Man's Dependence upon Energy

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All events in the universe are caused by the flow of energy. Nothing can ever happen without it and nothing will ever happen when this flow has ceased. Energy in its various forms has become the principal factor that affects Man's activities, and the continuance of its supply will determine whether he can maintain not only his mode of living, but also his numbers. Man has enormously increased the rate of use of energy in the recent past and is to increase it even more so in the near future. This poses the pressing problem of the depletion of the present convenient sources of energy at a time when new sources are not yet ready to take the place of the old.

In what follows we shall consider the various forms of energy, how man uses it, the various sources, especially hydro power and fossil fuels and their distribution and estimated depletion times. In the next lecture we shall look into the possibility of new sources of energy.

FORMS OF ENERGY

Energy appears in many obvious and hidden forms. The movement of a mass represents kinetic energy. Light and heat are forms of electromagnetic energy to which our eyes and skin are sensitive. Radio waves, X-rays, and other radiation are also forms of flowing energy. The energy of a hot body is the kinetic energy of its atoms. These are forms of energy in a state of flux and it is only flowing energy that is directly useful to man. Energy also exists in hidden forms. Dormant forces are always ready there to convert the hidden energy into a flowing form. There are three principal types of such forces: the gravitational, the electromagnetic and the nuclear.

The first of these is responsible for the energy of falling bodies. It is the principal large scale force in the universe and on the earth it manifests itself among other instances as water and tidal power. The electromagnetic force is responsible for the release of the energy of the chemical reactions, while the nuclear force releases the energy of fission and fusion.

Matter itself is a form of energy. In fact, in all processes in which energy is released some mass is lost. This is equally true of a hydro plant, a fire or a nuclear explosion. In ordinary chemical reactions the mass loss is one part in several billion; in fission it is one part in one thousand; in fusion it is about one part in four hundred. In the fusion of matter with antimatter the conversion is complete.

Thus energy appears in three basic forms: kinetic, electromagnetic and potential (as mass). These further subdivide into more specific types as illustrated in Figure 1.

All forms of energy, and also mass, are equivalent and can be converted to each other with the limitation that the flow of energy is from a higher to a lower concentration, i.e., it is downhill. In technical language it is said that the flow is such as to increase the entropy of the closed system in which the flow takes place. This is the second law of thermodynamics and it determines the efficiency with which useful energy, i.e., flowing energy, may be extracted by machines from fuels. Various forms of energy, such as low frequency, directed electromagnetic waves, directed kinetic energy, and some forms of gravitational energy (flowing water) can be converted to each other and to other forms at nearly 100% efficiency.

Flowing energy is in a state of degradation. From its more concentrated forms it changes finally to heat and is emitted by matter to space as infrared radiation. Eventually all flowing energy will end up that way, never to be reconcentrated, according to the laws of physics as we know them today.

Man makes various uses of energy. Anything he does, he does by expending energy; the number of things he can do is proportional to the energy he spends. With the aid of machines man has been able to direct

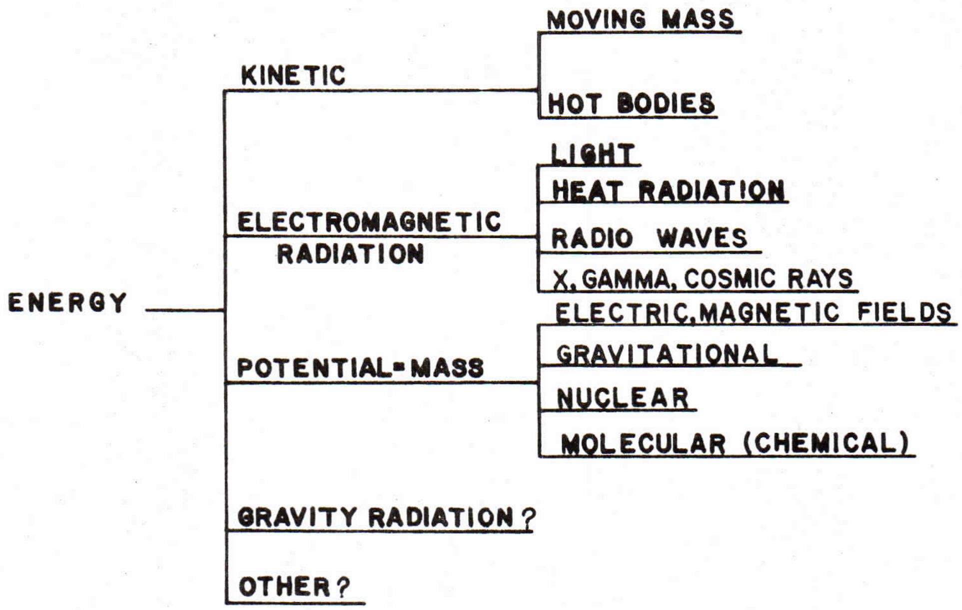


FIGURE 1 FORMS OF ENERGY

large quantities of energy into chosen aims. This has given him control and thus, with the expenditure of a small amount of his bodily energy, he can direct enormous amounts of external energy. As a result his power over the environment has increased accordingly.

Man uses all forms of energy for his various needs or desires: heat to keep him warm and to run some of his engines, kinetic energy to perform mechanical tasks, radiation for light and for carrying his messages. Energy in the form of electricity with its high versatility and ease of transmission has made possible the technological revolution.

SOURCES OF ENERGY

Figure 2 shows the various sources of our energy, both present and expected. Nearly all our present energy is derived, although mainly indirectly, from the fusion of protons on the sun. The total solar power intercepted by the earth is of the order of 25,000 times greater than the amount used by man.

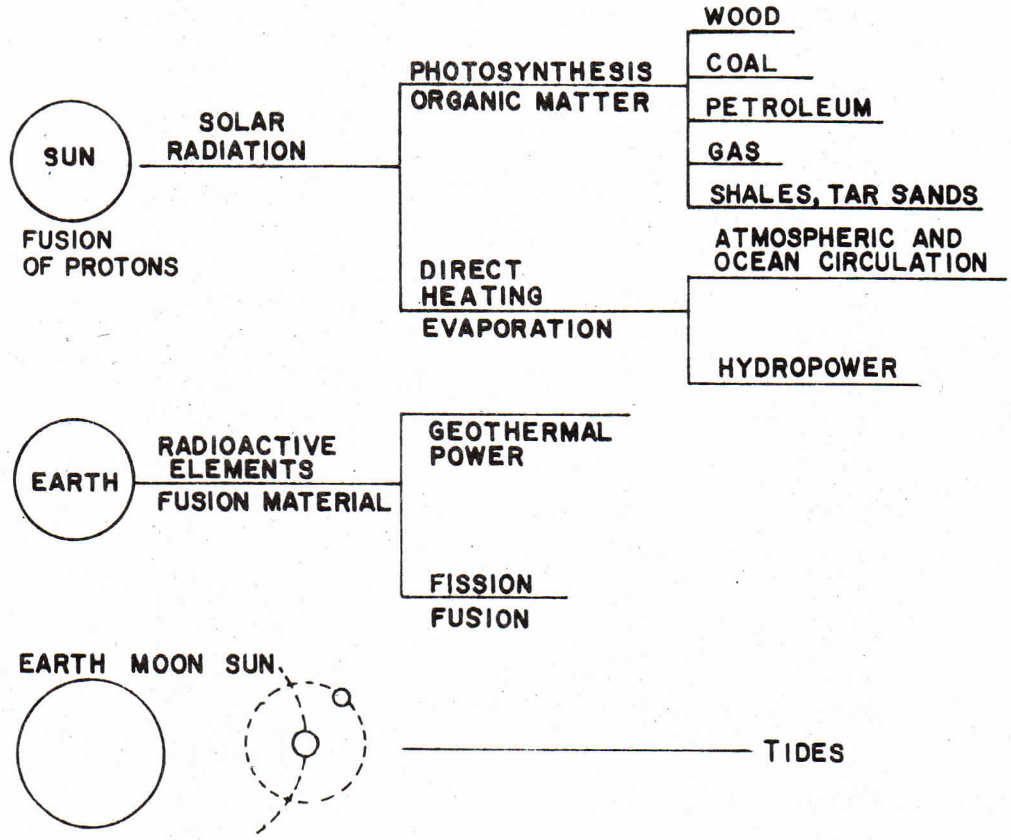


FIGURE 2 SOURCES OF OUR ENERGY

An infinitesimal amount of the solar radiation is presently used directly by man to supply a negligible part of his needs. Another small part (1 in 4000) is, through photosynthesis, captured and stored in the organic matter of the land and the sea. Man uses some of this in the form of wood. A small part of the organic matter trapped in the soil and the rocks remained there unoxidized over long periods of time and is now being used up rapidly in the form of coal, petroleum and gas.

The sun is also the ultimate source of hydropower, the winds and the ocean currents.

The earth is the source of geothermal power and the future forms of fission and fusion. Geothermal energy is believed to originate in the heating of the rocks by the radioactive elements. Some of these same elements are expected to be one of the main, if not the main, source of man's energy in the future as fuel in (breeder) fission reactors. The fuel of fusion, the feasibility of which is not yet proven, will be deuterium, which makes up one part in 7000 of all hydrogen in the earth.

The power of the tides is derived from the slowdown of the rotation of the earth through the action of the moon and sun.

The various sources of energy may be divided into renewable and non-renewable. Renewable are the winds, hydropower, wood, direct sunlight and tidal power. Non-renewable are coal, gas, petroleum, shale, peat, nuclear fuels and geothermal power. Of these, the fossil fuels are non-renewable and will be rapidly expended at the present rate of use, as will be the fissionable materials if nuclear reactors of the present type continue to be used. However, if breeder and fusion reactors are used the nuclear source of power will be of such long duration as to be considered inexhaustible. Finally, geothermal power is non-renewable since if it were to supply all of mankind's present needs the usable reserves would last only one year.

TABLE 1: ENERGY EQUIVALENTS

A variety of units is used in measuring energy. The equivalents given below should be useful in making conversions.

(a) The following are different ways of expressing the same amount of energy:

1 kg. of bituminous coal (most common type)
28,600 B.T.U.
7.2×10^6 calories
8.36 kw-hr.
0.70 kg. of average oil
0.76 m^3 of natural gas

(b) Other energy equivalents:

1 m^3 gas = 0.92 kg. oil
1000 kilocalories = 139 gm coal = 97.3 gm oil
1 km^3 natural gas = 1.32×10^6 metric tons of coal

(c) Other useful conversion factors:

1 B.T.U. = 252 calories
1 m^3 = 35.3 ft^3 = 6.2898 barrels
1 metric ton of average oil = 7.3 barrels

HISTORY OF THE UTILIZATION OF ENERGY

One of the principal differences between man and other animals has been his continually increasing control of external sources of energy. The only source of energy available to primitive man was his food, about 2000 kilocalories per day or 100 kilograms of coal equivalent per year. Hunting man could light fires, and this increased his energy supply by another one or two hundred kilograms of coal per year. The primitive agricultural man who lived in the Middle East 10,000 years ago improved his diet by planting crops and also used pack animals to do work. His energy use, other than as food, had thus increased to 400 to 500 kilograms of coal equivalent per year. The spread of slavery later probably kept the figure low until the middle ages when some water and wind power and also coal were used. This increased annual energy use per person to about 1000 kilograms of coal. With the industrial revolution of the nineteenth century, energy use began to accelerate rapidly, finally reaching the present levels of several tons of coal equivalent per person per year in the industrialized countries.

Today's use of modern energy (other than wood) in the world is shown in Figure 3. The picture is full of significance and tells a tale of wealth and poverty more dramatically than could be told by any book or traveller. Its full significance becomes clearer when it is considered that energy consumption is a general index of the things that make the good life, i.e. of the material standard of living, good health, education and culture, and that it varies roughly in proportion with them. Figure 3 shows clearly that the separation line between rich and poor lies between Japan and Latin America.

Even these low figures of modern energy use by the poor world are exaggerated since a large part of this energy is consumed by foreign mining companies (especially in Latin America and Africa) and by their small upper classes and their armies. The electric light has still to reach large segments of mankind.

At the other end of the scale, the figures for the United States and Canada far exceed those for most other countries, and are still increasing very rapidly. Sensitive people, and all those people grouped at the left end of Figure 3, tend to regard the two ends of the figure as revolting obscenities.

Figure 3 poses the question: Is there an optimum level of energy consumption, or is an increase in consumption always desirable? Excessive use of energy may not bring additional benefits in proportion to its quantity, but it does bring undesirable side effects such as pollution, noise,

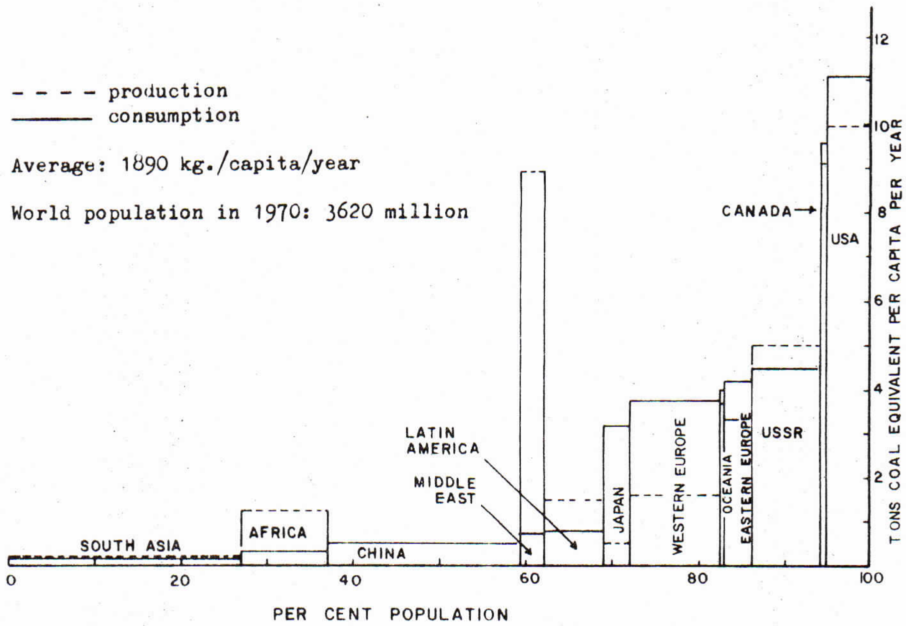


FIGURE 3 ENERGY IN THE WORLD, 1970. (Data from *United Nations Statistical Yearbook 1971.)*

traffic jams, urban sprawl and the resultant deterioration of cities. The more urbanized an area becomes, the greater are these effects for a given level of energy use. Comparison of European with American cities indicates that there does exist an optimum rate of energy consumption, and that it may, with present types of energy use, lie between the levels of Europe and the United States.

Figure 3 also shows the production of energy by area, and which areas are self-sufficient or deficient in it. The Middle East stands out conspicuously.

The consumption of modern energy for some countries is shown in Table 2. It will be noted that large variations may exist between neighbouring countries of the same region of Figure 3.

To complement Figure 3, the consumption of fuelwood for various regions and countries is given in Table 3 for the year 1961, the last year for which data exist. For comparison the figure for modern energy is also given for the same year. The figures show fuelwood is not used so much by those who have no other source of energy and need it, as might be expected, but by those who have a supply of wood. Thus Sweden uses a lot of it but India nearly none. South America and Africa have forests and their use of

TABLE 2: MODERN ENERGY CONSUMPTION BY COUNTRY, 1971. (All figures in kg. coal equiv. per capita per year.) From *UN Statistical Yearbook 1972*

Western Europe		Eastern Europe	
Sweden	6089	Czechoslovakia	6615
United Kingdom	5507	E. Germany	6308
W. Germany	5223	Poland	4374
France	3928	Bulgaria	4029
Italy	2682	Hungary	3291
Spain	1614	Romania	2975
Portugal	805	Yugoslavia	1608
South America		Others	
Venezuela	2518	South Africa	2895
Argentina	1773	Turkey	516
Brazil	500	Egypt	282
Bolivia	224	Kenya	171
		Ethiopia	32

fuelwood is high. Asian countries have little forest left and use little firewood. The total per capita consumption of energy in South Asia and Africa (excluding South Africa) is between 100 and 500 kilograms of coal equivalent per year. Their use of pack animals is also limited, since in overpopulated areas there is no room for animals. Thus their energy consumption is lower than the estimate for the primitive agricultural man given earlier. If energy consumption is a measure of standard of living, then their standard has dropped over the past 10,000 years. (This situation is further aggravated by the fact that at present their energy growth is hardly keeping pace with their rapid population growth, although the situation has been somewhat alleviated by improved health and education.) The third world does have large potential for production of hydro power (but no fossil fuels) and the possibility for rapid development exists. The obstacles are mainly political, e.g. for Africa and Latin America the balkanization into a great number of small states makes development extremely difficult.

The growth of world energy production over the past century is shown in Figure 4. The great increase of the past 20 years, due almost entirely to the growth in petroleum and natural gas, is the notable feature. Projections into the future at the recent rate of growth will double the present consumption in 15 years. Most of the increase is to be in petro-

TABLE 3: MODERN ENERGY AND FIREWOOD CONSUMPTION, 1961. (All figures in kg. of coal equiv. per capita per year. Firewood data from Food and Agricultural Organization of the United Nations (FAO), *World Forest Inventory 1963*.)

Region or Country	Modern Energy Consumption	Firewood Consumption
WORLD	1400	88
North America	7800	68
South America	514	232
Mexico	960	72
Brazil	345	430
Bolivia	145	795
Africa	310	237
Ethiopia	20	306
Europe	2600	75
Sweden	3520	188
W. Germany	3620	8
France	2514	6.6
Italy	1223	1.8
Spain	855	97
Greece	540	94
Asia	-	52
China	-	46
India*	150	7.5
Indonesia	140	243
Pakistan	68	37
U.S.S.R.	2920	138

*Another 60 kg of coal equivalent per capita per year is derived from cow dung

leum and gas; however, with the decline and depletion of these fuels in 30 to 50 years, coal will return to become the principal source of energy unless some of the new sources are ready by then.

Figure 5 shows the history of energy growth in the United States over the past century. The progression from wood to coal and to petroleum and gas over this period is notable. Wood still provides 4 to 5 times more energy than nuclear reactors. The effects of the Great Depression, which affected coal most, provide the main interruption in the growth curve.

Figure 6 shows in detail the sources and uses of energy in the

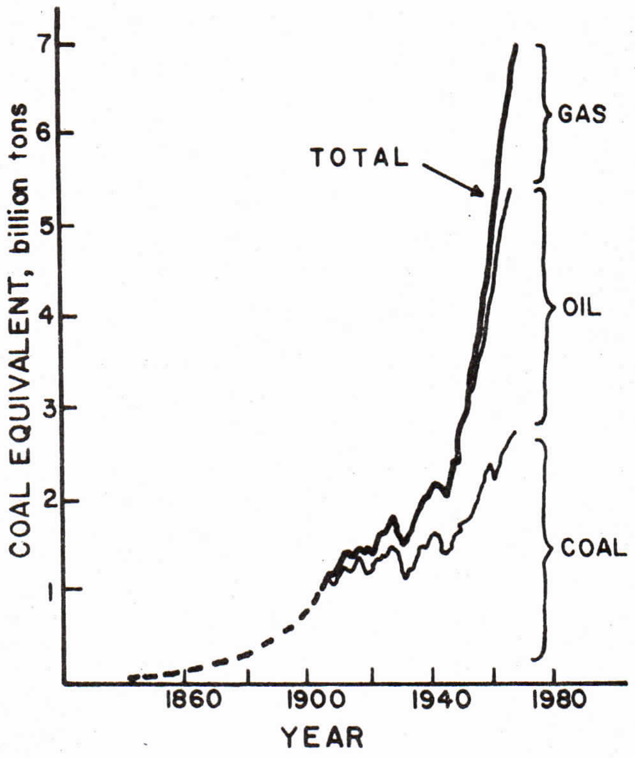


FIGURE 4 WORLD ENERGY PRODUCTION

United States in 1970, i.e. in the modern technological society. We note that gas and petroleum provide nearly equal energy inputs. Of the petroleum used, 28.5 percent or 180 million metric tons is imported. The input of hydro power is equal to the thermal energy that would be needed to produce electricity at 30% efficiency. (The other 70% consists of energy lost as waste heat, whose disposal has become a big cause of thermal pollution of water bodies.) The use of electricity is shared equally between industry on the one hand and households and commercial establishments on the other. Of the 640 million metric tons of oil used, 68% was used for transportation and nearly half by automobiles directly. It must be remembered also that some petroleum is used indirectly for the production, servicing, etc. of automobiles. It is reported that the new anti-pollution devices for automobiles reduce their efficiency such that 40% more gasoline would be needed, i.e. an additional 120 million tons of petroleum per year, if all cars were converted in 1970. If this is correct, it is hardly a

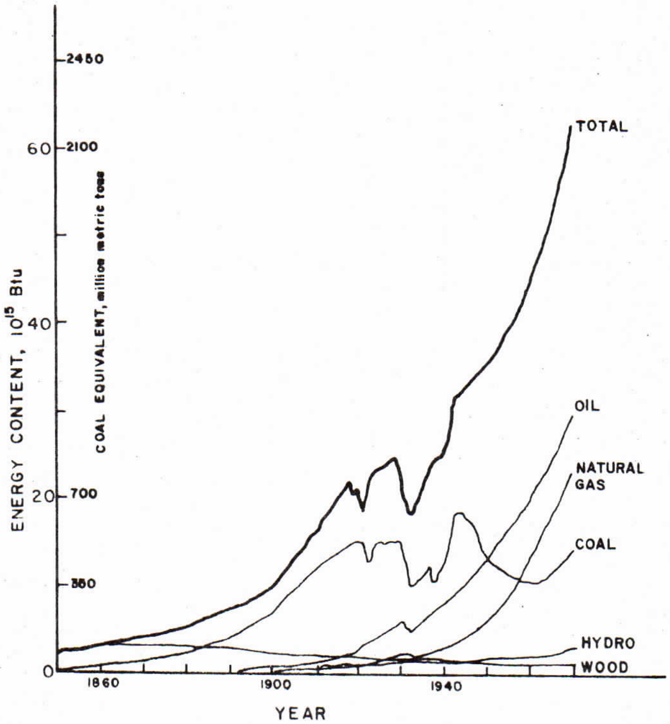
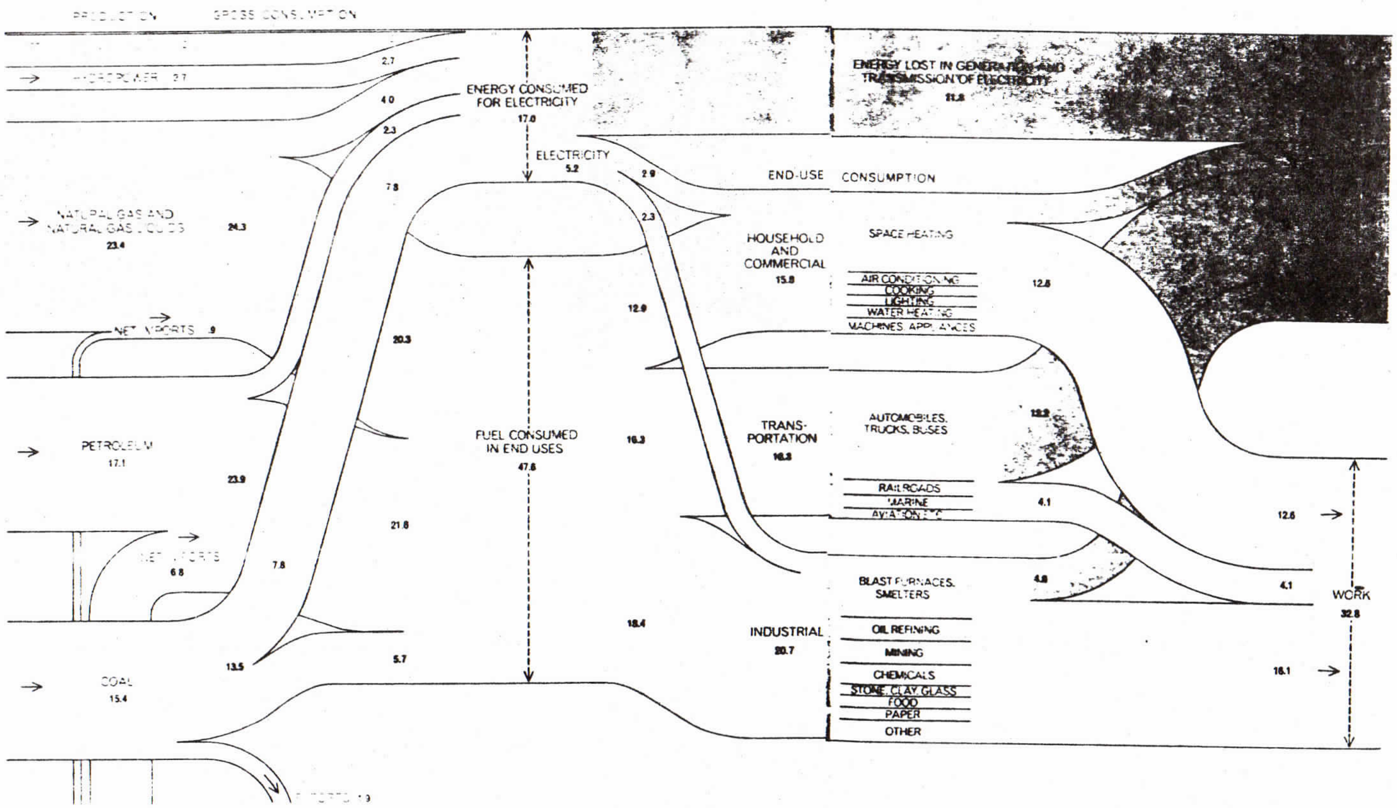


FIGURE 5 UNITED STATES ENERGY CONSUMPTION.

step in the right direction at a time when the country is faced with rapid depletion of its petroleum reserves.

Finally, it can be seen from Figure 6 that energy is used at 50% overall efficiency,i.e. only half goes to the desired use - the other half is wasted.

Western Europe presents a similar picture in the uses of energy except that petroleum for the automobile represents a smaller fraction of the total. In the U.S.S.R. and Eastern Europe the fraction for the automobile is negligible, while that for industry is larger than in the United States. Japan resembles Western Europe in the uses of energy.



(Data are for 1970)

FIGURE 6 ENERGY FLOW IN THE UNITED STATES. (All numbers in 10^{15} B.T.U./year. Reprinted from "The Flow of Energy in an Industrial Society" by Earl Cook, *Scientific American*, Vol. 224, No. 3, September 1971, pp. 138-139, with permission from W.H. Freeman and Co.)

ADVERSE ENVIRONMENTAL EFFECTS OF ENERGY USE

These effects are too well known to need much elaboration. The worst kinds are those associated with urban growth. Since both urban populations and the per capita use of energy are doubling every 15 years or so, the amounts of various types of pollution reaching a city resident increase by 16 times over a period of 30 years. The physical and psychological effects of this may be even greater, especially when certain safety thresholds are exceeded. Thus the net benefits of greater energy use are reduced and may even be negative. The higher living standard thus lowers the quality of life and defeats its own purpose.

The prospects for improvement in this area are as follows:

In the United States the antipollution devices on the new automobiles will slow down the overall growth of automobile pollution and will cause an absolute reduction after 1990. However relief may come sooner from another direction: the reduction in auto use from the impending oil shortage.

Emissions from power plants (carbon, nitrogen and sulfur oxides) cannot be controlled at the stack by any economical method and no improvement is expected. The only thing that can be done here is to use clean fuel or to remove power plants from the vicinity of cities. Most fuels (especially coal) are not naturally clean. They can be cleaned prior to use, but only at a considerable cost.

In general, localized pollution may be reduced, or at least prevented from growing too fast, but this requires much effort and time. The prospects for controlling global pollution, especially with the increased energy use in the future, do not seem good.

Nuclear plants are seen by many as the answer to these problems. But nuclear plants only appear clean. Potentially they are vastly more polluting and hazardous than the present types of energy sources. We shall consider them in detail in the next lecture.

THE GROWTH OF ELECTRICITY

Figure 7 shows the growth of electricity production in the world since 1952. The curve is almost a perfect exponential, with a growth rate of 7.8% per year and a doubling time of 9 years.

The installed capacity in 1970 was 1100 million kilowatts, of which 300 million was in the form of hydro power and 19 million available as nuclear energy. Output was nearly 5000 billion kilowatt-hours for a utilization factor of 52%. In the same year the amount of fuel in coal

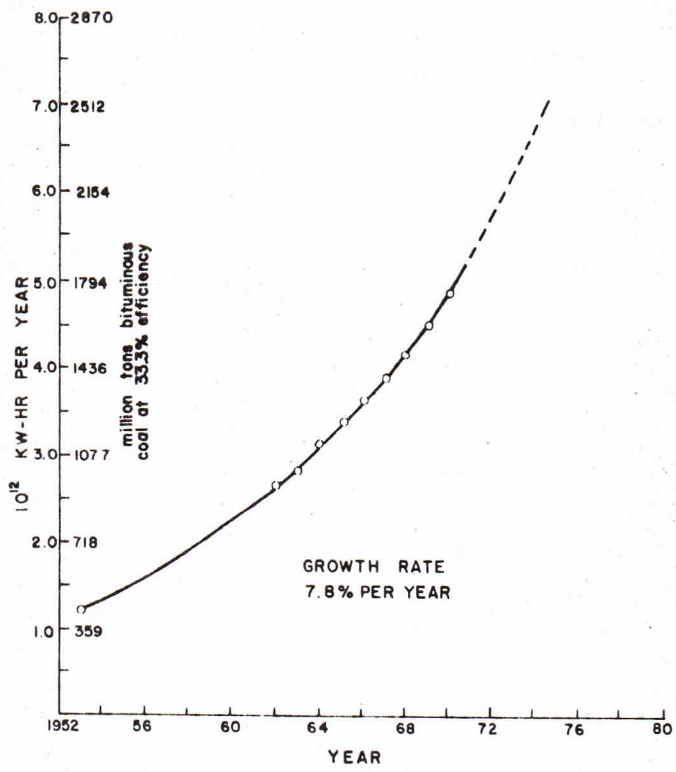


FIGURE 7 WORLD PRODUCTION OF ELECTRICITY, (Data from *United Nations Statistical Yearbook 1971*.)

equivalent that would be needed to produce this electricity at 33% efficiency was nearly two billion tons. The total fuel used in the world in 1970 was 7 billion tons, and it has been growing at 4.5 percent per year over the same period. With these rates of growth the energy going into electricity will exceed all other uses by 1993; if the growth were to continue at this rate, electricity alone would consume all fossil fuels by the year 2045.

Electricity is a highly desirable form of energy. It is versatile and clean, at least in its end uses. Its use is bound to increase greatly in the near future, and a large increase in its price may be necessary to slow its rate of growth. A sign of the growth of electricity is the spread of the unified electrical power network. Eastern North America is already under such a network. Europe and the U.S.S.R. have large networks, and in the near future a single unified network will stretch from Portugal to the Pacific. Superconductors in the future may make it possible to bring the

Old and New Worlds under two single huge networks.

Large networks make it possible to send power from areas that do not need it to areas that need it at a given moment, such as from one time zone to the next. Peak loads can be supplied more easily this way. For this reason large networks are very useful. On the other hand, their behaviour cannot be well predicted and neither mathematical nor laboratory models can describe them adequately so that proper protection might be provided. Thus it is possible for a local failure to spread to the entire network, as happened in East North America in 1965.

THE FOSSIL FUELS

The fossil fuels are the remnants of organic matter that was trapped in muds and in sedimentary rocks over periods of millions of years in the distant past, and remained there unoxidized to form the deposits of coal, petroleum and gas. Coal is the remnant of plants, but the origin of petroleum and gas is not known. One theory says that they are the result of buried animal life.

Of the total recoverable ultimate reserves of fossil fuels, about 8,000 billion metric tons of coal equivalent, nearly 89% are represented by coal, 5.0% by oil, 5.5% by natural gas, and 1% by tar sands and shale. Coal is thus the main fuel. The present importance of petroleum and gas is the result of their greater convenience and cleanliness. But their high extraction rate and their limited quantities guarantee short lifetimes for them and the early return of coal as the principal fuel.

Coal

Coal has been used for centuries and was the main fuel of the industrial countries in the 19th and early 20th centuries. The growth in its rate of use was slowed by the introduction of petroleum and gas, but it is beginning to rise again, especially in the United States where rapidly increasing energy demands cannot be met by supplies of petroleum and gas. Production of coal for the world is shown in Figure 4. Table 4 shows production by countries in 1970.

One estimate of the ultimate minable reserves of coal is shown in Figure 8. Since only a very small fraction of the ultimate coal has been mined up to now the figure represents the remaining reserves. Mineable coal is defined here as 50 percent of the coal in seams more than 30 centimeters thick and no more than 1200 meters deep. The omitted coal at more than 1200 meters depth is only 5 to 10% of the total. Fifty percent of

TABLE 4: MAJOR PRODUCERS OF COAL AND LIGNITE, 1970
(Source: *United Nations Statistical Yearbooks, 1971 and 1972*)

Country or Region	Coal and Lignite Production, million metric tons/year		Total Reserves billion metric tons
	1970	1971	
U.S.S.R.	577.4	591.5	5527
U.S.A.	546.9	508.9	1506
China	360	390	1711
E. Germany	261.6	263.6	30
W. Germany	219.2	215.6	132
Poland	172.8	180	60.6
United Kingdom	144	147.1	15.5
Czechoslovakia	109.8	113.4	21.4
India	76.5	73.8	108.3
Australia	73.5	68.3	111.6
South Africa	45.6	58.7	72.5
France	40.2	35.7	2.83
Japan	39.7	33.5	20.9
Bulgaria	29.2	27.0	2.26
North Korea	29.2	-	-
Yugoslavia	28.4	30.9	26.9
Hungary	27.8	27.4	6.4
Romania	20.5	20.9	1.96
Canada	15.1	16.7	85.1
South Korea	12.4	12.8	1.18
WORLD	2918	2930	8682

the coal is lost in mining, whether underground or surface. It should be noted that the thickness of coal seams is seldom greater than a few meters, except in Siberia where it reaches 70 meters. A small fraction of the coal (5% in the United States) lies near the surface and can be removed by strip mining. This results in cheap coal (1 to 3 dollars per ton) but also in the ravaging of large areas.

The quantities in Figure 8 are estimates. Only about 10% of the total has been accurately measured. However, the estimates are not far in error (10-20%), since coal is found in extensive slabs of uniform thickness and a few drill holes may thus provide a good indication of the extent of the deposit.

Figure 8 shows that more than half of the total coal is in the

U.S.S.R., and most of this is in Siberia, particularly in Yakutia (River Lena Basin). In recent Soviet publications, Yakutia is listed as having "one third of the world's fossil fuels". But the area is very distant and lies entirely in the permafrost zone. The difficulties in mining and transporting this coal may not be small. Nearly all of the remaining coal is in the U.S.A., Canada, Europe and Asia, mainly China. The Southern Hemisphere has nearly none. Some other estimates (World Power Conference, *Survey of Energy Resources*, London, 1968, Table 4) give a higher figure (8,700) for the overall reserves and double the figure for China and Latin America.

It is a curious fact that the deposits of both coal and the other fossil fuels lie along an east-west belt in the Northern Hemisphere. This suggests that in the distant past when the fuels accumulated the climate along this belt was uniquely favorable to the growth of organic matter or that this belt was near the equator, from where it moved away with the continents.

Coal is not only a fuel but is also used in metallurgy to reduce metals from their ores, e.g. each ton of iron requires 1.4 tons of coal. About one fifth of all coal goes to this use.

It will be noted that it is the industrialized countries that

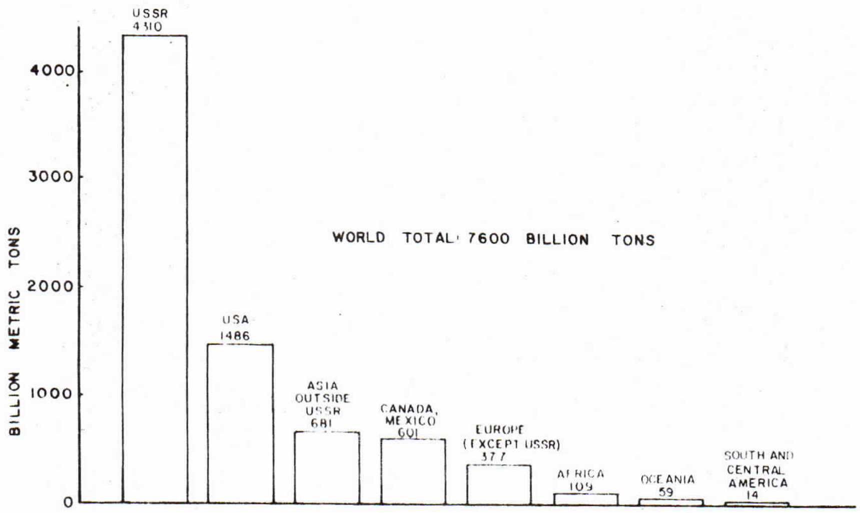


FIGURE 8 ULTIMATE MINABLE WORLD RESERVES OF COAL AND LIGNITE. (Data from Paul Averitt, "Coal Resources of the United States", *U.S. Geol. Survey Bull.*, 1275, January 1, 1967.)

possess the coal deposits. This is no mere coincidence. Industry began and grew where coal was available. No country without coal became industrialized, except recently when petroleum arrived.

Coal could supply the present rate of energy consumption in the world for over a thousand years, but the increased utilization rate in the future is expected to shorten this lifetime to 3 or 2 centuries. In addition to its direct use as fuel, coal can be transformed into petroleum and gas by various processes. Limited quantities of these fuels will come from this source in the future.

Petroleum

Figure 9 shows the growth of crude petroleum production in the world. The growth is nearly exponential. Production increased at an annual rate of 7.3% between 1950 and 1970, and 8.6% between 1960 and 1970. The doubling time is thus between 8 and 10 years. Production of petroleum by country, along with one estimate of reserves, is shown in Table 5. Production by major areas and the international flow of petroleum are shown in Figure 10. Present prices of crude range from $20 to $30 per ton, depending on location and quality.

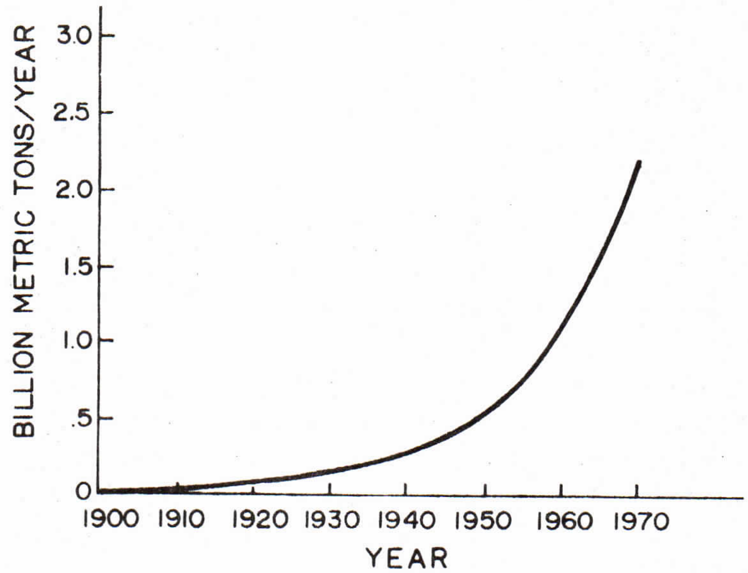


FIGURE 9 GROWTH OF WORLD PETROLEUM PRODUCTION.

TABLE 5: PETROLEUM PRODUCTION AND RESERVES.
Source: *United Nations Statistical Yearbook 1972.*

Country or Region	Production, million metric tons/year		Known Reserves, million metric tons
	1970	1971	1971
United States	475.3	466.7	5144
U.S.S.R.	352.6	377.1	8203
Venezuela	193.9	185.8	1966
Iran	191.7	223.9	8265
Saudi Arabia	176.8	223.4	18737
Libya	161.7	132.4	3695
Kuwait	137.4	146.8	10370
Iraq	76.5	83.8	4420
Canada	60.6	64.4	1126
Nigeria	54	76.4	1351
Algeria	47.3	37.7	1283
Indonesia	42.1	43.8	1459
United Arab Emirates	37.6	51.7	2222
Neutral Zone	26.9	29	1901
China	24	-	-
Mexico	22	21.4	397
Argentina	20	21.6	279
Qatar	17.4	20.5	626
Oman	16.6	14.7	649
Egypt	16.4	14.7	138
WORLD	2278.4	2399.4	76200

The Middle East is the major producer. Its production, along with that of Africa and the U.S.S.R., is increasing rapidly, while for the United States it reached its highest in 1970 and declined in 1971. Production in other areas increased slightly. In Canada it was 60 million metric tons with a growth rate of 6% over the last few years. Over half of Canada's production is exported to the United States, while a similar quantity is imported, mainly from Venezuela to serve the needs of the country east of Kingston. The great dependence of Western Europe and Japan on Middle East and African oil is shown clearly in Figure 10. The United States has been mostly self-sufficient in the past, and it only imported 27% of its needs (190 million metric tons) in 1970. However, demand and

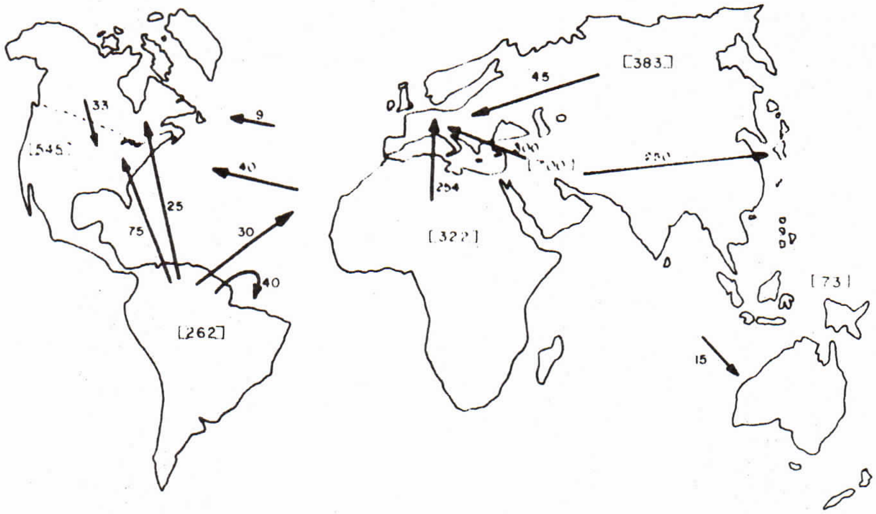


FIGURE 10 PRODUCTION AND FLOW OF OIL, 1970. PRODUCTION BY MAJOR AREAS SHOWN IN BRACKETS. NUMBERS ON ARROWS INDICATE MAJOR FLOWS. (All numbers in million metric tons per year. Data from *International Petroleum Encyclopedia*.)

local supply have begun to diverge rapidly and the imports must grow to great quantities in the future.

One projection of the international flow of oil in 1990 is shown in Figure 11. It is based on recent trends and future predictions of demand, e.g. in the United States the demand for 1985 has been projected by various competent organizations to be 1,500 million tons. The projection for Japan is the most uncertain. The rapid growth of the Japanese economy in the past two decades may not continue in the future. The Japanese government is making plans to deliberately reduce further growth.

The extractable reserves of petroleum for the world by area are shown in Figure 12. The expected future discoveries are a high estimate, the low estimate being only half the value. The figures for the known reserves differ from those given in Table 5; this is due to the estimates being made by different people at different times and using different standards. Those of Figure 12 are probably more accurate. The only major changes in the known reserves in the last two or three years have been the discoveries in West Siberia and in Saudi Arabia.

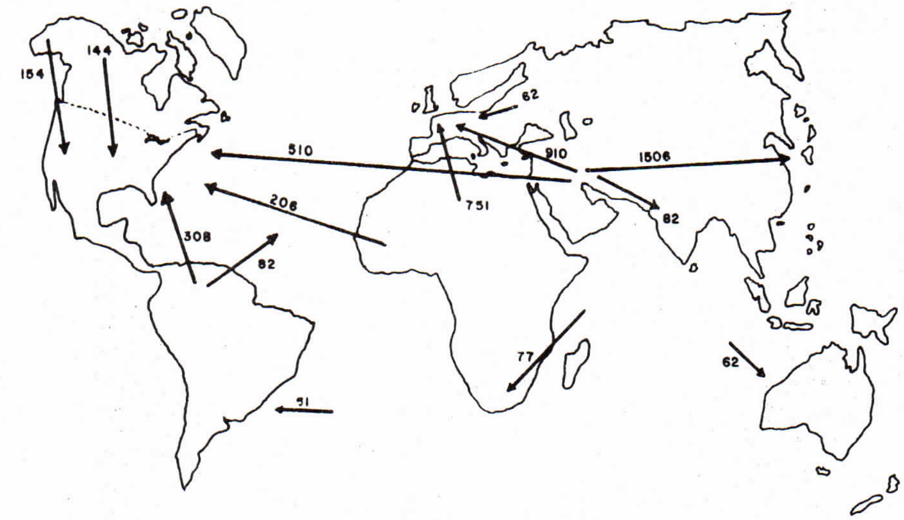


FIGURE 11 PROJECTED FLOW OF OIL IN 1990. (All numbers in million metric tons per year. Data from Shell Oil Co.)

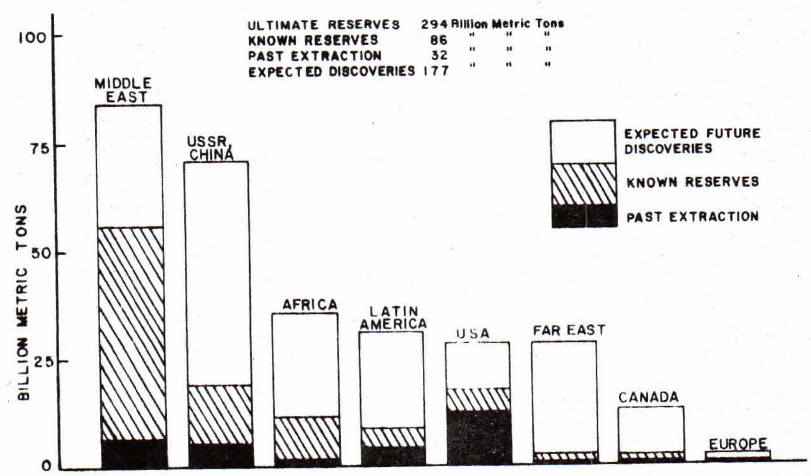


FIGURE 12 ULTIMATE PETROLEUM IN THE WORLD, HIGH ESTIMATE, 1970. (Source: Standard Oil Co. of New Jersey.)

The Middle East and (North) Africa are clearly the largest sources of known petroleum, having between them more than two-thirds of the world total. The known reserves of Canada are 1.2 billion tons and are equal to the recent big discoveries in Alaska. Either of them could last the U.S. a little over 2 years at current rates of use. Figure 12 gives a large value to the expected future discoveries in Canada but the recent explorations in the Arctic are not encouraging. However, the cost of finding additional oil has become so high that it may soon be cheaper to turn to the tar sands. Thus only a part of the amount in Figure 12 may be added to the known reserves of Canada.

At the 1970 rate of use of petroleum the known reserves of the world could last until the year 2008 and the ultimate reserves (the high estimate) to the year 2085. However, with an 8% annual growth the dates become 1989 and 2000 respectively. For the Middle East using the numbers in Figures 10 and 11, the depletion dates become 1994 for the known reserves and 1999 for the ultimate reserves. These dates show very well the absurdity of the projections for the consumption of oil and the complete lack of concern of those who make economic plans for the future and who have the power to plan otherwise.

Is there any possibility that the ultimate reserves for oil may be increased? The offshore continental shelves are mentioned as containing large quantities of petroleum. The part that can be extracted has already been included in Figure 12 (about 10% of total). There may be more further offshore but the problems of extraction and those of possible pollution of the sea are unsolved. Some hope may lie in another direction. At present only about one third of the oil in place is extracted. The remainder cannot be made to flow from the porous rock in which it is distributed to the drill holes. Future improvements may make it possible to go back to the old wells and get more oil.

The question arises as to how the estimates of ultimate reserves are made. The figures for the ultimate reserves are no more reliable than the methods used to obtain them. There are several methods for doing this. Geologically similar areas may be expected to hold similar amounts of petroleum. If these are known for one area they may be estimated for the others. The United States is the most thoroughly explored area, and by analogy deposits of other areas may be inferred from their geology. In combination with the exploration work in the other areas, a rather reliable estimate of the total reserves may then be made. Within the United States the best method for estimating ultimate reserves is illustrated in Figure 13. The amount of oil found per foot of exploratory drilling is plotted vs. the cumulative drilling, excluding Alaska. A smooth exponential decay

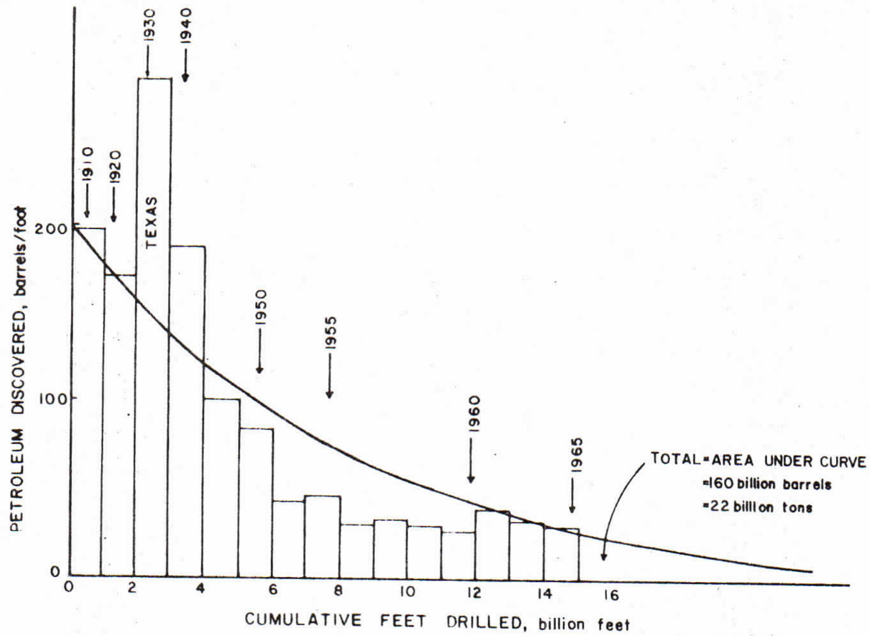


FIGURE 13 HOW ULTIMATE U.S. PETROLEUM RESERVES ARE ESTIMATED. (After M. King Hubbert in *Resources and Man*.)

curve may then be fitted and extrapolated. The area under the curve represents the total oil in the ground (extractable oil). Note that more than half of the total must be found in order to be able to fit an accurate curve. Thus, from Figure 13, the ultimate United States' reserves are about 160 billion barrels. A somewhat smaller estimate will result if a correction is made for the effect of improved technology in the last several years. This estimate for the United States is supported by other independent but less reliable methods, i.e. from the shape of the discovery rate vs. time curve and from the finds in "wildcat" drilling.

Natural Gas

Production and measured reserves of natural gas for some countries in 1970 are shown in Table 6. The United States produces 58% of the world total and uses an even higher fraction. Part of the Canadian production (36.5% in 1971) was exported to the U.S. In 1971, 125 cubic kilometers of gas were discovered in Canada and the reserves were raised to 1571 cubic kilometers at the end of 1971.

Natural gas in the past could move safely only by pipeline. The development of the high-pressure, large-diameter pipeline has made movement

TABLE 6: PRODUCTION AND RESERVES OF NATURAL GAS, 1970. (Production statistics from *United Nations Statistical Yearbook, 1972* Data on reserves from World Oil, Houston, Texas.)

Country or Region	Production, km^3/year		Known Reserves, km^3
	1970	1971	1971
U.S.A.	620.7	636.9	7895
U.S.S.R.	198	212.4	18010
Canada	64.4	70.7	1571
Holland	33.6	43.7	2498
Romania	24.8	26.7	250
Italy	13.1	13.4	142
W. Germany	12.4	15.1	388
Iran	11.2	15.6	3681
United Kingdom	11.1	18.5	1126
Venezuela	9	9.4	896
Poland	5	5.2	85
Kuwait	4	-	1119
Algeria	2.8	-	4417
WORLD	1071	1142	49900

on land over long distances practical. International movement of gas exists mainly on land, i.e. Canada - U.S.A., U.S.S.R. - Europe. The technology for liquid gas transport by ship is now ready, and large quantities will be moved by this method in the near future, mainly from the Middle East and Africa to Europe and to the U.S.A., and from the U.S.S.R. to the U.S.A.

No accurate separate estimate of natural gas reserves exists, but it has been found from long experience in the U.S.A. that the ratio of natural gas to that of petroleum is nearly constant at 1260 cubic meters per metric ton, (6,000 cubic feet per barrel). In heat content, this is a ratio of 1.1 to 1. Thus the reserves for petroleum in Figure 12 could be multiplied by 1.1 to give the gas reserves.

Gas and petroleum often occur together in the same area and the extraction of oil results in the escape of gas which was flared in the past (and still is in many places today). However, the development of liquid transport will reduce this loss to a minimum.

Present prices for natural gas are about one dollar per thousand cubic feet in the international market and 15 to 25 cents delivered to the pipeline in North America. These lower figures are the result of price control by government.

The depletion dates for natural gas may be taken to be roughly the same as those for oil if the two are to be used in equal intensity. But because of the later start, gas may last somewhat longer.

<u>Oil and Gas from Other Sources</u>

(1) The Tar Sands of Alberta

These are the largest tar sand deposits in the world, containing over 40 billion tons of oil, i.e. a quantity greater than the ultimate oil deposits of North America. They could provide Canada's needs at the present usage rate for 700 years and those of the U.S.A. for 60, if all the oil could be extracted, however, at present, only 3.6 billion tons are extractable.

The oil content of the sands ranges from 0 to 18% by weight and the depth from 0 to 600 meters. The oil can be separated by a hot water process, and one plant has been operating for a few years producing 2 million tons a year at a cost not much higher than oil from wells. This cost would be quite acceptable when no other sources of oil are available. However, 40% of the cost is due to the mining of the sand which at present is at the surface. Underground mining would raise the cost considerably. About 20% of the total sands can be removed from the surface. If a method could be found to recover the oil "in situ" the cost could be much reduced, as would the possibility of large scale pollution.

The tar sands are expected to provide 100 million tons of oil by 1990, mainly for export to the U.S. The problems that will have to be faced are enormous capital investment, possible shortage of water, pollution and, of course, adverse effects on the Canadian dollar and manufacturing industry.

(2) The Oil Shales

The oil shales of the world hold, in solid form, vast quantities of oil. The grade, or oil content, of these shales varies widely. The total quantities of oil available in various grades may be seen in the following table.

Grade, % weight oil	Oil available, billion metric tons
9 - 35	2,360
4 - 9	60,000
2 - 4	236,000

About 25 billion tons of this oil is considered recoverable under present conditions. Of these 25 billion, 11 billion are in the United States (Colorado, Utah). Brazil also has large deposits. Oil from shale is not similar to that from wells and cannot be processed in existing refineries. It is dirtier and has a bad odor. Its processing requires large quantities of water but success has been claimed for dry processes.

Recent pilot plant studies in the U.S. have shown that oil from shale may be produced at a cost of \$3.20 a barrel. Also, the distance to the markets is shorter, making shale oil cheaper than tar sand oil.

Whether the shales of the world become an important source of energy in the future will depend on whether other sources of energy become available. For some uses, such as motor vehicles, shale may provide an expensive and small quantity of fuel far into the future. However, the shales may become a large source of hydrocarbons for chemistry since a high cost of extraction can be tolerated in this case.

(3) Coal

By the addition of hydrogen to coal, it is possible to make both gas and crude oil. The technology of gas production is well advanced, although not yet on a commercial basis, and several processes are being tried. Processes for making crude oil from coal are still in their infancy. However, some cost estimates have been made for both cases. Gas can be produced for about \$1.25 per thousand cubic feet, delivered to the pipeline (compared with the present 15 to 25 cents from gas deposits). The estimate for petroleum is about \$5 per barrel. Both estimates assume the availability of cheap (\$1.25 per ton) coal. In *New Energy Technology*, H.C. Hottel gives an excellent survey of these processes.

These estimates suggest that coal may become a plentiful but expensive source of petroleum and gas for perhaps a century or two. However, there is a serious objection to these processes. They are very wasteful of energy - a large part of the energy of the coal is lost. One of the major problems in these processes is the supply of hydrogen which is derived from water using part of the energy of the coal. It is thus possible that conversion of coal to gas and oil will not be achieved on a large scale. Conversion of coal to electrical energy may be more efficient if the magnetohydrodynamic process succeeds. Electricity may then be used in place of gas and oil.

Depletion of the Fossil Fuels and Its Possible Effects

We have already seen that if the present growth in its rate of use continues, the ultimate world reserves of petroleum will be depleted by the year 2000. However, exponential growth cannot continue up to the end for various reasons, one of them being the difficulty of discovery and extraction as depletion is approached. King Hubbert has speculated that the actual depletion curve should be bell-shaped and nearly symmetrical about its maximum. This is illustrated in Figure 14. Using this concept, he predicted in 1958 that petroleum production in the United States would reach its maximum around 1968-1970. This turned out to be correct. For world production, Hubbert predicts that the maximum will be reached between 1990 and 2000, depending on the actual ultimate reserves. For coal the date will be between 2100 and 2150. There are two important factors that could distort the curve in opposite directions. On the one hand the high pressure of demand and improving technology could keep production growing until depletion is approached. The decline from there would be rapid. On the other hand deliberate efforts at conservation could arrest growth and stretch out the curve so that it descends slowly. In the case of petroleum the odds are against conservation. Most of the petroleum is in the Middle East and the possessing countries do not have the military power to enforce conservation, if they decided to do so. On the user side there are three competing independent blocks: Western Europe, Japan and the U.S.A. Only an agreement between the three could ensure conservation, and this is not likely, since conservation could create serious economic problems in the short run (depletion will create even more serious problems but in the

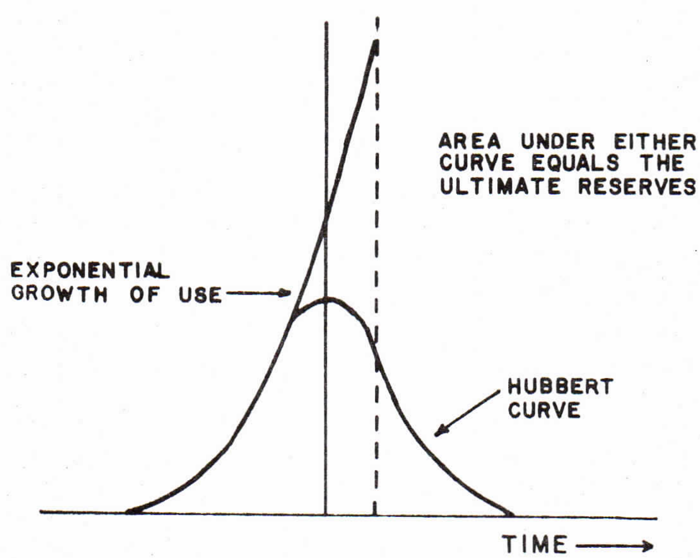


FIGURE 14 DEPLETION CYCLE FOR A RESOURCE. (After M. King Hubbert in *Resources and Man*.)

more distant future). Thus petroleum has the characteristics of common property and it is in the interest of each one concerned to grab as much as he can. This will ensure its early depletion. However the picture could change if one of the blocks were to acquire control of it.

Natural gas may follow the same course as petroleum. Coal, however, has a better chance. It is possessed by the user countries and in their self-interest they may exercise conservation. Its much larger reserves will also provide more time to plan conservation or to find alternate sources of power.

What are the reasons for the need to conserve the fuels?

The needs of chemistry, currently at 50 million tons per year, will grow to a much larger level in the future. In the form of fibres and plastics, the fuels are much more valuable than as a source of energy for non-essential uses.

The fossil fuels (especially petroleum and gas) can be converted to food and they could be used for this purpose in the event of great or consecutive crop failures.

Fossil fuels also provide an immediately available and usable energy reserve to meet disaster situations. This might prove of critical consequence if a nuclear war or other similar disaster occurred. Mankind, deprived of these readily available energy sources, might never be able to gradually recover, much less to jump to the state in which complex methods can once again be employed.

What would be the consequences of the depletion of fossil fuels, especially petroleum? It should also be remembered that other important materials, such as metals, will face depletion at about the same time. It is clear that our high material standard of living, typical of today, cannot be maintained. Automobiles especially will have to be reduced in numbers or eliminated altogether. Mass transporation, perhaps using electricity, will become a necessity. There will be no need for all the existing highways and expressways. Intercity travel will be by trains or their equivalent. The great spread of suburbs may have to be stopped since they cannot be served easily by mass transport. Air travel by contemporary airplanes will probably decline since its fuel costs are very high (it takes about the same fuel for one person to cover a distance by air or alone by automobile). Since these changes may be only a generation away, planning for the transition should begin now. The new type of life will not necessarily be uninteresting. The great spread of education and culture that is now taking place will make it possible to widen the interests and the opportunities of the individual. After all, automobiles today serve mainly as fillers of time. The book may serve the purpose equally well and perhaps better. Our cities can become great cultural centers instead of the enormous parking lots that they are today. Our modern technology will still make it possible to obtain our necessities by working for only a small fraction of our time. What can be done with the rest of it is only limited by our imagination. Making an intellectual out of everyone may not only be necessary but also possible.

HYDRO POWER

The total hydro power potential of the world that can be developed economically is about 3,000 million kilowatts. At higher cost this potential could be increased by 50%. These quantities are comparable to the total amount of power from all sources that is used in the world today.

The world distribution of hydro power is shown in Figure 15. South America, Africa and Southeast Asia together have over two-thirds of the total. This they owe to their heavy tropical rainfall and their elevated land. There seems to be justice in this distribution since the tropical

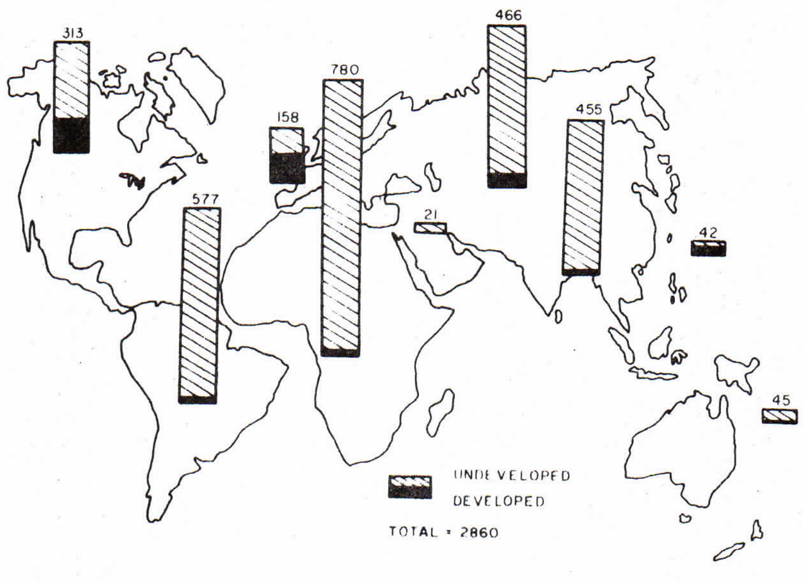


FIGURE 15 WORLD HYDRO POWER (in million kilowatts)

regions have only negligible quantities of fossil fuels. Most of Africa's hydro potential is to be found in the center of the continent. A single site at the mouth of the Congo River could provide 200 million kilowatts, enough to supply the needs of Western Europe. In Asia most of the potential is in the rivers that descend from Tibet into China, Indochina and India. In the U.S.S.R. it is Eastern Siberia that has the largest fraction, while the Alps and Scandinavia have most of Europe's. In North America most of the power is in the western mountains, while in South America it is uniformly distributed.

The developed hydro power potential of the world is about 300 million kilowatts, or 10% of the total, with 80% of this in North America, Europe and the U.S.S.R. In Canada, of the 43 million kilowatts of installed electric capacity in 1970, 28 million was hydroelectric. Non-hydro power is used mainly in Ontario and in the Prairies. Among the industrial countries only Switzerland and Scandinavia, in addition to Canada, derive most of their power from water. The total economic potential in Canada exceeds 100 million kilowatts. Quebec and British Columbia have 30 million kilowatts each of undeveloped power.

In the U.S.A. and Europe the best sites have already been utilized, while in the U.S.S.R. the rivers of Eastern Siberia are now being dammed. In the underdeveloped world, hydro is the main source of electric power. Power projects there are invariably connected with irrigation projects, except for the (numerous) plants that serve mining operations.

Hydro power is a highly desirable form of energy because it is clean and it consumes no fuel. Nearly the entire cost is in the initial installation, and maintenance is minimal. The low electricity prices that Canada enjoys are due to this fact. In addition it has a very desirable characteristic: it can respond quickly to load demands and can provide peak load at the relatively small additional cost of a few generators. It is much more expensive to provide peak load with thermal plants. Because of this, hydro plants are a desirable addition to the power networks of the industrialized countries. Pumped storage plants serve the same purpose.

Full development of the hydro potential of the planet would provide ample clean power for the world and would help conserve the fossil fuels which are very valuable as raw materials for chemistry. To the objections that may be raised against hydroelectric projects for their adverse environmental effects, the response is that unless power from other sources such as nuclear fusion, the sun or the winds becomes a reality soon, the alternatives to hydro power are even more objectionable.

The main obstacle that prevents this development is the long distance between sources and markets. For the most economical transmission of large blocks of power, the optimum voltage is about 1000 volts per mile. Thus to transmit across 1000 miles, a million volts are needed. Lines approaching this figure exist now in Quebec, Sweden and the U.S.S.R. Higher A.C. voltages are under test but the limit seems to have been approached. Direct current (D.C.) lines may reach higher, possibly 2.5 million volts. At present 1000 kilovolt lines can transmit electricity at a cost of about one cent per 60 kilowatt-hours per 100 miles, for long lines. The distance from the power sources of central Africa to Europe and from South America to the U.S. is about 6,000 miles. Thus to transmit electricity over this distance it would cost one cent per kilowatt-hour which is equal to the present cost of its production from thermal plants. For the user the cost would go from 2 to 3 cents per kilowatt-hour. Thus even at the present time it is possible to bring tropical electricity to the industrial countries. In Southeast Asia where distances to India and China are much shorter, transmission would not raise the cost very much. However, superconductors would provide a much better solution.

Superconductors

When cooled to near absolute zero, most metals and many alloys suddenly lose all their electrical resistance and become perfect conductors. Power can then be transmitted through such conductors at relatively low voltage over unlimited distances without loss. The highest temperature at which superconductivity has been achieved is 20 °K. At present, superconductors can only function when immersed in liquid helium. Even with this disadvantage, transmission of large blocks of power (over 5 million kilowatts) by superconducting lines is believed to be economical. Pumping and cooling stations for the helium would be needed at regular intervals along these lines. Such lines have been proposed to bring power from distant plants to large cities so that both overhead lines and power plants, with their pollution, may be eliminated from the vicinity of the cities. Present types of superconductors could be used for very long-distance transmission, e.g. from South America to the U.S. However, such lines have not been tested yet, and in addition to technical problems there may be others. A 20 million kilowatt line running through thousands of miles of countryside may have a high probability of failure and may also be an easy and attractive target for sabotage. Superconductors at room temperature would solve these problems, since expensive refrigeration would not be needed then and many parallel lines of lower capacity could be built to divide the load and thus reduce the probability of total failure and of effective sabotage. The search to find such superconductors is continuing, but for many years it has not been possible to push the maximum superconducting temperature above 20 °K. However, the possibilities have not been exhausted since this is a new field and much work remains to be done.

OTHER SOURCES OF ENERGY

(1) Geothermal Power

About one million kilowatts are presently obtained from this source in New Zealand, Italy, Mexico and elsewhere. It is a minor source.

(2) Tidal Power

A plant of 240,000 kilowatts capacity has been built in France, and some smaller plants in the U.S.S.R. The total potential is of the order of 50 million kilowatts. This is also a minor source.

(3) The Winds

Windmills are used for lifting water and to produce small amounts of electricity in isolated places. This is a very small source at present but will be important in the future.

(4) Animal Power

In the third world animals are used for transportation and for tilling the land. Although it is a minor source of energy, it affects large numbers of people and is used in essential tasks. For example, in India 70% of all transport is by oxen. Hence it is important. However, overpopulation leaves no room for animals and this source is being increasingly reduced.

SOME NEW CONVERTERS OF ENERGY

Magnetohydrodynamic (MHD) Power

The flames of combustion of fuels are at a temperature of over 1500 °C. In ordinary power plants steam is heated, at best, to 550 °C. A large drop in temperature and a decrease in possible efficiency is the result. In a magnetohydrodynamic generator, the combustion gases are first ionized by seeding with cesium or potassium, and then passed through a duct in which a transverse magnetic field is maintained. The positive and negative ions in the gas separate and are collected by properly placed electrodes providing external current and power. About 20% of the energy of the gases may be extracted this way. The gases are then taken to conventional equipment where additional energy is extracted. The overall efficiency could thus be 60% or higher, as compared with 40%, at best, for conventional equipment, i.e. a 50% increase. The importance of this for fuel conservation is obvious, considering that at present nearly 2 billion tons of coal equivalent are used in the world every year in the generation of electricity, and the amount doubles every 10 years. The amount of waste heat per unit of useful energy would also be reduced from 1.5 to .67 units. Pollution from MHD plants will be low or even negligible.

MHD power generation is now moving from the experimental to the operational stage. A 75,000 kilowatt plant is in operation in the U.S.S.R., while a large plant of 1.5 million kilowatts capacity and 60% design efficiency is to be built there soon. If this large plant proves successful technically and economically, conversion of existing plants to include an MHD stage may be expected to follow.

The amount of work being done at present on MHD power is of the order of $100 million per year, nearly all of it in the U.S.S.R.

Hydrogen

Hydrogen is often called the fuel of the future. When petroleum fuels become depleted, hydrogen is expected to take their place. Hydrogen can be produced by the electrolysis of water, provided electricity is available from other sources (hydro, wind, nuclear, etc.).

Hydrogen has two big advantages as a fuel. Among the chemical fuels it has the highest energy content per unit weight (61,000 B.T.U. per pound or 3 times that of gasoline). This property has made it attractive as a rocket fuel. It is also non-polluting, since the only product of its combustion is water. But it also has a big disadvantage: its boiling point is 20 °K. Thus in order to keep it in the dense liquid form, expensive refrigeration equipment must be used. This renders its transportation and storage difficult.

Hydrogen has been proposed as a possible substitute fuel for gasoline in automobiles. However the cryogenic container necessary to keep it in liuqid form would be heavy and expensive and the hazard from accidents too high. Some promise may lie in the ability of certain metals to absorb hydrogen and release it upon heating. At present the best that can be achieved is 2% hydrogen by weight of the metal. This is not sufficient since the storage of the equivalent of 10 gallons of gasoline would require 1500 pounds of metal. However some improvement in this can be expected.

Fuel Cells

These convert the chemical energy of fuels directly into electricity by chemical processes that are roughly the opposite of electrolysis. Their operation is free of noxious emissions and in theory their efficiency could be very high. In practice, however, they have not been successful.

The main problem in this failure is the slow movement of the reactants and reaction products, particularly their slow diffusion, at the electrodes. Fuel cells are expensive and they are used only where cost is a secondary consideration, e.g. in the Apollo moon project for which cells of a power of 3 kilowatts were developed at a reported cost of $100 million. Efficient and cheap central station power was believed possible but it is no longer considered so. Plans for such a station in Great Britain have been abandoned. It seems now that fuel cells will be useful only in small specialized applications where other sources of power are impractical.

Superconducting Generators

At present the maximum size of generators is limited by transportation and by problems of overheating, mainly as a result of power dissipation in the winding circuits. The use of superconductors of zero electrical resistance can greatly increase current densities and give high power outputs with relatively small machines. The upper limit in generator output can thus be raised considerably. Some experimental machines have already been operated successfully.

The Electric Automobile

As an alternative to the present type of automobile, the electrically powered car is desirable for two main reasons: to provide independent personal transportation when cheap petroleum is no longer available; to replace the present type of car as soon as possible within cities so as to reduce pollution. Early introduction of the electrically powered automobile would help prolong the lifetime of petroleum since the electricity for charging the batteries would be derived from a source other than petroleum.

For long-distance travel the electric car should satisfy two requirements: it should be capable of covering a reasonably long distance between battery changes and it should travel that distance at sufficiently high speed. The first requirement corresponds to a high energy density (energy per unit weight of the source) and the second to high power density.

Figure 16 shows some of the various types of batteries that might be used and their characteristics. Distance and speed lines at steady driving have been drawn in for an automobile weighing 2000 pounds with a 500-pound load of batteries. Only one type of battery (sodium-sulfur developed by Ford Motor Co.) could allow the covering of 200 miles at 60 miles per hour. The energy expended would be 65 kilowatt-hours and would cost 65 cents at one cent per kilowatt-hour. This is clearly a bargain. The battery cost is between $20 and $40 per kilowatt-hour. Steady engine power would be 23 horsepower and maximum power 75 horsepower. The lithium-chlorine battery (General Motors) would be even better except for its high temperature and the fact that lithium is a scarce metal. Both batteries are experimental and not proven yet. Other types not shown in the diagram are also being investigated, and it should become clear in the next decade whether the electric car may become a reality. For urban movement the requirements in both energy and power density may be relaxed so that the probability of success is better. An additional requirement is of course that the battery metals must be plentiful; this excludes from large scale utilization most of the types shown in Figure 16.

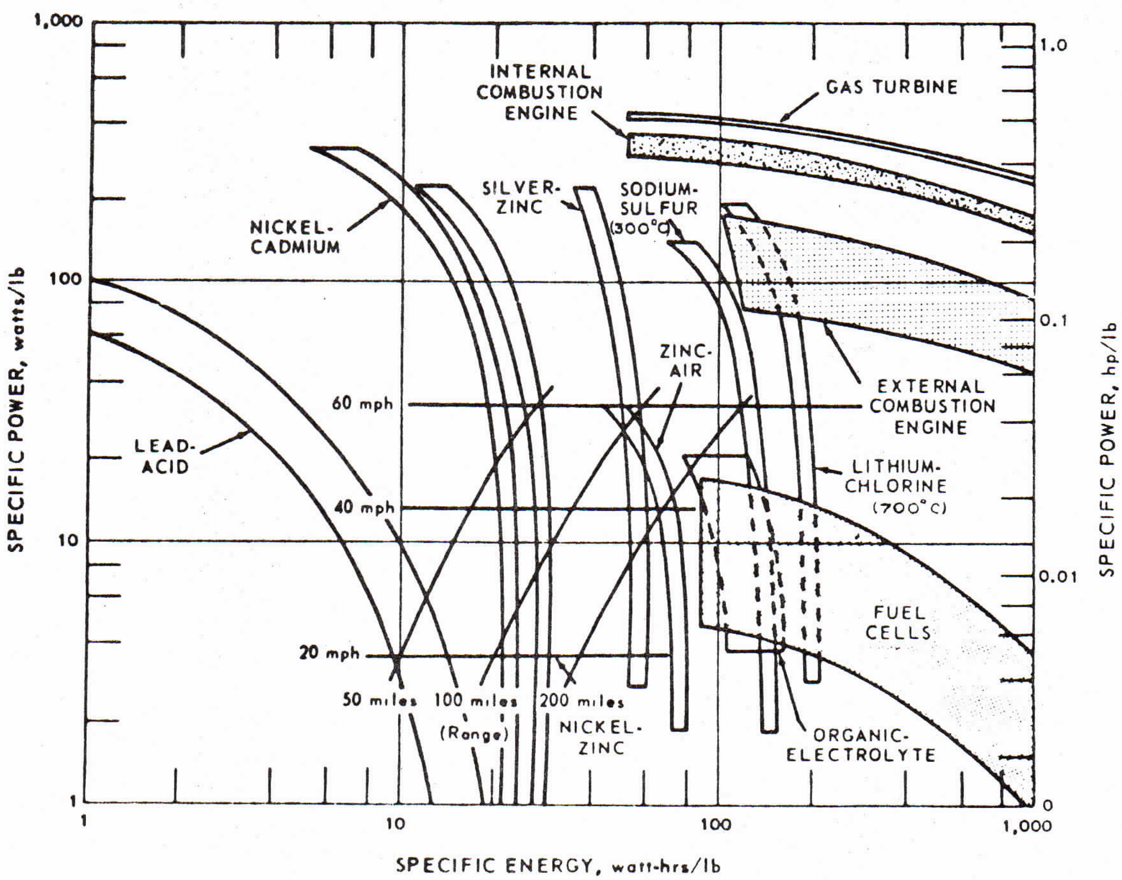


FIGURE 16 VEHICLE REQUIREMENTS AND MOTIVE POWER SOURCE REQUIREMENTS. ASSUMES 2,000-POUND VEHICLE, 500-POUND MOTIVE POWER SOURCE AND STEADY DRIVING. (Source: *Control Techniques for Carbon Monoxide, Nitrogen Oxide, and Hydrocarbon Emissions from Mobile Sources*, NAPCA Publ. No. AP-66, U.S. Dept. of Health and Welfare, National Air Pollution Control Administration, Washington D.C., 1970.)

THE PRESENT UNITED STATES ENERGY PREDICAMENT

The demand for energy in the United States is increasing rapidly. Local sources, including Alaska, of petroleum and gas are very limited and could be depleted in another 15 years or sooner if they were to supply all needs. Actually, the gap between demand and local supply has now begun to widen rapidly. Building of nuclear plants is being delayed or blocked for reasons of safety. Coal mining cannot be increased fast enough to meet the larger part of the energy needs, and coal is considered a dirty fuel anyway. Thus foreign sources must be found.

Canada is one of these sources. Under the "Continental Energy Plan" Canadian energy would become freely available to the U.S. But total known Canadian reserves of oil and gas could not meet total U.S. needs for more than 2 years. Another source is the U.S.S.R. and the U.S. is now (1972) seeking to buy 1400 cubic kilometers of gas from there at a reported price of $50 billion. Other sources such as Latin America, the Far East and Africa can only supply small amounts. By far the biggest and, in fact, the only adequate source is the Middle East; a large part of U.S. needs is expected to be supplied from there. But Western Europe and Japan also need increased quantities of Middle East oil. On the other hand, most of the countries possessing the oil want to conserve it by keeping the extraction rate low and raising the price instead. The situation is thus tense, and sharp conflicts may develop in the near future.

The best solution to the U.S. energy problem might be a stop in further growth and even a decrease in the rate of use of energy. The U.S. is already using energy at a per capita rate that is 3 times the West European level. The quality of life in the U.S. may not be higher than in Europe and it may even be lower; this could be partly due to the higher consumption of energy which creates pollution and contributes to urban sprawl and the destruction of cities by the automobile. Thus a reduction in energy use in the U.S. may not only be necessary but also beneficial. But this is considered a backward step and the public is not yet ready to accept it. It is moving in that direction though and in a few years it may be ready to do so.

CANADA'S ENERGY RESOURCES

On a per capita basis, Canada is perhaps the most richly endowed country in terms of energy resources. It possesses all the types of energy sources, both renewable and non-renewable. This good fortune is due to the large size of the country and to its small population. There are various small countries which are rich in one type of energy source, e.g. Saudi Arabia in petroleum and the Congo in hydro power, but no other country with the possible exception of the U.S.S.R., is so rich in a variety of sources.

The known and the additional probable resources for both non-renewable and continuous sources are listed in Table 7. All types of energy are converted to coal equivalent. Canada's present consumption is about 200 million metric tons of coal equivalent per year.

The known reserves of the fossil fuels are well documented. In the case of uranium, both the measured and estimated reserves up to a price of $15 per pound of U_3O_8 are included. The figures for the additional probable reserves for coal, petroleum and gas are often quoted in the literature. For uranium the figure is a guess, up to a price of $40 per pound of U_3O_8.

Even without additional discoveries and excluding uranium there are enough fuels to last many centuries at the present rate of use. The coal of Canada is mainly in Alberta. Transportation to Ontario by integral train to the Lakehead and by boat from there to Lake Ontario would add $7 per ton to its costs of extraction and would only raise the present cost of electricity in Ontario by about 25%. Tar sand oil would be more expensive than oil from present sources but not unacceptably more.

The continuous sources include mainly hydro power and wood. At present it is not yet clear whether the 30 million kilowatts of tidal power in the Bay of Fundy can be developed at acceptable cost. Wind power, a future possibility, is available to all and not unique to Canada. Solar power, even if it becomes reality in the future, may not become practical in Canada because of the northern latitude, but it may be used partly for space heating.

The presently economical hydro power sites could provide all of Canada's energy at the present level. At higher energy prices, additional sites will become economical. All hydro power in Canada can be brought to populated areas with present transmission technology. The hydro potential of north Quebec and Labrador (40 million kilowatts) is 50% larger than the presently installed capacity of Eastern Canada, including Ontario, and it

TABLE 7: THE ENERGY RESOURCES OF CANADA

(a) Non-Renewable[1] (in billion metric tons of coal equivalent). "Duration of supply" assumes present rate of use, i.e. 200 million tons coal/year

Fuel	Present		Future	
	Known Reserves	Duration of Supply, years	Possible Future discoveries	Duration of Supply, years
Coal	118	590	?	-
Oil	1.4	7	7	35
Natural Gas	2.2	11	7	35
Tar Sands	7	35	-	-
Uranium	10	50	30(?)	150
Totals	136	682	44	220

Grand Total = 180 x 10^9 tons or 900 years (excluding uranium, 700 years)

(b) Renewable (in million metic tons of coal equivalent per year).

Source	Present		Future	
	Present Supply	Fraction of total present energy needs	Additional possible	Fraction of total present energy needs
Hydro	200 (120×10^6 kw)	1.0	140 (80×10^6 kw)	0.7
Wood	200	1.0	200(?)	1.0
Totals	400	2.0	340	1.7

Grand Total = 3.7 times present needs.

could provide the power needs of this part of the country into the foreseeable future. The West has many times more potential hydro power than it presently uses.

The energy needs of Canada could also be provided by wood at a level perhaps exceeding the present rate of use. Of the 2 to 3 billion tons of carbon that is fixed by photosynthesis in Canada every year, 10% or more might be utilizable, especially with optimized growth and cutting of trees.

1 Source: Energy Policy for Canada, Vol. 1, Chapter 4, 1973.

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