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Energy: Facts and Future

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He is listed in *World's Who is Who in Science, American Men of Science, Who is Who in the West, Leaders in American Science, Who is Who in California, A Century of Honors,* IEEE; *Dictionary of International Biography,* and others. He consults in the fields of III-V-compound technology, solar cells, epitaxy, device technologies, and electrooptics.

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Chapter 1

INTRODUCTION

The word "energy" has become a synonym for all sources of power in the realm of human activity. With the advent of the Industrial Age the dependency of all human activities on energy sources has become all apparent. Especially since the shift from wood and coal burning to oil as the main energy carrier after World War II, the future of mankind became more and more connected to the problems of energy supply. In fact, no industrialization can occur without increased use of energy sources. The exponential rise in the number of people on this globe is intimately connected to the energy available, the resulting industrialization, and increased food supply due to the use of artificial fertilizer, an energy-rich compound.

Britain, for example, as the early example of an industrialized nation, started its rapid growth from the year 1700, the actual beginning of its industrialization by the use of coal in steam engines. (James Watt, 1736—1819, the Englishman credited with the invention of the steam engine.) Figure 1 shows the population development of Britain over the years. There is clearly a saturation of the birth rate as in most industrialized nations in the Northern Hemisphere. This is due to enhanced education, a function of industrialization, and the influence of literacy on lifestyle.

It is a fallacy to attribute this saturation of the exponential growth curve to the industrialization as such. Industrialization, forced upon a country from the outside without actual participation of an active population, does not automatically bring about an educated control of procreation. On the contrary, such rapid projection into the modern world where medicine and industrial knowhow combined with high energy dependence are implanted on an illiterate population, results in a catastrophic situation of environmental imbalance and total dependence on outside support. Much of the present predicament of developing countries has been generated by the rapid imposition of outside industrial techniques with their dependency on outside energy sources.

Even in underdeveloped countries with oil resources, the imbalance of population growth and industrial capacity has created situations far less desirable for these populations than those prevalent during colonial times. As the main energy source, oil, became more expensive, the growth of industrial capacity was decisively reduced. This increased more and more the imbalance between population growth and industrial growth.

Even in developed countries in North America and Europe, a main factor for the sudden and continuous growth of the army of unemployed and "unemployables" is the increase in the price tag for energy. The creation of the cartel of oil-producing and -exporting countries (OPEC) and its policy after 1972, has awakened all energy users to the fact that our usual energy sources are not limitless and that mankind can be faced with its greatest crisis when nonrenewable sources dry up.

This review is supposed to supply to the reader the necessary facts to judge where we stand today and what has to be done to save humanity from a catastrophic energy shortage.

It is a sad fact that nuclear energy has had its greatest contribution in the build-up of explosive forces, ready for a total annihilation of all global civilization.*[1]

While nuclear fission can supply a significant portion of the needed electrical and thermal

* In a 10,000 Mton nuclear rocket exchange, the total energy released corresponds roughly to 1000 times humanity's energy use per year. With 1221 kcal/kg of heat generated by the TNT equivalent, or 1.22×10^6 cal/kg, or 1.22×10^{19} cal/Mton, or 1.4×10^{16} Wh/Mton, an exchange of 10,000 Mton is equivalent to 10^{20} Wh or $10^{20}/3 \times 10^{14}$ Q $= 3.3 \times 10^5$ Q or 10^3 times humanity's energy use per year.[1]

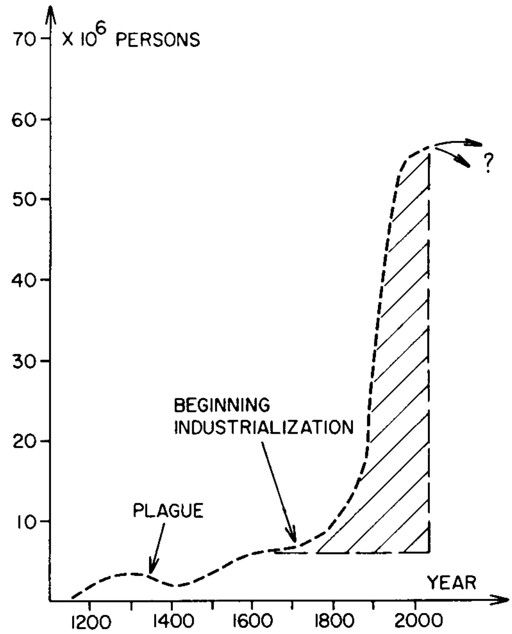

FIGURE 1. Saturation of an industrial population (England).

energy, nuclear fusion, thought to be the long-term remedy, has not yet shown the necessary progress in many years of research and expenditures of billions of dollars.

In looking at the alternate solutions available to man on Earth, especially direct sun energy conversion, some conclusions are drawn with respect to renewable sources, mainly direct photovoltaic conversion as a way out of the impasse if large-size plans for all mankind can be realized.

REFERENCE

1. Nuclear winter: global consequences of multiple nuclear explosions, *Science*, 222(4670), 1283, 1983; Long term biological consequences of nuclear war, 222(4670), 1293, 1983.

Chapter 2

ENERGY AND HUMAN DEVELOPMENT

The use of fire by early hominids, some 500,000 years back during the Pleistocene age, was an important step in the development of man. The gradual transformation of human gatherers and hunters into groups of steady agrarians was the first reason for extensive human multiplication and survival.

With the advent of a controlled growth of corn and grain and its storage, the energy of the sun was effectively used and stored for human subsistence.

Agriculture as a human activity became the platform on which all other human progress was based. The continuously developed skill in managing food production led to a decrease in the number of those working in the fields and enabled the formation of other human activities with a continuous subdivision into occupational groups. In this process, time and effort spent in the fields of technology and medicine improved the survival rate of children and increased the average life span continuously. The dramatic increase in the number of all living humans can be expressed by an exponential function with a growth coefficient, p (e.g., number of births in percent of population). As this number is now on the average in the 3 to 4% range, the time span to add 1 billion to the Earth's population decreases steadily (Figure 1). As a consequence, the doubling time for all humanity decreases and is about to reach the 20-year level (Figure 2).

In looking at the differences caused by different birth rates, one can see the enormous influence of the growth factor (Figure 3). A birth rate of 3% and more of population is prevalent in those countries where technical and educational levels are lowest, leading to a doubling time (D.T.) of 20 years. In China, the D.T. is on the increase due to reasonable birth control measures. The developed countries have relatively long D.T.s such as 90 years for the U.S. There are now countries in the Northern Hemisphere where the population is actually decreasing (W. Germany, Sweden, Great Britain).

Energy consumption is highest in the developed countries. It can actually be correlated to the birth rate figure. There are, of course, wide differences between the developed countries with respect to energy utilization. Figure 4 shows the energy figure in 10^9 MWh per annum (a) (1975) for some countries as a function of their population. On another ordinate we have plotted this figure divided by the population number (energy use per capita).

We see that the actual energy use is proportional to the number of inhabitants for countries like France, Great Britain, W. Germany (FRG), Japan, and the U.S.S.R. The U.S. ranges higher by a factor of 2. For the per capita use, France, Great Britain, W. Germany, and the U.S. are correlated. The per capita energy use is decisively lower in countries like Japan and the U.S.S.R.

The enormous deficit of countries like India and China can be evaluated when considering the need for energy for populations nearing the 1 billion mark.

The picture is different again if we plot the efficiency of energy utilization or the gross national product (GNP) per capita in dollars, divided by the energy use per capita vs. the number of people. In this form the plot shows that countries like Brazil, France, W. Germany, Japan, and Italy, e.g., are using their energy more efficiently than countries like Canada, Great Britain, U.S., and India. Very low on this scale is the U.S.S.R. which shows the lowest efficiency in using the energy (Figure 5).

The enormous backlog in the energy domain is visible when one plots the relative increase of the underdeveloped countries in the world population over the years (Figure 6).

When Great Britain was in the midst of its industrial upswing (1830), the world population was dominated by those countries which we now classify as developed (one half of the

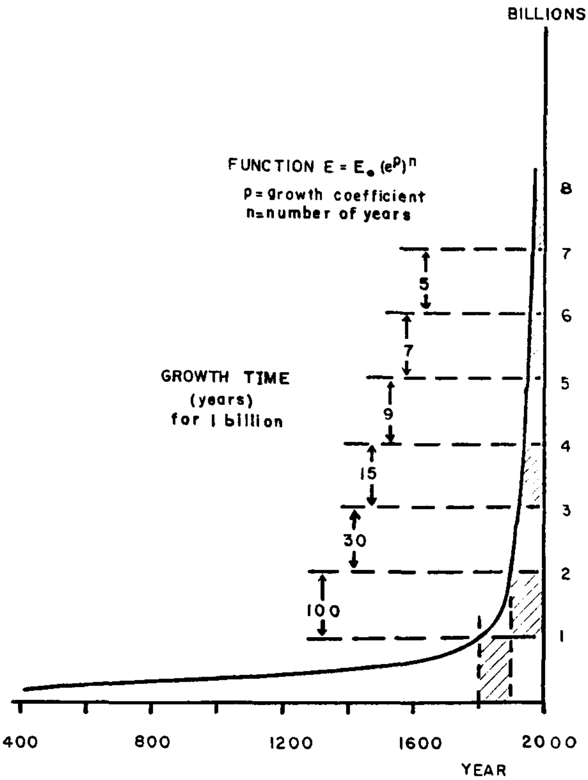

FIGURE 1. World population growth. Growth time (years) for 1 billion. Function $E = E_0 (e^p)^n$ where E_0 = starting value of the population, p = growth coefficient, and n = number of years.

world population). Over the years, the birth rate imbalance has swelled the underdeveloped world which soon will represent over 80% of all humans on this globe. We can infer from this figure how high the energy backlog for the underdeveloped world will be if they aspire to some comparable energy use.

The dramatic improvement in public health in the last century was achieved by utilization of the progress made in developed countries in the fields of bacteriology, medicine, applied science, and technology. The main points are the supply of pathogen-free water, plumbing, less crowded households, and improved (balanced) nutrition. All of these steps required energy in one form or another. Water has to be pumped into reservoirs or towers for distribution. Agribusiness requires fertilizer, a high energy product. Its distribution system is based on energy. Irrigation, tractors, railroads, etc. require electricity, oil, or coal. Increased productivity on the farms has resulted in a huge surplus of workers who then were partially absorbed by the growing industries. For example, when the U.S. population was 100 million, farm labor force was about 14 million people. When the U.S. population had doubled, the farm labor force had declined to 4 million, i.e., a relative increase in efficiency by a factor of 7 had occurred.[1]

This increased productivity with less workers was a direct consequence of technology and energy utilization. Man and animals were replaced by tractors and other machines using oil as a main energy source. Similarly, industrial activities, road construction, house building, etc. became more and more dependent on machinery causing a steady increase in oil consumption.

The increased consumption of electricity in industry and private life has practically been

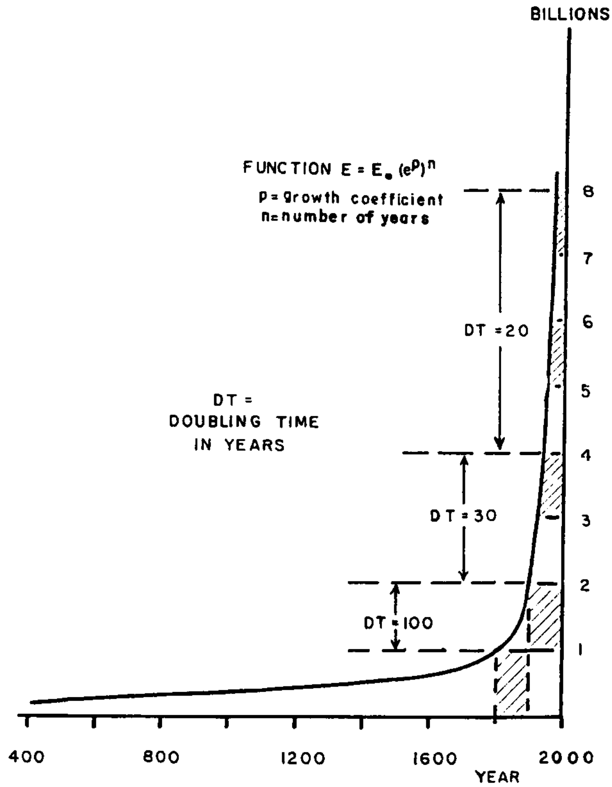

FIGURE 2. World population growth. Doubling time (years). Function $E = E_0 (e^p)^n$ where p = growth coefficient and n = number of years.

covered by the use of fission energy. As the number of atomic power plants increased, problems of refuse disposal and plant security became predominant, increasing the price tag for nuclear power much beyond the originally very favorable level. This increase and the 1978 consolidated costs of gasoline (oil glut) have retarded the development of alternate energy sources.

The enormous increase of the price for oil products after 1970 (~500% between 1970 and 1980) by OPEC has, however, had its mark on all planning. In developed countries, the increase in unemployment has one of its major roots here while in underdeveloped countries, loans cannot be paid back which had been taken under the assumption of a continued upswing in world trade. One has to consider that oil (or gasoline) is by far the energy carrier of highest density. Even compared to liquid (L) hydrogen, the average energy density of liquid fuel is three times higher: $E (H_2)_L = 3$ kWh/ℓ; $E (Fuel_L) = 8$ to 10 kWh/ℓ, depending on fuel (oil) grade.

The importance of easily available energy can hardly be overestimated for all human activities and survival. It has been shown at numerous occasions in the past that the finite character of all earthly riches sets limits to human industrial growth. While the awesome predictions of the "Club of Rome"[2] have been rejected as exaggerated, recent studies of the question of world population growth in connection with raw materials plus energy supply point in the same direction. For example, the relative energy, oil, copper, and cotton consumption of the U.S. vs. the world, shows a sharp decline since the 1950s. This is solely due to the sharp increase of the global consumption as compared to the U.S. (Figure 7).

Some authors try to prove that there has been an over pessimistic evaluation of our

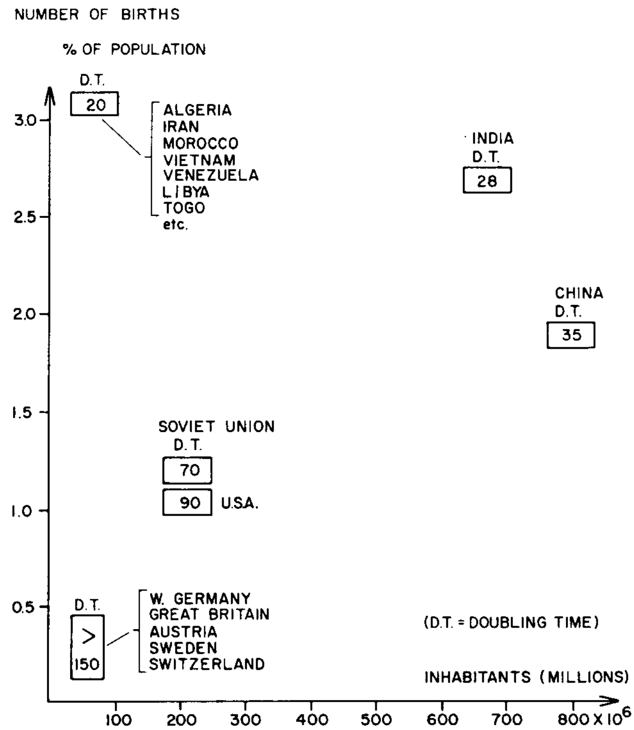

FIGURE 3. Birth rate and doubling time (D.T., years) vs. population.

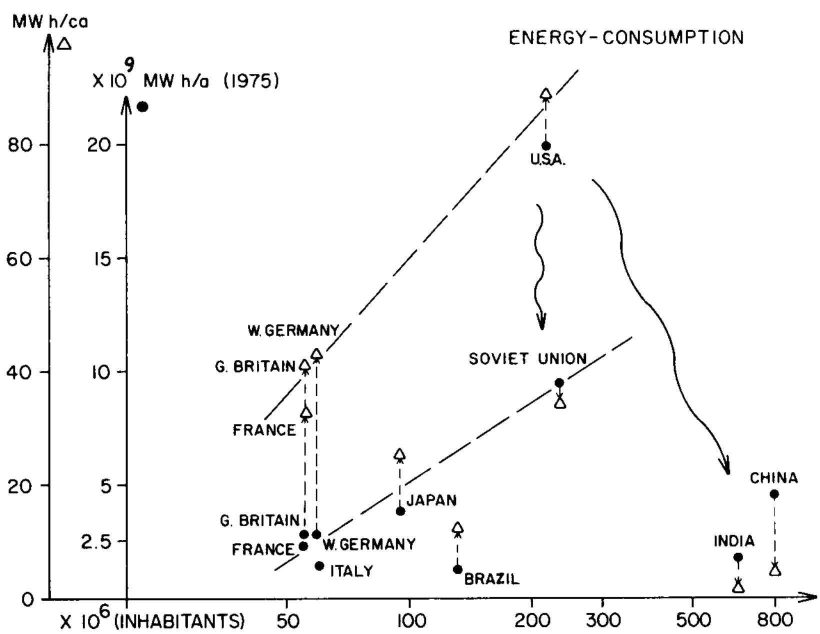

FIGURE 4. Energy utilization expressed in megawatthours per capita and megawatthours per annum (1975).

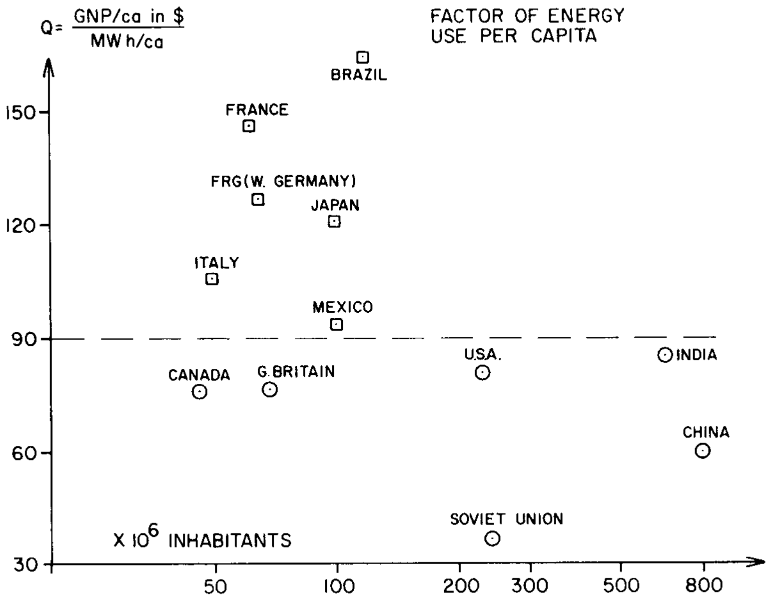

FIGURE 5. Factor of energy use per capita expressed as ratio: Q = GNP/ca (capita annum) in $ per MWh/ca.

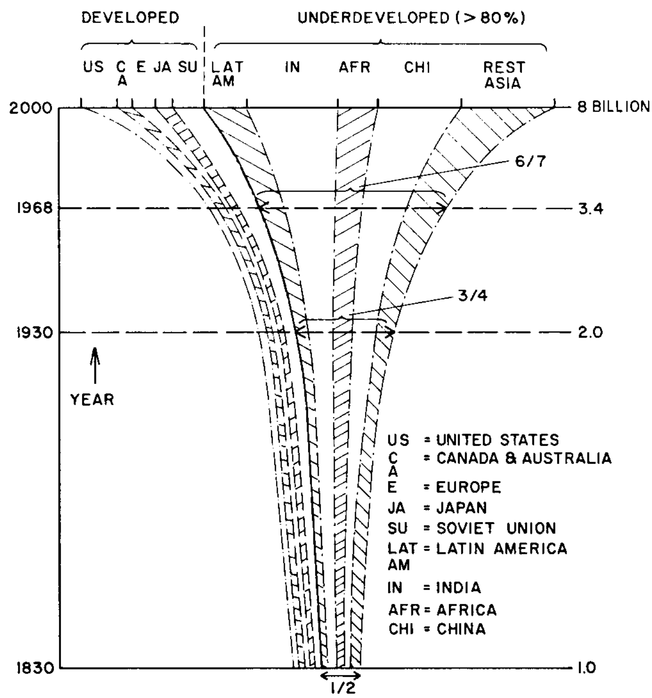

FIGURE 6. Relative increase of the underdeveloped countries in the world population.

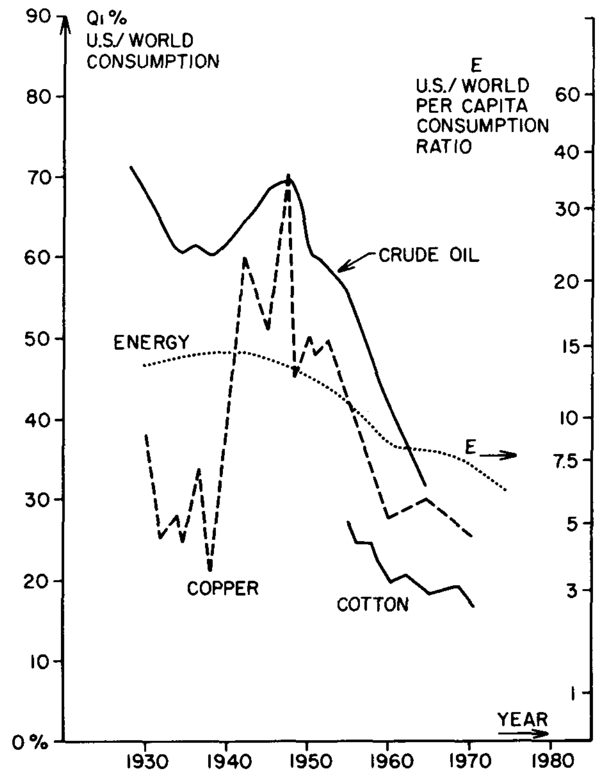

FIGURE 7. U.S. consumption of crude oil energy, copper, and cotton in relation to the world consumption (%) (scale Q_1). U.S./ world per capita consumption (scale Q_2).

predicament and that all is well because the per capita food production has increased from 1950 to 1976.[3] Simon[3] states that in spite of the exponential population growth, more food will be available per capita and there will not be a scarcity of raw material. He forgets energy. His opinion is based on data which show a transitional increase in food per capita. In plotting the per capita food production (Figure 8), it appears that there is a steady increase in spite of the enormous population growth. (Food production increased by 30% while whole population doubled.) A simple extrapolation of this trend of food increase would however, omit a number of decisive other facts. The increase in yield, realized since the 1950s (Figure 9) leading to a decreased area per capita ratio, is due to agricultural production practices that are leading to excessive rates of soil erosion.[4] Since the 1950s, most increases in food output have come from raising yields on existing cropland through the use of energy-intensive chemical fertilizers and irrigation. In fact, U.S. consumption of nitrogen, potassium, and phosphorus fertilizers drastically increased in this period (Figure 10).

Another reason for the per capita food production growth during this period is the fact that the gap between food production and food consumption became more positive in the developed countries, while this gap became more negative in the developing countries. For 16% of world population this gap grew to $+152 \times 10^6$ metric tons while it grew to -47% for about 50% of the world population.[5]

Thus, there is a compensating effect at work here as long as food export to the underdeveloped countries can be sustained. This food export is largely also an export of energy, as we have noticed (fertilizer production is largely a process of energy conversion). As Barr noted,[5] the cost of productivity gains in the next decade is likely to continue to increase,

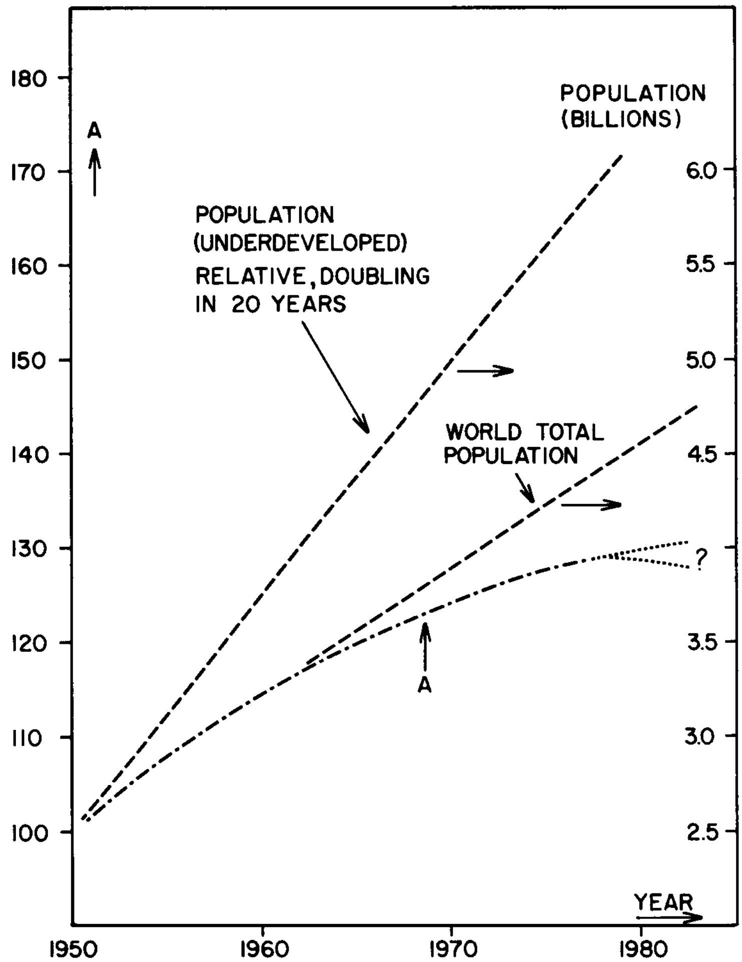

FIGURE 8. Saturation of per capita food production: curve A (in kg) and relative population increase in the underdeveloped world (1948/52 = 100) (left scale). Increase in total world population (right scale).

with prices of energy-based inputs — including fertilizer, pesticides, and fuels — unlikely to remain stable for any extended period.

Looking at the changing pattern of world grain trade, we notice that only North America, Australia, and New Zealand remain positive with respect to export.

Pattern of world grain trade: export, in 10^6 metric tons, positive; import, negative.[4]

Region	1934—1938	1948—1952	1960	1970	1980
North America	+5	+23	+39	+56	+131
Australia, New Zealand	+3	+3	+6	+12	+19
Latin America	+9	+1	0	+4	−10
Western Europe	−24	−22	−25	−30	−16
Eastern Europe, U.S.S.R.	+5	0	0	0	−46
Africa	+1	0	−2	−5	−15
Asia	+2	−6	−17	−37	−63

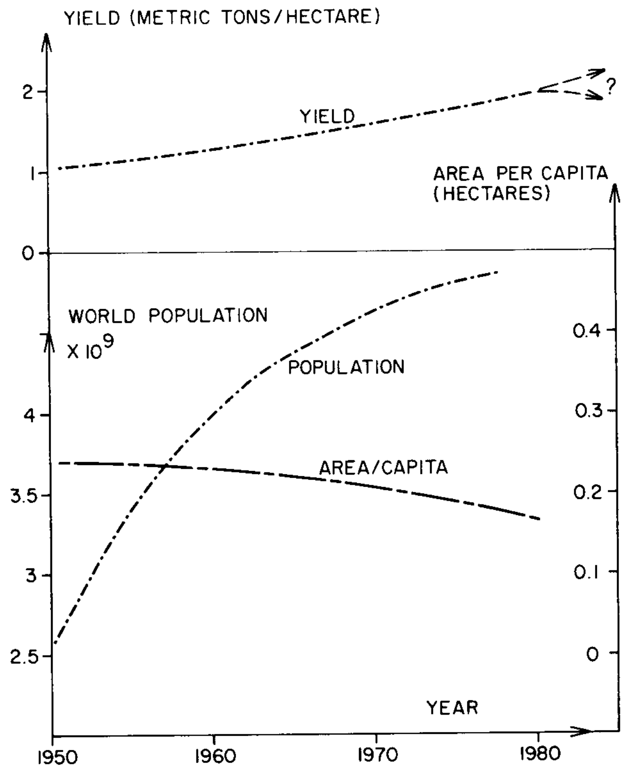

FIGURE 9. World cereals production yield. Upper scale: metric tons per hectare. Below: population increase and area per capita (in hectares: right scale).

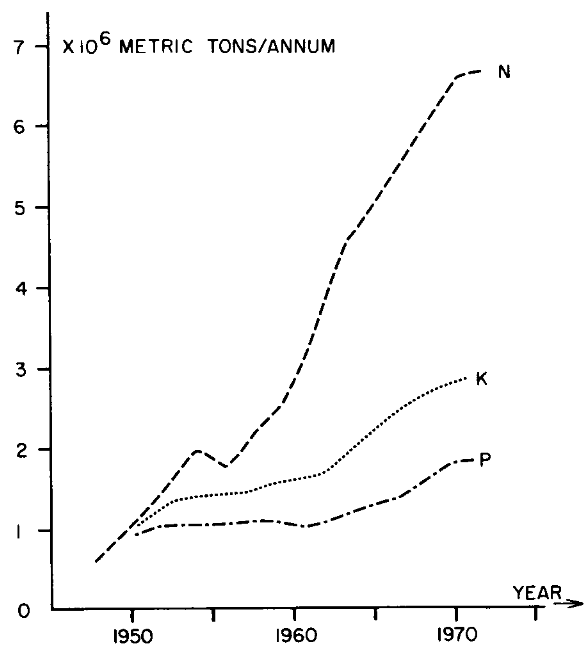

FIGURE 10. U.S. consumption of nitrogen (N), phosphorous (P), and potassium (K) fertilizers. Scale in 10^6 metric tons/annum (corresponding to 2×10^{10} kWh).

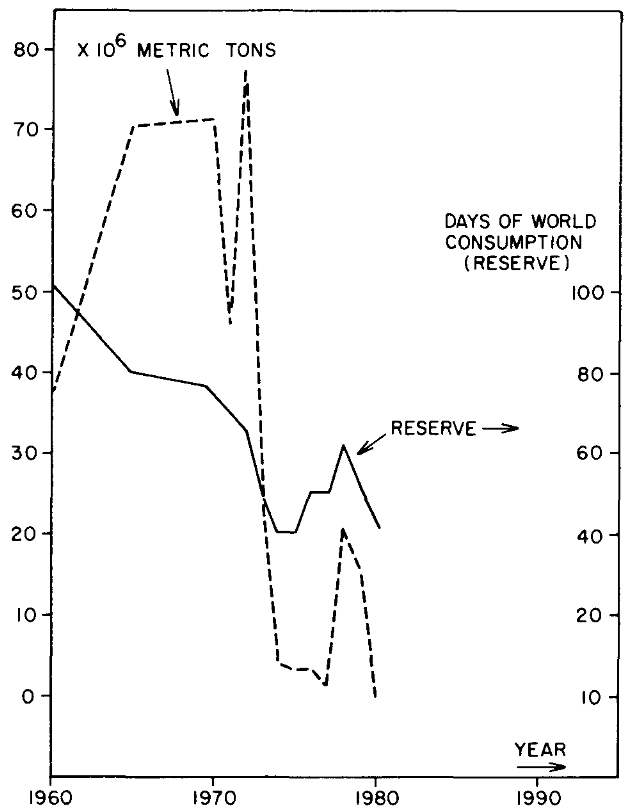

FIGURE 11. Grain equivalent of idled U.S. cropland. Left scale in 10^6 metric tons. Reserve in days of world consumption (right scale).

Obviously, the export surplus of North America and Australia (with New Zealand) of + 150 covers exactly the import of the other countries.

Over the years the "grain equivalent of idled U.S. cropland" has, therefore, decreased drastically and the reserve has decreased for 60% (Figure 11). U.S. and world grain reserves have decreased as a consequence (Figure 12). The reason for this is that with intensive fertilizer use, farmers abandoned traditional rotations that included soil-retaining pastures and hay in favor of continuous cropping of corn and other row crops. While the overall gain in production since the 1950s is impressive, the price paid in lost topsoil has been high. Soil lost this way cannot be replaced within our lifetime or that of our children's. We generally notice, therefore, a loss in crop area per person (Figure 13). An additional reason for this fact is, of course, the loss of farmland due to the extension of cities, road building, etc. on fertile land.[4]

The burden carried by the grain exporting countries is increasing. The dependency of the world grain production on fertilizer production causes a shift from countries with arable land only to those with arable land but also access to cheap energy sources. In Figure 14 we have plotted the development of the world grain production over the years 1935 through 1985 (in 10^6 metric tons) and the world fertilizer use over this period in 10^6 metric tons. There is a definite decrease in incremental grain/fertilizer response ratio (line C). As far as the energy amount is concerned, to produce this quantity of fertilizer, we mention that 10^6 metric tons of fertilizer require 2×10^{10} kWh or 100×10^6 metric tons require 2×10^{12} kWh, the amount of electricity generated by all German fossil fuel power plants.

The shift in population from developed to underdeveloped countries has additional effects

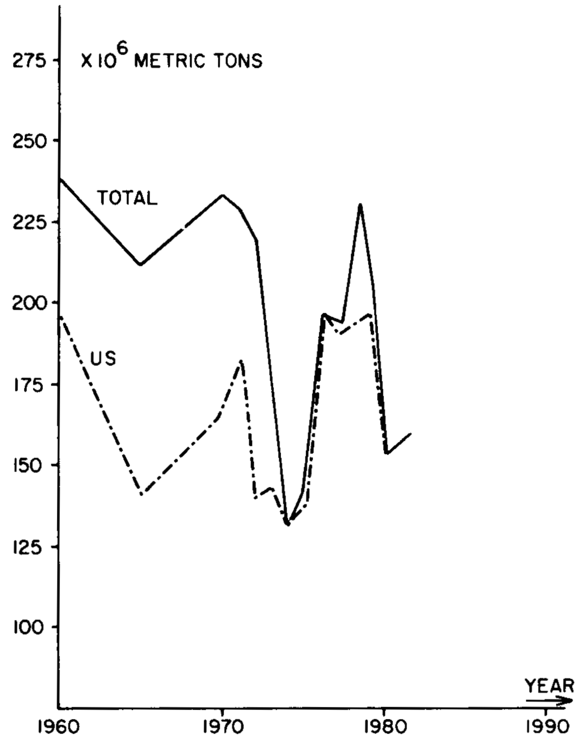

FIGURE 12. Grain reserves: U.S. and world in 10^6 metric tons.

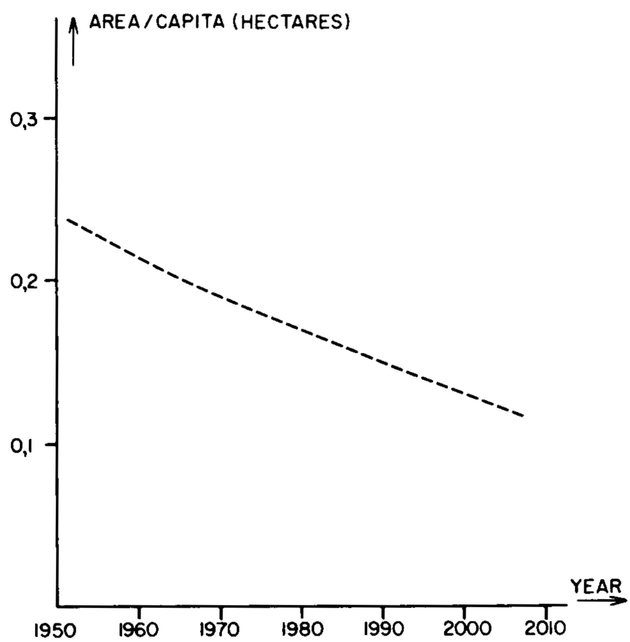

FIGURE 13. Crop area per person (world) in area per capita (hectares).

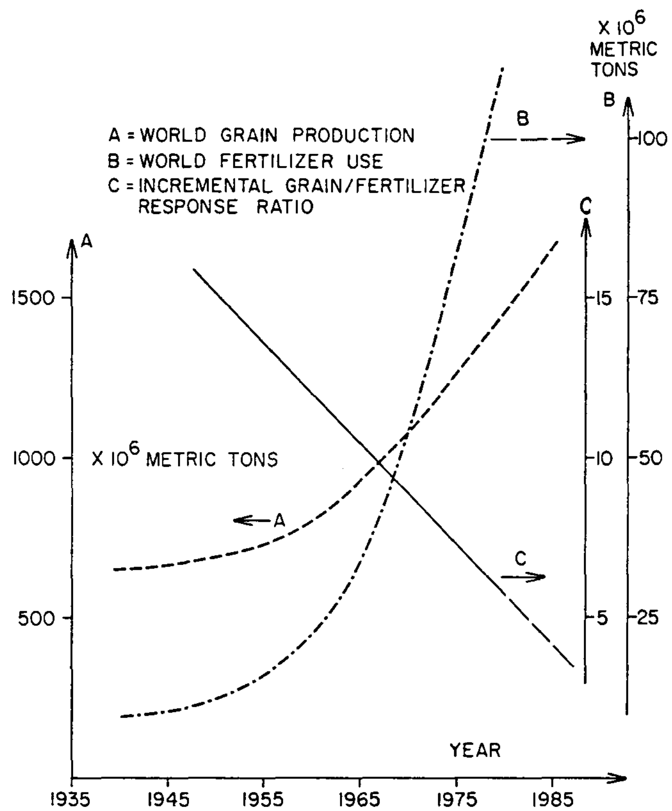

FIGURE 14. World grain production (scale A in 10^6 metric tons). World fertilizer use (scale B in 10^6 metric tons). Incremental grain/fertilizer response ratio (scale C).

on the future human situation, as to technical-industrial skill available. The question arises of how much time will be necessary to bring the underdeveloped world to a status of scientific and managerial competence to master the many difficult future decisions with respect to the energy supply needed, grain yield, antibiotics, labor distribution, advanced technologies, and organization of labor and industry in harmony with the environment?

One has to consider that the help given to the underdeveloped world during the years after World War II was particularly fruitful with respect to the production of food. While before 1950 most increases in food output came from an expansion of the area under cultivation, these years brought new grain types of higher yield and a heavy use of chemical fertilizers and energy-consuming irrigation and food processing. World cereal production per person climbed from 251 kg in 1950 to 330 kg in 1971. This gain of 30% is the reason for the optimism expressed by Simon.[3]

This optimism is not well founded. As we have seen (Figure 9), the area cultivated per person is bound to decline, while the population growth remains unchecked. Due to the use of high-yield seeds, artificial fertilizer, and automated irrigation, the overall yield has, however, increased into the 1980s. As mentioned, this has also seriously depleted much of the available soil. Not enough cropland is left to alternate. Expansion of the area under cultivation has ceased and since 1971 gains in output have barely kept pace with population growth. Idled U.S cropland has been put to use entirely and grain reserves are at their lowest point in 20 years. The loss of irrigated land, due to ecological problems (waterlogging and salinity), is another factor to consider. The intense use of agricultural land in the U.S.S.R.

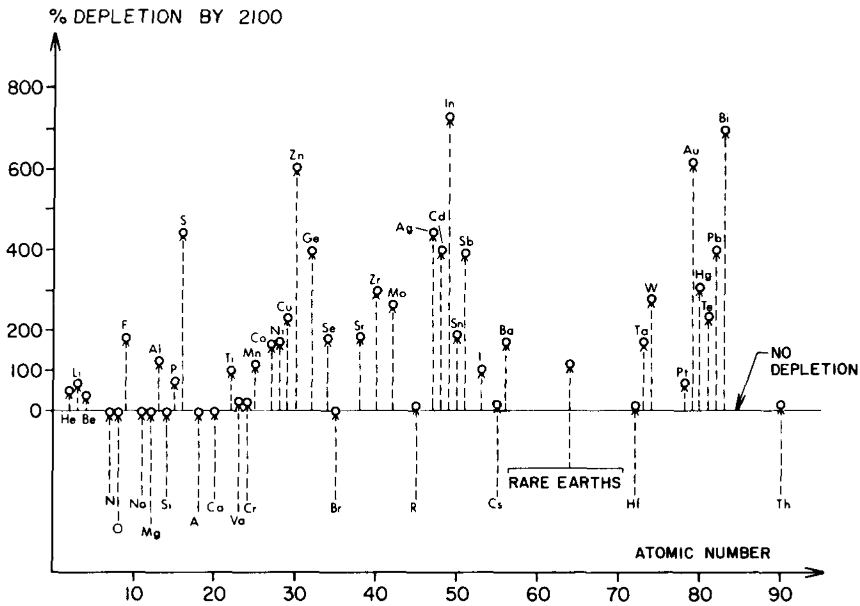

FIGURE 15. Percent depletion of important elements by the year 2100 arranged by atomic number.

and in many Third World nations has denuded the soil. Thus, soil erosion is at the root of the steady increase of import figures for grain by countries who formerly were food exporters.

Those able to pay in hard currency or gold are the preferred buyers. These are again the countries with a developed technology or oil or other important raw material reserves. This creates a situation where just those countries that have the largest percentage of population growth go hungry. In some cases, oil is available but is not sufficient as a base when all technical infrastructure is missing.[5]

In his optimistic paper on resources, Simon[3] makes the point that a smaller number of workers grow more grain today than a larger number some 20 years ago, without mentioning that it is energy in the form of motorization and thus the availability of oil which makes this replacement of human labor possible. He also states that availability of raw materials like copper cannot be ascertained in the future but it may be made from other metals (!) or it may be found in the sea and on other planets! The energy amount needed to do all these things like element transformation, seawater extraction, and mining on other planets in the universe is so high that this type of recommendation sounds like a joke.

In this context it is useful to study the "optimistic" report on "Infinite Resources" by Goeller and Zucker.[6] These authors realistically project a world population of 8.5 billion people by the year 2100 and calculate the depletion of the important elements by that time in percent of overuse. In Figure 15 the depletion calculated on account of proven reserves and increase factor of use and supply is shown for most of the industrially important elements. We note that almost all elements with over 100% depletion by the year 2100 belong in the category of high technology use. Al, Ti, Mn, Cu, Zn, Ge, Se, Mo, In, Ag, Sn, Au, W, Bi, Hg, Te, etc. will all be exhausted.

From where do Goeller and Zucker draw their optimistic outlook? They indicate new resources, heretofore, untapped. For example, aluminum could be mined from clay and anorthosite. Copper could be extracted from manganese nodules. Manganese could be extracted from seawater directly and tungsten could be gathered from lower grade ores. In many cases no alternate source is given and those which are mentioned are vague and would

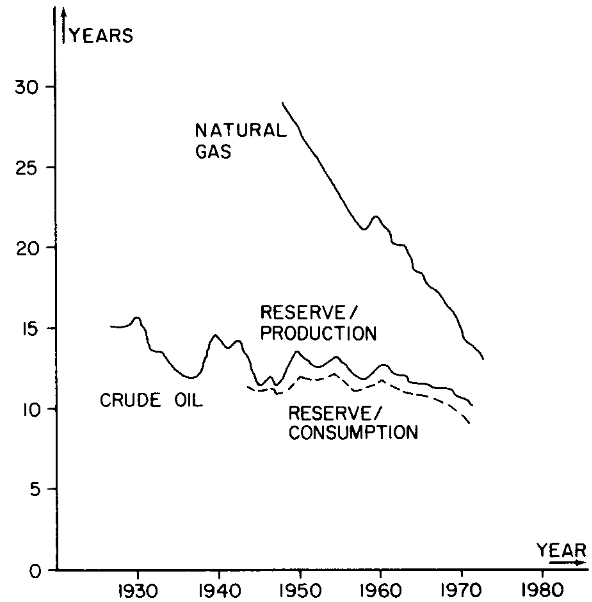

FIGURE 16. Years of remaining production of natural gas. Relative shrinking of reserves of crude oil in the U.S.: R/P = reserve/production, R/C = reserve/consumption (for further data, see Reference 8).

require large amounts of additional research and development and energy. Again, it is the amount of energy available which will decide upon feasibility to create alternate raw material sources.

Here again, energy as a factor is not taken into proper account. A glance at the years of remaining production of crude oil and natural gas shows that the inevitable decline of these resources will not permit energy-intensive processes of metal extraction by the year 2000. Figure 16 shows the trend in the U.S. and also the ratio R/P (reserve/production) and R/C (reserve/consumption).

The so-called excessive use of energy by the U.S. (see Figure 4) is partially justified by the enormous export of grain. Grain is energy in the true sense of the word. It incorporates not only the energy of the irrigation, the oil-dependent mechanization, but also the highly energetic fertilizer, a derivative from ammonia. The energy intake from ammonia, respectively, the NH_3 formation, requires huge amounts of watthours. Firstly, the formation of hydrogen and nitrogen is energy intensive. Hydrogen is produced from coal and water or through direct electrolysis of water. Nitrogen is formed from air by a low temperature separation from oxygen, another energy-intensive process. In addition, formation of ammonia from these elements in the Claude-Haber process is very energy intensive.

The liquefication of air yields 100 ℓ N_L per 23 kWh. The hydrogen equivalent of 300 ℓ requires 0.7 kWh and the Claude-Haber process requires *in toto* 1 kWh/kg NH_3.

There are other energy inputs such as temperature and supply of the catalyst (see Appendix A). A U.S. export of 100 million metric tons of grain requires the energy amount of 2×10^{12} kWh. This is ten times the energy amount used, e.g., by all chemical industry in W. Germany, or the total energy production of W. Germany.

There are recent, more optimistic projections of U.S. trends based on improved efficiency and more use of coal, especially in the form of electricity generated by coal-firing power plants. Also, the ratio of energy-dollar per GNP is assumed to decline further and to continue this trend from the 1970s on to the year 2000 and even beyond.[7] This ratio is dependent on