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THE PROSPECTS OF LATIN AMERICA'S PETROLEUM IN THE ENERGY CRISIS

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The views expressed in this paper are those of the author and do not necessarily represent those of the U.S. Geological Survey.

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ENERGY INTAKE AND ECONOMIC ACTIVITY

Energy in the physical world is, literally speaking, the underpinning of change. And in the practical world of civilized man various sources of energy are the underpinnings of civilized life, which consist of various forms of change - in plowing the land, in irrigating and cultivating it; in producing fertilizers and pestidides; in operating shovels, mining and drilling equipment to produce coal, petroleum, minerals; in transporting materials, products, and persons; in operating machine tools and the various devices invented by man; in driving motors, electrical generators, generating radio waves, operating electronic computers; etc., etc. All of these expressions of civilized life would come to a stop without adequate and economic sources of energy. The essence of economic activity is change, and so is energy.

The degree of economic development and the consumption of energy of nations are closely related. The physical counterpart of the concept of GNP is the total annual consumption of energy. The first measures the economic activity, say in dollars per year, and the second measures the total energy required to drive the economy, say in equivalent tons of oil per year.

When the nations of the world are ranked by GNP per capita, the Latin American (L.A.) nations are found to occupy an intermediate position between the twenty-odd most industrialized nations and the truly underdeveloped nations, (See Appendix 1). Moreover, the bulk of the L.A. nations are already right behind the most industrialized nations.

A rather strong statistical correlation exists between GNP per capita and total consumption of energy per capita. The first quantity appears to increase somewhat faster than linearly with the second quantity. That is, a doubling of the GNP per capita implies somewhat less than doubling the energy consumption per capita.

To obtain a measure of the total energy intake of a nation all forms of energy must be converted to a common unit. From the point of view of physics, there are two fundamental forms of energy: kinetic energy and potential energy. The first one is equal to $(1/2)mv^2$ where m is the mass of the object moving and v is its velocity. The object could be a small fundamental particle as an electron, for instance, or any other object. Heat is a form of kinetic energy - the aggregate of the kinetic energy of the atoms in the body where heat is studied. Potential energy has to do with the existence of internal or external forces in a system, which left alone would drive it to some other configuration. Hence, change is of the essence - in both of these fundamental forms of energy - whether through velocities of objects, or actual or virtual configuration changes in a system. For statistical purposes, the energy of fuels is conventionally expressed in kg of oil equivalent. Also electric energy and mechanical work can be converted to kg of oil equivalent because of the equivalence of heat and mechanical energy. Some basic conversion factors used in the calculation of total energy are summarized in Appendices 2 and 3. A complicating factor is the various efficiencies of the energy conversion processes which are utilized. The total useful energy obtained with a given total initial fuel input varies with the relative use of the various energy processes. Therefore a society could obtain greater useful energy from a given fuel input by structural changes. But we do not enter into this question here, although it is important.

The correlation between consumption of total energy per capita and GNP per capita is easily demonstrated by the statistical data. This data reveals that to merely catch up with the group of the more industrialized nations (Table 1) Latin America (Table 2) would require energy intakes greater by factors of approximately 2 to 3. A detailed examination of the situation for the various L.A. nations indicates that the ratio between GNP per capita and kg of oil equivalent per capita ranges between 0.34 and 7.33 in $/kg of oil equivalent. Therefore the economic output achieved from a given intake of energy varies greatly.

Table 1

1971 PER CAPITA ENERGY CONSUMPTION OF INDUSTRIAL NATIONS

Country	GNP per capita 1/	Oil eq. kg/capita 2/
USA	4,760	7,189
Canada	3,700	5,962
Czechoslovakia	2,230	4,229
Dem. Rep. Ger	2,490	4,033
Belgium	2,720	3,910
Sweden	4,040	3,893
UK	2,270	3,521
Denmark	3,190	3,406
Fed. Rep. Ger.	2,930	3,339
Norway	2,860	3,318
Netherland	2,430	3,241
USSR	1,790	2,899
Finland	2,390	2,771
France	3,100	2,511
Switzerland	3,320	2,285
Japan	1,920	2,084
Italy	1,760	1,715

1/ World Bank Atlas 1972

2/ U.N. Statistical Yearbook 1972

Table 2

LATIN AMERICA 1971 PER CAPITA ENERGY CONSUMPTION

Country	GNP per capita 1/	Oil equivalent kg/capita 2/
Trinidad and Tobago	860	2,536
Venezuela	980	1,612
Surinam	530	1,427
Panama	730	1,357
Argentina	1,160	1,135
Chile	720	970
Jamaica	670	856
Mexico	670	813
Cuba	530	737
Guyana	370	637
Uruguay	820	613
French Guiana	940	600
Colombia	340	408
Peru	450	397
Brazil	420	320
British Honduras	590	310
Costa Rica	560	285
Nicaragua	430	249
Ecuador	290	202
Dominican Republic	350	169
Guatemala	360	160
Honduras	280	150
Bolivia	180	143
El Salvador	300	143
Paraguay	260	91
Haiti	110	15

1/ World Bank Atlas 1972

2/ U.N. Statistical Yearbook 1972, but converted to oil

LATIN AMERICA'S ENERGY SUPPLY PATTERN

The energy sources presently utilized in Latin America consist mainly of: renewable vegetable fuels, animal work, fossil fuels, and hydroelectric potential energy, and, to a minor extent, solar and geothermal energy. Nuclear energy has not yet been used for commercial purposes in Latin America, although there are several experimental reactors. Of the above resources, on a worldwide basis, the fossil fuels are depletable within rather short time spans (a few decades to a few centuries) at the projected trends of utilization. Petroleum, in particular, stands as the first of the major fossil fuels with a foreseen worldwide exhaustion within several decades.

Total energy consumption and production of the various Latin American countries, ranked in decreasing order of total energy consumption, are shown in Table 3 for the 1969 data. It is to be noted that about 2/3 of the L.A. nations have a deficit of total energy, that is they have to import some of the energy they need, and about 1/3 have a surplus. But most of the major L.A. nations, with the exception of Brazil, have a surplus of total energy. That is Mexico, Argentina, Venezuela, Colombia, Chile and Peru have a net total energy surplus or are about in balance.

The largest absolute deficit of total energy corresponds to Brazil (17.5 million ton oil equivalent), followed by Cuba (6.2 million ton oil equivalent), (Table 4). The import dependence with respect to total energy is well below 80 percent for Bolivia, Colombia, Trinidad and Tobago, Venezuela, Mexico, Argentina, Peru, Chile, and Brazil, but for the others it is above 80 percent. Of the largest L.A. nations, Brazil is the only one with an import dependence higher than 50 percent (actually 57 percent).

The L.A. pattern of relative consumption between the various energy resources varies systematically with the GNP per capita of each country, (Table 5). Up to about $400 per capita the major contributor to the energy supply are agricultural residues, followed in importance by oil. Above about $400 per capita the major contributor becomes petroleum, followed

Table 3

LATIN AMERICA 1969 ENERGY DATA 1/

Energy data in million tons of oil equivalent 2/

Country	Consumption 3/	Production 3/
Brazil	49.67	36.12
Mexico	43.10	51.40
Argentina	27.00	27.22
Venezuela	14.73	230.54
Colombia	12.59	20.22
Cuba	10.93	4.46
Chile	8.18	11.61
Peru	7.83	8.54
Trinidad and Tobago	3.64	11.33
Ecuador	1.72	2.47
Uruguay	2.11	0.42
Jamaica	2.08	0.48
Guatemala	1.60	0.97
Rep. Dominicana	1.58	1.06
Bolivia	1.46	3.14
Haiti	1.23	1.11
El Salvador	1.12	0.75
Panama	1.04	0.30
Surinam	0.92	0.43
Costa Rica	0.89	0.56
Nicaragua	0.86	0.51
Honduras	0.83	0.53
Guyana	0.80	0.32
Paraguay	0.64	0.46

1/ La Industria del Petróleo en America Latina, ECLA, 1973

2/ Oil calorific value assumed: 10,700 kcal/kg

3/ Including locally used energy from agricultural residues.

Table 4

1971 NET OUTSIDE ENERGY DEPENDENCE OF LATIN AMERICA'S ENERGY DEFICIT COUNTRIES

Country	Deficit in million tons oil equivalent 1/	% of consumption
Panama	2.00	100
Dominican Republic	0.70	99
Guatemala	0.83	98
Cuba	6.21	97
Nicaragua	0.48	95
Honduras	0.21	95
Uruguay	1.68	94
Jamaica	1.61	94
El Salvador	0.48	93
Surinam	0.50	87
Ecuador	1.07	84
Costa Rica	0.43	84
Brazil	17.48	57
Chile	3.85	40
Peru	2.20	39
Argentina	2.61	10
Mexico	3.52	9
Venezuela, Colombia, Bolivia, Trinidad and Tobago	0	0

1/ Derived from U.N. Statistical Yearbook 1972

Table 5

ENERGY CONTRIBUTIONS TO LATIN AMERICA'S 1969 ENERGY DEMAND

		% Energy Contribution 1/				
Country	GNP/cap (1970)	(Gas + Oil)	Petroleum	Hydro	Coal	Agric. resid.
Venezuela	980	(47 + 40)	87	6	2	5
Argentina	1160	(17 + 72)	89	1	3	7
T & T	860	(38 + 55)	93	0	0	7
Mexico	670	(24 + 46)	70	5	10	15
Chile	720	(6 + 51)	57	15	16	12
Jamaica	670	(0 + 77)	77	2	0	21
Panama	730	(0 + 71)	71	10	0	19
Guyana	370	(0 + 60)	60	0	0	40
Cuba	530	(0 + 59)	59	1	1	39
Peru	450	(2 + 57)	59	14	2	25
Brazil	420	(1 + 44)	45	20	5	30
Costa Rica	560	(0 + 37)	37	28	0	35
Colombia	340	(8 + 36)	44	15	13	28
Nicaragua	430	(0 + 41)	41	10	0	49
Guatemala	360	(0 + 39)	39	4	0	57
Dominican Rep.	350	(0 + 33)	33	1	0	66
El Salvador	300	(0 + 33)	33	13	0	54
Ecuador	290	(0 + 39)	39	4	0	57
Honduras	280	(0 + 36)	36	8	0	56
Paraguay	260	(0 + 29)	29	7	0	64
Bolivia	180	(0 + 32)	32	13	0	55
Haiti	110	(0 + 9)	9	0	0	91

1/ Derived from: La Industría del Petróleo en America Latina, ECLA, 1973, p. 11.

by either agricultural residues or hydro. Moreover, Venezuela is the only L.A. country for which natural gas is the major contributor, oil following in second place. The contribution of petroleum increases markedly with the GNP/capita. Only a few countries (Mexico, Chile, Colombia) have a fairly diversified pattern of energy supply between the various energy sources, although petroleum comes first even in those countries.

Overall, in Latin America oil provides 65%, natural gas 16%, hydro 14%, and solid fuels 5% of the commercial energy, that is agricultural residues excluded. Of the major regions of the world, Latin America depends to the greatest extent on petroleum (80.8%), as shown by the data in Table 6, which follows.

Table 6

Comparative Use of Commercial Oil and Natural Gas Energy, 1969 1/

Region	% of region demand
Latin America	80.8
North America	72.9
Asia, Africa, Oceania	57.7
Western Europe	54.2
Eastern Europe and Other Countries	36.6

1/ La Industría del Petróleo en America Latina, ECLA, 1973.

About half of the L.A. countries, including most of the major L.A. nations, have petroleum production. But only Venezuela, Ecuador, Trinidad and Tobago, Colombia, and Bolivia have a net surplus for export. The three most important L.A. petroleum producers are in order of decreasing rank: Venezuela, Mexico, and Argentina, followed by Ecuador, Colombia, Brazil, and Trinidad and Tobago. But it should be noted that Venezuela's oil production accounts for about 71 percent of the total. Latin America follows after the Middle East and Africa in being a net provider of oil for other world regions. By far the highest net importer region of oil is Europe, followed far behind by North America and Asia.

PETROLEUM

Background

Petroleum occurs naturally and widely in certain sedimentary basins and geosynclines. It forms in sedimentary rocks, wherein organic matter buried with the sediments becomes petroleum in the course of geologic time under the action of pressure, temperature, and physical-chemical processes. Not all sedimentary accumulations are favourable for petroleum. Those with a regional maximum thickness of less than about 2,000 ft. and those too severely deformed are to be excluded. Moreover, petroleum can be wasted away from a basin or geosyncline by water flow and erosion.

The basic requirements for the existence of petroleum accumulations are: source rocks, reservoir rocks, adequate petroleum migration and accumulation conditions. Not all of the determinant factors can be ascertained beforehand. And, what is more important, not all the relevant factors are known even today after more than a century of petroleum exploration and development. But what can be learned about the manner of occurrence of petroleum more than justifies the undertaking of geologic and geophysical surveys for selecting the places where to drill.

Petroleum deposits vary greatly in size of the accumulation, quality of the petroleum, proportions of oil and gas, and geologic factors controlling each accumulation. The history of petroleum exploration consists of periods of expansion following some previous model of occurrence, what is called a play, followed by periods of frustrating lack of success, and then the introduction of a new successful model. Because of this it is extremely difficult to predict the ultimate recoverable amounts of oil from the earth. Each overall prediction springs forth from past experiences, and dares to tread into new hypothesis only cautiously.

The exploration proceeds from reconnaissance, to regional, to detailed phases. In the regional appraisal some of the main factors taken into consideration are: area of sedimentary basin or geosyncline, maximum thickness of the sedimentary column, type of sediments, existence of structural and stratigraphic traps, and identification of favourable migration and entrapment conditions for petroleum. The detailed exploration aims at the rather accurate location of wildcat wells on locations judged the most favourable for the discovery of an oil or gas deposit.

As the exploration proceeds one must modify earlier pictures with the new information obtained, reassess the situation, plan the next move, and do this repeatedly until the operator decides to quit or finally succeeds. The complexities of this game can be appreciated by the many instances when an operator quits an area to be followed by someone else with a different concept who succeeds.

Microeconomics of the petroleum industry. Conventional financial statements are of limited value for assessing the problems of the petroleum industry as a whole, or the financial posture of individual companies. This is mainly because such statements do not explicitly disclose some very important issues. Those statements which are published are prepared mostly for income tax and stockholder purposes, in the manner that is usual for business corporations. Undoubtedly, petroleum companies can trace very well their own financial operations, but because of competitive considerations they may be unwilling to disclose in full their financial and reserve positions.

The major factors that need to be taken into consideration to properly understand the financial issues are: statistical risk of petroleum exploration, discretionary decisions about the distribution of reinvested earnings among the different phases of exploration and development, depletion allowance, and expensing versus capitalization choices.

It is proper to ask several questions. How critical is the tax environment for the financial and operating policies of the industry? Past experience indicates that charges for depreciation, depletion, and other retirements represent a sizable percentage of gross income. Should the bulk of capital for expansion continue to be provided from reinvested earnings, or should the industry resort more to outside financing? How does the industry use the different statutory choices concerning the expensing or capitalizing of certain items of cost? Which is the mechanism used, on the average, to establish the depletion allowance? Which has been the predominant financial policy of the industry - either to maximize current profits, to maximize return on net worth, to maximize present value of future earnings, to minimize the federal tax bill, or to maximize tax deductions, for instance?

Complexities of the petroleum industry.

(1) In comparison to most other industrial undertakings, petroleum exploration is a very risky business. In fact, it is in the nature of a game requiring judgment of statistical risks.

(2) Because of the nature of petroleum exploration and development, an appreciable lead time is required between a decision to search for new reserves and the actual bringing in of production from the fields eventually discovered. This lead time is at present on the order of a minimum of three to five years.

(3) In many countries the petroleum industry's tax environment is quite unique, and significantly conditions its financial and operating policies. A special tax treatment has been given to the industry, as well as to other industries that exploit wasting assets.

The depletion allowance, as applied for instance in the United States, is an interlocking set of rules, which cannot be easily comprehended by mere verbal discussions. It involves cost depletion and percentage depletion within the context of various alternative choices and with limits which act as cutoff points. A further complication is that the depletion calculation has to be handled separately for each oil property. Aggregate data, therefore, can give at best only a fuzzy average of what actually happens - that is, how the depletion is handled in the various properties held by a particular company.

Aside from the depletion allowance, there is a further preferential treatment in the manner of choices, at the discretion of each company, as whether to expense or capitalize certain expenditures. These choices bear upon the flow of funds and the tax bill, and they interact with the depletion allowance calculations.

(4) Another important issue in the financial operation of a petroleum

company is the reallocation of reinvested earnings among the different facets of exploration and development. A company may increase its petroleum reserves by buying proven acreage, it may choose to lease new lands, or it may utilize or develop secondary recovery techniques on its own land or carry out various geological and geophysical surveys in lands under its control. Some of the exploration prospects may be drilled, and may turn out to be dry holes. Others may result in discovery wells which may be implemented by development effort. The many discretionary choices interact with each other. They have different lead times.

(5) Consumption of petroleum products is very sensitive to and closely parallels the business cycle. Thus the petroleum industry must adapt its rate of operation to a cycle conditioned by the overall dynamics of the economy, which is unrelated to the statistical fluctuations of newly discovered petroleum reserves and to the lead time between exploration and production.

In some countries a unique tax environment has permitted the industry to ride the ups and downs of the business cycle, yet providing funds for expansion with adequate anticipation. On the other hand, if the volume of reinvested funds were to vary inversely with the business cycle, then the financial and operating position of the industry might be thrown out of kelter by the business cycle. Despite the fact that the last business fluctuations of the economy have been relatively small and their period has shortened to two to three years, past history indicates that the cycle has a period of about five years, which is about the same as the lead time of petroleum exploration with respect to development. That is, in a period of recession the petroleum industry might find itself with reduced funds. This would force a reduction in the exploration effort, which would be reflected about five years later in reduced production at the time of another recession.

On the Appraisal of Petroleum Resources

The Concepts of Resources and Reserves. The span of the various resource and reserve terms for oil are shown in Fig. 1. The situation for gas is similar.

First we have the initial oil in place (OIP), that is the amount prior to any exploitation which is to be found in undiscovered and discovered fields. Obviously, the OIP is difficult to estimate. As to the undiscovered (unknown) fields, an estimate has to be made based on the discovered (known) fields. This would be all right if the unknown fields were of similar characteristics to the known fields, or if both would form a reasonable statistical population. However, actual exploration shows that often a certain discovery alters the concept of the petroleum accumulations to be found in a given area. Projections from an old model become obsolete. The logical difficulty is hard to overcome. Perhaps the best we can hope with respect to the OIP value is to set lower bounds for it, and to raise the lower bound whenever wider knowledge about the petroleum geology of the region considered justifies it.

Second comes the concept of recoverable resources, that is the amount of oil which can be recovered, within technological and economic limits, both from undiscovered and discovered fields. This is often denoted as the Estimated Ultimate Recovery (EUR). The relative amount of oil which is recoverable varies greatly, and has not been well established on a worldwide basis. At the moment a figure of 40 percent probably represents a target figure for recovery. With modern production practices primary and secondary methods have become well integrated and a sharp distinction is not justifiable. How much oil still remains in the ground even after the best production practices is not really known. Perhaps the recovery can be as high as 80 percent of the oil in place. Another factor that conditions the amount of recoverable resources is the economic limits. These will change with time, so the forecast of the recoverable resources should vary with the time span of the forecast.

Third comes the concept of cumulative past procuction, that is the total oil which has been produced from the discovered fields. It is

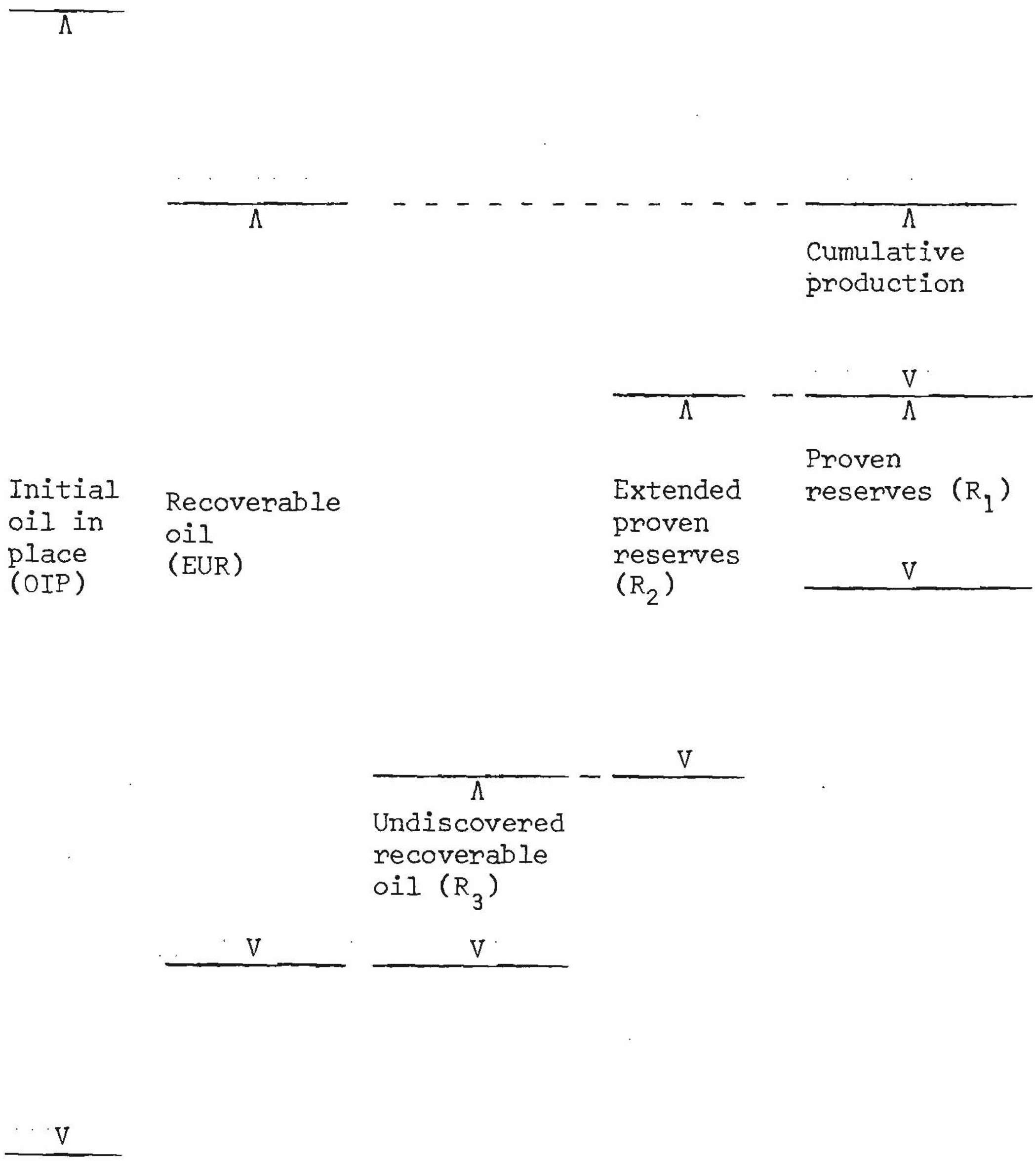

Fig. 1 SPAN OF THE VARIOUS RESOURCE AND RESERVE TERMS FOR OIL

the figure that can be ascertained more readily.

Fourth comes the concept of proven reserves (R_1). Proved reserves, designated here as R_1, are defined as the amounts of petroleum which can be considered for certain to be producible from explored acreage within present economic and technological limits. To convey a qualitative sense to the above definition I would say that in known fields the amounts of petroleum that can be obtained with certainty, say higher than a 90 percent probability, can be estimated within $\pm$ 25 percent or so. The main uncertainty in this estimation process would be covered by the span of the error ($\pm$ 25 percent). The increments of oil to be expected from known fields would fall off rapidly below a 90 percent probability. Essentially then we would have a rather narrow estimation distribution function for the proved reserves - the estimation of the magnitude of a quantity which is known to exist.

Fifth comes the concept of expanded proven reserves (R_2) and which represents the expected amounts, in a statistical sense, of oil from revisions and extensions of discovered fields. We deal here with a different kind of uncertainty: the speculation that some petroleum may exist beyond the known parts of fields and as extensions of them. For most of the non-OPEC developing countries I can make the following generalization. An additional quantity equal to the proven reserves can be obtained with probability 0.8, and another equal additional quantity with probability 0.5. Hence the expected value of the expanded proven reserves, designated here as R_2, would be $(1 + 0.8 + 0.5)R_1 = 2.3\ R_1$.

The recoverable petroleum that with certainty can be said to have been found so far in a given country is the sum of the cumulative plus the proven reserves. The expected value from discovered fields is somewhat larger. For this purpose I have introduced the concept of EVRD = Expected Value of Recoverable Discoveries, defined as

EVRD = cumulative production + expanded proven reserves (R_2).

Finally, the difference between the 'recoverable resources' and the sum (cumulative production + expanded proved reserves) is the undiscovered recoverable resources (R_3). Hence an estimation of R_3 involves an estimation of the recoverable resources.

On how to appraise the petroleum resource base. The issue underlying the sudden increase of oil prices is a wide realization that the petroleum resources would be depleted within a few decades. Yet how to appraise the extent of the remaining petroleum resources is a source of confusion. For long-range economic planning it would be useful to have rather accurate estimates of the total amount of recoverable oil in a given country. But because of the rather scattered occurrence of petroleum deposits and of technological limits of the search techniques it is not practical nor possible to discover ahead of development all the fields in the remaining resources.

Therefore, to appraise the long-range supply of oil and gas we need to go beyond mere projections from present trends. First, one should estimate the magnitude of the resource base, regardless of economics and uncertainty of discovery. Then one should subdivide the resource base according to various intervals of unit costs, in increasing order from present levels. Future technological developments or changed market conditions would allow the exploitation of certain resources which currently are uneconomical. Secondly, the resource base should be subdivided according to certainty of occurrence. Improvement of exploration techniques and increasing knowledge of actual geologic conditions would allow incorporating into the available supply some resources whose existence now is considered uncertain. Such a conceptual framework for the long-range appraisal of resources has already been proposed by McKelvey (1972)[1]. It provides a much more meaningful basis for long-range forecasts than before.

The language of mathematical statistics is required to define more rigorously the problem of appraisal of petroleum resources. The recoverable reserves for one fully developed oil field can be estimated with a relatively great accuracy, (say within 25 percent); but the estimation for a new field, a petroleum district, a sedimentary basin, one nation, or the earth are exercises of increasing difficulty, and with correspondingly wider ranges of uncertainty. A few basically original estimates have been made of the world petroleum resources, but there is a vast

[1] McKelvey, V. E., 1972, Mineral resource estimates and public policy: Am. Scientist, v. 60, no. 1, p. 32-40.

amount of published data which in fact amounts to "regurgitations" of somebody else's data, or somebody else's regurgitations of somebody else's, etc.

To carry the analysis a step further one can pose the question of whether the amount of recoverable oil and gas of a given part of a region could be of a given magnitude. The answer can be given only in probabilistic terms. That is, we are faced here with the a priori probability density function of the recoverable amount of petroleum for an undrilled area. Such probability density function is really not known for an area such as the Argentina continental shelf, and it can only be surmised.

Conceptually, at a given time one could first classify the remaining resources R as to the probability of being found with continued exploration. This probability, say p, can be considered to be the product of the probability of existence of a field and of the probability of actually locating the undiscovered field. The resources that at a given time we know with certainty is a certain amount. Next, we could consider the resources having a probability of eventually being found equal or greater than 80 percent but smaller than 100 (certainty). In this manner one could conceptually proceed to classify the undiscovered resources as incremental quantities dR corresponding to ranges of the probability p, down to some low value of the probability, say 5 to 10 percent. The resource base, say B, could be defined as the expected value of the resources, that is the integration of the incremental resource amounts multiplied by the probability of finding them, that is $R = \int p \, dR$.

Upon this first classification scheme we have now to impose the constraints that result from economics. Only a fraction of the segment of resources within a certain probability range can be considered to be economically recoverable, as per the conditions at the time when the assessment is made. In the future the economic limits should widen, although not necessarily so, thus permitting a larger proportion of each segment to be exploitable.

Moreover, it would seem that the a priori probability density function is not narrow, and would definitely fall off only beyond the largest conceivable size of the recoverable amount of petroleum. That is, the probability density corresponding to a very small size of the recoverable oil, or gas, is significant and different from zero. Similarly, the probability density for, let us say, an amount of recoverable oil comparable on a unit area basis to a given known oil basin is significant and different from zero. As we do not know the shape of this probability density function and as it appears to be quite broad, it is not proper to give only one value for the amount of recoverable oil or gas, nor to expect that its standard deviation is a small fraction of the magnitude of the recoverable amount. As a first approximation a uniform, or flat, probability density function could be taken for the petroleum estimates of an unexplored area. To give one figure for the petroleum resources of an unexplored area seems to be a futile undertaking.

Although the above scheme might appear to be conceptually clear, it is operationally very difficult. Below a certain uncertainty value, say 60 percent, the situation becomes highly speculative. There is very little basis on which to construct the actual scheme. And yet the largest expected contributions to R should come from resources with low probabilities of eventually being found. However, one could strive to gradually perfect such a picture, considering the past record of discovery as a basis for estimating parameters of theoretical statistical models.

Perhaps one of the most perverse effects of the conceptual difficulties of petroleum resource assessment is the accuracy delusion. By that I mean the misconception that published figures for undiscovered resources have a somewhat narrow distribution function. That is, that the possible values form a gaussian distribution about the published figure with not too great a standard deviation, say 20 percent. For new tracts of territory, as exemplified by the continental shelves, it is not possible yet to provide such a gaussian distribution. A team of company specialists might agree among themselves on a "most probable" value, but from team to team the "most probable value" will be found to vary substantially. The wide scatter observed in bids for offshore petroleum leases can well be attributed to this effect.

A better approximation to the underlying uncertainty function of resource estimates than the gaussian curve of the accuracy delusion is a modified uniform distribution function. It would extend with uniform probability from zero up to a resource amount somewhat greater than an amount corresponding to the richest known similar tract elsewhere, and then would drop rapidly to zero probability for larger resource amounts. By analogy with other tracts and from knowledge on adjoining areas one might justify modifying the uniform distribution on the low side also, that is to drop quickly to zero probability for resource amounts smaller than a certain amount.

To appraise the petroleum resource potential of new tracts of territory one should consider the basic scheme (Table 7) which underlies petroleum resource exploration and development. After the sedimentary basins have been identified, a pre-drilling potential estimate is made based on factors such as: area, maximum thickness of sediments, type of sediments, existence of structural traps, existence of stratigraphic traps, reconstruction of geologic history, occurrence of oil and gas seeps, adjoining petroleum provinces.

The estimated magnitude of the resource base, and its subdivision according to economics and degree of uncertainty in finding sets targets for long-range petroleum exploration. In this we are not restricted to the high degree of certainty required by short-range considerations. This is because in the exploration of large unknonn areas the plot unfolds as the exploration proceeds.

Table 7

STAGES IN PETROLEUM RESOURCE DEVELOPMENT

Geological and Geophysical Exploration

Existence of Sedimentary Basins — Yes ↓ — No → Out

Pre-drilling Information:

- Area of basins
- Maximum thicknesses sediments
- Type of sediments
- Existence of structural traps
- " of stratigraphic traps
- Reconstruction of geologic history
- Oil or gas seeps
- Adjoining petroleum provinces

Pre-drilling Potential →

Exploratory Drilling Campaign

Post-drilling Estimate of Petroleum Potential →

Further Geological and Geophysical Work

Further Drilling

Development of Oil Potential

The Drilling Finding Rate. The density of drilling, that is the number of wells drilled per square mile of prospective area, is a useful indicator of what needs to be done in young petroleum provinces, as in most of Latin America. Because of this it is necessary to review the relationship between wells drilled and petroleum found. Total footage is a measure of the amount of drilling.

A common assumption is that the average amount of proven reserve found each year is proportional to the amount of drilling in that year. Moreover, it is generally assumed that this finding rate, in bb of oil or MCF of gas per ft., decreases as the cumulative drilling increases. Offhand this appears to be a reasonable assumption.

Why should the finding rate decrease steadily as the cumulative drilling increases? It cannot be simply because the oil resources in a region are being depleted as the exploratory drilling increases. For it could happen that the finding rate remained constant or even increased during most of the exploratory phase of a region and then dropped rapidly as the limits of the resource base are finally approached.

It has been claimed that the finding rate should decrease because the larger fields would be discovered first. Of course this is what one would like to do, but the record of exploration in basin after basin reveals that this is not so. The onset of giant fields occurs some 30 years after exploration begins in a region. And there does not appear to be any "pickling effect" to thus justify a decrease of the finding rate.

Maximum depth of drilling has been increasing worldwide. For given basins and time lapses of 10-20 years the average drilling depth may show a trend of increase. This would introduce a decreasing trend of the finding rate with time. The year to year fluctuations of the finding rate, however, can be considerably larger than the effect per year of this basic trend.

An exploratory well aims at a very specific target, which has been selected among undrilled unrecognized targets on the basis of prior data obtained in a region plus the specific geological and geophysical surveys in the particular prospect. The various targets that exist in the basin may be categorized in various groups - such as folded anticlines, fault traps, reefs, domes over salt domes, pinch outs, etc. Moreover the geologic definition of the targets in each group could be quite specific.

When the petroleum industry in a given basin is pursuing a given 'play' in fact it would be running after targets in one of these groups. Ahead of drilling, the actual existence of petroleum in one of these targets can only be ascertained with a certain probability even after consideration of all the information that can be established ahead of drilling. One could say, for example that one out of four structures of a certain type on a certain part of a basin would contain oil. Moreover the magnitude of the accumulation would be essentially determined by the group type, the actual size being almost unpredictable.

In this manner, the statistical success of drilling would be about the same almost to the very end of the play, except for the effect of the enhancement of knowledge because of interaction with previously obtained data. One could thus describe the outcome, in say barrels of oil or MCF of gas found per foot drilled, as a random sample from normal distribution, having a certain mean and a certain variance which characterize the play. When several plays are being pursued the outcome would consist of random samplings from the various normal distributions corresponding to each group.

In none of these models would there be a decreasing finding rate as a normal situation. The exploration would reach the limits of the resource with little warning signals on the finding rate, and bottom would be hit rather unexpectedly.

An analogy here may help to visualize the problem. Let us suppose an experienced hunter with a shotgun hunting rabbits in a large enclosed field. Let us further assume that there are 20 rabbits initially in the field, and that the hunter requires three shots per rabbit, as per his early experience in similar fields. Then one would expect that on the average he will require three shots per rabbit from the first one he downs until the very last rabbit. But in the case of a series of exploratory wells in a given region the aim could improve. This is because of the enhancement of the geologic picture as the data from an increasing number of wells and exploration surveys becomes available.

A quantitative assessment of the role of a finding rate, which is a function of the cumulative drilling, reveals that the finding rate plays a major role in defining the supply curve for petroleum. A decreasing finding rate, even a mild linear decrease with cumulative drilling, imposes a definite roof (an asymptotic value) to the supply curve. No matter how high the price would go the supply would not go above it. As the price increases, the supply increases at a more and more sluggish pace. Thus the assumption that in general the finding rate is a decreasing function of cumulative drilling seems to be spurious, sustained neither by the historical data nor by consideration of the petroleum search game.

The Impending Worldwide Depletion of Petroleum Resources

Some of the best informed petroleum resource estimates available are those made by petroleum companies having far flung activities and which have maintained exploration activities in many countries for several years. Such companies have had or obtained access to data gathered in various exploration and development campaigns in sedimentary basins throughout the world. Some of these companies have made it a practice to send small teams of geologists to gather the data and to sense the course of petroleum events from time to time so as to update their appraisals of the various basins. These companies try to examine all basins that may have an impact on their worldwide activities, and not merely those in which they have carried operations by themselves. Such petroleum resource estimates are thereby based on actual exploration data, and not merely on quotations from published literature or extrapolations from aggregate published figures.

A difficulty is that petroleum companies in the best positions to know have been reluctant to reveal the extent of their knowledge. But from time to time a comprehensive assessment of petroleum resources does appear from inside one of these companies. As an example, I would like to mention the estimates given by K. O. Emery */, and stated to be based mainly on data gathered by the Mobil Oil Company. For the world petroleum recoverable resources he gives the figure of 217 × 10^9 metric ton (1,365 billion bb), a figure which obviously must have a wide margin of error. But for the sake of argument, let us suppose that we accept it. Now, world demand for 1971 was 2.393 × 10^9 metric ton. If world demand were to increase at 5% cumulative, then the above-mentioned world recoverable resources would be completely exhausted by the year 2008. Despite the fact that this is a mere exercise, it does reveal the rather impending depletion of oil resources. Even if the figure for world recoverable resources were five times greater than given by Emery the depletion would be postponed only to 2045.

*/ Emery, K. O., Resources of Fossil Fuels, report to U.S. National Research Council, July 23, 1973.

On the other hand, by reviewing the overall situation independently, I have arrived at a somewhat larger world potential. For this I considered certain best explored areas in the world as benchmarks. Thus I have estimated that the ultimate petroleum recovery (EUR) for the world is between 2,600 to 6,500 billion bb of oil, and 13,000 to 34,000 trillion (that is 10^{12}) cu. ft. of gas. Of these amounts, about 305 billion bb of oil and 741 trillion cu. ft. of gas had been produced by the end of 1973. Moreover, by allowing for the eventual discovery of Middle East-size accumulations one should increase the above figures. The expanded reserves of the Middle East are 595 billion bb of oil and 612 trillion cu. ft. of gas, and the corresponding EUR's can be surmised to be at most equal to a few times these amounts. Yet even with the above larger estimates for the world EUR's one can predict a depletion of the petroleum resources within several decades if demand continues to grow even at a few percent per year.

LATIN AMERICA AND PETROLEUM

The Oil Price Squeeze and Latin America

The current great public concern with energy issues is caused by the drastic increase of the crude oil prices imposed by the OPEC organization on December 23, 1973. F.o.b. prices of Middle East crude were then increased from a level of about $2.20 in January 1973 to about $7.65 per barrel. After consideration of the various excise taxes imposed by consumer countries on oil products (gasoline taxes, import taxes, other use taxes) the effective cost per barrel of crude to consumer has been raised from a range of $5.70 - $8.9 per barrel to $14.85 - $23.15 per barrel, (Table 8). The lower of these limits refers to a level of excise taxes of 30-percent and the upper of 70-percent. The drastic price increase demanded by the producing countries and the existence of the substantial excise taxes on consumption are feasible because of the large consumer surplus in the demand curve for petroleum products. It may be said that the consumer countries's excise taxes on petroleum products are an attempt to preempt this consumer surplus.

The schemes for oil revenue sharing adopted by oil exporting countries starts with a reference price per barrel. Ecuador, for example (Table 9), established in January 1974 a reference price of $13.70 per barrel, whereby it would collect as royalties, export tax, income tax, and workers share the amount of $9.55 per barrel. The resulting fob cost, ex-producing companies profit, with this scheme would be $10.06 per barrel. At the foreseen rate of production, estimated at 84 million bb per year, Ecuador's total share would be about $802 million per year.

To gauge the oil balance of payments position of the various L.A. countries one must first consider the net physical deficit (or surplus) in barrels of oil of each country. This position fluctuates from year to year, aside from time trends.

The latest consolidated figures readily available are for 1971 (Table 10), which may be still indicative of the current position, with the important exception of Ecuador. All L.A. countries, other than Venezuela,

Table 8

PRICE STRUCTURE OF MIDDLE EAST CRUDE, $/BARREL

(An estimate)

		Jan. 73		Dec. 23, 73	
a)	Production cost	0.10		0.10	
b)	Company profit	0.55		0.55	
c)	Country "take"	1.55		7.00	
d)	f.o.b. market price		2.20		7.65
e)	Tanker transportation		1.20		1.20
f)	Impact of consumer country gasoline excise taxes 1/		2.30 - 5.50 2/		6.00 - 14.30 3/
g)	Effective $/bb on consumer		5.70 - 8.90		14.85 - 23.15
	Country "take"		1.55		7.00
	Consumer country tax		2.30 - 5.50		15 - 23

1/ A yield of 21 gal gasoline per bb crude assumed.

2/ Gasoline excise rates of 30 to 70 percent assumed

3/ Product price increases in proportion to crude cif price assumed.

Table 9

ECUADOR'S OIL REVENUE SHARING

($/bb)

(An estimate)

Reference price (January 1974)		13.70
Production cost	0.21	
Pipeline tariff	0.30	
Royalties	2.26	
Export tax	2.06	
		4.83
Gross revenue		8.87
Income tax	3.90	
Workers Share	1.33	
		5.23
Companies net revenue:		3.64
Country's share:		9.55
On 84 × 10^6 bb/yr :	$802.2 × 10^6	

Table 10

L.A. OIL EXCHANGE BALANCE, 1971

Oil deficit countries	$\times 10^6$ bb 1/	Million \$ 3/ (Est. at \$2 - 3/bb)
Brazil	124.2	(348)
Cuba	43.8	(131.4)
Mexico	24.3	71 2/
Chile	23.0	91.4 2/
Argentina	15.0	(45.0)
Peru	14.5	(43.5)
Uruguay	11.6	(34.8)
Jamaica	11.2	(32.5)
Ecuador	7.4	(22.2)*
Guatemala	5.7	11.5 2/
Panama	5.4	(15.7)
Dominican Republic	5.0	(14.5)
Nicaragua	3.5	(10.1)
Surinam	3.3	(9.6)
Guyana	3.3	(9.6)
El Salvador	3.1	(9.0)
Costa Rica	3.1	(9.0)
Honduras	2.6	(7.5)
Paraguay	1.6	(4.6)
Haiti	0.6	(1.7)
	312.2	\$ (922.6 million)

(Table 10, continued)

Oil Surplus Countries	$\times 10^6$ bb 1/	Million $ 3/
Venezuela	1,032.9	2,889.6 2/
Colombia	31.4	72 2/
Trinidad and Tobago	30.4	(85.1)
Bolivia	6.6	24.7 2/
	1,101.3	$(3,071.4 million)
Balance (Positive)	789.1	$2,148 million

1/ Calculated from World Energy Supplies, United Nations, 1973, p. 16-21. Coal equivalent data reduced to m^3 of oil using specific gravities from Statistical Yearbook 1972, United Nations, p. 180.

2/ Economic Survey of Latin America - 1971, United Nations.

* Now Ecuador has an oil surplus.

3/ Actual deficit figures, otherwise estimates shown within parenthesis.

Ecuador, Colombia, Trinidad and Tobago, Bolivia, have a net deficit. The largest deficit (about 124 million bb) corresponded to Brazil, followed by Cuba (about 44 million bb). The accumulated deficit of all the L.A. deficit countries was about 312 million bb. On the other hand, the accumulated surplus of the surplus countries was about 1,100 million bb. In 1971 the oil balance of payments amounted to a deficit of about $923 million for the deficit countries, and to a surplus of about $3,071 million for the surplus countries. So the total L.A. oil exchange balance was a surplus of about $2,148 million.

The situation has changed drastically by the price increases announced in January 1974, as shown by the following figures:

<u>1971</u> { Surplus: 789.1×10^6 bb crude oil
At $2.80/bb
cif value is $2,209.5 billion

<u>1974</u> { At $8.25/bb
cif value is $6,510.1 billion

The L.A. surplus can now be projected at $6,510 million, but the deficit of the deficit countries would increase from about $923 million to about $2,576 million. The full impact of the new prices has not been felt yet because of the delaying effect of long-term purchase agreements. But as these agreements expire, the effect of the new price structure will be severe.

Latin America's Petroleum Potential

To appraise the L.A. petroleum potential we can use the following basic factors:

- magnitude of the prospective areas,
- total number of wells and footage which has been drilled,
- cumulative production + proven reserves to date, and
- comparison with certain benchmark regions.

Magnitude of the prospective areas. My estimates of the sedimentary areas with a petroleum potential for the major regions of the world, and including continental shelves down to 200 m depth, are as follows:

	(sq. mi.)
developed economies, except USSR	7,916,000
Latin America	4,890,000 (19%)
Africa and Madagascar	4,722,000
USSR	3,480,000
S and SE Asia	2,993,000
Middle East	1,200,000
China (Mainland)	900,000
	26,101,000

Thus Latin America holds about 19 percent of the world's prospective area for petroleum; yet it currently produces only 9 percent of the total oil.

The distribution of the prospective acreage between the various Latin American countries, for onshore and offshore, is shown in Table 11.

Extent of drilling for petroleum. The extent of the past drilling effort in Latin America up to 1972 can be judged by the following comparison:

Table 11

LATIN AMERICA'S PETROLEUM PROSPECTIVE AREA

Country	Prospective area (10^3 sq. mi.) Onshore	Offshore
Brazil	1,480	240
Argentina	590	215
Mexico	305	170
Peru	400	9.5
Colombia	350	26
Venezuela	141	33
Bolivia	254	—
Paraguay	78	—
Ecuador	60	18
Chile	58	5
Nicaragua	25	28
Honduras	30	20.5
Uruguay	31	17
Guatemala	33.5	4.8
Panama	14.5	22

Region or country	No. wells	wells/sq. mi.
USA, lower 48 states	2,222,300	1.17
USSR	≈530,000	0.15
Latin America	≈100,000	0.02
Argentina, Mexico, Venezuela	59,000	0.05
Other Latin America	≈41,000	0.01

Therefore in much of Latin America the drilling density is two orders of magnitude smaller than what has been achieved in the United States. Even in the aggregate of Argentina, Mexico and Venezuela - which are the rather more densely drilled countries in the region - the drilling density is only about 4 percent of that achieved in the United States.

Consolidated drilling statistics for petroleum are not readily available. Estimates that I have made with Miss D. Nielsen for the various Latin American countries are given in Table 12. The notes to the table indicate the period covered, data gaps, and other explanations. The average depth of the well is somewhat greater than 4,300 ft. About 14 percent of all wells are exploratory, and about 35 percent of the latter have been successful.

Outcome of past petroleum development. The outcome of past efforts may be judged by the amount of petroleum which has been found per unit of prospective area. This can be estimated by the expected value of recoverable discoveries (EVRD) per unit area, which I have defined before. My estimates for major world regions are as follows:

	EVRD(sq. mi.)	
	Oil (bb)	Gas(10^6 cu. ft.)
Middle East	496,000	510
USA, lower 48 states	101,600	556
USSR	49,500	453
Africa and Madagascar	30,700	92
Western Europe	27,000	207
Latin America	24,200	52
Argentina-Mexico-Venezuela	56,700	96
S. and SE Asia, mainland	2,500	60

Table 12

RÉSUMÉ OF PETROLEUM DRILLING IN LATIN AMERICA

		Wells			
Country	Period covered	Expl	Successful	Total[1]	Footage drilled
Brazil	1949-1972	1,441(est)	303(est)	3,680	≈16,130,000
Argentina	1951-1972	1,725	522(est)	20,644	68,543,000(est)
Mexico	1949-1972	2,662	801(est)	16,554	71,805,000(est)
Peru	1948-1972	734	292(est)	(est)9,700	20,200,000(est)
Colombia	≤ 1972	920(est)	250(est)	3,857	18,755,000(est)
Venezuela	1949-1972	2,655	1,401(est)[2]	28,571	118,900,000(est)
Bolivia	1949-1972	231(est)	72(est)	765	4,847,000(est)
Paraguay	1949-1972	22	—	29	76,082
Ecuador	1949-1972	309	166	2,970	4,887,193[4]
Chile	1945-1972	353	78	1,520	10,488,000(est)
Nicaragua	1949-1972	20	—	20	> 178,912 [2]
Honduras	1949-1972	6	—	6	56,277
Uruguay	≤ 1972	—	—	—	—
Guatemala	1949-1972	17	0	17	> 68,410[3]
Panama	1949-1972	12	—	12	> 65,484[2]
Surinam	1949-1972	33	0	33	102,148(est)
Guyana	1949-1972	9	0	9	48,336
Cuba[4]	1949-1964	>201	> 11	> 524	> 1,712,723
French Guiana	< 1972	—	—	—	—
Dominican Rep.[4]	1949-1970	18(est)	0	18(est)	>44,419
Jamaica	1949-1972	8	—	8	> 29,581[3]
Belize	1949-1972	28	—	28	> 94,987[3]
Trin. & Tobago	1949-1972	515(est)[4]	230(est)[4]	(est)8,450	25,266,001
El Salvador	≤ 1972	0	0	0	0
Haiti	1949-1972	3	0	3	> 12,930[2]
Costa Rica	< 1972	19	—	19	131,103
Barbados	1950-1971	17	6	19	149,760[3]
Cumulative sums		11,958	4,132	91,962	362,592,346

(Table 12, continued)

Averages

av. depth well: >4,263 ft.
exploratory wells: 14% of total wells
successful exploratory wells: 35% of exploratory wells

Notes

1/ Underlining indicates an overall cumulative value up to 1972.

2/ One year data gap.

3/ Two year data gap.

4/ Several years data gap.

5/ 1924-1972

6/ 1918-1972

est = estimate for the period covered by filling in the gaps in the data.

The fact that the EVRD per sq. mi. of prospective area for Latin America is rather low is a direct consequence of the limited amount of drilling. Most of the EUR is in the ground and undiscovered.

The petroleum outcome of past efforts through 1971, measured in cumulative production plus proven reserves, is shown in Table 13 for the various L.A. countries.

The Latin American petroleum fields are of average size by world standards, with but a few giant accumulations already discovered. The largest oil fields are: Poza Rica, Naranjos-Cerro Azul, Arenque, Ebano-Panuco in Mexico; Lama, **Lamar**, Boscan, La Paz, and Quiriquire in Venezuela; Comodoro Rivadavia in Argentina; and La Brea-Pariñas-Talara in Peru. All of these had EUR's of 1 billion bb of oil or more.

For further analysis, one can set three subroups: a) Venezuela, Colombia, Trinidad and Tobago; b) Mexico and Argentina, and c) all the remaining Latin American countries, as shown in Table 14. The first subgroup owes its petroleum development essentially to the efforts of international petroleum companies. The second subgroup owes its major petroleum development to the efforts of national petroleum companies. The other countries in the third subgroup are until now smaller producers or have both international petroleum companies and national companies operating.

The first subgroup accounts for 69 percent of the oil and 61 percent of the gas, as cumulative production-plus-proven reserves, while it possesses only 12 percent of the prospective area. Non-producer countries account for ten percent of the total prospective area.

Comparison with certain benchmark regions. I have selected three areas as benchmarks in order to estimate the EUR for Latin American. These benchmark areas are: (a) conterminous USA, b) USSR, and c) Middle East. From a study of the range of estimates for the conterminous USA and the USSR, I have adopted a range of 100,000-250,000 bb of oil and of 500-1,300 million cu. ft. of gas per sq. mi. of prospective area as indicative of large continental units. These values are an order of magnitude lower than those for the Middle East.

Table 13

PETROLEUM OUTCOME FOR LATIN AMERICA

Country	Cum. prod. + proven reserves to 1971 1/ Oil(10^6 bb)	Gas(10^9 cu. ft.)
Brazil	1,648	1,344
Argentina	4,811	10,424
Mexico	7,941	20,687
Peru	1,394	4,314
Colombia	3,393	5,408
Venezuela	43,908	70,380
Bolivia	381	5,357
Ecuador	6,170	4,533
Chile	319	5,762
Cuba	na	na
Trinidad & Tobago	2,984 (-)	6,574 (+)
Barbados	1	0
Cum. sums	72,950	134,783

1/ "Summary Petroleum and Selected Mineral Statistics for 120 Countries, Including Offshore Areas", U.S. Geological Survey Professional Paper 817, 1973.

Table 14

DRILLING AND PETROLEUM OUTCOME FOR LATIN AMERICAN GROUPS OF NATIONS

Group	Total wells 1/	Cum. prod. + proven reserves to 1971 2/ Oil(10^6 bb)	Gas(10^9 cu. ft.)
A) Venezuela, Colombia, Trinidad and Tobago	40,878	50,285 (69%)	82,362 (61%)
B) Mexico and Argentina	37,198	12,752 (17%)	31,111 (23%)
C) All the other Latin American countries	>13,866 3/	9,913 (14%)	21,310 (16%)
	≃100,000	72,950	134,783

1/ Estimates from various sources up to 1972.

2/ "Summary Petroleum and Selected Mineral Statistics for 120 Countries, Including Offshore Areas", U. S. Geol. Survey Prof. Paper 817, 1973.

3/ Some data, mostly prior to 1949, not included.

Estimates of the EUR's for Latin America. In the manner described above I have estimated that the EUR's for Latin America are

$$(490 \text{ to } 1{,}225) \times 10^{9} \text{ bb of oil, and}$$

$$(2{,}450 \text{ to } 6{,}370) \times 10^{12} \text{ cu. ft. of gas.}$$

The above figures do not include any allowance for the occurrence of giant size accumulations like the Middle East. These cannot be excluded; moreover, I suspect that the Caribbean area and the Argentine continental shelf are two regions where they could occur.

Note on the petroleum outlook of the Argentine continental shelf. When reviewing the petroleum opportunities throughout Latin America it becomes apparent that outstanding possibilities are met in the Argentine continental shelf.

This shelf, down to 200-m depth, has an area of 306,500 sq. mi. Five sedimentary basins have already been identified on it: Salado, Bahia Blanca, San Jorge, Magallanes, and Malvinas. The maximum thicknesses of sediments in these basins, according to a 1960 survey by the Lamont Geological Observatories, would be >5 km, 4-5 km, about 4 km, about 5 km, and possibly more than 7 km, respectively. Two of the basins - San Jorge and Magallanes - are seaward continuations of important onshore petroleum producing basins.

The Argentine continental shelf may be compared with the Gulf Coast basin and with the US Atlantic continental shelf. For the US Atlantic continental shelf potential figures in the range of 10-50 billion bb of recoverable oil resources have been published by the US Geological Survey. Taking into consideration the fact that the area of the Argentine continental shelf is 4 times larger, the greater thicknesses of sediments, and the known existence of two basins with production onshore, one would be justified in choosing for the Argentine continental shelf a potential at least four times as great.

On How to Develop the Latin American Petroleum Potential

From the point of view of resource development one should consider which alternatives are available to carry out petroleum exploration in the developing nations considered, namely: bilateral foreign assistance, international petroleum companies, national oil companies, and private entrepreneurs. In the sequel I will discuss some of the issues involved, without advocating any particular solution.

Foreign participation in petroleum development often raises delicate issues both in a host country and abroad. The factors involved are many, most of them being subject to various interpretations. The main issues appear to be: form of ownership and control, fair participation in the profits, backward and forward linkages of the petroleum activity,and compatibility of the rate of development and production and marketing policy with the interests of the host country.

The extent of bilateral assistance would depend on the circumstances of each nation and the tasks to be accomplished. For countries with no know-how and limited resources, financial aid to undertake the basic geologic and geophysical reconnaissance may be required. These basic surveys can provide a basis for negotiation, and for formulating adequate leasing policy. A few million dollars per 100,000 sq. mi. of prospective area would be enough for this initial task. To continue on with exploration, involving wildcat drilling, substantially larger sums are required. They are of the order of tens of million dollars per 100,000 sq. mi. of prospective area. The assessment of an area like the Argentine continental shelf, on the other hand, is a vaster undertaking. Roughly 500 million dollars may be required, and even so when all the results were known if unsuccessful, one would still find some petroleum companies willing to continue exploring.

The assistance of foreign companies and private entrepreneurs may be engaged in various ways: concession, service contract, technical assistance, partnership in mixed companies, financing. Exploration and development are the more sensitive sectors for foreign participation, whereas it has been more readily accepted in pipeline transportation, refining, petrochemicals, and marketing.

Mixed enterprises and service contracts have the advantage of readily bringing to bear technical, managerial, and financial capability. The contract terms, however, are difficult to work out so that no subsequent difficulties arise. In a mixed enterprise a foreign (government or private) entity may join with a host-country government entity. The initial exploratory risk may be entirely absorbed by the foreign entity. All the capital may be contributed by the foreign entity, with a formula for sharing in the profits and for capital contributions by the government entity depending on the outcome of the exploration.

Service contracts have been awarded in some countries to undertake programs of: a) exploration/development, b) exploration, c) development, and d) drilling. The contractor may be paid outright, or by means of a share of the petroleum production. But it is difficult to foresee in preparing a service contract all subsequent exploration and development issues, to consider all cost contingencies, and changed marketing conditions. Service contracts have been used in some cases with success, in others they have ended in controversy. They should be undertaken only when a host government is fully aware of the issues and is ably represented in the negotiations. Such contracts ought to be comprehensive, followed by adequate public disclosure.

The underlying force of successful international petroleum corporations is a top level small team - highly skilled petroleum executives, geologists, geophysicists, petroleum engineers. For some of the prospective areas involved only the skills of such groups could probably succeed in finding in a reasonable time the undiscovered petroleum accumulations. Concessions or service contracts are alternative means to engage this expertise. In other cases only large international petroleum companies may have the financial capability, and be willing, of risking the large amounts of risk capital that may be required, and of readily bringing to bear upon the assessment of a new territory skilled expertise with worldwide experience.

As for national petroleum companies, one should distinguish two quite different types:

1) national company that has found its petroleum, and 2) national company that has acquired its current petroleum by nationalization of the assets of private international corporations. Some of the companies in this first group have been very to moderately successful. There are others in the group 1) of national companies which have had little success. On the other hand, the group 2) of national companies cannot yet claim to have demonstrated a petroleum finding capability. If a country decides to use national enterprises for petroleum exploration, some mechanism must be found to provide radical changes of exploration strategy when failures predominate. This may be difficult in the context of political criticism - to endure a sustained effort or to acknowledge a protracted failure.

The USSR provides another type of national petroleum undertaking. In the USSR's system there is a basic resource reconnaissance phase - regional geology and geophysics, stratigraphic and core drilling - which is followed by detailed exploration and development. The control of the first phase is tightly held by the top scientific organizations of the country. They appear to have done an excellent job of basin appraisal. The second phase is entrusted to operational bureaus. Only in a fully planned economy, having an effective upper technological and scientific echelon, could this system work, as it has in the USSR.

LATIN AMERICA'S ENERGY RESOURCE BASE

From a long-range point of view, the energy position of Latin America has to be judged in terms of its energy resource base. Yet, the published energy resource data seems to be utterly insufficient and to grossly underestimate the energy resource potential of Latin America.

To gauge the extent of its energy resource base we can make a comparison with the United States, for which figures have been published on proven reserves, identified resources, and unidentified resources (Table 15). The basis for such comparison is provided by the many geologic analogies between the frameworks of the North and South American continents. There is a close parallelism between cratonic areas, folded geosynclinal areas, marginal cordilleras, internal basins, and many other features. Moreover, the United States is only a part of North America. The area of Latin America is about twice that of the United States.

The similarities extends to a close parallelism between major mineral and petroleum occurrences. For instance, the petroleum producing areas of the North Slope of Alaska may be matched with those in northern Venezuela. The petroleum producing shelf of California may be matched to the producing shelf of Ecuador, Peru, and Central Chile. The most important petroleum province in North America is the Gulf Coast, to which the Argentine Continental shelf would be the corresponding unit in South America.

The proven reserve figures that have been published for oil, gas, oil shale, coal, and uranium for Latin America are only a small fraction of those for the United States. The discrepancy is even greater for identified and undiscovered resources. A few examples might suffice here. The figure for the identified oil resources for South America is 74 billion barrel, and no figure has been given for the undiscovered resources. For the United States, on the other hand, the figure of 290 billion barrels is given for the identified resources and 2,850 billion barrels for the undiscovered resources.

For coal the figure of 20 billion tons has been published for the identified resources, and of 10 billion ton for the undiscovered resources.

Table 15

L.A.-US ENERGY DATA COMPARISON

	USA	L.A.
Area (× 10^6 km^2)	9.40	19.9
Oil		(10^9 bb)
Proven reserves	52 1/	29 2/
Other identified resources	290 1/	74 3/ (S.A.) (?)
Undiscovered resources	2,550 1/	? Others
Gas		(10^{12} cu. ft.)
Proven reserves	290 4/	72 2/
Other identified resources	170 4/	?
Undiscovered resources	4,000 4/	?
Oil shale		(10^9 bb oil yield)
Identified resources	2,000 5/	800 6/
Undiscovered "	23,850 5/	41,200 6/
Tar sands		(10^9 bb bitumen)
Identified resources	29 7/	1,200 7/ (Ve, Co)
		? Others
Coal		(10^9 metric ton)
Identified resources	1,587 8/	20 (?) 9/
Undiscovered "	1,637 8/	10 (?) 9/

Table 15 (continued)

		(10^3 metric ton U_3O_8)
Uranium		
Identified resources	6,436 10/	11.4 (Ar, Me) 10/
Undiscovered "	8,382 10/	? Others

1/ Energy Resources of the United States, 1972, Geol. Survey Circular 650, p. 7.

2/ U. N. Statistical Yearbook 1972

3/ Resources of Fossil Fuels, K. O. Emery, July 1973, Nat. Res. Council report.

4/ Ditto 1/, but p. 9

5/ Ditto 1/, but p. 26

6/ United States Mineral Resources, U.S.G.S. PRof. Paper 820, 1973, p. 501.

7/ Ditto 6/, but p. 101

8/ Ditto 1/, but p. 3

9/ Ditto 6/, but p. 140

10/ Ditto 1/, but p. 23-24

These figures seem to underestimate the potential of Latin America by a factor of 100. We can mention just two basins, one in Southern Chile and the other in Colombia, which indicate a potential much greater than the figure given for all of Latin America.

Analogy of geologic conditions, and examination of the rationale used in forward-looking resource assessment such as being carried out by the United States Geological Survey, would indicate that most of the published energy resource base figures on Latin America are worthless. As a new start, I believe one can presume that the energy resource base of Latin America is about twice that of the United States.

LATIN AMERICA'S ENERGY OPTIONS

I can close by pointing out that many significant energy options appear open to the various L.A. countries. As immediate options there are: hydro expansion, import hydroelectricity, coal production, land petroleum resources, marine petroleum resources, geothermal resources, nuclear energy, and solar energy. As midrange options there are: coal liquefaction, coal gasification, shale oil, bituminous sands, solar energy, nuclear energy. Some countries (Brazil, Chile, Argentina, Mexico, Venezuela) have a wide variety of options. Most of the other countries have a more limited range of options either because of their resource base, stage of economic development, or absolute size of the economy. The most outstanding energy options of all the available appear to be: develop land petroleum resources (Bolivia, Peru, Colombia), develop marine petroleum resources (Argentina, and Caribbean countries), coal liquefaction (Chile, Colombia), coal gasification (Chile, Colombia), shale oil (Brazil), bituminous sands (Venezuela, Colombia).

Taken as a whole, Latin America appears to have a very strong energy resource base; individual countries, however, are exposed to short- and mid-term energy crunches. Whether the potential becomes a reality hinges on economic, institutional, and political factors, rather on constraints of the resource base.

Bernardo F. Grossling
August 2, 1974

Appendix 1

ROLL OF NATIONS WITH POPULATION 1 MILLION OR MORE RANKED AS PER GNP/CAPITA

World Bank data for GNP per capita for 1970 for 122 nations plotted in rank of decreasing GNP per capita.

Rank	Country	$/cap	Rank	Country	$/cap
1	U.S.	4,760	26	Ireland	1,360
	Sweden	4,040		*Argentina*	1,160
	Canada	3,700		Greece	1,090
	Switzerland	3,320		Spain	1,020
5	Denmark	3,190	30	*Venezuela*	980
6	France	3,100	31	Hong Kong	970
	FRG	2,930		Romania	930
	Norway	2,860		Singapore	920
	Australia	2,820		*T & T*	860
10	Belgium	2,720	35	*Uruguay*	820
11	New Zealand	2,700	36	Bulgaria	760
	DRG	2,490		South Africa	760
	Netherlands	2,430		*Panama*	730
	Finland	2,390		*Chile*	720
15	UK	2,270	40	*Jamaica*	670
16	Czechoslovakia	2,230	41	*Mexico*	670
	Austria	2,010		Portugal	660
	Israel	1,960		Yugoslavia	650
	Japan	1,920		Albania	600
20	USSR	1,790	45	Lebanon	590
21	Libya	1,770	46	*Costa Rica*	560
	Italy	1,760		*Cuba*	530
	Puerto Rico	1,650		Mongolia	460
	Hungary	1,600		*Peru*	450
25	Poland	1,400	50	Saudi Arabia	440

Rank	Country	$/cap
51	*Nicaragua*	430
	Brazil	420
	Zambia	400
	China	390
55	Iran	380
56	Malaysia	380
	Guatemala	360
	Dominican Rep.	350
	Colombia	340
60	North Korea	330
61	Iraq	320
	Turkey	310
	Ivory Coast	310
	Ghana	310
65	Angola	300
66	*El Salvador*	300
	Algeria	300
	Papua New Guinea	300
	Syria	290
70	*Ecuador*	290
71	*Honduras*	280
	Rhodesia	280
	Paraguay	260
	Tunisia	250
75	South Korea	250

Rank	Country	$/cap
76	Jordan	250
	Liberia	240
	Mozambique	240
	Morocco	230
80	Senegal	230
81	Philippines	210
	Egypt	210
	Vietnam	200
	Thailand	200
85	Sierra Leone	190
86	Cameroon	180
	Bolivia	180
	China (Red)	160
	Kenya	150
90	Central African Rep.	140
91	Mauritania	140
	Togo	140
	Malagasy Rep.	130
	Khmer Rep.	130
95	Uganda	130
96	Nigeria	120
	Laos	120
	Sudan	120
	Guinea	120
100	Yemen (People's Dem. Rep.)	120

Rank	Country	$/cap
101	Sri Lanka	110
	India	110
	Haiti	110
	Tanzania	100
105	Viet Nam (North)	100
106	Pakistan and Bangladesh	100
	Niger	90
	Dahomey	90
	Zaire	90
110	Chad	80
111	Nepal	80
	Burma	80
	Yemen (Arab. Rep. of)	80
	Indonesia	80
115	Ethiopia	80
116	Afghanistan	80
	Malawi	80
	Somalia	70
	Mali	70
120	Upper Volta	60
121	Burundi	60
122	Rwanda	60

Appendix 2

BASIC CONVERSION FACTORS FOR ENERGY CALCULATIONS

1 BTU = 252 cal

1 joule = 10^7 erg = 0.2389 cal

1 kWh = 8.6×10^5 cal = 3,413 BTU

1 barrel = 42 U.S. gallons = 0.15899 m^3

Coal's heat of combustion assumed for coal equivalents	6,880 cal/gr
Ditto, for oil equivalents	10,700 cal/gr

Calorific values equivalence: 1 kg coal ↔ 0.64 kg oil

Appendix 3

HEAT EQUIVALENCE FACTORS

U.N. coal heat equivalence factors of 1 ton of: [1]	Tons, coal standard
coal briquettes	1
brown coal and lignite briquettes	0.67
pechkohle	0.67
coke	0.9
brown coal and lignite	0.3 - 0.33
peat	0.5
crude petroleum and shale oil	1.3
motor spirit, kerosene, fuel oils	1.5
of 1,000 m^3 standard of:	
natural gas	1.332
manufactured gas	0.6
refinery gas	1.75
of electricity:	
1,000 kWh [2]	0.125

ECLA, 1973, overall thermoelectric plant efficiency

1 kWh = 3,000 cal

[1] U.N. Statistical Yearbook 1972

[2] The efficiency of the conversion of heat into electricity in a thermal plant is not considered in this factor.