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THE DEPLETION AND PROVISION OF PETROLEUM RESERVES IN THE LIGHT OF GROWING DEMAND - THE NEXT THIRTY YEARS

by

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SUMMARY

The exponentially growing demand for petroleum as one of the most important primary energy components is fast depleting the world's discovered reserves. Large new reserves of these fuels will need to be found by exploration and augmented by improved recovery techniques.

Potentially vast resources lie under the ocean bed in sediments of the continental shelf and beyond. Secondary, tertiary, and further recovery techniques should add more reserves providing they are economically feasible, price being the critical factor. Australia has already found substantial oil and gas reserves offshore - about four times those onshore - at lower overall exploration effort and in shorter time. Much larger potential resources are indicated on the Australian continental shelf. Current oil prices do not encourage wide application of tertiary recovery techniques, but the escalation of world oil prices may change this.

Coal, heavy oil, oil shale, and tar sands will become important sources of liquid and gaseous fuels in the future; economics will decide how soon and to what extent.

Nuclear and solar forms of primary energy are distined to satisfy our future energy requirement to a significant extent.

Petroleum may be more effectively used in the protein foods manufacture of petrochemicals, fertilizers, etc. than as an energy source.

1. INTRODUCTION

The basic premise concerning mineral resources, including petroleum, is that irrespective of their magnitude they are non-renewable and therefore subject to depletion. Natural processes which may be involved in the generation of petroleum in Recent sediments are so slow as to be of no significance whatever in the replacement of reserves at a rate sufficient to maintain current and future demand. It follows that it is only a matter of time either that all natural resources will be completely exhausted or that the cost of finding and developing any remaining resources will become prohibitive.

Although inevitable, this terminal situation is by no means just around the corner, neither is it likely to develop suddenly in the future. The accelerating world demand for petroleum in the coming decades will be met by the geographically and environmentally extended, intensified, and improved science and technology of exploration, development and recovery, conservation, and partial or total substitution by other forms of energy. The process of phasing out of petroleum, and of crude oil in particular, from the primary energy field is unavoidable not only because it is becoming dearer and more difficult to find, but also because it is wasteful to burn it instead of using it for the manufacture of more valuable petrochemical products.

2. DEMAND, DEPLETION AND REPLENISHMENT

2.1 World

The rate at which world petroleum reserves have been depleted reflects the continuous and accelerating demand for this important fuel. If the 7 percent annual rate of growth in demand for crude oil were to continue in the future ' ..... demand would double over the next decade, expand eight-fold over the next generation, and more than a thousand-fold

in one century'[1]. Another source [2] has reported a much higher annual growth rate - between about 11 and 13 percent - over the 1966-1970 period. George Weber [3] has estimated the 1980 world consumption of oil and natural gas liquids at about 86 x 10^6 barrels per day, amounting to some 4.3 x 10^9 t in that year, and the total demand in the ten-year period to 1980 at some 230 x 10^9 barrels or 30.86 x 10^9 t, which about equals the cumulative oil production of 110 years to 1970. Warman[4] has indicated an annual world oil production in the 1990's of the order of 50 x 10^9 barrels or 6.71 x 10^9 t, and a requirement to find some 1100 x 10^9 barrels or 143 x 10^9 t of new oil reserves by the end of the century to maintain a ten-year reserves/production ratio. This means that the world petroleum industry will have to discover and prove in the next 30 years reserves of oil some 35 percent larger than those found in all its history to date, with ' ..... all the easy areas ..... gone'. [5]

Natural gas is not so critically placed as crude oil; gas appears to occur more widely and its reserves are being depleted at a slower rate than those of oil; substantial reserves are being found more frequently in many new areas. This, however, is a very generalized observation; in large sedimentary areas of our globe gas has not yet been found, and in some areas, e.g. U.S.A., reserves are being depleted faster than they can be found. As the role of natural gas in the overall energy requirement is fast becoming of great importance and transportation restrictions are being rapidly overcome, its consumption, with the attendant depletion of reserves, will correspondingly accelerate. The contribution of natural gas to the primary energy output in the non-communist world has been estimated by Symmonds [6] to escalate as follows:

(a) NON-COMMUNIST WORLD

YEAR	BTU x 10^{15}	KJ equivalent x 10^{15}	CUBIC METRES REQUIREI x 10^9
1960	14.5	15.4	410
1970	28.3	30	802
1975	38.2	40.5	1082
1980	50.1	53	1419

In the Soviet Union[7] the following picture emerges:

(b) U.S.S.R.

1960	1.8	1.7	45.3
1970	7.8	7.4	198
1971-75 Plan	11.6	10.9	310
1980	19.8	18.7	500

So, the combined natural gas production in 1980 of the "free world" and the Soviet Union only* may be of the order of 1920×10^9 m^3 or 72×10^{15} kJ. Assuming a continuing average 10 percent annual increase of demand for natural gas the combined production in 1990 would be of the order of 4920×10^9 m^3 or 185×10^{15}kJ and in 2000 would be $12{,}820 \times 10^9$ m^3 or 480×10^{15}kJ. The corresponding accumulative production in the 1971-1980, 1981-1990, and 1991-2000 decades would be 16.64×10^{12} m^3 or 623×10^{15}kJ, 33.4×10^{12} m^3 or 1250.4×10^{15}kJ and 86.7×10^{12} m^3 or 3242.8×10^{15}kJ respectively. The 2000-2010 decade production is extrapolated to amount to 224.8×10^{12} m^3 or 8410×10^{15}kJ.

The world** recoverable gas reserves at the end of 1970 were estimated [8] to be of the order of 1482×10^{12}ft^3 or 42×10^{12}m^3 (1571×10^{15}kJ). Were there no significant additions, these reserves would not last for 20 years and would become exhausted before 1990. In order to prevent this, new reserves would have to be found and developed many years (the more the better) ahead of that time. Assuming this advance period to be the next decade it

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*Only scanty information concerning China's natural gas production and reserves is available to the author. Also, information on natural gas in most East European countries is sketchy. (Pierre Berard in an article entitled 'La Chine Face aux Problems de l'Energie' in the house magazine of Compagnie Francaise des Petroles - Total Information 1972 No. 49 - estimates China's gas resources as $500{,}000 \times 10^6$m^3 or 17.657×10^{12} ft^3 in 1970 and those of crude oil, as $10{,}000 \times 10^6$ t or $74{,}454 \times 10^6$ barrels. Current production of natural gas runs at about 4000×10^6m^3 or $141{,}256 \times 10^6$ft^3. Crude oil production is given as follows: 0.3×10^6 t or 2.236×10^6 barrels in 1950, 8.5×10^6 t or 63.36×10^6 barrels in 1965, and 25×10^6 t or 186.35×10^6 barrels in 1971).

**Excluding China and most East European countries.

would be necessary to find and desirable to develop 86.7 x $10^{12}m^3$ of reserves by 1990 and 224.8 x $10^{12}m^3$ by the end of the century. In other words, between now and the year 2000 it would be necessary to add to the 1970 reserves some 319 x $10^{12}m^3$ of new reserves - a 7.6-fold increase.

2.2 Australia

Australia's consumption of equivalent crude oil to meet local demand for petroleum products in the 1960/61-1969/70 period amounted to 1292.5 x 10^6 barrels or 173.4 x 10^6 t, and the forecast consumption in the decade to 1979/80 is 2553 x 10^6 barrels or 342.5 x 10^6 t[9]. Extrapolating at a 6.5 percent annual increase, the 1980/81-1989/90 requirement will be 4763 x 10^6 barrels or 639 x 10^6 t, and in the following ten years 8942 x 10^6 barrels or 1199 x 10^6 t. The cumulative 30-year requirement would amount, then, to 16,258 x 10^6 barrels or 2181.1 x 10^6 t.

Part of the requirement would be met from the production of reserves already proven, and the balance from imports and from reserves which may be found and developed in the future.

Out of the aggregate crude oil reserves of 2075 x 10^6 barrels or 278.4 x 10^6 t proven to date, 66.5 x 10^6 barrels (8.9 x 10^6 t) were produced by mid-1970, leaving 2008.5 x 10^6 barrels or 269.5 x 10^6 t for further recovery. At an estimated average daily production rate of 330000 barrels or 44272 t (120.5 x 10^6 barrels or 16.2 x 10^6 t per annum over the 10-year-period to 1979/80) some 1205 x 10^6 barrels or 161.7 x 10^6 t would be produced in that decade, leaving about 803 x 10^6 barrels or 107.8 x 10^6 t, the recovery of which would exhaust the available proven reserves well before the end of the 1980/81-1989/90 decade. The overall deficit in the 30-year period to the end of the century, to be made up by imports and/or finding and developing new and additional reserves, would amount to some 14250 x 10^6 barrels or 1911.7 x 10^6 t - seven times the amount of oil reserves proved to mid-1972.

Australia's consumption of natural gas in 1971 amounted to some 86 x 10^9ft^3 or about 2.43 x 10^9m^3. Assuming the average annual increase in the 1971-1980 period to be 20 percent and then declining to an assumed world average increase of 10 percent per annum over the next 20 years,

the total requirement to the year 2001 would be about 30 x 10^{12} ft^3, or about 0.85 x 10^{12} m^3 - slightly more than twice the size of Australia's proven gas reserves to date. In the absence of further additions the reserves would be exhausted early in the 1990-2000 decade.

However, the magnitude of the currently indicated gas reserves, to be proven onshore and offshore, is much greater than the suggested deficit, and as petroleum exploration continues, further gas reserves will be added; not only will Australia's needs be satisfied, but also considerable volumes of gas will be available for export.

3. SOME BASIC SOLUTIONS

The purpose of these extrapolations is to illustrate the immensity of the task facing the petroleum industry in its endeavour to satisfy the exponential growth of demand for its products in the next thirty years.

How is this task to be accomplished? An obvious answer lies in the finding and developing of new reserves and more efficient and economical exploitation of found reserves - an elementary philosophy of all extractive industries concerned with the depletion of their basic material.

In the U.S.A. new petroleum reserves have been categorized [10] and annually reported as those resulting from discoveries of new pools in old fields and from extensions to known and partly developed fields. Additional reserves result from the improved development of discoveries and extensions, largely by the application of secondary and tertiary recovery techniques.

3.1 Finding New Reserves

Discoveries of new fields and pools are the result of successful exploration programs; they will have to be considerably more successful than hitherto in terms of frequency and magnitude of discoveries. The problem is formulated in the following comment by L.B. Curtis [11]: 'In eras past we were confident that a new and adequate crude oil supply was just another "basin" or a "little geology" away.....However, as consumption rises, the incremental addition to reserves with each new find or improved recovery has less effect on the dynamics of the system. It becomes a smaller and smaller part of the total.'

As for magnitude, various authors have pointed out that the greater portion of world's petroleum reserves is located in a relatively limited number of giant fields of 500 x 10^6 barrels (67 x 10^6 t) or more of ultimately recoverable oil reserves and 3.5 x 10^{12} ft^3 (0.1 x 10^{12} m^3) of gas reserves. The subject of giant oil and gas fields and geologic factors affecting their occurrence and formation, and criteria for their prediction, has received a great deal of attention[12] [13] from some evinent geoscientists in the U.S.A., U.S.S.R., Poland and others.

Areas where giant accumulations of oil and gas may be found on land include some still unexplored basins in South America, Africa, and Asia - including China and parts of the Soviet Union - as well as those of the Ar, and Antarctic regions. Hitherto, these areas have received little or no attention from explorers because of their remoteness, hostile natural environment, unfavourable sociological and political conditions, etc. Eventually, however, we must greatly intensify and extend our search for and development of petroleum reserves offshore in the sediments of the continental margin and even parts of ocean deeps. Since the 1940's large reserves of petroleum have already been found and developed in many parts of the continental shelf. Currently about 13 percent of world oil and gas production is obtained offshore, and it is estimated that by the end of this decade about one third of the world production will come from the continental terrace [14]. Weeks [15] has estimated that in the part of the continental terrace to the 500 m bathymetric contour, there are some 1,550 x 10^9 barrels (208 x 10^9t) of potential petroleum resources (expressed as oil equivalent) made up of 790 x 10^9 barrels (106 x 10^9 t) of petroleum liquids, 400 x 10^9 barrels (53.7 x 10^9 t) of petroleum gas, and 360 x 10^9 barrels (48.3 x 10^9 t) of secondary-recovery oil; they constitute about one half of the petroleum resources on land estimated by the same author. It must be understood, however, that these figures are relatively speculative and do not necessarily represent economically recoverable reserves.

It is tempting to speculate on Australia's offshore potential petroleum resources using Weeks' figures adjusted to the 200 m isobath, which give the total world continental shelf area as some 17.33 x 10^6 sq. km. Assuming that the Australian continental shelf area of 2 x 10^6 sq. km [16] is sufficiently large to be representative of the world continental shelf area (26 x 10^6 sq. km to 300 m line and 17.33 x 10^6 sq. km to 200 m line) the calculation of Australia's petroleum potential on the continental shelf would be as follows:

$$1550 \times \frac{17.33}{26.00} \times \frac{2}{17.33} = 120 \times 10^9 \text{ barrels} = 16 \times 10^9 \text{ t}$$

of oil equivalent. This is roughly 12 times the aggregate of proved and probable reserves of petroleum liquids and gas which may be estimated to have been found to date beneath the Australian continental shelf.

Exploration and development of petroleum resources in sediments of the continental shelf is only an early stage of the quest for energy supplies. R.H. Beck (17) has expressed the view held by a growing number of geoscientists by concluding that '.....attractive hydrocarbon prospects do not end or even necessarily diminish at the edge of continental shelves.....even in this century the deeper oceans will satisfy an important part of the world's hunger for energy'.

However, operations in waters beyond the edge of the continental shelf become much riskier, and infinitely more costly and more difficult. A. Bouillot (18) has voiced the views and experience of the offshore operators by pointing to technological and economic limitations to drilling and production operations imposed by deep waters, so that '.....only very big fields are commercial discoveries'. The conclusion is valid so long as the price of petroleum remains largely unchanged - an unlikely situation.

An optimistic view of offshore petroleum potential is justified in the light of the accumulating evidence that the continental terrace contains on the average a greater thickness of young sediments than the adjacent continents; bearing in mind that about 70 percent of world's oil and gas production is attributable to sediments of Tertiary and younger Mesozoic ages, the implications of the situation are obvious. Weeks (15) gave reasons why many factors favour the offshore over the onshore; included in his list is a record of much larger wildcat success ratios, larger average size of discoveries, and larger average yields per acre and per well drilled. Other factors mentioned are lower geological and geophysical costs, and rapid (but not cheaper) drilling of many wells from a single platform. The marine environment favours the planning and execution of efficient exploration and early achievement of success (18).

The abovementioned conclusions have been amply confirmed on Australia's Gippsland and Northwest shelves, where by late 1971 nearly three quarters of the country's petroleum resources had been found in Tertiary and Mesozoic sediments [19]. The energy value represented by these offshore resources amounted to some 50×10^{15} kJ. Since then, further discoveries of oil and gas have been recorded offshore as well as on land, and it would not be unreasonable to estimate Australia's petroleum resources today to be of the order to 100×10^{15} kJ, of which more than 80 percent are located offshore. It was pointed out [19] that the first expenditure on offshore expenditure in Australia, amounting to only $300000, was incurred in 1960; it was less than 2 percent of total exploration costs for that year. The first offshore well was spudded-in only four days before the end of 1964. To the end of 1971, offshore exploration amounted to $290.66 million, 120 wells and 1099367 feet (335071 m) of hole. In the same period, onshore exploration costs amounted to $383.18 million, 955 wells and 5267632 feet (1605496 m) of hole. Table I gives annual comparisons of these two sets of figures.

3.2 Improving Recovery

An important source of petroleum reserves is to be seen in additions of significant amounts of liquid petroleum obtained through the application of improved recovery technology to discovered and developed accumulations. Such additions result from updated estimates of primary recovery reserves, i.e. those volumes which may be produced by taking advantage of the natural reservoir drive mechanism involved, and of secondary and tertiary recovery reserves through the application of an external drive mechanism or other means of recovery stimulation.

The effects of improved recovery technology, which is no less than the basic element of conservation of petroleum resources, are particularly significant in situations of diminishing returns from exploration such as in the U.S.A. for instance, illustrated in Figure 1 and Table II. [20] It will be seen that during the period 1955-1969 the overall recovery efficiency in the onshore oil fields of the 'Lower 48' States rose from slightly better than 25 percent to just below 30 percent - an annual average of 0.34 percent and 0.4 percent in the past five years.

A 45 percent overall recovery efficiency is postulated as being 'within reach from present discoveries' for the 'Lower 48' States as well as for North Slope, and 50 percent for U.S. offshore including South Alaska. Additional oil is ultimately to come from the application of improved techniques which would result in a 60 percent overall recovery efficiency from total discoverable oil in place in all U.S. areas onshore and offshore. The 60 percent overall recovery efficiency is an ultimate goal which would require not only a much wider application of the existing techniques of improved recovery but also the invention of new techniques. It also means that future recovery techniques will have to be capable of achieving early and higher production rates as well as larger total extraction of oil from reservoirs. This requirement in the opinion of one expert (21) will direct the emphasis '.....to the better fields that contain major reserves'.

Displacement of oil by water occurring naturally in a reservoir as either 'edge' or 'bottom' water has been found to be the most efficient of the natural-drive mechanisms of primary recovery; a recovery of between 50 and 60 percent of oil in place is generally expected, and in favourable conditions up to 80 percent of OIP may be recovered. When water is applied from an external source during waterflood production operations the average ultimate recovery is 40 to 50 percent of OIP. In either event, about one half of oil remains on the average to be recovered by further improved means. (The efficiency of a gas or air repressuring secondary recovery technique is, on the whole, lower than that of waterflooding.)

The applicability of 'tertiary' or even further generation of recovery techniques, some of which have demonstrated a near 100 percent efficiency, depends largely on economic considerations, the most important being the price of oil. For this reason any additions to Australia's depleting crude oil reserves must for the time being come largely from discoveries of new accumulations and extensions. At the current world petroleum prices neither development of sub-marginal discoveries nor the application of improved third generation recovery techniques, which could result in additional reserves, would be feasible. On the other hand, the expected escalation, amounting to several multiples of the present prices, in the near future (22) (23) should encourage planning and preparations for the introduction

of later-generation recovery techniques to at least some production operations in Australia. Wells and production facilities need not be irretrievably abandoned, and arrangements for the re-entry of 'abandoned' wells might be given advance consideration; the 'securing' of wells rather than abandoning might be the kind of operation ending the primary or even secondary production stage of an oil pool or field.

4. OTHER POSSIBLE SOLUTIONS

There are at least three important sources from which additional fuel will come in the near future - heavy oil, tar sands, oil shales, and coal. New improved technologies for extracting liquid and gaseous products from large deposits of these materials are being developed with some urgency in the U.S.A. for instance, and with the escalation of prices of crude oil, mining and conversion are likely to become economically feasible.

Nuclear and solar forms of energy will have to satisfy most of our future requirements. This may occur even before petroleum reserves are fully depleted, because the costs of exploration and production may well become prohibitive, and because petroleum is more valuable as petrochemical feedstock than as fuel. (1) (24) Australia is well endowed with coal and uranium reserves, and has more and longer sunny days in a year than a great many parts of the world.

5. CONCLUSIONS

Demand for petroleum in the next three decades is assumed to grow at an average annual rate of around 7 percent for crude oil and 10 percent for natural gas. Such demand will put a very heavy strain on the discovered reserves and accelerate their depletion.

In an effort to postpone the inevitable moment of exhaustion of this non-renewable resource and to meet the growing demand, certain solutions will be applied, the most obvious being extension and intensification of exploration designed to find new reserves, and a much wider use of improved recovery techniques for the provision of additional production from the discovered and developed pools and fields.

These efforts will be considerably assisted by escalating prices of petroleum, expected to be in the 1980's several multiples of the current prices. Offshore offers the greatest chances of finding a substantial part of the petroleum required in the next decades. Exploration and development will extend from the continental shelf into deeper waters overlying the continental slope and rise and even the deep sea bed. These will be very costly and difficult operations; only large discoveries may be commercial.

Imports notwithstanding Australia's growing petroleum requirement in the next decades will in all probability come largely from offshore. More than 80 percent of our petroleum resources, representing an estimated energy value of 100×10^{15} kJ, are located on the Northwest and Gippsland shelves in Tertiary and Mesozoic sediments. Compared with the onshore petroleum resources, they have been found at a lesser exploration effort in terms of cumulative expenditure, footage, wells drilled, and time.

A much wider application than hitherto of improved secondary and Tertiary recovery techniques is expected to slow down the rate of depletion of developed accumulations. Their successful and widespread application will depend to a considerable degree on the economics of individual projects, the price of oil being the critical factor.

The expected continuation of the escalation of world oil prices could make it economical for operators to try to recover by improved techniques a significant portion of the 50 or so percent of oil remaining in the ground.

Anticipating some such development a suggestion is made that pools or fields depleted by primary production may not all have to be completely abandoned, and some wells and other surface and subsurface production facilities may be 'secured' so that they may be re-entered at some later date.

Other possible solutions of our problem of depleting petroleum reserves include mining and extraction of coal, oil shale, and tar sand deposits for the production of liquid and gaseous fuels. Again, economic consideration will decide how soon and how extensively such operations may be undertaken. Nuclear and solar forms of energy will have to satisfy a significant portion of our future requirements.

It should be stressed once more that the pattern of escalation of crude oil prices is likely to initiate another process, namely the substitution by other, cheaper forms of energy; therein lies a danger that at some point in the future oil may be priced out of the energy market.

Finally, a prediction is made, following opinions publicly expressed elsewhere, that petroleum, and crude oil in particular, may be partly phased out of the primary energy field and used as a more valuable petrochemical feedstock.

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TABLE 1. EXPLORATION IN AUSTRALIA (EXCLUDING PAPUA NEW GUINEA)

Year	ONSHORE			OFFSHORE		
	No. of Wells Drilled	Footage Drilled	Total Exploration Cost ($x10^6$)	No. of Wells Drilled	Footage Drilled	Total Exploration Cost ($x10^6$)
1960	25	85,106	15.5	-	-	0.3
61	24	111,975	17.4	-	-	0.6
62	78	301,819	30.95	-	-	0.9
63	100	487,828	39.16	-	-	1.7
64	160	809,830	42.72	-	767	5.1
65	152	870,762	56.55	4	33,774	9.0
66	98	602,400	51.44	3	24,831	14.3
67	74	379,334	26.02	13	118,172	37.75
68	65	361,282	25.46	25	236,771	47.88
69	76	425,081	24.83	33	250,524	58.30
70	91	455,541	27.29	27	255,487	59.27
71	62	376,674	25.86*	15	179,041	55.56*
Total 12 yrs	955	5,267,632	383.18*	120	1,099,367	290.66*

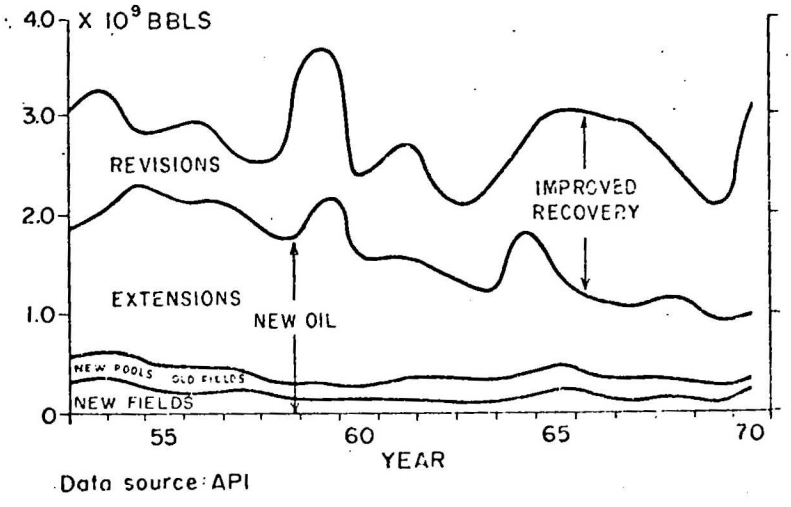
*Estimated

TABLE 2. U.S. OIL RESERVES, PRODUCTION AND RECOVERY EFFICIENCY - THE "LOWER 48" STATES (AFTER L.E. ELKINS (20))

End of Year	Total Original Oil in Place (10^9 Barrels)	Total Production and Reserves (10^9 Barrels)	Total Recovery Efficiency (%)
1955	326.70	82.046	25.11
1959	349.30	92.199	26.40
1964	370.65	103.071	27.81
1969	380.58	113.759	29.89

Source: API

FIGURE 1 - U.S. OIL DISCOVERY AND RECOVERY TRENDS 1953-1970 FOR ALL AREAS EXCEPT NORTH SLOPE (AFTER L.E. ELKINS [20])



Data source: API