THE INTER-RELATIONSHIP OF POPULATION, LIVING STANDARD AND ENERGY PRODUCTION-PAST, PRESENT AND FUTURE

by

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PREFACE

All human affairs and activities involve the interactions of people in relation to their environment. People need more food, clothing, housing, education and recreation to maintain their living level and to raise their living standards. This means that people need more resources of energy to accomplish these aims. The growth of world population in the past and in the foreseeable future is increasing rapidly. This indicates that the demand for energy is increasing. Also, with the advance of scientific technology, more and more energy is required. In fact, in the world as a whole, projections of the demand for energy greatly exceed the population growth. For this projected problem, it is interesting to study the relationship between energy, population and living standards of that population.

We know that the future is uncertain. However, even the best statistics for the past trends of resources and population estimates are not sufficient. Due to this restriction, in Chapter 2, which deals with energy, most of the information is based on the paper "Energy Resources" by M. King Hubbert (3), 1968. The data on energy before 1930 is based on the book Energy in the Future, by Putnam (12), 1953. Those materials from 1930 to 1968 are mainly based on the United Nations Statistical Yearbook (17).

Because of the more complete records and the high development in the United States, it is reasonable to take this country as a reference of the world as a whole.

It is hopeful that the past and future picture about the relation between population, energy and the living standards, which is described here, can help the realization and elimination of the gap between developed and developing countries.

There are many factors in social, political, economical and historical cultures that affect the type of growth of each area. The whole population, with its resources and technology, cannot be considered as a single pool. However, the growth in any one region cannot be without effect on the people of other regions.

For the purpose of this study, and its general conclusion, the important problem of distribution of energy will be largely ignored. That is to say, when dealing with future world estimates, averages will be used. In the practical case, inequitable distribution will undoubtedly still occur, and the world problem will be even more pessimistic than shown here.

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CHAPTER I

POPULATION

The acceleration of the world's population growth has resulted from a rapid decline in mortality rate with a sharp increase in fertility. Precise statistics are not available for births and deaths. Figure 1 gives the estimation of the world population growth for the period from 1000-2000 A.D., inclusive, using Putnum's (12) estimation for the period 1000-1890, United Nations (18) estimation for the period 1900-1969, inclusive, and the estimates of Frank W. Notestein (8, page 17) for the period 1970-2000. These data are given numerically in Table 1, and graphically in Figure 1.

The first doubling of world population after 0 A.D. occurred at about 1690, the second at about 1845 and the third at about 1937. Thus, during the interval since 0 A.D. the first doubling required 1690 years, the second 155 and the third 92. The United Nations (18) estimate of the population in 1950 was 2.517 billion. By 1960 this had increased to 3.005 billion. This corresponds to a rate of increase of 1.82 percent per year, at which rate the population would double in only 38.2 years. By 1969, with a total population of 3.552 billion, the period from 1960 to 1969 had an annual rate of population increase of 1.9 percent, at which rate the world population would double in 36.8 years, or by the year 2005. Should the trend continue, the population would increase to approximately six to seven billion by the year 2000.

TABLE 1

WORLD POPULATION ESTIMATES

Year	Population (Millions)	Sources
10,000 B.C.	1 x 10	Putnam*
1 A.D.	275 + 80	"
225	290 Max.	"
700	270 Min.	"
1000	295	"
1200	310	"
1400	350	"
1650	493	"
1750	694	"
1800	887	"
1850	1,170	Carr-Saunder
1890	1,500	Putnam
1900	1,550	United Nation**
1925	1,907	"
1930	2,070	United Nation***
1940	2,295	"
1950	2,517	"
1960	3,005	"
1963	3,176	"
1965	3,295	"
1968	3,483	"
1969	3,551	"
1970	3,655	Notestein****
1975	4,080	"
1980	4,562	"
1985	5,092	"
1990	5,687	"
1995	6,278	"
2000	6,919	"

* Putnam, Palmer Cosslett, 1953, Energy in the Future; New York, D. Van Nostrand Co., Page 16-17.

** United Nations, 1958, The Future Growth of World Population; New York Department of Economic and Social Affairs, page 17.

*** United Nations, 1969, Statistical Year Book.

**** Notestein, Frank W., 1962, (8, page 17)

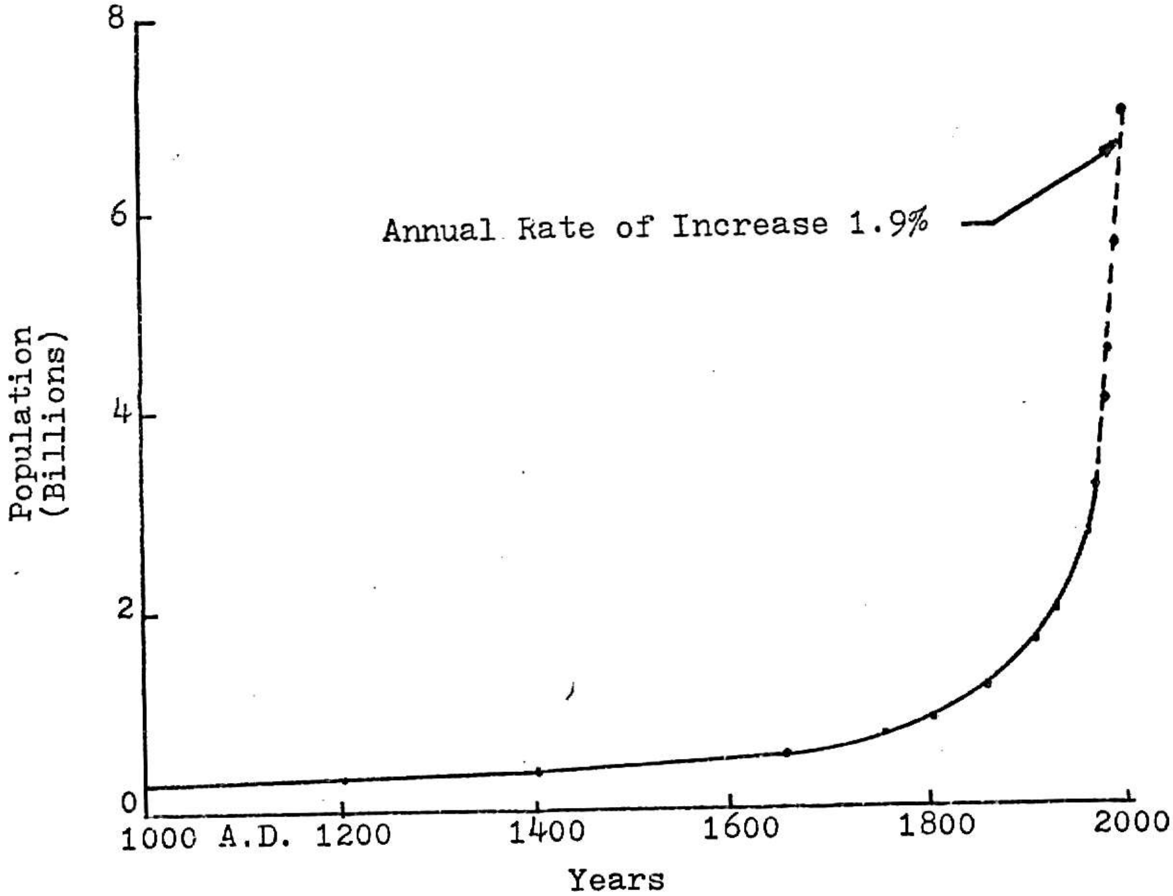


Figure 1. Growth of World Population (Data from Table 1)

Table 2 shows the estimated population of the world and of its major regions. The projected populations for 1980 and 2000 (which are based on the annual rate of increase from 1960 to 1969, prepared by the United Nations) are also shown. If the annual rate of population growth shown in Table 2 is kept constant during the next half century, the years required to double the population for each area are shown in column four of this table. Also shown in the last two columns are the percentage for each area referred to the whole world at 1969 and 2000, respectively. The distribution of the world population as shown in Table 2 at the year 1969 is quite uneven. Africa, Asia and Latin America share almost three-fourths of the world population. If the projection is correct, they would contain nearly 80 percent of the world total population for the year 2000. Actually the recent statistical data shows that there is no evidence that the increase of population growth (shown in Table 2) will change soon. If the population growth rate continues to rise, then the population number will be even higher than those projected in Table 2.

The population size of the earth depends on supplies of food and energy and on our knowledge of the technology that can support the maximum population. Of course, the rapid increase of population growth will become a large burden for the less developed countries. According to the studies of Harold F. Dorn (11) in world population growth, "if there is not sufficient food and energy to support the increase in population, population will not continue to increase. This is a biological law that no species has even been able to evade. A stage has been reached in the

TABLE 2

ESTIMATE OF POPULATION OF THE WORLD AND ITS MAJOR REGIONS IN SELECTED YEARS

Major Regions	1900	1930	1940	1950	1960	1963	1969	1980	2000	Annual Rate of Increase (1960-1969) (%)	Years Required To Double Population	Percent of World Population 1969	2000
World Total	1550	2070	2295	2517	3005	3176	3552	4450*	6600*	1.9	36.8	100	100
Africa	120	164	191	222	278	297	345	580	720	2.4	29.3	9.7	11.1
North America	81	134	144	166	199	208	224	263	347	1.4	50	6.3	5.4
Latin America	63	108	130	163	213	232	276	377	670	2.9	24.3	7.2	10.3
Asia	857	1120	1244	1381	1660	1760	1988	2420**	3670**	2.0	35	56	56.8
Europe#		355	380	392	425	437	460	515	625	0.9	76	12.9	9.7
West Europe		108	113	123	135	140	148	165	200	1.0	69.6	4.1	3.1
Oceania	6	10	11.1	12.7	15.8	16.8	18.9	24.8	36	2.1	33.4	0.5	0.6
United States						189	203	240	318	1.4	50	5.6	5.1

Sources; For 1930 to 1969, Data Extracted From <u>United Nations Demographic Yearbook</u>, 1969.
For 1900 Data Extracted From Ref.19.

Exclude USSR
* Projection Based on 2 Percent Annual Growth Rate.
** Projection Based on 2.1 Percent Annual Growth Rate.

demographic development of the human race when the rate of reproduction in any part of the earth may affect the health and welfare of the rest of the world's population, It is in this sense that there is a world population problem." There is no other choice for man but either a high mortality rate or a low fertility rate in order to control the now rapid growth of population. Time will tell how successful we can be.

CHAPTER II

ENERGY RESOURCES

The underdeveloped countries of the world have literally had a population explosion in recent years. Rapid increases in population have also been sustained by most of the more highly developed countries. The high rate of population increase has led to serious concern about the capacity of the natural environment to sustain the growth. Clearly, the population problem is not simply one of numbers of people, but also of natural resources and how they are used. One resource about which there is great concern is energy. The fossil fuels, coal, petroleum and natural gas account for the greater part of the world's present consumption of energy. We shall first concern ourselves with these resources. We shall consider data on the available commerical resources of coal, crude-oil, natural gas, natural gas liquids and hydro-electric systems.

Energy from Fossil Fuels

The fossil fuels, (coal petroleum and natural gas) account for the main part of the world's present consumption of energy. Hubbert M. King (8, page 33) stated that "-these are the residues of organisms which become buried in the sedimentary muds and sands over a period of some 500 million years of geological history. Their energy content represents solar energy, stored by photosynthesis as chemical energy, during that same span of time. Geologically, this process is still continuing but probably at a rate not greatly different from that of the past. Hence, the new fossil fuels to be generated during the next million years will probably not differ greatly from 1/500th of that of the last 500 million years, and that for the next 1,000 years correspondingly less." For this reason, once the existing reserves are used up, these fuels will have gone forever for practical purposes.

World Production and Potential of Coal

The latest world summary of original coal in place is that prepared by Paul Averitt (3, page 202) as given in Table 3.

If we plot a curve with production rate, P, against time, t, on arithmetic paper, this will represent the following properties: (3)

(A) The curve must begin with P=0, and, after passing through a maximum value, it must ultimately decline to zero. This last state would be due either to the exhaustion of the resources or to the abandonment of its production for other reasons, such as high costs, etc.

(B) The cumulative production Q up to any given time is given by the equation

$$Q = \int_0^t (dQ/dt)dt = \int_0^t p\ dt$$

and this, on the graphical plot, is proportional to the area, A, between the rate of production curve and the time axis.

World production statistics are not available before 1860. Statistical data of the world energy consumption rate from 1860 to 1968 is shown in Figure 2. The growth from 1860 to 1913 is nearly a straight line. This indicates that during that period

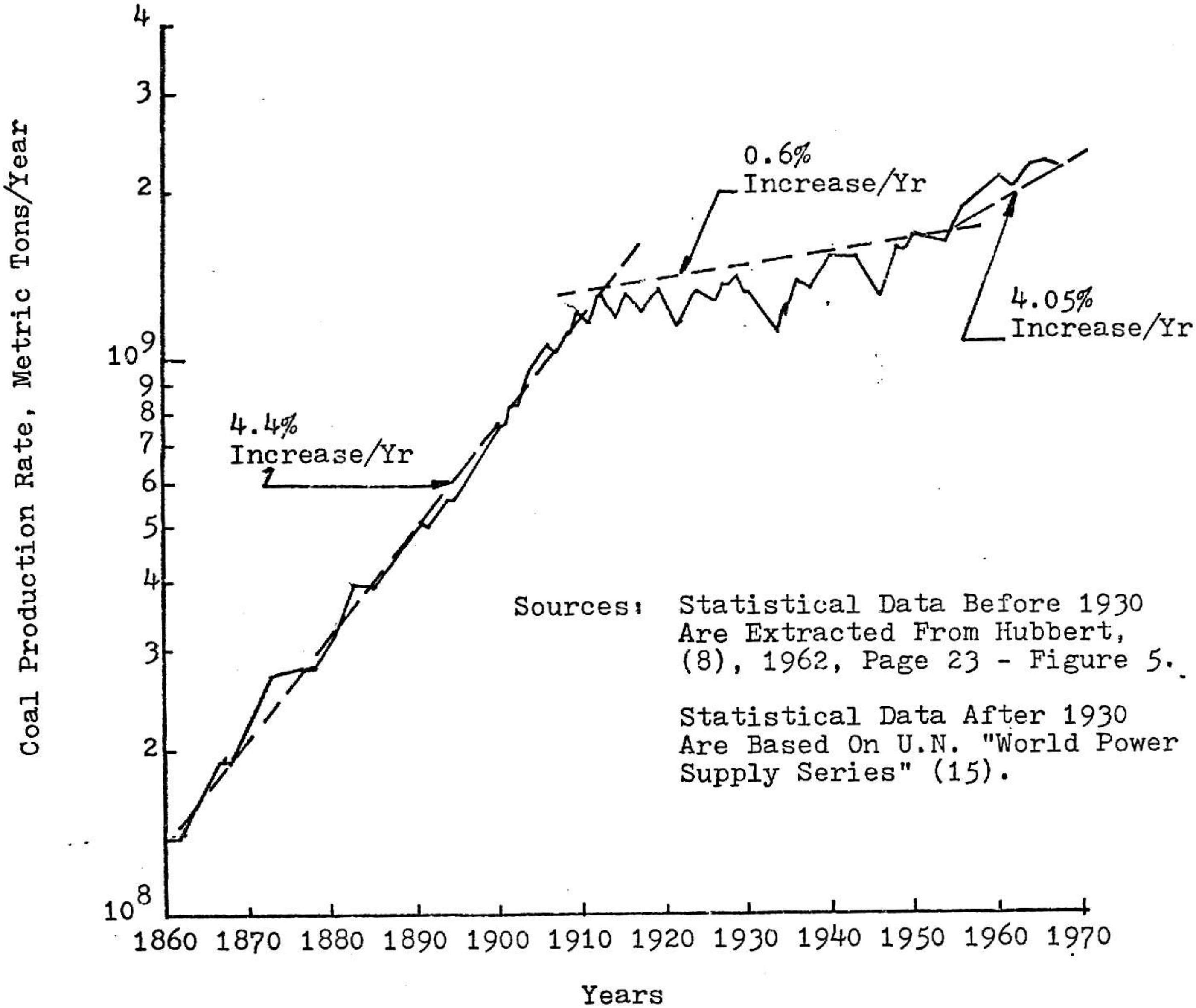


Figure 2. Estimate of World Production of Coal

TABLE 3

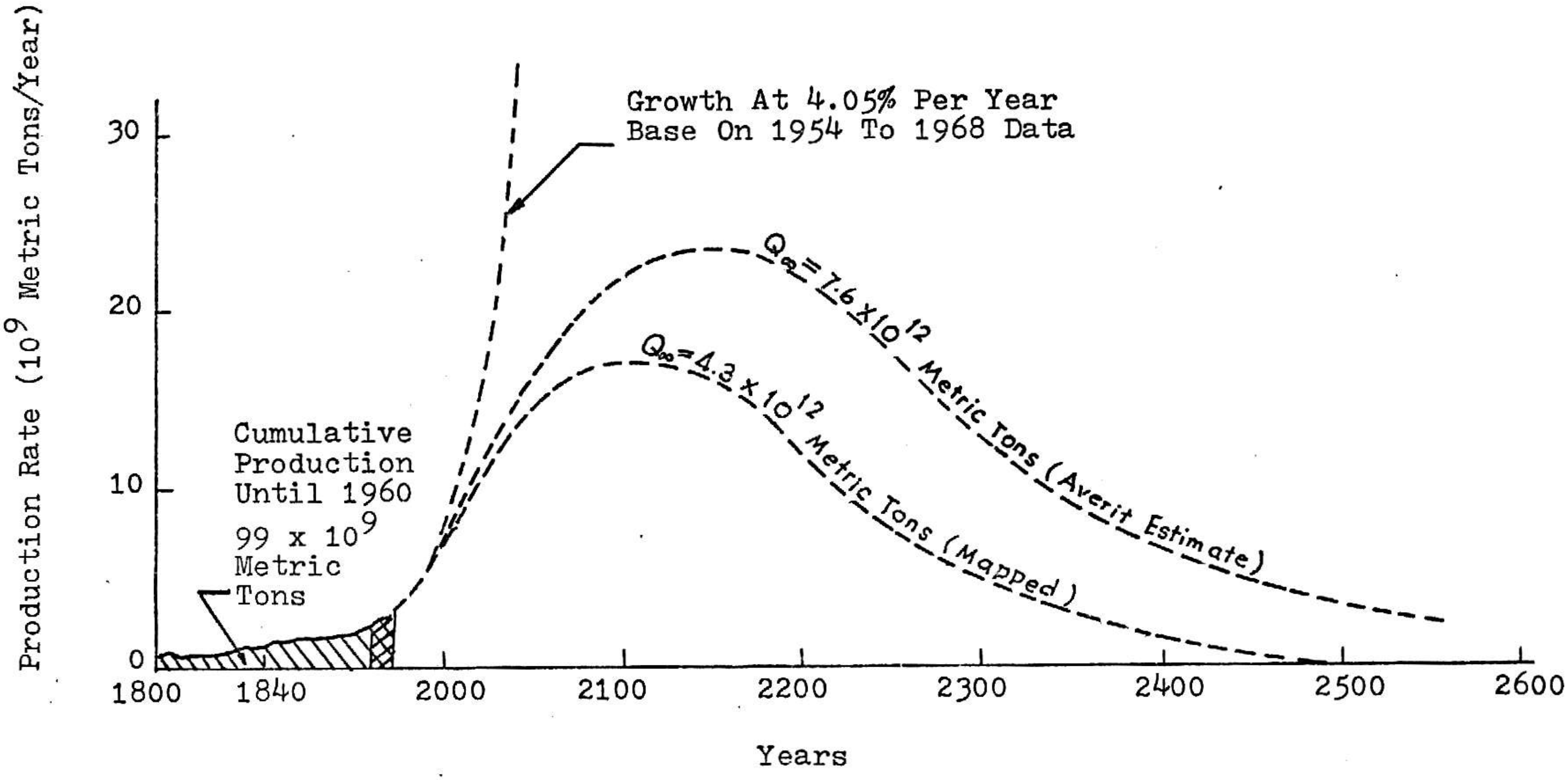
ESTIMATES OF TOTAL ORIGINAL COAL RESOURCES OF THE WORLD BY REGIONS (IN BILLION OF TONS)

Regions	Resources Determined by Mapping and Exploration	Probable Additional Resources in Unmapped and Unexpected Areas	Estimated Total Resources
Asia & European USSR	7,000	4,000	11,000
North America	1,720	2,880	4,600
Europe	620	210	830
Africa	80	160	240
Oceania	60	70	130
South & Central America	20	10	30
Total	9,500	7,300	16,830

Source: Reproduced from Hubbert (3), 1968, page 202, Table 8.6

the rate of coal production increased with time at the rate of 4.4 percent per year with a doubling period of 16 years. From 1913 to 1954 the production increased more slowly, averaging only about 0.6 percent per year. From 1954 to 1968 the rate of production increased to 4.05 percent with a doubling period of 20 years.

World cumulative production by the end of 1960 is 99 x 10^9 metric tons which is shown by M. King Hubbert (8, page 39). Averitt's (3, page 203) estimated the world ultimate coal production within 4.3 x 10^{12} metric tons. The complete cycle of world coal production is shown in Figure 3. The graph must show a continuing growth until it passes through some maximum point, then turns down approaching zero asymptotically. The area under the curve represents the total world reserve of coal energy, which can't exceed a value that lies between 4.3 x 10^{12} metric tons and 7.6 x 10^{12} metric tons. For the larger value (7.6 x 10^{12} metric tons), the peak product rate would occur about 170 to 200 years hence. The time required to consume the middle 80 percent would be approximately 340 years in the period between 2040 and 2380. For the smaller value of 4.3 x 10^{12} metric tons and with a production rate that is six times the present rate, the world peak rate would occur about 140 years from now. These data are based on M. King Hubbert's estimate. This is under the assumption that the world would continue to depend upon coal as the main fuel resource in the future.



Source: Reproduce From Hubbert, (3), 1968, Page 204, Figure 8.25.

Figure 3. Complete Cycle of World Coal Production for Two Values of Q_∞

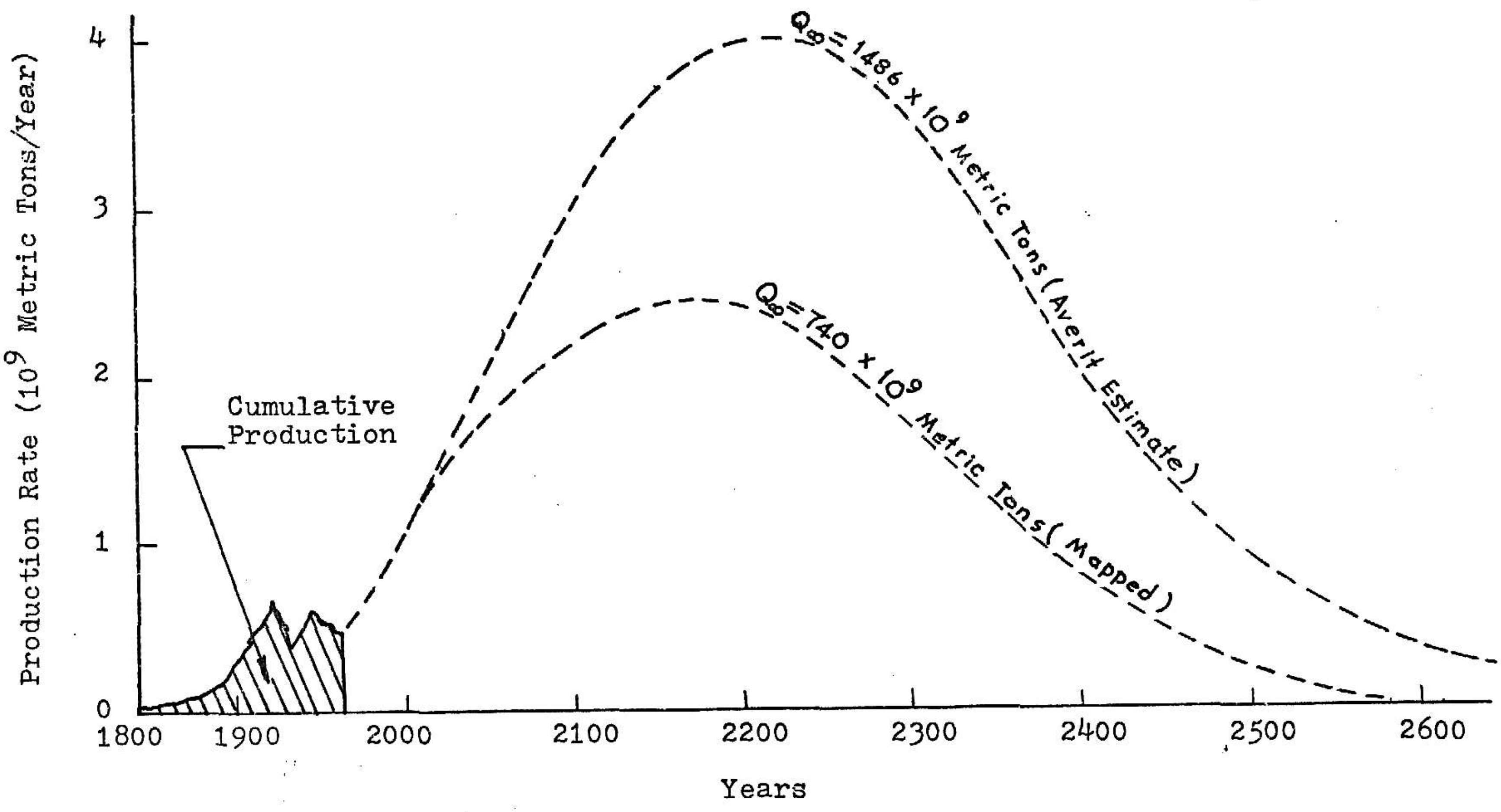


Figure 4. Complete Cycle of United States Coal Production For Two Values of Q_∞

Source: As Figure 3 Shows

U.S. Production and Potential of Coal

For the United States, Averitt's (3, page 204) recent estimate of the initial U.S. coal reserves is between 740 x 10^9 metric tons and 1489 x 10^9 metric tons. Figure 4 shows the complete cycles of the United States coal production for two values of Q_∞. Using the larger value (1 489 x 10^9 metric tons), the time required to consume the middle 80 percent would be approximately 400 years in the period between 2040 and 2440. The U.S. coal reserves in the ground are estimated to be sufficient for about 500 years, based on the current rate of consumption (1).

At the present rate of consumption of 2.2 billion tons per year of the world, and with an increase in the rate of 5 percent per year, there would seem to be enough coal to last for more than two centuries. However, not all the coal in the ground can be brought to the surface. Further, the possible output of usable coal is reduced by inevitable mining losses. Mining costs will also increase as living standards rise, since mining is a labor-intensive industry. Before we can convert the coal to clean energy, the contribution to environmental pollution by coal will restrict the use of coal, too. Also, Table 3 shows the regional distribution of coal deposits is uneven. About 65 percent of the world's initial coal was in Asia and about 27 percent in North America. The United States, the Soviet Union, Canada and China account for nearly 80 percent of all the world coal reserves. These problems show that the world position in using coal is not favorable. While the USA, USSR, China and Canada will have ample supplies of coal for many centuries, several local shortage may occur in the rest of the world within the next few decades.

World Production and Potential Reserves of Crude-Oil

There are several estimates of the ultimate recovery of crude-oil. Table 4 shows the estimated ultimate crude-oil recovery for the world. The proven reserves (571 x 10^9 bbls) as of January, 1967, and those estimated by W. P. Ryman (3, page 194) (2,090 x 10^9 bbls) are quite different. M. King Hubbert suggested that the world's ultimate production of crude-oil at the present time is roughly within the 2090 x 10^9 bbls as estimated by Ryman, and 1350 x 10^9 bbls, which is about two-thirds of the Week's estimate of 2000 x 10^9 bbls.

Figure 5 shows the production of crude-oil for the world from 1850 to 1968. The production rate of crude-oil is increasing about 1.4 percent annually.

Figure 6 shows the complete cycle of the world crude oil production for two ultimate potential reserve values. For the original value of 1350 x 10^9 bbls, 80 percent of the cumulative production will be used during a 58 year period from 1961 to 2019 (3). A peak production rate of about 25 x 10^9 bbls/year is estimated to occur in the year 1990 if this model of use is correct. For an original value of 2100 x 10^9 bbls, the peak production rate of about 37 x 10^9 bbls/year will occur in about the year 2000 according to this model. The time required to produce the middle 80 percent of the ultimate cumulative production is the 64 years period from 1968 to 2032. The actual annual production

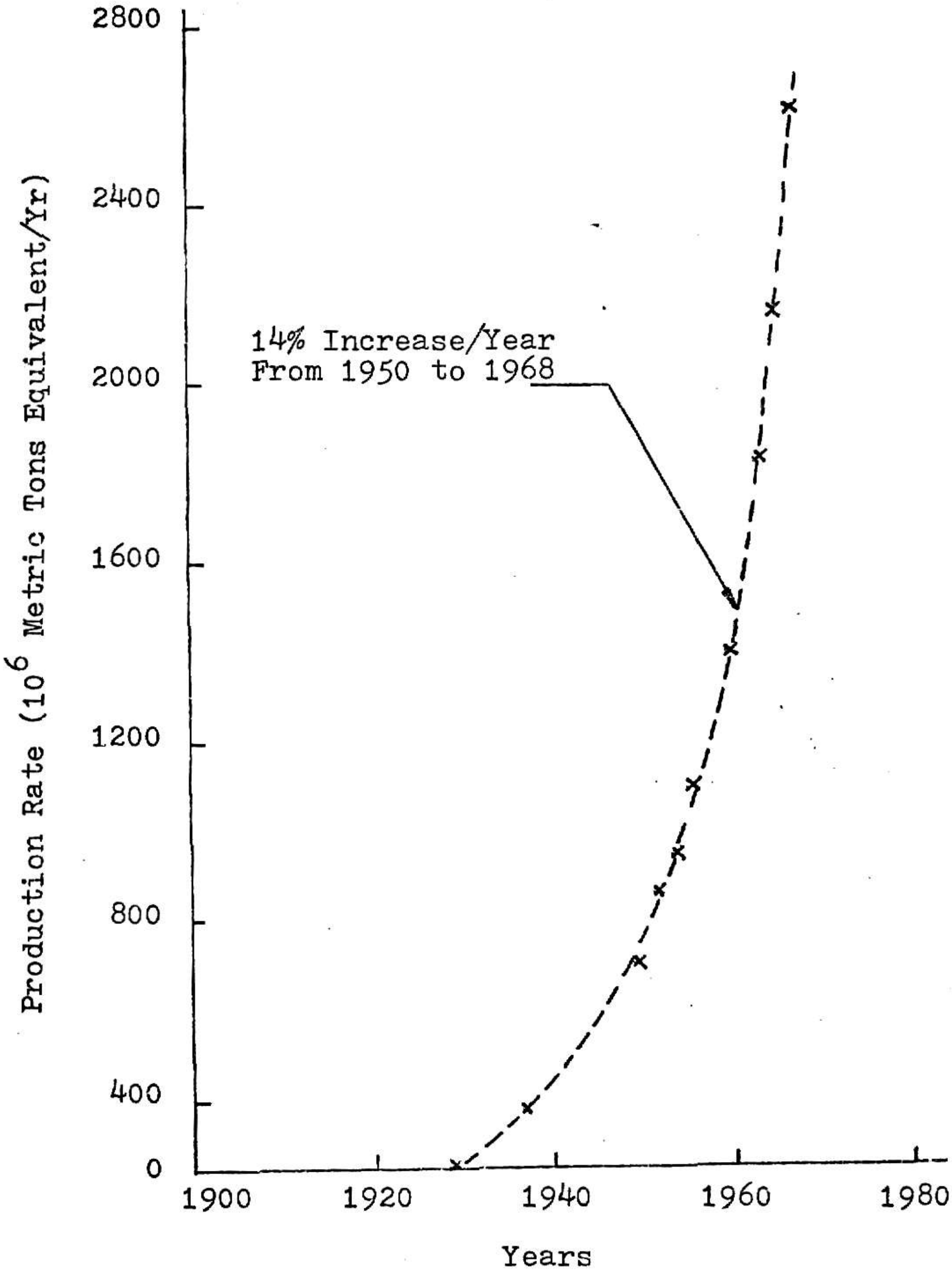
TABLE 4

ESTIMATED ULTIMATE RECOVERY OF WORLD CRUDE-OIL
BY GEOGRAPHICAL AREAS
(EUR IN U.S. BILLIONS OF BARRELS)

Areas	World Oil Jan. 1967 Proven Reserves	World Petr., Dec. 1966 Proven And Probable Reserves	L.G. Weeks 1962 EUR	W.P. Ryman 1967 EUR
Free World*				
Europe	3.6	4.0	19	20
Africa	31.9	49.0	100	250
Middle East	237.7	304.1	780	600
Far East	15.1	17.1	85	200
Latin America	56.9	64.4	221	225
Canada	10.9	11.4	85	95
Total	392.1	450.0	1290	1390
United States	113.4	128.6	270	200
Total Free World	505.5	578.6	1560	1590
USSR and China and Satellites	65.5	86.7	440	500
Total World	571.0	665.3	2000	2090

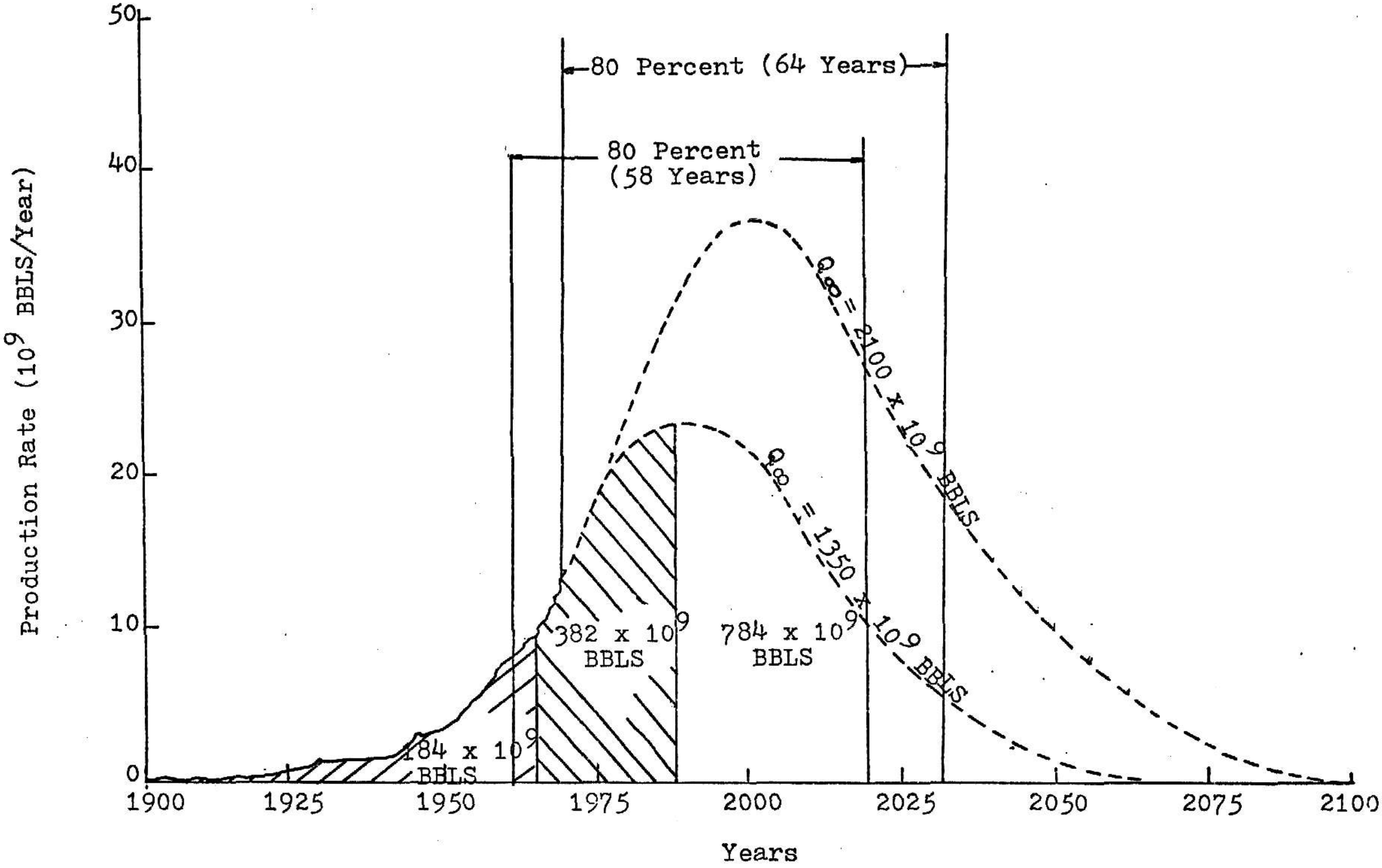
Source: Hubbert (3), 1968, Table 8.2, Page 194.

* Free World Outside United States.



Source: U.N. 1969 Statistical Demographic Yearbook

Figure 5. World Production of Crude Petroleum



Source: M. King Hubbert, (3), 1968, Page 196.

Figure 6. Complete Cycle of World Crude-Oil Production for Two Values of Q_∞

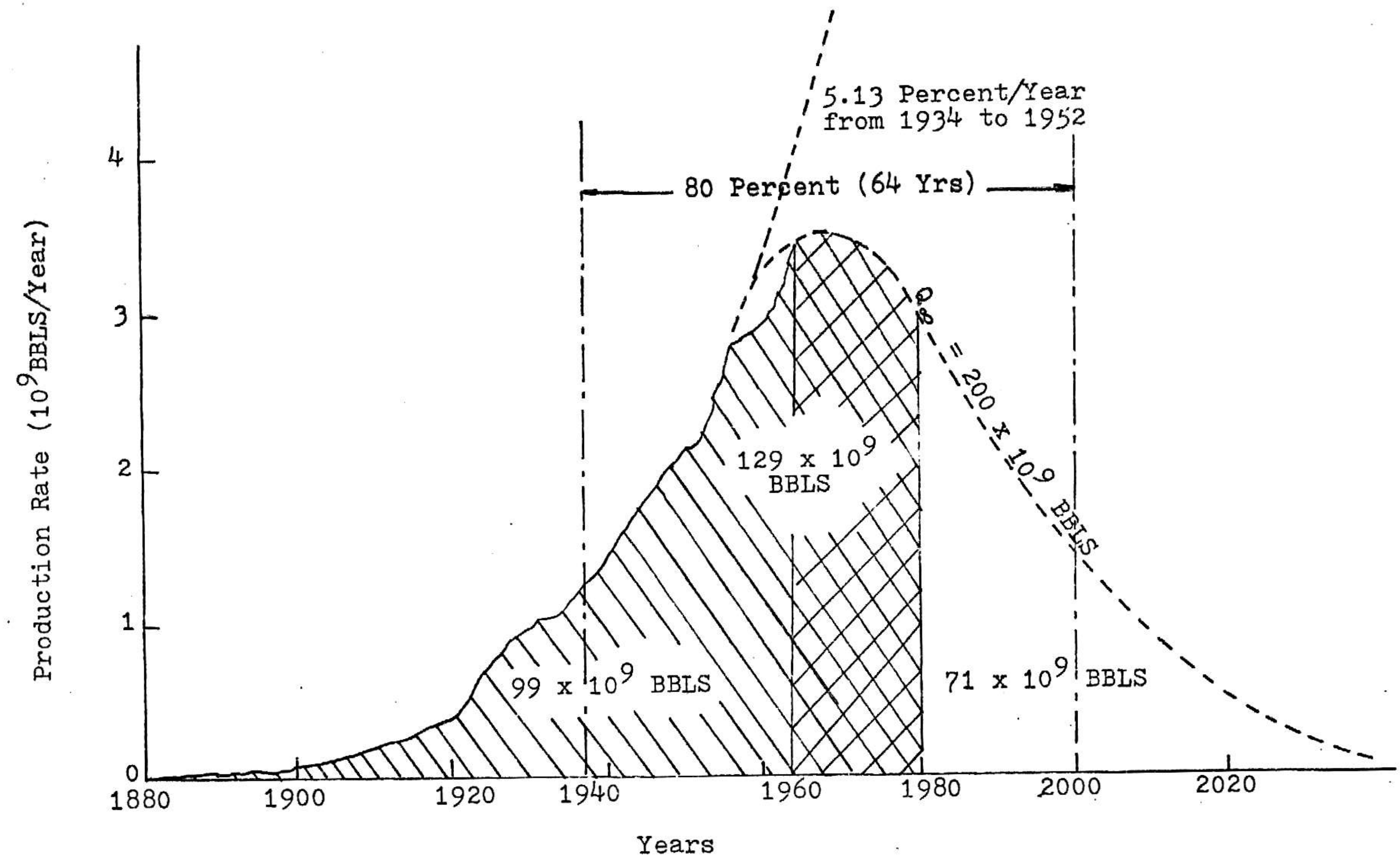
of commercial energy from crude-oil is also shown in Figure 6 as a solid line. The years 1929 and 1937 were peak years of economic activity in much of the world during the inter-war period. The crude-oil production figures for these two years actually are greater than those shown by the curve.

Production of Crude-Oil in the United States

The complete cycles of the production of crude-oil in the United States is shown in Figure 7. Hubbert estimated 165 x 10^9 bbls of crude-oil as the ultimate recoverable figure. To this he added 36 x 10^9 bbls of natural gas liquids, the ultimate quantity of that fuel. The total is 201 x 10^9 bbls. Of this, 129 x 10^9 bbls have been found, and 90 x 10^9 bbls consumed by 1966. Hubbert shows 80 percent of the original total petroleum fluids (crude-oil, natural gas, natural gas liquids) in the U.S. will have been found and consumed in 64 years, with production peak value at about 1970. About 18 million bbls a day of oil is required today in the U.S. With the present consumption rate, in less than ten years, the U.S. will need from 20 to 25 millions bbls a day.

World Reserves of Natural and Natural-Gas Liquids

To control air pollution, it is natural to expect that most of the remaining natural gas and natural-gas liquids production will be used for industrial purposes in the near future. There are many facts indicating the trend, such as the increase in gas consumed in industry near the centers of gas production, the development of cryogenic tankers for the transportation of natural



Source: M. King Hubbert, USGS, Energy Resources for Power Production, Aug. 1970

Figure 7. Complete Cycle of Production of Petroleum Liquids in U.S. and It's Possessions Exclusive of Alaska

gas in liquid form and the building of large diameter pipelines for the transmission of gas from remote production areas to main industrial areas of consumption.

Until now, the United States is the most advanced country in the petroleum industry. Since there are no accurate statistical data for the whole world production of natural gas and natural-gas liquids, it is better to estimate the potential reserves by comparing the estimated reserves of crude-oil and the amount of natural gas and natural-oil liquids per bbl and crude-oil in the U.S. According to Hubbert's studies (3, page 197), during the last 20 years, the ratio of natural-gas discovered to crude-oil has averaged about 6,000 cu. ft/bbl, and the corresponding ratio of natural-gas liquids to crude-oil is about 0.22 bbls/bbl. Applying these ratios to the ultimate world production of crude-oil, we obtain the corresponding estimates for the ultimate world production of natural gas and natural-gas liquids as shown in Table 5. The estimates given by W.P. Rayman (3, page 197) at the Vanconver Conference for the ultimate world production of natural gas and natural-gas liquids were 12,000 x 10^{12} cu. ft. and 375 x 10^9 bbls, respectively. Both of these figures were within the range indicated in Table 5.

Tar or Heavy-Oil Sands

Not until 1966, when the first large-scale moving and extraction plant, developed by a combination of major oil companies, went into successful operation were such sands exploited. Table 6 shows that the best deposits of tar, which possibly are the

TABLE 5

ESTIMATES OF ULTIMATE WORLD PRODUCTION OF NATURAL-GAS LIQUIDS, TOTAL PETROLEUM LIQUIDS AND NATURAL GAS, BASED UPON TWO ESTIMATES OF THE ULTIMATE PRODUCTION OF CRUDE-OIL.

Ultimate World Crude-Oil Production (10^9 bbls)	Ultimate Natural-gas Liquids Production (10^9 bbls)	Ultimate Petroleum Liquids Production (10^9 bbls)	Ultimate Natural-gas Production (10^{12} ft^3)
1,350	250	1,620	8,000
2,100	420	2,520	12,000

Source: Hubbert, 1968, (3, page 197)

TABLE 6

TAR-SAND DEPOSITS OF ALBERTA, CANADA

Area	(10^9 bbls)
Athabasca	266.9
Bluesky-Gething	20.6
Grand Rapids	13.3
Total	300.8

Source: Hubbert, 1968, (3, page 198)

world's largest, are located in the province of Alberta, Canada. If we compare the magnitude of the reserves of these deposits with those of the crude-oil resources of the United States, their potential importance in the comparatively near future, when domestic crude-oil production begins its decline, is immediately apparent.

Oil Shales

Hubbert mentioned that although the major deposits of carbonaceous shales throughout the world is estimated to be 2×10^{15} bbls as the total oil-equivalent content of these shales, only 190×10^9 bbls (including 80×10^9 bbls from the Green River Formation in Colorado, Utah and Wyoming in the U.S.) is listed as recoverable under present conditions. It is concluded by Hubbert that the organic contents of the carbonaceous shales appear to be more promising as a resource of raw material for the chemical industry than as a major source of industrial energy. Processes for extracting the oil are not yet competitive in cost, but improvements are being sought because vast deposits of oil shales hold promise of increased oil supply.

ENERGY FROM NUCLEAR POWER

A few years ago fossil fuels and water power were most generally used as energy in central station power plants. For many reasons, such as economy, air pollution and finite potential of fossil fuel reserves, nuclear energy is now providing a significant portion of these requirements and will become a larger energy supplier to the utility industry in the future. Even though the percentage of generation by fossil fuel is expected to decrease, the actual value will increase. However, nuclear energy depends on the availability of uranium which is also limited in quantity. The development of breeder reactors to replace reactors which are now in use will reduce, but not eliminate the dependency on raw uranium. These breeders are expected to be in commercial operation in the early 1990's.

United States and World Electrical Utility Industry Capacity

The U.S. energy consumption is doubling every fifteen years, and electrical energy consumption is increasing at twice that rate. Figure 8 shows the U.S. electric utility industry installed capacity between 1950 and 1968, and a projection of future capability through the year 2000. The present and projected nuclear capability, which will attain a level of 700,000 to 1,000,000 electrical megawatts (MWe) by the year 2000, is also shown. The nuclear power growth forecast up to year 1980 was based on the Atomic Energy Commission (AEC) prediction of between 120,000 and 170,000 MWe with the best single estimate of 150,000 MWe (9). At the end of 1966, the USA nuclear-power was 1,800 MWe. Thus, a mean exponential growth rate of 36.8 percent per year is expected. The corresponding forecast of total US electric-power capacity for the same period was increased from 233,000 MWe at the end of 1966 to 579,000 MWe by the end of 1980 - a mean growth rate of 6.5 percent per year. The comparison of raw energy sources and electric generation shows that nuclear power will increase from 0.4 percent

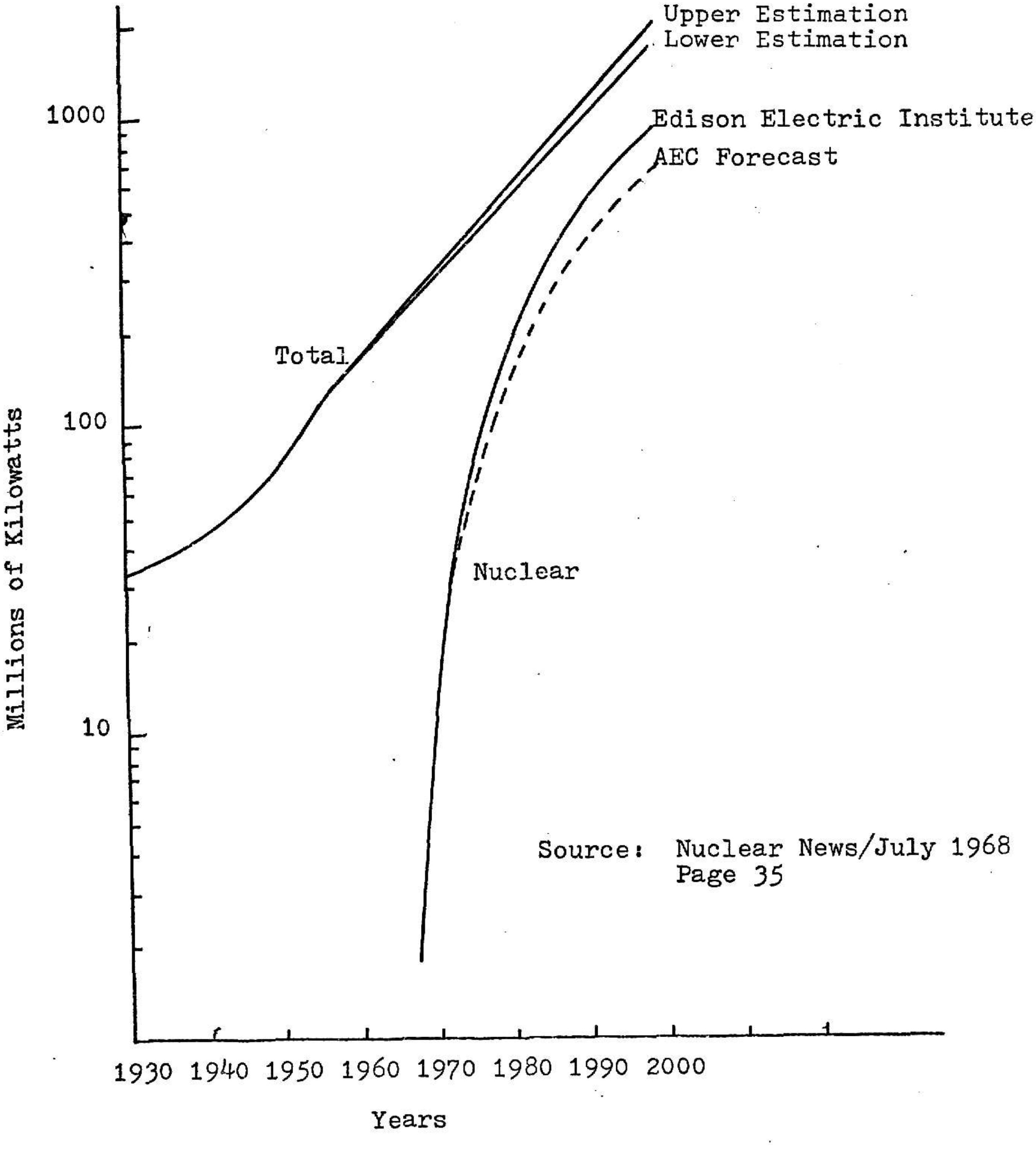
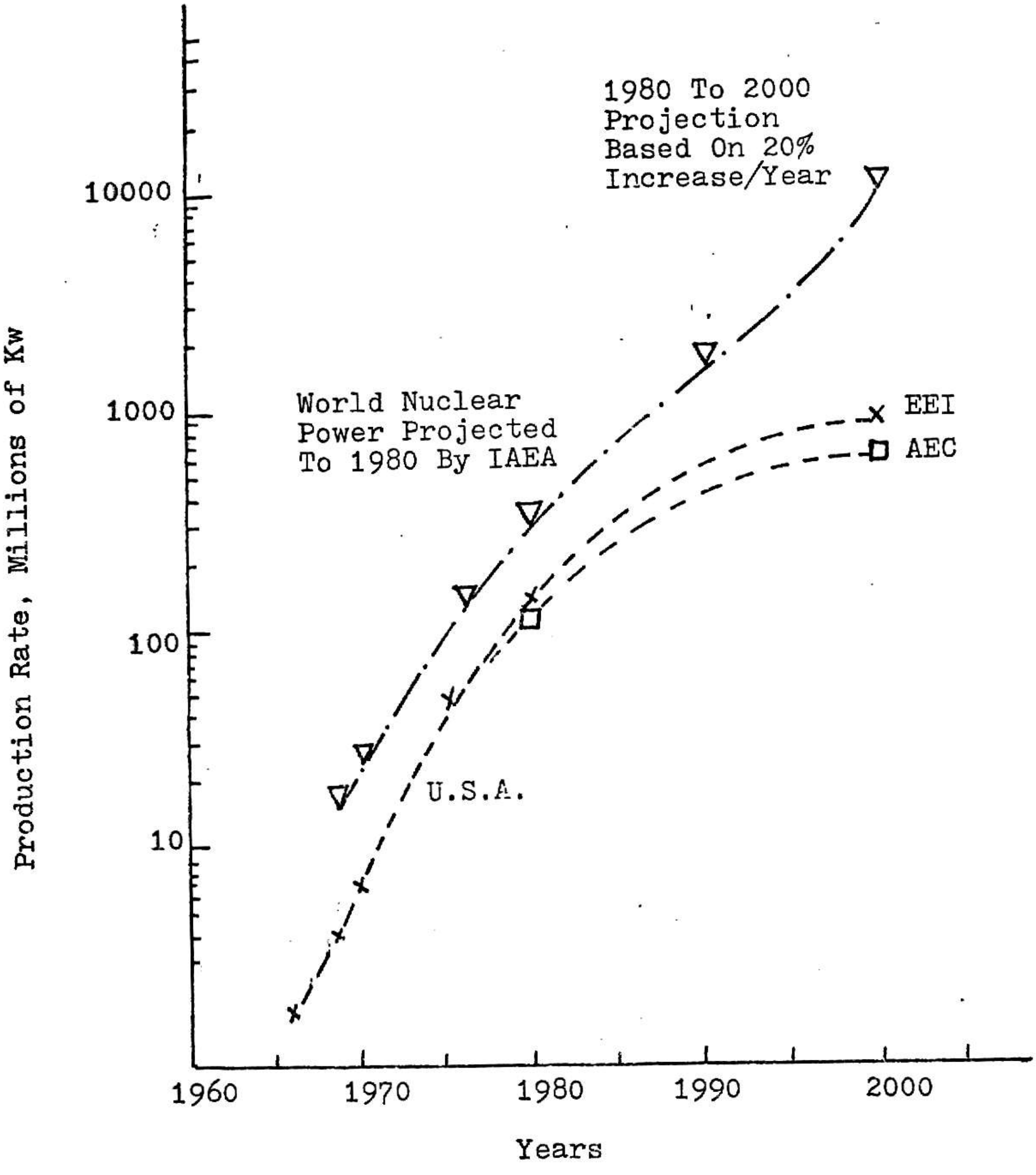


Figure 8. U.S. Electric Utility Industry Capacity

to 50-60 percent in 1965 and 2000, respectively. In 1967 about 50 percent of the new capacity purchased was nuclear (13). This shows the rapid expansion of nuclear power. Figure 9 shows the installed nuclear capacity of the world compared with the U.S.A. The world capability at the end of 1969 was nearly 15,500 MWe (91 reactors in 14 countries). By the year 1970 the capability should attain 24,250 MWe (109 reactors in 15 countries). By 1976 the number of countries having nuclear reactors is expected to be 28 and the capability (with 298 reactors) is estimated to be 147,000 MWe. The installed nuclear capability should exceed 200,000 MWe by 1980. John J. Nassikas (2), chairman of the Federal Power Commission, projected the total electric generating capacity growth from the present level of 300,000 MWe to 1,260,000 MWe by 1990.

By employing breeder reactors the nuclear fuel supply can be amplified roughly a hundredfold (4). The depletable supply of nuclear fuel for ordinary reactors in the U.S. is about $3{,}000 \times 10^{11}$ watt-years, or 8.97×10^{18} BTU, and that of the world is about $3{,}000 \times 10^{12}$ watt-years, or 8.97×10^{19} BTU. The nuclear depletable supply of the world for breeder reactors is about $300{,}000 \times 10^{12}$ watt-years, or 8.97×10^{21} BTU.

Figure 9 shows the world nuclear power as projected to 1980 by IAEA. From 1980 to 2000 it was assumed that the annual increasing rate will follow the IAEA prediction of 19.2 percent per year. The world nuclear production rate thus will attain 10,000,000 MWe by the year 2000.



Sources: Data Extracted From Ref. 7 And 2.

Figure 9. Projection of Nuclear Power To 2000 For The World And The United States

It is hard to predict the future trends from the present limited data. But if the depletable supply of nuclear fuel for ordinary reactors of 3,000 x 10^{12} watt-years, or for the breeder reactors of 300,000 x 10^{12} watt-years, is true, the future will be brilliant and the trend of the consumption curve will attain some peak point, then will go downward with the area under curve equal to 3,000 x 10^{12} watt-years for ordinary reactors and 300,000 x 10^{12} watt-years for breeder reactors.

Uranium Requirement for the World and the United States

According to the report on Uranium Resources, Production and Demand, by OECD's Nuclear Energy Agency (NEA) and the International Atomic Energy Agency (IAEA), the uranium demand for the World's nuclear power capacity, currently about 18,000 tons metal per annum, is predicted to rise to 60,000 tons metal per annum by 1980 and 100,000 tons metal per annum by 1985 (10, page 844).

Rafford L. Fanker, Director, Division of Raw Materials, United States Atomic Energy Commission, gives reserve estimates of uranium in the rages (3, page 223): (A) less than \$ 10/lb U_3O_8 (\$ 26/Kg uranium metal). (B) \$ 10-15/lb U_3O_8. (C) \$ 15-30/lb U_3O_8.

For the category in the price up to \$ 30/lb U_3O_8, the world totals are (10, page 844).

Reasonably Assured Resources (RAR)	866,000 tons U
Estimated Additional Resources	916,000 tons U
Total	1782,000 tons U

The figures for the \$ 10-15/lb U_3O_8 category of the world are:

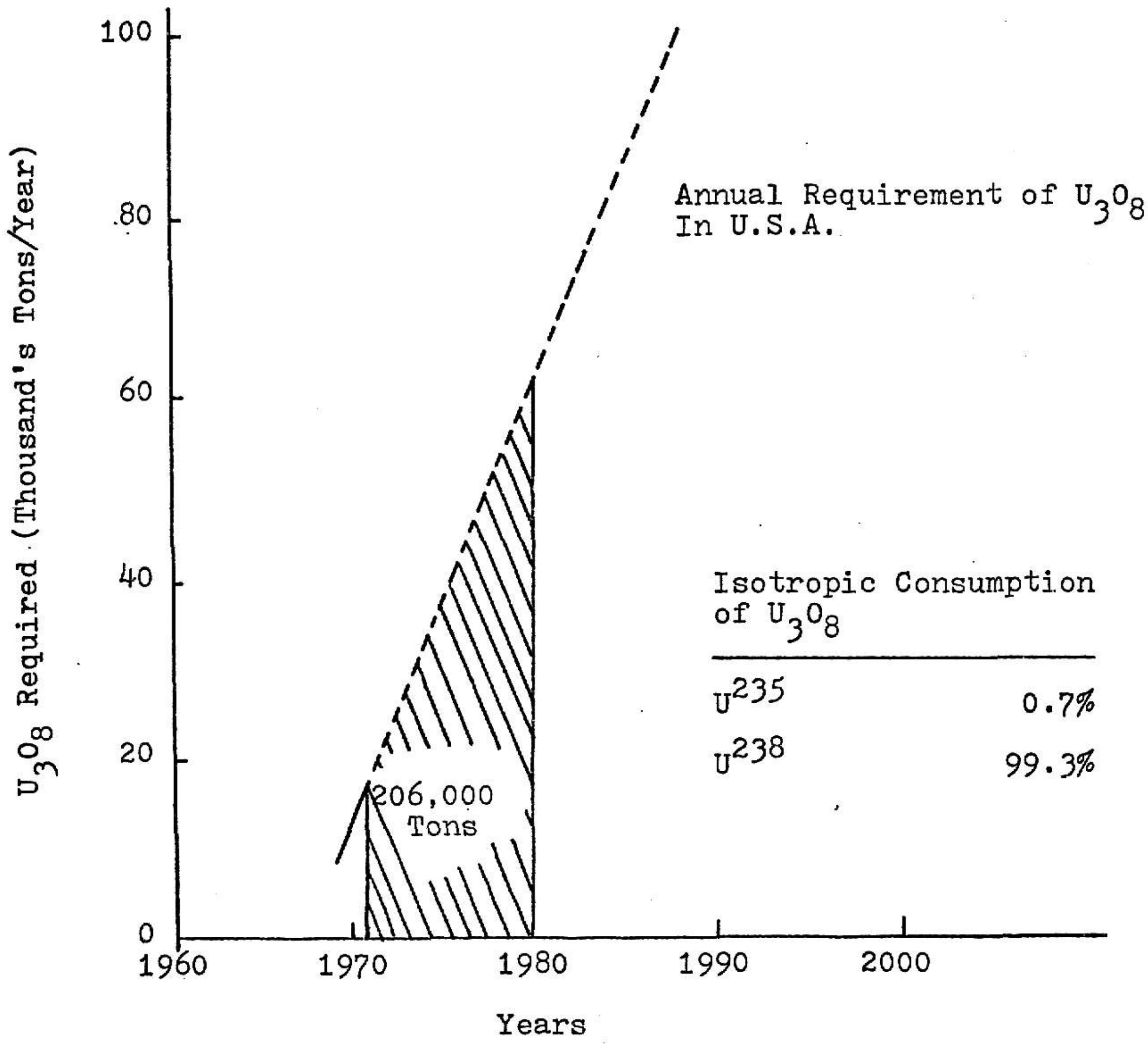
Reasonably Assured Resources	680,000 tons U
Estimated Additional Resources	632,000 tons U
Total	1312,000 tons U

For the less than \$ 10/lb U_3O_8 category Fanker estimates for the U.S.:

Reasonably Assured Resources	310,000 tons U
Estimated Additional Resources	350,000 tons U
Total	660,000 tons U

The Uranium Resources Production and Demand report (10) shows that by the year 1990, installed nuclear generating capacities are expected to be 370 million KW for the EEC; 540 GW(e) in North American (of which 500 is the U.S.A.); and 100 GW(e) in Japan. This report shows that the resources of U_3O_8 now existing are adequate to meet the requirements of the projected growth of nuclear electric plants until the early to mid-1980's. Urgent steps to discover new uranium sources is definitely necessary in order to ensure that the production levels required are achieved and to avoid an unstable market in the 1980's.

Figure 10 shows the annual uranium requirement in the U.S. for present reactor designs to meet the energy growth requirement according to the model used in Figure 9. Early in 1968 the U.S. known uranium reserves exploitable at US \$8/lb or less were 148,000 tons, and those exploitable at US \$10/lb or less were 242,000 tons. About 120,000 tons should be obtained as by-products of phosphate manufacture and copper leaching. In addition, about 350,000 tons of US \$10/lb are estimated to be recoverable. Following the AEC prediction that the nuclear capacity in 1980



Source: July 1969/Combustion (15), Page 6

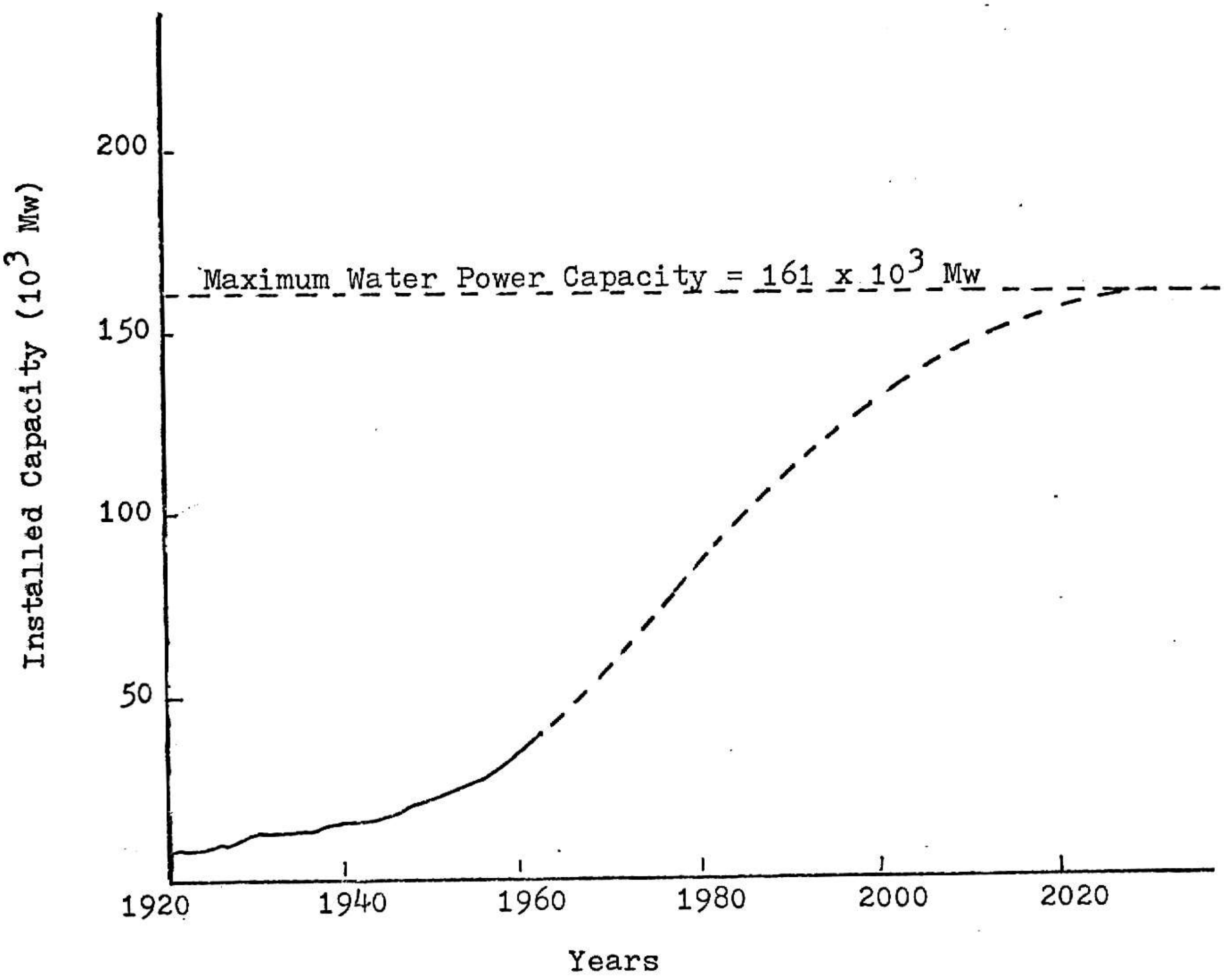
Figure 10. U.S.A. Annual Uranium Requirement for Today's Reactors To Keep Pace With Figure 9 Growth

will be 150,000 MWe in the U.S., the amount of U_3O_8 required rises to 650,000 tons. The US $8/lb or less domestic ore balance will satisfy commercial requirements through about 1970, and US $10/lb ore will cover another three years (14, page S.10). However, as breeder reactors eventually take the main role for nuclear power generation the uranium requirement will be expected to drop. Thus, although we had some slowing in the progress of the present nuclear program, nuclear power growth in the next decades will be significant as the demand of energy continues to increase without any other significant new resources available.

ENERGY FROM HYDRO-ELECTRICITY

Since the development of electrical-power transmission at the early part of the century, large-scale generation and transmission of water power capacity has resulted. The ultimate potential water for the U.S. is estimated to be about 161,000 MWe by the Federal Power Commission (3, page 208). The solid line in Figure 11 shows the U.S. hydro-electricity growth. Figure 12 shows the world installed and potential water power capacity where the solid line represents the production rate of world hydro-electricity. The world total potential of water power is about $2,857 \times 10^3$ Mw. By 1964 the hydro-electricity of the world amounted to 210,000 Mw which is about 7.5 percent of its potential capacity.

Table 7 gives the potential water power capacity of the world's major regions. This is prepared from a summary by Francis L. Adams (3, page 99) of the Federal Power Commission, utilizing basic U.S. geological survey data. The South American, Africa and Southeast



Source: Hubbert (3), 1968, Page 208.

Figure 11. United States Installed and Potential Water-power Capacity

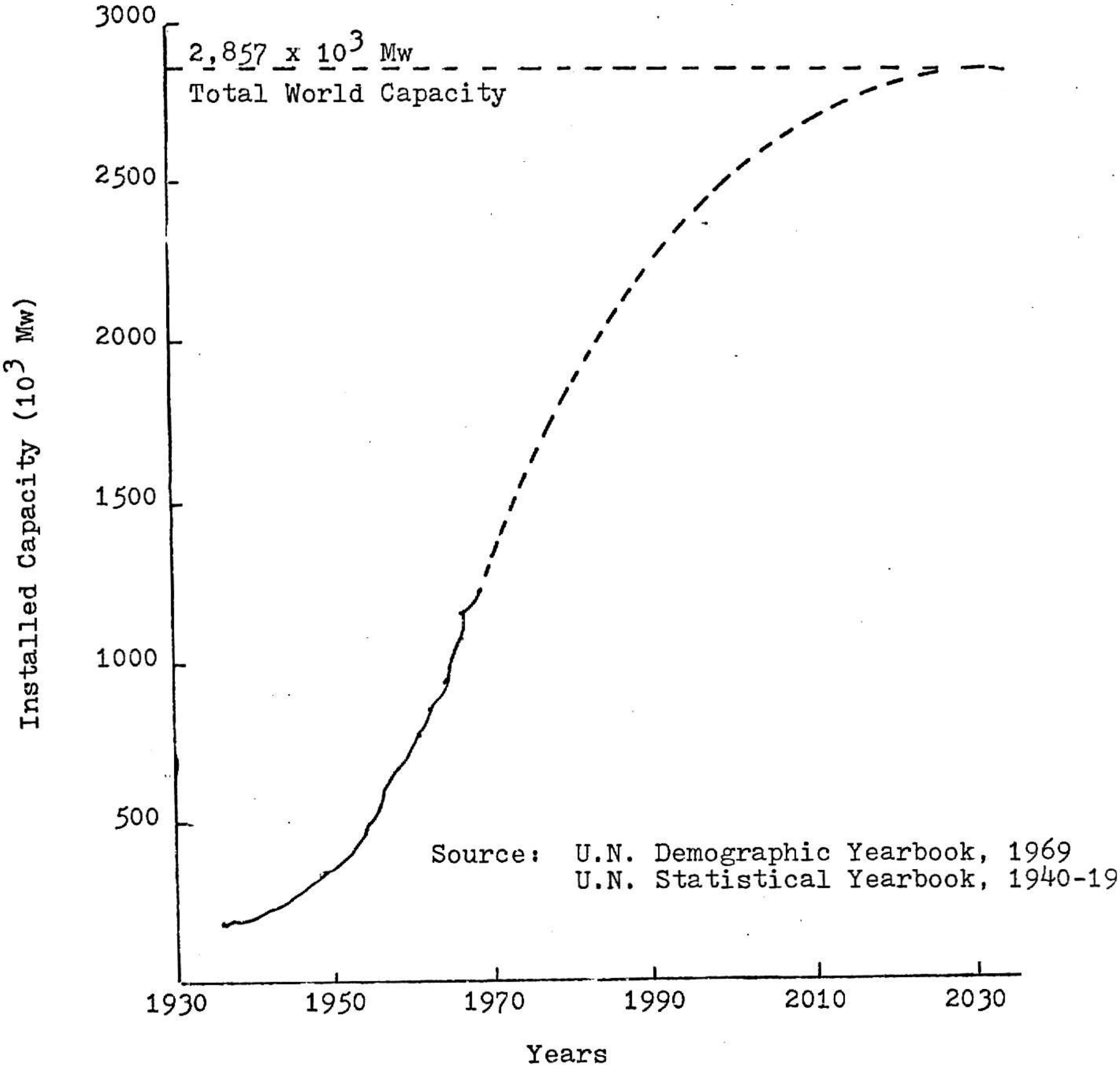


Figure 12. World Installed And Potential Water Power Capacity

TABLE 7

WORLD WATER-POWER CAPACITY

Region	Potential 10^3 Mw	Percent of Total	Developed 10^3 Mw	Percent Developed
North America	313	11	59	19
South America	577	20	5	1
West Europe	158	6	47	30
Africa	780	27	2	.2
Middle East	21	1	--	--
Southeast Asia	455	16	2	.4
Far East	42	1	19	45
Australia	45	2	2	4
USSR and China and Satellites	466	16	16	3
Total	2,857	100	152	5.3

Source: M. King Hubbert (3), 1962, Table 8, Page 99.

Asia together have nearly 65 percent of the world total potential, but only the areas in North America and West Europe have some degree of present development.

ENERGY FROM FARM WASTE AND WOOD

Wood and farm waste were the only fuels available until the centuries of the Christian era, when coal came into use. No accurate statistics are available about the use of farm waste as fuel, but Putnum (12) has estimated that these may have contributed 10 to 20 percent of the world total energy in 1950 and that about 380 million tons of coal equivalent annual is the maximum that can be expected from this source. Methane gas could be provided from farm wastes without impairing their fertilizer value. In many countries, efforts are being made to build small power plants to utilize this gas in village communities.

Wood was the major source of the world's energy until 1880. By 1950 wood provided about 4 percent of the total energy supply. It has been estimated that the world's forests may be made to provide wood equivalent to 2,000 million tons of coal a year. After subtracting for the requirements of construction, paper manufacture and other essential uses, a maximum of about 500 million tons of coal equivalent per year is available.

NEW SOURCES OF ENERGY

Naturally, the world's energy demand is increasing as the population increases and as the human expectation for increasing living standard increases. In addition to the ways in which conventional resources could be utilized in a more effective manner, it is important to consider new possible sources of energy.

Solar Energy

At present, the principal uses of solar energy, in addition to the natural process of photosythesis and maintenance of the atmospheric hydrologic and oceanic circulations, exist only on a small-scale practical level. According to Farrington Daniels (3), 1964, Direct Use of the Sun's Energy, the average useful solar power at the earth's surface amounts to about 500 cal/sq cm/day. This, when averaged over a full day, gives an average solar power input of about 2.4 x 10^{-2} watts/ sq cm. The area of the earth's surface required to collect 10^{10} watts of solar power (modern power stations fall largely in the range of 10^{8} to 10^{9} watts each) would be 42 sq km. It is physically possible to cover such an area with energy collecting devices, and to transmit, store, and ultimately convert the energy so collected into conventional electric power.

Tide Power

As Hubbert (3) states "--a summary which is based on the data compiled by Trenholm (1961) and by Bernshtein (1965), is given of the average tidal ranges and basin area for most of the more promising tidal energy localities of the world. The total maximum rate of energy dissipation for these localities amounts to 64,000 Mw. Assume a liberal allowance for the actual average power recoverable at each of these sites, we get 13,000 Mw as the approximate magnitude of the average value of the world's potential tidal power. It only amounts to less than one percent of the world's potential water power, and to an even smaller fraction of the world's power need. It has the advantage of producing no noxious wastes, of consuming no exhaustible energy resources, and of producing a minimum disturbance to the ecologic and scenic environment. There are accordingly many social advantages to the utilization of tide water wherever tidal and topographical factors combine to make this practicable."

Geothermal Energy

Summarizing, from Hubbert (3) "--In special geological situations in volcanic areas, underground water is trapped in porous or fractured rocks and become superheated from volcanic heat. Wells drilled into such reservoirs of superheated water or steam permit the steam to be conducted to the surface where it can be used as an energy source for a conventional steam electric power plant." Within recent decades large geothermal-electric power plants have been built. According to Hubbert's (8) estimate, the present installed geothermal-electric power capacity of the world amounts to 828 MWe with a planned increase of 1,125 MWe by 1971-72. Donale E. White (3) has investigated the better known geothermal areas of the world at which heat is discharged to the surface of the earth and has estimated the amount of stored heat above surface temperatures to depths of 3 kilometers and 10 kilometers. Hubbert estimated that the world's total natural heat flow from all hydro-thermal areas is of the order of 3×10^{10} cal/sec. or about 1.3×10^{11} thermal watts. He also estimated the total stored heat of all hydro-thermal systems to a depth of 20 kilometers amounts to 8×10^{21} thermal joules, while to a depth of 10 kilometers amounts to 4×10^{22} thermal joules. In Hubbert's (3) statement "--White assumed that about one percent of the hydrothermal energy can be converted into electric energy. For a 0.25 conversion factor, and assuming the energy was to be withdrawn during a period of 50 years, the average annual geothermal electric power for the depth of 10 kilometers would be $4 \times 10^{22} \times 1\%$ $\times 0.25 \times 50 = 60{,}000$ MWe. However, the total amount of geothermal energy is only one percent of the world's potential water power from conventional sources." It is only a small part of the world's total energy requirements and this for only a limited period of time in a limited number of areas.

THE POSSIBLE TRENDS OF ENERGY

We can't quite be sure of the effects on the economy of increases in the real cost of energy. To avoid the risk of impeding the economy, we should research alternative sources of energy which are not too expensive. Whatever these new sources are, the problem reveals that technically the prospects seem good, while economically they are gloomy.

By using the conversion factor extracted from Putnum (12), 1952, (page 326), as shown in Table 8, and collecting all the energy resources as previously discussed, we can obtain the composite cycle of the major fossil fuel energy resources for the world as it varies with time as presented in Figure 13. Nuclear resources are excluded although it can be argued that they are also fossil fuels.

TABLE 8

FUEL AND POWER CONVERSION FACTORS

Fuel	Equivalent to One Short Ton of Bituminous Coal	BTU per Unit
Bituminous-average	1.000 ton	26.2×10^6 per ton
Crude Petroleum	4.517 bbls	5.8×10^6 per bbl
Natural-Gas Liquids	6.532 bbls	4.011×10^6 per bbl
Natural Gas	24,952 cu ft	1,050 per cu ft
Tar and Pitch	3.889 bbls	6.72×10^6 per bbl

Source: Putnum (12), 1952, page 326.

In Figure 13 the data before 1930 is based on Putnum (12, page 73), Energy in the Future. The total energy in fossil fuel consumption up to 1968 is approximately 819×10^{15} BTU for the world total. This is about 0.38 percent of the ultimate fossil fuel energy reserves of the world. It is evident that in Figure 13, coal, crude-oil, natural gas and natural-gas liquids are the major part of fossil fuels to the year 2100. After 2100, coal is the only main resource of fossil fuel, while the other fossil fuels

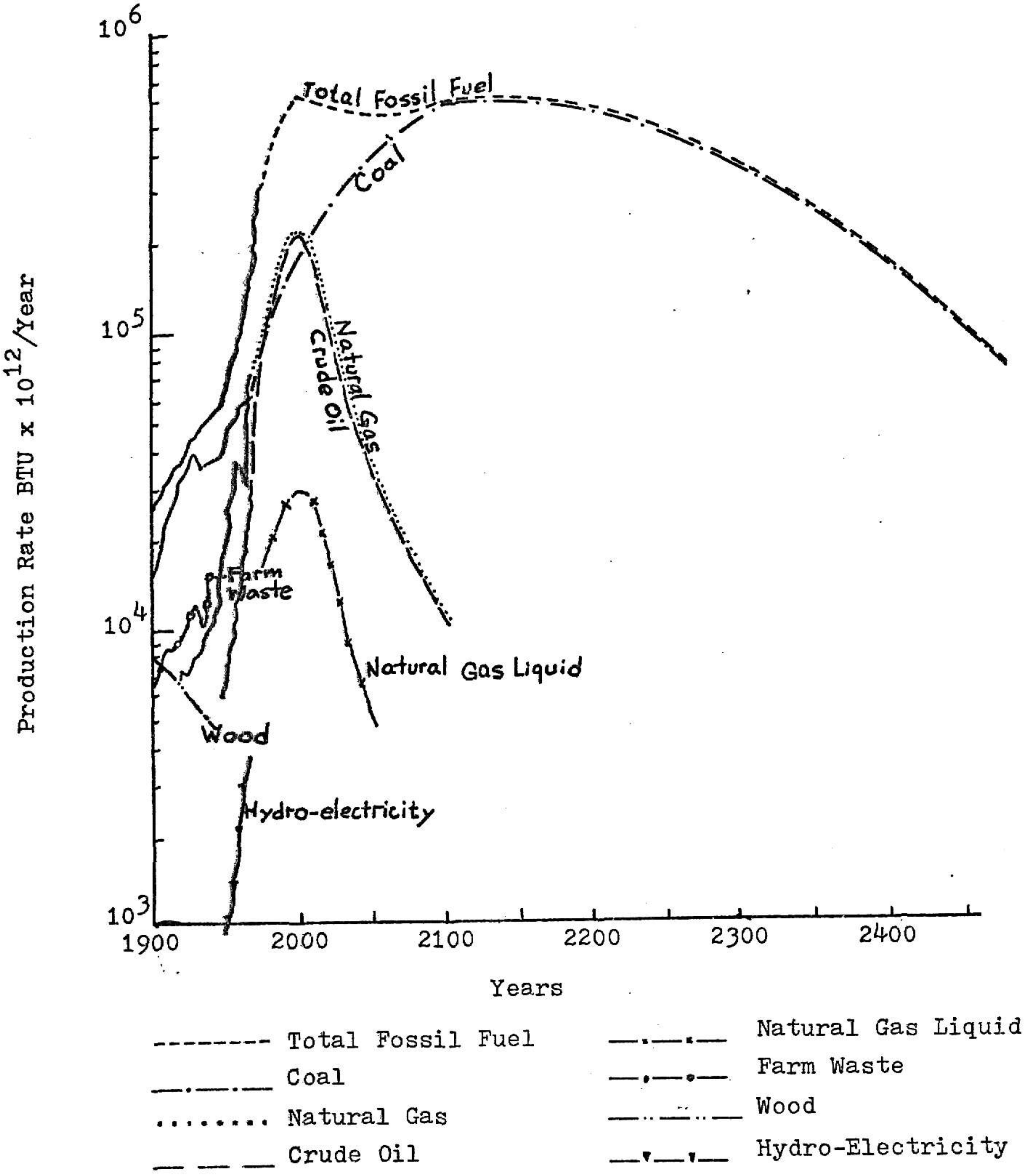


Figure 13. World Total Fossil Fuel Reserves

will have been largely depleted. Of these, Hubbert (8) concluded that if fossil fuels continue to be consumed as the main power source (and there is no evidence that the energy requirements will decrease), the time required to consume the middle 80 percent of the ultimate reserves of the petroleum family (crude-oil, natural gas, natural-gas liquids, tar-sand oil and shale oil) will probably be about a century, and that of the world's coal reserves would be about 300 to 400 years, but only 100 to 200 years if coal is used as the only energy source. Without nuclear power or other new resources the situation is gloomy. But according to the IAEA prediction in nuclear power growth, the future is optimistic. Figure 13 indicates that the total energy of the world will increase linearly to the year 2000 and at a rapid rate.

Table 9 shows the U.S. major energy groups from 1950 to 1990 which has been estimated by U.S. Department of Interior. In 1965, for the production of U.S. electric power, coal accounts for 54 percent of the total, natural gas 21 percent, oil 6 percent, hydro-electricity 18 percent and nuclear less than one percent (13). The total fossil fuel consumption in 1900 was 76 percent of the total U.S. energy consumption. In 1965 the fossil fuel consumption is estimated to drop to 87 percent, while the nuclear power will increase to at least 11 percent. The nuclear power will probably supply as much as 50 percent within 25 years.

For the long range view, as Figure 13 shows, we know that there is a limited growth of natural gas utilization. Industrial use of natural gas is a short-term answer to the air pollution problems. This may still exist until sulphur-removal methods for

TABLE 9

U.S.A. ENERGY USE 1850-1990

	Major Energy Groups				Subtotals	
In BTU's Trillions	Total Energy	Hydro-Electric	Fossil* Fuel	Wood Fuel	Coal Bit. Only	Petroleum Oil**
1850	2,300	--	220	2,140	110	--
1880	5,000	--	2,150	2,850	1,340	90
1900	9,590	250	7,320	2,020	5,430	230
1930	23,750	780	21,510	1,460	11,920	6,150
1950	35,320	1,600	32,550	1,160	11,900	12,300
1960	44,820	1,630	43,290	--	9,970	18,610
1965	53,790	2,090	51,700		12,030	21,360
				Nuclear Fuel		
1970	70,000	2,200	69,500		15,000	28,000
1980	108,000	2,700	103,000	2,000	24,000	43,000
1990	145,000	2,900	126,000	15,900	31,000	59,000

Source: U.S. Dept. Interior From Historical Statistics of The USA.

* Include Natural Gas Liquids.

** Exclude Natural Gas Liquids.

coal and oil become economic. Due to limited reserves, higher requirements for anti-air pollution, expensive cost in refinery methods and the demands of lighter fractions from crude-oil, the crude-oil price will increase and finally cause production to decrease. With nuclear power still not fully developed, coal is still largely needed. It can be expected that coal prices will go upward during the next decade. The large amount required, the high costs for anti-air pollution, the high costs of labor and the requirement of mine safety regulations are the main factors. Because of the price of coal and its transportation cost new methods of coal transportation are urgently needed. It is not surprising to see that vast amounts of time, effort and money need to be spent to develop processes for converting coal to clean energy. However, the pressure of nuclear competition will force the fossil fuel energy market to maintain a reasonable price.

Figure 14 shows the world total energy consumption specified by case 1 (curve A) which is the total fossil fuel consumption plus the nuclear energy consumption by the ordinary reactor. Case 2 (curve B) shows the total fossil fuel and nuclear energy consumption by the breeder reactor. The estimated consumption of fossil fuel and of nuclear energy are also shown here as references. The trends of the consumption of nuclear energy by the ordinary and breeder reactors are based on the information given previously. The depletable suppy of nuclear fuel by the ordinary reactor is 8.97×10^{19} BTU. Using the IAEA projected data from 1980 to 2000, let us assume that the rate of increase of consumption of nuclear energy by the ordinary reactor is 20 percent per year. After 2040

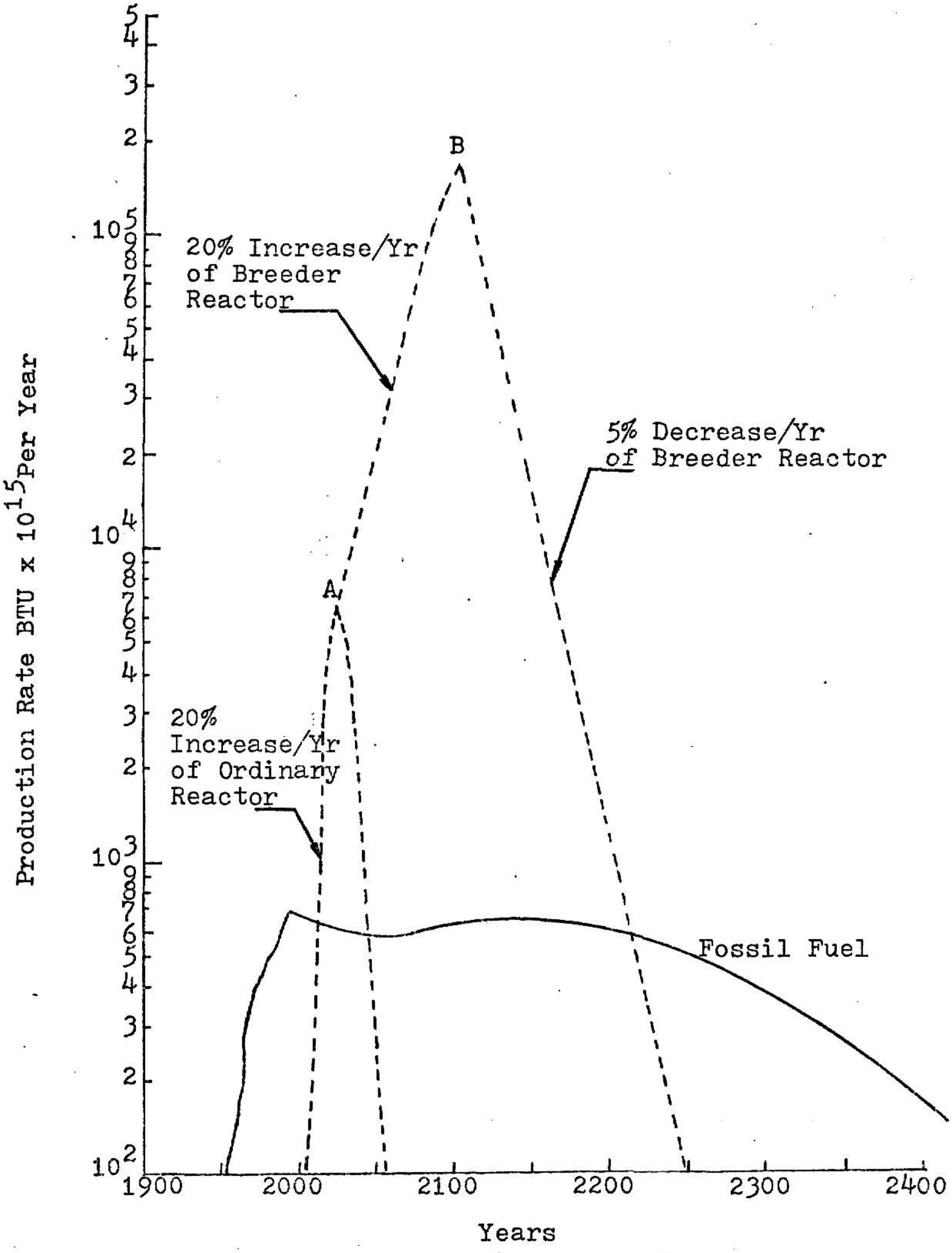


Figure 14. World Total Energy Estimation

the rate of decrease is assumed to be 5 percent. Before 2030 the trend is the same for both type of reactors. The rate of increase between 2040 and 2100 is assumed to be 5 percent per year. After 2100 it is assumed that there is a decrease of 5 percent per year.

If the trends of nuclear energy consumption are correct, the peak value of world total energy consumption will occur about 2100. The breeder reactor may raise the world total energy supply and maintain this supply for at least 100 years. After the world depletion of petroleum and nuclear sources the energy supply will come from coal. Should new sources of available energy be found, such as fusion, the future supply may have no practical limit. Should new resources of energy not be found after 2200, we will be forced to use the remaining limited fossil fuel again. If fossil fuel is not available, we will have only solar energy and some limited types of energy such as those supplied by water, wind, tide and geo-thermal sources.

CHAPTER III

POPULATION AND LIVING STANDARDS

It is necessary to consider the maximum world population that can be supported considering potential energy resources. No general agreement about the maximum possible population has been established yet, since estimates of the world maximum capacity vary with the standard of living to be supported. The problem of population pressure should be viewed from the more relevant standpoint of how would the regional and world population pressure affect the problem of achieving higher living standards. Although food, clothing, housing, traveling and education can affect the existing disparity in consumption level among people in different parts of the world, there is no single index of the living standard as a whole that can be applied internationally. For example, even with the simple consideration of energy resources as a measure of living standard, there are many factors, such as technological, economical, social, political and climate factors, affecting the forecasting problem. For this reason, the per capita national income is taken as an international index of the level of living standard in this thesis.

The Disparity in per Capita National Income and the Impending Effect of Rapid Population Growth on Raising the Living Standard

Table 10 shows the per capita national income for the world's major region in selective years in US dollars valued at a 1969 level. As mentioned in Table 2, in 1969 nearly three-fourths

TABLE 10

ESTIMATES OF WORLD PER CAPITA NATIONAL INCOME AND RATE OF INCREASE PER YEAR IN SELECTED YEAR (IN 1969 U.S. DOLLARS)

Regions	1949	1958	1963	1965	1967	1980*	Annual Rate of Increase % (Period)
World Total	230	420	530	610	--	1540	6.46 (58-65)
Africa	75	100	120	130	--	244	4.28 (58-65)
North America	1100	2061	2475	2821	3196	7440	6.76 (58-68)
Latin America	170	250	300	340	370	740	5.33 (58-67)
West Europe	380	730	1060	1250	1390	3680	7.78 (58-68)
Asia	100	140	160	185*	--	564	7.7 (58-63)
Oceania	560	730	1060	1250	1390	3680	9.72 (58-68)
United States		2115	2562	2921	3310	7830	6.76 (58-68)

Source: Demographic Yearbook, 1969, United Nations.

* Projection Based on Annual Rate of Increase In The Last Column.

of the world's people lived in Asia, Africa and Latin America where the population grows rapidly, but where generally less wealth and energy is available than in North America, Europe and Oceania. People in these less developed countries desire to reduce the gap in living standard between them and the developed countries. But their goal and effort for elevating their living standard is overburdened by the large rate of increase of their populations. For example, in 1965 Africa, Asia and Latin America together shared 14.5 percent of the world national income but contained 70 percent of the world population. If the per capita national income of Europe in 1965 (US $1250) were established as the goal for nations in Asia, Africa and Latin America, then these nations would have to increase their national income by about 20.7 times in Africa, about 5.2 times in Asia and about 7.3 times in Latin America. From the year 1963 to 1968, the average annual rate of increase of national incomes for Asia is 7.7 percent, for North America is 7.9 percent, for Latin America is 5.82, for Europe and the Oceania countries it is 7.16 percent for each. The world average annual rate of increase of national income from 1963 to 1965 is 7.54 percent, showing that these less developed countries are, in general, falling behind.

The Trends of the Relation between Population and National Income Per Capita under Constant Annual Rate of Increase

Assume that the annual growth rate of national income calculated from 1963 to 1965 will remain constant in the future, and that the Asian countries are to attain the per capita national income of North America in 1965 (US $2821). These countries with the present per capita income of US $450 and a growth rate of 7.7 percent per year in national income, would require about 24.7 years to reach the level attained in North America in 1965. If we take the world with the average per capita income in 1965 (US $610), and with 7.54 percent income growth rate per year as an example, it would require about 15.3 years to attain the level of North America in 1965 (US $2821). For simplicity, existing population pressures, political and social stability, technical problems, variations in available resources, etc., were not taken into consideration in the above example.

As the generation of national capital rose and the national consumption patterns changed, the per capita national income rose at a slower rate due to the appreciable increase in population. This is extremely clear in most of the countries in Asia. Nevertheless, since available capital for development is scarce in the less developed countries, rapid population growth would greatly impede the efforts of less developed countries to close the gap.

The Projection of National Income Per Capita and Population at Constant Annual Rate of Increase

Let X = the estimated population after t years

Y = the estimated national income per capita after t years

X' = the original estimate of population

Y' = the original estimate of national income

x = the annual rate of population increase

y = the annual rate of national income

Assume that the annual rate of population increase, x, and the annual rate of national income, y, keep rising at constant rates, Then, the population after t years is:

$$X = X'(1 + x)^t \qquad (A)$$

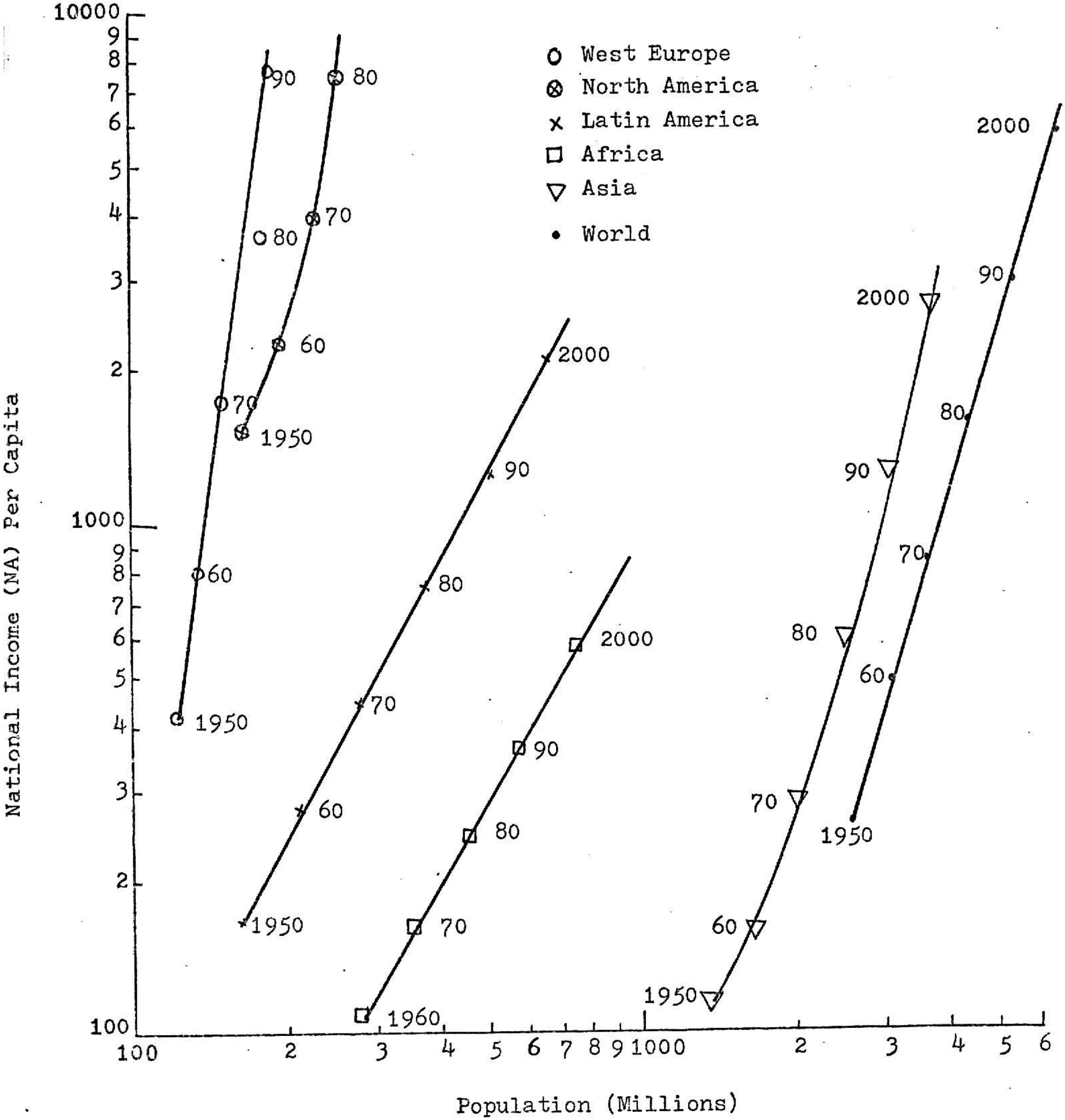
and, the estimated national income per capita is:

$$Y = Y'(1 + y)^t \qquad (B)$$

Taking the logarithm of both sides and eliminating the parameter t from equation (A) and equation (B), we obtain the relation between per capita national income and population which is expressed as a power function. This is shown in equation (C):

$$Y = X^{\frac{\ln Y' \ (1 + y)}{\ln X' \ (1 + x)}} \qquad (C)$$

Select the national income per capita as the vertical axis and the estimates of population as the horizontal axis in logarithmic coordinate. By using the data shown in Table 2 and Table 10, we get the result of the world's major areas and regions shown in Figure 15. From Figure 15 we can estimate the national income per capita for each area if we know the population estimates and vice versa. This is under the assumption that the annual rate of



Source: Based On U.N. Statistical Yearbook, 1969. The Data After 1970 Are Projected On The Basis of The Data From 1950 to 1968.

Figure 15. Estimated Population For The World Major Lands vs NI Per Capita

national income per capita and the annual rate of population increase are kept constant during the estimation period. For example, the estimate of the population in 1963 is 3176 million and the national income per capita is US $530. With the annual population increase at the rate of 2.0 percent kept constant, the world population will double in 35 years, or about the year 2000. For this doubling period of 35 years, the average national income of the world in the year 2000 can be found from the diagram as US $5600, about 10.5 times the value in 1963. From the diagram it can be seen that the steeper the slope of the curve the higher the gain in national income per capita. Comparing each area we find that most of the regions in the world, like Asia, Africa and Latin America, are below the world standard level in the year 2000. Those areas in Western Europe show a more rapid improvement because of the slow population growth. Projecting to 1990, the growth in Asia will have a national income greater than those in Latin America, although the Latin America groups now obtain more national income per capita than do the Asian countries. This is due to the rapid increase in the annual population growth rate in Latin America, the highest rate in the world at the present time.

The Relationship Between Population and National Income Per Capita which Follows the Hyperbolic Equation

Assume that the world population can be changed, and that total world income (W.I.) is constant for any one year but increases year-by-year according to estimates. If we double the estimated population, then the world income per capita should decrease to one-half of the original estimated value. Bearing this idea in mind, let us draw the curves for world per capita income vs. population at various projected future times. This curve is a hyperbola for any one year. By using the same notation shown before, the corresponding curves are expressed as equation (D).

$$XY = \text{constant} \qquad \text{(D)}$$

Figure 16 was drawn according to the principle stated above. Using the world data of Figure 14, according to the curves in Figure 16, we can project the future world income per capita as a function of the population estimates at any year, and vice versa.

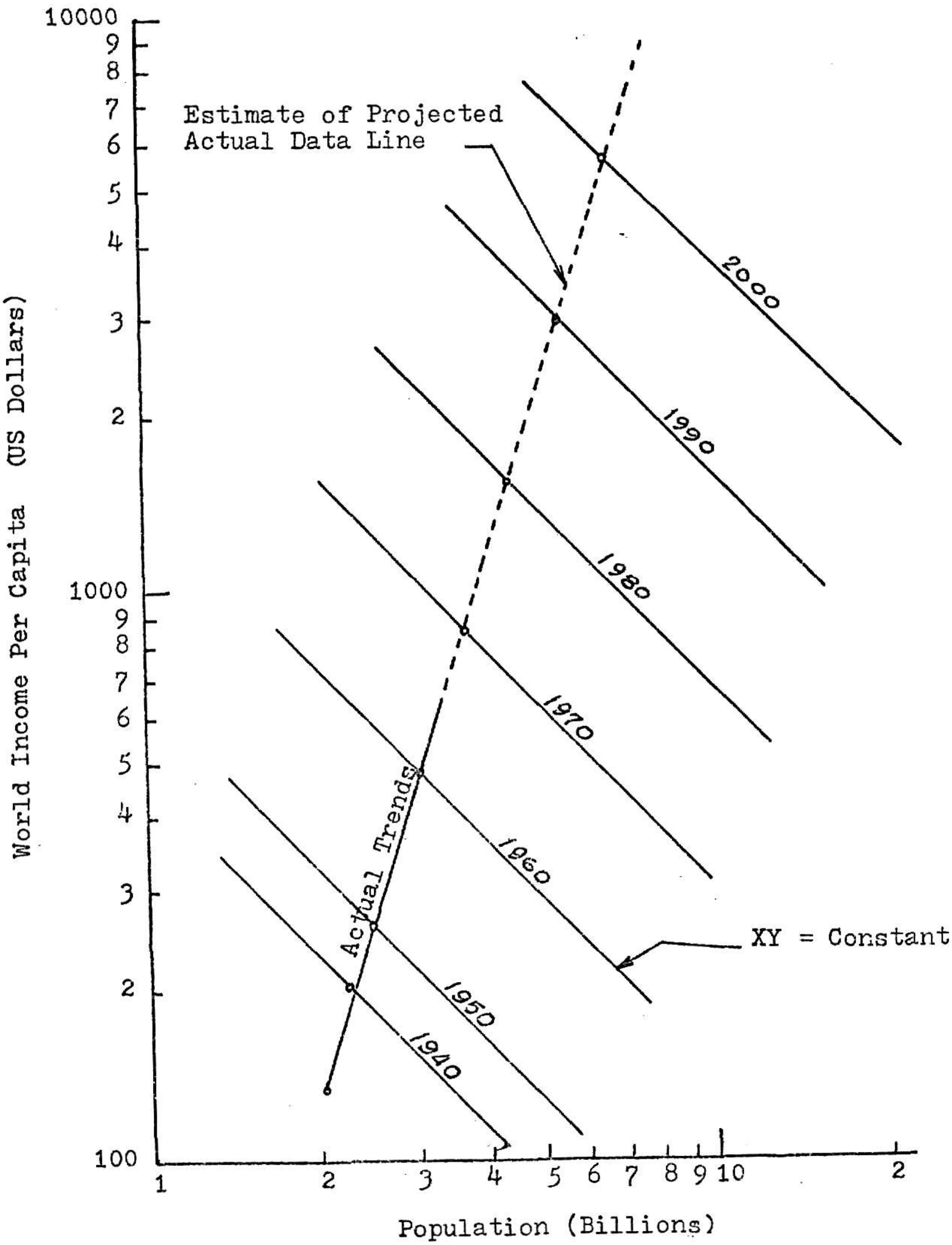


Figure 16. World Population vs World Income Per Capita With The Assumption of XY = Constant

CHAPTER IV

POPULATION AND CONSUMPTION OF ENERGY PER CAPITA FROM COMMERCIAL SOURCES

Changes in levels of the consumption of energy in the several major areas of the world are indicated in Figure 17. Because of increasing population, the per capita consumption of energy rose at a somewhat lower rate in the 21 years period from 1929 to 1950, averaging 1.0 percent annually for the world as a whole, but ranging from 0.2 percent in Europe to 3.7 percent in Latin America. The fuel and power supplies of particular areas not only increased generally but also underwent some diversification in the period 1929-1950. After 1950 Asia increased about 6 percent per year, the world average 3.5 percent per year, and North America 3.45 percent per year. Should this trend continue, on the basis of 1960, the two projecting curves of North America and the world will intersect after 173 years, or in A.D. 2133. On the same basis, the two projecting curves of Asia and the world will intersect in 74 years, or in A.D. 2034. Table 11 shows the projected per capita consumption of commercial energy in selected years, under the assumption that the estimates of the energy demand per capita from commercial sources for the world, North America, Latin America, Africa, Asia, Europe, and Oceania are based on an annual rate increase of 3.5 percent, 3.45 percent, 3.7 percent, 3.1 percent, 6 percent and 3.9 percent, respectively. These rates are based on the data for the year 1960. Following the estimates for the year 2000, world consumption of energy from commercial sources

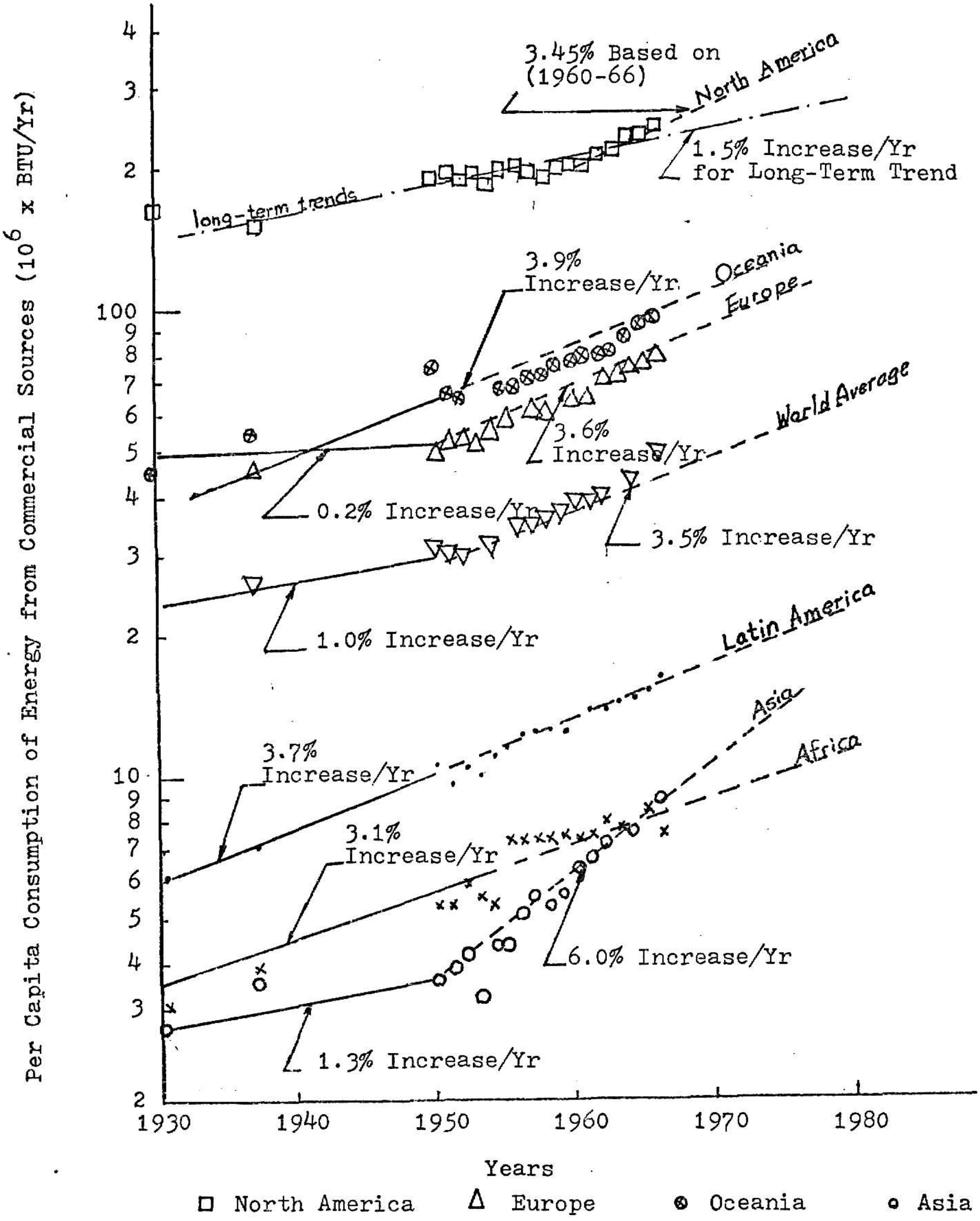


Figure 17. World and Main Regional Consumption of Energy from Commercial Sources

TABLE 11

PROJECTION OF CONSUMMED COMMERCIAL ENERGY AND PER CAPITA CONSUMMED COMMERCIAL ENERGY IN SELECTED AREAS AND SELECTED YEARS.

Areas		1960	1970	1980	1990	2000
World	A	111	166	235	330	465
Total	P	36.7	51.7	73	103	145
Africa	A	1.57	2.13	2.9	3.93	5.33
	P	7.4	10	13.6	18.4	25
Asia	A	5.6	10	17.9	32	57.3
	P	6.28	11.25	20.2	36.2	65
Latin	A	1.6	2.3	3.3	4.73	6.78
America	P	13	19.2	27.5	39.6	56.8
North	A	40.6	58.5	84.1	121	174.5
America	P	204.7	295	425	612	880
West	A	21.7	30.9	43	62.6	89.3
Europe	P	66.7	95	135	193	275
Oceania	A	1.2	1.81	2.63	3.86	5.65
	P	79.6	113	165	242	355
United	A	45	70	88.6	145	175
States	P	252.55	340	488	653	946

A: Aggregate (In Quadrillion BTU = 10^{15} BTU = Q)

P: Per Capita (In Million BTU = 10^{6} BTU)

Source: Projections Based On Figure 16.
U.S. Projected By U.S. Dept. of Interior From Historical Statistics of The USA.

will reach 465Q, or 465 x 10^{15} BTU, which is about four to five times that of 1960, and the world per capita consumption of commercial energy will rise to 145 x 10^{6} BTU.

The projected results appear to be favorable for the less developed countries, especially for Asian countries which will increase their consumption of energy in the year 2000 to nearly ten times that of the 1960 figure, to 57.3 Q, or 57.3 x 10^{15} BTU. However, there still will be great disparities existing in the world at that time. In 2000, North America, Western Europe and Oceania, with less than 10 percent of the world population between them, accounted for more than half of the aggregate energy consumption as presented in Table 11. Actually, it is very difficult to analyze the future trends, since there are so many factors and various assumptions.

The Consumption of Energy in the United States

The United States makes up six percent of the earth's population but uses approximately 40 percent of the world's producing fuels. According to a study by the Petroleum Industry Research Foundation (7), the nations energy consumption in the United States since 1965 has been rising about five percent a year, and is doubling every fifteen years. Estimates of the energy demand per capita for the United States are based on an annual increase of 3.43 percent over the 7.4 x 10^{4} Kwh, or 252.547 x 10^{6} BTU, per capita in 1960. The extrapolation here is shown in the last row of Table 11 and Table 9. We find that in 1960 the U.S. used nearly seven times the energy per capita than the average of the world. This is a large gap. Theoretically potential energy reserves in the U.S. could bring supply and demand into harmony at least in the next few decades. However, it can no longer be taken for granted that the energy will remain cheap and inexhaustible. The remaining fuel must be used where it will perform most effectively.

Energy Per Capita vs Population

If we choose the per capita consumption of energy from commercial sources as the vertical axis and the estimates of population as the horizontal axis, the use the data derived from Table 2 and Table 11, we can use equation (C) which describes the relationship between per capita consumption of energy from commercial sources and the population as a power function. This is shown in Figure 18. Whenever we know one of the two characteristics, by using Figure 18 we can easily find the other one, and vice versa.

It is interesting to compare Figure 18, (population vs consumption energy per capita) and Figure 15, (population vs national income per capita) in that they have almost the same type of trend. Looking at Figure 18, except the two areas in Africa and Latin America, all have concave upward curves. West Europe has a much steeper slope. This means that countries in West Europe gain more energy per capita than they grow in population. This is due to their very slow increase in population growth. Asia also has a steeper slope, just below that of Western Europe. Due to the potential of their energy sources, the Asian countries have the opportunity to attain a high level of energy consumption per capita

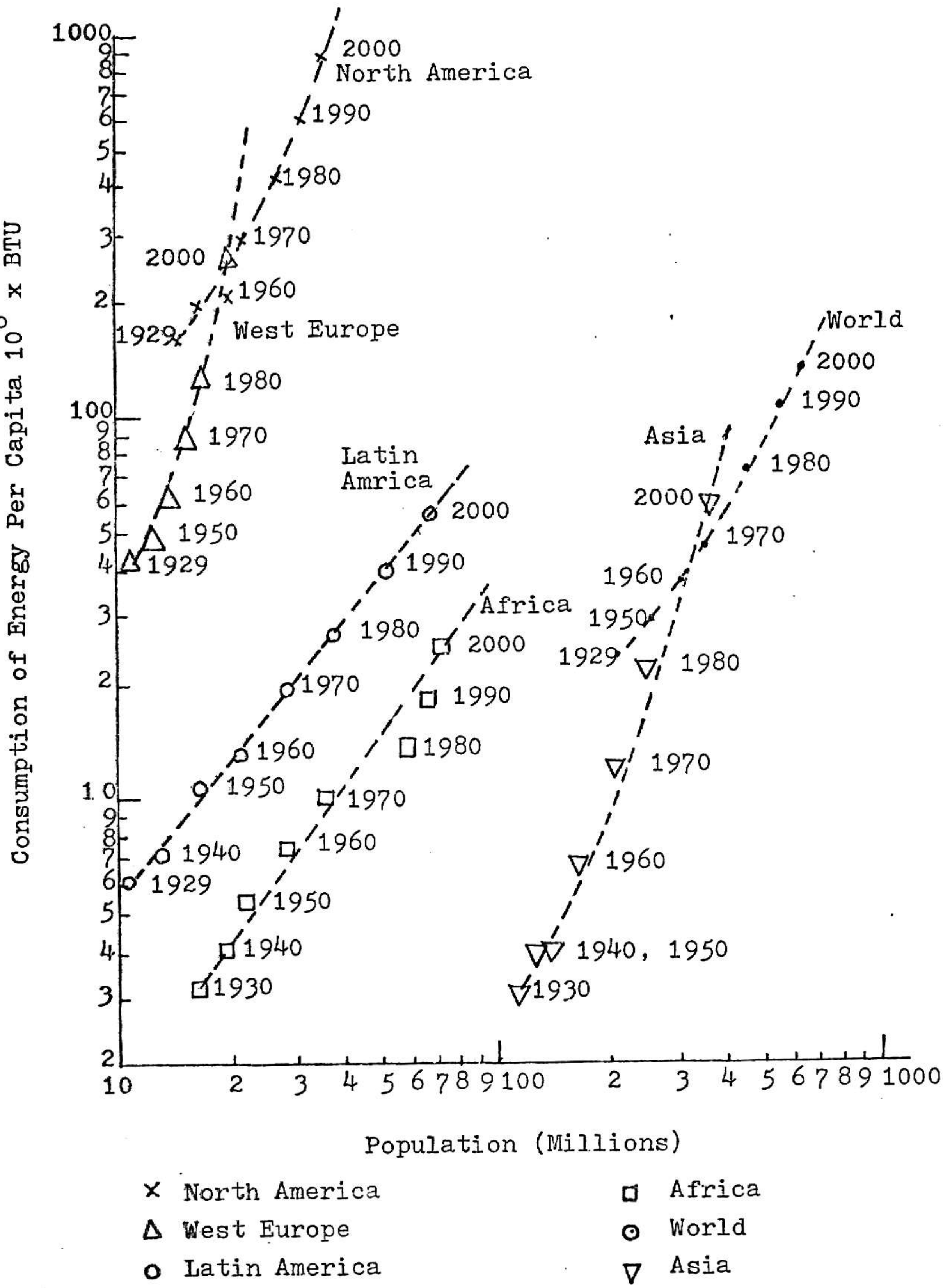


Figure 18. Energy Per Capita vs Population in Selected Areas and Selected Years

But, due to the large population they have to support, Asian countries are still very much below the standards of North America and West Europe. Those in Latin America, due to the high rate of population growth, will rise slower than other areas.

The "Energy Servants" and Population and Energy Consumed Per Capita

It was suggested by Reid (22, page 48) that a reasonable average useful work output for an 8-hour day is 0.05 horsepower. That is, a laborer working strenuously for 8 hours produces only some 0.4 horsepower hours, or 0.3 Kwh to earn his daily pay. As an example, in the United States the energy per capita in 1970 is established to be 340×10^6 BTU per year, or 0.93×10^6 BTU per day. Taking the 8-hour working day as a reference, this energy is converted into 930 "energy servants", each doing 1000 BTU of work during the day. However, it would be literally impossible to cloth, house and feed them in human form, if all the energy were converted to the form of "energy servants".

The developing countries, with large populations, will benefit more from the help of these "energy servants" as such countries increase their use of inanimate energy, but the highly increasing population growth has slowed the consumption of energy per capita, which is extremely clear in the Latin America areas.

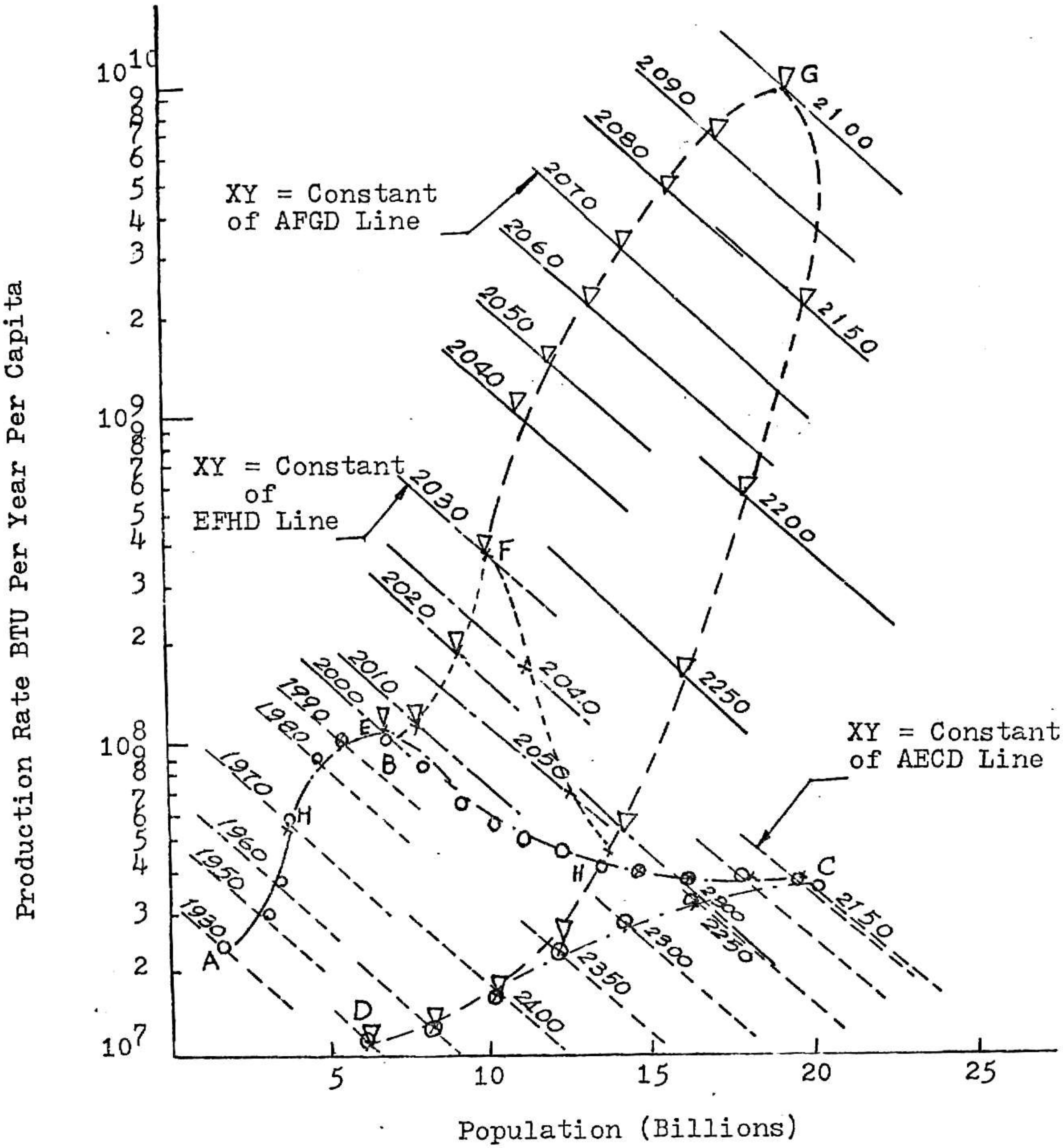
Energy Consumption Per Capita and Population Under a Linear Assumption

Since the raw materials of nuclear energy is limited, the total energy consumed either by the ordinary nuclear reactor or by the breeder nuclear reactor is also limited. It is assumed we will use the raw materials of nuclear energy carefully, so as to conserve them while there is still no new energy resource discovered. Based on the prediction of nuclear power development by IAEA (2), if the present nuclear reactor consumption trends continue at the 19.2 percent per year rate we can assume that the nuclear reactor consumption energy peak value will occur about the year 2030. After 2030, the rate will drop to about 5 percent per year and the total nuclear raw materials will probably diminish to an insignificant amount, if only the present nuclear reactor design is available. Assuming that the breeder nuclear reactor is available by 1980 and that nuclear fuel available to the breeder nuclear reactor increases 20 percent per year we postpone the peak consumption value about 100 years to 2150. After the year 2030 we might assume the breeder reactor consumption increases only 5 percent per year. If the peak consumption energy occurs at 2060, the breeder reactor consumption may increase about 10 percent per year.

With the present rate of increase of population, i.e., two percent per year, the world population will attain 47.8 billion in the year 2100. However, even if there are no controls imposed by governmental regulations, the food supply, pollution, living standard and resources of energy will restrict the total world population. If we assume that the peak consumption of nuclear energy is a warning against further population expansion, then we can predict the maximum world population as the population near the year that have the peak consumption energy. Any further expansion of population means that humanity will face a decreasing energy supply per capita in the following years. Let us then suppose that the rate of increase of population is maintained at two percent per year until the year 2040. Then the total population will be 10.8 billions. From 2040 to 2150, assume that the rate of increase of population will be one percent per year. Then the total population will be 20 billion. Assume that after 2150, the population decreases two billion for each ten years until the year 2500. The population will decrease with total energy to maintain a high living standard. In another case, let's assume that after the year 2030 the population starts to decrease with the rate of one percent per year. Then at the year 2150 the population will be 3.15 billion. Between 2150 and 2200 the population may remain constant or start to decrease slowly with the decrease of natural fossil energy resources.

Figure 19 shows the population vs. energy consumption in BTU per capita. Three cases are discussed. In Figure 19 the hyperbolic lines represent year lines which show the relationship between population and BTU per capita for those years. Case one is the most pessimistic trend, i.e., the total energy fossil fuel plus nuclear energy with the ordinary reactor. Case two is the most probable trend, i.e., the total energy equals the fossil fuel plus nuclear energy by breeder reactor. Each case is shown with the estimated population growth. In Figure 19, case three (curve ABCD) represents the unlikely trend of the total fossil energy per capita vs. population with no nuclear energy, by using the total fossil fuel energy data from Figure 13 and assuming the population model as stated above. The curve AHFCD shows case 1, the possible trend of the total energy of the ordinary nuclear breeder and fossil fuel, with the assumption as stated above. The curve AHEFGD represents case 2, the possible projection of the total energy of the breeder nuclear reactor and fossil fuel, with the assumption as stated above. Although we know the nuclear and fossil raw materials are limited, there is a considerable production rate possible. The projection data depends on the rate of consumption per year. This means that the projection of the energy consumption depends on how soon we will deplete all of our reserve energy potential. Hence, between the most pessimistic trend and the most probable trend, there are numerous possible projections.

If the rate of consumption increases more than that projected, the peak value of consumed energy will happen sooner. If that happens the protected maximum population limit will be less than the projected 20 billion. "A self-regulating system is thereby at work which drives the condition of the depressed area down far enough to stop the increase in people (6)." If the population is well controlled through the cooperation of the whole world, and a revolutionary discovery of new energy happens, the BTU per capita will turn upward without limit. However, from Figure 19, we see



× Case 1 (Ordinary Nuclear Reactor + Fossil Fuel) / Population

∇ Case 2 (Breeder Nuclear Reactor + Fossil Fuel) / Population

o Case 3 Fossil Fuel / Population

Figure 19. World Population vs BTU Per Capita

that in the near future, unless we have a decrease in the population expansion or we fully develop nuclear fuel or find new sources of energy, we will be forced to use less energy per capita than the present trend. If this prediction is correct, a turning point will be around the year 1990.

Energy Consumption (BTU) vs. National Income (NI)
on Per Capita Basis

A broad correlation between per capita national income and energy consumption for the world and its major areas has been made from the data of Table 10 and Table 11. This is illustrated in Figure 20.

The steam engine provided the ubiquitous sources of power which gave great impetus to the industrial revolution in the West and provided rapid transport by land and sea. A century later the use of energy to provide light, heat and power has done so much to lighten the burden of man, and to increase the standards of health and comfort. The impact of this revolution was felt mainly in the West. The rate of advancement of countries differed greatly for various reasons, and their standards of living which, as Figure 20 shows, are clearly connected with the average consumption of energy per capita. The dotted lines shown in Figure 20, which indicates the correlation between NI per year and BTU consumption per year per capita for each world area, have different slopes. This is due to the difference in many factors, such as population growth. Along the calendar year lines in Figure 20 we find an interesting fact that the energy consumption per year per

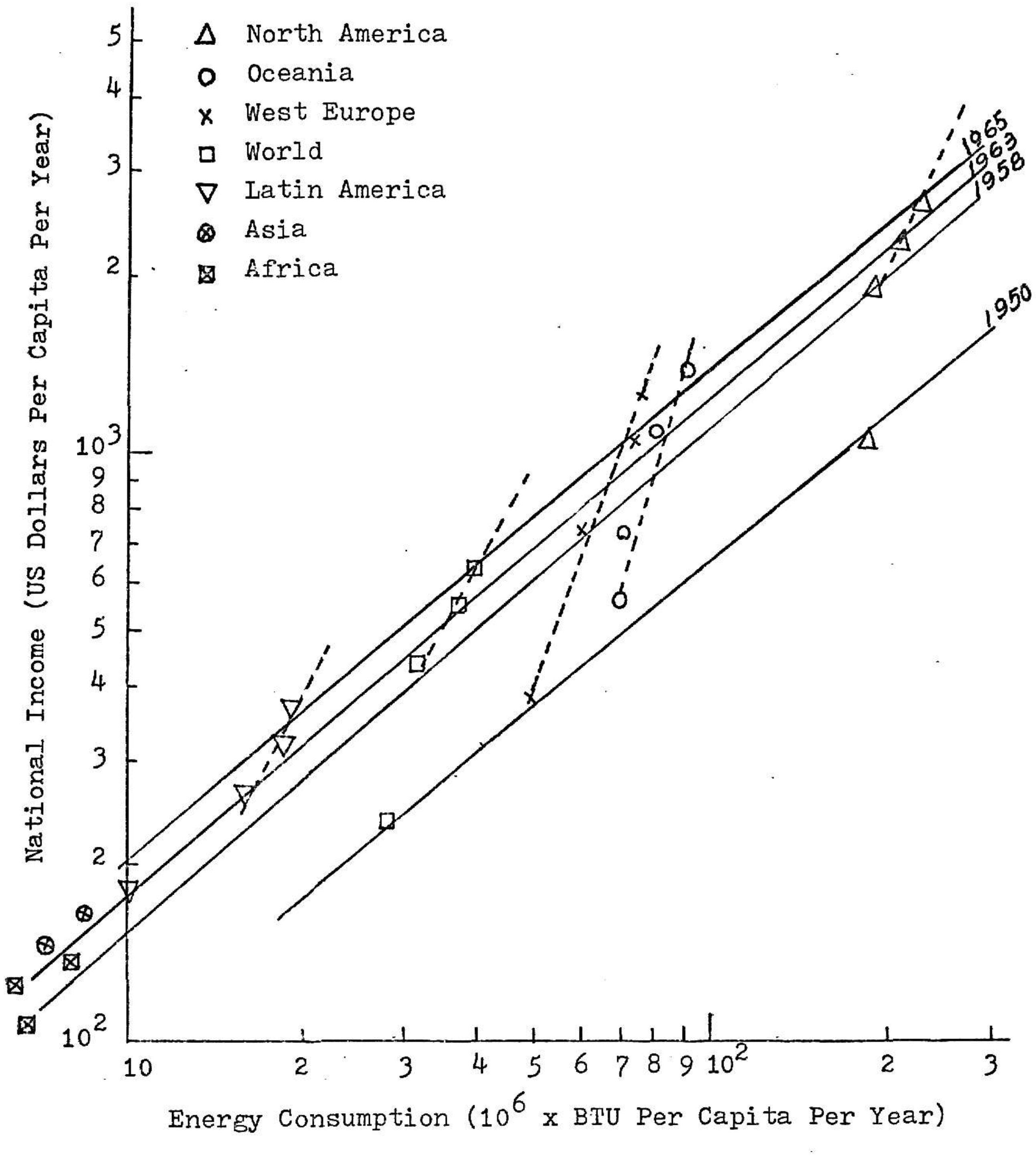


Figure 20. National Income vs BTU/Year Based On Per Capita

capita is the greatest for North America, followed by Oceania, West Europe, World total average, Caribbean and Latin America, Asia and Africa in that sequence. This is also true for the NI per year. Most of the major areas of the world have an increase in energy consumption per year per capita and also an increase in their national income per year, thus, raising their living standards when their energy consumption increases. So we may conclude that living standards are proportional to energy consumption, i.e., energy consumption can approximate the degree of living standard. For example, the Caribbean and Latin America countries from 1950 to 1958, gained 54 percent in energy consumption per year per capita and increased 47 percent in national income per year per capita, while from 1958 to 1965 they gained 18 percent in BTU per year per capita and 16 percent in NI per year per capita.

The relation between living standards and energy consumption is not a simple one, as many factors are involved. However, there can be no doubt that the availability of energy is one of the major factors in the advance of material progress. Looking at the disparities of income and energy consumption, as shown in Figure 20, it will not be easy to close the gap between the highly advanced and the less developed areas in a short period of time. Increasing the availability of energy and raising the living standards will be primary objectives for the human race.

CONCLUSIONS

Looking toward future trends, we are not persuaded that in the next few decades we will see any general or marked deterioration in living standards because of increasing scarcity of raw materials. On the other hand, prospective rates of population growth are high in many countries and do not afford much insurance that living levels can be increased very rapidly in those countries. But these future trends do warn us that, due to various factors, it is likely that some of the areas in the world will run short of raw materials. These areas must find new resources, or must trade with the rest of the world, as Japan does now.

In the less developed areas of the world statistical data are scarce and projections hazardous. In the less developed areas there is the hope that living conditions will improve provided population growth can be controlled. What happens today in the developed countries may happen to the underdeveloped areas in the near future. The projected results may be inaccurate because it is difficult to evaluate accurately all the factors involved in the predictions. It is better to revise the prediction year by year.

However, as the broken line HBCD in Figure 19 shows, if the world's population grows at 2 percent per year, and the energy production for only fossil fuels follows the best estimates, the world's population will reach about six to eight billion between 1990-2000 when the peak energy consumption will occur. This world average peak is estimated to be about 100×10^6 BTU per year per capita. This is about 72 percent of today's living standard for North America. After 2000 a rather sharp drop in energy consumption would be expected to occur if fossil fuels are the only source of energy. In the year 2100 the population might be about 18 billion, but the energy consumption would then drop to only 40×10^6 BTU per year per capita. This corresponds to a living standard of only US $680, or about that of the West European countries average national income in 1958 or to the 1965 world average. With the assumption of Figure 19, we can see the gap between demand and supply. This gap may be solved, if nuclear power is developed in time. This means that present nuclear reactors must be replaced by fast breeder reactors. Failure to do this will probably cause a severe energy shortage. However, even if we do close the energy shortage gap, the high thermal pollution due to the conversion from matter to energy may be so serious at the high peak production rate, a new technology to solve thermal pollution will be definitely necessary. Otherwise the production rate of energy supply will reach some limit within which the thermal pollution can be handled.

Clearly, a balance of population and energy consumption will be reached through social and economical control, (unless significant new energy resources can be developed). This would appear to occur near the year 2000, with a world population of six to eight billion. After that time the population may be expected to increase slowly until energy production falls, near the year 2100. Thereafter, population will probably fall drastically, through social control, to preserve the living standards at a reasonable level for those left in the world. The stable point might be expected in 2500, where only the direct application of solar energy (renewable sources, wood, water power, etc.) would be left. Then living standards can only be controlled by controlling population, perhaps at the 2-6 billion level.

BIBLIOGRAPHY

1. Avert, Paul, 1961, Coal Reserves of the United States and of the world, p. 5 in Domestic and World Resources of Fossil Fuels, Radioactive Minerals, and Geothermal Energy, Preliminary prepared by Members of the U.S. Geotheological Survey for the Federal Science Council.

2. Aymond, Nassikas, Tallman, Eiaenbud, "Role of Nuclear Power Stressed at EEI Annual Convention," Nuclear News, July, 1970, p. 26-35.

3. Committee on Resources and Man, Energy Resources, Chapter 8, W. H. Freeman and Company, 1969.

4. Chauncy Starr, "Energy and Power," Scientific American, September, 1971, Vol. 225, No. 3, p. 43.

5. "Getting More Power to the People," Time, April 19, 1971.

6. Jay W. Forrester, "Counterintuitive Behavior of Social Systems", Technological Forecasting and Social Changes, 1-22 (1971).

7. L. C. McCable, World Sources and Consumption of Energy, Paper No. 2 in the U.N.E.S.C.O. Dission Them, 1951, "Energy in the Service of Man," (U.N.E.S.C.O./NS/75, June, 1951, p. 28-35).

8. M. King Hubbert, "Energy Resources," a report to the Committee on National Resources, (Washington, D.C., 1962).

9. Myron C. Beekman, "Incentives for Development of Fast Breeder Power Plants," Nuclear News, July, 1968, p. 34-35.

10. Nuclear Engineering International, November, 1973, Vol. 18, No. 210.

11. Philip M. Hauser, "The Population Dilemma," The American Assembly, Columbia University, 1963.

12. Palmer Cosslet Putnum, "Energy in the Future," D. Van Nostrand Company, Inc., New York, 1953.

13. Raymond R. Bennett, "Energy for the Future," Combustion, April, 1970, p. 8-11.

14. R. Keith Evans, Sheldon D. Strauss, Rene J. Bender, ed., "Fuel," Power, Vol. 122, June, 1968, a special report.

15. Samuel J. Kaufman, Donald Bogart, John V. Miller and Richard E. Gluyas, "Nuclear Reactor Heat Sources for Further Power Generation," Combustion, July, 1969.

16. United Nations, "World Power Supply Series," Ser. J., No. 1-11.

17. United Nations Statistical Yearbook, 1940-1969.

18. United Nations, Deomographic Yearbook, U.N. 1958, The Future Growth of World Population, New York/Dept. of Economic and Social Affairs.

19. United Nations, Method and Principles for Projecting Future Energy Requirements, U.N. Economic Commission for Europe, New York, 1964.

20. United States Atomic Energy Commission, The Nuclear Industry, 1970, pp. 10, 37, 40, 44, 159, 162.

21. "The Population of the World," Voice of America Forum Lectured, 1967.

22. William T. Reid, B.S., F.A.A.A.S., Inst. F. "The Melechett Lecture, 1969, The Energy Explosion," Journal of the Institute of Fuel, February, 1970.

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THE INTER-RELATIONSHIP OF POPULATION, LIVING STANDARD AND ENERGY PRODUCTION-PAST, PRESENT AND FUTURE

by

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B.S., Taiwan Provincial Cheng Kung University, 1964

AN ABSTRACT OF A MASTER'S THESIS

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requirement for the degree

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KANSAS STATE UNIVERSITY
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1974

ABSTRACT

This thesis deals with world problems of energy resources, energy consumption and living standards. Chapter I contains a prediction of population growth. Chapter II presents a list of energy resources. Chapter III deals with a correlation between living standards and assumed rates of population growth. Chapter IV correlates population and per capita energy consumption.

A probable peak consumption rate of energy is predicted. From this peak future population figures are projected.

Fossil fuels, current nuclear reactors and fast breeder reactors can supply our energy requirements for the next few hundred years. The final goal of a brilliant future will depend probably on our success in developing fussion reactors.

VITA

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