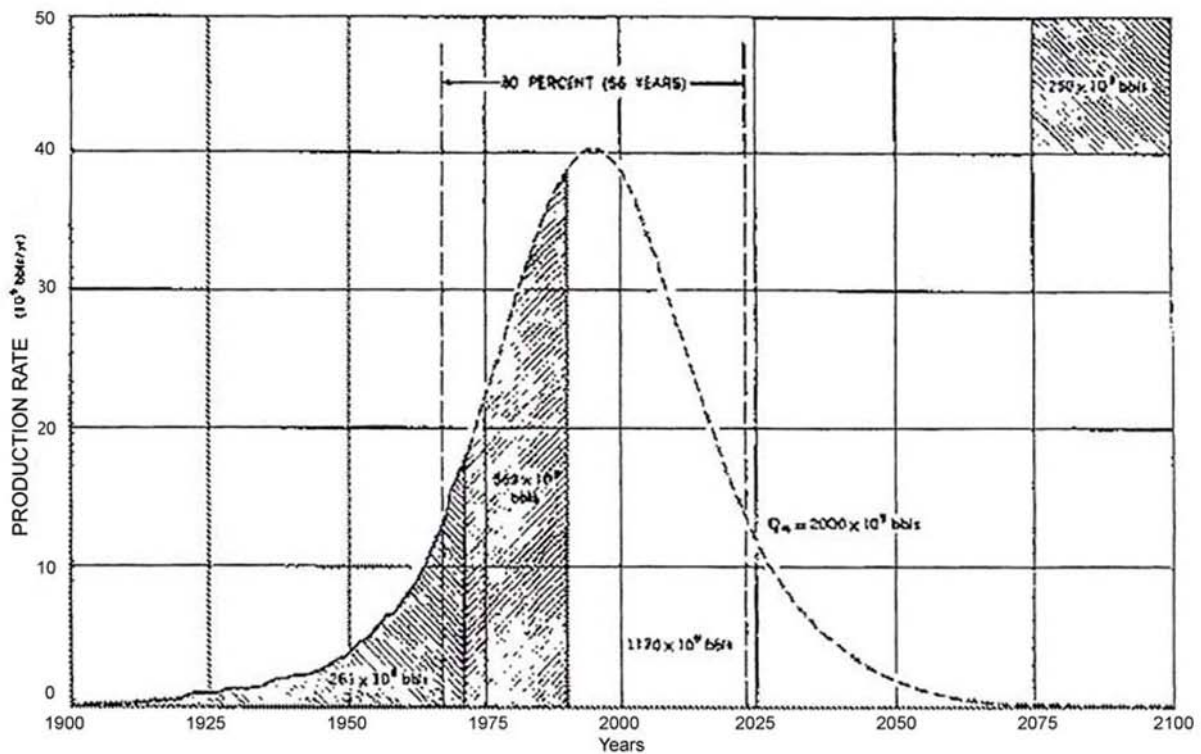


Figure 5.2 Complete-cycle curve for world crude oil production (ibid., Hubbert, 1974)

The Hubbert-curve corresponds to the derivative of the logistic, S-shaped, production curve shown in fig. 4.5.

As shown in fig. 5.2, Hubbert expected in 1974 that world conventional crude oil production would peak at about 110 million barrels per day (40 Gb per year) by the end of the century. However, he did not foresee that the sudden soaring of the oil price at that time would result in the plummeting of demand and production shown in fig. 5.3. Assuming that ultimate reserves are 2,150 Gb, as against Hubbert's estimate of 2,000 Gb, and that the peak occurs when 50% of the ultimate reserves have been produced, the peak occurs by 2012 as shown in fig. 5.3.

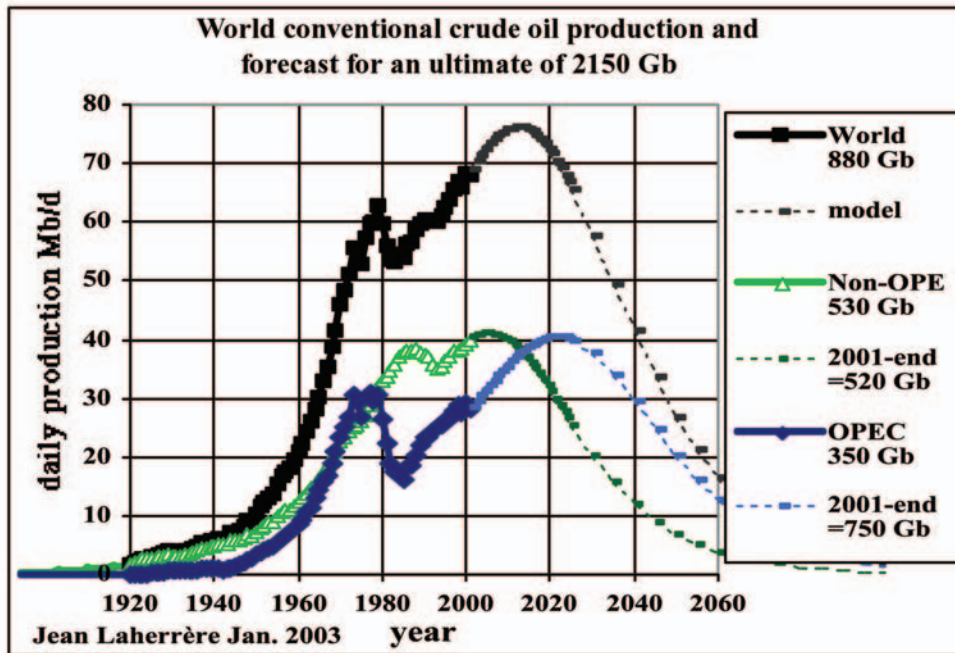


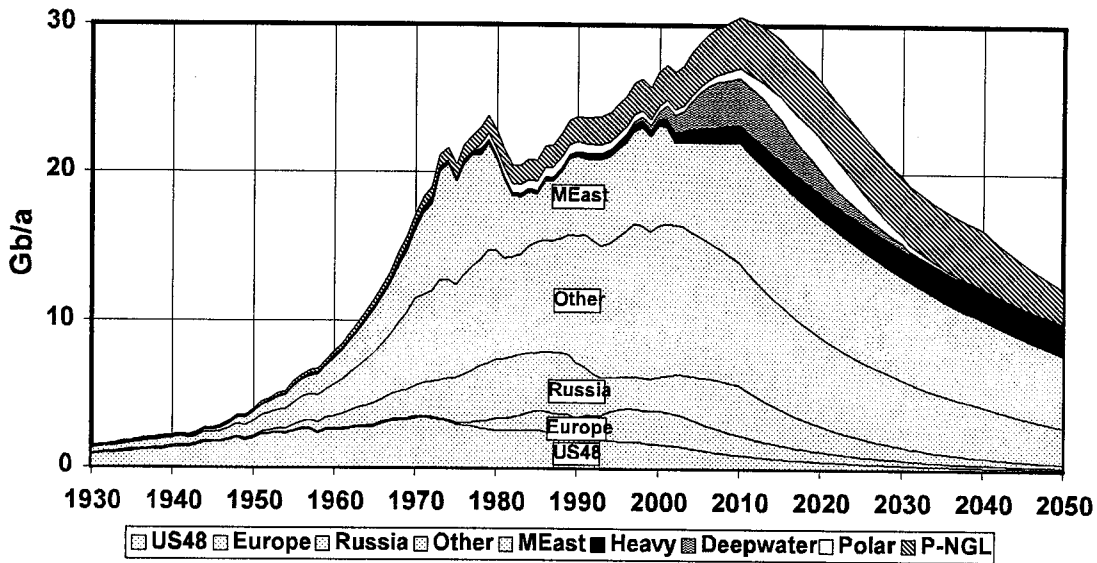
Figure 5.3 World conventional oil production for 2150 Gb of ultimate reserves. Jean Laherrère: *Future of oil supplies*. Seminar Center of Energy Conservation, Zürich, May 7 2003.

5.3 Campbell's depletion scenario

Campbell's depletion scenario, shown in fig. 5.4, is based on the data shown in table 4.1. In this scenario it is assumed that conventional oil production (called regular oil in fig. 5.4) remains constant at a level of about 22 Gb per year (60 million barrels per day) until 2010, whereupon it declines irrevocably at a rate of about 2% per year. The time (2008) when the decline in total conventional production sets in is determined by the production capacities in Russia and the Middle East, the production in the other regions being in decline before 2008. The Russian production remains almost constant until the decline sets in around 2010. The Middle East production grows by about 50% from 2000 to 2010 whereupon it remains constant until the decline sets in by 2025.

The growth in total oil production from 27 Gb/ year in 2003 to 31 Gb/ year in 2010 is covered by growth in non-conventional (non-regular) production (heavy oil, deepwater wells, polar oil fields, and natural gas liquids (NGL)). After 2010, total oil production declines at an annual rate of about 2%.

Oil & Natural Gas Liquids 2003 Base Case Scenario



PRODUCTION to 2075								
Amount		Gb	Annual Rate - Regular				Mb/d	
Regular Oil			Category	2005	2010	2020	2050	Total
Past	Future	Total	US-48	3.5	2.6	1.4	0.2	195
Known Fields	New Fields		Europe	5.1	3.7	1.9	0.3	76
896	871	133	Russia	8.6	9.4	4.9	0.7	200
All Liquids			M.E.Gulf	17	22	22	13	749
986	1714	2700	Other	26	22	17	8	680
Status end 2002			Total	60	60	47	22	1900
Base Case Scenario :			Annual Rate - Non-Regular					
Flat demand to 2010 for Regular Oil from recession. M.East Swing Role ends in 2010			Heavy etc	2.8	4	5	6	300
Regular Oil includes condensate but excludes liquids from gas plants			Deepwater	6.6	9	4	0	63
			Polar	1.2	2	6	0	30
			Gas Liquid	8.2	9	11	6	400
			TOTAL	78	83	72	33	2700

Figure 5.4 Campbell's depletion scenario, based on table 4.1. Reproduced from ASPO Newsletter No. 30, May 2003. (ASPO: The Association for the Study of Peak Oil)

Campbell foresees that the ability of Middle East producers to act as swing producers and thus to regulate the oil price ends in 2010. At that time global production will begin to decline although all producers will be producing at their maximum capacity. This means that as long as oil is traded on a free market, the upper limit of the oil price will be determined by the price elasticity of oil demand, which is small in the world community's affluent societies but high among the less prosperous. The consequences for the world economy are hard to predict, but a surge in capital flows to oil companies and oil exporting countries caused by a high oil price will have serious effects on the balance of payment accounts of many countries and it will become even more difficult to accomplish the UN poverty alleviation programmes. Eventually, a global economic recession caused by a

decline in oil supplies may, however, have relatively stronger impacts on the welfare of the affluent societies.

5.4 EIA's R/P based depletion scenarios

“A larger resource base generally leads to a later production peak. World oil resource base estimates have trended upwards over the years, from 600 billion barrels estimated in the early 1940's to as high as 3,900 billion barrels estimated this year by the U.S. Geological Survey (USGS).”

“To illustrate the important factors affecting estimates of the peak production year, EIA postulated 12 scenarios based on three current USGS world conventional oil resource base estimates (2,248, 3,003 and 3,896 billion barrels - corresponding to high, mean and low probabilities of occurrence) and for world oil production annual growth rates (0, 1, 2 and 3 percent)”.

“Using a relatively simple algorithm, peak production years were estimated.”

“EIA's relative optimism is based on:

- (1) use of the current USGS world conventional oil resource estimates, which are both larger and more technically sound than past estimates.*
- (2) use of a methodology for estimating the post-peak production path that is based on the reserve to production (R/P) ratio observed in the United States since oil production peaked in 1970.*

Other factors, e.g. choice of different production curve hypotheses, market dynamics, technological advances, and economic policies, could change the results, perhaps substantially.”

Excerpts from the executive summary of the EIA presentation “Long Term World Oil Supply (A Resource Base/Production Path Analysis” (2000). www.eia.doe.gov

In the presentation *Long Term World Oil Supply, 2000* (www.eia.doe.gov), the US Department of Energy's Energy Information Administration (EIA) presented a number of scenarios (see examples in figs. 5.5 and 5.6 below) which “*illustrate the important factors affecting estimates of the peak production year*”. The EIA uses a “*relatively simple algorithm*” to estimate the year when the peak occurs under different assumptions as to ultimate reserves, annual consumption growth rates, and production decline rates after the peak. Considering the results of these illustrative scenario computations, it declared its “*relative optimism*” regarding conventional oil supplies in the next decades, see the quotations in the box above.

Annual Production Scenarios with 2 Percent Growth Rates and Different Decline Methods

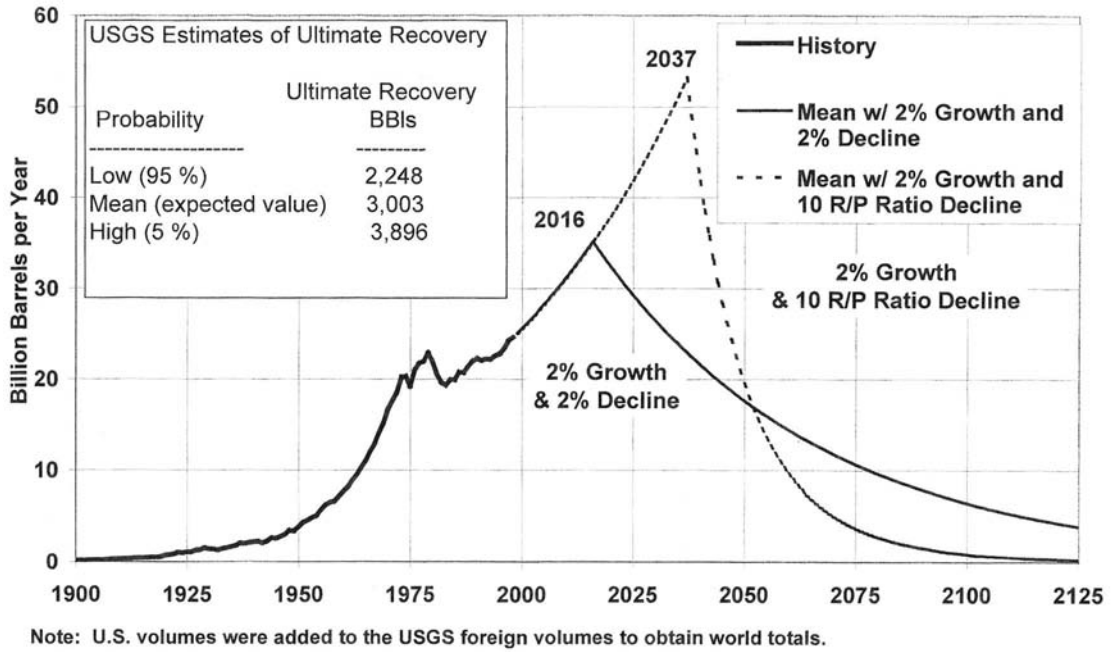


Figure 5.5 Conventional oil production scenarios. US Department of Energy, Energy Information Administration (EIA), 2000.

Annual Production Scenarios with 2 Percent Growth Rates and Different Resource Levels (Decline R/P = 10)

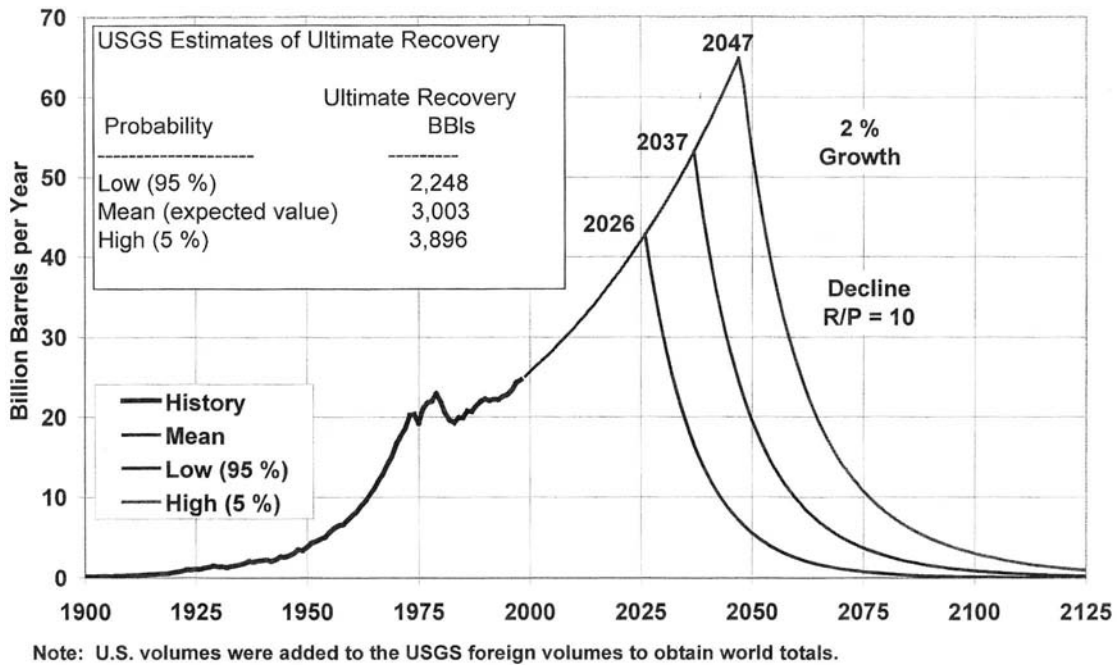


Figure 5.6 Conventional oil production scenarios. US Department of Energy, Energy Information Administration (EIA), 2000.

Note: In fact, the USGS does not estimate “Ultimate Recovery” or “Ultimate Reserves”. The amounts given in figs. 5.5 and 5.6 are potential reserves by 2025, see section 4.3.3.

In these graphs, the growth curve is the historical production curve extrapolated exponentially by a certain future growth rate (2% p.a. in the examples shown). The decline curve is either an exponential decline curve (decline rate 2% in fig. 5.5) or the graph of a constant R/P function (R/P= 10 in fig. 5.5 and 5.6). The “*relatively simple algorithm*” computes the time of the peak and the decline curve so that the area under the combined growth and decline curve equals ultimate reserves. In the constant R/P case, the decline function P is given as:

$$P(t) = k * R(t)$$

$$R(t) = UR - CP(t)$$

$$t > t_{\text{peak}}$$

where $P(t)$ is production (Gb/year) at the time (year) t ,

k is a constant (1/year), equal to 1/10 in the scenarios shown,

$R(t)$ is remaining reserves (Gb),

UR is ultimate reserves (Gb), and

$CP(t)$ is cumulative production (Gb) from 1900 to t .

Thus, given the growth rate until peak, the decline rate after the peak or the R/P ratio k , the algorithm simply performs an iteration procedure to compute the peak year - i.e. the point of intersection between the growth curve and the decline curve - so that the area under the curves equals ultimate reserves.

Provided that the assumption that global conventional oil consumption continues to grow at a constant rate until the peak occurs is realistic, the scenarios illustrate how the following assumptions and factors influence the peak production year:

- C the production growth rate before the peak occurs
- C the choice between the hypotheses:
 - (a) that the decline is exponential (constant annual decline percent)
 - (b) the decline function is a constant-R/P function
- C the assumed decline rate (a) or the R/P constant (b),
- C the ultimate reserve value

Thus, these scenario computations illustrate that when one adopts different, mathematically simple hypotheses as regards global growth and decline functions and different ultimate reserve estimates, the computations result in peak years ranging from 2016 to 2047 in the examples shown in figs. 5.5 and 5.6. As the hypotheses adopted are unverifiable⁵⁵ and the ultimate recovery estimates range from 2,248 Gb (95% probability) to 3,895 Gb (5% probability), the computational results do not indicate a time interval within which the peak is likely to occur. Naturally, the development in the global conventional oil supply in the next decades cannot be credibly assessed by means of a very

⁵⁵ It should be noted that in the constant-R/P scenario shown in fig. 5.5, the R/P ratio declines continuously from about 85 years in 2000 to about 15 years at peak time in 2037. At the peak a discontinuity occurs as the ratio suddenly drops to 10 years and remains constant from then onwards. No technical or geological reason for such a shift from continuous decline to a constant, lower level is given.

simple hypothetical model which describes global development in terms of a few aggregate parameters.⁵⁶

Regarding the R/P rate assumed in its scenarios, the EIA refers to the decline in US production since it peaked in 1970, implying that the decline in world production should follow a constant-R/P decline function with the same R/P rate as in the US. However, comparing the growth-and-decline curve for production in the US 48 Lower States, shown in the same presentation (see fig. 5.7), with the curves computed for world production (figs. 5.5 and 5.6), it appears that the curves are topologically different, the curve for the US 48 Lower having the shape of a Hubbert-curve, shifted about 12 years from the reserve growth-and-decline curve. Thus, the empirical evidence gained from the recorded development in the US 48 Lower does not support the constant-R/P hypothesis upon which the EIA scenarios are based.

The implications of the sudden shift from exponential growth to steep decline in the EIA scenarios are noteworthy. The curves depict a world economy becoming technologically more and more dependent on conventional oil until, suddenly, a steep decline in the supply of conventional oil sets in. At that time, no economically competitive alternatives to conventional oil are in place: If competitive alternatives were in place, the demand for conventional oil would not continue to grow exponentially. Thus, the scenarios depict a most unfortunate development resulting in a sudden, steep decline in the supply of a resource upon which the world economy at that time has become even more dependent than it is today.

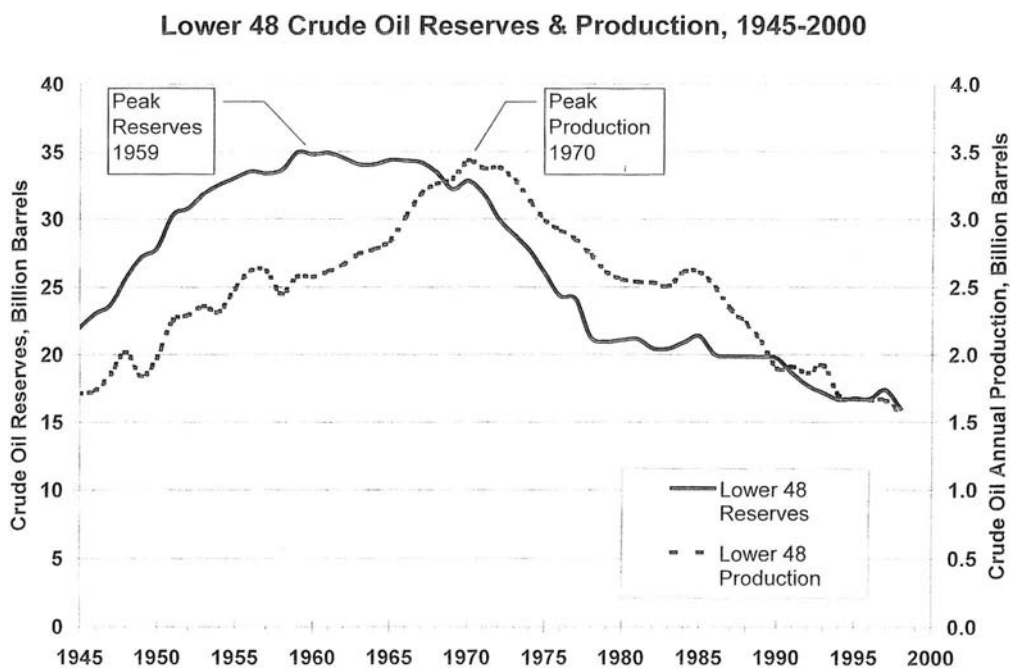


Figure 5.7 Conventional oil reserves, currently reported as proved, and production 1945-2000. US Department of Energy, Energy Information Administration (EIA), 2000.

⁵⁶The EIA claims that the current USGS conventional oil resource estimates are technically more sound than past resource estimates (see the box above). The USGS estimation method is described in section 4.3.3 above. The EIA does not give reasons why it deems this probabilistic method technically more sound than other methods which are based on empirical data.

5.5 OILPROSPECTS scenarios

Oil is a basic resource for the world economy. A decline in oil supply for which the economy is technologically unprepared will result in unforeseeable disruptions in every sector of the economy. Therefore, governments should not base technological development and technological infrastructure policies on scenario projections based on empirically unsubstantiated theoretical hypotheses as to future breakthroughs in reserve growth and production. Hypothetical breakthroughs which significantly change the trends observed in the past may occur. However, to rely on their occurrence is hazardous, considering what is at stake.

Therefore, a scenario model should be consistent with historical evidence and the trends which appear from historical recordings, unless there is credible evidence that such trends will change within the foreseeable future. Moreover, the manner in which basic geological and technological conditions for the future development in oil production are represented in the model should be explicitly specified. However, because of the uncertainties of the data and the hypotheses upon which scenario computations for the future are based, no additional information can be gained from more sophisticated mathematical models as compared to simpler models which are consistent and transparent.

Historical evidence and trends concern:

- C Past production in the existing oil provinces
- C The development in ultimate reserve estimates, including
 - reserve growth in existing fields
 - reserve growth by the addition of new fields.

See Chapter 4 above.

Basic geological and technological conditions to be observed concern:

- C Depletion of existing fields. At a certain time, production in an oil field begins to decline because of the lowering of the pressure and/or because water accumulated in the reservoir rock below the oil-filled layers reaches the boreholes. In some cases, pressure can be sustained for a longer time by the injection of pressurized water in the aquifer below the water-oil contact, gas in the gas cap above the oil-gas contact, or CO₂ into the reservoir rock. Thereby production can be maintained at a level near the peak level for an additional period of time. However, when the pressure eventually begins to drop irrevocably and/or water begins to fill the boreholes, the production drops more steeply.
- C Production in new oil fields. The production from new oil fields follows discovery with a certain time-interval. Production from the fields discovered in a certain year comes on-stream some years later, grows to a peak and then declines. Thus, at a certain time in future the total production from new fields, i.e. fields discovered after the present time, is the sum of the production functions (production as a function of time) for the new fields discovered before that time.

In order to examine on these grounds the prospect for the future balancing of oil demand and oil supply, a program OILPROSPECTS has been developed for the Danish Board of Technology and the Society of Danish Engineers.⁵⁷

⁵⁷ The author of the OILPROSPECTS program is Dr. Klaus Illum, ECO Consult, Denmark.
e-mail illum@post1.tele.dk

The OILPROSPECTS program computes scenarios for the future balancing of demand and supply on the basis of a set of variables specifying future demand and potential supply development. The values of these variables are chosen at runtime. Thus, for any proposition as to the variable values to be assumed, the future balancing of demand and production can be readily displayed.

The results of the scenario computations should not be interpreted as predictions. They show what could possibly happen. Meaning that if demand develops as specified in the input-data and future reserve additions and ultimate reserves happen to be as specified, then demand and supply can be balanced as shown by the computational results. Naturally, the results are of little interest if the assumptions made are quite unrealistic. However, the future is unforeseeable and, therefore, it is of interest to examine a range of possible scenarios for the future development, based on plausible assumptions.

The characteristic feature of the results shown below, is that although the production capacities in the different regions as well as the production from new fields follow smooth curves, total production capacity suddenly drops steeply.

A sudden oil shortage in a world economy in which demand is growing at low oil prices is a possibility which cannot be ruled out.

Regarding conventional oil, past production, existing reserves, yet-to-find reserves, present production, and production capacities, data can be entered for each country or for regions comprising a number of countries. In the examples shown below, the world is divided into 8 regions.

Non-conventional oil production is in this context oil production which is not included in the data specifying conventional oil production. It may comprise:

- Heavy and extra heavy oil, bitumen (from tar sands) etc.
- Deepwater oil
- Polar oil
- Natural gas liquids (NGL)

Present non-conventional oil production and forecasts for future production is specified as totals for the world as a whole.

An input-data file contains values of the following variables:

C Present global demand and future global demand growth rates. Different growth rates may be specified for different periods of time.

C For each country or region:

- Past production (Gb)
- Existing reserves (Gb, including reserve growth in existing reserves)
- Yet-to-find reserves (Gb)
- Present production (million barrels per day)
- Maximum production capacity, present and projected future capacities (million barrels per day). The specification of these values is optional but they should be entered for swing producers.

- A cumulative production to ultimate reserves ratio k . Production is assumed to peak at the time when $(\text{cumulative production}) = k * (\text{ultimate reserves})$. The Hubbert-theory assumes a k -value around 0.5 for large regions. The application of enhanced recovery techniques may increase the value, i.e. postpone the occurrence of the peak. (After a peak in production in a certain region has occurred, growth in production may be resumed after some time because new reserves have been found. Then, some time later, a new peak occurs. Such multi-peak cases are common but, naturally, unforeseeable. As they are unforeseeable singular events, they cannot be specified in the input-data file. However, past multi-peaks may be taken into account when specifying the k -value for a certain region or province.)

C For the world as a whole:

- Time-series data for the projected production of the different types of non-conventional oil.
- Present conventional oil discovery rate (Gb per year), as the past five-year average.
- The year when future annual discovery is assumed to peak. If the peak-year is later than the first scenario year, the discovery growth rate (zero or positive) until the peak-year is specified. After the discovery peak, annual discovery is assumed to be declining as described below.
- Data specifying assumed average production profiles for new field discoveries:
 - number of years from discovery until production begins.
 - the production curve, for simplicity assumed to be a parabola with a time span proportional to the reserves discovered.

For each year, all new field discoveries are aggregated to one virtual field discovery. The production from new fields is delayed if total conventional and non-conventional production otherwise exceeds demand. Therefore, generally the production curve for a new field will not be a parabola, although initially specified as a parabola. The parabola specification only serves to model a smooth development in the production from new fields, a development which is modified so as to balance total production against total demand. As shown in the examples below, this computational procedure results in a production curve for new fields which resembles a Hubbert-curve. Future production from new fields can by no means be exactly predicted. Hence, based on the assumed future reserve additions from new fields, this computational procedure is as reasonable as any.

Concerning existing conventional oil fields in a country or region, the decline function - i.e. annual production as a function of time after the peak has occurred - cannot be accurately predicted. However, it is reasonable to assume a logistic decline function (an inverted S-curve with a positive initial value and a zero initial decline rate which gradually increases to a maximum value and then decreases as the curve asymptotically approaches zero).

The area covered by the decline curve equals the reserves remaining at the time when the peak occurs. Under this constraint, changing the shape of the decline curve within reasonable boundaries has little effect on the projected production capacity.

After the peak in future annual discoveries has occurred, the new-discoveries function - i.e. future annual discoveries as a function of time - is assumed to be a declining logistic function, the area covered by the discovery curve being equal to total new discoveries. Thus, production from new discoveries follow a bell-shaped curve covering an area which is also equal to total new discoveries.

No theoretical hypotheses are inherent in this model, except the assumption that the decline functions are inverted logistic functions. The information gained from the scenario computations is consistent and conditional: *If demand growth, existing conventional reserves, yet-to-find reserves, non-conventional production, etc. assume the values specified in the data file, then demand and production will follow the curves shown in the result graphs.* The sensitivity of the results - the peak-year and the subsequent decline rate - with respect to the variable values assumed can be examined, simply by running the program with modified values.

Examples of scenario computation results are shown in figs. 5.8 and 5.9 below. Fig. 5.8 shows the results computed from the values shown in the 'Reserve and Production Assumptions' box. These values correspond to the values given in table 4.1 above. In fig. 5.9, demand growth is reduced to 1%/year and existing and yet-to-find reserves are increased by 20% as compared to the values shown in the box.

In both cases a sharp peak in total oil production occurs. Reducing demand growth from 1.6% to 1% and increasing existing and yet-to-find reserves by 20% postpones the peak by 5 years and reduces the decline rate after the peak from 1.3 Gb/year or 3.7%/year to 1.1 Gb/year or 3.1%/year.

In the different regions, enhanced recovery may postpone the peak and increase reserves. Plausible values representing such enhancements can be entered and effects computed.

The examples shown in figs. 5.8 and 5.9 should not be interpreted as forecasts. They are only examples which show that the occurrence of a sharp peak followed by a steep decline is consistent with assumptions which cannot be deemed implausible or unrealistic with reference to historical evidence or current reports from the industry.

The declining production curves for existing fields correspond to a post-peak Hubbert curve and the bell-shaped production curves for new fields resemble a Hubbert curve. Thus, figs. 5.8 and 5.9 illustrate that when Hubbert curves for several domains, here the domains comprising existing fields and the domain comprising new fields, are superimposed, the resulting production curve need not be a Hubbert curve.

Reserve and production assumptions

	Conventional oil, 2000				
	Produced Gb	Reserves Gb	Yet-to-find Gb	Production Mb/day	
Middle.East	225	483	43	22.0	
FSU	176	126	31	11.0	
Latin.America	102	84	18	8.0	
Africa	75	81	11	6.7	
North.America	187	28	7	5.5	
Europe	40	30	6	6.3	
Asia	40	28	5	4.0	
Other	27	22	23	1.6	
Total	872	882	144	65.8	
Other liquids. Production Mb/day:					
	Heavy oil, etc.	Deepwater oil	Polar oil	NGL	Total
2000	1.4	1.0	1.1	6.0	9.5
2005	2.8	5.6	1.2	8.2	17.8
2010	4	8	2	9	23
2015	4	6	4	10	25
2020	5	4	6	11	26
2025	5	3	5	10	24
2030	5	3	4	9	21
2035	5	2	3	9	19
2040	6	1	2	8	17
2045	6	1	1	7	14
2050	6	0	0	6	12
Total conventional production to date (2000) = 872 Gb					
Existing conventional reserves (2000) = 882 Gb					
Undiscovered conventional reserves (2000) = 144 Gb					
Total: Ultimate conventional reserves = 1898 Gb					
Other liquids produced before 2000 = 85 Gb					
Other liquids produced 2000-2075 = 473 Gb					
Total production of liquids until 2075 = 2456 Gb					
Initial new-findings rate (in 2000) : 10 Gb/year					

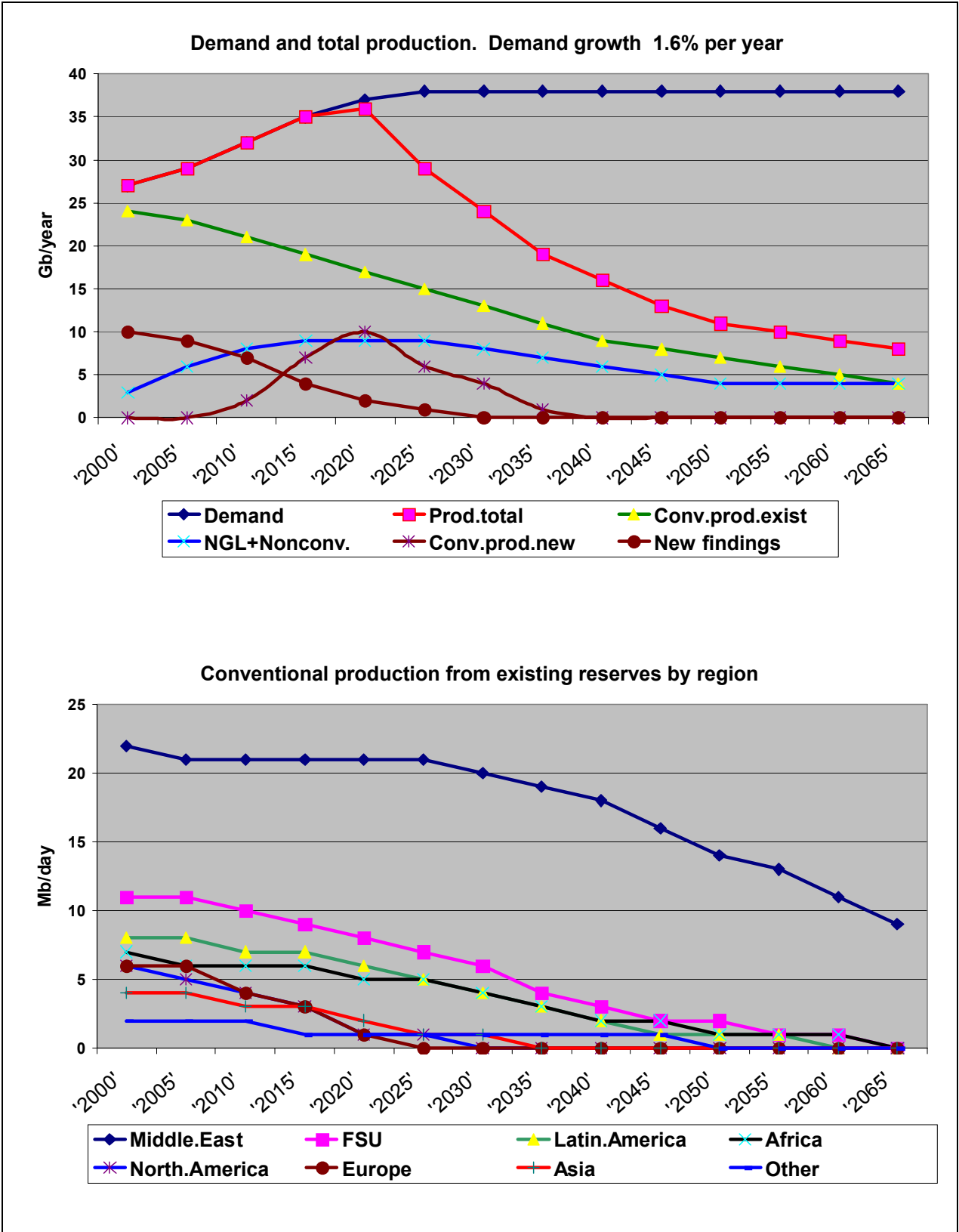


Figure 5.8 Demand and production scenario computed from the data shown in the box above and a 1.6% demand growth until 2030. In this example, it is assumed that production from existing reserves in a region begins to decline when 50% of the ultimate reserves in the region has been produced.

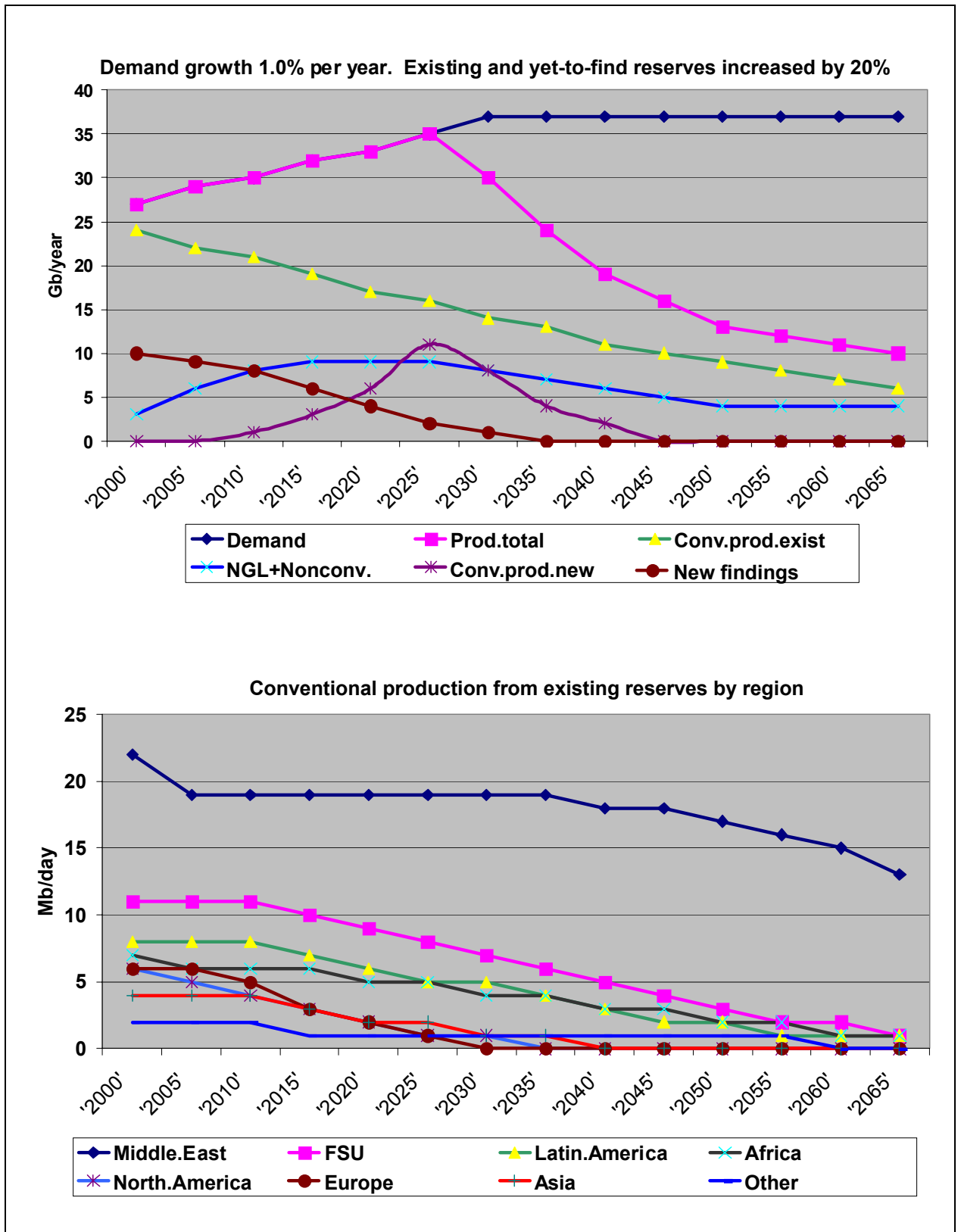


Figure 5.9 Demand and production scenario resulting from a 20% increase of remaining reserves (2000) and new findings as compared to the values given in the box above and a reduction in demand growth to 1%.

6. On the Economy of Oil

The economy of oil is not only the economy of oil supply. Even though the purchasing of oil from refineries worldwide amounts to only about 2% of the global GDP (the percentage being a little smaller in the developing countries than in the OECD countries), the economy of oil in the real sense of the term: the utilisation of this precious resource for the welfare of human societies, concerns every sector of the social economy.

The oil industry is an upstream industry with an annual turnover worldwide second to none. Its refinery products nourish the second largest industrial complex: the motorcar, lorry and aeroplane industries, including the military hardware industries. When you buy a car, you buy not only the vehicle produced in the factory but also what it takes to make use of the car for its lifetime: the maintenance provided by the garages into which the motorcar industry branches out; the building and maintenance of roads, bridges, parking lots etc., mostly paid as taxes, duties and tolls; and the gasoline to be bought at filling stations, which are the points where the motorcar industry and the oil industry are joined. The same goes for other vehicles and also for aeroplanes, using airports, maintenance hangars and oil bunkers instead of roads, garages and filling stations.

Thus the oil industry and the industries it nourishes form a widely ramified oil-technology complex or rather a cheap-oil technology complex, 'cheap' in the sense that the price of oil has not so far been so high as to be a limiting factor for the proliferation of the products of these industries.

6.1 On the economy of the cheap-oil technology complex

Because of the low costs of oil supply, the efficient use of oil has not been a high priority objective for the technological development of oil-consuming vehicles and machinery. Of course, the aeroplane industry, whose customers are not private consumers but the airlines, has sought to reduce fuel consumption per person-kilometre but speed has a higher priority. Regarding the transportation of goods, cheap diesel oil and access to public roads and motorways at low costs have given trucking an economic advantage in the competition with railways and ships.

6.1.1 Motorcars

Assume that the outlet price of a car is 30,000 Euro (the price of a medium size car in Denmark, incl. purchase taxes); that its lifetime is 15 years; that maintenance costs amount to 10,000 Euro, for simplicity assumed to be evenly distributed over its lifetime; that its total mileage is 300,000 km; that it does 15 km/litre of petrol; and that the consumer price of petrol is 1 Euro/litre, making the total cost of petrol 20.000 Euro. Depreciating the costs to present value at an interest rate of 5% p.a., the total consumer costs, excluding other taxes and insurance, become:

Purchase costs	30,000 Euro	59%
Maintenance	7,000 -	14%
Petrol	14,000 -	27%
<hr/>		
Total	51,000 Euro (present value)	
Total petrol consumption 20,000 litres		

Suppose that petrol became more heavily taxed so that the consumer price gradually over, say, 12 years rose to 3 Euro/litre while over the same period of time the purchase tax was reduced. This would induce consumers to look for more energy-efficient cars. The car industry might then develop a smaller, lighter, less powerful and less luxurious car with a petrol consumption of 30 km/litre which could be sold for 20,000 Euro, the purchase tax being lower and the car cheaper to produce. The cost account could then be:

Purchase costs	20,000 Euro	42%
Maintenance	6,000 -	13%
Petrol	22,000 -	45%
<hr/>		
Total	48,000 Euro (present value)	
Total petrol consumption 10,000 litres		

For most families, the smaller, lighter and less powerful car would serve their daily needs for transport at a lower total cost, consuming only half the amount of petrol. The taxation revenue would be the same or somewhat higher, in which case taxation of labour could be reduced. The annual turnover in the motorcar industry would probably be the same because some families would buy two cars instead of one in order to obtain more transportation flexibility without increasing their total annual mileage, which would be costly because of the high price of petrol.

A car which does 30 km/litre is a modest achievement for a modern car industry.⁵⁸ Cars doing 50 km/litre have already been built⁵⁹. Moreover, most motorcars on the roads worldwide today do less than 15 kilometres/litre of petrol. Thus, a 50% reduction of the oil consumption in motorcars is technically possible, even at increasing transportation volumes (as measured by person-kilometres), and - as illustrated by the examples above - a shift of taxation from purchases and labour to resource consumption could shift consumer preferences to energy-efficient cars or other less energy-consuming and more healthy means of transport.

⁵⁸ The *VW Lupo 3L Diesel* does 33 km/litre. A modified Renault Twingo, the prototype *Twingo SmILE* developed in a project initiated by GREENPEACE, achieved 30 km/litre of petrol.

⁵⁹ See for example: Ernst von Weizsäcker, Amory B. Lovins, L.Hunter Lovins: *Factor Four, Doubling Wealth, Halving Resource Use*, Earthscan, 1997, in which the Hypercar is described.

This means that at least 50% of today's oil consumption in motorcars or 25% of the oil produced (motorcars consume about 50% of the world's oil production) does not serve to provide comfortable, flexible transportation of persons but rather to satisfy a certain vanity attached to the car as a status symbol. A vanity the cultivation of which is affordable as long as the consumer price of gasoline is low.

6.1.2 Speed of long-distance transportation

High speed is a property of the cheap-oil economy. It is a noteworthy coincidence that the density of the atmosphere, determining the speed of sound, is such that the circumference of the Earth corresponds to the distance covered by an airliner travelling at the maximum subsonic speed in about 48 hours. Therefore, a holiday or business flight to the opposite side of the globe takes less than 24 hours. At the current price of jet fuel, quick long-distance holiday and business trips as well as shorter regional trips at this speed are affordable. Hence, the rapid growth in the aeroplane industry, the airport industry and the tourist industry in the last 40 years - temporarily slowed down after September 11th.

When the oil price grows by a factor two or three, speed becomes more expensive. On long-distance routes, slower but more energy-efficient turboprop planes could thus gain a competitive advantage against the faster jet planes, and on regional intercity routes modern trains could replace the airlines. Such a transition to more energy-efficient means of long-distance and regional transportation implies major changes in the products offered by the aeroplane industry, the railway industry and the tourist industry.

6.1.3 Trucking

The sections above summarise nothing but trivial observations of well-known characteristics of the cheap-oil economy. However, it is an even more trivial observation that the trucking of goods across countries and continents, which ensures that the market principle of comparative advantages for distant producers is adhered to, is conditioned by cheap diesel oil. Had diesel not been so cheap, producers of tomatoes, potatoes and apples in Southern Europe would not have comparative advantages as against local producers in Northern Europe. Milk would not be transported hundreds of kilometres from farms to dairies and from there to distant consumers. Flowers for Danish homes would not be raised in Holland while flowers from Danish nurseries are exported to Germany. Unless, that is, an efficient railway network ensuring that, for example, a container loaded on a train in Madrid would reach Stockholm within 48 hours had been developed. Such railway networks would save substantial amounts of oil, reduce air pollution, curtail traffic congestion, and lower maintenance costs of motorways and roads. The failure to develop such railway networks may prove a costly legacy of the cheap-oil era.

6.2 *On the new economy of oil supply*

Considering the oil industry's long production line from the exploration and development of oil fields to the transportation of crude oil in tankers and through pipelines to refineries and the final distribution to consumers, it is a remarkable achievement of the industry that it has so far been able to deliver petrol, diesel and fuel oil in time to meet the

growing demand all over the world. In other words, to ensure the matching of the oil market and the growing market for oil-consuming engines and boilers. Only when OPEC's national oil companies in 1973 restricted their production for political reasons, did temporary shortage occur.

However, the balancing of investments in the oil industry's production lines on the one hand and investments in production lines for oil-consuming machinery on the other has taken place under conditions which will not remain the same in future. As shown in figs. 4.3 and 4.4, most of the oil industry's easily accessible resource base was found between 1920 and 1980 and a substantial part of the present production comes from oil fields developed more than 30 years ago (see Matthew R. Simmons, section 1.3 above). As production from this aging resource base of cheap conventional oil begins to decline, the industry needs to make huge investments to meet future demand (see Harry J. Longwell, section 1.3 above). And, most importantly, when the Middle East swing producers, mainly Saudi Arabia, have exhausted their capacity and therefore no longer can compensate for disruptions in other countries' production (such as the disruptions in Venezuela and Iraq this year), it will become increasingly difficult to ensure that supply meets demand at all times.

In a recent article in the Oil&Gas Journal, A.M.Samsam Bakhtiari, the National Iranian Oil Co. Tehran, suggests that this situation could occur sooner than hitherto expected in spite of - or perhaps because of - investments made to increase the production capacity:

*"...even Saudi Arabia has its limits. These came to light during the 2003 war in Iraq. Pumping at full capacity, the Saudis could produce only 9.3 million b/d [barrels/day]. This prompted most institutions to downgrade Saudi oil production capacity from their lofty heights of 10.5 - 12 million b/d to a more realistic 9.5 million b/d, which is now accepted as the fresh standard for Saudi capacity. The Saudi problem is that output heavily relies on its unique Ghawar oil field. And Ghawar's sustainability is a well-kept secret. The only hint that there may have been problems was the drilling of some 200 horizontal wells in 1992-99. Although these new wells ushered in a recovery boom, they are a Damocles Sword hanging over Ghawar's head. For, as French petroleum consultant Jean H. Laherèrre pointed out: 'When the water level hits the horizontal well, it is finished. Ghawar has not yet peaked, but when it will, it is going to be a cliff'."*⁶⁰

In the same article, Bakhtiari reports from Oman:

"...Oman has been one of the great success stories of the past two decades. During the 1980s, Omani oil production gradually ramped up to 700,000 b/d from 300,000 b/d; then during the 1990s it continued to rise, reaching 960,000 b/d by 2000. Being outside OPEC's quota system, Oman could fully open its throttle. And it was no surprise that new records were set year after year, with Royal Dutch/Shell Group serving as technical advisor to Petroleum Development Oman I.I.C (PDO) - a joint venture of the government of Oman 60%, Shell 34%, Total SA 4%, and Partex (Oman) Corp. 2% - that controls roughly 94% of Omani oil output.

⁶⁰ A.M. Samsam Bakhtiari: *Middle East oil production to peak within next decade*. Oil&Gas Journal, July 7, 2003.

Then, abruptly, at the dawn of the 21st century, everything seemed to unravel for the PDO. Output began to plunge. Within two years PDO's black oil production had dropped to 703,000 b/d (Shell's target for 2003) from 840,000 b/d. Interestingly, all this is happening as about half of Omani proved reserves have been produced, as Shell said candidly that "the decline... (was) partly because of a poor understanding of reservoirs".

PDO pulled out all the stops to reverse the production plunge, applying enhanced oil recovery techniques, including gas injection at both the 181,000 b/d Fahud-Lekhwair and Natih fields and water injection at Saih Rawl. In addition, PDO drilled horizontal wells and implemented an underbalanced drilling program at Nimr and Saih Rawl fields, among others.

This application of EOR and advanced drilling technology might allow for some plateauing, but the inevitable decline may be irreversible, especially when bearing in mind that Campbell's estimate of Oman's "yet-to-find" reserves stands at only 1.6 billion barrels."

With these and other striking observations in the same article, Bakhtiari draws attention to the new conditions for the oil industry. Where oil has hitherto flowed in abundant amounts from old fields, substantial amounts of money must now be invested in Enhanced Oil Recovery techniques (EOR) to sustain the production capacity and gain access to additional reserves.

Other analysts point out that the replacement of depleted reserves is becoming more expensive and that the industry's expectations of lower oil prices in the coming years render the investments currently made insufficient to meet future demands. The *Oil & Gas Journal* (June 11 2003) reports a recent industry study giving evidence to this assertion:

"The worldwide oil and gas industry faces increasing challenges in replacing reserves and growing production, according to 2002 statistics from the Merrill Lynch Global Securities Research & Economics Group. Recently, companies have announced missed production targets and have slashed 2003 production forecasts.

.....

Although technological advances led to lower finding and development costs in the early 1990's, F&D costs have increased since 1997, Merrill Lynch analysts said in the May 29 report. Unless capital efficiency improves through renewed technology changes similar to those seen in the early 1990's, finding and development costs are likely to rise because of deteriorating returns within an aging resource base.

'Companies have already captured most of the benefits from earlier breakthrough technologies in mature areas, and are now required to increase their maintenance capital just to maintain production levels from their established production base', the report said.

.....

Despite the fact that oil prices have averaged over \$ 23/bbl since 1997 and \$ 28 since 2000, the integrated oil companies have established a normalized oil price of \$ 18 - 20/bbl in determining whether they will pursue new projects. Our view is that a normalized oil price in the \$ 24 - 26/bbl range is likely for the foreseeable future."

Nevertheless, the oil industry is making advances. *World Environment News* (London, 10 October 2002)⁶¹ reports on deepwater oil, which could increase global reserves by an amount corresponding to two years' consumption:

“The global oil industry, armed with ever-improving technology, is drilling deeper and deeper under the oceans for oil that could provide a welcome complement in coming years to OPEC energy, analysts say.

About 60 billion barrels of oil equivalent (boe) are proven to lie under the world's seabeds - mostly in waters off the Gulf of Mexico, Brazil and West Africa - and seismic studies show the possible presence of another 40 billion.

Oil equivalents include gas and analysts estimate that two-thirds of the deepwater reserves comprise crude oil.

‘Deepwater oil is the growth play in the oil industry’ said a recent Deutsche Bank report. ‘We believe deepwater is the lowest risk and best-returning growth play available to global oils’.

....with better technology, Deutsche Bank estimates average development costs halved from the 1980s to less than 4 \$ per barrel which is in line with conventional onshore costs.

And last year Unocal broke the three-kilometre barrier at a well in the Gulf of Mexico.

.....

Analysts say however that even the largest deepwater fields cannot have the cost advantage of producing conventional oil on land in countries such as Libya and Iraq, though taxation structures are usually more attractive than in most OPEC states.

And overall deepwater reserves are smaller. This means that deepwater oil is not an alternative but only a short to medium term non-OPEC solution to world supply.”

6.3 Administering a market with low marginal production costs

Before 1970, when US oil production peaked, the Texas Railroad Commission was accredited the responsibility of regulating US oil production by the issuing of production quotas so as to prevent the market from being flooded and the oil price to plunge. In other words, to administer a market where marginal production costs were close to zero.

In the 1980's and 1990's OPEC has played a similar role on the world market. Saudi Arabia, as OPEC's main swing producer with marginal production costs of about 1 \$ per barrel, ensured that the price of crude oil remained high enough to make exploration and development of offshore oil fields in the North Sea, the Mexican Gulf and off the West African coast profitable, yet not so high as to inhibit growth in the world economy. Apparently, a tacit agreement between the US and the House of Saud to this effect ensured that US interests in the Gulf's oil production, as enunciated in the 1980 Carter Doctrine, were not violated. This year Saudi Arabia helped to prevent a surge in the oil price when the oil production in Venezuela was disrupted and the invasion of Iraq almost brought the country's production to a standstill.

⁶¹ www.planetark.org/avantgo/dailynewsstory.cfm?newsid=18117

As Saudi Arabia is still the main swing producer, the marginal production costs of delivering an additional barrel of crude oil to the world market is presently only 2 - 3 \$. However, the average production costs in the world's oil fields are much higher, the costs being about 15 \$/barrel in some offshore fields. Moreover, the oil price must be relatively high (more than 20 \$/barrel, see table 4.4 above) to make it profitable for the oil industry to attain growth in global production or merely to sustain the production level by means of enhanced recovery techniques and the exploration and development of new oil fields in hostile and environmentally sensitive areas.

Therefore, although a relatively high price of crude oil means that oil exporting countries with low marginal production costs gain huge unearned incomes at the expense of the importing countries, it is a short-sighted strategy to seek to attain a low price by the elimination of the OPEC quota administration of producers with low marginal production costs.

As long as producers with low marginal production costs have the capacity to act as swing producers - as in the US before 1970 - their production must be administered by institutions such as the Texas Railway Commission and OPEC. Otherwise a plunging oil price will make the increasingly more costly investments in exploration, development and enhanced recovery techniques unprofitable. This would shorten the time until the peak in conventional oil production occurs and make the decline thereafter steeper.

However, Iraq may be the only country whose capacity as a low-cost swing producer could be increased within a few years. High hopes that unthrottled production in an Iraq outside OPEC⁶² would make the oil price plunge to about 15 \$/barrel and thus help to accelerate economic growth were expressed in the autumn 2002. However, as the consequences of such a low price for oil companies operating offshore in the Mexican Gulf, off the coast of West Africa and elsewhere were recognised, these hopes were no longer so loudly pronounced. In the meantime a surge in the Iraqi oil production has been postponed for some time. This should be a relief to the oil industry and to the oil-exporting countries, not the least Russia, whose economic recovery to a large extent depends on its oil export. For poor oil-importing developing countries it is bad news in the short run.

In his speech at the Copenhagen conference 2003, Peter Stewart⁶³ drew attention to the fact that the world crude oil price is determined by benchmark prices of crude from a few fields (Dubai, Oman, Tapis, WTI, Brent) which together produce less than 3% of the total global production, and that all these fields are in decline. As this has a distorting effect on the oil price, oil depletion is already an important issue regarding the proper pricing of crude oil on the market.

⁶² In an article titled *One Purely Evil Cartel* in Wall Street Journal, July 29 2003, editorial writer Claudia Rosett describes OPEC as “*a gang of price-fixing oil-rich thug regimes [who] meet to reinforce assorted terrorist-sponsoring tyrants at high costs to world consumers*” and translates the acronym as OPEC: the Outrageous Predatory Energy Cartel.

⁶³ *Mr. Peter Stewart*, Crude Oil Manager Europe, Platts Global Energy, McGraw-Hill Companies, London

6.4 Market experiments with the global economy

Governments should ensure that the demand for conventional oil peaks before conventional oil production peaks. They should also ensure a substantial decline in the CO₂ emission. Imagine, as an utopian thought experiment, that to these ends governments worldwide bring about a transformation of the cheap-oil technology complex to a much more energy-efficient technological complex, along lines such as those stipulated in section 6.1 above. The incentives used to induce industries and consumers to engage themselves in the process could be a shift of taxation from labour to resource consumption, the introduction of harsh energy efficiency standards, or some kind of rationing of oil consumption.

In a free oil market where the peak has not yet been reached, the decline in demand thus achieved will result in excess production capacity and thereby a decline in the price of crude oil. Under these circumstances, few investments in the exploration and development of new oil fields (conventional or non-conventional) or enhanced recovery in existing fields will be undertaken. Hence, a decline in demand may not significantly postpone the peak and it may not make the decline in production after the peak less steep.

Thus, if the peak is impending, it may occur at about the same time whether or not oil-saving measures are successfully employed. But, of course, if the surge in the oil price following the peak occurred at a lower production level and with less reserves having been depleted, the higher oil price would render postponed investments in additional production capacity profitable. After some years, production capacity might then again become sufficient to meet demand. However, as there would be no excess capacity it would be a seller's market where the price would be determined by the producers with the highest marginal production costs. The situation would be very much the same as today and a new peak would be imminent.

As a matter of fact, the experiment has already been made. In 1980, after a couple of decades with declining oil prices followed by a steep increase in 1973, OPEC staged a surge in the crude oil price, thereby causing a plunge in demand and, consequently, a plunge in production to the same effect as if a peak in production capacity had occurred. Thus, OPEC staged an artificial peak in oil production. The oil industry rushed to find new oil and gas fields outside OPEC; power utilities hastily switched from oil to coal or gas; and many oil boilers were replaced by gas boilers or electric heating. After some years new producers with production costs much higher than in most OPEC countries came on-stream. And, thanks to OPEC's production quotas, the market remained a seller's market where the price only occasionally dropped below the level at which costly offshore production was profitable. From a production level somewhat lower than it would have been without the OPEC-staged peak, production is now climbing towards an impending peak - which is not artificial.

However, the experiment made in the 1980's is unique. It cannot be repeated with the same outcome. When the real peak occurs there will hardly be another North Sea and Mexican Gulf to be explored and developed within a few years and there are few oil-fired power stations and boilers to be switched to coal or gas. There will still be oil, but there will be no swing producers around to adjust the price of oil produced from dwindling conventional reserves and whatever non-conventional reserves that may come on-stream.

Until the peak occurs, a continued growth in demand - meaning that the global economy becomes ever more dependent on a growing cheap-oil technology complex - can be met by supplies of cheap oil from conventional sources. Then, within a short period of time we may experience a drastic shift in the economy as oil becomes a scarce resource.

Suppose that conventional oil production declines by about 2% or about 0.7 Gb/year while demand grows by 1.5% or 0.5 Gb/year, and that heavy oil from tar sand should close the gap between demand and conventional oil production. Then 15 tar sand pits of a capacity of 0.08 Gb/year (the capacity of Shell's tar sand pit in Alberta, see section 2.2.1) with refineries and pipelines would have to be opened every year. If it were technically possible and environmentally acceptable to increase the oil production capacity from tar sand at this rate and in such a manner that production could be sustained once the surface layers have been mined, it would imply a drastic change in the oil economy.

The industry would have to spend large amounts of money on investments in non-conventional oil production. At the same time, as the oil price surges, the national oil companies of the OPEC countries would gain large additional unearned profits from cheaply produced conventional oil. In this context, the outcry against OPEC (see footnote to section 6.3 on the Wall Street Journal article 'One Purely Evil Cartel' above) can be understood: The argument is that the private oil industry, not the OPEC countries's national oil industries, should gain these profits so as to obtain the financial means to invest in expensive non-conventional oil production without having to borrow the petrodollars (or petro-Euros as it could be at the time) from the OPEC countries. Thus, when there is no more swing production capacity, the role of the OPEC countries becomes financial rather than regulatory.

Moreover, the increase in oil price would result in a lower or even negative growth in demand. This implies a lower or even negative growth in the world economy as long as the economy depends on oil supply to sustain the functioning of the cheap-oil technology complex. In the course of a number of years, new technologies and infrastructures driven by other energy sources may come into place, making the economy less dependent on oil. However, as long as oil is cheap, such new technologies will not be introduced on the market. Therefore, when the peak occurs, there will be no production lines ready to supply such new technologies. Money for these investments will have to be raised at a time of economic recession.

Thus it appears that the shift from growth to decline in the production of cheap conventional oil entails a host of environmental, economic, political and technological problems to be solved within a short period of time. Just to wait and see which solutions may turn up is to wait to see the uncertain outcome of a hazardous experiment.

