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On Energy Demand

by Wolf Häfele

Introduction

Since the energy crisis, a number of energy plans have been proposed, and almost all of these envisage some kind of energy demand adaptations or conservation measures, hoping thus to escape the anticipated problems of energy supply. However, there seems to be no clear explanation of the basis on which our foreseeable future energy problems could be eased. And in fact, a first attempt at a more exact definition of energy demand and its interaction with other objectives, such as economic ones, shows that it is a highly complex concept which we still hardly understand. So it may be appropriate to explain in some detail why it is so difficult to understand energy demand.

Energy Flow Schemes

Figure 1 shows the flow of energy through the economy of the Federal Republic of Germany in 1975 in millions of tons of coal equivalent, or gigawatt years. By far the largest share of the primary energy undergoes a conversion into forms of energy that are more convenient and more easily handled, which are called secondary energy. Electricity and gasoline, the most prominent examples, are transported to the consumer. The largest consumer sector is households and commercial activities, consuming 45% of all secondary energy; industry follows with 36%, and transportation with 14%. The use of secondary energy also leads to conversion losses, which are as high as 56%.

Besides these principal lines of energy flow in Figure 1, there are numerous other thinner lines and sidelines that cannot simply be overlooked in a discussion of energy demand and its future evolution. District heating, for instance, is meant to play a major role in the future, possibly together with cogeneration. Its present share is only 4 million tons of coal equivalent of secondary energy, but it may be significantly larger in the future. When taking into account all lines and connections of this diagram one faces quite some complexity and it is necessary to use fairly well defined categories and terms. We have tried to do this in Figure 2. One has to recognize primary energy. It may be coal, crude oil, uranium, and others. Conversion into another form of energy leads to losses and to what we call secondary energy. Transportation and conversion provide useful energy that is locally consumed. Useful energy is meant to provide for a service which may be, for instance, a warm room, a legible book, or a running car. As we will see later, such services are not on the same conceptual level as energy; and are encircled, therefore, rather than in a box.

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Conversion Efficiences

How can energy be saved? We saw in Figure 1 that in one way or other, roughly 75% of the primary energy input is lost. Is that necessary? Let us go through the various stages of energy flow and consider that question. In converting primary energy into secondary energy (see Figure 3), the best known process is electricity generation in power stations. In fact, actual energy is converted from thermal energy into mechanical energy, and only then into electrical energy. Thermal energy here is the sum of all kinetic energies of the molecules of a gas or a liquid, which have randomly distributed directions of motion. But, by necessity of the laws of physics, there is an upper limit for converting energy from thermal to non-random forms. Such limit is widely known as the Carnot efficiency, which always is less than unity. When the outlet temperature of the working fluid or gas is 500°C, the Carnot efficiency is close to 63%; however, power stations never obtain such efficiences because of the technical losses that occur. Although the losses can be made smaller, they cannot be reduced to zero. Improvements in efficiency require know-how and capital. The long-range trend of such efficiency improvements for power stations are given in Figure 4.

Let us take a small detour here to briefly look at this trend in more detail. In Figure 4, the logistic curve is plotted as a straight line. In normal plotting, a logistic curve is S-shaped, describing a differential growth in a limited environment (see Figure 5). The S-shape implies a transition from a low limit to a high limit and it is governed by a time constant. As we will see, a surprisingly large number of processes follow this behaviour, so that it makes sense to compare the time periods for a transition from one point on the curve to another.

Figure 4 shows that there has been a steady upward trend in the efficiency of power plants. Given a sufficiently long time span, one can in general expect such an upward trend to continue. This gain in efficiency saves energy because it decreases the consumption of primary energy for a fixed output of secondary energy.

But there are opposite trends too. In the past wood and coal were used directly and there were no losses due to conversion to secondary energy. There were, however, large losses in the extraction of useful energy. Only when a modern economy demanded handier forms of energy did conversion become a necessity. In the future, with primary energy forms that cannot directly be used, such conversions will become a greater necessity — even when handiness will not be an issue. Figure 6 conceptualized this observation. Nuclear energy and solar energy are cases in point. Their future large-scale uses beyond the year 2000 would significantly increase conversion losses, while today we are still enjoying a situation where natural gas has no conversion losses whatsoever and the conversion losses of crude oil are only small. It should be realized that future large-scale uses of coal will also lead to large conversion losses, because the market tends not to accept solids any more, and conversion into a liquid or a gas will be necessary, as shown in Figure 7. In the year 1950, as much as 80% of secondary energy was in solid form but then the market pressed for liquids and this led to a maximum of liquids in the early seventies. The use of gas has also been expanding rapidly, as has electricity. Electricity is now holding a share between 10 to 12% of all secondary energy, and many projections for the year 2000 expect a share close to 20 to 25%.

At this point a fairly important observation about nuclear energy must be made. In the past, nuclear energy was developed and used almost exclusively for the generation of electricity.

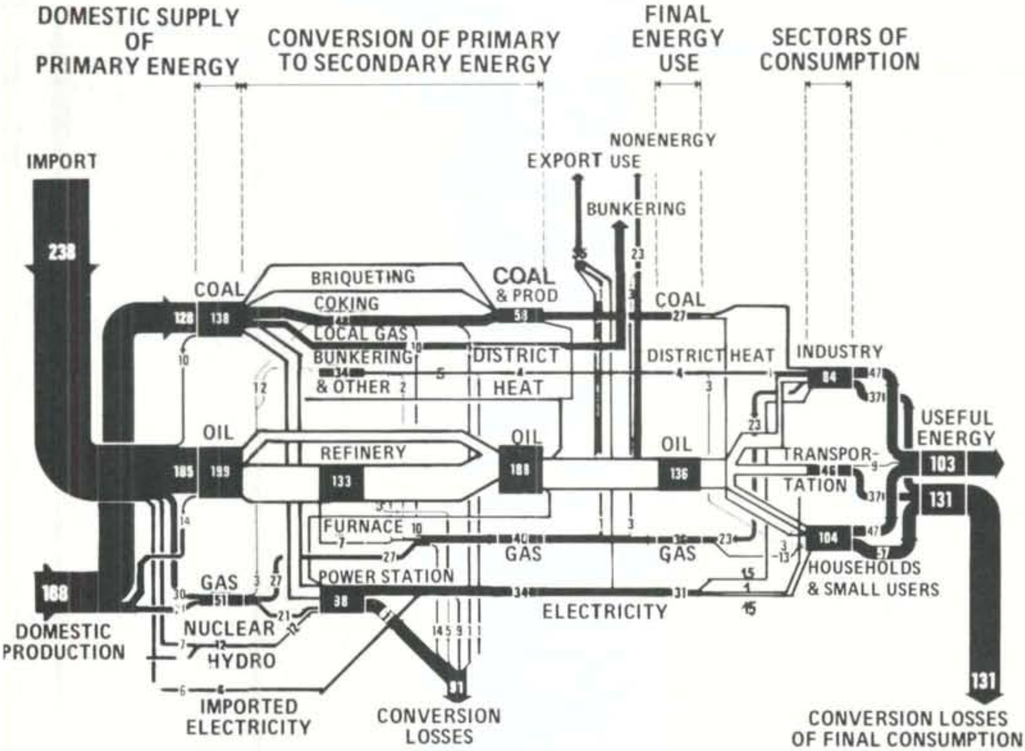


Figure 1. Flow of Energy through the economy of the Federal Republic of Germany in 1975 (in millions of tons coal equivalent or gigawatt years). By dividing the units by a factor of 33.5, one obtains quads (10^{15}Btu). The primary energy available was 239 (imports) plus 168 (domestic production), equalling 406 million tons of coal equivalent or giagwatt years, or 12 quads. As much as 59% was imported, the vast majority being crude oil (45%) and some natural gas (7.3%). Domestic coal was 31.5%. All other sources did not contribute very much in 1975. By far the largest share of the primary energy undergoes a conversion into forms of energy that are more convenient and more easily handled which are called secondary energy. Electricity and gasoline, the most prominent examples, are transported to the consumer. Conversion and transportation losses make up for as much as 91 million tons of coal, or 22% of the primary consumption. The largest consumer sector is households and commercial activities, consuming 45% of all secondary energy; industry follows with 36%, and transportation with 14%. The use of secondary energy also leads to conversion losses, which are as high as 56%. Therefore, out of 406 million tons of coal equivalent only 103 or roughly 25% are productively used, which means, for instance, that they are converted into mechanical motion or light (or devoted to other uses).

That made sense because nuclear energy by necessity had to be converted into a secondary energy, and electricity had already been connected to large-scale energy conversion long before the development of nuclear energy. But the pressing energy problem in the medium- and long-range future is to find substitutes for cheap natural oil and gas, which serves at least 75% of the secondary energy market, and not the production of more electricity.

If nuclear power is to assume more than 25% of secondary energy it must produce a gas or a liquid – a challenge which nuclear technology should fully face and adapt itself to. Beyond a price of $20 to $25 per barrel of oil equivalent, this seems feasible. Nuclear power's natural partner is coal, and this makes sense, too.

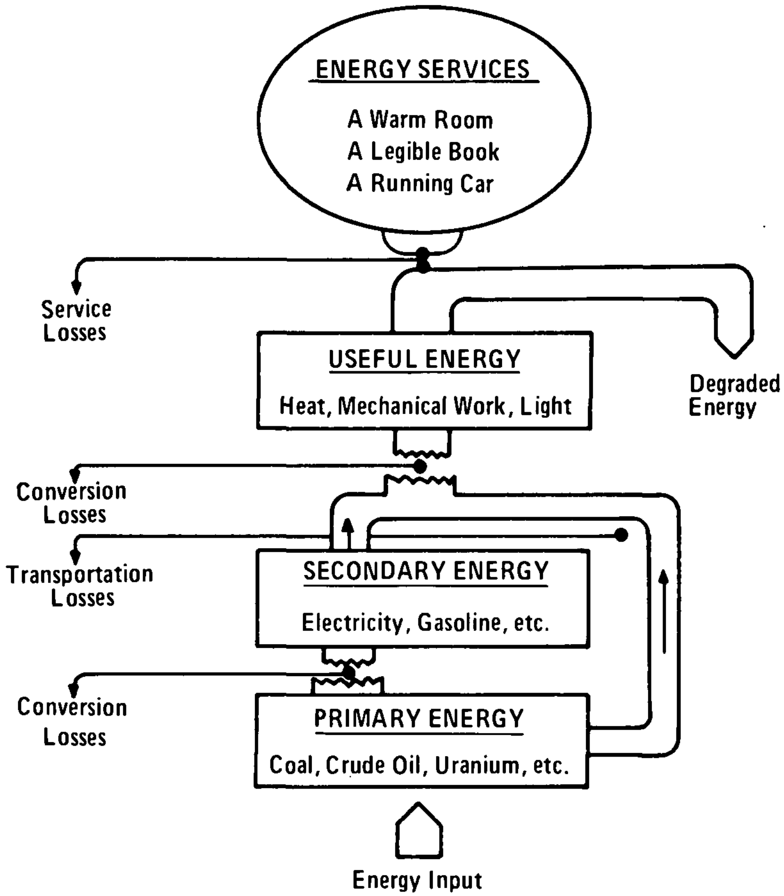


Figure 2. Simplified schematic of energy flow and energy services.

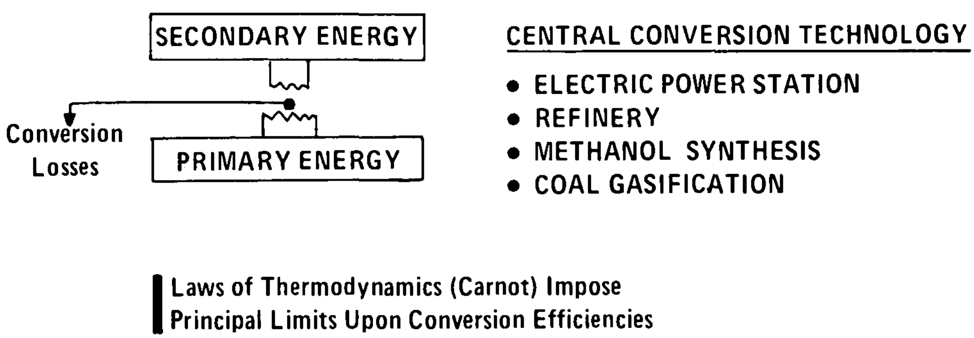


Figure 3. Conversion of primary energy into secondary energy inevitably leads to losses.

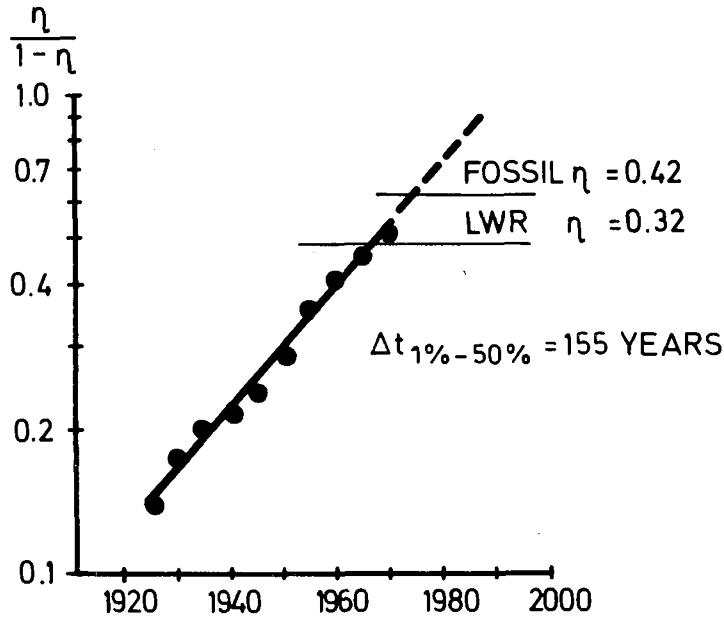


Figure 4. Long-range trend in gain in efficiency of power plants. (Source of data: See Reference [9]).

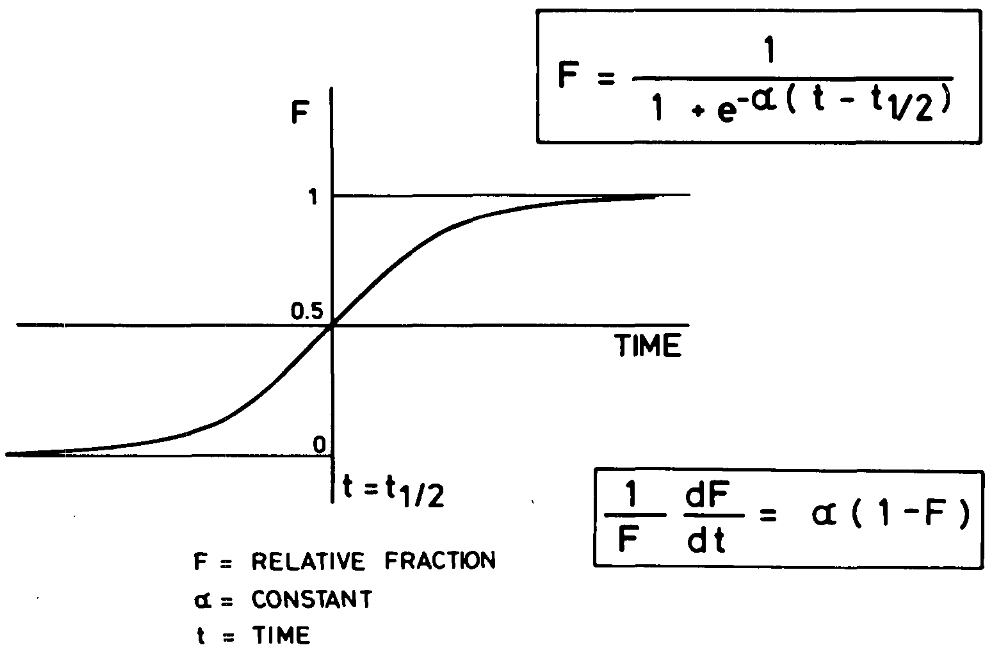


Figure 5. S-shaped logistic curve describes differential growth in a limited environment. The S-shape implies a transition from a low limit (F=O) to a high limit (F=1) and it is governed by a time constant. A large number of processes follow this behaviour, and it is often worthwhile to compare the time periods required to bring the variable F from, for instance, 0.01 to 0.5, the centre point of the curve.

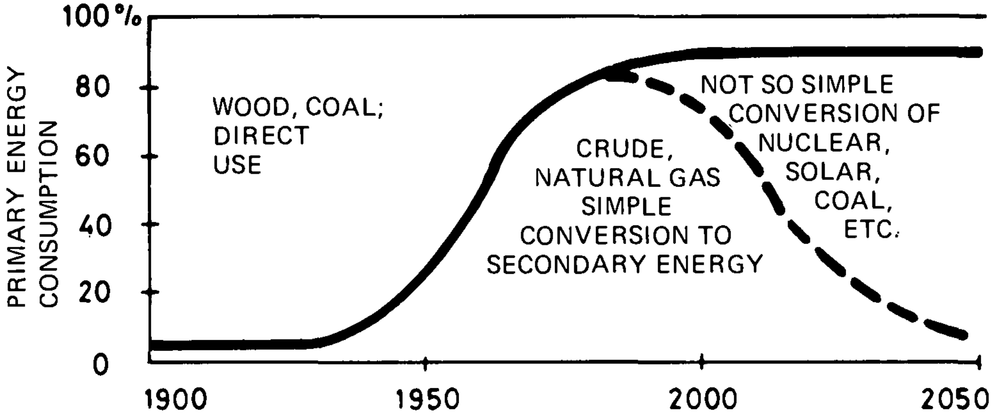


Figure 6. Projection of energy consumption in the Federal Republic of Germany shows a widening gap between primary energy and secondary energy. The future large-scale use of nuclear energy and solar energy beyond the year 2000 would significantly increase conversion losses.

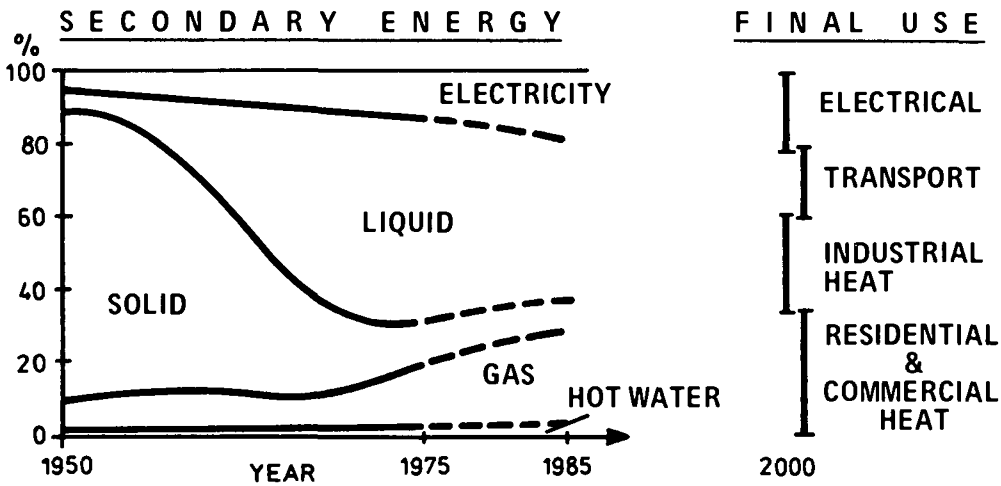


Figure 7. Partitioning and final use of secondary energy in the Federal Republic of Germany is shown. Because the market trend is away from solid fuels, conversion of coal into a liquid or gas will be necessary. In 1950 about 80% of the secondary energy was in solid form. By 1975 liquid fuels predominated. In recent years, the use of gas and electricity has increased.

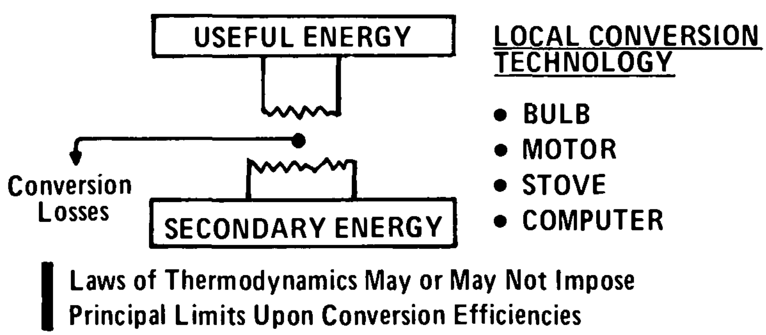


Figure 8. Conversion from secondary energy to useful energy is accompanied by losses.

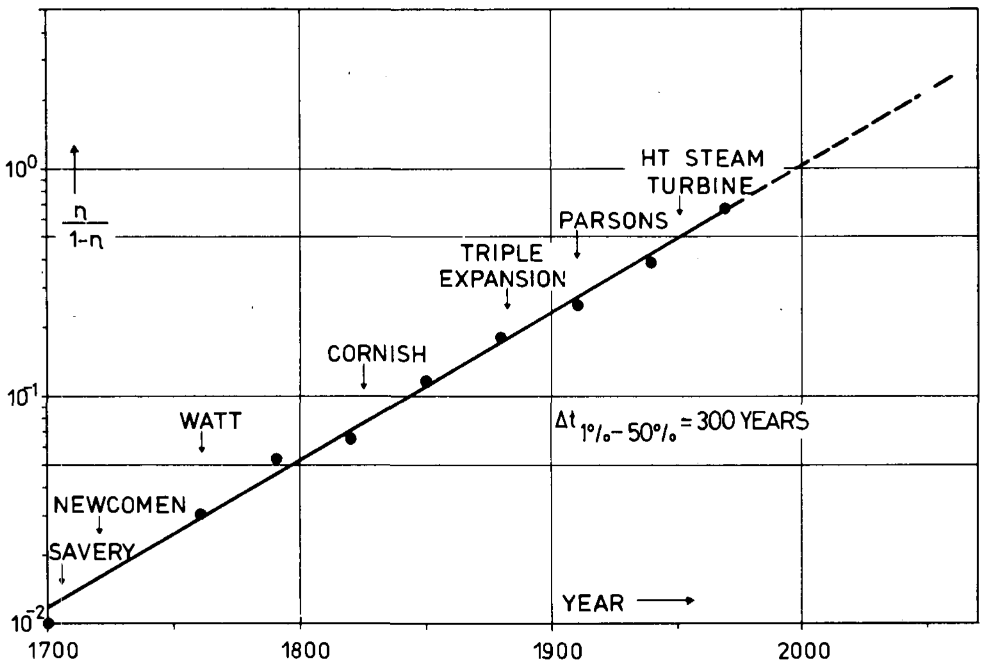


Figure 9. Efficiency of prime movers has shown a consistent trend upwards.

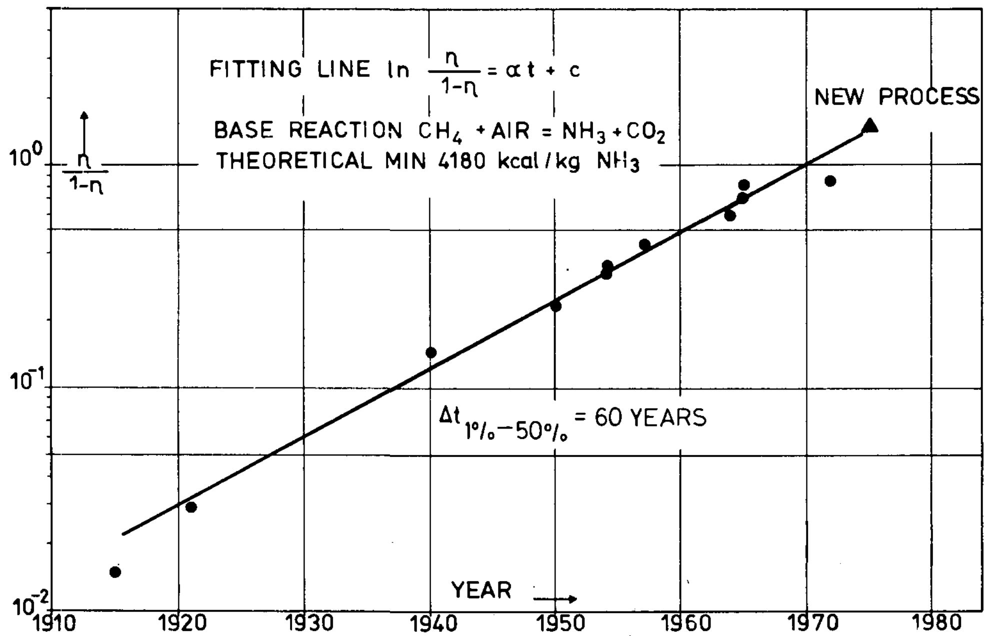


Figure 10. Efficiency in the production of ammonia also has steadily improved. (Source: Reference [13]).

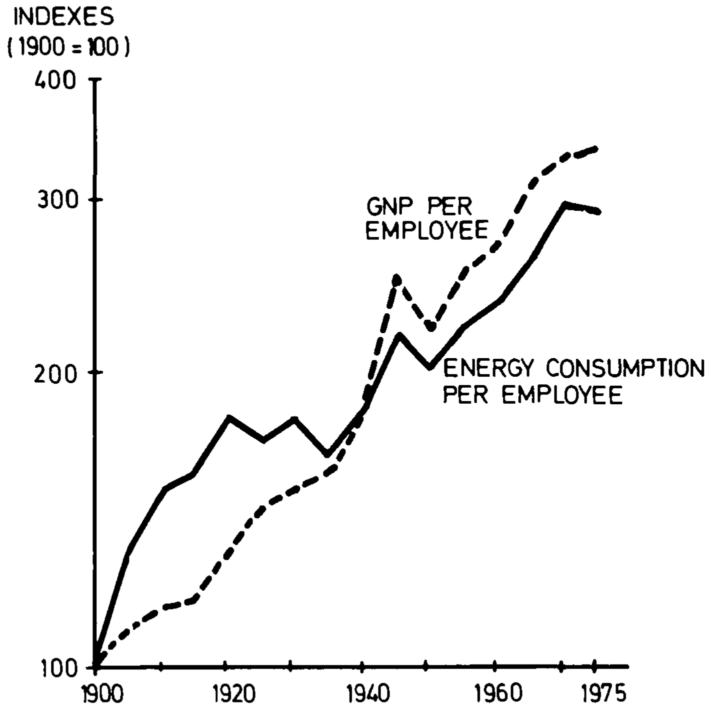


Figure 11. Gross National Product (GNP) per employee and energy consumption per employee in the USA (Source: Reference [12]).

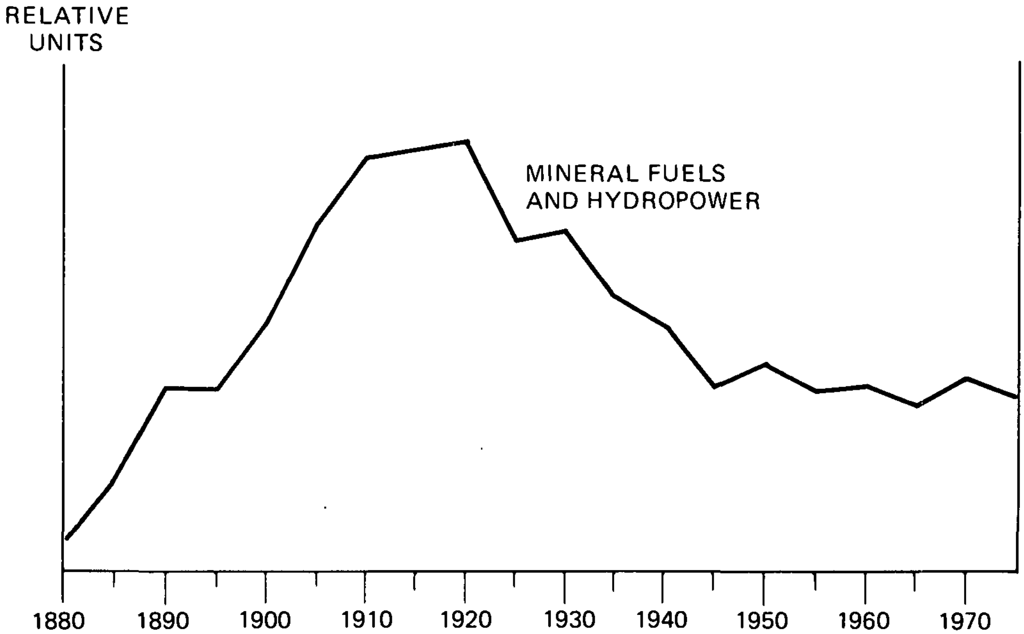


Figure 12. Energy consumption per unit of GNP in the USA increased until 1920 and has been falling since then. (1880–1950 Data: S.H. Schurr and B.C. Netschert, Energy in the American Economy, 1960; 1955–1975 Data: J. Alterman, Bureau of Economic Analysis, to be published).

For nuclear power the conversion losses do not pose a problem in the long run. When breeding is introduced, uranium supply will no longer be a problem. Then it does not matter that conversion losses increase primary energy consumption for a given demand of secondary energy. Instead the problem of capital investment comes to the fore.

But let us go on with our reasoning. The conversion from secondary energy to useful energy is also accompanied by losses (see Figure 8). Transportation losses may be subsumed here. In some applications, Carnot efficiencies impose principal limits, in others they do not, but there is always room for improving efficiencies. For instance, in the case of prime movers there has been such a consistent trend upwards (see Figure 9), and the same is true for ammonia production (see Figure 10). It is remarkable to what extent the transitions to higher efficiences follow the logistic curve behaviour and how large the related time periods are.

In contrast to the conversion of primary energy to secondary energy, which usually occurs in large centralized and efficient power stations, the conversion of secondary energy to useful energy is decentralized and takes place in millions of cars, stoves, bulbs, and other end-use devices. Such decentralized, local use of energy often tends to be inefficient; consider, for example, old stoves in old apartments or the use of open fire-places. These millions of end-use devices are part of the economic and cultural infrastructure, and it is both difficult and time-consuming to make changes for the sake of energy conservation, or better, for intelligent uses of energy.

Energy and Economy

At the point of end-use, energy acts as an input to the economy, and the millions of end-use devices can best be dealt with in economic terms. This is often done in a highly aggregated way, i.e. in terms of macro-economic evaluations. The relation between gross national product (GNP) and energy consumption is well known. Figure 11 gives indexes of both the GNP produced per employee and the energy consumption assumed per employee for the USA during the last 75 years.

Two observations can be made:

1. Obviously both curves are roughly parallel, and increase in GNP per employee requires roughly the same relative increase of energy per employee.

2. A closer look at the curves reveals that the relative increase in energy per employee is slightly less than that in GNP per employee; energy is either better used or substituted by something else.

Indeed, one may interpret this as pointing to a potential of energy saving. Figure 12 shows the ratio of energy consumption (mineral fuels and hydropower) and the GNP in the USA. At the time of the first industrial revolution in the USA, the ratio increased. It then passed through a maximum and has been falling ever since because the GNP has increasingly come to incorporate sophisticated products, such as electronics, and general services (the tertiary sector of the economy) as well as heavy machinery.

An important characteristic of an economy is the value of its capital stock, i.e. the sum of invested goods necessary for the production of the GNP . Labour and energy are the drivers of this capital for the production of a GNP. It therefore is interesting to consider energy consumption per capital stock, as shown in Figure 13. The ratio is close to one watt per dollar. In centrally planned economies, the ratio is higher than the world average, which is probably due to the emphasis on heavy machinery in these countries.

Furthermore, it is striking to realize that the ratio is very much the same for both developed (0.71) and developing countries (0.77), while their respective capital-stock-per-capita figures are very different. This leads one to think that the kind of economy producing the GNP is similar in both types of countries, while the relative participation of the population in the economy differs widely. The point I am driving at is urbanization. The development of the developing countries seems to pass through the stage of urbanization, which leads to the same scheme of energy consumption of primary, secondary, and useful energy as in the industrialized countries.

Figure 14, which compares energy consumption and settlement densities in the Federal Republic of Germany and in India, seems to support this idea. The average energy consumption density differs greatly (roughly by a factor of 12), while the energy consumption density in urban areas differs by a factor of only 1.5. Although the technical infrastructure of cities in the two countries is similar, there are 6000 people per km^2 in the urban areas of India and only 1500 in the Federal Republic of Germany. In other words, the infrastructure characteristics seem to be strongly determined by the amount of services provided, and only the number of people that use it varies widely.

The relatively high energy consumption per m^2 in India's cities is due largely to the high population densities in the cities. The differences in the average values for the Federal Republic of Germany and India must then come from the rural areas. In rural areas of FR Germany, roughly 20 times more energy is consumed per m^2 than in India, while the population densities are very similar. The point is that one should not underestimate the coupling of the energy infrastructure to the general economic infrastructure. Developing countries have often been recommended to use an alternate route in their development. Soft technology, such as wind and local uses of solar energy, have been mentioned, especially in a decentralized mode, that is, in rural areas. But rural areas are not where the action is.

The coupling between an energy infrastructure and the general economic infrastructure, i.e. the complex pattern of energy uses, needs elaborate quantitative analysis. One way of learning to understand it is to study the interplay between energy consumption and energy prices, as attempted by econometric methods developed and used, particularly in the USA. Names such as Jorgenson, Houthakker, Nordhaus, and Manne may be considered representative. Their fundamental input are various elasticities, elasticity being the percentage change of energy consumption per percentage change of another quantity, e.g. GNP. Elasticities are derived from numerous statistical data over a series of years, whereby implicit reference is made to an existing energy/economy infrastructure. Within such a frame, it is then considered possible to study the likely energy consumption for a near-term period of, say, ten years. Figure 15 reproduces characteristics of this econometric approach. For example, demand functions are construed with the help of elasticities. They relate per-capita net energy consumption, the relative net price of energy, and the per-capita real gross domestic product.

Names such as Chapman or Slesser stand for another approach known as energy analysis. It is a more engineering-type of approach, involving the study of the energy content of goods and services. Figure 16 illustrates some result of that procedure. It gives values of

	ENERGY-CAPITAL INPUT RATIO W/US $ (1973)	CAPITAL STOCK PER CAPITA US $ (1973)
WORLD	0.87	2000
DEVELOPED MARKET ECONOMIES	0.71	8500
DEVELOPING COUNTRIES	0.77	380
CENTRALLY PLANNED ECONOMIES (WITHOUT CHINA)	1.43	2700

Figure 13. Energy consumption and capital stock (in watts per US dollar) is much the same for developed market economies and developing countries, even though their capital stock per capita is quite different. (Capital stock data: W. Ströbele, 1975).

	ENERGY CONSUMPTION DENSITY W/m^2			POPULATION DENSITY cap/km^2		
	Average	Urban*	Rural+	Average	Urban*	Rural+
FRG	1.2	7.5	0.75	245	1500●	150
INDIA	0.10	12	0.04	168	6000■	135

* Conurbations

+ Farms and small towns

● 45% of total population

■ 9% of total population

Figure 14. Energy consumption and settlement densities in the Federal Republic of Germany and India are compared. In rural areas of FR Germany, about 20 times more energy is consumed per m^2 than in India.

kWh(th) per dollar of final economic output for various sectors of the French economy of 1971. There are high numbers for steel and non-ferrous metals and for indirect energy consumed for fabricated metals, and fairly high values for the building and the glass sectors. It is obvious how well this reflects an existing infrastructure and technology.

Energy Services and Information

Energy use is not an end in itself. We observed that labour and energy are the drivers of existing capital for the production of a GNP, which is measured in dollars and not in kWh. What happens when kWh help to produce dollars? The use of energy provides a service and

$$\text{ELASTICITY } (\beta, \gamma) = \frac{\%\text{ CHANGE OF DEMAND}}{\%\text{ CHANGE OF PRICE, INCOME}}$$

$$\boxed{Q_t = \text{const} \cdot \prod_{\theta=0}^{n} P_{t-\theta}^{\frac{\beta}{n}} \cdot \prod_{\theta=0}^{m} Y_{t-\theta}^{\frac{\gamma}{m}}}$$

Q_t = Net Energy Consumption/Capita
P_t = Relative Net Price of Energy
Y_i = Real Gross Domestic Product/Cap
β = Price Elasticity
γ = Income Elasticity

Figure 15. Econometric approach for determining the interplay between energy consumption and energy prices involves the use of the concept of "elasticity", the percentage change of energy demand per percentage change of another quantity such as price, income, etc.

INDUSTRIAL SECTOR	TOTAL ENERGY CONSUMED PER OUTPUT	DIRECT ENERGY CONSUMED	INDIRECT ENERGY CONSUMED
Food	2.20	1.72	0.48
Building	16.07	13.98	2.09
Glass	16.03	14.54	1.49
Steel	34.85	28.28	6.57
Non-ferrous Metals	33.16	31.33	1.83
Fabricated Metals	11.44	1.32	10.12
Electro-mechanical	6.01	1.59	4.42
Chemical	11.41	9.40	2.01
Clothes	2.92	2.09	0.83
Paper	5.62	4.44	1.18
Other	4.93	3.00	1.93

Figure 16. Total energy consumed in kWh(th) per dollar of final economic output for various sectors of the French economy in 1971 are shown. The high values for the steel, non-ferrous metals, glass and building sectors reflect the existing infrastructure and technology. (Source: Reference [2]).

it is not the only service (see Figure 17). Consider for instance a potter who produces pottery. To have his disk running is one thing, but to have the skill to produce pottery without much scrap is another thing. He also needs a stock of capital investment. The higher the skill and the more appropriate the investments, the less energy he needs to produce an anticipated amount of pottery. If he has no skill he must try extremely often to produce a pot and the amounts of energy consumed per pot are high. Also, the better his mental image of the pottery, the higher the GNP he produces. Or consider a warm house. The amount of energy service needed may vary considerably, depending on insulation. The care with which the heat is managed is also important, whether doors and windows are kept closed or not, etc. It also makes a big difference whether energy services are available when, and only when, they are actually needed.

Another crucial point is the cleanliness of energy services. Many types of industry require electricity rather than another form of energy because it can easily and cleanly be controlled and handled, which S.H. Schurr calls the high economic efficiency of electricity. All this points to the fact that energy services must be seen in line with other services which, when taken together, make up for the acquisition of a desired pattern, such as a pot or a warm room. The difference between a warm room and the warming of a room is significant. The former is a pattern, and the latter refers to uses of tools, for instance, energy use. The level on which patterns are formed is more abstract than the level of the tools.

Energy service, therefore, means to transpose energy uses into that more abstract level, which we call the level of "information". Loosely referring to Shannon's formal information theory and the concept of entropy and negentropy, it is true that science today does not yet allow for the accounting of skill, capital stock, and energy services in a unified theory; which indeed is the ultimate reason why it is so hard to really understand energy demand. The problem is often referred to when people say that the quality of energy uses must be taken into account.

The relation of energy use and information is open-ended. In the extreme, one can provide energy services without consuming any energy. This can quite dramatically be demonstrated in a Gedanken-experiment, or thought-experiment (see Figure 18). Let us envisage a place in the ocean. The sun shining from above produces a temperature gradient in the upper layers of the ocean. This gradient can be used quite traditionally with a Carnot machine. Heat is taken away from the upper layer of the ocean at a temperature T_2 and is used in the Carnot machine, and part of the heat is transformed into mechanical work. The rest of the heat is given to the lower oceanic layers at temperature T_1. If the mechanical work is used to compress air, the air heats up at isothermal conditions and the energy from the mechanical work is returned to the upper oceanic layer from which it came. When the bottle with compressed air is taken to a city, certainly no energy transport is taking place. The internal energy of an (ideal) gas depends only on temperature and not on pressure, and the temperature here is assumed always to be T_2. The energy content of the ocean remains the same, but the entropy of that oceanic place has been increased, a phenomenon known as mixing entropy. The same amount of entropy with a negative sign, i.e. negentropy, has been transported as pressurized air away to the cities. If the processes are carried out reversibly, the created negentropy is equal to the production of entropy in the place. In the urban infrastructure, the air is allowed to expand pushing, for instance, a car. Recall that, in our terminology, a running car is an energy service, representing a pattern of information. Upon expansion the air cools off and the surrounding atmosphere provides

I "INFORMATION" MEANS INPUTS FOR ACQUIRING A DESIRED PATTERN

A POTTER NEEDS ENERGY SERVICE AND INVESTMENT AND SKILL TO PROVIDE POTTERY

A WARM HOUSE REQUIRES MUCH OR LITTLE ENERGY SERVICE, DEPENDING ON INSULATION AND CARE

AVAILABILITY, RELIABILITY, VERSATILITY, AND CLEANLINESS OF ENERGY SERVICES ARE ALSO "INFORMATION" INPUTS

II ENERGY SERVICE MEANS TO TRANSPOSE ENERGY USE ONTO THE LEVEL OF " INFORMATION "

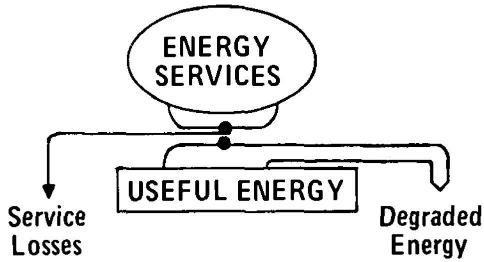


Figure 17. Energy services and "information".

the necessary amount of heat as an input to the expansion engine. When the car is running the resulting friction degrades the mechanical energy to friction heat. With the degradation of the quality of energy, the heat is given back to the atmosphere where it was taken from; and the energy content of the urban place remains unchanged as well.

By disturbing the material pattern of the place in the ocean we have created a pattern of "information" which is used in an economy; in other words, the economy is running without consuming energy. The Gedanken-experiment would end with the gradual restoration of the oceanic gradient, and one could repeat the exercise keeping the economy running in this way. This experiment shows that it is at least ambiguous to speak of energy consumption, since, as has been demonstrated, an economy can be driven without energy consumption. What is being consumed is "information".

This experiment highlights the fundamental difference between energy use and energy service, or "information". Indeed, there is a law of conservation for energy as there is one for mass and momentum, while there is none for entropy and information. Entropy remains constant or keeps increasing. One can thereby release indefinite amounts of negentropy or information. Or, in other words, the relation of energy use and information depends on patterns in use and to that extent is open-ended.

And it is precisely for that reason that it is so difficult to understand energy demand. It was observed that it is the infrastructure of an economy that relates energy use and GNP. GNP is one of the phenomenological measures of information in the sense in which it is used here. But this leads one to observe that the possible development of an economy basically is open-ended, which means that there are no laws of nature to impose limits upon growth. This is a fairly sweeping statement. Before using it one should recall the level of sophistication that one is led into when exploring this open-endedness. The direction of an economic evolution cannot but lead to more and more immaterial activities. And when one emphasizes the growing importance of the service sector of an economy one says just that. And this could lead to less energy service per output of GNP.

It might be appropriate to illustrate this by a practical example, which is admittedly extreme but real. The early digital computers of the 1950's, such as the IBM 650, used several kilowatts of electric power and a certain amount of time to allow for data processing, while today only milliwatts of power and much less time are required to provide the same service. The difference is four to five orders of magnitude of energy consumption. But this progress required a deeper understanding of solid state physics and the building up of a sophisticated industry. A whole body of know-how and scientific progress had to be developed, and energy savings have been only one of many important consequences. It probably requires such a vast and pluralistic richness of scientific, technological, and managerial progress to change the infrastructure that relates energy use and energy services, and which in turn also influences energy demand.

Time for Evolution

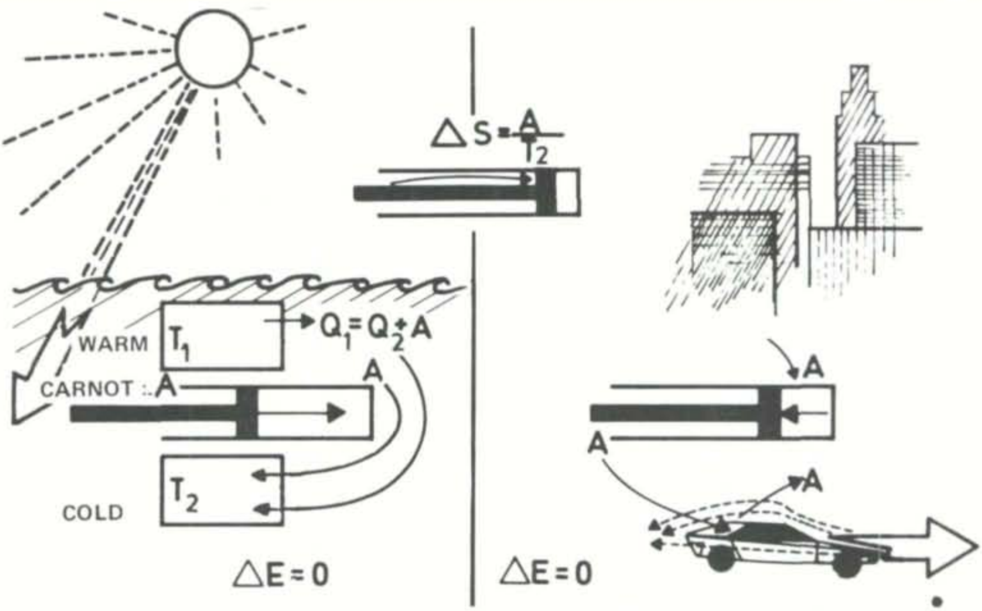
Such developments take time. Time is the key to modern energy strategies, which makes it appropriate to conclude with the time characteristics of the evolution of energy demand. There are three components (see Figure 19). For one, there is population growth. It is true that it does not immediately increase the demand for energy. Without capital stock or infrastructure, population growth cannot be translated into greater demand for energy; we looked into that when comparing India and FR Germany. But in the long run, population growth will affect energy demand. In developed countries there is a more immediate feedback from population growth to energy demand, and within the next 40 to 60 years, the possible doubling of the world population would certainly influence the world's demand for energy.

The second element influencing the evolution of energy demand is economic growth. An economic growth rate of 5% per year means a doubling of the GNP in 15 years. Without a significant change in the infrastructure, this may also roughly double energy demand. Only the third element leads to a change of the infrastructure; it is a change of patterns for using services, and in particular, energy services. We have seen that such changes quite deterministically follow a logistic curve behaviour, and related data lead us to observe that a significant change that would cut energy demand in half probably requires 50 to 100 years.

Final Remarks

It has been the purpose of this outline to point to the vast complexities of energy demand. By contrast, the features of energy supply, as in the past, appear to be much simpler. Energy supply is accomplished through large centralized technological facilities, and the science and art of engineering them is highly developed. It makes use of laws of nature that are well understood, for instance, the laws of energy, momentum, and mass conservation. It is therefore not surprising that in the past analysis mostly concentrated on the supply side.

The problems of energy demand are also partly technological in nature, but the variety and plurality of energy use and, in particular, the fundamental difference between energy use and energy services lead into open-ended considerations that cannot be handled by scientific laws of conservation. Even on the level of basic research much is left to be done before energy demand can be clearly understood.



(A : WORK , E : ENERGY , Q : HEAT , S : ENTROPY , T : TEMPERATURE)

Figure 18. Negentropy City Gedanken-experiment (thought-experiment) illustrates an economy that runs without consuming energy. On the left, heat from the sun produces a temperature gradient in the upper layers of the ocean. The heat amount Q_2 is taken away from the upper layer of the ocean at a temperature T_2 and is used in the Carnot machine, whereby share A is transformed into mechanical work while share Q_1 is given to the lower oceanic layers at temperature T_1. If the mechanical work A is used to compress air, the air heats up at isothermal conditions and the energy amount A is returned to the upper oceanic layer from which it came. When the bottle with compressed air is taken to a city, certainly no energy transport is taking place. The internal energy of an (ideal) gas depends only on temperature and not on pressure, and the temperature here is assumed always to be T_2. Indeed, while at the ocean only the heat amount Q_1 has been transferred from temperature T_2 to temperature T_1, the energy content of the place remains the same. Instead, the entropy of that oceanic place has been increased, a phenomenon known as mixing entropy. The same amount of entropy with a negative sign, i.e. negentropy, has been transported as pressurized air away to the cities. If the processes are carried out reversibly, the created negentropy is equal to the production of entropy in the place. In the urban infrastructure the air is allowed to expand pushing, for instance, a car. Upon expansion the air cools off and the surrounding atmosphere provides the necessary amount of heat A as an input to the expansion engine. When the car is running the resulting friction degrades mechanical energy A to friction heat A. With the degradation of the quality of energy the heat is given back to the atmosphere where it was taken from; and the energy content of the urban place remains unchanged as well. (Source: Reference [10]).

• POPULATION DOUBLING	≈ 40 – 60 YEARS
• DOUBLING OF ECONOMIC GROWTH OF 5%	15 YEARS
• CHANGE OF "INFORMATION" PATTERN IN USE	MORE THAN 50 YEARS

Figure 19. Time characteristics of the evolution of energy demand.

We have also seen that the potential for improving efficiencies of energy uses can change only slowly with the underlying infrastructure. While much can be expected from that in the long run, one has to be careful about the time characteristics of related improvements, which probably take generations.

The overall conclusion is to be cautious about statements on energy demand. Not to use energy is no remedy for a society's energy problems. Only changes of pattern that comprise societal, economic, technical, and scientific evolutions into the abstract domain can bring about changes here, and this takes time, much time.

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