OIL RESOURCE ESTIMATES--
HOW MUCH DO WE KNOW?

Susan Arthur

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INTERNATIONAL INSTITUTE FOR APPLIED SYSTEMS ANALYSIS
A-2361 Laxenburg, Austria

PREFACE

A key unknown in energy studies and forecasts is the ultimate amount of recoverable oil. Numerous estimates have been made over the last thirty years. Recently many researchers in oil resources have claimed that estimators have reached a consensus of opinion at around 2000 billion barrels of recoverable oil, including past production. Other researchers claim that estimates have risen steadily over the last 30 years and will continue to do so. These two views naturally lead to very different outlooks for an oil future.

In this report we take a short, critical look at a long series of oil resource estimates. We conclude that neither the consensus view nor the steadily rising view of estimates can be corroborated. Instead, one must accept a wide interval of possible values for total recoverable world oil resources. In addition, we indicate some biases and shortcomings of oil resource estimates in general which should be kept in mind when judging any such estimate.

IIASA has been involved for several years, through the work of Michel Grenon and his WELMM group, in looking at world mineral resources. This report goes hand-in-hand with the earlier work. It is based upon and analyzes the survey work of the WELMM group with respect to oil resources.

Janusz Kindler
Chairman
Resources & Environment Area

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The statistical interpretation presented in this short essay is based almost exclusively on the information collected by Michel Grenon and his group at IIASA. The work would not have been possible without Grenon's exhaustive and informative survey paper on ultimate world oil resource estimates, forthcoming EPRI Report TPS80-763.

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At the core of the energy problem is the limited nature of the world's fossil fuel resources, especially oil resources. But just how limited are oil resources--how much oil is down there? This question can, of course, never be answered exactly and we are left with estimates. How good are these estimates? How much can we trust them?

Two views on resource estimates have begun to emerge recently. The first, held by a large number of researchers, is that a consensus of opinion has been reached--a consensus at about 2000 billion barrels of ultimately recoverable oil (including past production and known reserves). Studies of possible energy futures tend to accept this figure, erecting long-term energy forecasts and policies upon it. But the consensus view has been vigorously challenged by an opposing view. A few researchers, in particular Odell (1973), Odell and Rosing (1975, 1980), and Schubert (1980) feel that estimates have been increasing steadily, and will continue to do so for some time. This short study takes a critical look at both these points of view, and at oil resource estimates in general, asking in effect: How much do we really know?

WORLD OIL RESOURCE ESTIMATES, 1946-1980

There is certainly no shortage of oil resource estimates. Forty-two estimates made since 1946 are detailed in the Appendix. Figure 1 displays these estimates chronologically, showing how they have changed over time.* Estimates are of ultimately recoverable oil, including past production and known reserves.

What can one discern from this dense collection of figures? It is clear that uncertainty about ultimate oil resources has not decreased in the last thirty years--indeed, the present range of estimates is larger than ever. And certainly the upper limits to speculation have dramatically increased, especially in the last five to ten years. Apart from these two observations, it is difficult to see what inferences to draw from a diagram such as Figure 1.

Evidence for an increasing trend is very weak in the data of Figure 1. Only inclusion of the low, pre-1950 estimates would give significance to the kind of linear fit proposed by Odell and Rosing. Estimates for the last twenty years would hardly corroborate any regression line except one with zero slope. The jump in estimates between 1950 and 1958 was undoubtedly due to the introduction of offshore sources. It is certainly possible that similar jumps in estimates may occur along with major improvements in recovery practices or major new finds, but there is no evidence, among the estimates in Figure 1, for a steadily increasing trend. A different collection of estimates might, of course, give better support for a linear trend. I try to cover this possibility, in the next section, by looking at independent estimators only.

What of the view that a consensus of opinion has been reached? The idea of a consensus or convergence of estimates has been prevalent in the oil literature since it was first mentioned by Warman in 1972 and Hubbert in 1973. It was certainly given additional

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*These estimates are from a study by Michel Grenon (forthcoming EPRI-Report TPS80-763), with the addition of the estimate by Styrikovich (1976, 1977).

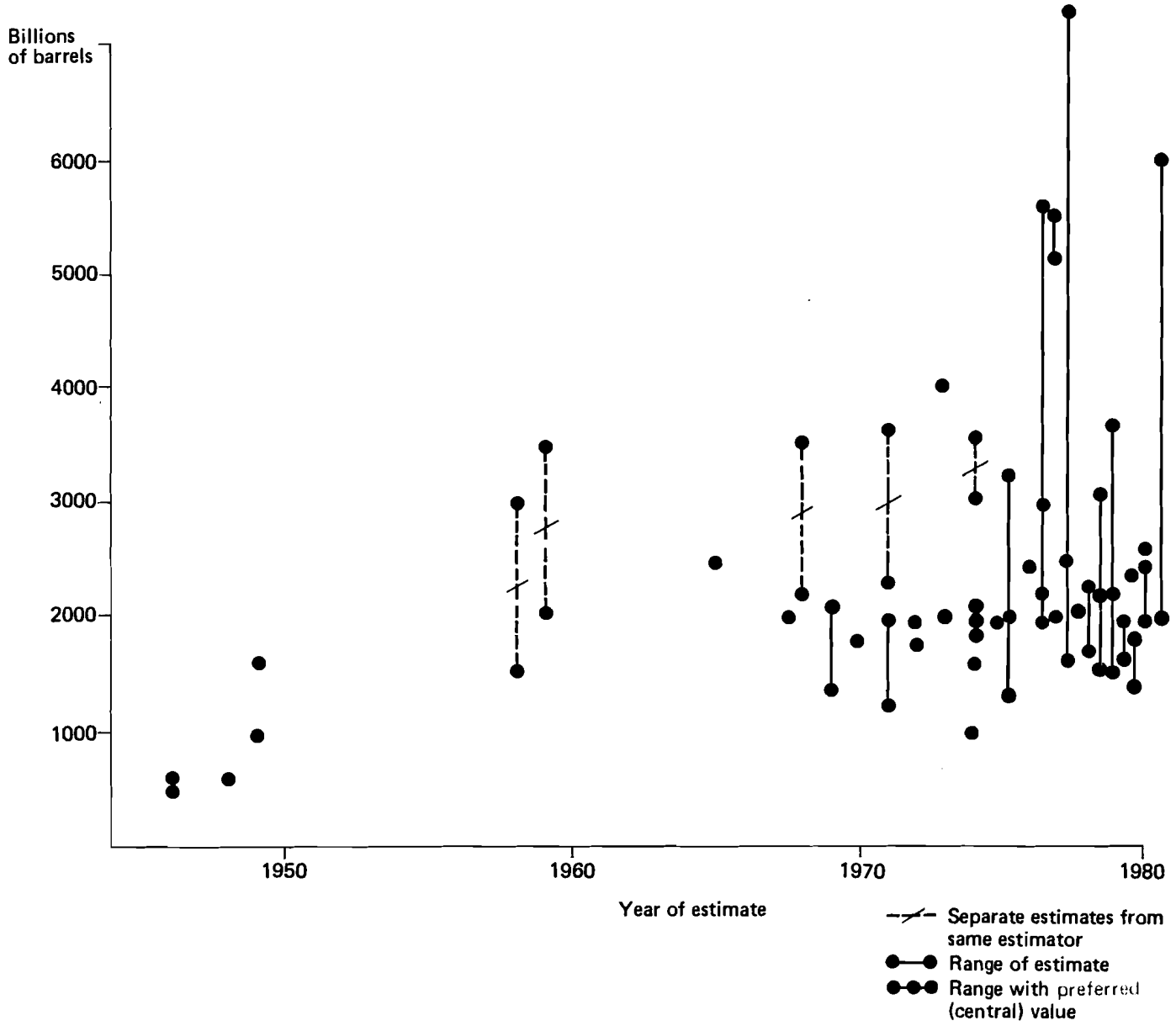


Figure 1. World oil resource estimates, 1946-1980.

impetus by the influential 1975 estimates of Moody and Geiger and of Moody and Esser, all of which were centered near 2000 billion barrels, and is now the most prevalent view of the state of oil resource estimation.

As shown in Figure 1, very many estimates since 1971 have indeed clustered around 2000 billion barrels. However, one must be careful in judging such a cluster to be evidence for a consensus. The similarity of estimates for world totals hides gross underlying differences, in regional estimates and in the proportion of ultimately recoverable oil assumed to come from already-discovered as opposed to undiscovered sources. For example, Nehring (1978) estimates total ultimate recoverable oil resources at 1700-2300 billion barrels, of which 263-555 billion barrels are to come from as-yet-undiscovered sources. Moody and Esser (1975) estimate a similar expected total of 2000 billion barrels. But here an expected 963 billion barrels are to come from as-yet-undiscovered sources. Such smoothing out in the grand total of major differences in sub-totals leaves room for doubt. Does a consensus actually exist, or is it a self-perpetuating artifact?

In judging evidence for either the consensus view of the increasing trend view from lists of estimates such as those in the Appendix, a major difficulty lies in the interdependence of the estimates. Some estimates are updates of earlier estimates made by the same researcher, some rely on regional estimates from an assortment of studies, some are reworkings of earlier estimates using, for example, different recovery rates, and some are, like this study, simply analyses of previous estimates. A second difficulty is that estimates are not wholly comparable. Different resource definitions and different recovery rates are used. Some estimators include polar and deep offshore oil, others do not, and so on. The effects of dependence and non-comparability cannot be entirely removed, but they can be somewhat mitigated. Once some of these effects are removed, we will see that there is little evidence for either a consensus figure or for a linearly increasing trend in estimates.

INDEPENDENT WORLD ESTIMATES

Grenon (forthcoming EPRI Report TPS80-763), who has also pointed out the importance of looking at independent estimates, has identified seven independent estimators (geological or statistical/geological methods only). They are Hendricks, Weeks, Moody, Jodry, the West German Geological Survey (Bundesanstalt für Geowissenschaften and Rohstoffe), Grossling and Nehring. For the purposes of this study Jodry was excluded because there is only a second-hand reference to his method (Hubbert 1974), and the West German Geological Survey because it uses regional estimates from various other sources. Styrikovich was not included because of lack of information on his method. This leaves five estimators since 1958--authors of major, well-documented studies, using widely varied methods of estimation. Their estimates are reasonably, although not totally, independent of other workers. (Moody, for example, cross-checked his results using King Hubbert's method of extrapolating from existing production data.) Note that three of the five estimators (Hendricks, Grossling, and Nehring) were not associated with any oil company.

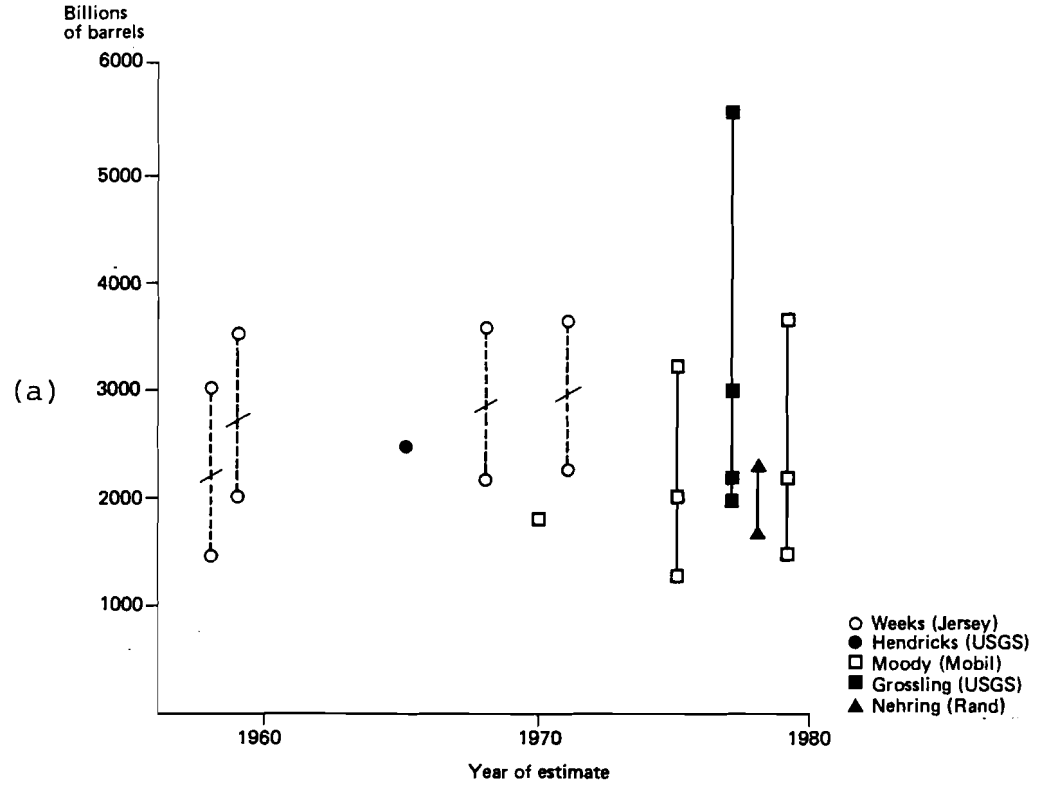
The group of independent estimators is listed in Table 1 and shown chronologically in Figure 2a. In Figure 2b we have attempted to make the set of independent estimates more comparable. Only the most recent estimate for each estimator is shown. A single value was chosen to represent each range. In choosing the value we have tried to standardize, as far as possible, to a recovery rate of 40%. For Grossling this was not possible, and two values were chosen--the midpoint of each of his two ranges of values. For Moody the expected value was taken as representative, for Weeks the secondary recovery value (compatible with 40% recovery), and for Nehring the midpoint of the range.

There is little evidence in Figures 2a and 2b of the increasing trend hypothesized by Odell and Rosing. One would expect such a trend to be particularly apparent in updated estimates such as those from Weeks and Moody, but even these two series show only small increases. (Two estimates made by Weeks in 1948 and 1949 are much lower than the post-1958 estimates due to lack of knowledge of off-shore potential. The four later estimates, spanning thirteen years, are surprisingly stable.)

Table 1. Independent geological estimators of world oil resources, 1958-1980.

Estimator	Estimate	Comments
Weeks (Jersey, later consultant)		
1958	1500/3000	Primary recovery only/primary and secondary
1959	2000/3500	" " " "
1968	2200/3550	" " " "
1971	2290/3650	" " " "
Hendricks (U.S. Geological Survey)		
1965	10,000/6200/(2480)	Oil originally in place/ ultimately discoverable/ (if 40% recovery)
Moody (Mobil, later consultant)		
1970	1800	
1975 (& Geiger)	2000	
1975 (& Esser)	1317-2000-3237	Probability range. Middle number is expected value.
1975 (& Esser)	1705-2030-2505	40% recovery.
1979 (& Halbouty)	1500-2200-3700	
Grossling (U.S. Geological Survey)		
1977	2200-3000/1960-5600	Two separate ranges given.
Nehring (Rand)		
1978	1700-2300	Method based on giant fields. Ultimate recovery: 40-50% for U.S.; for world maybe higher.
1979	1600-2000/(2100-2500)	Revision with no explanation, so not included in following analysis. (If major breakthrough in recovery technology)

(a) All estimates



(b) Summary estimates (40% recovery)

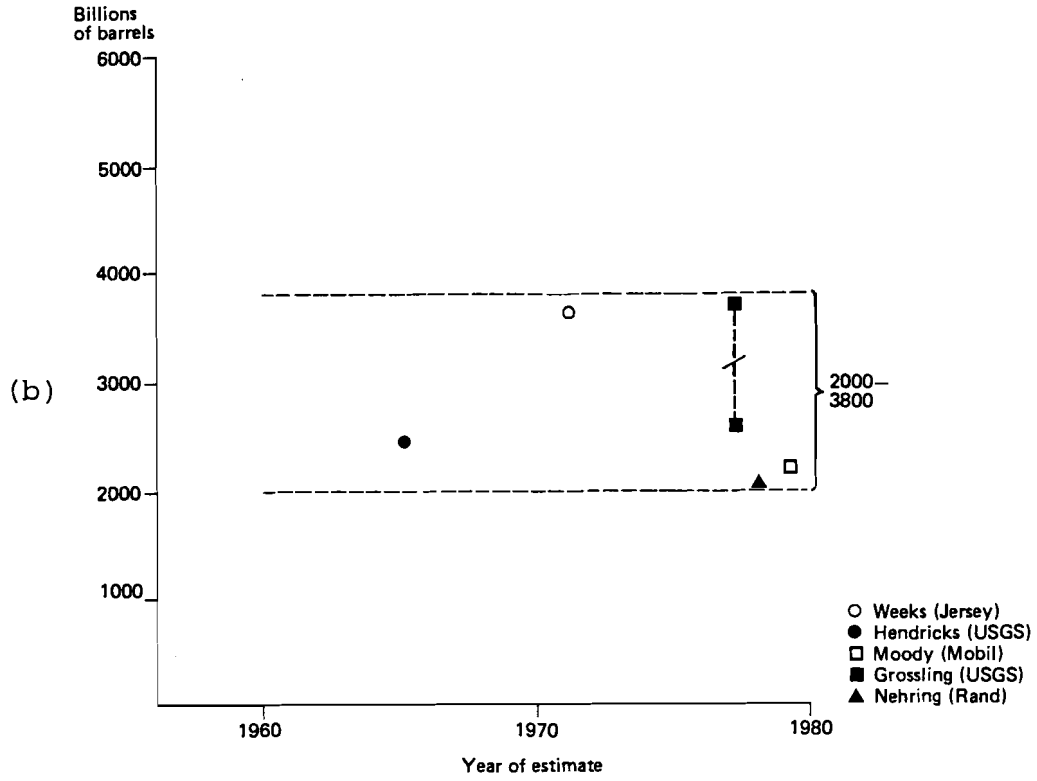


Figure 2. Independent world oil resource estimates, 1958-1980.

Figures 2a and 2b show very clearly the lack of any sort of "consensus" among the independent geological estimators of world oil resources, or even among the oil company estimators. (It is interesting that Moody and Nehring, the two estimators who come closest to the 2000 billion barrel mark, show particularly large discrepancies in the sub-totals. These discrepancies show up in regional sub-totals as well as in the amounts of oil estimated to come from as-yet-undiscovered sources, as mentioned earlier.) Instead of a consensus, we find a very wide range of opinion, with the highest summary estimate (3800 billion barrels) nearly twice the so-called consensus figure. The spread of estimates is so wide that use of a single value such as 2000 billion barrels is clearly misguided--it implies a much higher level of certainty than actually exists. The best we can do is to offer an interval which includes the bulk of the independent estimates.

A suggested "central" interval, 2000-3800 billion barrels, is marked in Figure 2b. A wider interval, including upper and lower limits of the five independent estimators, and including almost all of the original forty-two estimates, is 1300-5600 billion barrels. It is important to note that the left-hand limits of these intervals are very much firmer than the right-hand limits. Speculation on upper limits has been as high as 7300 billion barrels (Desprairies' Delphi study 1978). The intervals are summarized in Table 2.

Table 2. Intervals for ultimate world oil resource estimates (in billions of barrels)

Firm Lower Limit	Central Interval	Upper Limits to Speculation
1300	2000-3800	5500 Styrikovich 5600 Grossling 6000 Odell, Rosing 7300 Desprairies' Delphi Study

REGIONAL ESTIMATES

World oil resource estimates are clearly in a state of disagreement. What about regional estimates? One would expect that for at least some well-explored areas (such as the U.S. and Canada), we would have more precise estimates. Unfortunately, this is not the case. A detailed collection of past and present regional estimates will not be listed here. But to give the reader a brief idea of the extent of uncertainty in regional estimates, we present results of the Delphi study made by Desprairies (1978).

The study consisted of two questionnaires sent to forty-two oil experts, asking for estimates of world oil resources broken down by region. The second questionnaire allowed modification of estimates in light of the answers received on the first round. Twenty-nine answers were received to the first questionnaire, twenty to the second.

There are some major disadvantages to this type of study. Participants are anonymous, that is, they are not linked to their estimates. And they are busy. For both these reasons estimates are certainly much less carefully thought out than when a researcher spends a year or more on a study that will bear his name. Estimates may also be more likely to tend to a common value, as participants reach for the same well-known papers on world oil resources as starting points. Indeed, the object of Delphi studies is to reduce disagreement. However, despite these disadvantages, such a study does offer a large set of readily comparable regional estimates.

The regional estimates from the Delphi study (in this case estimates of resources remaining to be produced) are shown in Table 3. Although one would expect this type of study to understate the true uncertainty, notice that the magnitude of uncertainty suggested by the range of values is extremely large. It is very large even for relatively well-explored areas. We can conclude that uncertainty in world estimates cannot be attributed to lack of knowledge in a few unexplored areas.*

*Note that adding the minimum values and maximum values for each region is not an appropriate way to suggest a range for world estimates.

Table 3. Regional breakdown of Delphi oil resource estimates (in billions of barrels).

Region	Minimum* Estimate	Maximum* Estimate	Size of Range* (max-min)	Median Estimate
USA & Canada	45	366	321	198
Latin America	58	402	344	146
Western Europe	37	161	124	73
USSR, E. Europe & China	200	704	504	432
East & South Asia (incl. Japan, Australia, New Zealand)	40	219	179	95
Middle East & North Africa	401	2195	1794	732
Africa South of Sahara	20	293	273	66
Deep Offshore & Polar	0	1683	1683	179

*Tabulations originally done by M. Grenon in gigatonnes (forthcoming EPRI Report TPS80-763).

SOURCES OF UNCERTAINTY AND BIAS

We have so far taken oil resource estimates at face value, looking at the range of estimates as an index of uncertainty. It is time to look a bit more critically at the estimates, identifying some possible biases and overlooked sources of uncertainty.

In estimating world oil resources, two major sources of uncertainty are:

-- the amount of undiscovered oil; and
-- ultimate recovery rates

The studies considered in this report concentrate effort on estimating the first of these, the amount of undiscovered oil. The importance of estimating ultimate recovery rates has been largely overlooked. Studies tend to assume a value for ultimate recovery rates rather than addressing the problem directly. But recovery rates are themselves uncertain, and will make a large difference to the amounts of oil ultimately available for use. Each one percent increase in recovery rate will increase total recoverable oil resources by one percent.

At the moment recovery rates are about 25-30% (Desprairies 1978). Forty percent represents a lower limit to most opinions on ultimate recovery rates. Nehring (1978) foresees possible rates of 50% or more. One researcher (Moore 1962) has estimated the ultimate recovery rate for the U.S. at 65-85%. To see how influential the recovery rate can be, note that our central interval, 2000-3800 billion barrels, based on 40% ultimate recovery, becomes 2500-4750 billion barrels if ultimate recovery reaches even 50%.

Both oil discovery and recovery rates will be heavily influenced by world oil prices. Certainly this point, if not appreciated before, should be obvious since the advent of OPEC. However, the importance of oil prices has been almost totally ignored by estimators of oil resources, except in the studies by Desprairies (1978) and by workers at the West German Geological Survey (Barthel et al. 1976). This seems to be a critical oversight of almost all oil resource estimates.

Oil, and oil expertise, is dominated by large international business organizations. The majority of world oil resource estimates are made by these companies, and some inevitable biases result. First, oil companies tend to have a short-term view and are far more interested in reserves than resources. Where they are interested in resources, it is not the actual amounts that are of interest, but the relative quantities to be expected in various regions--that is, where the relatively best opportunities for new discoveries lie. This purpose is openly acknowledged. As the well-known consultant Weeks puts it, his estimates are "primarily for quantitatively rating basins of the world" (1953), and are "aimed at efficiency in expenditure of the exploration dollar" (1968). Putting these relative regional estimates together to form a world estimate is often an afterthought.

Second, since estimates are aimed at exploration investments, oil companies are highly sensitive to political limitations. There is a strong tendency to underestimate amounts of discoverable or recoverable oil in areas where companies have suffered under political restrictions, or have been nationalized. This seems to have been the case for Latin America, and a large part of the Third World. For a fuller discussion of this point, see Odell (1980).

Finally, oil company estimates are often presented without any details on the method or data used. This is at least partly due to the feeling that these are "company secrets", to be used in making exploration investments. As Warman (1971) says, "It is not...discrete as an employee of an actively exploring oil company to review in detail the prospects of oil discovery around the world." This attitude is understandable, but it does make judging the accuracy of estimates very difficult.

CONCLUSION

It is clear from this short, critical look at oil resource estimates that both world and regional estimates are very uncertain. Estimates cover a wide range of values--there is no evidence for a consensus of opinion. Nor is there strong evidence for a steadily increasing upward trend. Factors such as ultimate

recovery rates and economic feasibility are, in general, inadequately taken account of. And many biases remain. In short, what we know about ultimate oil resources is surprisingly little. Energy studies must, for now, allow for the fact that the best we can do is talk about a wide interval of possible values for the world's ultimate conventional oil resources.

APPENDIX. World oil resource estimates (in billions of barrels), 1945-1980.*

Year	Researcher	Organization	Estimate	Comments
1946	Duce	Aramco	500	
1946	Pogue		605	
1948	Weeks	Jersey	610	
1949	Levorsen	Stanford Univ.	1625*	Introduction of off-shore sources
1949	Weeks	Jersey	1015	Comment on Levorsen
1958	Weeks	Jersey	1500/3000	Primary recovery/primary and secondary
1959	Weeks	retired	2000/3500	Primary recovery/primary and secondary
1965	Hendricks	U.S. Geological Survey	10,000/6200 (2480)	Oil originally in place/ultimately discoverable (if 40% recovery)
1967	Ryman	Jersey	2090	Not published; referred to by Hubbert (1969)
1968	Weeks	Consultant	2200/3550	Primary recovery/primary and secondary
1969	Hubbert	U.S. Geological Survey	1350-2100	Based on Weeks and Ryman
1970	Moody	Mobil	1800	
1971	Warman	British Petroleum	1200-2000	Includes analysis of other estimates
1971	Weeks	Consultant	2290/3650	Primary recovery/primary and secondary
1972	Warman	British Petroleum	1800	Anal. other estimates; first mention of consensus
1972	Jodry	Sun	1952	Not published; referred to by Hubbert (1974)
1973	Hubbert	U.S. Geological Survey	2000	Based on Warman and probably Jodry. "Convergence of estimates"
1973	Odell	Erasmus Univ.	4000	Extrapolation to year 2000 of regression line based on series of estimates
1974(a)	Parent, Linden	Inst. of Gas Technology	3000 (4000)	No info. on method (if recovery > 45%)
1974(b)	Parent, Linden	Inst. of Gas Technology	3580	Uses several data sources

*Estimates from M. Grenon, "A Review of World Hydrocarbon Resource Assessment", EPRI report TPS80-763 (forthcoming) except for estimate by Styrikovich.

Appendix (continued)

1974	Hubbert	U.S. Geological Survey	1800-2000-2100/2500	Analysis other estimates. /If natural gas liquids incl. "Convergence of estimates"
1974	Kirkby, Adams	British Petroleum	1600	Analysis other estimates. "Consensus"
1974	Mackay, North	Bank of Montreal, Carleton Univ.	1000-1050	Uses oil discovery rates from Warman
1975	Odell, Rosing	Erasmus Univ.	4000	Confirmation 1973 estimate
1975	Moody, Geiger	Consultant, Mobil	2000	Monte-Carlo simulation
1975(a)	Moody, Esser	Consultant, Mobil	1317-2000-3237	Probability interval. Middle number is expected value.
1975(b)	Moody, Esser	Consultant, Mobil	1705-2030-2505	Probability interval (95%-50%-5%)
1975	--	Exxon	1948	Discussions at IX World Petroleum Congress. No info. on method
1976	Barthel et al.	W. German Geol. Survey	2445	Various sources for data, incl. Moody
1976	Grossling	U.S. Geological Survey	2200-3000/1960-5600	Two separate ranges given
1976	Styrikovich	USSR Academy of Science	5100-5500	Considered "cautious" by estimator (quotes 9000 bbl estimate by M.S. Modelevsky, but no exact reference or year)
1977	Parent, Linden	Inst. of Gas Technology	2000	Analysis other estimates
1977	Desprairies	French Petroleum Inst.	1600-2500-7300	Delphi study, 29 estimates
1978	Nehring	Rand	1700-2300	Emphasizes giant oil fields
1979	Wood	Cities Services	1500-2200-3100	Probability interval (90%-50%-10%)
1979	Halbouty, Moody	Consultants	1500-2200-3700	Update previous Moody est. Probability interval (90%-50%-10%)
1979	Nehring	Rand	1600-2000	Revision
1979	Bois et al.	French Petroleum Inst.	2340	
1979	--	Exxon	1350-1850	No info. on method
1980	Parent	Inst. of Gas Technology	2053-2446	Update. Analysis other estimates
1980	Schubert	W. German Geol. Survey & World Energy Conf.	2584	Various data sources
1980	Odell, Rosing	Erasmus Univ.	2000-6000	Based on past estimates

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