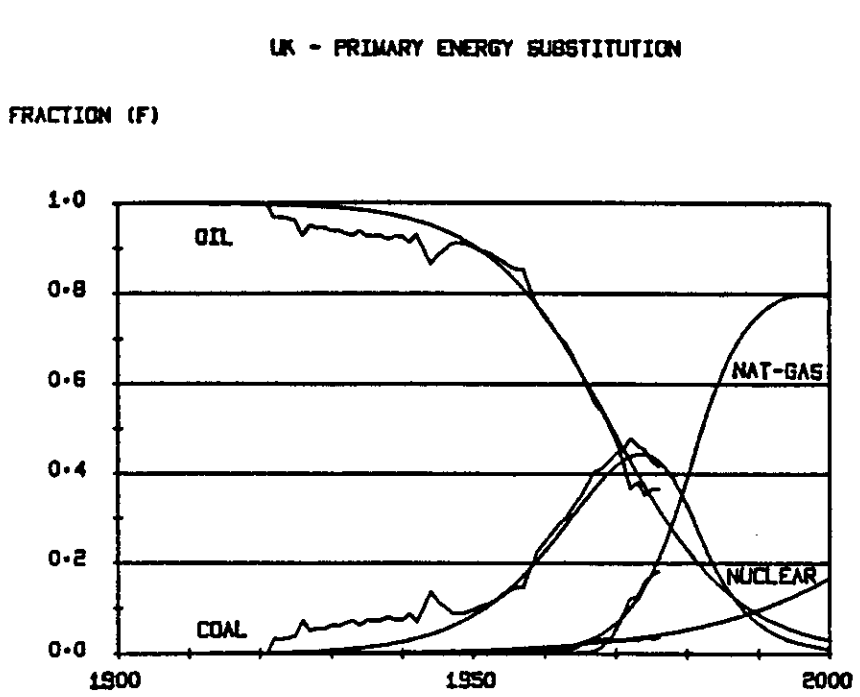
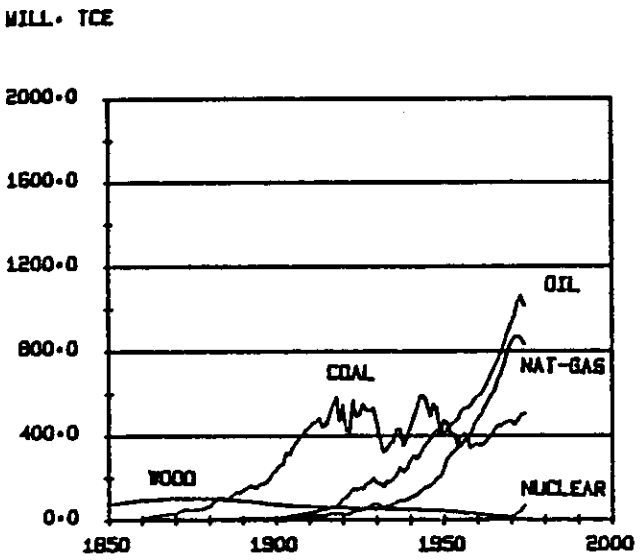


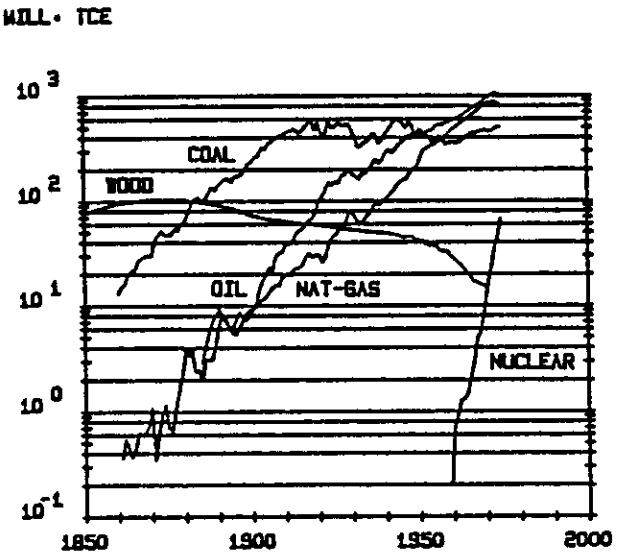

This plot shows that although nuclear energy in the UK had a very fast start in 1964, later it slowed down considerably. Today there are 24 GW(th) of installed nuclear capacity, which at the current utilization rate is about 4 percent of primary energy consumption. Additional plants with a combined capacity of 9 GW(th) are under construction and expected to be in commercial operation by 1979. Another 3.23 GW(th) from nuclear plants are planned by 1986. This makes a total of 36.3 GW(th) installed capacity to be available by 1986. With a utilization factor of 75 percent and the current growth rate in energy consumption of 3 percent per year, this would give a 7-percent market share by 1986; we assumed 6 percent.

**MARCHETTI-28_pt.2**

USA - PRIMARY ENERGY CONSUMPTION




USA - PRIMARY ENERGY CONSUMPTION

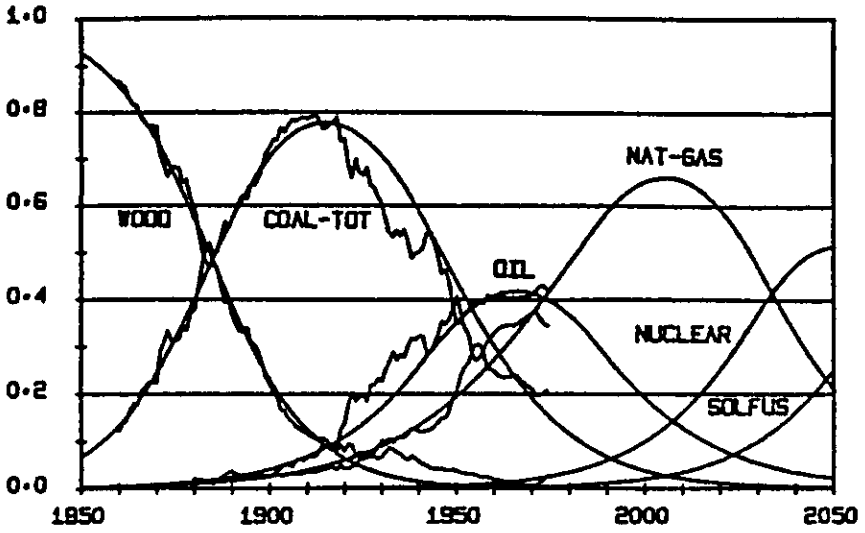


The historical data on primary energy consumption in the United States since 1860 were taken from Schilling and Hildebrandt (1977) for coal, oil, natural gas, and nuclear energy. All data were reported in millions of tons of coal equivalent except nuclear energy. Nuclear consumption rates were reported in millions of kilowatt hours, and we converted them to million tce.

The fuel wood time series come from the U.S. Bureau of the Census (1975a) for the period from 1860 to 1970. The wood consumption after 1970 was neglibible; thus, it was not necessary to add the last few years. The source we used for the data on wood from 1860 to 1945 was Schurr *et al.* (1960), who in turn used two different sources: from 1850 to 1930, Reynolds and Pierson (1942), and from 1935 to 1955, the U.S. Department of Agriculture (1958). Thus, the discontinuity in the penetration rate of fuel wood in the 1930s could be attributed to discrepancies between the two sources.

USA - PRIMARY ENERGY SUBSTITUTION

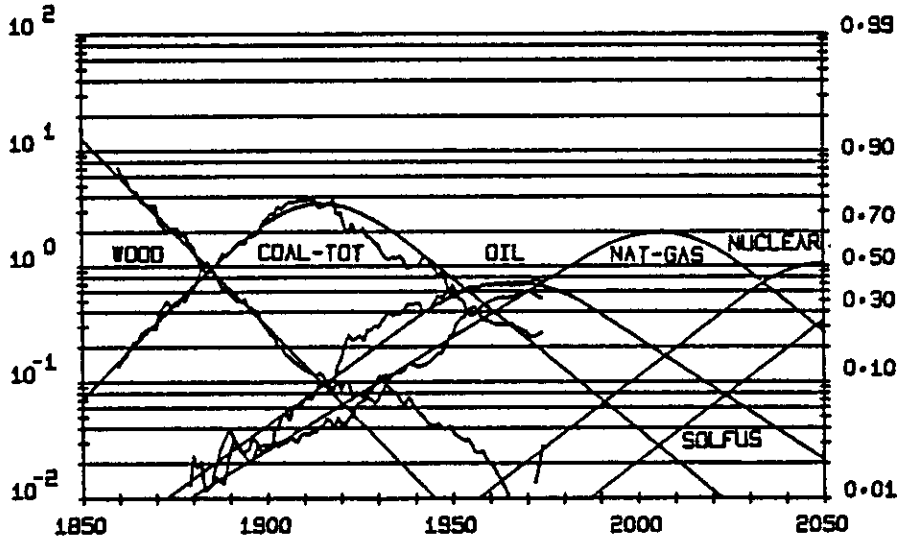
FRACTION (F)




USA - PRIMARY ENERGY SUBSTITUTION

F/(1-F)

FRACTION (F)



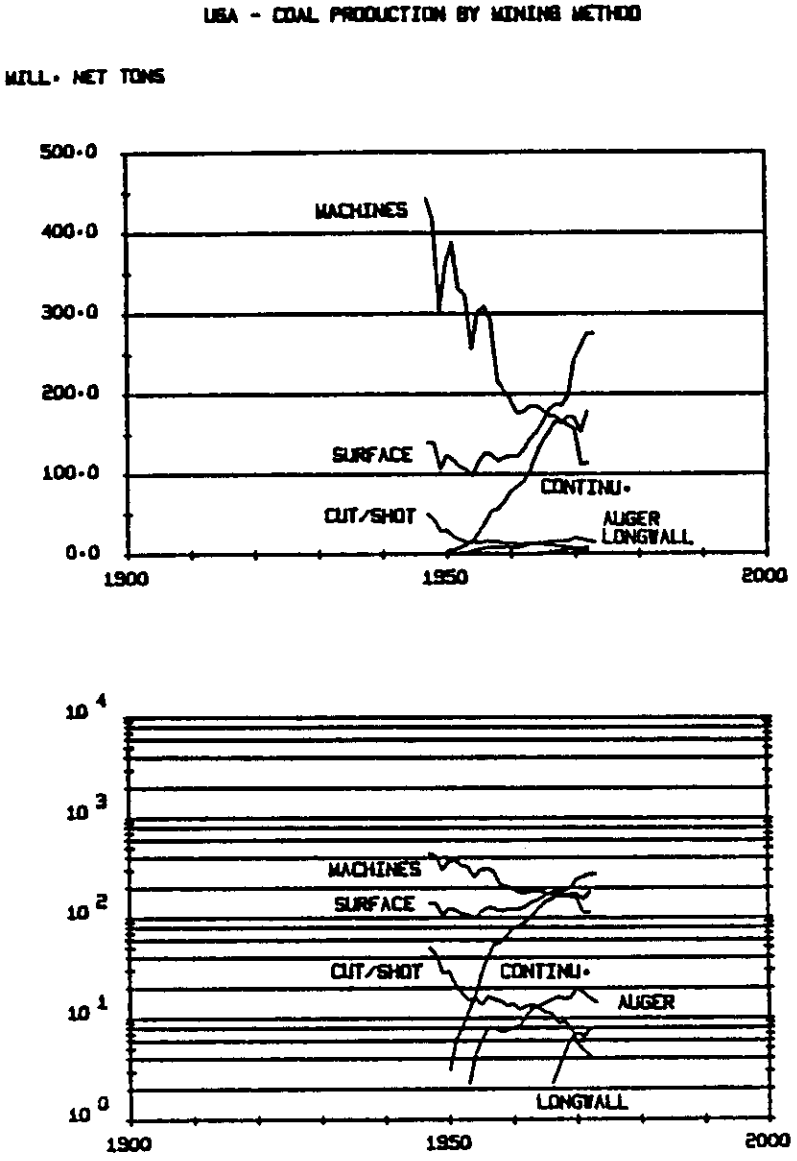
The logistic analysis again makes order out of the mess of statistical data. Substitution appears to move extremely smoothly until 1920 (facing page, top), in agreement with other economic indicators. Coal peaks around that date and oil at the beginning of the 1960s, 40 years later. As early as 1900, both peaks could have been predicted with good precision; consequently, they are not linked to forthcoming events like wars or embargos. Here, as in all the other cases examined, embargos and large price increases actually produced disproportionately small dents in the curves. The deviation in the lowest part of the wood curve is connected to a change in the statistical source, and most probably due to a change in the accounting and estimating method.

At the bottom of the facing page is a log–logistic plot of primary energy substitution in the United States. One thing left to be explained is the sudden rise in oil production, much above the trend line, essentially during the depression years. This rise induced a corresponding low share of coal, but it did not affect gas. The analysis should perhaps look deeper into the possibility that rapid introduction of automobiles may have caused the perturbation. The striking fact in the process, however, is that after a while, the perturbation was reabsorbed and the secular trend resumed in 1940, 20 years later! This again points to a system memory and clocks!

Contrary to all other predictions, natural gas appears to be the dominating energy source for the next 50 years, which leads to the question whether the United States will import more natural gas in the form of LNG, increase imports from Canada and Mexico, or whether the numerous less accessible sources, like geopressurized zones, will be exploited.

The nuclear market share in the United States was about 3 percent of the primary energy in 1974 and about 5 percent in 1977. This, however, may still not be enough to determine the long-term trend of nuclear penetration rates. By 1990, there should be about 610 GW(th) installed capacity. This estimate is based on the power plants currently under construction and those planned to be in service by 1990 (IAEA 1977). With the long-term energy consumption growth of 3 percent per year, this would imply a 15-percent share in 1990, assuming an overall utilization factor of 75 percent. To account for all possible delays, we assumed a 10-percent share by the year 2000 in our nuclear scenario.

We have also included an alternative future energy source (SOLar-FUSion) that enters the market in 1990 with the same penetration rate as nuclear. There is no basis whatsoever for this assumption, except that a new source could not reach a 1-percent market share before then. As in the world case, a change in the rate of penetration of nuclear will not change the situation of oil, and only after the year 2000 will it change that of natural gas.

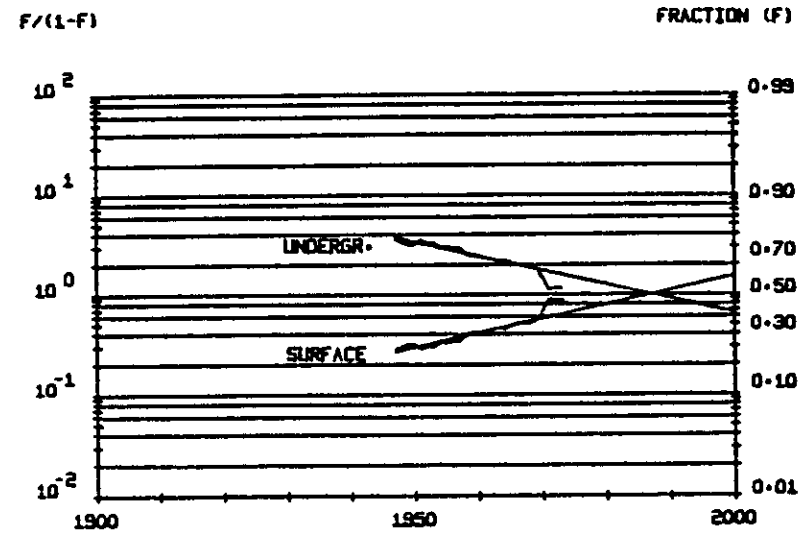


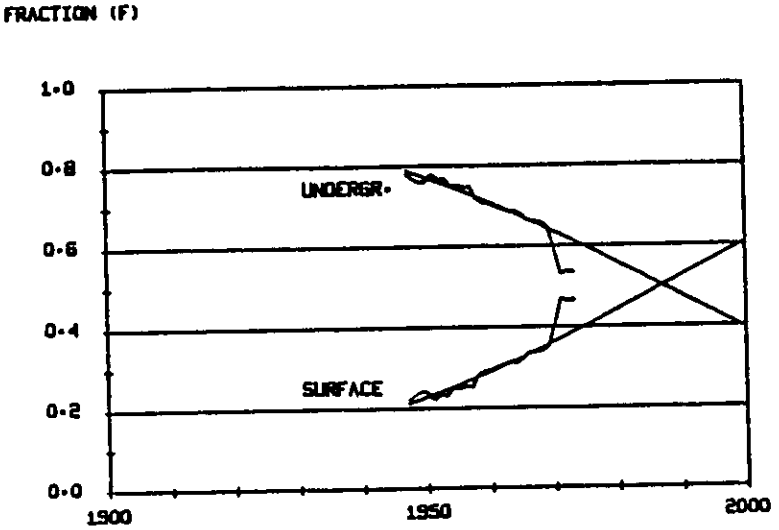

Key:

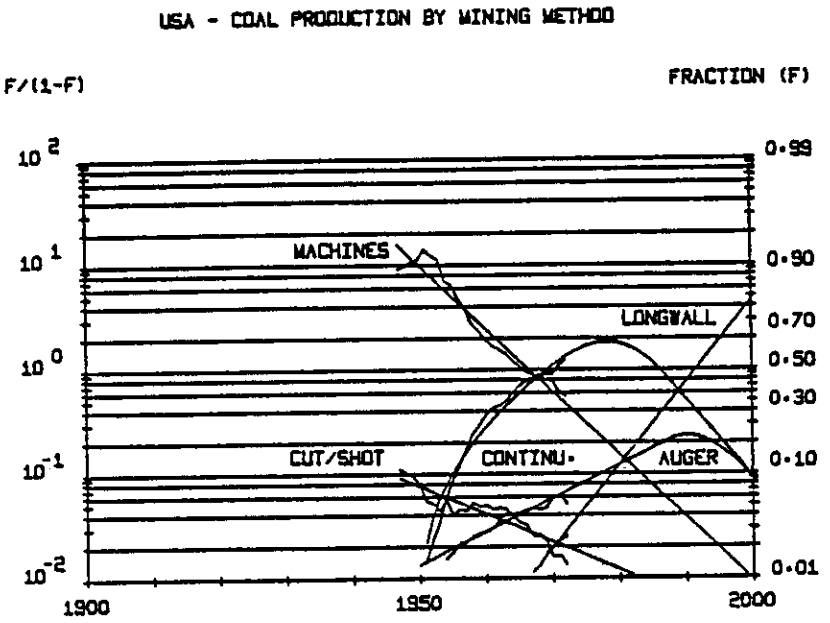
CUT/SHOT – cut by hand and shot from solid
CONTINU. – mined by continuous mining machines
LONGWALL – mined by longwall machines
MACHINES – cut by machines
AUGER – mined at Auger mines
SURFACE – from surface mines

The evolution of mining techniques in the United States is examined here. It is a very appropriate field for logistic substitution analysis. In these two figures, the amount of coal extracted according to the various techniques is reported on linear and semilog coordinates. As usual, no simple patterns appear.

USA - UNDERGROUND AND SURFACE MINING



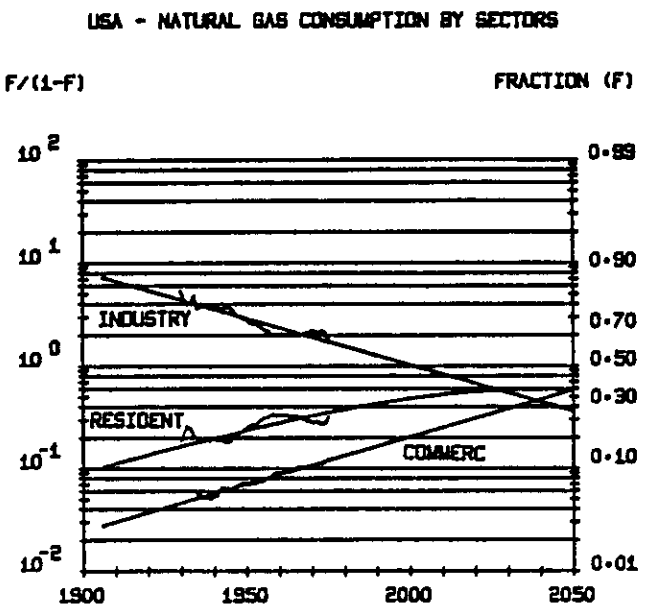






Due to the increasing dominance of strip mining, the competition between strip mining and underground mining is dealt with explicitly (see facing page). A check of the total amount extracted shows that the sharp kink in the logistic plot is due to a sudden drop in deep mining production. These sudden drops are not new in a socially turbulent structure like the U.S. mining industry, but this time it may be due to the introduction of stringent safety rules in the mines. Most probably, the perturbation will be reabsorbed in a few years. If not, deep mining would disappear in the United States in 1980, a very unlikely if not impossible occurrence. Strip mining legislation seems to bring in the corrective reaction.

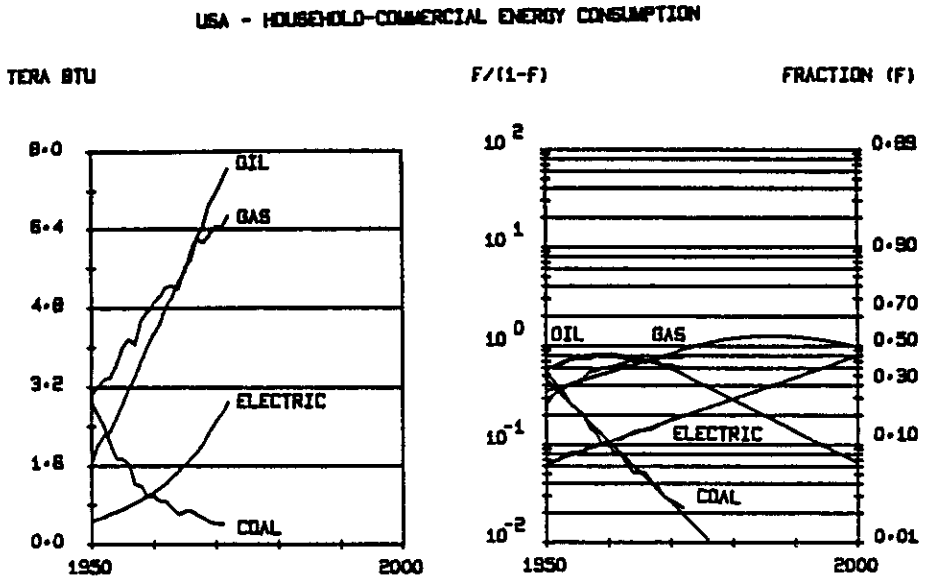
As deep mining presents such an array of competing technologies, it is interesting to analyze their struggle, leaving out all surface mining techniques except Auger, which could be considered as both underground and surface technology. The longwall technology becomes dominant in the next 20 years, winning the last battle of a lost war, as underground mining seems bound to disappear in about 50 years.

With ups and downs, coal production in the United States stayed constant over the last 50 years at a level of about $0.5 \cdot 10^9$ tons/year. Since the phaseout of coal in the United States is a slow process, during the next 20 years, the U.S. mining industry should equip longwall mines for production that is slightly larger than the total production of FRG coal mines now. The abbreviations are defined on page 42.

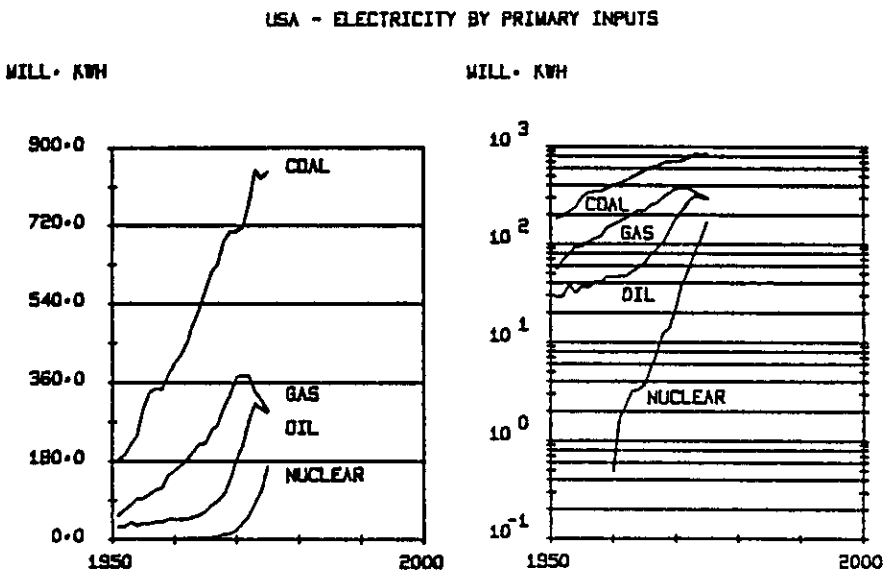



When we view the system through dynamically competing subsystems, we may think that *different branches of the economy compete for the same resource*, a statement much in line with the *Weltanschauung* of economists and laymen. In this spirit, we made a logistic analysis of the shares of natural gas consumption of three large parts of the U.S. economy: the industrial, the residential, and the commercial.

It appears that the small consumers are gradually winning a larger share of natural gas, which is quite reasonable in view of how simple it is to use and how little it pollutes. The process of competition, however, appears to have long time constants, and only in the year 2050 will the natural gas input be equally distributed among the three competitors.

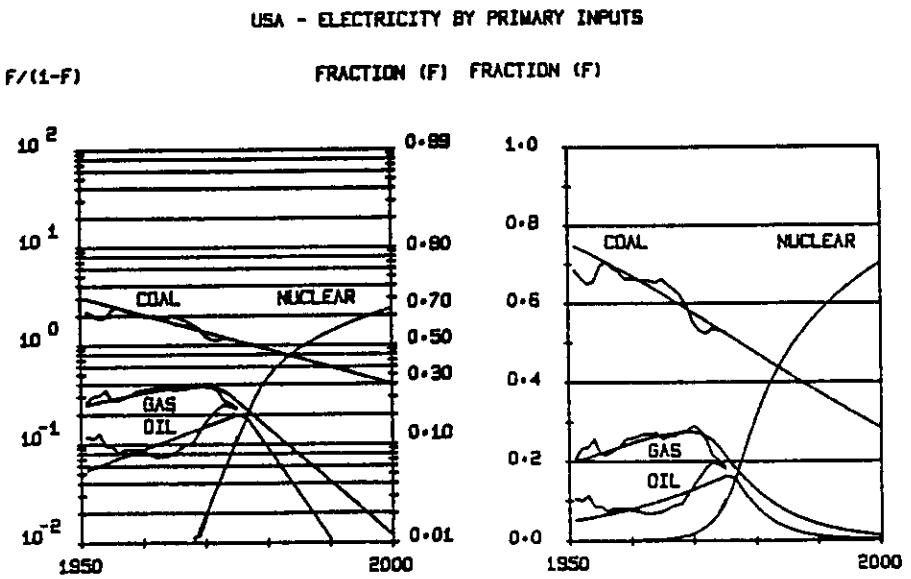



Reversing the previous reasoning, one can think that the various forms of energy compete for a certain sector. In this case, it is the household–commercial sector.



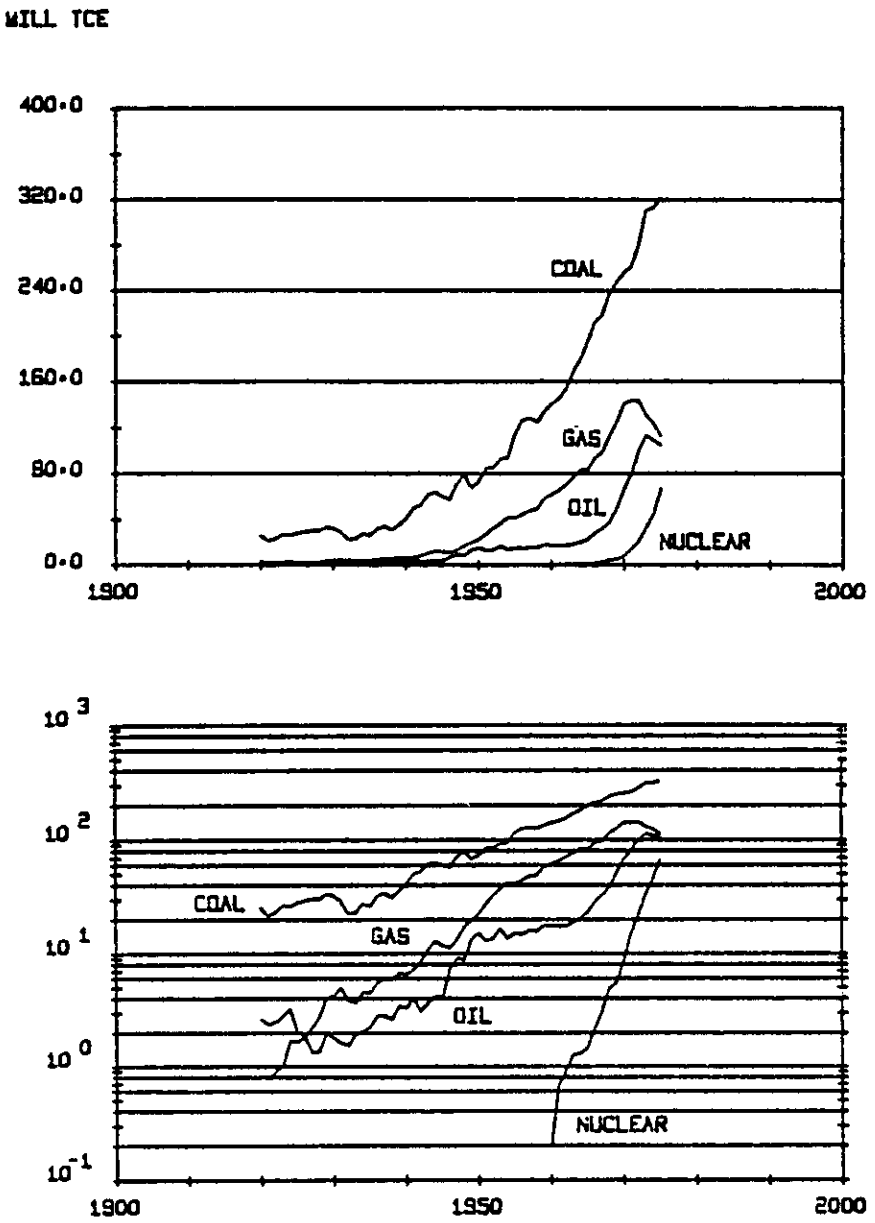

The electrical utility market is very important for primary energy producers. It is large, fairly homogeneous, highly technological, and rather profitable. Therefore, it is a good test-bed for observing the progress of new technologies. In these two figures, we plotted the evolution during the last 25 years of the production of electricity according to the various primary fuels, both in linear and semilog form.

The historical data on electricity generation according to primary energy fuels in millions of kilowatt hours (kWh), as well as the data on primary energy consumption for electricity production in billions of British thermal units used later in this report, have been taken from the U.S. Bureau of the Census (1975, 1976, 1977). The two data sets show implicitly the relative conversion efficiencies for electricity generation according to the various energy inputs used.



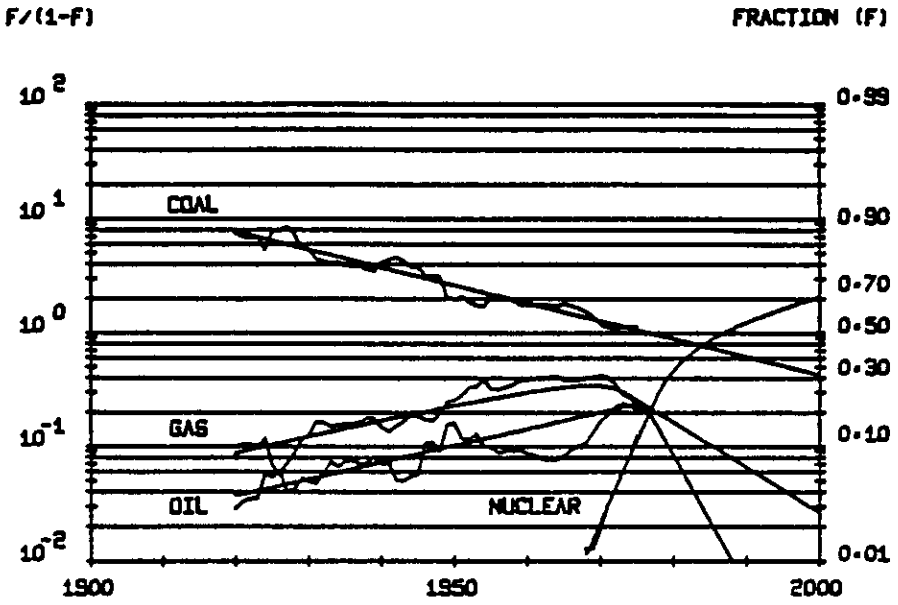

Electricity generated using coal, oil, or gas is shown here in a logistic representation. This is an indirect way of showing the competition of the various primary energies.

USA - PRIMARY INPUTS TO ELECTRICITY

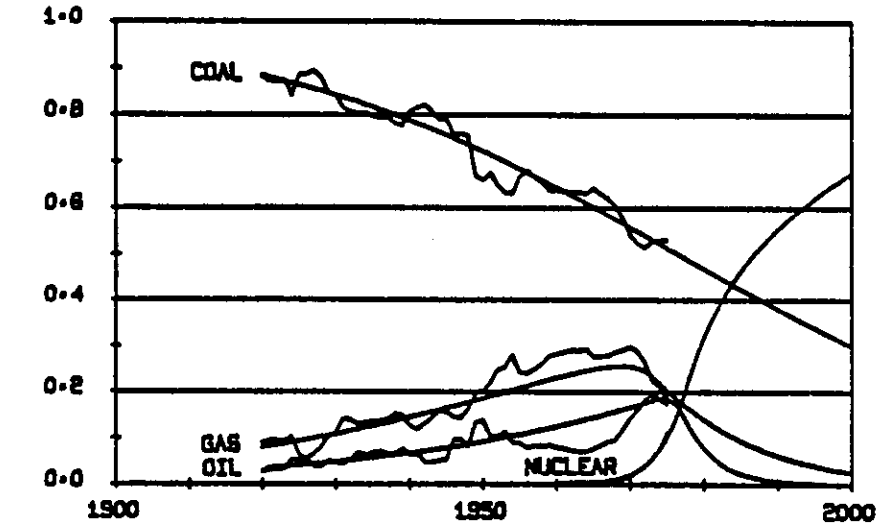


Here the competition is expressed more explicitly in terms of millions of tons of coal equivalent (tce) of different fuels entering the electricity market. It is clear that coal has been under constant attack by oil and gas, which have progressively eroded its position. A perturbation appears in the period from 1955 to 1970, showing an excessive consumption of gas with respect to oil. This may appear strange since during this period oil was "cheap and abundant." But in the United States, gas was still cheaper because of stringent price regulation. Oil recovers, however, and regains its position from 1973 to 1974!

USA - PRIMARY INPUTS TO ELECTRICITY



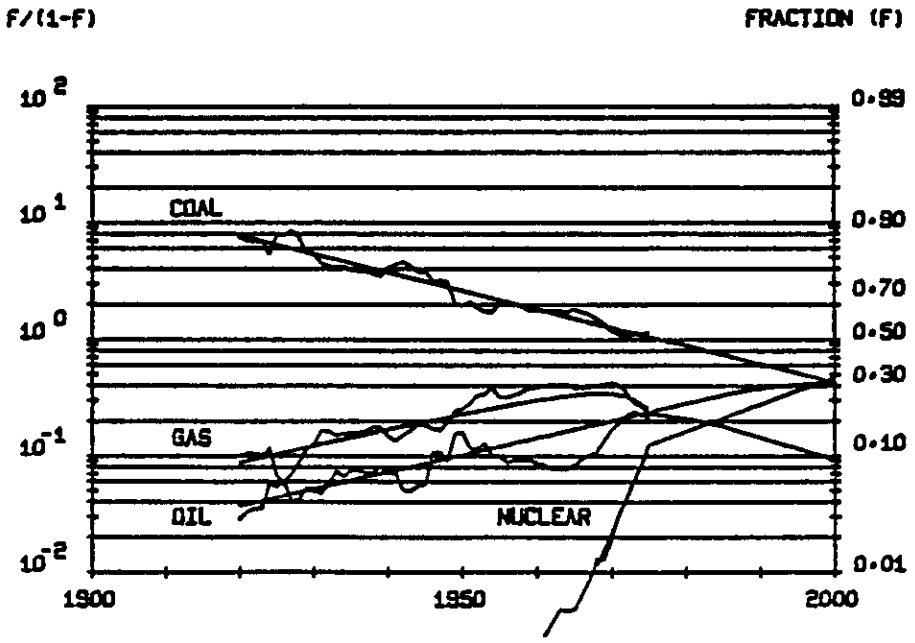

USA - PRIMARY INPUTS TO ELECTRICITY



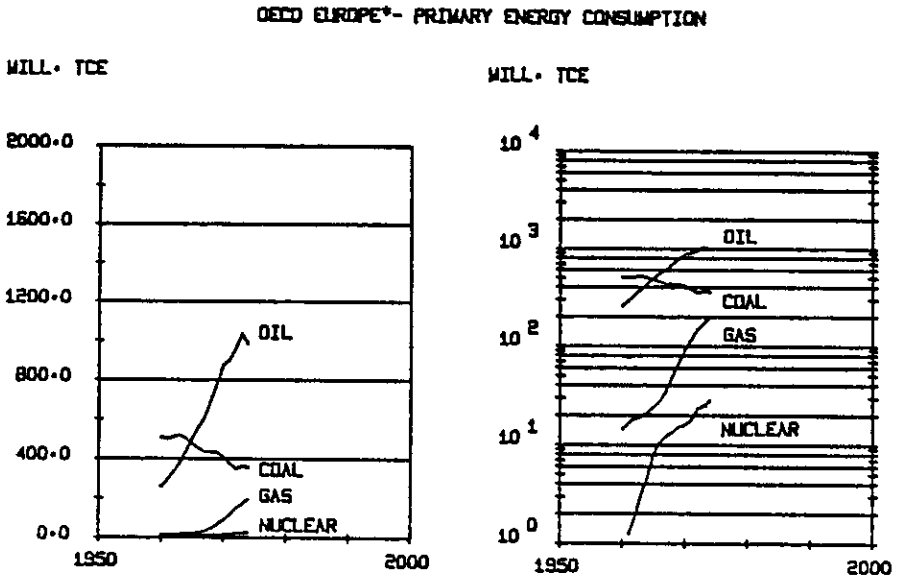
The substitution of different primary inputs in electricity generation is discontinuous when nuclear enters the market with a powerful drive and phases out oil and gas before the end of the century (facing page, top). Coal appears perfectly unperturbed and finally dictates the pace of introduction of nuclear from 1980 on. It is interesting, even if a little shocking, that this pace had been finally determined by the penetration rates of oil and gas *in the twenties*. Many problems surface from the expected structure of the system in the next 20 years. For example: What kind of peaking system will be provided? Will it be through medium-Btu gas from coal and gas turbines or through storage?

The lower figure on the facing page reports the same results but in linear terms in order to make it easy to interpret. Connected with the fast substitution of nuclear energy in the electricity market is the possibility of a kink in the nuclear penetration curve during the coming years, leading to lower market substitution and a smooth transition.

USA - PRIMARY INPUTS TO ELECTRICITY

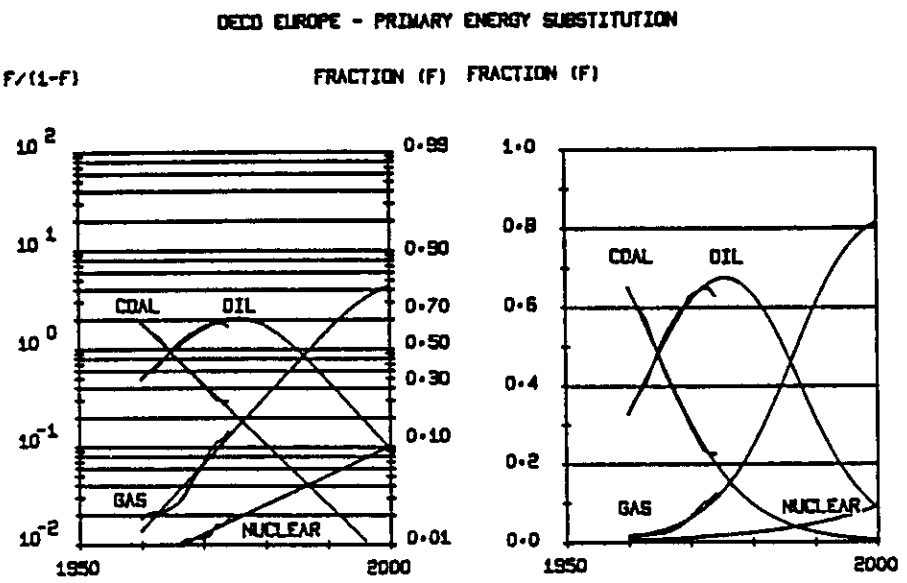


When the nuclear energy penetration of the market is plotted starting with a market share lower than the 1-percent share reached in 1967, no change of the substitution rates can be observed; in most other examples, nuclear energy and natural gas stabilize to a slower penetration rate once they take a few percent of the market (e.g., for nuclear energy see pages 31, 33, and 36, and for natural gas see pages 33, 36, 63, and 66). Assuming that this kink will occur before the end of this decade, we observe higher natural gas and oil shares, and coal remains unaffected. The nuclear share in the year 2000 is more than halved to about 30 percent. This slower penetration of nuclear energy has been determined by a scenario based on the nuclear share in 1976 and the expected share in 1990 calculated from the nuclear installed capacity under construction and the planned power plants (610 GW(th); see page 41), and the historical growth of the electricity market at 6.2 percent per year. The result is sensitive to the value for that historical growth.



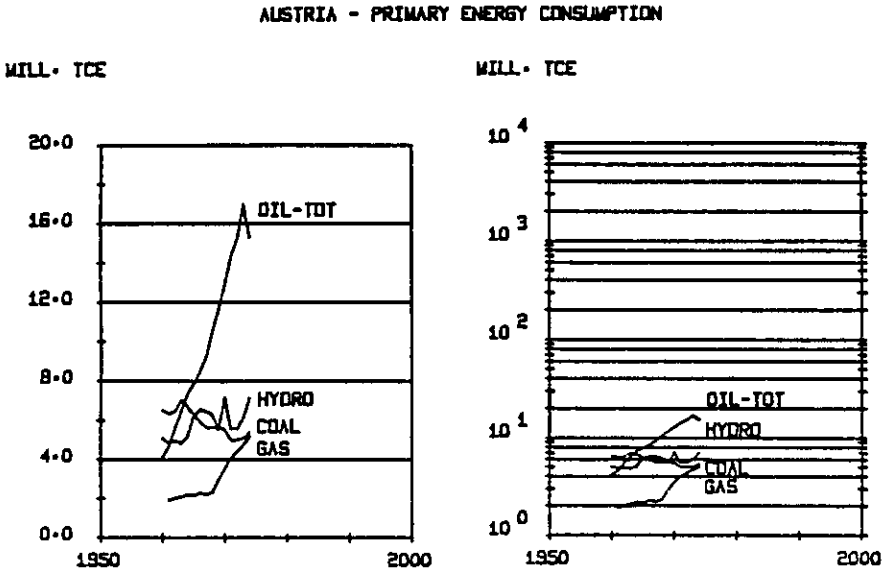

The data come from the OECD (1976). We made a logistic analysis for the European OECD states lumped together and for some of the states separately. The data base is relatively short, 15 years, but the curves appear very stable. The overall OECD case is presented here.

*Austria, Belgium, Luxemburg, Denmark, Finland, France, FRG, Greece, Iceland, Ireland, Italy, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland.




The logistic analysis for OECD is presented here in the log and linear form. Coal and oil behave very regularly. Natural gas has prolonged the start-up vagaries up to 10 percent of the market. The fact that it shows a penetration rate virtually identical to that of oil is a sign that tends to confirm the good quality of the projections. Nuclear has penetrated only to 2 percent; consequently, the projection is still somewhat uncertain. Any change in rate, however, would not change the projection that gas will become the next dominant primary energy source.

Two facts emerge; one is that natural gas, with a penetration rate much similar to that of oil, appears to be the primary source in the year 2000. It appears to drive oil to an impressively low level of 10 percent in that year. Second, the curve for nuclear seems quite regular, although the definition of the final substitution rate is still open owing to the current low level of penetration. With the present rate, nuclear would reach a somewhat unimpressive share of 10 percent of the market in the year 2000, leaving Europe completely dependent on hydrocarbons. SOLFUS has not been included as a scenario. It would possibly make nuclear saturate the market during the first half of the next century.

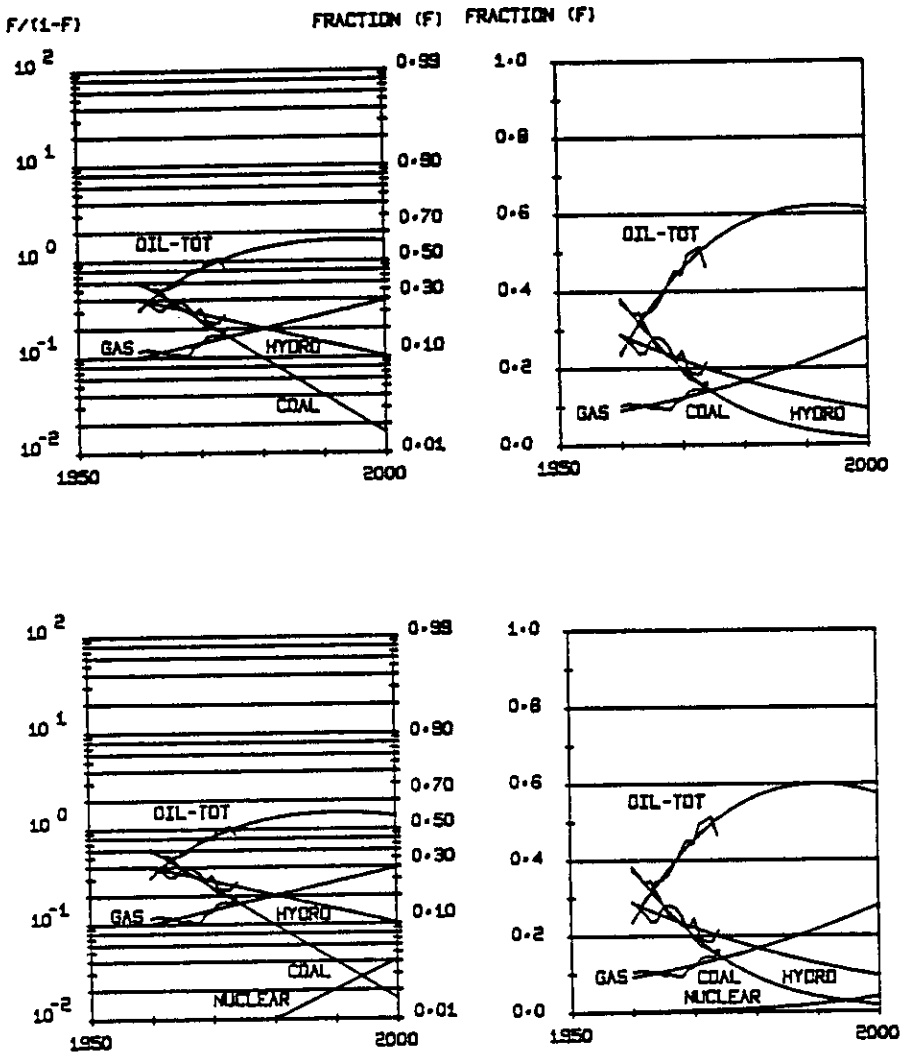



The primary energy consumption for Austria displays minimal dispersion except for rapid growth in oil consumption. Hydropower has been included in the set of primary energies because it is quite an important energy source for Austria. The market appears dominated by oil, with natural gas still low but increasing fast.

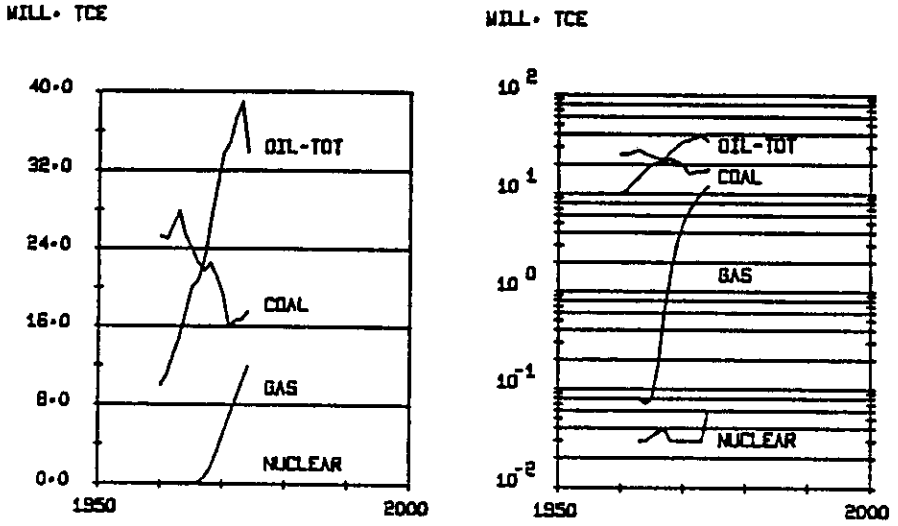
On the facing page, the data are presented in the log and linear logistic format. In the first row, no new sources are introduced. This may not have many consequences before the year 2000 because the time constant of the country appears to be so large (about 100 years). The situation with respect to nuclear is extremely confused. One power station was built but is not in operation owing to a referendum. No second power station is in sight, but nuclear electricity is being imported from neighboring countries.

The figures in the second row should then be considered as a sensitivity analysis indicating the potential influence of nuclear energy on the other primary sources. If we hypothesize a 4-percent penetration in the year 2000, the medium-term effect would be a slight reduction of oil imports. Gas consumption would be affected only after 2020. Only an improbable, very fast nuclear penetration could make Austria reasonably independent of oil in the next 30 years.

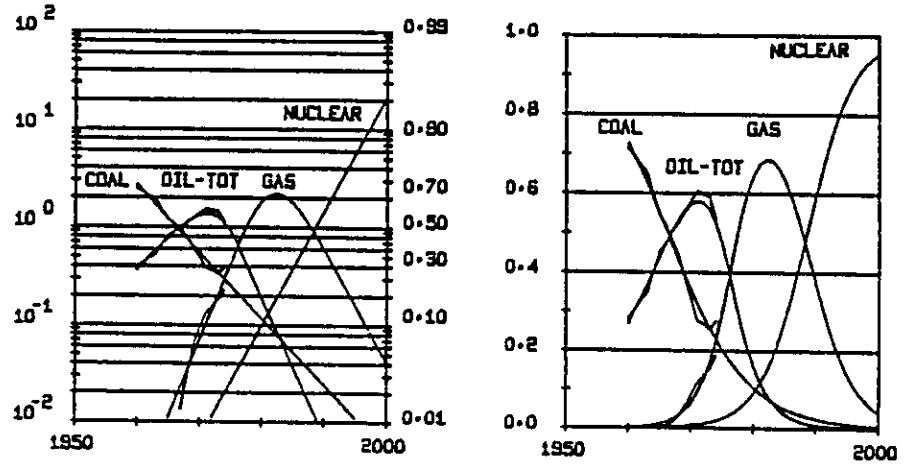
AUSTRIA - PRIMARY ENERGY SUBSTITUTION



BELGIUM - PRIMARY ENERGY CONSUMPTION




BELGIUM - PRIMARY ENERGY SUBSTITUTION

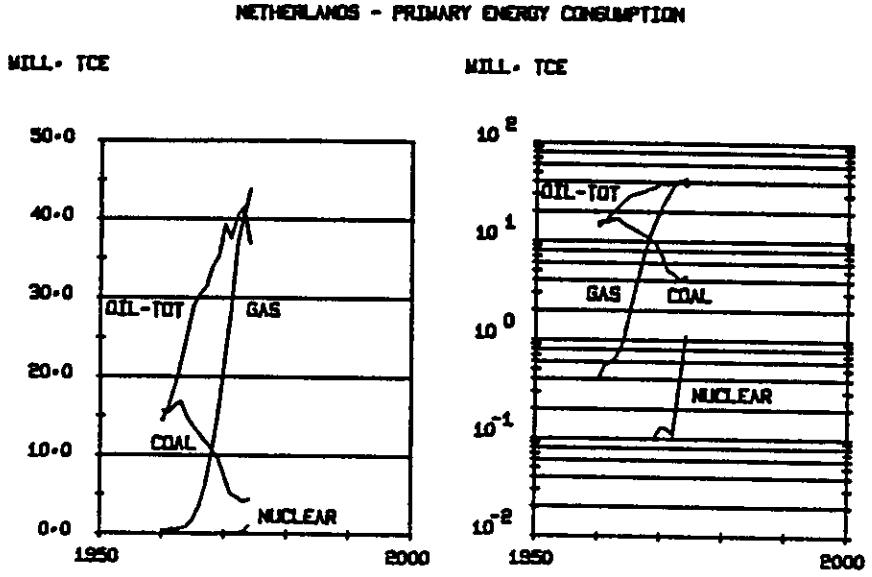


Without logistic analysis, the data on primary energy consumption in Belgium suggest that oil is the dominant primary energy, with no limits to its future (upper figure on the facing page). Coal is rapidly phasing out and gas is phasing in. Nuclear is barely perceptible (in 1974).

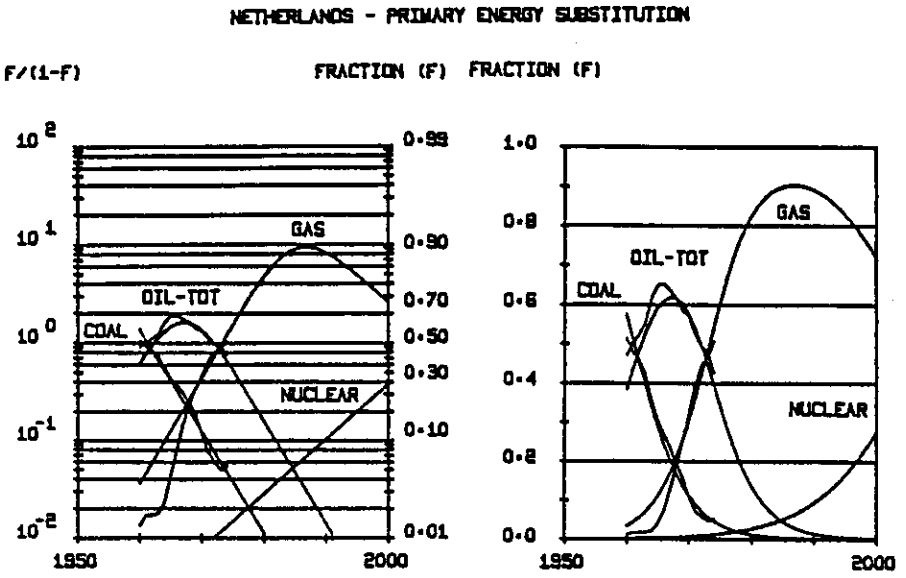
In the lower figure, logistic analysis reveals the hidden order. Although the data cover a short period of time, the good quality of the fit gives weight to the following considerations.

Coal seems to disappear around the year 2000, which is more or less in line with the ideas in the country. Oil, including the trade balance in oil products, peaks around 1973 and seems to phase out in 1990. This prediction, which, by the way, repeats itself in a similar form for the Netherlands, the FRG, and the UK, is a bit hard to swallow on technical grounds. How will cars run in 1995? Will they use increasing amounts of methanol produced from coal and natural gas? This would in fact preserve their compatibility with gasoline, necessary at least for long-distance traveling. If coal is the primary source, a new curve may be required for underground coal gasification, i.e., for new coal. Electric, hydrogen- or methanol-electric, and pure hydrogen cars are in principle possible, but do not seem very probable in this time period.

We could also have overestimated the rate of penetration for gas. External interests prop up the penetration of a new technology at very high rates, usually until it has penetrated a few percent of the market. One could make the hypothesis that a particularly favorable environment, in this case the prior existence of an efficient distribution net for gas, and the spacial concentration of population, has prolonged this initial stage up to 10 percent. Yet, a change in the penetration rate from that point would only delay the disappearance of oil by a few years. A similar tampering with the rate of penetration of nuclear, which is still fairly hypothetical because of many lingering doubts, shows other possible small gains, but is not really decisive. So the problem is substantially left open. If we believe in the predictive capacity of our methodology, something fairly drastic will occur in the automotive field during the next 20 years, and the focal area will be in Belgium, the Netherlands, or the FRG.

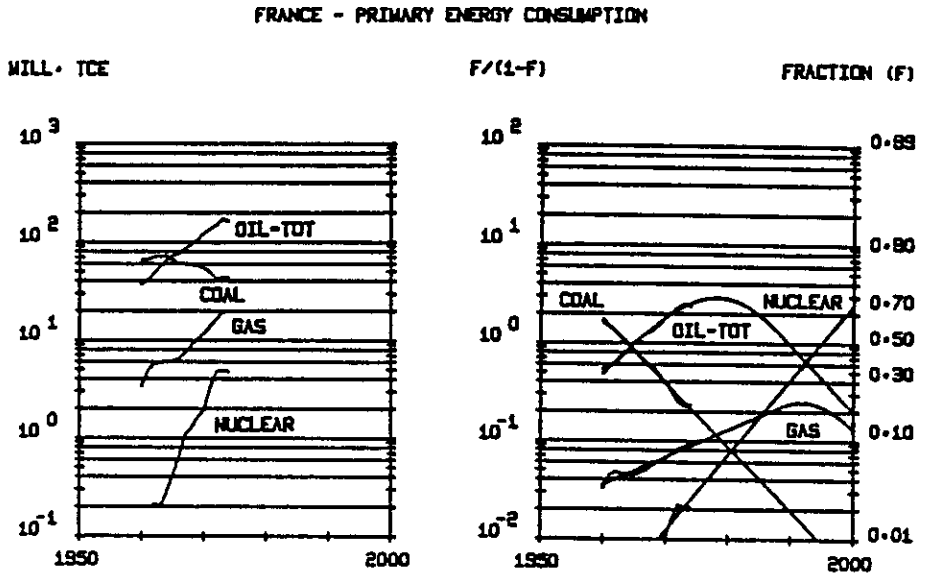



Primary energy consumption in the Netherlands is here reported by primary source, in linear and semilog form to stress the starting period. No particular tendency emerges; coal is phasing out and oil is phasing in. Gas made a very fast inroad after the discovery of the Gröningen field. Nuclear is just emerging.

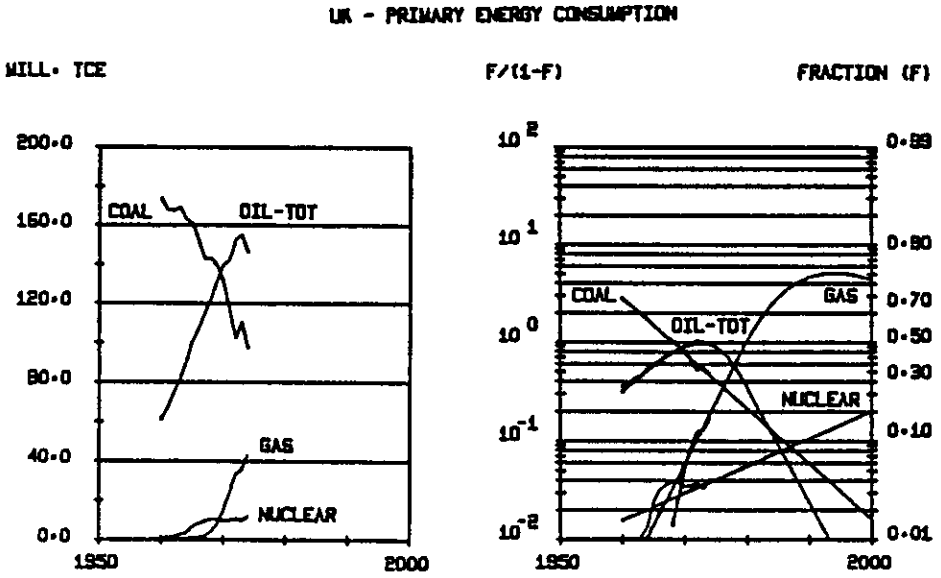



The logistic analysis shows here a quite precise structure. Coal is bound to disappear in 1980 and oil in 1990, opening the question about cars discussed already in the case of Belgium. The problem of nuclear is perfectly open and our scenario is pure guessing. It must be clear that if nuclear electricity is imported in spite of antinuclear opposition, nuclear should still be included in the energy budget. However, since natural gas has such a dominating role, the rate of introduction of nuclear energy will have little influence on the fate of oil. Thus, the car question is left open.

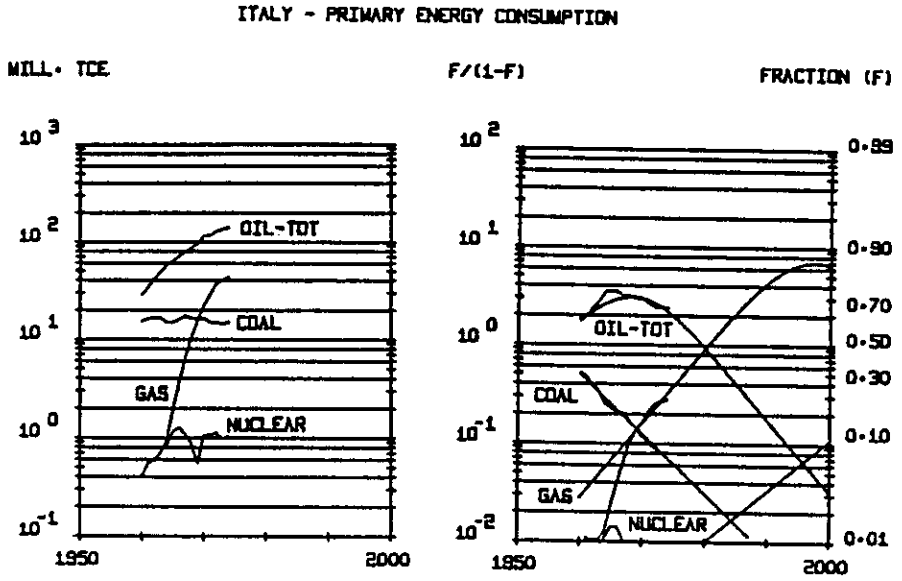
Seen in the light of our analysis, the Netherlands' alternatives appear to be natural gas or nuclear, and, thus, one understands better the importance of the debate about nuclear energy.




The primary energy substitution for France is repeated here using OECD data sources. The result is substantially the same as on page 33, although different data and a shorter data base are used, which leads to minor discrepancies in the long run. For the nuclear scenario we estimated an 8-percent penetration in 1980, which comes from the fitting of the data, although the current market share is still below 2 percent. However, nuclear energy is growing fast in France and the situation should become clear in a few years.

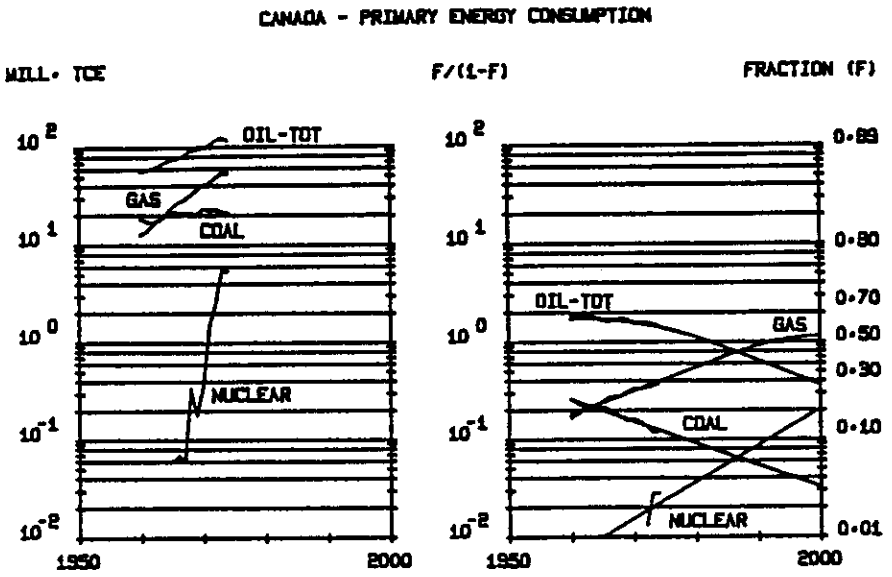



The primary energy substitution for the UK is repeated here using OECD data. In spite of some discrepancies with other data sources, the predictions differ only in relatively small details from those on page 36. Even if nuclear should penetrate the market more rapidly, it would produce only a small dent in the dominance of gas during the next several decades.



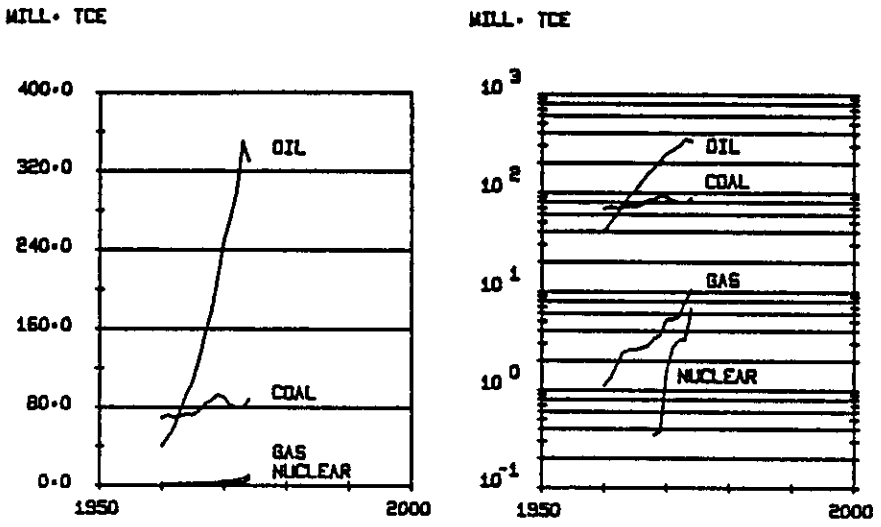

The primary energy consumption (left) and substitution (right) for Italy are shown here with a 15-year OECD data base. The penetration of nuclear energy (10 percent by the year 2000) is hypothetical and based on the assumption that Italy will not be very different in that respect from other European OECD countries.

The future appears very bright for gas to reach dominance in the next decade. Although this is supported by the efforts to link Italy with the Netherlands, the Soviet Union, and North Africa, via a pipeline under the Mediterranean, it is certainly beyond the rosiest plans of the gas industry. If we assume that gas growth was "forced" up to 10 percent and consequently fit the logistic with later data, and set nuclear penetration (improbably) as fast as gas, we reach a more acceptable but not very different conclusion.

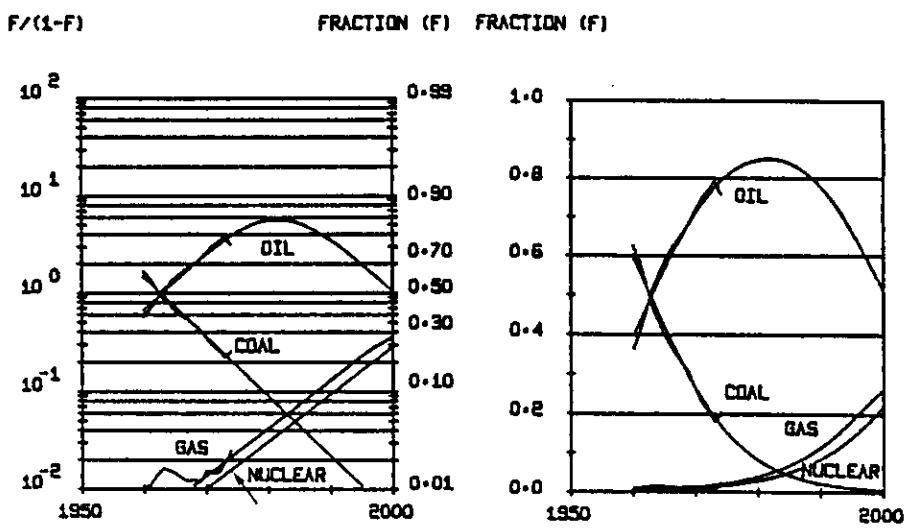



The primary energy consumption data for Canada do not show any particular pattern, except a very fast inroad of nuclear energy, although at a relatively low level. The logistic analysis reveals extremely smooth transitions, much similar to those of Austria, with time constants on the order of 70 to 80 years. In spite of Canadian devotion to nuclear energy, we drew a prudent scenario, assuming about 16-percent nuclear in the year 2000. As in most of the world, gas appears to peak and become dominant in the year 2000.

JAPAN - PRIMARY ENERGY CONSUMPTION




JAPAN - PRIMARY ENERGY SUBSTITUTION



The primary energy consumption data for Japan are taken from the OECD and cover the period 1960 to 1974 for coal, oil, natural gas, and nuclear; they are all expressed in millions of tons of coal equivalent (tce). The oil data include consumption of crude oil and petrochemical products. Nuclear is just beginning. Today there are 20 GW(th) of installed capacity (IAEA 1977), amounting to about 2 percent of primary equivalent.

In spite of Japan's unique situation as a country with very large, recently developed industry linked to an almost complete dependence on imports, the primary energy substitution shows nothing very unusual. *Coal* is being replaced by oil, a trend begun after World War II that appears to end in the nineties. The dependence on oil is fundamental, but only a little higher than that of France and similar to that of Italy. Oil starts to saturate now, as the equations could have predicted (using data before the oil crisis!). According to the equations, oil should be phased out around 2030, much later than for France or Italy.

*Gas* enters the scene somewhat late, at the end of the sixties, perhaps because it has to be imported using the complex technology of LNG. Perhaps for the same reason it does not seem to play the same central role as in Europe or the United States. According to the equations, it should peak around the year 2010, in consonance with the world peak.

*Nuclear* is fairly hypothetical, although we have tried to use the various forecasts prudently. The isolated point near gas (see arrow) indicates the actual situation. With nuclear penetration reaching 10 percent in the nineties, the rate coincides with that of other fuels. Nuclear would then become dominant during the first half of the next century, even if a new source is introduced around the year 2000.

Today there are 20 GW(th) of installed capacity (IAEA 1977), amounting in terms of primary equivalent to more than a 2-percent share. Additional plants with a total installed capacity of 27.6 GW(th) are under construction and should be in commercial operation by 1982. Another 14.7 GW(th) are planned to be available by 1984 (IAEA 1977). Assuming that the long-term energy consumption growth prevails during the next decade and that the utilization factor is 75 percent, we project a nuclear share of about 7 percent by 1984. Our scenario of the long-term nuclear penetration rate assumes that licensing and political and construction problems will lead to delays. Thus, we predict a 7-percent share 4 years later in 1988.

At the turn of the century, oil, gas, and nuclear appear to share the market equally, which implies an extraordinary advance in the technologies of transporting natural gas (or some derived products?) overseas and a virtual saturation of the electricity market by nuclear power stations.

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