Latin America's Petroleum Prospects in the Energy Crisis

GEOLOGICAL SURVEY BULLETIN 1411

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UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1975

UNITED STATES DEPARTMENT OF THE INTERIOR

STANLEY K. HATHAWAY, *Secretary*

GEOLOGICAL SURVEY

V. E. McKelvey, *Director*

Library of Congress Cataloging in Publication Data

Grossling, Bernardo F 1918-
Latin America's petroleum prospects in the energy crisis.
(Geological Survey bulletin ; 1411)
Bibliography: p.
Supt. of Docs. no.: I 19.3:1411
1. Petroleum industry and trade--Latin America. I. Title. II. Series: United States. Geological Survey. Bulletin ; 1411.
QE75.B9 no.1411 [HD9574.L3] 557.3'08s [338.2'7'282098] 75-619165

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402
Stock Number 024-001-02694-5

CONTENTS

ILLUSTRATION

TABLES

LATIN AMERICA'S PETROLEUM PROSPECTS IN THE ENERGY CRISIS

By Bernardo F. Grossling

SYNTHESIS

A country's economic development and its consumption of energy are closely related; in fact, the physical counterpart of the gross domestic product is the total annual consumption of energy. The Latin American countries in order to just begin to catch up with the more industrialized nations would have to double or triple their per capita energy intake.

Taken as a whole, Latin America appears to have a strong energy resource base, and, although individual countries are liable to medium-term energy crunches, the long-term prospects for expanding per capita energy consumption are excellent.

The energy sources now used in Latin America are renewable vegetable fuels, human and animal power, fossil fuels, hydroelectric energy, and, to a minor extent, solar and geothermal energy.

About two-thirds of the countries of Latin America have a total energy deficit—that is, they have to import some of the energy needed—and about one-third have a surplus.

Overall, oil provides 65 percent, natural gas 16 percent, hydroelectric power 14 percent, and solid fuels 5 percent of the commercial energy used. Of the major regions of the world, Latin America depends more than any other on petroleum (80.8 percent) for energy. Its pattern of relative consumption of the various energy resources indicates that for GNP less than about $400 per capita, the major contributors to the energy supply are agricultural residues, followed by oil; for GNP more than about $400 per capita, the major contributor is petroleum, followed by agricultural residues or hydroelectric power.

For Venezuela, natural gas is the main contributor to energy supply, followed by oil. Only three countries—Mexico, Chile, and Colombia—have a fairly diversified pattern of energy supply, although in these countries petroleum also comes first.

Latin America is next in importance to the Middle East and Africa as a net provider of oil to other world regions. About half of the Latin American countries, including most of the major ones, produce petroleum; but only Venezuela, Ecuador, Trinidad and Tobago, Colombia, and Bolivia, in order of decreasing surplus, have an export surplus. The three most important petroleum producers, in order of decreasing rank, are Venezuela, Mexico, and Argentina; they are followed by Ecuador, Colombia, Brazil, and Trinidad and Tobago.

Except for Venezuela, Ecuador, Colombia, Trinidad and Tobago, and Bolivia, all the Latin American countries have a net physical oil deficit. The largest deficit, about 200 million barrels, corresponds to Brazil, followed by Cuba with a deficit of about 53 million barrels. The deficit of the Latin American deficit countries is about 448 million barrels and the surplus of the surplus countries is about 1,237 million barrels.

Because market prices (f.o.b.) of Middle East crude were increased from about $2.20 per barrel in January 1973 to about $7.65 per barrel effective in January 1, 1974, the effective cost per barrel of crude, including various excise taxes, has been raised from a range of $5.70–$8.90 per barrel to $14.85–$23.15 per barrel, depending on the consumer country involved. With this drastic price increase, the Latin American balance of payments surplus can be projected at $9,150 million, but the deficit of the deficit countries would increase from about $923 million to about $5,094 million. The full impact of the new prices has not been felt yet because of the purchase agreements in force.

A complicating factor, as well as a source of confusion, are the methods used in estimating the extent of the remaining resources. Because of the nature of petroleum deposits and because of technological limitations, it is not possible to locate all the remaining deposits.

To appraise the long-range supply of oil and gas, it is insufficient to merely project from present trends. One of the most perverse effects of the conceptual difficulties of petroleum assessment is the accuracy delusion, the misconception that published figures of undiscoverable resources have a somewhat narrow uncertainty function.

Density of drilling is a useful indicator of what needs to be done in Latin America. A common assumption is that the average amount of proven reserve found each year is proportional to the amount of drilling in that year and that this finding rate decreases as the cumulative drilling increases. A closer examination of this question indicates that this generalization is not true and obscures a much more complex process.

The exploration record in basin after basin reveals that the larger fields are not discovered until some 30 years after exploration begins in a region. The year-to-year fluctuations of the finding rate cannot be explained by increased depth of drilling. The actual statistical data does demonstrate rather erratic fluctuations of the finding rate. Consideration of the oil finding as a game of search does not support the assumption of a decreasing finding rate.

Latin America has 19 percent of the world's prospective-petroleum area, yet it currently produces 9 percent of the oil. 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, the drilling density is only about 4 percent of that achieved in the United States. The outcome of past efforts has been about 24,200 barrels of oil and 52 million cubic feet of gas found per square mile of prospective area, compared to 101,600 barrels of oil and 556 million cubic feet of gas in the United States. Hence in Latin America most of the oil is still in the ground and undiscovered.

By taking certain areas of the world as benchmarks, I estimate that the recoverable petroleum for large continental units is about 100,000–250,000 barrels of oil and 500–1,300 million cubic feet of gas per square mile of prospective area. Moreover, these figures do not allow for giant size accumulations as in the Middle East, which cannot be excluded in Latin America. With that exclusion I estimate the ultimate recovery for Latin America to be $(490 \text{ to } 1{,}225)\times 10^9$ barrels of oil and $(2{,}450 \text{ to } 6{,}370)\times 10^{12}$ cubic feet of gas.

Some industry estimates for the remaining world petroleum recoverable resources indicate that these would be exhausted by the year 2008 if consumption were to increase 5 percent per year. By my own estimates of resources, which are two to five times larger, the exhaustion would be postponed only a few decades beyond 2008.

Published data on Latin America are completely inadequate and grossly underestimate its energy resource potential. The extent of the energy resource base can be gauged by comparing it to that of the United States, for which significant published data are available. Published proven reserve figures 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.

As for petroleum, after sedimentary basins have been indentified, a pre-drilling potential estimate is made on the basis of geological factors. Using such a basic scheme as this, I could justify for the upper bound of the potential of the Argentine continental shelf a figure of about 200 billion barrels of oil—that is, four times as large as a figure published for the recoverable oil resources for the United States Atlantic continental shelf.

The published figure for coal is 20 billion tons for identified resources and 10 billion tons for undiscovered resources, both of which estimates seem to me to underestimate the Latin American potential by two orders of magnitude.

As a new start, I believe one could assume that the energy-resources base of Latin America is about twice that of the United States.

The immediate energy options for the Latin American countries are hydroelectric expansion, import of hydroelectricity, coal production, onshore petroleum resources, offshore petroleum resources, geothermal resources, and nuclear energy. Coal liquification, coal gasification, shale oil, bituminous sands, solar energy, and nuclear energy are the mid-range options.

Some countries—Brazil, Chile, Argentina, Mexico, and Venezuela—have a wide variety of options. The options of others are more limited, either because of their resource base, their stage of economic development, or their size.

The principal options appear to be: development of onshore petroleum resources (Bolivia, Peru, and Colombia); development of offshore petroleum resources (Argentina and the countries of the Caribbean); coal liquification and coal gasification (Chile and Colombia); shale oil (Brazil); and bituminous sands (Venezuela and Colombia).

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 and irrigating and cultivating it; in producing fertilizers and pesticides; in operating shovels, mining and drilling equipment to produce coal, petroleum, and minerals; in transporting materials, products, and persons; in operating machine tools and the multitude of 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 economic development of nations and their consumption of energy are closely related. The physical counterpart of the concept of GNP (gross national product) 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 20-odd most industrialized nations and the truly underdeveloped nations (table 16). 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 $(\frac{1}{2}) mv^2$ 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 through actual or virtual configuration changes in a system. For statistical purposes, the energy of fuels is conventionally expressed in kilograms of oil equivalent. Also electrical energy and mechanical work can be converted to kilograms 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 tables 17 and 18. 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 I do not discuss 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 kilograms 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 by industrial nations*

Country	GNP [1] (per capita)	Oil equivalent [2] (kg/capita)
United States	4,760	7,189
Canada	3,700	5,962
Czechoslovakia	2,230	4,229
German Democratic Republic	2,490	4,033
Belgium	2,720	3,910
Sweden	4,040	3,893
United Kingdom	2,270	3,521
Denmark	3,190	3,406
Federal Republic of Germany	2,930	3,339
Norway	2,860	3,318
Netherlands	2,430	3,241
U.S.S.R.	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] Statistical Office of the United Nations (1973).

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

TABLE 2.—*Latin America 1971 per capita energy consumption*

Country	GNP [1] (per capita)	Oil equivalent [2] (kg/capita)
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] Derived from Statistical Office of the United Nations (1973).

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 for 1969 of the various Latin American countries, ranked in decreasing order of total energy consumption, are shown in table 3. It is to be noted that about two-thirds of the L.A. nations have a deficit of total energy—that is they have to import some of the energy they need; about one third of the countries have a surplus, but most of the major L.A. nations, with the exception of Brazil, have a surplus of total energy. Specifically, 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 above 80 percent generally for the smaller countries only; of the larger L.A. nations, Brazil is the only one with an import dependence higher than 50 percent (actually 57 percent).

TABLE 3.—*Latin America 1969 energy data* [1]

[Energy data in millions of 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	.42
Jamaica	2.08	.48
Guatemala	1.60	.97
Dominican Republic	1.58	1.06
Bolivia	1.46	3.14
Haiti	1.23	1.11
El Salvador	1.12	.75
Panama	1.04	.30
Surinam	.92	.43
Costa Rica	.89	.56
Nicaragua	.86	.51
Honduras	.83	.53
Guyana	.80	.32
Paraguay	.64	.46

[1] Comision Economica para America Latina (1973).
[2] Oil-calorific value assumed: 10,700 kcal/kg.
[3] Including locally used energy from agricultural residues.

TABLE 4.—*1971 net imported-energy dependence of Latin America's energy-deficit countries*

Country	Deficit, in millions of tons oil equivalent [1]	Percentage of consumption
Panama	2.00	100
Dominican Republic	.70	99
Guatemala	.83	98
Cuba	6.21	97
Nicaragua	.48	95
Honduras	.21	95
Uruguay	1.68	94
Jamaica	1.61	93
El Salvador	.48	94
Surinam	.50	87
Ecuador	1.07	84
Costa Rica	.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] Statistical Office of the United Nations (1973).

The L.A. pattern of relative consumption of the various energy resources varies systematically with the GNP per capita of each country (table 5). For GNP less than about $400 capita, the major contributor to the energy supply are agricultural residues, followed in importance by petroleum. For GNP greater than about $400 per capita, the major contributor becomes petroleum, followed by either agricultural residues or hydroelectric power. Moreover, Venezuela is the only L.A. country for which natural gas is the major contributor to the energy supply, oil following in second place. The contribution of petroleum increases markedly with the GNP/capita. Only a few countries (Mexico, Chile, and Colombia) have a fairly diversified pattern of energy supply between the various energy sources, although petroleum comes first, even in these countries.

Overall, in Latin America oil provides 65 percent, natural gas 16 percent, hydroelectric power 14 percent, and solid fuels 5 percent 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 percent), as shown by the data in table 6.

About half of the L.A. countries, including most of the major L.A. nations, produce petroleum. But only Venezuela, Ecuador,

TABLE 5.—*Energy contributions to Latin America's 1969 energy demand*

Country	GNP/cap (1970)	Percent energy contribution [1] Petroleum	(Gas plus oil)	Hydroelectric	Coal	Agricultural residues
Venezuela	980	87	(47+40)	6	2	5
Argentina	1,160	89	(17+72)	1	3	7
Trinidad and Tobago	860	93	(38+55)	0	0	7
Mexico	670	70	(24+46)	5	10	15
Chile	720	57	(6+51)	15	16	12
Jamaica	670	77	(0+77)	2	0	21
Panama	730	71	(0+71)	10	0	19
Guyana	370	60	(0+60)	0	0	40
Cuba	530	59	(0+59)	1	1	39
Peru	450	59	(2+57)	14	2	25
Brazil	420	45	(1+44)	20	5	30
Costa Rica	560	37	(0+37)	28	0	35
Colombia	340	44	(8+36)	15	13	28
Nicaragua	430	41	(0+41)	10	0	49
Guatemala	360	39	(0+39)	4	0	57
Dominican Republic	350	33	(0+33)	1	0	66
El Salvador	300	33	(0+33)	13	0	54
Ecuador	290	39	(0+39)	4	0	57
Honduras	280	36	(0+36)	8	0	56
Paraguay	260	29	(0+29)	7	0	64
Bolivia	180	32	(0+32)	13	0	55
Haiti	110	9	(0+9)	0	0	91

[1] Derived from Comision Economica para America Latina (1973, p. 11).

TABLE 6.—*Comparative use of commercial oil and natural gas energy, 1969* [1]

Region	Percentage 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] Comision Economica para America Latina (1973).

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; they are followed by Ecuador, Colombia, Brazil, and Trinidad and Tobago. It should be noted, however, that Venezuela's oil production accounts for about 71 percent of the total. Latin America follows the Middle East and Africa as a net provider of oil for other world regions. Of the net importing regions, Europe imports the greatest by far amount of oil; North America and Asia follow far behind.

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 favorable for occurrence of petroleum. Those having a regional maximum thickness of less than about 610 m (2,000 ft) and those too severely deformed are to be excluded from consideration. 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, and 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 drilling sites.

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, 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.

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 favorable migration and entrapment conditions for petroleum. The detailed exploration aims to rather accurately locate wildcat wells where they are most likely to discover 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 only to be followed by someone else who succeeds using a different concept.

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 petroleum-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 expenses due to 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 a minimum of 3 to 5 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 preferential treatment in the manner of choices, at the discretion of each company, as whether to expense or to 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 [1]. 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 kilter by the business cycle. Despite the fact that the business fluctuations of the economy have tended to become relatively small and their periods have shortened to 2 to 3 years, past history indicates that the cycle has a period of about 5 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 5 years later in reduced production at the time of another recession.

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[1] I have confined this discussion to the resource-development issues of the petroleum industry; therefore, industry phases such as transportation, refining, and marketing are not discussed here.

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 figure 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. Actual exploration, however, shows that often a certain discovery

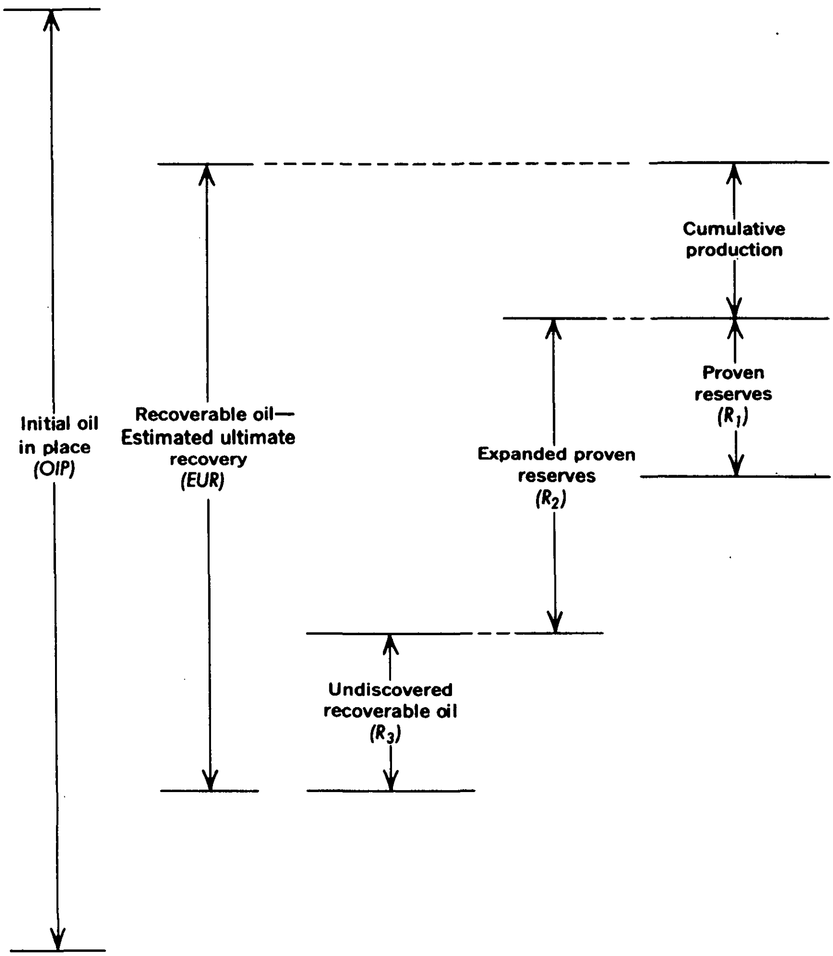

FIGURE 1.—Span of the various resource and reserve terms for oil.

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 of production 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 production, that is, the total oil which has been produced from the discovered fields. This is the figure that can be ascertained more readily.

Fourth comes the concept of proven reserves (R_1). Proven reserves, designated in figure 1 as R_1, are defined as the amounts of petroleum which can be considered with certainty 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 ± 25 percent or so. The main uncertainty in this estimation process would be covered by the span of the error (± 25 percent). The increments of oil to be expected from known fields would fall off rapidly below a 90 percent probability. Essentially then there would be 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), 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 a probability of eight-tenths, and another equal additional quantity can be obtained with a probability of five-tenths. Hence the expected value of the expanded proven reserves would be $(1+0.8+0.5)R_1=2.3R_1$.

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 production plus the proven reserves. The expected value from discovered fields in somewhat larger. For this purpose I have introduced the concept of EVRD = Expected Value of Recoverable Discoveries, defined as: EVRD = cumulative production + (R_2).

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

HOW TO APPRAISE THE PETROLEUM RESOURCE BASE

The issue underlying the sudden increase of oil prices is the 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 high degree of unpredictability of the actual location of petroleum deposits and because of technological limitations in the search techniques, it is not economically viable nor technically possible to discover prior to development all the fields in the remaining resources.

Therefore, to appraise the long-range supply of oil and gas we need to do more than merely project 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). 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 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 specific amount. Next, we could consider the resources that have a probability of eventually being found equal or greater than 80 percent but smaller than 100 percent (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: $B = \int p \, dR$.[2]

[2] This integral, which may be multiple, is to be carried over the parameters defining the position of dR.

Upon this first classification scheme we now have 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 standards 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 contribution to *B* should come from resources with low probabilities of eventually being found. One could strive, however, 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 listed in table 7.

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
- Existence of stratigraphic traps
- Reconstruction of geologic history
- Oil or gas seeps
- Adjoining petroleum provinces

Pre-drilling potential (End of first cycle of appraisal)
Exploratory drilling campaign
Post-drilling estimate of petroleum potential (End of second cycle of appraisal)
Further geological and geophysical work
Further drilling
Development of oil potential

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 unknown areas the plot unfolds as the exploration proceeds.

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 barrels of oil or millions of cubic feet of gas per foot, 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 discovery of giant fields typically 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 in 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 grouped into various categories, such as folded anticlines, fault traps, reefs, domes over salt domes, pinch outs, etc. Moreover, the geologic definition of the targets in each category 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 categories. Before drilling, the actual existence of petroleum in one of these targets can only be ascertained within a certain probability even after consideration of all the information that can be established prior to 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 mainly determined by the category itself, 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 in millions of cubic feet 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 distribution 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 the bottom would be hit rather unexpectedly.

An analogy here may help to visualize the problem. Let us suppose an experienced hunter is hunting rabbits with a shotgun in a large enclosed field. Let us further assume that there are 20 rabbits initially in the field and that the hunter requires 3 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 beginning with the first one he downs and ending with 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 petroleum-resource estimates available are those made by petroleum companies which have farflung exploration activities and which have maintained activities in many countries for several years. Such companies have had or have 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 [3] and stated to be based mainly on data gathered by the Mobil Oil Co. For the world petroleum recoverable resources, he gives the figure of 217×10^9 metric tons (1,365 billion bbl), a figure which obviously must have a wide margin of error. But for the sake of argument, let me accept it. Now, world demand for 1971 was 2.393×10^9 metric tons. If world demand were to increase at 5 percent 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 indicate the rather impending depletion of oil resources. Even if the figure for world recoverable resources were five times greater than that given by Emery, the depletion would be postponed only to 2045.

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 bbl of oil and 13,000 to 34,000 trillion (that is 10^{12}) cu ft of gas. Of these amounts, about 305 billion bbl of oil and 741 trillion cu

[3] K. O. Emery, 1973, Resources of fossil fuels, unpublished report to U.S. National Research Council.

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 bbl 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 at just 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. market prices of Middle East crude were then increased from a level of about $2.20 per barrel in January 1973 to about $7.65 per barrel in January 1974.[4] 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–$8.90 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 higher to a level 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 $9.55 per barrel as royalties, export tax, income tax, and workers share. The resulting f.o.b. cost, ex-producing companies profit, with this scheme would be $10.06 per barrel. At the foreseen rate of production, estimated at 84 million barrels 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 sur-

[4] Posted price Saudi Arabian light crude was increased from $2.591 to $11.65 in same period (table 19).

TABLE 8.—*Price structure of Middle East crude in dollars per barrel—an estimate*

	January 1973		December 23, 1973	
Production cost	$0.10		$0.10	
Company profit	.55		.55	
Country "take"	1.55		7.00	
F.o.b. market price		2.20		7.65
Tanker transportation		1.20		1.20
Impact of consumer country gasoline excise taxes [1]		2.30–5.50 [2]		6.00–14.30 [3]
Effective dollars per barrel to 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 gallons gasoline per barrel of crude assumed.
[2] Gasoline excise rates of 30 to 70 percent assumed.
[3] Product price increases in proportion to crude c.i.f. price assumed.

TABLE 9.—*Ecuador's oil revenue sharing in dollars per barrel—an estimate*

Reference price (January 1974)		$13.70
Production cost	$0.21	
Pipeline tariff	.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 bbl/yr: $\$802.2\times10^6$		

TABLE 10.—*Latin American petroleum exchange balance, as to requirements of each national economy*

Petroleum-deficit countries	Crude oil [1] (million barrels)		Million dollars, 1974 estimates: Inter-American Development Bank [2]	Million dollars, 1974 estimates: International Monetary Fund [3]
Brazil	[2] −200	(1974)	−2,105	−3,000
Cuba	−53	(estimate)	[4] (−636)	
Mexico	[3] −40	(1974)	−450	−333
Argentina	[2] −32	(1973)	−375	−467
Chile	[5] −28	(1973)	−400	−455
Jamaica	[6] −13	(1972)	−157	−177
Uruguay	[2] −13	(1970–72 average)	−155	−176
Dominican Republic	[2] −12	(1974)	−150	−140
Peru	[2] −12	(1974)	−190	−164
Panama	[7 8] −7.4	(1973)	[7] −97	
Guatemala	[2] −6.9	(1973)	−96	−122
Costa Rica	[6] −4.1	(1974)	−60	−84
Nicaragua	[2] −4	(1974)	−43	−58
Guyana	[6] −3.8	(1972)	[4] (−46)	−53
El Salvador	[6] −3.6	(1972)	−51	−53
Honduras	[5] −3.5	(1973)	−47	−41
Paraguay	[2] −1.7	(1974)	−24	−32
Haiti	[2] −1.3	(est. 1974)	−12	−13
Total	[9] −447.9		−5,094	

TABLE 10.—*Latin American petroleum exchange balance, as to requirements of each national economy*—Continued

Petroleum-surplus countries	Crude oil [10] (million barrels)	Million dollars, 1974, Inter-American Development Bank [2]
Venezuela	[5] 1,137 (1973)	13,167
Ecuador	[2] 70 (1974)	685
Trinidad and Tobago	[7 8] 15.4 (1973)	102
Bolivia	[2] 14.3 (1974)	200
Colombia	Small	Small
Total	1,237	14,244
Overall balance (positive)	789	9,150

[1] Crude imports—crude exports—stock changes and losses+products balance; negative.
[2] Div. Country Studies, Dept. Economic and Social Development, Inter-American Development Bank, 1974, Impacto de la crisis del petroleo en America Latina en 1974, unpub. report.
[3] Robichek (1974).
[4] Dollar estimate based on an assumed cost of $12 per barrel.
[5] U.S. Bureau of Mines, unpub. data.
[6] U.S. Bureau of Mines (1974).
[7] Inter-American Development Bank, oral commun.
[8] Excludes bunkers.
[9] Note that figures added are not for same year.
[10] Crude production less domestic demand.

plus) in barrels of oil of each country. This position fluctuates from year to year, aside from time trends.

The latest readily available figures on the L.A. petroleum exchange balance are shown in table 10. All L.A. countries, other than Venezuela, Ecuador, Trinidad and Tobago, Bolivia, and Colombia, have a net deficit. The largest deficit (about 200 million bbl) corresponds to Brazil, followed by Cuba (about 53 million bbl). The total deficit of all the L.A. deficit countries is about 448 million bbl). On the other hand, the total surplus of the surplus countries is about 1,237 million bbl. 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:

1971	Surplus:	789.1×10^6 bbl. crude oil
	At $2.80/bbl.	
	C.i.f. value is	$2,209.5 billion.
1974	At an average of $11.60/bbl.	
	C.i.f. value if $9,150 billion.	

The L.A. surplus can now be projected at $9,150 million, but the deficit of the deficit countries would increase from about $923 million to about $5,094 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:

1. Magnitude of the prospective areas.
2. Total number of wells and footage which has been drilled.
3. Cumulative production plus proven reserves to date.
4. Comparison with certain benchmark regions.

MAGNITUDE OF THE PROSPECTIVE AREAS

My estimates for the major regions of the world, including continental shelves down to a depth of 600 feet, having sedimentary areas with a petroleum potential are as follows:

	Square miles	
Developed economies, except U.S.S.R.	7,916,000	
Latin America	4,890,000	(19 percent)
Africa and Madagascar	4,722,000	
U.S.S.R.	3,480,000	
South and Southeast Asia	2,993,000	
Middle East	1,200,000	
Peoples Republic of China	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.

TABLE 11.—*Latin America's prospective petroleum 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

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:

Region or country	*Number of wells*	*Wells/sq mi*
USA, conterminous 48 States	2,222,300	1.17
U.S.S.R.	≈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 relatively 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 and Diane Nielsen have made 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 yearly Foreign Development issues of the "Bulletin of the American Association of Petroleum Geologists" were used to extract the following information.

1. Number of exploratory wells completed, including stratigraphic, structural, and core holes deeper than 2,000 feet.
2. Successful number of exploratory wells.
3. Total number of wells completed, that is, development plus exploratory.
4. Total footage drilled during each year in wells completed, plus drilling footage during the year in wells being drilled at the end of the year.

Outpost or stepout wells were counted as either exploratory or development, when so classified by the rapporteur in the Bulletin; when not so classified we have counted them as development wells.

When the data had small gaps, estimates have been made for: a) the total footage drilled in a missing gap by interpolating an appropriate average well depth and multiplying by the total number of wells in the gap, and b) estimates for the number of successful exploratory wells have been made by interpolating an appropriate average success ratio *if* the success ratio did not fluctuate too much.

TABLE 12.—*Résumé of petroleum drilling in Latin America*

[Average depth of wells is 4,263 feet. Exploratory wells constitute 14 percent of total wells; 35 percent of exploratory wells were successful. Underlined numbers indicate overall cumulative values up to 1972]

Country	Period covered	Wells			Footage drilled
		Exploratory	Successful exploratory	Total	
Brazil	1949–72	[1] 1,441	[1] 303	3,680	≈16,130,000
Argentina	1951–72	1,725	[1] 522	20,644	[1,4] 68,543,000
Mexico	1949–72	2,662	[1] 801	16,554	[1] 71,805,000
Peru	1948–72	734	[1] 292	[1] 9,700	[1,4] 20,200,000
Colombia	≤1972	[1] 920	[1] 250	3,857	[1] 18,755,000
Venezuela	1949–72	2,655	[1] 1,401	28,571	[1,4] 118,900,000
Bolivia	1949–72	[1] 231	[1] 72	765	[1,4] 4,847,000
Paraguay	1949–72	22	----	29	76,082
Ecuador	1949–72	309	166	2,970	[4] 4,887,193
Chile	1945–72	353	78	1,520	[1] 10,488,000
Nicaragua	1949–72	20	----	20	>[2] 178,912
Honduras	1949–72	6	----	6	56,277
Uruguay	≤1972	----	----	----	----------
Guatemala	1949–72	17	0	17	>[3] 68,410
Panama	1949–72	12	----	12	>[2] 65,484
Surinam	1949–72	33	0	33	[1,2] 102,148
Guyana	1949–72	9	0	9	48,336
Cuba [4]	1949–64	>201	>11	>524	>1,712,723
French Guiana	≤1972	----	----	----	----------
Dominican Republic [4]	1949–70	[1] 18	0	[1] 18	>44,419
Jamaica	1949–72	8	----	8	>[3] 29,581
Belize	1949–72	28	----	28	>[3] 94,987
Trinidad and Tobago	1949–72	[1,4] 515	[1,4] 230	[1] 8,450	25,266,001
El Salvador	≤1972	0	0	0	0
Haiti	1949–72	3	0	3	>[2] 12,930
Costa Rica	≤1972	19	----	19	131,103
Barbados	1950–71	17	6	19	[3] 149,760
Cumulative sums		11,958	4,132	91,962	362,592,346

[1] Estimate made by myself and D. Nielsen by filling in the gaps in the data for the period covered.

[2] One-year data gap.

[3] Two-year data gap.

[4] Several-years data gap.

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 (barrels)	*Gas (10^6 cubic feet)*
Middle East	496,000	510
USA, conterminous 48 States	101,600	556
U.S.S.R.	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
South and Southeast Asia, mainland	2,500	60

The fact that the EVRD per square mile 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.

Cumulative production plus proven reserves through 1971 are shown in table 13 for the various L.A. countries.

The Latin American petroleum fields are of average size by world standards; only a few giant accumulations have been discovered so far. 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 bbl of oil or more.

For further analysis, one can set three subgroups (1) Venezuela, Colombia, Trinidad and Tobago, (2) Mexico and Argentina, and (3) 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 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, whereas it possesses only 12 percent of the prospective area. Nonproducer countries account for 10 percent of the total prospective area.

COMPARISON WITH CERTAIN BENCHMARK AREAS

I have selected three areas as benchmarks in order to estimate the EUR for Latin American. These benchmark areas are: (1) conterminous USA, (2) U.S.S.R., and (3) Middle East. From a study of the range of estimates for the conterminous USA and the U.S.S.R., I have adopted a range of 100,000–250,000 bbl of oil and of 500–1,300 million cu ft of gas per sq mi of prospective area as being indicative of large continental units. These values are an order of magnitude lower than those for the Middle East.

ESTIMATES OF EUR'S FOR LATIN AMERICA

In the manner described above I have estimated that the EUR's for Latin America are (490 to 1,225) $\times 10^9$ bbl of oil, and (2,450 to 6,370) $\times 10^{12}$ 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.

TABLE 13.—*Petroleum outcome for Latin America*

[N.a.=not available]

Country	Cumulative production plus proven reserves to 1971 [1] Oil (10^6 barrels)	Gas (10^9 cubic feet)
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	N.a.	N.a.
Trinidad and Tobago	2,984	6,574
Barbados	1(−)	0(+)
Cumulatitve sums	72,950	134,783

[1] Albers and others (1973).

TABLE 14.—*Drilling and petroleum outcome for Latin American groups of nations*

Group	Total wells [1]	Cumulative production plus proven reserves to 1971 [2] Oil (10^6 barrels)	Gas (10^9 cubic feet)
A. Venezuela, Colombia, Trinidad and Tobago	40,878	50,285 (69 percent)	82,362 (61 percent)
B. Mexico and Argentina	37,198	12,752 (17 percent)	31,111 (23 percent)
C. All the other Latin American countries	[3] >13,866	9,913 (14 percent)	21,310 (16 percent)
	≈100,000	72,950	134,783

[1] Compiled from table 12.
[2] Albers and others (1973).
[3] Some data, mostly prior to 1949, not included.

NOTE ON THE PETROLEUM POTENTIAL 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 there: Salado, Bahia Blanca, San Jorge, Magallanes, and Malvinas. The maximum thickness of sediments in these basins, according to a 1960 survey by the Lamont Geological Observatories, would be respectively, less than 5 km, 4–5 km, about 4 km, about 5 km, and possibly 7 km. 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 U.S. Atlantic continental shelf. For the Atlantic continental shelf of the United States, figures in the range of 10–50 billion bbl of potentially recoverable oil resources have been published by the U.S. Geological Survey. Taking into consideration the facts that the area of the Argentine continental shelf is four times larger than the U.S. shelf, that the thicknesses of sediments is greater in Argentina, and that two of the Argentine basins produce onshore, one would be justified in estimating for the Argentine continental shelf an upper bound for the potential at least four times as great as that for the U.S. Atlantic continental shelf.

HOW TO DEVELOP THE LATIN AMERICAN PETROLEUM POTENTIAL

From the point of view of resource development, one should consider which alternatives are available to the L.A. developing nations to carry out petroleum exploration, namely: bilateral foreign assistance, international petroleum companies, national oil companies, and private entrepreneurs. 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 square miles 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 10,000 square miles of prospective area. The assessment of an area like the Argentine continental shelf, on the other hand, is an even more vast undertaking; roughly $500 million may be required, but even if the results were 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: (1) exploration and development, (2) exploration, (3) development, and (4) 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 of highly skilled petroleum executives, geologists, geophysicists, and petroleum engineers. For some of the prospective areas involved, only the skills of such a group 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 willingness, to risk the large amounts of risk capital that may be required and to readily bring 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.

The first type is a national company that has found its petroleum, and the second type is a national company that has acquired its current petroleum by nationalization of the assets of private international corporations. Some of the companies in this first type have been very to moderately successful. There are others in the first type of national companies which have had little success. On the other hand, the second type 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 U.S.S.R. provides another type of national petroleum undertaking. In the USSR's system there is a basic resource reconnaissance phase—regional geology and geophysics and 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 gage 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 validity of such comparison is suggested 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 include 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 barrels, 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 2,550 billion barrels for the undiscovered resources (Theobald and others, 1972).

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

These figures seem to understimate 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 potential resources much greater than the sum of the figures of identified and undiscovered resources 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 U.S. 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.

TABLE 15.—*Latin American-United States energy data comparison*

Area ($\times 10^6$ km^2):	United States of America 9.40	Latin America 19.9	
	10^9 barrels		
Oil:			
Proven reserves	[1] 52	[2] 29	
Other identified resources	[1] 290	[3] 74	(South America),
Undiscovered resources	[1] 2,550	?	other countries?
	10^{12} cubic feet		
Gas:			
Proven reserves	[4] 290	[2] 72	
Other identified resources	[4] 170	?	
Undiscovered resources	[4] 4,000	?	
	10^9 barrel oil yield		
Oil shale:			
Identified resources	[5] 2,000	[6] 800	
Undiscovered resources	[5] 23,850	[6] 41,200	
	10^9 barrels bitumen		
Tar sands:			
Identified resources	[7] 29	[7] 1,200	(Venezuela, Colombia)
		?	others
	10^9 metric tons		
Coal:			
Identified resources	[8] 1,587	[9] 20	(?)
Undiscovered resources	[8] 1,637	[9] 10	(?)
	10^3 metric tons U_3O_8		
Uranium:			
Identified resources	[10] 6,436	[10] 11.4	(Ar, Me)
Undiscovered resources	[10] 8,382	?	others

[1] Theobald, Schweinfurth, and Duncan (1972, p. 7).
[2] Statistical Office of the United Nations (1973).
[3] K. O. Emery, 1973, Resources of fossil fuels, unpub. report to the U.S. National Research Council.
[4] Theobald, Schweinfurth, and Duncan (1972, p. 9).
[5] Theobald, Schweinfurth, and Duncan (1972, p. 26).
[6] Culbertson and Pitman (1973, p. 501).
[7] Cashion (1973, p. 101).
[8] Theobald, Schweinfurth, and Duncan (1972, p. 3).
[9] Averitt, 1973, p. 140.
[10] Theobald, Schweinfurth, and Duncan (1972, p. 23–24).

LATIN AMERICA'S ENERGY OPTIONS

Many significant energy options appear open to the various L.A. countries. Immediate options are: hydroelectric expansion, import hydroelectricity, coal production, onshore petroleum resources, offshore petroleum resources, geothermal resources, nuclear energy, and solar energy. Midrange options are: coal liquefaction, coal gasification, shale oil, bituminous sands, solar energy, and nuclear energy. Some countries (Brazil, Chile, Argentina, Mexico, and 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 those available appear to be: develop onshore petroleum resources (Bolivia, Peru, Colombia), develop offshore petroleum resources (Argentina and Caribbean countries), coal liquefaction (Chile and Colombia), coal gasification (Chile and Colombia), shale oil (Brazil), and bituminous sands (Venezuela and Colombia).

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

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TABLES 16–19

TABLE 16.—*Nations of population 1 million or more ranked as per 1971 GNP per capita* [1]

Rank	Country	$/cap
1	United States	5,160
	Sweden	4,240
	Canada	4,140
	Switzerland	3,640
5	Denmark	3,430
6	France	3,360
	Federal Republic of Germany	3,210
	Norway	3,130
	Belgium	2,960
10	Australia	2,870
11	Netherlands	2,620
	Finland	2,550
	New Zealand	2,470
	United Kingdom	2,430
15	Austria	2,200
16	Israel	2,190
	German Democratic Republic	2,190
	Japan	2,130
	Czechoslovakia	2,120
20	Italy	1,860
21	Puerto Rico	1,830
	Ireland	1,510
	Libya	1,450
	U.S.S.R.	1,400
25	Poland	1,350
26	Greece	1,250
	Argentina	1,230
	Singapore	1,200
	Hungary	1,200
30	Spain	1,100
31	*Venezuela*	1,060
	Trinidad and Tobago	940
	Hong Kong	900
	Bulgaria	820
35	*Panama*	820
36	South Africa	810
	Chile	760
	Uruguay	750
	Romania	740
40	Yugoslavia	730
41	Portugal	730
	Jamaica	720
	Mexico	700
	Lebanon	660
45	*Costa Rica*	590
46	Saudi Arabia	540
	Cuba	510
	Albania	480
	Peru	480
50	*Brazil*	460
51	*Nicaragua*	450
	Iran	450
	Republic of China	430
	Dominican Republic	430
55	Malaysia	400
56	*Guatemala*	390
	Zambia	380
	Mongolia	380
	Angola	370
60	*Colombia*	370
61	Iraq	370
	Algeria	360
	Turkey	340
	Ivory Coast	330
65	*El Salvador*	320
66	Papua New Guinea	320
	Tunisia	320
	Rhodesia	320
	Democratic Republic of Korea	310
70	*Ecuador*	310
71	*Honduras*	300
	Syria	290
	Republic of Korea	290
	Mozambique	280
75	*Paraguay*	280
76	Congo	270
	Morocco	270
	Jordan	260
	Ghana	250
80	Senegal	250
81	Philippines	240
	Republic of Vietnam	230
	Egypt	220
	Thailand	210
85	Sierra Leone	210
86	Liberia	210
	Cameroon	200
	Bolivia	190
	Mauritania	170
90	Peoples Republic of China	160
91	Kenya	160
	Central African Republic	150
	Togo	150
	Malagasy Republic	140
95	Nigeria	140
96	Pakistan	130
	Uganda	130
	Khmer Republic	130
	Laos	120
100	Peoples Democratic Republic of Yemen	120
101	Sudan	120
	Haiti	120
	India	110
	Tanzania	110
105	Dahomey	100

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TABLE 16.—*Nations of population 1 million or more ranked as per 1971 GNP per capita*[1]*—Continued*

Rank	Country	$/cap	Rank	Country	$/cap
106	Democratic Republic of Vietnam	100	115	Burma	80
	Sri Lanka	100	116	Indonesia	80
	Niger	100		Ethiopia	80
	Guinea	90		Afghanistan	80
110	Zaire	90		Somalia	70
111	Malawi	90	120	Bangladesh	70
	Nepal	90	121	Upper Volta	70
	Arab Republic of Yemen	90		Mali	70
	Chad	80		Burundi	60
			124	Rwanda	60

[1] World Bank Atlas (1973).

TABLE 17.—*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.
Oil's heat of combustion assumed for oil equivalents .... 10,700 cal/gr.
Calorific values equivalence: 1 kg coal $\leftrightarrow$ 0.64 kg oil.

TABLE 18.—*Heat equivalence factors*

	Tons, coal standard
United Nations coal heat equivalence factors[1]	
Of 1 ton of:	
Coal briquettes	1
Brown coal and lignite briquettes	.67
Pechkohle	.67
Coke	.9
Brown coal and lignite	.3–.33
Peat	.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	.6
Refinery gas	1.75
Of electricity:	
1,000 kWh[2]	.125
Comision Economica para America Latina, 1973, overall thermoelectric plant efficiency 1 kWh=3,000 cal.	

[1] Statistical Office of the United Nations (1973).
[2] The efficiency of the conversion of heat into electricity in a thermal plant is not considered in this factor.

TABLE 19.—*Evolution of oil prices 1955–74*[1]
[Current dollars per barrel, Saudi Arabian light crude, 34° API, f.o.b. Ras Tanura]

Date	Posted price	Estimated market price
January 1, 1955	1.93	1.93
1957	1.93	1.93
1959	2.08	1.70
[2] 1961	1.80	1.45
1963	1.80	1.40
1965	1.80	1.33
1967	1.80	1.33
1969	1.80	1.28
1971	1.80	1.33
[3] 1972	2.285	1.75
1973	2.591	2.20
April 1, 1973	2.742	2.30
June 1, 1973	2.898	2.70
August 1, 1973	3.066	2.85
October 1, 1973	3.011	3.00
Kuwait, October 16, 1973	5.11	3.65
January 1, 1974	11.65	7.65

[1] United Nations Economic and Social Council (1974).
[2] After OPEC.
[3] After Teheran agreements.