ON THE LONG-TERM HISTORY OF ENERGY MARKETS AND THE CHANCES FOR NATURAL GAS

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FOREWORD

Many of today's most significant socioeconomic problems, such as slower economic growth, the decline of some established industries, and shifts in patterns of foreign trade, are inter- or transnational in nature. But these problems manifest themselves in a variety of ways; both the intensities and the perceptions of the problems differ from one country to another, so that intercountry comparative analyses of recent historical developments are necessary. Through these analyses we attempt to identify the underlying processes of economic structural change and formulate useful hypotheses concerning future developments. The understanding of these processes and future prospects provides the focus for IIASA's project on Comparative Analysis of Economic Structure and Growth.

Our research concentrates primarily on the empirical analysis of interregional and intertemporal economic structural change, on the sources of and constraints on economic growth, on problems of adaptation to sudden changes, and especially on problems arising from changing patterns of international trade, resource availability, and technology. The project relies on IIASA's accumulated expertise in related fields and, in particular, on the data bases and systems of models that have been developed in the recent past.

In this paper, Cesare Marchetti presents a review of the development of world energy markets over the last two centuries. This is then used as a springboard for projections of the likely future penetration of natural gas. Marchetti's hypothesis is that society can be viewed as an ensemble of component structures engaged in Darwinian competition; his analysis leads to interesting and perhaps surprising conclusions on long-term energy price stability, the future role of natural gas, and the vexed question of whether or not there really is a global energy shortfall.

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Project Leader
Comparative Analysis of
Economic Structure and Growth

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INTRODUCTION

Tradition gives a sense of security, and a sense of security is badly needed in the battered area of energy. So I will delve into tradition, i.e. the last couple of centuries, to detect the constant factors and try to answer these prickly questions from a solid, long-term perspective.

I must say the image I will draw is basically reassuring. Energy will not be short during our lifetime and, quite possibly, it never will be. Politics apart. Prices have remained curiously constant, in constant money, over the centuries, with relatively short spikes. The OPEC spike will be reabsorbed in the next few years. The market penetration of new primary sources proceeds with the stately speed of glaciers and never runs uphill. So we are safe from the devilish return of coal, and also from "green" concoctions. Natural gas will be the fuel of our lifetime, with nuclear slowly increasing its share and the rest slowly fading into oblivion. All that will emerge from the maze of cycles and epicycles that make Western society such an admirable and predictable clockwork system.

These results have been obtained using a single heuristic hypothesis: *Society can be decomposed into formal structures that compete in a Darwinian way.*

THE ENERGY MARKETS

Let us begin to analyze the energy market at the world level. After all, the supertanker has made energy a world commodity. Following our hypothesis, the primary energy sources, such as wood, coal, oil, gas, and nuclear, can be seen as "structures", i.e. socio-techno-economic networks, competing to conquer the energy market. The struggle can be displayed if we measure the market and the sources in homogeneous terms, like tons of coal equivalent, and if we plot the various market shares versus time. Energy consumption by source is given in Figure 1, and shares are reported in Figure 2, where the basic equation of competition, $\log F/1-F = at + b$, is used to fit the data. F is here the share of one of the competitors (usually the winner), and $1-F$ is that of the other. The parameter a expresses the rate of the penetration, and b locates the process in time (Marchetti and Nakicenovic 1979).

In the case of Figure 2, where various competitors are present at the same time, the arithmetic is slightly more complicated formally, but the substance is the same (Nakicenovic 1979). We are now dealing with simple solutions of the Volterra-Lotka differential equations for ecological competition (Montroll et al. 1971).

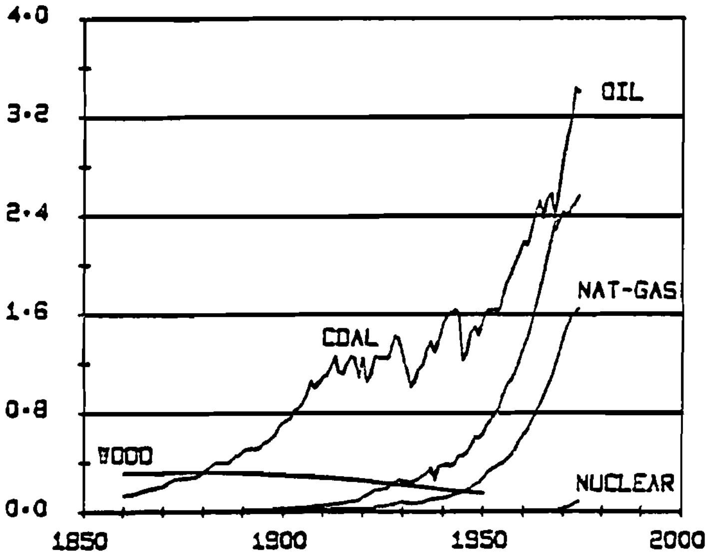


FIGURE 1 World primary energy consumption (10^9 tce).

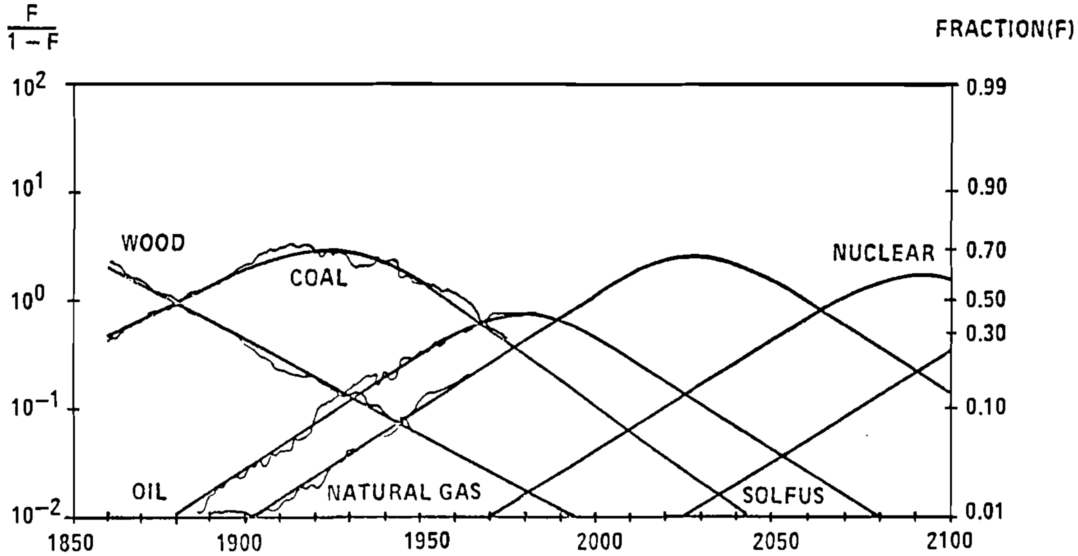


FIGURE 2 World primary energy substitution.

Some of the reassuring features announced in the Introduction can be already seen by inspecting Figure 2. Straight lines that span a century mean that the rate constants a have stayed constant, i.e. that the behavior of society toward acceptance or rejection of a certain type of primary energy did not change for a century. Which is remarkable, to say the least.

These equations involve two parameters, as we have seen, and consequently only two points, e.g. the data for two years, are in principle necessary to fit them. Because the data are noisy, as can be seen from the wriggling lines in Figure 2, longer swaths are needed to smooth out the noise. Figure 3 shows an experiment in forecasting and "backcasting" using a swath of twenty years, between 1900 and 1920, as a data base. The inputs are the wriggling lines in the grey area. The equations, represented by the smooth lines, are fitted using them. The data outside the grey area have been superposed afterwards. This particular example shows the remarkable capacity of this competition model to forecast and backcast primary energy market structures even fifty years forward and backward. There is nothing magic in it, except for the fact that aggregate social behavior is incredibly stable. Just like in physics, where the individual drives and actions of single molecules are balanced and compensated, resulting in the smoothness and stability of thermodynamic laws.

I keep stressing the question of stability because it is a necessary concept for supporting the bright future of natural gas expressed in the right side of Figure 2. And I would like to strike the nail once more.

People living in a given era tend to think it represents the high point of human history, and is quintessentially different from anything that went before. In our own era, World War II is seen as marking a fundamental break for Western societies.

To dispel this excessively proud and widespread sentiment, I present Figure 4, where the hundred years *before* World War II are backcast, using only data from the period *after* 1945 to fit the equations. If our world were really different, we could not extract from it such vital and precise information about the past.

My arguments are not confined to what is shown in world processes. The same type of analysis can be done for substructures, such as nations or industries, and for technologies competing inside industries, or even in the field of science. After a lecture I gave at CERN in Geneva, the capacity of various machines to seduce customers was analyzed in the same way with excellent results. At present, I have a portfolio of about four hundred cases, mostly studied at IIASA, showing the breadth and precision of this exceedingly simple and powerful tool of analysis. Surely, Darwin did not expect to have gone so deep. Some of these result are reported in Marchetti (1980a, 1983a) and Sanford (1983).

THE EXPANDING RESOURCES

The previous considerations refer to the structure of the market but say really nothing about quantities and their relation to physical resources. Certainly, multiplying market fractions by market size, we get absolute quantities, but for market size prediction I could not find an equally stringent logic.

For the world market, totals including noncommercial energy are reported in Figure 5. The only clear pattern here is that in the last century or so, energy consumption grew quite steadily by 2.3% per year. The simplest decision is to assume "business as usual" for the future. To err on the pessimistic side, I assumed 3% annual growth for the future considered. I feel that these figures

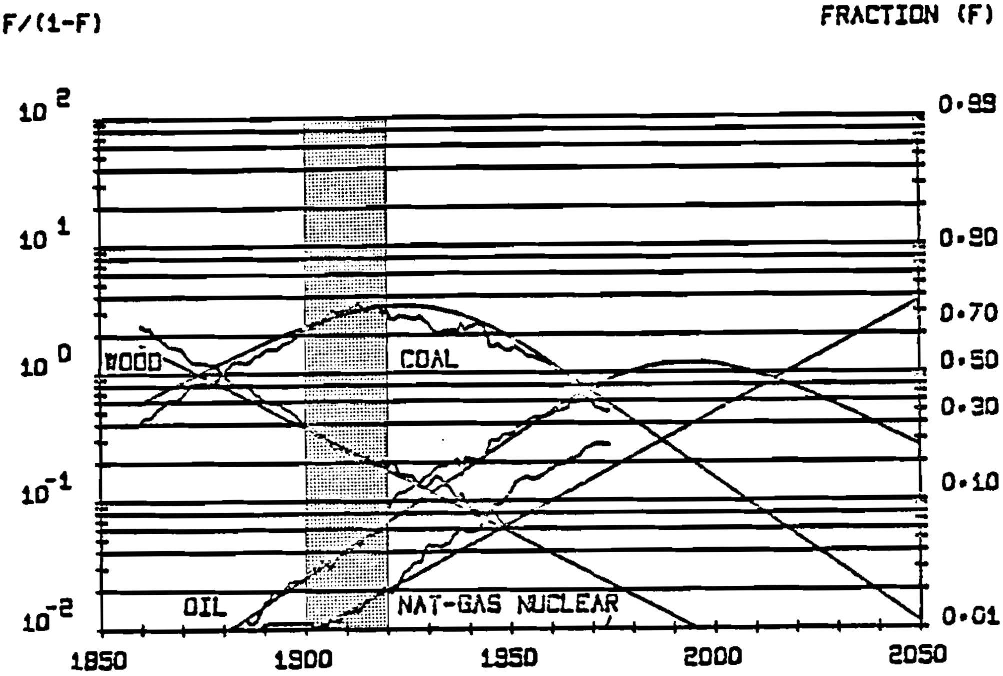


FIGURE 3 World primary energy substitution (short data).

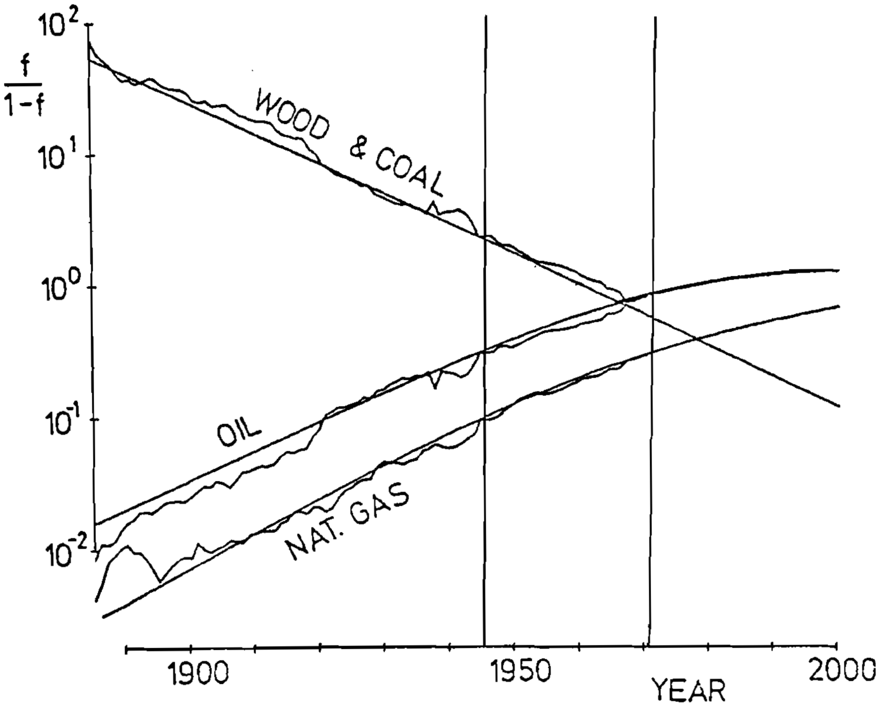


FIGURE 4 World primary energy "backcasting" from postwar data (after Peterka).

are fairly safe, since through analyzing in detail the development of energy use I found that much of the virtual expansion came via increasing efficiency in use. And mean (second-law) efficiency of energy use for society as a whole is still low – less than 5%. Consequently, a lot of expansion is still possible there.

Taking the assumption at face value, and multiplying the fractions of Figure 2 by the totals of Figure 5, we obtain the physical quantities shown in Figure 6 for each of the primary energies, homogeneously expressed in tons of coal equivalent. The smooth lines are the products of the equations and the wriggling lines as usual represent the statistical data.

TABLE 1. Cumulative world energy consumption (10^9 tons of coal equivalent).

	Wood	Coal	Oil	Natural Gas	Nuclear	Solfus[a]	Rejected Atmos. CO_2
1860–1974 2.3% growth rate	25	125	55	25	0.4		65
1975–2050 3% growth rate	2.5	80	210	550	750	250	190
Reserves		1000	100	100			
Resources	30[b]	10000	400	300			

[a] Solar, fusion, etc.
[b] Renewable annual output.

Assumptions on market shares:	Nuclear 1% in 1970 and 10% in 2000; Solfus 1% in 2000 and 10% in 2030.

In this exercise I make integrals over periods of time and compare this demand with resources and reserves, as reported in Table 1. This comparison is interesting because, for example, it explodes the myth that the driving force for exploiting new primary energy sources is the exhaustion of the previous ones. This is certainly not true for wood and coal, where resources are such, at the world level, that we could happily run our system on either of them for a considerable number of years ahead. And also for oil, there is no physical reason for a downturn. Incidentally, as shown in Table 2, estimates for final reserves have kept increasing since 1940, which is just a manifestation of our slowly growing knowledge about the location of oil deposits. As shown by Menard and Sharman (1975), this knowledge is really acquired mostly through drilling and, from this angle, the Earth's crust is mostly unexplored. A palpable hint of the truth of such statements is Table 2, which reports oil findings per meter of exploratory wells drilled in various parts of the world. Not only virgin Africa, but also worn-out Europe fare outstandingly well.

Before leaving these global considerations, I would like to present a piece of evidence, which points to the dominance of subjacent physical rather than monetary indicators. The sinusoid in Figure 7 is the fit to deviations in electricity and total energy consumption with respect to the secular trend in the United States. The line with peaks over it is the indexed (up to 1880) and constant-money price for energy in the United States or on the international

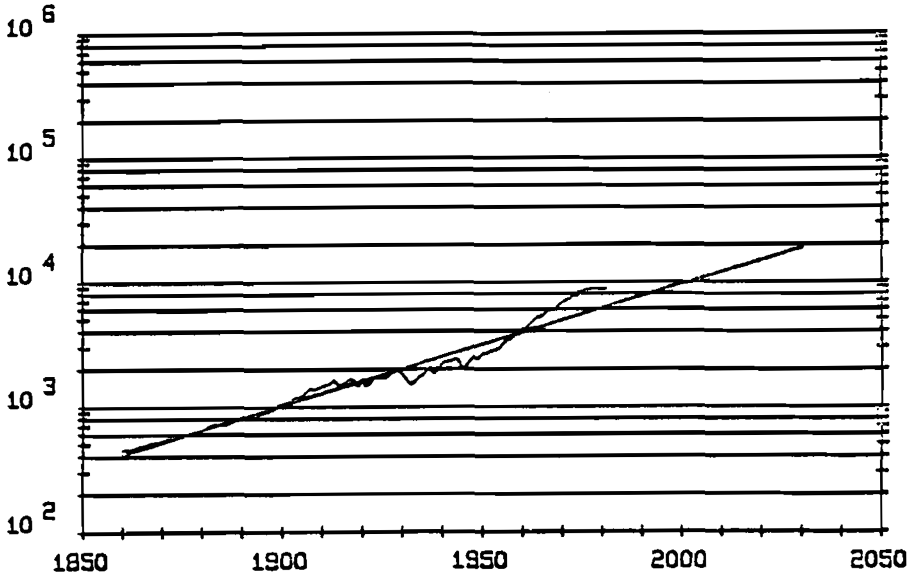


FIGURE 5 World primary energy consumption (10^6 tce).

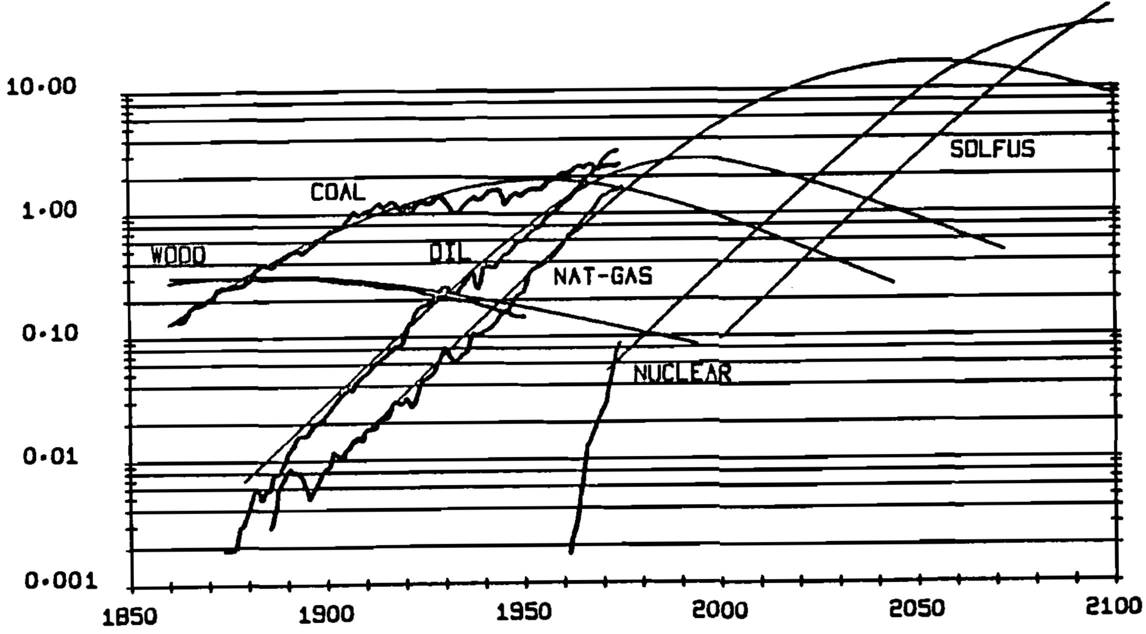


FIGURE 6 World primary energy inputs (10^9 tce).

TABLE 2. Drilling finding rates (barrels per foot drilled).

Period	United States	Western Europe	Latin America	Africa
1970–1974	7	520	200	520
1960–1964	6	17	57	380
1950–1954	7	40	80	37

Source: B.F. Grossling.

market after oil started to be internationally traded. The flares in prices neatly coincide with the first parts of the downswings in consumption shown by the sinusoid, which by the way has a strong connection with economic activity, invention and innovation waves plus Kondratiev cycles, as discussed in detail in Marchetti (1980b). Because the flares in price have a width of about ten years, a substantial fall in oil prices is due shortly.

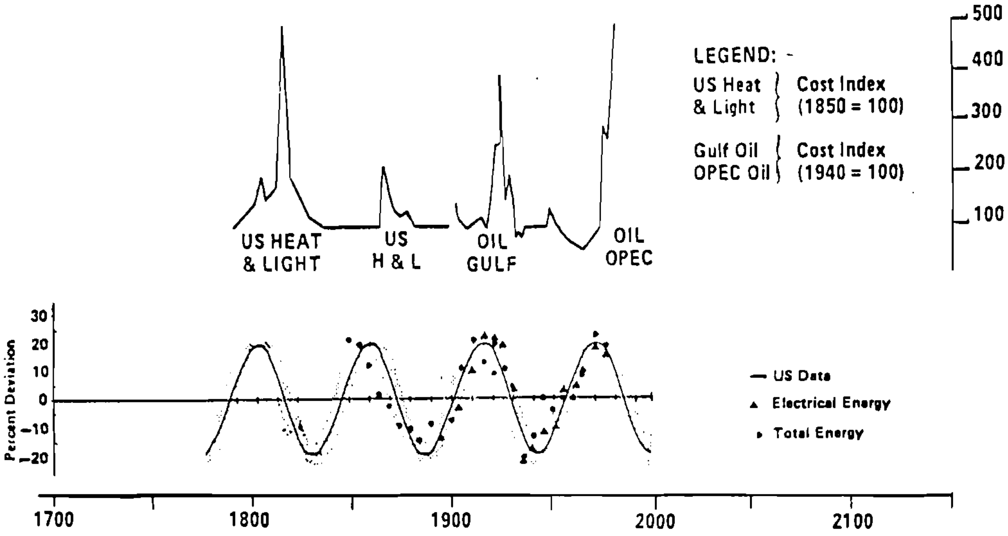


FIGURE 7 Invention and innovation waves – the secular set.

METHANE FOR KING!

Much has been said about the future mix of primary energies that will keep us warm and moving for the next fifty years with the revival of this and that and with ingenious new ways to utilize old energies. My statements are condensed in the aseptic curves of Figure 2. The time constants of societal behavior will keep the contribution of new technologies on the negligible side, whatever the degree of state support, as recent American experience clearly demonstrates. On the other hand, no case of technological substitution I have ever analyzed has shown a revival. This argues directly against a newly increasing share of coal in the global energy budget. So, as the figure shows, we are left with gas, becoming progressively dominant during the next fifty years, and nuclear clawing its way up, albeit with a fifty-year handicap. This is certainly not a condemnation of nuclear, which incidentally was born at the right time in the cycle as detailed in Marchetti (1980b), but only a refocusing of interest and potential into the natural gas area.

Natural gas has a long history of managed use, and already by the year 1000 methane wells and a net of bamboo pipelines served the capital city of Peking. The same fields are active today and there is a suspicion that this methane is of nonorganic origin, i.e. linked to volcanic seeps, which could explain the longevity of the fields.

The success of methane really began in the last century, with the advent of the steel pipeline. So something that was originally considered a nuisance, making crude oil fizz, could be burned somewhere for some useful purpose. This "by-product" tag has always accompanied natural gas, and showed up in consistently low prices with respect to oil, calorie for calorie, and in monumental blasphemies uttered when oil men, after long and expensive toil, discovered "dry" gas.

The situation changed drastically, if gradually, after World War II, and for different reasons in different places. In America a well-established market and ramified transportation system made it easier to tie up the unlucky, but finally profitable, dry gas fields. In Holland and Italy the discovery of a consistent gas deposit was considered a blessing, if a somewhat second-rate one, as these countries had no oil. My interpretation, if not contradictory, points in another direction. Things tend to happen when they "fit" (Marchetti 1980b). Methane is distributed by a network of pipelines, which becomes competitive when a certain minimum *spatial density* of energy consumption is reached.

Spatial density increases with the population density in a certain area and the level of individual consumption. All over the world, the population implodes into the cities, and, becoming richer, consumes more. So the critical level is surpassed at an increasing rate. After that, the distribution net being usually oversized in terms of capacity, every increase in consumption can be accommodated at basically zero marginal cost, making the implant irreversible.

On the other hand, its secondary features make methane ideal for urban areas: it does not interfere with transportation, it does not pollute, it is friendly to the equipment used to burn it, and, finally, it makes life automatic.

I am drawing a rosy picture here, which is an attempt to interpret the stately market penetration of Figure 2. The black side is still the fact that gas is costly and complicated to transport over long distances, which is a clear cause of immense waste, e.g. in the Middle East. The curves are a challenge to the ingenuity of scientists and engineers.

One solution could be to transform methane into methanol at source. Present processes have about as much elegance as killing mosquitos with dynamite, but soil bacteria make the transformation in one go at room temperature. Chemists are trying to steal their subtle "tour de main" so far without success, but there is always hope for the future. Methanol can be transported by supertanker or cheap pipeline, and mixed with the gasoline pool as a nonlead anti-knock component at first, and finally as a straight fuel. Much work is going on to check this business end of the line.

The second line of attack is to install pipelines larger than the present maximum of about 1.5-meter diameter. The Russians started with a 2.5-meter project, but I do not know of other attempts. The rationale lies in the fact that transportation costs are roughly inversely proportional to pipe diameter, so the 3000 km accessible to a 1.5-meter pipe could, without excessive economic strain, become 6000 km with a 3-meter pipe. Throughput would be about seven times larger, but sources and markets of sufficient size already exist, such as e.g. Europe and Siberia, the Middle East and Western Africa, or Japan and Siberia.

All that is speculation, but let us look at what is happening in the real world, and haruspicate from that.

I am currently making a study of the deployment of large infrastructures, like canals, railways, roads, telegraphs, and telephones, over the last three centuries, to see what might be more appropriate in terms of anticonjunctural public works, i.e. devices that could counteract the adverse impacts of secular trends and cycles. After all, the recession is going to stay with us for another ten years, as analyzed in Marchetti (1980b, 1983b).

One of the important infrastructures for the next fifty years will obviously be the gas network, and I will describe here some of the results of the analysis, if still in a preliminary state.

The simplest way to describe the evolution of a spatial network is to measure its length vs. time. The final length can be calculated approximately depending on the actual stage of deployment and noise in the data. For the three-parameter logistics presented here, my guess is a 10% error, regardless of the qualitative considerations I will draw from the cases. The fitting is done by visual interpolation of the data on the linear transform, for different saturation values, till a straight line is obtained.

The case of trunklines (major gas pipelines) is reported in Figure 8 for the European Community, in Figure 9 for Italy, and in Figure 10 for the FRG. In all three cases we are not far from a 50% stage, where the final objective is reported as the number in parentheses. For Italy it is around 30,000 km and for the FRG 60,000. The time constants are of about 40 years, and the present stage of realization about 50%, meaning that this spurt should thin out in twenty years. My proposal, in passing, would be to condense this activity into ten years as an anticonjunctural device for suffering industries, like steel and civil construction. Figure 11 illustrates the situation for the entire gas pipeline system in the EEC.

At this point, a natural question arises: if it has to be gas, where will all of this stuff come from? The answer may appear naive: from the bowels of the earth.

Gas is a simpler and more abundant substance than oil. Beyond a certain depth, *only* gas can be found. It is also more mobile, facilitating displacement into traps. The maturing of coal releases large amounts of gas, but no oil. And, last but not least, there is increasing evidence that methane is part of Mother Earth's exhalations, together with the more classical ones H_2O, SO_2 and H_2S. This may give rise to large pools of abiogenic gas, unexpected on the basis of normal geological thinking, and consequently not looked for. A workshop on the subject was held in May 1983 at Oak Ridge to review the evidence on such a hypothesis, originally presented by the astrophysicist Tommy Gold.

Another area so far overlooked is that of unsealed layers where methane is kept in place by capillary forces. Large deposits have been found in Canada, following that lead, and now one is being explored in Germany that reaches all the way to Britain.

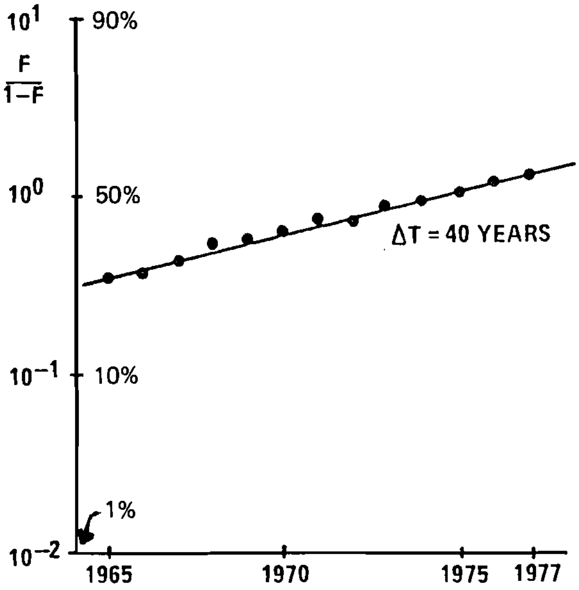


FIGURE 8 Major gas pipelines in the European Community (final "objective" 160,000 km).

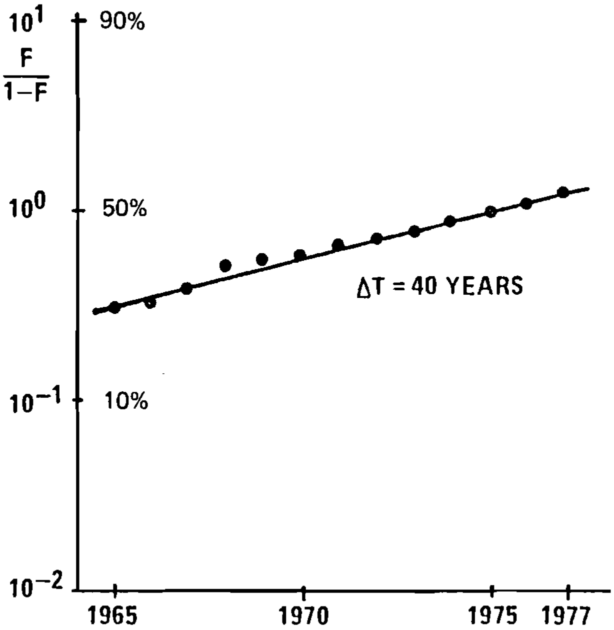


FIGURE 9 Gas trunk lines – the FRG (final "objective" 60,000 km).

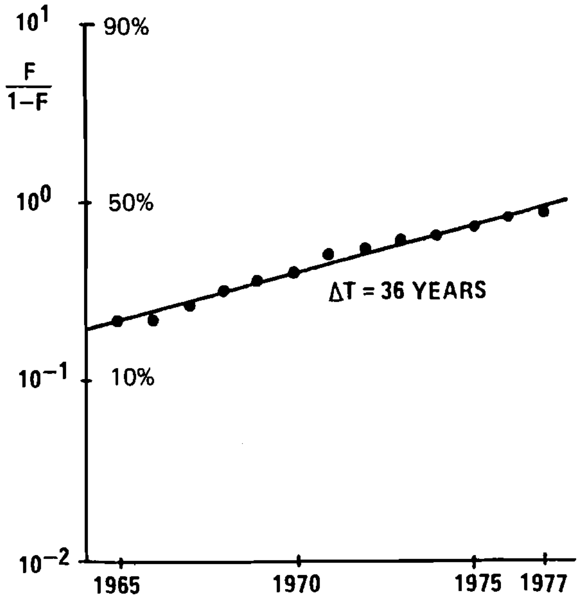


FIGURE 10 Gas trunk lines – Italy (final "objective" 30,000 km).

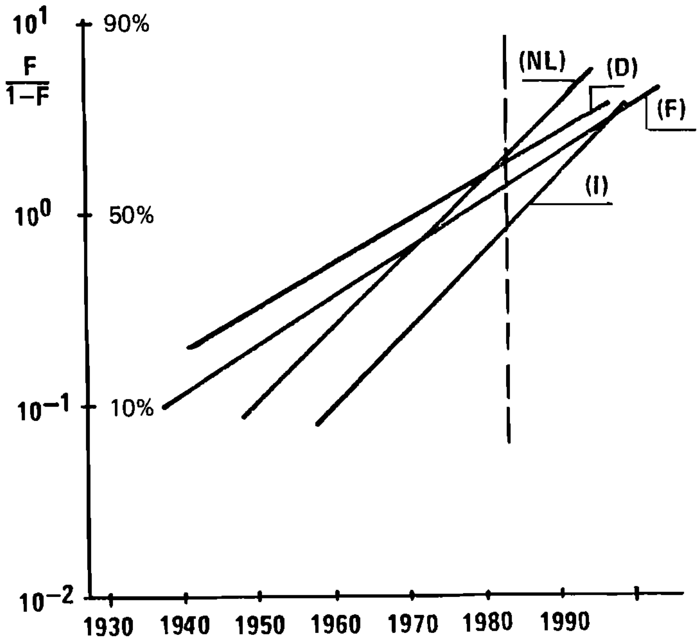
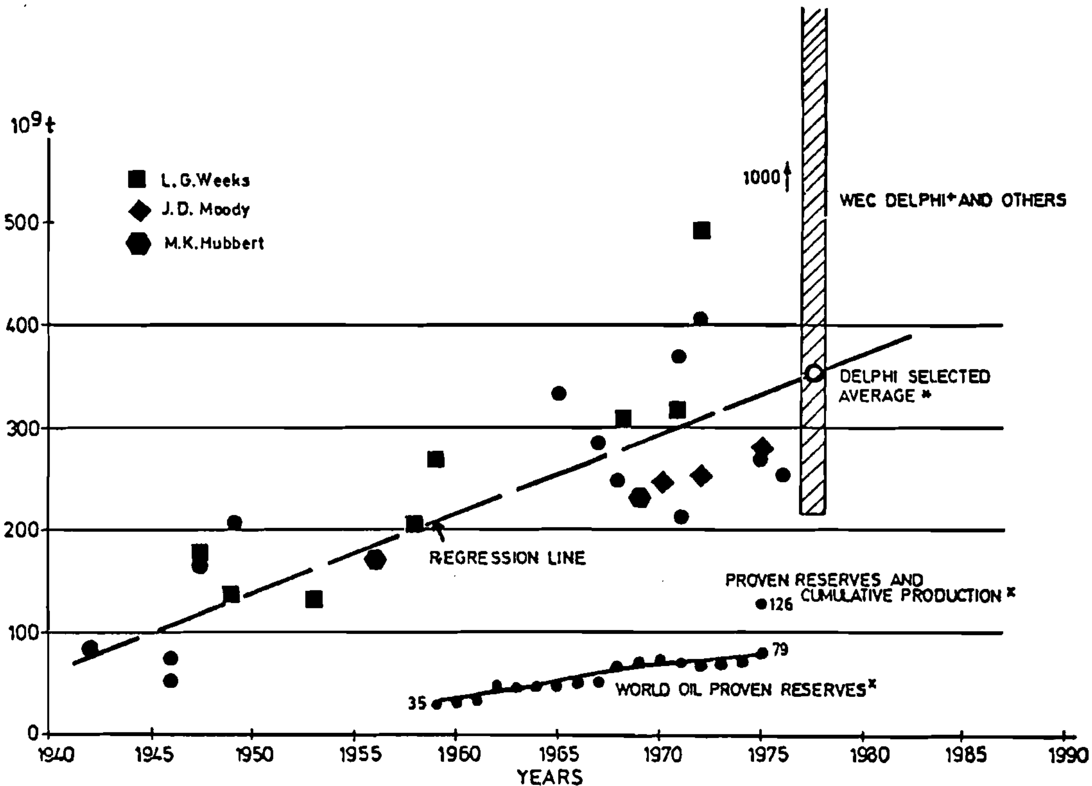


FIGURE 11 Gas transportation and distribution pipeline length (source: ENI Inf., 1976).

Without attaching any figures to these new exploration areas, it is evident to me – being in touch with those closely involved – that they will add a lot to the figure for reserves reported in Table 1. After all, we need only a doubling of this figure which, according to the trends of Figure 12, may only need 20 years of searching.



×World Oil–August Issues 1960 to 1976 *Conservation Commission. Report on Oil Resources.

FIGURE 12 Estimates of world ultimate reserves of crude oil.

CONCLUSIONS

I would like to close and draw some conclusions at this point. Although my analysis of the behavior of the energy (and social) system, using Darwinian principles and systems-analysis practice, is still in a fluid stage, the conclusions are clearly optimistic, in a broad sense. In a nutshell, society operates through stable mechanisms that make its long-term aggregate behavior predictable; energy is abundant by all measures; the next form of primary energy has all the prerequisites to satisfy consumers, producers, environmentalists, and perhaps even steelmakers; "soft" energies have essentially no chance for the next fifty years, which saves us from pangs of conscience; and last but not least, prices will fall shortly.

In the short run, however, both temporally and spatially, there is no doubt that problems still lurk. Energy is too important not to be coveted by politicians as a tool for their designs. I hope that throwing light into the mechanisms involved will reduce the amount of tampering.

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