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Energy-related Issues in Early Economic Literature

Summaries and Bibliography

Juan Martinez-Alier

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The Energy Research Group consists of eminent members of the international community of energy analysts and policymakers from developing countries. This independent Group has been set up to review energy-related research and technology and its relevance to developing countries, to assess the research capacity of developing countries, and to suggest the priorities for energy research in these countries.

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Summaries and Bibliography

Juan Martinez-Alier
(with the assistance of Klaus Schlüpmann)

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PREFACE

The developed countries of today were developing countries a few centuries ago, some a few dacades ago. Energy-related problems of developing countries look serious today. Did they look difficult in the developing countries of the past? What solutions were explored then?

These questions called for an answer when the Energy Research Group was charged with the task of suggesting energy research priorities for developing countries. So we turned to Professor Juan Martinez-Alier, a habitué of the great libraries of Berlin, Paris and Oxford, who was in search of energy researchers of the nineteenth and early twentieth centuries. This paper presents some of his early results.

Professor Martinez-Alier seeks the views of early European researchers on two questions: (i) the efficiency of the human body and the productivity of human physical activity, and (ii) the exhaustibility of fossil fuels and other mineral resources. In his search he encounters a strange and fascinating set of people: Serhii Podolinsky, a socialist and adherent of Marx and Engels, Eduard Sacher and Wilhelm Ostwald, pioneers in what may be called the energetic theory of civilization; Justus Liebig, inventor of synthetic phosphatic fertilizer; Patrick Geddes, a biologist who was led by eye trouble into a melange of aesthetics, energetics and economics; Frederick Soddy, a colleague of Rutherford who, after winning a Nobel Prize in chemistry, turned to economics and would have revolutionized it if anyone had listened to him; Howard Scott, the evangelist of technocracy; Josef Popper, a physicist whose pornography won Freud's acclaim; and Karl Ballod, a utopian who tried to provide a blueprint that Marx forgot to make for the post-revolutionary society. Martinez-Alier's account brings some colourful folklore into the somewhat arid subject of energy studies.

Ashok V. Desai

INTRODUCTION

The role of energy in the economy seems a recent preoccupation, which some readers would trace back to the oil crisis of 1973 and other, perhaps better informed readers would associate with Georgescu-Roegen's **The Entropy Law and the Economic Progress** (1971). But in fact there is a long history of study of energy in the analysis of the economy from the ecological point of view.

The period covered in our work begins with Jevons's **The Coal Question** (1865) -- a time when the laws of thermodynamics had been estabished. It is more difficult to choose an ending point for a history of ecological economics. The best-known early attempt to work out the economic theory of exhaustible resources was by Hotelling (1931). We accept this as the culmination of the dialogue between natural scientists and economists, because the economic theory of exhaustible resources took into account the physical characteristics of this type of resource. Economists had finally agreed that some resources were exhaustible, although this consensus would take a long time to seep down to the textbooks. The 1930s is a convenient ending point also because short-run problems of excess capacity came to dominate macroeconomics and the question of whether the availability of resources would stop economic growth was no longer on the agenda. However, Keynesian economics rapidly became also an economics of long-run growth (Harrod, 1939). Economists were concerned with national income, investment, consumption and the incremental capital-output ratio, and they paid no attention whatever to physical realities, as Ise (1950) pointed out (p. 415-416).

In fact, there is no end in sight to the ecological critique of economic theory, to which our work makes a further contribution by resurrecting the arguments of half-forgotten authors.

Applied work on the economics of natural resources and energy use did not become a branch of economics until recently. The best work was still being done in the 1950s, 1960s and 1970s by noneconomists (Cottrell, 1955; Rappaport, 1967; Odum, 1971; Pimentel, 1973; Leach, 1975; Chapman, 1975; Foley, 1976). One striking finding was that the productivity of agriculture has not increased, but decreased. This does not, however, mean that a new criterion of economic efficiency should be introduced, such as energy return to input; agricultural products have use values often related not to their energy content or energy cost, but rather to their protein or vitamin content, or simply to the pleasure to be gained by eating or drinking them. Nevertheless, studies of the flow of energy in agriculture suggest it may no longer be appropriate to analyze economic growth in terms of an increased productivity of agriculture (based upon technical progress) which, together with the low income-elasticity of demand for agricultural products, frees labour to other sectors of the economy.

It might be that the increase in agricultural productivity by using oil has been assessed only at the oil prices that have tained. If the value of oil to future generations has not been taken into account, the increase in productivity is fictitious. To economic theorists, the question may be one of giving values across the generations to the stocks of fossil fuels and other exhaustible resources, to show an acceptable, or even optimal rate of depletion. Such an exercise usually refers to Hotelling's (1931) rule, which compares the difference in net return between now and a future date with the interest to be gained by selling now and investing the proceeds. But this criterion appears invalid; compound interest can only accrue if the economy grows -- a point emphasized by Soddy (1922). Thus, we might discount the future if we assume that the future will be more prosperous than the present; this is usually assumed in the theory of economic growth, where current consumption is sacrificed to invest and increase future consumption, and where the rate of interest equalizes the present discounted value of consumption over time. But one should rather minimize present use of exhaustible resources if one assumes a long life for humanity. In any case, there is clearly no way of escaping an ethical choice. The methodology to be used in making such a choice is difficult to decide on behalf of economic agents who, being not yet born, cannot bid in today's markets.

The first authors we shall consider did not deal, however, with such abstruse methodological questions, but with straight energy accounting of agriculture. It appears that Serhii Podolinsky, a Ukrainian socialist doctor, first developed the concept of energy return to energy input in different types of land use, trying to combine in articles (1880a, 1880b, 1881, 1883) this ecological approach with the Marxist theory of economic value. Although one of these articles was published in **Die Neue Zeit,** there has been no discussion of his views in the Marxist literature on agricultural development. The relations between Marxism and the natural sciences (centred on the notion of **Produktivkräfte)** is one of the topics that need to be studied.

The energy analysis of agriculture was not picked up, either, by populist, pro-peasant authors, although they could have developed an argument in favour of peasant farming. Chayanov did not read Podolinsky. Many years later it was pointed out that the Green Revolution of the 1960s was not green at all, either in the old populist sense or in the new sense; it not only favoured rich peasants or farmers over poor peasants and landless labourers, but it also meant farming with petroleum.

While Podolinsky's intellectual efforts at least received a nonenthusiastic report by Engels and considerable later attention in his own country and abroad, complete silence appears to have greeted Eduard Sacher (1881, 1899), who also studied, as we shall see, the flow of energy in agriculture. Sacher himself was keen on energy-intensive farming, but he was aware of the increase in the energy input that chemical fertilizers and steam threshing implied. He also had the idea of correlating stages in the history of humankind with energy use per capita.

There is also interesting material on energy accounting in agriculture in the work of another Austrian author, Josef Popper-Lynkeus (1912), who published **Die allgemeine Nährpflicht,** a fundamental text of ecological economics, full of detailed computations of resources and of their use. He proposed an economy that would make decreasing use of exhaustible resources. He considered to what extent renewable energy from agricultural crops could be substituted for coal (in the form of alcohol from potatoes, **Kartoffel Spiritus),** taking a pessimistic view because he quite properly included in his accounting the energy cost of growing such crops. Such analysis is directly relevant to the discussion today on energy cropping versus food production, as for instance in Brazil.

Popper-Lynkeus was a physicist, a friend of Ernst Mach; he was influential in the Vienna Circle. Particularly did he influence Otto Neurath (1973, 1979), whose economics based upon a **Naturalrechnung** will be considered in our work. Another influence on Otto Neurath's economics was that of Karl Ballod (1898, 1927), a Berlin economist, and, like Popper-Lynkeus, a left-wing ecologist and author of a scientific utopia.

Around 1840 -- before the laws of energetics were established -- the new agricultural chemistry had started with Liebig (1869, 1873) in Germany and Boussingault (1845) in France. Liebig often appears in textbooks as a founding father of ecology (cf. Kormondy, 1965) because of his work on the cycles of carbon and some plant nutrients. He liked to think that his own work, of which he became a commercial propagandist, would help greatly to avoid a crisis of subsistence in Europe. This would occur unless "heaps of dung and guano deposits of the size of English coalfields" were discovered -- a phrase admiringly quoted by Kautsky (1899) -- or unless the new gospel of inorganic chemical fertilization was adopted. But was it often pointed out that European agriculture was starting to draw upon nonrenewable material subsidies? Did anybody point out that Peru was exporting much more energy than it was importing? Did perhaps some economists discuss (though not yet using such technical terms) the "shadow-price" of guano which would ensure an optimal rate of depletion? Such questions are clearly rhetorical; about 100 years later the exports by Peru of enormous amounts of basically the same resource -- though this time at an earlier stage in the trophic chain (in the form of fish-meal for North-Atlantic animals) -- did not prompt such a debate.

Around the turn of the century, there was indeed a discussion on the energy cost of substituting for Chilean saltpetre nitrogen taken from the air by hydroelectricity (Jurisch, 1908); the analysis of the flow of energy in modern agriculture could have become a well-trodden study much earlier than it did.

Going back to the more general theme of the relation (or lack of it) between economics and the study of the flow of energy in human society, one should also consider the views of Jevons. Jevons, one of the progenitors of pure economic theory, was up to date in science as shown in his exchanges with John Herschel, Clerk Maxwell and others (1972), and also by his treatise on the **Principles of Science** (1879). In **The Coal Question** (1865) he did not develop the economic theory of the intergenerational allocation of this exhaustible resource. He rather addressed himself to the substantive issues of coal reserves and of improving the thermodynamic efficiency of coal-driven machines. He expressed the dismal view that as thermodynamic efficiency increased, so would the use of coal. One certainly cannot dismiss Jevons as a professionalized economist ignorant of natural sciences. The question we ask is why, despite his interest in coal, he did not consider the intertemporal allocation of exhaustible resources in his work on "marginalist" economics.

We shall also briefly touch upon the work of Walras (1965), who rarely mentioned physical matters except to remark often on the analogy (which also pleased Jevons) between the equations of mechanics and of economic equilibrium. This analogy was also noticed later by Lotka (1921). But the most interesting point of contact between Walras and ecological economics was the correspondence he had with Patrick Geddes, the Scottish urban and regional planner.

Geddes (1881, 1884, 1885) is difficult to classify and certainly difficult to read. He criticized the attempt to explain demand by the notion of "utility" on the grounds that it was tautological. The new economics -- he wrote to Walras in 1883 -- was unsatisfactory also on the supply side, as production should be studied with the help of physics. He developed the basic principles of a sort of **tableau economique,** and he criticized economic accounting because it did not keep track of the losses of energy and materials in the economic process. He believed that a part of consumption could be explained by biology, but he was by no means a reductionist (despite his training in biology and his Comtean view of the relations between the sciences). His favourite economist was John Ruskin, who had emphasized esthetic values. Geddes was also one of the first authors who tried to interpret history in terms of changes in the use of energy. Another historian who, at the turn of the century, had this idea was the American Henry Adams (1918, 1919, 1969).

In general, physicists seem to have been reluctant to invade the terrain of historians and economists, yet many of them rushed into theology; there was a vogue for metaphysical speculation because of the second law of thermodynamics. We have found few examples of explicit discussions of the economy from the standpoint of physics. One is by Rudolf Clausius (1885) on the energy reserves in nature and their benefit for humankind. This is significant not only because of its author's personality, but also because of what it says on the sources of economic growth -- "we have found stocks of coal from old times ... These we are now using and we behave just as a happy heir eating up a rich legacy." The history of ecological economics is not an exercise in legitimization of today's green movement; left-wing ecologism was not invented in the 1960s and 1970s but nearly 100 years earlier. Clausius, however, must be understood in another context.

Why did other natural scientists not trespass into the economists' field? Natural scientists, mathemeticians and engineers, including Carnot (1978), Babbage (1971), Thomson (1860) and Clausius himself, had long been concerned with the efficiency of power-producing machines, especially the steam engine. Some, such as Babbage, are also catalogued as economists. From the mid-nineteenth century onward, the physiologists also came to consider the efficiency in the transformation of energy of plants and animals (including the human body), as a central question in their research. But we can ask why the entropy law and the economic process did not become a well-established field of study in the 1850s, as might have happened. Clearly, to answer this question requires studies of the ideological and political background of scientists. These are themes related to the work of authors such as Cannon (1978), Gregory (1977), Musson (1972), and Krohn et al. (1978). For instance, there has been work on the views of Clausius on physics and the foundations of science (Truesdell, 1980; Schneider, 1979), and a part of his biography has been written (Ronge, 1955); we shall have more to say about the economic, political and cultural context of this.

One other physicist (of minor importance in his own discipline) who wrote on the economy was Leopold Pfaundler. In a brief article (1902) he analyzed the carrying capacity of the Earth, with detailed calculations on the solar energy falling on the soil and photosynthesized by plants and of the need of food energy for human nutrition. His article states clearly that the expression "energy crisis" should be reserved for situations in which there are humans unable to obtain the 1500 or 2000 Calories per day (6278-8372 kJ/d) that they would need for sustenance, and that the cause of such energy crises is not the niggardliness of nature, but poor social organization, mainly the restrictions on mobility placed by frontiers.

Pfaundler's main thesis was that the carrying capacity of the earth was determined not by the availability of materials but by free energies, because the law of conservation of matter enables materials to be completely recycled (an early statement of what Georgescu-Roegen calls the "energetic dogma"). One other contribution by Pfaundler was his awareness of the possible links between socialdarwinism and the study of the use of energy and materials by humanity. He frequently used the expression **der Kampf um Dasein,** the struggle for life, yet he refrained from expressing such links in any eugenicist and racist way. Socialdarwinism is inevitably one theme that crops up in our research, against our wishes and those of some of our authors, who held strongly egalitarian and anti-socialdarwinist views.

The human species is distinguished by enormous differences between its members in their use of energy and materials, a point usually attributed to Lotka (1925). We can envisage a dog crossing the Atlantic by Concorde at a great expense of fuel, but if we exclude human intervention, intraspecific differences in the use of energy and materials are small in all species compared to those for humankind.

In our list of authors, Frederick Soddy (1912, 1922, 1926, 1947) deserves a prominent place. To emphasize the role of agriculture in the economy, Soddy drew a distinction between the "vital" use of energy and its "laboral" use. From 1903 onwards he told economists to study the human use of energy. He blamed economists for mistaking chrematistics for economics. It is difficult to classify Soddy as an optimist or a pessimist on economic growth. He certainly believed in the progress of scientific knowledge but not that this necessarily entailed technical progress, though he sometimes got carried away by the energy vistas opened up by radioactivity. Soddy's main point was that economists were mistaking financial capital for real capital. He pointed out that the payment of interest could only arise from either growth or the impoverishment of debtors, and that there was no pure theory of economic growth since growth depended in the last analysis on physical factors, that is, the availability of energy. The using up of fossil fuels could only be squandering, even if fossil fuels were spent in the construction of so-called capital goods.

Ostwald's contribution was less polemical against the economists than Soddy's and directed more to the historians. He failed in his upper-handed attempt at dialogue with them and with social scientists. He later became the recognized ancestor of ecological anthropology in the United States (through Leslie White). The true heads of this lineage ought to be Podolinsky, Sacher, Geddes.

Our approach to Ostwald's social energetics will be by way of Max Weber's detailed and little-known critique (1909), not yet translated into English. Of particular interest is Weber's discussion of the relations between the sciences. Ostwald was epistemologically a Comtean, and Comte did not understand (Weber wrote) that each science dealt separately with an object of knowledge, using a set of hypothetical-theoretical propositions, the validity of which did not depend on the findings of any other discipline. Discussing Ostwald's view that the development of culture went together with an improvement in the efficiency of the transformation of energy, Max Weber cleverly pointed out that it was energetically cheaper to weave cloth by hand than mechanically; nevertheless mechanical weaving was presumably a sign of cultural progress. Ostwald had missed his **salto mortale** from physics to economics. One may well imagine that scientists (or peasant ideologues) who nowadays point out to economists that modern agriculture implies a worsening of the energy output-input ratio will be told the issue has nothing to do with economics.

To sum up, the study of the questions raised by our authors will make it clear that ecologic economics could have been developed long ago. The question remains why few natural scientists wrote on the economy in the second half of the nineteenth century and at the beginning of the twentieth century (we have not yet made a complete count, but it is clear that there were not many). A related question is why so little attention (at least until 1973) was paid to interdisciplinarity by economists and economic historians, who should have known better. And, finally, why was the left-wing ecological critique of economics not adopted as an ideology by any social group until quite recently? These are questions about the separation and the relations between the sciences, about the social and ideological functions of science, about the sociology and the history of science (cf. Graham et al., 1983). We hope to make some contributions to such issues.

Before 1973 and even now one could go through many volumes of economic theory, economic history and agricultural economic history without finding as a central question the use of energy and of material resources. There is no entry for energy in the index to David Landes's **Unbound Prometheus** (1969).

Such elements of economics as productivity, technical progress, net investment and growth of productive capacity and value added seem nowadays singularly metaphysic. The belief in economic growth may help to explain the resilience of economics faced with the ecological critique.

On the other hand, we would stress that a reductionist methodology that attempts to explain human use of energy and material resources with the help of the natural sciences could not account for the complexities of human history. Ecology cannot explain why some members of humanity use perhaps one tonne of petroleum yearly to feed each one of them (for tractors, transport, fertilizers, herbicides, refrigerators, etc.) while many other members feed themselves without using one single drop of petroleum. The allocation of energy and material resources to different uses cannot be explained (for the human species) only by natural sciences.

THE STUDY OF THE FLOW OF ENERGY IN AGRICULTURE: PODOLINSKY

"The beginning of the influence that the second law of thermodynamics was to have on ecological theory" has been traced back to Lotka (1925) by E.P. Odum (1968, p. 15). In fact, the study of the flow of energy and of energetic efficiencies in human societies started earlier, though it did not become an academic discipline. There is nothing startling in this. Too often a rich past of ideas, concepts, controversies, personal failures and successes falls into oblivion as the history of disciplines that have finally found their academic niches is written. Thus, "the ecosystem approach to ecology which was developed by the Odum brothers out of the thoughts of Lindeman ... (based upon) food chains, energy flow, trophic levels, and ecological efficiencies" (Colinvaux, 1976; cf. also Ellen, 1982, p. 95) began much earlier than the names quoted would suggest. We should like to introduce some writings that, although published about 100 years ago, read like recent contributions to ecological anthropology, human ecology and energy economics, as they were based on computations of energy returns to energy inputs in different activities. Such initial attempts (around 1880) were generally received with silence; hence one cannot exclude the possibility of precursors in the 1850s, 1860s and 1870s.

The work we shall consider could have been a foundation stone for human ecology, ecological anthropology and energy economics. The study of the flow of energy and the cycles of materials in small human groups (Rappaport, 1967; Lee, 1979) is usually classified as ecological anthropology while, for instance, **Energy Flows in Rural China** (Smil, 1979) belongs to human ecology. However, anthropologists like Leslie White and, more recently, R.N. Adams, have also attempted work of the widest scope. Moreover, some small-scale studies, for instance Brooke Thomas (1976) on the flow of energy in a settlement of Quechua shepherds in Puno, Peru, which shows the reasons for the use of dung as fuel, are classified as human ecology. This is perhaps because they do not attempt links with other fields -- social organization, religious beliefs and rituals -- as the anthropologists do. Although comparative studies on energy flows in agriculture (Pimentel, 1973, 1979; Leach, 1975) clearly belong to agricultural energy economics, they use the findings of ecological anthropolgists on output-input energy ratios in traditional systems, such as tropical slash-and-burn agriculture or Chinese rice or Mexican maize growing.

From the 1850s and 1860s onwards it was possible to adopt a quantitative view of the flow of energy from the sun (though that the sun worked by nuclear fusion was not understood until the 1930s); it was also possible to determine how much of the energy from the sun was radiated back from the Earth into space, and how much (or, rather, how little) could be transformed by plants into carbon, which they took from carbon dioxide in the atmosphere. The process of nutrition as oxidation of carbon was also understood, as was the use of energy in metabolism and in work.

Therefore, it is not surprising that there should have been attempts to measure the energy output-input ratio in agriculture. One of the first was by Serhii Podolinsky (1850-1891). This has become known mainly because Engels's letters to Marx on Podolinsky were mentioned and even printed in full in the 1920s, both in the literature on the relations between marxism and natural sciences and in biographical works on Podolinsky's role in Ukrainian populism and socialism in the 1870s. Engels had some knowledge of the elementary energetics of human physiology, and in a note of 1875 (cf. Engels, 1972) he referred to Fick's and Wislicenus's experiment in climbing the Faulhorn in 1865, which became popularized under the name "A day of hunger for science".

Adolf Fick (1829-1901) had written already in 1857 and 1858 on the amount amount of energy (2 700 Calories/d) a man would use when not working (1906, vol. IV, p. 418). Different types of work would imply different energy expenditures over that rate. An idea circulated at the time -- for instance, in an article (Anonymous, 1877) in **Das Ausland** -- was that physical values of different kinds of work could be established. Engels explicitly rejected this notion in 1875.

On 19 December 1882, Engels wrote to Marx that Podolinsky had "discovered" the following facts (already well known): If the food intake of one person per day was equal to 10 000 kcal (41 860 kJ) then the physical work done would be a fraction of this energy. This physical work would become economic work if employed in fixing solar energy, for instance through agriculture. Whether the energy fixed by the work of one person per day was equal to this amount, half, twice or 100 times it would depend only on the degree of development of the means of production. Establishing an energy budget was in any case possible only in the most primitive branches of production, such as hunting and fishing.

In agriculture (here Engels was most perceptive) one would have to reckon the energy value of such inputs as fertilizers and other aids, a difficult thing to compute. In energy accounting in industry it would be impossible to calculate the energy costs of a needle, screw or hammer. Economic relations could not be expressed in physical terms. All that Podolinsky had managed to show (wrote Engels to Marx, 22 December 1882) was the old story that all industrial producers have to live from the products of agriculture; this well-known fact could, if one so wished, be translated into the language of physics, but little would be gained by it.

Podolinsky's original article appeared in similar Russian, French, Italian and German versions between 1880 and 1883. We shall summarize it:

He began by explaining the laws of energetics, quoting Clausius: although the energy of the universe was a constant, there was a tendency to the dissipation of energy or, in Clausius's terminology, a tendency for entropy to reach a maximum. "Entropy" referred to the quantity of energy that would no longer be transformed into other forms of energy. Podolinsky did not discuss the difference in thermodynamics between open, closed and isolated systems, although he stated explicitly, as the starting point of his analysis, that at present the Earth was receiving enormous quantities of energy from the sun, and would do so for a very long time. All physical and biological phenomena were expressions of the transformation of this energy. He did not discuss either the controversies regarding the creation of the universe and its "heat-death" or the relation between thermodynamics and the theory of natural selection and evolution of species. In March 1880 he had published an article against socialdarwinism. He certainly realized that the availability of energy was a crucial consideration for the increase (or decrease) of population. However, he thought that distribution arose from productive relations, that poverty could not be explained by ecological analysis -- "in the countries where capitalism triumphs, a great part of work goes towards the production of luxury goods, that is to say, towards a gratuitous dissipation of energy instead of towards increasing the availability of energy."

The energy available to humankind came mainly from the sun. Podolinsky gave figures for the solar constant (taken from Secchi) and for energy from other sources. He explained how coal and oil, wind energy and waterfalls were transformations of solar energy, and after mentioning tides as another possible source of energy, he went on to his main piece of analysis.

A part of the flow of energy from the sun was assimilated by plants -- a very small part, he wrote, without explicitly discussing photosynthetic yield, a subject that had already been under scrutiny for some years. The work of human beings and animals directed by humans was able to increase the energy budget on the surface of Earth by agricultural activity. This he showed by comparing the productivity of different types of land use in France (Table 1).

Table 1. Average annual production and energy input from work by humans and domestic animals, France, 1870s

Land Use	Product	Production		Energy input
		Weight kg/ha	energy Mcal/ha	Mcal/ha
Forest	Dried wood	900	2295	Nil
Pasture				
Natural	Hay	2500	6375	Nil
Sown	Hay[a]	3100	7905	37[b]
Wheat	Wheat[a]	800	8100	79[c]
	Straw	2000		

[a] Excludes seed.

[b] Corresponding to 50 horse-hours and 80 manhours.

[c] Corresponding to 100 horse-hours and 200 manhours.

Source: Podolinsky, 1880. Podolinsky's sources were **Statistique de la France,** 1874, 1875, 1878; Ch. Laboulaye, **Dictionnaire des arts et de l'agriculture,** 4th ed., 1877, articles on agriculture (by Hervé Mangon) and on carbonification; Pelouze et Frémy, **Traité de Chimie;** Hermann, **Grundzüge der Physiologie,** 5th ed., 1877.

Podolinsky's figures correspond to the biologists' "net production". He said nothing about the energy spent by plants in respiration which, although of great interest to the biologist, has less interest for the ecological anthropologist or economist. He compared wheat production and sown pastures with natural pastures and forest, concluding an input of human and animal work increased their production. Thus, there was an increase of 41 calories in the output of pastures for every calorie of human and animal work expanded. Podolinsky counted the energy input in terms of the work done, and not of the food energy intake, which is the measure sometimes taken in contemporary studies in ecological anthropolgy. Comparing wheatfields to natural pastures, each calorie put in produced an increase of 22 calories. If forests were taken as the baseline the energy productivity of human and animal work was, of course, even higher. Labour, he said, could increase "the accumulation of energy on Earth". Energy accounting thus gave a scientific basis to the labour theory of value, a point that neither Marx nor Engels appreciated.

Although he mentioned guano and although he must have been keenly aware of the war then raging for Chilean saltpetre, he did not subtract from output or include in the input the energy cost of fertilizers. Nor did he consider the energy input of steam engines in agriculture, though he was fully aware of their use for threshing. In its essentials, though, his methodology was like that used much later to establish the energy balance for particular crops, for small-scale societies or for the agricultural sectors of entire countries (Cottrell, 1955; Rappaport, 1967; Pimentel, 1973, 1979; Leach, 1975; Brooke Thomas, 1976; Naredo and Campos, 1980).

Podolinsky did not include solar radiation in the energy input, and here too he anticipated the agricultural energy economics of today. If we wanted to study the energy economics of domestic heating, we would pay attention to the fossil fuels, wood or dung used to increase the temperature to (say) 15°C from -10°C or -20°C, but we would take for granted the first long tranche, up from -273°C, which is mostly due to solar energy. Although solar radiation was not included as input, Podolinsky was interested in how much of this energy could be transformed by plants. He attributed the energy of the sun to "dissociation" (quoting Secchi and H. Saint-Claire Deville), and he explained Kirchhoff's law of radiation. He quoted not only Clausius but also W. Thomson on the degradation of energy.

He wrote: "We have in front of us two parallel processes which together form the so-called circuit of life. Plants have the property of accumulating solar energy, but the animals, when they feed on vegetable substances, transform a part of this saved energy into mechanical work and dissipate this energy into space. If the quantity of energy accumulated by plants is greater than that dispersed by animals, then stocks of energy appear, for instance in the period when mineral coal was formed, during which vegetable life obviously was preponderant over animal life. If, on the contrary, animal life were preponderant, the provision of energy would be quickly dispersed and animal life would have to go back to the limits determined by vegetable wealth. So, a certain equilibrium would have to be built between the accumulation and the dissipation of energy." Apart from plants, human labour could be seen as retarding the dissipation of energy. It achieved this by agriculture; but also the activities of a tailor, a shoemaker or a builder would qualify, in Podolinsky's view, as productive work as they afford "protection against the dissipation of energy into space."

Podolinsky, in the second part of his article, considered how the human organism can do work -- "we have not yet said anything on the capacity of the human organism to do work, without which it would be difficult to explain the accumulation of energy on the surface of the Earth under the influence of labour." Quoting from Hirn and Helmholtz (but not, though he could, from Adolf Fick, Pettenkofer and Voit) he concluded that "man has the capacity to transform one fifth of the energy gained from food into muscular work." He named this ratio, in accordance with normal practice at the time, "economic coefficient", remarking that man was a more efficient transformer of energy than a steam engine. Taking into account that not everybody can work (because of health and age), and that there are other human needs beyond food energy, perhaps the best possible economic coefficient would be a 10th. He then arrived at a general theoretical principle on the minimum "natural conditions of human existence." He used a metaphor to put this principle across: in Sadi Carnot's sense, "humanity is a machine that not only turns heat and other physical forces into work, but succeeds also in carrying out the inverse cycle, that is, it turns work into heat and other physical forces which are necessary to satisfy our needs, and, so to speak, with its own work turned into heat is able to heat its own boiler."

For humanity to ensure its conditions of existence, each unit of human work must have then a productivity (this is his own term) of at least 10; or in more general terms, the energy productivity of human work must be equal to or greater than the economic coefficient, that is, the efficiency of the human body as a thermic machine. Without that level of energy productivity "scarcity appears and, many times, a reduction in population." Despite remarks such as this, Podolinsky was -- as we said before -- explicitly anti-socialdarwinist. In economics he thought he had reconciled the physiocrats with the labour theory of value. He knew the physiocrats could not have made a study of energy flows, as the mechanical equivalent of heat was established only in the early 1840s. His combination of an energy theory of value and a labour theory of value was a distinctive contribution. Sending his article to Marx in 1880, he explained that he wanted to bring the doctrine of surplus labour (and implicitly of surplus value) into harmony with physical theory.

It is a simplification to say that the human body has an efficiency of 20%, which would become 10% taking into account other needs apart from food and the fact that not everybody works. But what matters in the present context is the idea that one could determine the minimum conditions of human survival through an analysis of energy flows and efficiencies.

Podolinsky was on solid ground here. The first thoughts on the physiological applications of the laws of energy had been voiced in the 1840s. Thus, Tait (1864, p. 344), patriotically noted that Joule had anticipated Helmholtz when he said in a public lecture in April 1847, that "the knowledge of the equivalency of heat to mechanical power is of great importance in solving a great number of interesting and important questions. In the case of the steam engine, by ascertaining the quantity of heat produced by the combustion of coal, we can find out how much of it is converted into mechanical power, and thus come to a conclusion how far the steam engine is susceptible to further improvement. Calculations made upon this principle have shown that at least ten times as much power might be produced as is now obtained by the combustion of heat. Another interesting conclusion is that the animal frame, though destined to fulfil so many other ends, is, as a machine, more perfect than the best contrived steam engine; that is, is capable of more work with the same expenditure of fuel."

Neither Joule nor Helmholtz (1854) could have really calculated the theoretical efficiency of a thermic machine before the second law of thermodynamics was established in 1850 and 1851 by Clausius and Thomson. But the thermodynamic comparison between the steam engine, animals and human body was made before 1850 and had become a commonplace by the 1860s. Thus Tait could give as a homely example of the application of conservation of energy to animal processes -- "the greater supply and choicer quality of food required by convicts in penal servitude, than by their less (sic) fortunate comrades who are merely imprisoned" (1864, p. 362). The elementary energetics of nutrition and hard work had therefore been well established by the 1880s. It was now only necessary to bring together the well-known facts that biomass could be measured in energy units and that the human body is a thermic machine before the idea could emerge that one could relate the principles of human ecology and economy to the concept of energy return to human energy input.

Podolinsky also saw clearly the difference between using the flow of solar energy and the stock of energy in coal. The task of labour was to increase the accumulation of solar energy on Earth rather than simply transform into work the energy already accumulated, especially as work done with coal was inevitably accompanied by a great dissipation of heat-energy into space. He was not, however, at all pessimistic about the prospects for the economy, and he hoped solar energy would be directly used industrially, referring to the "solar engine of M. Mouchot". One could envisage that solar energy would one day be used directly to make chemical syntheses of nutritive substances, bypassing agriculture. Thus, demographics had to take into account "the relation between the general quantity of energy on Earth and the quantity of humans who live on it", and this was more relevant, in his view, than either the Malthusian prognosis or the socialdarwinist approach of Haeckel, which he repudiated.

Podolinsky's contribution to human ecology, ecologic anthropology and economics could have been picked up much earlier in the scientific debate. For instance, any of the many students of the Russian and Ukrainian peasantry could have had the idea of using the energy-accounting methods of this sympathetic author. An argument (which Podolinsky himself did not develop) in favour of greater energy efficiency in peasant agriculture could then have been made, perhaps by populist authors, several decades before Geogescu-Roegen. Moreover, the marxists could have paid greater attention to him. His article was published in socialist journals in France and Italy and in the theoretical organ of the German socialist party. We do not know yet the channels it followed on its way to **Die Neue Zeit,** edited by Kautsky. Engels might have recommended its publication, despite his lack of enthusiasm for it. But Kautsky (1899) did not include a study of energy flow in his **Die Agrarfrage.** Thus, although Podolinsky can be placed at the crossroads of well-trodden intellectual paths, his work can still be presented as a novelty. We do not claim, however, to have "discovered" him; he has never been forgotten by his countrymen.

EDUARD SACHER'S FORMULATION OF PODOLINSKY'S PRINCIPLE

In 1881 the reputable publishing house of Gustav Fischer in Jena issued a book by a somewhat obscure author, Eduard Sacher, entitled **Foundations of a Mechanics of Society.** Sacher (1834-1903) published another book in 1899 with a similar title and many of the same numerical examples, in which he expanded his critiques of the economists' different theories of interest. We do not know yet whether there were any relations between Sacher and other members of a sort of Austrian school of ecological economics (Pfaundler, 1839-1920; Josef Popper, 1838-1921) or with Mach (1838-1916). Ostwald, who was younger than any of them, did not do the kind of empirical work on energy accounting that the Austrians did, although he is usually given the major role in social energetics. Hayek (1952), himself an Austrian, included Ostwald but not any of his countrymen (except Neurath) in his list of social energeticists (nor did he include Podolinsky). We learned of Eduard Sacher through Zmavc (1926), which barely mentions him, say that he introduced Sacher to social energetics, and explains that his work had no impact. Be that as it may, Sacher is, with Podolinsky, one of the earliest authors who wrote on energy and human society.

In his preface Sacher (1881) stated the natural sciences could provide a basis for a rational economy. In the introduction he explained the mechanical conversion of heat, introducing the energy unit kilocalorie or 424 kilogrametres, which Clausius called 1 **Werk.** Throughout the book he used 1 W as a unit where W stands both for **Wärmeeinheit** (i.e. kilocalorie) and for Werk.

He began by considering human beings as thermic machines. Physiology explained the amount of work that a person could do. From the different estimates of Poisson, Dupin and Saussure and Christian, he concluded that the maximum that one worker can achieve is 1000 kcal/d, and that to do this work he needs at least 3000 kcal energy. Not all activity that is work in the physical sense is work in the economic sense. Therefore, he estimated (after various considerations on the share of the economically active population, number of holidays etc.) that the work performed per worker-day would be equivalent perhaps to 450 kcal. He then put forward an initial conclusion, which he later argued in more detail: "The economic task of the available labour force consists of winning from nature the greatest possible amount of energy" (p. 24). This would depend on its skill, on its instruments, on the fertility of the soil, on the availability of waterfalls and on the climate. One could say that northern nations were poor because of lack of sunshine.

Energy sources were agricultural and forest production, hydraulic power, minerals such as coal, wind power, domestic animals and the products of hunting and fishing, all of them ultimately traceable to solar radiation. He then estimated the energy available per person-year in central Europe. Thus, one hectare of pine forest would produce per year some 8.3 m^3 of wood, equivalent to 4980 kg of dried wood, which, at 3600 kcal/kg, was nearly 18 million kcal/ha.yr. No sources were quoted. Sacher compared this output of energy with the amount of solar energy to which that hectare of land during the year was exposed and remarked on the small percentage converted. This image of an immense flow of energy from the sun reflected back into space, with only a minute amount being assimilated by plants, moved him to write, as if making a point in his classroom: "Nature is incredibly rich." On one hectare of wheat, 2590 kg of wheat and 3000 kg of straw would be harvested -- such high yields were consistent with the high yearly labour input of 180 workdays per hectare Sacher assumed, which was perhaps realistic for eastern European conditions. Subtracting 3 milion kcal from the production on account of seed and fertilizer (unfortunately, no details were given either in the 1881 or in the 1899 versions), we obtain 15 million kcal/hr.yr. Considering the use of land in Australia and in Prussia (Prussia had 17.25 million hectares of arable land, 6.25 million hectares of pasture land, 8 million hectares of forest, for a population of 26 million), about 19 million kcal/yr would be available per person.

He went on to compute energy available from domestic animals. One horse in one day can do work equivalent to 2 160 000 kilogrametres (this is not the dietary intake but the equivalent of the mechanical work carried out). This amounts to 1.5 milliom kcal/yr, counting about 300 days of work. Since there were two million horses in Prussia, their work during one year would be equivalent to 3 trillion kcal, or some 115 400 kcal per person. There were many other domestic animals, and using the equivalents one cow = 0.66 horse = 10 sheep = 4 pigs = 12 goats, one could reckon that Prussia had the equivalent of 557 000 kcal/yr per person from domestic animals. Another point is that cows, pigs etc. are not for work nor even primarily a source of food energy but rather a source of protein: Sacher's analysis should have counted the energy made available as food (and not as work) by all animals except horses. But this would have changed his accounts very little. Whether in work or food energy, there is also a problem of double counting, as the animals will feed on the pasture and will use the straw etc. Sacher dealt later with this problem.

Sacher gave an unexplained estimate for energy from waterfalls, which "could become a significant source of wealth" (p. 29), directly or in the form of electricity. He considered coal; reckoning only 6000 kcal/kg, the amount of energy available per person in Prussia would be 9 million kcal/yr, as annual production in Prussia was 40 million tonnes of coal. Sacher was aware of the difference between primary and useful energy, which for coal used in steam engines would be very large.

According to Sacher, one should also reckon the chemical energy in the metals produced, but he confessed that he did not know how to estimate this. Finally, figures were given without explanation on the energy made available from hunting and fishing. Sacher presented the information in Table 2.

Table 2. Energy available per person/year in central Europe, c. 1880.[a]

	Thousand kcal
From land	19 000
From domestic animals	557
From water power	36
From coal	9 000
From hunting	5
From fishing	20
	28 618

Source: Sacher, 1881.

However, Sacher considered that domestic animals consumed as food 15 times the energy they delivered and therefore to avoid double counting one should subtract 8.3 million kcal. Thus, some 20.3 million kcal per person/year remained available. How was this energy used by society? Sacher discussed nutritional needs, quoting Ruhlman, and gave as an example the diet of a German soldier at war, concluding that at least a million kcal/yr per person would be needed as food. However, adding the food wasted at different stages, one could estimate minimum food energy use per person at 2 million kcal/yr. The energy spent in housing, clothing and other minimum necessities of life would perhaps amount to 1 million kcal more. The difference between the available 20 million kcal and the 3 million kcal of subsistence requirements could be used for all the amenities of civilization, and to build machines for investment.

Sacher tried to correlate stages in cultural progress with energy availability before Geddes and long before Henry Adams and Wilhelm Ostwald. Podolinsky had wanted to correlate modes of production and energy availability, but he did not do it in any of the versions of his article, and illness prevented him from further work. Sacher was unaware of Podolinsky's work (though the preface to his book is dated May 1881, one year after Podolinsky's article appeared in the **Revue Socialiste**).

Sacher gave the following figures on energy available per person per year: "savages", 3 million kcal; "nomads", 6 million kcal; "agriculturalists", 14 million kcal; contemporary central Europeans, 20.5 million kcal. While he had discussed in some detail the figures corresponding to savages and central Europeans, he did not give any explanation for the other two categories. The figure for agriculturalists is way off the mark, in the sense that there is great variation in this group of people. Research into human ecology many years after Sacher (Hardesty, 1977; Ellen, 1982) shows that many agricultural peoples survive and even give up a surplus to landowners or to the state with a lower level of available energy. We would be reluctant to use the word "adapt" of functionalist ecological anthropology and human ecology, as the history of the resistance of many such peoples to exploitation is well known. In any case, consistency would have demanded that Sacher subtract all the energy derived from coal from his estimate for agriculturalists. Nevertheless, such criticisms are not wholly relevant. Sacher not only developed this view of the stages of history, a clear antecedent of evolutionary ecological anthropology, but also paid great attention to how the surplus of energy, beyond the subsistence needs, was appropriated by some groups of society to the exclusion of others. A large part of his books (particularly that of 1899) is devoted to a discussion of the economics of distribution, with an attack on interest, profit and rent.

Sacher went on to calculate the energy return to human energy input in agriculture. For wheat agriculture he calculated a net energy balance. The net energy output (including straw and net of seed and fertilizer) was 15 million kcal/hr.yr. The human energy input (corresponding to 180 workdays at 450 kcal/hr.yr) was 81 000 kcal/ha.yr. Sacher did not consider the energy input from domestic animals in this balance; he may have been thinking of a purely manual agriculture. The ratio of energy output to human energy input is then 185.

The first requirement in comparative work in ecological anthropology is to standardize the method of measuring human energy input. Sacher estimated not the energy intake, but work done. The ratio of 185 still appears very high, but this is because the energy output includes straw. It is a figure comparable to those found in much modern work in ecological anthropology. Sacher explained that to do work equivalent to 450 kcal/d workers have not only to be fed, but also clothed and housed. Perhaps the minimum expenditure of energy per person would be 9000 kcal/d (this was a "savage" standard, in his view) converted into 450 kcal/d of effective work, with an efficiency of 1:20. Thus for every 20 kcal that the agricultural worker, working on wheat cultivation, uses for food, clothing or housing she or he delivers 185 kcal. In other words, "one person working on wheat growing can feed nine other persons", a finding that Sacher later amended by subtracting the energy value of the straw. In any case, Sacher was trying here to explain that it was differences in the energy production of labour that caused different countries to have different proportions of their populations in agriculture. In England, the remarkably low proportion of population in agriculture was due not only to food imports but also to the fact that "many agricultural machines are used, therefore saving labour power, which is substituted in part by the chemical energy of coal, in the steam plough" (p. 35).

This tantalizing remark shows that Sacher was on the brink of doing a proper, comprehensive output-input analysis of energy flow in agriculture. He was aware of fertilizers as part of the energy input. He almost expressed the view that the high energy productivity of labour, in a country such as England, was perhaps the consequence of the substitution of energy from stocks (of Chilean nitrates and coal) for the flow of human and animal energy.

Sacher then tried to link energy analysis with the theory of economic value, defining three types of value by energy. This is, we find, not a very useful part of his analysis, but we include it for the sake of completeness. It would have been more useful to pursue to the end his inkling that modern agriculture was energy-intensive and to draw up a balance. Of course, an energy balance does not distinguish between renewable energy and energy from stocks. A balance in money would simply take prices and not consider whether such prices have really incorporated the most peculiar judgements on the present value of future demand for energy in stocks. We shall pick up these themes again in other chapters of this report. The example of coal will clarify Sacher's definitions of his three types of value. In Prussia, each miner produced on average 198 tonnes of coal per year (Sacher, 1881, p. 59). If we assume the heavy daily work of a miner as equal to 750 kcal with 300 workdays per year, then the total amount of work done per year would be equivalent to 225 000 kcal. This would mean 1136 kcal per tonne of coal, and this could be called the "exchange value" of a tonne of coal, on a human energy theory of value. The "absolute value" of a tonne of coal -- that is, its enthalpy, though Sacher did not use the word -- would be 6.5 million kcal. But its "use value" would be much less because of various losses and especially because of the low efficiency of the steam engine. The energy from a tonne of coal that really could replace human labour would be only around 180 000 kcal.

Taking a house as an example, its exchange value would again be its human energy cost; its use value would be the energy, not gained in this case, but saved by living in the house, compared to the extra energy needed if its residents lived in the open air. Similar considerations would apply to clothes.

Hypothetical figures were given by Sacher (1881, p. 74): in agriculture the use value produced from a hectare of wheat would amount to 4.81 million kcal/yr (with the yields that Sacher had assumed), once the production of straw had been reduced fifteenfold because it was used as feed for animals and taking other losses into account. The human energy input would be, as already explained, 81000 kcal/ha.yr, and this was the exchange value. The ratio between use value and exchange value (4810/81 = 59) was given the curious name of "specific value"; it is in fact the energy productivity of human labour.

The energetic efficiency of an agricultural worker (his or her "value as a machine", as Sacher put it) would be of the order of 1:20, because one cannot consider food energy only and because not everybody is available for work. Here, Sacher's analysis becomes interesting again, because it states Podolinsky's principle. For an economy to be viable, the use values (i.e. energy gained or saved) must be on average at least 20 times greater than exchange values (i.e. human energy costs, measured as work done)(Sacher, 1881, p. 63). In other words, the energy productivity of human work must be equal to or greater than the efficiency of human beings as thermic machines. Agriculture fulfilled this condition very amply, and so did coalmining, as the figures showed. Of course, the viability of the reproduction of a socioeconomic system should include a time perspective, and this Sacher did not discuss. Moreover, he was an "energetic dogmatist", in Georgescu-Roegen's sense, that is, he did not consider the availability of such resources as water or metals. He was nevertheless aware that an energy theory of exchange value was not really tenable -- he devoted many obscure pages to explaining why prices differed from such energy values, and he mentioned explicitly that artistic work had value that could not be expressed by its human energy cost.

The role of skill and innovations he considered to have importance in economic development beyond their role in energy availability. Thus, from Charlemagne, who had introduced new field rotations, to the inventors of the steam engine, who had made coal useful for work, mental work had contributed to wealth, and it could not be measured by energy cost. A corollary of this view was that it was inappropriate to relate wages to the expenditure of human energy, as skill and training played a great role in the value of human work.

With such provisos in mind he thought nevertheless that the "wealth of nations" (1881, p. 77-78) was basically determined by the energy return for human energy input. The higher the energy gained (or spared) -- "use value" -- and the lower the human energy cost -- "exchange value" -- the more energy was available beyond pure subsistence and the wealthier the nation. Whether this wealth was permanent or transient was not discussed by Sacher who, unlike Podolinsky, did not mention the second law.

As there were physical limits to the wealth of nations (despite the important role of human skill and innovations), how this wealth was to be distributed became a burning question. Chapters 7-14 of Sacher's first book, and most of the second, are devoted to a discussion of theories of rent, interest and profits. The real capitalists, however, were the plants that assimilated solar energy (1881, p. 84), and Sacher was strongly **antirentier** and anticapitalist, which might go some way to explaining the poor reception of his ideas in academic circles, though not in the socialist or anarchist **demi-monde.** Podolinsky's and Sacher's basic principle of human ecology reappears time and again, their initial contributions having been ignored. Why were they forgotten? To point to the separation between the natural and the social sciences is really to explain nothing, because this separation itself needs explaining.

Although we are aware of the difference between the painstaking estimates of energy and material flows by modern ecologists and the armchair counts of Sacher and Podolinsky, we stress the continuity in method and the discontinuity in time and intellectual tradition between their work and modern human ecology and ecological anthropology. As for economic history, the first academically successful attempt at this kind of approach was not made until Cipolla (1962).

BOUSSINGAULT, LIEBIG, GUANO AND AGRARIAN CHEMISTRY

Technical progress has meant that agriculture, which had always been a source of energy, is no longer one in every part of the world. Modern agriculture transforms fossil energy into food. The nourishment of one average citizen of a rich, peasant-less, meat-eating country now requires not less than one kilogram of petroleum a day. The beginning of the change in agricultural practices (which have increased harvests in those countries, while producing a spectacular decline in the number of agricultural workers) came with mechanization and agrarian chemistry.

The high energy intensity of modern agriculture derives not only from the energy required to run the machines, but also from the manufacture of fertilizers, herbicides and insecticides. Nitrogen fertilizers were first produced with hydroelectricity at the end of the last century in Norway. The cycles of nitrogen, phosphorus and potassium had been discovered only a few decades before. Many economists thought that agrarian chemistry, understood as technical progress, would reverse the tendency to decreasing returns or, to put it another way, would shift the production function upwards.

The new agrarian chemistry was inaugurated in the 1840s by Boussingault (1802-1887) in France and by Liebig (1803-1873) in Germany. Liebig liked to think and say that his research was important to prevent a subsistence crisis in Europe. The development of agrarian chemistry admits an externalist, sociological interpretation of scientific and technical advances.

Liebig's basic idea was to change from an agriculture of spoliation to an agriculture of restitution. He had to understand first that plants are nourished by minerals. Liebig was the man who discovered the importance of phosphorus; Boussingault was the one to analyze the nitrogen cycle, which Liebig did not understand. Both of them analyzed Peruvian guano. Boussingault explained that Fourcroy and Vauquelin were the first to draw attention to the nature of guano, and that the specimen they examined had been brought to Europe by Humboldt (1845, **p. 380). Mayer's article, Bemerkungen ueber die Kraefte der unbelebten Natur** (Observations concerning the forces of inanimate nature), which established the mechanical equivalence of heat and the law of conservation of energy, was been **published in 1842, in the Annalen,** edited by Liebig. The idea of a flow of energy in agriculture had appeared in Mayer (1845), which Liebig had refused to accept. What interested Liebig and Boussingault about guano was its chemical composition; neither studied the flow of energy in agriculture or costed the energy of fertilizers, though Boussingault did research on nutrition and photosynthesis. To defend the need to develop agrarian chemistry, they often remarked that guano supplies would run out (and that Chilean saltpetre, which is nitrate of soda and potassium, would not last either). Boussingault wrote according to the calculations of Humboldt made clear that it would take three centuries to form a layer no more than a centimeter thick of the excrement of those birds. An astonishing time was necessary for layers 20 to 30 metres thick to accumulate. Such layers existed until quite recently in many places, but the guano was disappearing rapidly since it had become an object of commercial enterprise (1845, p. 381).

The guano trade has been a favourite subject for Peruvian historians (Bonilla, 1974) aiming to demonstrate the misdeeds of imperialism, which left Peru without guano and having received little in exchange (the money from guano remained in Europe to pay off loans). There is another point of view: the heteronomy of European agriculture from an energetic and material subsidy from outside -- did it provoke no ecological argument similar to those of today? Did no one say that the increase in productivity of European agriculture was the reverse side of the exhaustion of resources and disruption to human lives in a place as distant and desolate as the guano islands in the Humboldt stream? To avoid an agriculture of spoliation in Europe and to restore to the soil the nutrients incorporated in plants, other territories were despoiled. An economic history from a materialist and energetic standpoint would be required to complete the research into financial transactions and the political struggles and failures of an incipient Peruvian bourgeoisie with a calculation of that spoliation in physical terms.

Students of agricultural economics still learn nowadays about Liebig's "law of the minimum", namely: no single element of the indispensable minerals is superior to any other; all have equal value for the life of the plant. Therefore, if one element is missing from the soil, the others cannot produce a properly developed plant (1859, p. vi). The students are not taught his opinions about the political economy of agriculture. Agriculturalists (he wrote) must not rely on guano; its price was double what it had been before; no man with any sense would want the production of his country to depend on the supply of a foreign manure (op. cit., p. 269). It was therefore necessary to develop chemical fertilizers, in spite of his pride in the fact that science (that is, Liebig himself), "guided by a careful study of the elements of the food of plants", pointed out in 1840 to the agriculturalists that guano was "one of the most infallible means of raising the produce of corn and flesh, and most urgently recommended its application" (op. cit., p. 265). One hundredweight (51 kg) of guano contained the mineral elements necessary to produce between 25 and 30 hundredweight (1275-1530 kg) of wheat; this led to the belief that "the guano beds of America" possessed an "immense value with reference to the production of corn in Europe" and that guano would come to have a decisive role in the history of Europe unless it were replaced in time: "bloody wars have sometimes sprung from causes of much less importance" (op. cit., p. 269-270).

Liebig and Boussingault believed in replacement, perhaps because they were chemists rather than physicists; the dissipation of matter is not an established law of physics, whereas the degradation of energy is. However, they believed in replacement not by hypothesis, like the economists who write production functions with two or more inputs, but because they thought they would be able to manufacture chemical fertilizers possessed of virtues similar to those of guano or other manures that had always been known but whose chemical constituents they had analyzed. They never said that, if the price of guano rose enough, there would undoubtedly be an alternative fertilization technology (a backstop technology, in today's economic terminology): they worked to develop that alternative. Neither of them, however, drew attention to the fact that chemical fertilizers would be made with energy from exhaustible fossil fuels.

Guano had been known as a fertilizer since before the Incas. Analysis of its chemical composition and that of manures and human excrement and other fertilizers known to agriculturalists laid the foundations of agrarian chemistry, especially in Liebig's laboratory in Giessen. Liebig's name can be associated with a new leading sector of the chrematistic economy: the manufacture of fertilizers. It can also be associated with a more ecologic vision, because he developed an argument against latifundist agriculture and for a ruralized urbanism. He wrote that when 2000 people live in one square mile (2.56 km^2), it is impossible to export cereals and meat, as the produce of the land is just enough to feed them. Also, all the mineral elements in the products consumed can easily be returned without loss to the fields. But if this land falls into the hands of big owners, spoliation will take the place of the system of restitution and compensation. The small owner gives back to the land almost all he takes from it; the big owner, on the other hand, sends the grain and the meat to be sold in the major centres of consumption and so forfeits the conditions necessary to reproduce them. Good luck brought guano, but guano would run out, and what would we do then? (1859, pp. 229-231). Quoting Carey, he pointed out that in the United States there were hundreds and thousands of kilometres between the production centres of cereals and the markets; the result was that the soil was becoming almost exhausted everywhere (op. cit., p. 20).

At the same time, he praised the Chinese practice of fertilizing the fields with human excrement and thought that the landowners of the great countries should form societies to set up reservoirs where human and animal excrement could be collected and prepared for transportation to the fields. (1859, p. 268). The urban accumulation of excrement and refuse was the other side of the problem of spoliation. From this, two clear lines of argument emerge: an ecological line and a line of economic growth based on agrarian chemistry, sewers and the treatment of urban refuse, which large-scale urbanization required.

Liebig's digressions on the recycling of excrement were considered either to be rhetorical exaggeration or to refer to Chinese eccentricities. While most natives of China were taking excrement to their own fields, some thousands of them, held in debt peonage, were digging out bird excrements in Peru and sending them on to Europe.[1]

What was appreciated about Liebig was the promise of an agriculture with great yields, separated from the big cities and based on chemical fertilization. That made him famous, which was much to his liking.[2]

The discussion about the substitution of industrial fertilizers for Chilean nitrate came after Liebig. Chilean saltpetre was imported in great quantities; for example, about 10 kg per person per year in Germany toward 1900 (far less than the present imports of petroleum of about 4 kg per person per day). Boussingault remarked early on that nitric acid came from nitrogen and oxygen and that to unite these gases with an electric spark, the mixture must be moist, according to Cavendish (1845, p. 323-324). Boussingault was still not envisaging the practicality of industrial nitrogen fertilizers manufactured with electricity. That discussion would come later, explicitly on the energy costs of substitution. For example, there are detailed calculations of the kilowatt-hours necessary to manufacture nitrogen in Popper-Lynkeus (1912) and especially in Jurisch (1908). World War I gave it a great impetus, nitrogen being necessary for explosives, thus fulfilling Joseph Henry's prediction 70 years earlier that one day the bolt of Jove (electricity) would come to the aid of Mars, the god of war.

Soddy did refer to Cavendish's "great discovery of the 18th century". In the Birkeland-Eyde process, instead "of the energy of a patient attendant turning the handle of a frictional electric machine ... the power of hundreds of thousands of horses, derived chiefly from the 'white fuel' of the Norwegian and Swiss hillsides, are (sic) ceaselessly at work, turning dynamos which produce powerful high-tension arcs in the air, so converting it partially into nitrous and nitric acids." As so many other British writers did after 1900, he referred to Sir William Crooke's famous presidential address to the British Association for the Advancement of Science, wherein he drew attention to the future failure of the

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[1] Liebig's opinions about the agriculture of China (and Japan) were formed under the influence of the Prussian scientific missions, then investigating the possibilities of colonies, in which the geographer Richthofen (1833-1905) later participated.

[2] The edition of his **Letters on Modern Agriculture** we have used announced the sale of busts of the author. There is a book on Liebig and English agriculture in preparation by Vance D.M. Hall (cf., Centaurus, vol. 26, 1982-83, p. 232), to be added to the excellent studies by Rossiter and Krohn.

wheat supply unless chemists solved the problem of the fixation of atmospheric nitrogen. They had indeed succeeded (with the Haber process they were to succeed further), but Soddy remarked that "the question, as to how long the Chile saltpetre beds will last, has simply been merged into the more general problem of how long the natural resources of energy of the globe will hold out. Insofar as such developments utilize the natural energy running to waste, as in water power, they may be accounted as pure gain. But insofar as they consume the fuel resources of the globe they are very different. The one is like spending the interest on a legacy, and the other is like spending the legacy itself. The wheat problem ... is one particular aspect of a still hardly recognized coming energy problem." Soddy therefore anticipated "a period of reflection in which awkward interviews between civilisation and its banker are in prospect" (1912, p. 135-139). The alarm about agricultural yields in the absence of chemical fertilizers was as old as Liebig, if not as Humphry Davy, but the view that modern agriculture was energy-intensive was still a novelty in 1912, and it surprisingly remained a novelty until the 1970s.

PATRICK GEDDES'S CRITIQUE OF ECONOMICS

One early attempt at an ecological critique of economics was made by Patrick Geddes, who was also one of the first authors to correlate human history and expenditure of energy. This chapter will consider Geddes's early economic writings, though Geddes is mainly known by his later work in which he insisted on the need to carry out ecological studies of urbanization. To study a process ecologically means to establish its energetic and material "budget", analyzing its flow of energy and the cycles of materials.

Walras and Geddes

Patrick Geddes, a Scot, born in 1854, died at Montpellier in 1932. He began his scientific career studying biology with T.H. Huxley (1825-1895) in London. An eye disease contracted during an expedition to Mexico and his own interest in urban questions, first aroused in Edinburgh, led him to give up biology. In 1879 he had published an article entitled **"Chlorophylle animale et la physiologie des planaires vertes"**, which indicated his familiarity from the beginning of his career with the principles of the use of energy by plants and animals.

In 1884 he published two articles on economic topics. Later he made many urbanistic plans, primarily in Scotland, England and India. His best known book is **Cities in Evolution** (1915). In this chapter, our interest in Geddes is as one of the first energy economists, and his wider significance for regional and urban planning will not be considered in detail. His articles of 1884 on the economy develop themes that may also be found, abridged, in his correspondence with Walras (1834-1910), the founder with Jevons and Karl Menger of marginalism.

One of Walras's works had reached him through an economist (Foxwell of Cambridge) whom Walras used to expand the circle of adherents of the new formalized marginalist economics. On 15 November 1883, Geddes thanked Walras for the article and explained his objections to that form of economics. The mathematical economists, he wrote, thought that "... they can do everything with no assistance from applied physics for studies of material production, no assistance from biology for the study of the organisms which make up society, with no assistance from modern psychology (a very different thing from the psychology of the old economists) or from the research done by the historical or anthropological school!" The study of material production requires the assistance of physics, but it is not necessary to agree with Geddes on the (dubious) benefit to be gained from biology in studying the evolution of "social organisms". Geddes that Walras make a distinction (discussing the application of mathematics to economics) between statistics, the theory of exchange (termed pure catallactics by Geddes) and studies of the material resources of a country or the conditions of life of its inhabitants. The distinction between the theory of exchange and studies of the use of resources is exactly the distinction between orthodox economics and ecological institutionalist economics.

Geddes wrote also: "Another objection, it has always seemed to me that Mr. Jevons, by wanting to apply mathematics to the study of utility, is failing to recognize that this **Utility** is simply an abstraction which he has inherited from the metaphysical school and not a true scientific fact or generalisation -- that the **Utility** of a clock or of an opium pill is merely the "clockness" of the one and the **virtus dormitiva** of the other. I do not deny that commodities are useful; they are, certainly, just as the animals and the plants which I deal with are alive, but I maintain that Utility is a rather unscientific abstraction, as pernicious to real progress in political economy as Vitality has been in biology and medicine." This is an objection to the commensurability of consumer goods in economics.

Walras did not agree with these observations in his reply, but the discussions went no further. Walras hardly ever touched on physics except to point out frequently the formal analogy shown in his equations between static mechanical equilibrium and economic equilibrium. He had an interesting exchange of letters with Herman Laurent (a specialist in actuarial calculus), who wanted to know whether Walras would agree that an invariable standard of value would have to be based on physical realities. Walras did not want to know anything about an invariable standard of value. He repeated that value depended on supply and demand (and that behind the function of demand, there was for each consumer a function of utility, the value of which the consumer wished to maximize.)

Another of Walras's correspondents was Winiarski, an author -- there were several around the turn of the century -- who wrote both about "phychic" or "mental" energy, as if that had anything to do with the energy of the physicists and biologists and also about "utility" or "intensity of desire". This confusion led him to say that Walras's equations expressed exchanges of that mysterious psychic energy. But we will leave Walras and his correspondents and return to Geddes.

Ruskin and Geddes

Geddes and Soddy were admirers of **Unto This Last** by John Ruskin (1819-1900), a critique of conventional economics. The date of publication (1862) would have allowed an ecological critique of economic theory. Ruskin also published in 1863 **Munera pulveris**, a critique of economics as the study of transactions in the market, pointing out that economics really should not mean the study of material provisioning in human societies. It is not, however, an ecological critique with accounting of energy and materials.

Ruskin criticized the aesthetic disasters of industrial capitalism. He rejected the idea that the market reflected the real needs that human beings had in order to live surrounded by beauty. Therefore any accusation of physicalist reductionism in the notions of need that are to be found in Geddes (and Soddy) is misplaced. To think that the admirers of Ruskin had seriously proposed replacing economic -- or rather chrematistic -- calculus with energy accounting **and nothing else** would be absurd. Energy accounting serves as a critique of money accounting (inasmuch as it questions how the value of inputs and products should be measured). Energetic calculus does not classify economic questions; it complicates them. It is in **no way** a theory of value, but a contribution to the critique of theories of value.

In **John Ruskin, economist** (1884), Geddes wrote that to say that a loaf of bread or a diamond has no value beyond its utility is to say no more than that these phenomena share the idealistic aspect attributable to all phenomena. When economists say things have only utility value, they merely express the indisputable fact that from that idealistic point of view they have no other aspect. We should leave the academics in their cloisters and walk out into the world, look around us and try to see the loaf and the diamonds objectively. We shall find that they have various physical and physiological properties; bread is a quantity of fuel and its heat-giving power can be measured in units of energy of work; the diamond is a sensory stimulus, which varies according to Fechner's Law.[1] We can easily understand what Ruskin was trying to explain, however ridiculous it may seem to orthodox economists: intrinsic value is the absolute power of something to support life. An ear of corn has a certain value for sustaining the body, a litre of air has a certain power to maintain the body's temperature and a bunch of flowers has the power, through its beauty, to animate the senses and the heart.

Geddes paid tribute to Stanley Jevons for having seen truths that his contemporaries either could or would not see, such as the waste of Britain's coal reserves. According to Geddes, Jevons had argued that coal was not merely an article with a subjective value and consequently a subjective exchange value; it represented a quantity of stored energy that imposed strict and calculable limits on industrial activity. The economics of coal, therefore, was not a question of increasing the wealth of the mine owners, as Ricardo would have explained with his theory of differential rent; nor was it a question of raising miners' wages, as union economists would say (not that there were many such economists). The question was the relation between reserves and present and future demand and a careful study of that demand; it was prevention of waste of energy, and stopping the spread of soot. Businessmen and their academic supporters, the market economists, with their advocacy of **laissez-faire** , were exactly opposed to Ruskin's views.

In Geddes's view, Ruskin was the legitimate heir of the physiocrats and, with the aid of the physical and biological sciences, the precursor of their rehabilitation. Moreover, by expressing the aims of practical economics as the improvement of the quality of life, by treating art criticism and other aspects of production from this point of view and by stressing the essential unity of economics and morality and not their discrepancy (assumed by other economists), Ruskin became a classic.

Although Ruskin is not a classic of economics, this appraisal is significant to the understanding of Geddes's critical program of research on economics, ecologic on the one hand and moral and aesthetic on the other. In 1884 he also published **Analysis of the Principles of Economics,** papers he read to the Royal Society of Edinburgh (whose secretary was Peter Guthrie Tait), which amount to some 40 pages in which he developed ideas presented three years before in **The Classification of Statistics.** In the chapter on physical principles he wrote: "Without ignoring the historic services of the physiocratic school, the application of the conceptions of modern physics to economics may be fairly said to date from Professor Tait's discussion of the **Sources of Energy in Nature,** published about twenty years ago ... The subject has been developed to some extent

[1] Geddes's quotation of Fechner implies that one could measure in some way the "sensory stimulus" given by diamonds. Fechner (1801-1887) was the founder of psychophysics, and he proposed a law that relates stimulus and sensation (as in the logarithmic relation between noise, measured in decibels, and sensation). Max Weber in 1908, in his campaign for separation between the sciences, was rightly to deny any possibility of basing marginal utility theory on this fundamental psychophysical law.

by other physicists, as Siemens, Thomson etc., but seldom by economists, with the distinguished exception of Professor Stanley Jevons" (p. 952).[1]

Geddes proposed an input-output table, certainly inspired by the **Tableau Economique.** The first column contains the usable sources of energy (according to Tait's classification) as well as the sources of materials used not for their potential energy, but for their other properties, which shows that Geddes was not a believer in the "energetic dogma". This energy and these materials are transformed into products in three stages: extraction of fuels and raw materials, manufacture and transport and exchange. The intermediate products used for the manufacture of the final products must be subtracted from the final products. It is also necessary to estimate the losses (dissipation and disintegration) at each stage.

It was legitimate to apply to the economy the concepts of physics that measure matter and energy. A quantity of matter is exploited -- let us say, x units; so much is lost at each stage of production (a+b+c), and the final product remaining is [x - (a+b+c)]. Part of this will be available for recycling, after consumption, as scrap. Moreover, so many units of energy, x, are exploited; the processes of extraction, transport and so on cost so many units, a; the remainder (x - a) is the available energy. The difference passes to the manufacturer; the material and energy wasted by him are shown in the same way; the remainder, after a deduction for losses incurred in transport, is the quantity of final product, which could be separated into a permanent and a transitory part (for immediate consumption).

It was possible to express the work done by human beings in units; from a physical point of view they were thermic machines (automata, said Geddes). The horsepower of a machine could equally well be called "manpower", and vice-versa. To talk of horsepower was, in fact, pure convention. Producers and machines were not only interchangeable but commensurable.

The quantity of energy and materials exploited during a given time and the part disintegrated or dissipated during the process were shown in the diagrams with which Geddes explained his ideas. The amount of final product seemed incredibly small in proportion to the potential amount. This disparity was intended to show the enormous losses of energy and material, which often exceeded by many times the final product, because of the imperfection of our processes. These losses of energy or matter were included in Geddes's accounting scheme. In conventional economics they were excluded; what was being paid for at each stage was not the energy and matter lost, but only that available for that stage. For example, the energy from the coal that moves machines is accounted for in money, but not the other 90-97% which is dissipated. The final product, what would today be called added value, was not **added** value at all; it was the value remaining from the energy materials available at the beginning.

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[1] The material by Tait to which Geddes refers, published in the **North British Review** (vol. XL, 1864, pp. 40 and 337), which was a review of literary criticism, is a thorough history of the discovery of the laws of energetics from Fourier (1768-1830), Rumford (1753-1814) and Sadi Carnot (1796-1832) to Clausius (1822-1888) and William Thomson (1824-1907), where Joule (1818-1889) is given high praise and Mayer (1814-1878) is ignored. It includes a classification of the sources of energy available for the production of mechanical labour (p. 364): fossil fuels, animal fodder, power from flowing water, tides, winds, ocean currents, volcanos and geothermic water, and explains the physical origin of each of these energy sources. The idea that it is possible to do energy accounting of economic processes is implicit (for example, in comparing the thermodynamic efficiency of steam engines and the human body, p. 344), but it is not developed.

The part of the final product that took the form of capital (or productive apparatus, as Geddes called it) could easily be expressed in physical units; the part however for consumption consisted of matter and energy. Certainly, if we considered consumers as **automata,** their maintenance needs could be expressed in physical terms, but we could **not** explain human consumption without introducing psychological and social considerations. Geddes observed great disparities in consumption. For example, the Russians', Norwegians' and Scots' consumption in monetary terms was respectively £7, £14 and £30 sterling per person per year. How could the huge difference be explained, given similar geographic conditions and similar needs for food and fuel? We must divide consumption into "necessary" and "super-necessary": the variation in super-necessary consumption may be called the esthetic element, and final products could be analyzed in terms of their necessary and aesthetic elements. The paradoxical conclusion thus arrived at is that although production was fundamentally for maintenance, it was principally for art, a conclusion that fits in with his eulogies of Ruskin; obviously it is absurd to classify Geddes among the supporters of a theory of energy-value.

An ecological critique of industrial urbanization

Geddes's ideas on cities are well known, especially through the work of Mumford, although they are less original as ecological critiques of economics than the articles of 1884. As far as we know, he never analyzed the flow of energy of a specific city; nonetheless that was the idea he had in mind and any urbanist who read his work could have begun the task many years ago. Cities have always lived off the energy (and materials) supplied by the countryside as cereals and other foods. Today's great cities are characterized by the size of this absorption, considerably aided by modern transportation (which is, to a great extent, the result of chrematistically cheap energy).

Geddes's thoughts on urbanism, however, have a different starting point: cities on top of coalfields. The map of population in Great Britain changed with the inception of coal-based industrialization. But not only had the cities near coal deposits grown; others -- especially London -- also grew enormously into conurbations. Coal made this possible. This development had taken place against a belief in industrial progress based on unlimited supplies of coal; the objections of Carlyle, Ruskin and Morris were dismissed as "romantic" or "aesthetic". Their ideas were however in accord with those of the physicists. Geddes was fond of bringing the assumed certainties of the "hard" sciences (including a doubtful biology of human groups) to bear upon the woollymindedness of the economists. The fact is, however, that the physicists were in general enthusiastic about industrialization and urbanization. This does not detract from Geddes's conclusion, that there should be no confusion between the development of resources and the dissipation of energy. Such dissipation might produce extraordinary wealth in money, but what did it really mean? An improvement in the quality of life? The new type of economist would want to preserve real wealth by planting trees, for example, to replace those cut down: the forest is a bank where real wealth grows. Geddes was exercising here the **leitmotif** of ecological economics: plants as the real capitalists, the economists' confusion between wealth and debt. He introduced also the distinction between "paleotechnical" or coal-based industrialization and urbanization and "neotechnical", but he did not specify the technologies of this neotechnical era (compared, for instance, to Popper-Lynkeus's detailed quantitative analysis) other than eulogizing the integration of cities with agriculture and offering optimistic visions concerning electricity (a renewable source of energy only when produced from waterpower). The new neotechnical urbanism would create Utopias; the old conurbations were really Kakotopias. Geddes's analysis of the evolution of cities is nearer a true human ecology based on the careful tracing out of the flows of energy and materials than the misnamed "human ecology" of the Chicago urban sociology of Park, Burgess and Hawley in the 1920s (Naredo et al., 1979). However, there was no systematic quantitative comparison of the energy intensity of different patterns of urbanization, that is, of the calories or kilowatt-hours per inhabitant that would have to be brought from outside for the city to function. In later urban analyses and planning (for instance, by Lewis Mumford) such comparisons are still missing. In Le Corbusier, the very idea of the relevance of ecological analysis disappeared. Perhaps one of these days, going full circle, we shall read an apology for the great city as a true apotheosis of autopoiesis, organizing, cajoling and extracting energy and materials from territories near or remote.

MAX WEBER'S CRITIQUE OF WILHELM OSTWALD

One of the few natural scientists who wrote on social energetics and had some impact on one of the social sciences (cultural anthropology) was Wilhelm Ostwald (1853-1932). He developed the view that human history was linked to greater availability of energy and an improvement in the efficiency with which it could be transformed. He wrote books along these lines, one of which foreshadowed modern evolutionist ecological anthropology, as Leslie White came to realize. Weber held views on economic history that were similar, as we shall see, to those propounded almost simultaneously by Soddy, who was 25 years younger, and which had also been propounded by Podolinsky, Sacher and Geddes in the 1880s and by Pfaundler (with whom Ostwald was in contact) in 1902. Ostwald quoted none of them.

Ostwald's views on economic history were based on an energeticist critique of economic theory. But they were not strictly dependent on his energeticist viewpoint in physics and chemistry, which denied the relevance of atomism both before its experimental stage and for some years after the discovery of radioactivity. Soddy had been speculating since 1903 on the potential of atomic energy in the economy. In any case, we shall not be dealing with Ostwald's energeticism in the natural sciences (in the sense in which this word was used at the time), but with his energeticism in human history.

Ostwald had a talent for advertising his wares. He coined a slogan -- which he described as an **energetische Imperativ,** to be used not only as a moral guide but also as a principle of interpretation of the course of human history -- **Vergeude keine Energie, verwerte Sie (Waste no energy; value it).** One could see in it one of the origins of the theories that link natural selection and the use of energy (from Lotka to Prigogine) and that, when applied not to different species, but to humankind, may link energy analysis and socialdarwinism. Ostwald himself did not develop this line of thought -- how societies adapt to the available flow of energy and how they modify it -- and he did not do any empirical analysis of the use of energy in any society.

Max Weber (1864-1920), who wrote a review of Ostwald's 1909 **Energetic foundations of the science of culture** and published it also in 1909 (Weber, 1968) rightly criticized Ostwald for his failure to provide data. But he did not quote any of the authors (from Podolinsky to Pfaundler, apart from others that we might have missed in our research) who had done empirical work on the flow of energy in human societies. Max Weber explained Ostwald's main thesis and defended the separation between the sciences, almost making fun of Ostwald's **salto mortale** into economic history. Weber could certainly have been more cruel in his critique. He reserved his fiercest irony for Solvay, the industrialist who had also written on energy and society, and he did not dwell excessively on Ostwald's nonsense on "mental" energy or on such flights of fancy as Ostwald's proposal for a universal language to save the energy spent on translations.

The development of culture, Ostwald had said, depended on the availability of energy and the efficiency of its transformations. Max Weber's first points were that Ostwald did not provide detailed figures and that he forgot about the availability of materials. Weber thus anticipated Georgescu-Roegen's strictures against the "energetic dogma". Ostwald started from the fact that almost everything that happened on the Earth took place because of the energy radiated by the sun. Therefore, a permanent, viable economy ought to be based exclusively on solar radiation. Ostwald had written, however, that the rapid expenditure of solar energy, converted and stocked as coal, was of little importance. How could the squandering of such an inheritance be of little importance? asked Weber. The answer, according to Ostwald, was that the efficiency of the transformation of solar radiation was capable of enormous improvement not so much because of an increase in the photosynthetic yield of plants, as because of the direct industrial application of solar energy through photovoltaic conversion.

Perhaps Ostwald was right in this view, but why did he not analyze the reserves of iron, and of the copper and zinc so important for the transmission of electricity? Ostwald foresaw that future energy supplies would come from solar energy converted into chemical and electric energy. Accordingly, it would have been useful to consider to what extent aluminium (which, Weber wrote, was practically inexhaustible and was falling rapidly and consistently in cost) could replace copper and zinc. To sum up: Ostwald did not believe that the flow of solar energy either had or would decrease; so there was be no need to economize on energy from the sun, although the availability of materials, some of which were required for the transmission of energy itself, needed consideration. The law of entropy -- of dissipation through use -- wrote Weber, applied to materials as much as to energy.

Moreover, if the prospects for the industrial use of solar energy, which up to now had been used only through live or fossil plants, were as good as Ostwald preached, why should we worry about the efficiency of the transformation of energy? Was thermodynamic efficiency not increasingly irrelevant, also taking into account that birth rates were falling?

Ostwald defined cultural progress as the increase in the availability of energy and the substitution of human energy by alternative forms. He had defined cultural progress also as an increasingly efficient energy use. Was not Ostwald contradicting himself? Max Weber pointed out that a peice of cloth woven by machine must have a higher energy cost than a piece of cloth woven by hand, yet nobody could doubt that weaving by machine represented technical and cultural progress. In any case, price and cost made weaving by machine advisable. The study of prices and costs was the province of economics; energetics was irrelevant.

About the first Ostwaldian criterion for cultural progress -- the increase in the availability of energy and the relative decrease in the use of human energy -- Weber had little to say beyond a reminder of Sombart's arguments in his discussion of Reuleaux's concept of "machine". Weber also remarked that between classical antiquity and the present there had been a great decrease in the relative importance of human energy. Therefore there had been cultural progress if one defined it tautologically in this way. Paraphrasing Weber, we could say that Ostwald could have saved himself some embarrassment by avoiding the use of the word "culture", since his energetic definitions would make Austin, Texas in the second half of the twentieth century a more "cultured" city than Florence in the Renaissance. We can only agree with Weber's critique of the energetic definition of "culture", but it is a pity that it distracted him from the useful question: do we gain any better understanding of human history, and particularly of economic history, by studying the changes in the flow of energy in human societies?

The second Ostwaldian criterion of cultural progress -- the improvement in the thermodynamic efficiency of energy use -- was, for Weber, even more absurd. Although each generation of steam engines certainly improved efficiency, industrial processes that tend to decrease rather than increase thermodynamic efficiency are, nevertheless, often described as technical progress. For instance, wrote Weber, if we calculate the energy radiated by the sun and contained in coal used for each unit of machine-woven textiles, and if we draw up a similar account for hand weaving, we would find that energetic efficiency was greater in hand weaving than in machine weaving, that the energy unit cost was lower in pre-industrial processes.

In an exchange economy, however, the relation between money unit costs, which were decisive in competition, did not necessarily parallel the relation between energy unit costs, though of course -- wrote Weber with a smile -- the energy spent would always have an "energetic" influence in money costs. For instance, if Ostwald was right in saying that a device could be introduced to convert solar radiation into electric energy, it was clearly possible that, even if its thermodynamic efficiency was much inferior to that of a steam engine, the competitive edge of this form of energy would be overwhelming. In fact, the most primitive tool in nature, human muscle, was more efficient in the use of the energy than the best electric dynamo, and yet it lost out in the economic comparison.

Neither Max Weber nor Ostwald considered how the prices of exhaustible resources are determined. Weaving by hand was more expensive than weaving by machine because the steam engine had been invented and coal was cheap. Why was coal cheap? If the answer was the abundance of supply, we would have to look at the allocation of coal over time. How was future demand valued at present? Weber did not go into this question. Insofar as he was an economic historian (although not, perhaps fortunately, a pure economic theorist) he should have gone into it to see whether he could clinch his argument. For instance, with the benefit of hindsight we can say that the internal combustion engine gained a competitive edge in some parts of the world at a certain time because oil was cheap owing to abundant supply and low extraction costs. But to understand why the supply of oil was considered abundant relative to demand one has to consider a permutation of beliefs and attitudes: that future discoveries would be equal to or higher than use at that time; that, if oil ran out, it would be replaced by something else; that the demand of future generations could be discounted; that the demand of the poor sections of humankind could be ignored. Even the neoclassical economics of slavery has to embrace study of the demography of those slaves; the economics of natural resources has to embrace study of the reproduction of such resources. Only the most fanatic of methodological individualists, who really believed that the physical characteristics of commodities did not matter at all, could argue that, because a natural resource is cheap, it must be abundant.

Steam engines, at the time Weber was writing, had efficiencies as low as 5 per cent, whilst the human body can convert food energy into work with an efficiency of 20 per cent. Even today, if we take into account that a power station will dissipate two-thirds of the energy of coal or oil, and if we also take into account the energy cost of extraction and transportation of coal or oil and the losses in the transmission of electricity, it might turn out that work done with an electric engine is energetically less efficient than if done by human power.

However, it is obvious that the amount of work done nowadays in an industrial economy could not be done with human and animal power. This was indeed one of Ostwald's points: greater availability of energy and a concomitant decrease in the share of human energy were signs of cultural progress. In societies with a generalized market system, the substitution of new forms of energy for human and animal energy has been brought about because work done with machines powered by coal, oil etc. is cheaper. But the price of coal or oil and the market-led allocation of resources incorporate forecasts of technical change and ethical judgements on the conservation of such exhaustible resources for future generations. Prices and costs are firmly embedded in the interpretation of physical reality that economic agents take from the history of science and technology, and in the social distribution of moral values concerning the demands of future generations. A greater (or lesser) weight given to future needs or a less (or more) optimistic view of technical change could have pushed up (or down) the price of coal or oil, and so changed the relations between costs that Max Weber thought decisive for an explanation of economic history. Max Weber's economics, in this particular piece of writing, should be called chrematistics or catallactics -- the study of individual transactions, from which a pattern of prices anad quantities emerges independently of the social causes of the valuations that are made.

FREDERICK SODDY'S CRITIQUE OF THE THEORY OF ECONOMIC GROWTH

The ecological critique questions the definitions of the terms of economic discourse, such as "production". To that extent, it has always been destructive of theories of economic growth, though this does not mean that the early ecologists were technologic pessimists.

One persistent critic of economic theory who could not always be called a technological pessimist was Frederick Soddy (1877-1956). He worked with Rutherford on his early atomic research in Montreal and subsequently at Scottish universities. He discovered and named the isotopes, and won the Nobel Prize for chemistry in 1921. In 1919 he returned to Oxford as professor of chemistry, on his second attempt to secure a chair at the university where he had been an undergraduate. Neither the scientists nor the economists paid any attention to his economic doctrines, and he remains an unknown name even among the economists of his old university, despite the recent articles by Trenn (1979) and Daly (1980).

From 1903 onward Soddy believed that energy from atoms could change the economic prospects of mankind, though he was doubtful about developing the technology for accelerating the fission of the self-splitting atom.

He gave the title **Cartesian Economics** to the lectures delivered to the London School of Economics and Birkbeck College students in 1921 to emphasize that his critique was based not on romantic gloom about the technological prospects, but on a rationalist approach. We, on our side, emphasize the title he gave to his lectures, as it is now the fashion to set "ecological thought" in opposition to the scientific method and to analytical thought (for instance, in the work of the Californian mystic Fritjof Capra, 1982), a fashion much favoured by the irrationalist philosophies of science prevalent in the 1960s and 1970s (cf. Newton-Smith, 1982).

In those lectures, Soddy took issue directly with Keynes's views on long-term growth. Soddy defined wealth as a flow, which could not be saved, only spent. Real wealth came only from the flow of energy from the sun, which was consumed as it arrived and could not be stocked. Part of this wealth took the form of so-called capital goods and was carefully measured as financial capital -- as credits against the community. Real wealth, in the form of a wheat crop, for instance, would rot if stored for any time, whereas wealth in the form of so-called capital goods, registered as financial capital, was supposed not to rot but to grow independently at compound interest **ad infinitum.** This was a convention of human society, subject to contingent ethical values. Such values could indeed be historically variable, but they could not run permanently counter to the principles of thermodynamics. One could readily agree that a chauffeur had a spiritual life that transcended the mechanism of his car, but if his spirit should move him to try to run the car on fuel already spent, we would consider him an ass.

The economists were victims of this delusion. Keynes seemed to believe that wealth -- and not debt -- increased according to the rules of compound interest, a "fact" he opposed to the Malthusian population "law". He had written that one geometric progression could overcome another; the nineteenth century had been able to forget the fertility of the human species because of the dizzy virtues of compound interest. Capital, according to Keynes, was something like a cake that one day, thanks to compound interest, would be large enough to satisfy everybody, unless prematurely consumed in war. Once the stock of capital had increased sufficiently, excessive work, overcrowding and hunger would disappear, and mankind would devote itself to the exercise of its nobler faculties. Now we all know, remarked Soddy, that we cannot have our cake and eat it. Capital could not really be stored. It was subject to a law of continuous decrement, because physically it was energy embodied in certain objects, subject to the law of entropy. Neither physiocrats, orthodox economists nor marxist economists had a relevant answer to the basic question: how does mankind live? The answer was, "by sunshine". Without the sun the world would be lifeless not only because there would be no plants and animals, but also because even inanimate nature would stand still. The volcanoes would still erupt, the tides would ebb and flow in dead oceans, the newly discovered phenomena of radioactivity would persist, but there would be no rain and no wind. The starting point of economics should be the first and second laws of thermodynamics. Soddy did not pay attention to exhaustible resources other than fossil fuels and radioactive materials. Yet he was not a partisan of an energy theory of values, being extremely conscious of the difficulties in defining the objectives of human life. He stated explicitly that he did not understand the proposals to substitute a system of "energy certificates" for the price system (1926, p. iv, cf. Chapman, 1975). In the unlikely event that he had been surrounded by economists converted to ecological reductionism, he would certainly have quoted Ruskin's eulogy of aesthetic objectives of economic activity.

Although life followed the principles of the steam engine for its physical preservation, it was also "the expression of the interaction of two totally distinct things represented by probability of free will" (1922, p. 6). The natural sciences dealt with the phenomena of probability; there was room for sciences of intelligence and free will. Economists needed to understand the laws of physics, but they also had to grasp the effect that the intelligent behaviour of humanity could have on the physical world. The biological and human sciences had to study the equivalent of Maxwell's demons. It was the capacity of using energy externally, and not only like other plants or animals internally, that made necessary a specific economic science, which could not be reduced to natural sciences. Soddy's distinction between the vital and laboral uses of energy was introduced in his 1921 lectures; it is similar to that of Lotka, so often quoted, between the endosomatic and the exosomatic uses of energy.

Vital use refers to photosynthesis in plants and carbon oxidation in animal and human nutrition. Animals and humans cannot use solar energy directly (except to warm themselves); they have no chlorophyll. Laboral use means the use by humankind of instruments moved by wind, waterfalls, steam or internal combustion engines etc. Such external uses of energy can also have recreative purposes, and this is why Lotka's distinction between endosomatic and exosomatic uses of energy is more comprehensive than Soddy's.

Soddy pointed out that, although the vital use of energy could not vary much from person to person, the laboral use varied enormously from one person, one country and one historical period to another. This is something noticed from the beginning of ecological economics by Podolinsky, Sacher and Geddes; it is a characteristic of humankind. There was a change in the nineteenth century in that previously the flow of solar energy had been exploited for vital and laboral uses, whereas now a stock was being used for laboral purposes. "Wind power, water power and wood fuel are parts of the year-to-year revenue of sunshine no less than cereals and other animal foods. But when coal became king, the sunlight of a hundred million years added itself to that of today and by it was built a civilisation such as the world had never seen" (1922, p. 20). The fundamental feature of this civilization, however, was that the internal combustion of the human body could not directly be fed by fossil fuels but only by vegetables, either directly or indirectly in the form of animal products. One could certainly use water power or fossil fuels to make electricity and manufacture nitrogenous fertilizer, which would increase crops, but the penultimate step must always be the storage of energy by plants. Photosynthesis marked the true limits of human welfare on the Earth.

Britain had been able to exchange commodities made with the energy stored in fossil fuels for food from other territories: by this process "the whole world gradually drew more and more for its labour-use on the capital energy of fuel, and used it to widen the area under cultivation and to transport the harvests from the most distant regions of the world and so **indirectly** augmented the revenue of sunshine upon which it is still entirely dependent for its life-use" (1922, p. 11). This shortlived phase could be prolonged by imperialism, but nothing could change the fundamental fact that the use of coal (or oil) meant using capital instead of revenue, and coal (or oil) could only be used indirectly to sustain life. Thus there arose the paradox that capitalism was not capitalist as regards the means of livelihood. It was, to coin a word "revenual" -- which helped to explain the resilience of peasant farming, which was able to retreat into subsistence by giving up the use of capital.

It was absurd, however, to talk of an "accumulation" of capital. The capital stored in coal was spent, not accumulated. The flow of energy from the sun "may be embodied in some concrete commodity, in food which rots, in houses which fall into desuetude if not kept permanently under repair, and in all the tangible assets of our civilisation, in railroads, roads and public works, factories, wharves, shipping and the like. All alike are subject to a process of compound decrement ... The wealth is the revenue **and it cannot be saved"** (1922, p. 14). The individual, however, although he will rarely have enough real wealth to keep alive for a single week, can store not wealth but currency -- "whether a cowrie stone or a mental counter, but now, more and more, a simple paper note" -- and the community acknowledges the right of the holders of such tokens, who do not create real wealth, to indent on the revenue of wealth flowing through the markets at any given moment. The more wealth is spent, the greater the total amount of indebtedness, which becomes, as Ruskin said, "power over the lives and labours of others" (1922, p. 15).

It could be said in answer to Soddy that in economic accounting, the part of capital goods that depreciates yearly is subtracted from production. Thus, the gross national product (GNP) includes all investment, and only a part of it will be counted as net investment, the rest being amortized and subtracted from GNP to get net production. Soddy's strictures seem out of place, unless one recalls that the national accounts do not include any provision (or only a minimal one) for the depletion of natural resources, on the accounting convention that the discovery of new reserves compensates for the expenditure of that "capital", which is therefore not amortized.

Work on Soddy's economic thought would be incomplete if we did not deal with his view that the distinction between the vital and the laboral use of energy would lose importance if enough energy were available to produce synthetic food. What were the prospects for a great increase in the availability of energy? "The extraordinary developments since the beginning of the century in the study of radioactivity and of the internal structure of the atom have proved that there is resident in ordinary materials amounts of energy of the order of one million times that which can be obtained from fuel during combustion, but to liberate this store the transmutation of the elements one into another must be first made possible" (1922, p. 22). The decisive factor was knowledge; humanity has shivered for thousands of years on top of coalmines and nearly died of hunger next to the Niagara that now produced more food through fertilizers. It was true that the future of civilization depended on the summer holidays of university teachers, who then had a few weeks for uninterrupted research. Soddy, it must be said, spent his research time on economics instead of trying to split the atom, and his role in nuclear physics, comparable in importance to that of Rutherford up to 1920 (cf. Trenn, 1977), was negligible afterwards. It would be wrong, however, to say that his interest in the economy arose only in going back to Oxford: he had from the beginning of his career noticed the connection between the economy and the availability of energy.

Soddy believed in scientific progress, but he did not believe that it was synonymous with technical progress. He realized at the turn of the century how the newly discovered source of energy could change history, but he thought all his life that warlike applications were more likely than peaceful ones. He asked himself what would be "the effect of the discovery that, so far, we have been subsisting on the mere by-products of natural energy, and have remained ignorant even of the existence of the primary supplies in the atoms of matter" (1912, p. 240). The effect was likely to be destructive. H.G. Wells used Soddy's warnings to anticipate not only the industrial employment of atomic energy but also a universal atomic war. In 1917 Soddy wrote that if humanity succeeded in controlling this aspect of nature, war would probably cease to be an interminable agony because a section of the world, or the whole world if necessary, could be swiftly and effectively stripped of its population (Freedman, 1979, p. 259; Trenn, 1979, p. 267). His early alarm at the destructive possibilities of nuclear energy was not shared by other scientists. Millikan, for example, himself a Nobel Prize winner and head of Caltech, openly ridiculed it (Sinsheimer, 1978). Years later, in 1947, when Soddy was 70, he gave a lecture in which he detailed the discoveries of atomic theory, from Becquerel, Röntgen and J.J. Thomson between 1895 and 1897 to Otto Hahn in 1939. There was a double achievement -- "both the sudden liberation of a sensible part of the atomic energy of uranium by the atomic bomb, and the controlled release by the uranium pile" -- the graphite-moderated reactor. "Of the effectiveness of the former for destruction the facts speak for themselves": more deaths from a single atomic bomb than from all the air-raids in England during the war. On the other hand, he was far from hopeful that atomic energy could have peacetime applications for two reasons -- the "poisoning" of the reactor, which shortened its life, and "the virtual impossibility of preventing the use of the non-fission products of the pile, such as plutonium, for war purposes" (1947, pp. 10-12).

He had long wanted to discover why science had proved at least as much a curse as a blessing, in view of the contingency, which had seemed remote but was now immediate, that the powers of destruction might suddenly be increased a millionfold. This line brought him to the idea that "all history could be strung on the one thread, the growing power of men to control and use the energy of nature to supplement their own relatively puny strength" (1947, p. 12). Soddy was not in the habit of observing scholarly conventions in his economic writings; he did not quote either Podolinsky or Sacher (whom he did not know), or Patrick Geddes, or indeed Ostwald, whom he certainly knew. It is likely that Soddy independently made the connection between energy availability and the course of human history, more or less at the same time as Ostwald but stimulated by his work on radioactivity (which was quite alien to Ostwald's outlook in chemistry and physics).

Be that as it may, by 1947 Soddy could complain of a double frustration of science: the technological benefits of scientific work were not made available to humankind at large because the economic system made for unequal distribution; moreover, some of the developments of scientific discoveries could not be more appalling. The destructive power of atomic energy was already here: "we [should] wait for the natural orderly growth of technology to harness in due course the new source of power, rather than feverishly attempting to cook the hare before catching it", and "rather than starting our engineers on a wild-goose chase elaborately cracking peanuts with steam-hammers, for purely political window-dressing as yet another carrot to keep the masses hopefully jogging along, it would be better to concentrate for a while on the purely research side" (1947, p. 12).

In politics he apparently had no friends. Although he sometimes praised Marx, he was opposed to Soviet communism. In his lecture in 1947, he supported Bertrand Russell's proposal for the U.S. to prevent, by force if need be, the atomic armament of the Soviet Union. He died in 1956, before the Campaign for Nuclear Disarmament (CND) was founded. Sometimes he embellished his writings on the capitalist system with unnecessary comments on Jewish bankers; he also occasionally wrote of the "white race" having to fight over sources of energy. We do not believe that these comments show other than run-of-the-mill Eurocentrism and antisemitism, and Bernal and his friends thought well enough of him to ask for a preface to a collective work on the "frustration of science" (Hall et al., 1935). He had at least one German disciple (Bruggen, 1934) and he was mentioned by Zmavc (1926, p. 6), but his impact in Britain and outside was very limited. He joined the Union of Scientific Workers, an unlikely step for an Oxford professor to take. He refused to pay the fee to receive his M.A., which meant that he was barred from attending the general meetings of the university. He was widely considered to be a strange character.

TECHNOCRACY, INC.

The technocrats took Soddy to be one of their precursors. The technocracy movement developed in the early 1930s in the United States and died away quickly in a welter of internal recrimination and nonsense. It was led by Howard Scott, a man of no intellectual distinction. The movement profited for some years from the collaboration of M. King Hubbert, then a young geophysicist at Columbia University, who more than 40 years later became widely known because of the prediction he had made in the 1950s that U.S. domestic petroleum production would peak around 1970. In his work of the 1950s, he analyzed the depletion of energy and material resources by bell-shaped curves that show how much of total reserves are still available at any one time. Many recent books on energy and environmental questions emphasize Hubbert's analysis (for instance, Foley, 1976; Ehrlich, Ehrlich and Holdren, 1977). Another author who had some connection with the technocrats was Stuart Chase.

The disintegration of the technocracy movement after World War II was not a great loss. There can be no doubt about its narrow nationalism, its anti-intellectualism, its support for domination over Mexico and the Caribbean and further south (under the guise of continentalism) and its tendency to see a conspiracy of big business, Wall Street, international bankers and party politicians, all this embellished by Howard Scott's style ("technocracy smashes the price system", "the syphilis of business", "the dementia of democracy"). This curious, parochial group numbered a few thousands and was active under the name of Technocracy, Inc. They organized cavalcades of grey cars, predicted the apocalyptic collapse of the system and had a fixation on the Vatican. In 1959 what remained of the movement was so out of touch with reality that one of its periodicals asserted Fidel Castro was a Vatican fascist.

It is painful to bring such people out of oblivion into our work, but some of their themes in the early 1930s were certainly relevant. They emphasized the Veblenian theme of the role of technicians in production efficiency. They were on the whole optimistic for a great growth of production, which was frustrated by lack of effective demand, a strong theme at the time which the policies of the New Deal took away from them. They believed in the progress of automation, and they also put forward the "viewpoint of social change as determined or limited by the amount of nonhuman energy available to society" (Elsner, 1967, p. 217). This was not a new viewpoint, but Elsner rightly points out that it had never been used as an ideology by any political or semipolitical group. Technocracy was subjected to some energetic jokes. In February 1933 **The Nation** published an article by Henry Hazlitt entitled "Scrambled Ergs: An Examination of Technocracy", and in the same month a book by John Lardner and Thomas Sugrue, **The Crowning of Technocracy,** was published: in it the Technocrats were mocked from the foreword by "Horace Power Ergenjoule, Soddy Professor of Implied Science", to the typesetters' note on the final page: "This book ... was made by one machine in five energy hours, using twenty-six British Thermal Units" (Elsner, 1967, p. 15).

M. King Hubbert's guiding theoretical light was mainly expressed in the various editions (between 1934 and 1947) of the **Technocracy Study Course.** Elsner summarized the section that deals with social energetics (1967, p. 117):

> Taking off from the physical science approach, the first few lessons in the book are concerned with the basic concepts and measurements of energy and its transformations and with the use of engines to convert energy into work. At this point the concept of efficiency is introduced (the ratio of work output to energy input). Man as an engine is discussed briefly and his approximately twenty-five per cent maximum efficiency is noted. Armed with these concepts, the student Technocrat approaches the network of life, energy, and resources.

The flow of life-giving energy is traced from the sun through plant photosynthesis, herbivorous and carnivorous animal life. The "dynamic equilibrium" or balance of nature established among the various life forms in a given area is examined. Man's place in this arrangement is described as uniquely disturbing in that he has increasingly learned how to divert a larger share of energy away from other animals to his own use. Domestication of plants and animals and the early utilization of metals and fuels is examined. Thus, the key to man's history is seen in his developing use of "extraneous" energy -- energy other than derived from the food he eats. Any people who have "a superior energy-control technique" tend to dominate others with lesser abilities in this area.

The jump from the study of the characteristics of the human use of energy, compared to other animals, to the intraspecific analysis, rings the familiar socialdarwinist bells.

In their economics, the technocrats mentioned the limited availability of resources for the growth of some industries. The main emphasis -- naturally enough in the early 1930s -- was on the "limitations on individual purchasing power imposed by price system distribution" (Elsner, 1967, p. 118). They were however not egalitarians, believing in a natural pecking order, which they also called "functional priority". Society would be in trouble -- this was a truly technobureaucratic theme -- if it mistook inherited social position for ability.

Though the technocrats recommended Soddy's and Fred Henderson's books, Soddy did not collaborate with them, to judge both from Elsner's research and from Soddy's own remarks in 1933 against energy certificates, one of the technocrats' pet ideas. If this is the case, it shows good sense on Soddy's part, as this was a political group that could have exploited his reputation. Thus, one of the first official publications of Technocracy, Inc. (Howard Scott and others, **Introduction to Technocracy,** John Lane The Bodley Head, London, 1933, 61 pages) includes Soddy's **Wealth, Virtual Wealth and Debt** (1926) in the list of recommended publications.

One possible influence apart from Soddy might have been Ostwald's **Energetische Imperativ,** which neatly encapsulated what was to become one of the technocrats' main themes. As we know, the connection between energy use and social development was not an original idea of Ostwald; it seems plausible that even the most learned of the group would not have known about some of his predecessors, but they must have heard about Ostwald, a truly "technocratic" thinker in social matters.

Thorstein Veblen's contribution to the technocrats' ideology was not related to the energy viewpoint but was important (Scott had known Veblen around 1920 in New York), so much so that disclaimers were issued: "You cannot express Veblen's economic theory in terms of Scott's theory of energy determinants." Veblen's stand against the rationality of the price system and in favour of a technical rationality, and his view that in the unlikely event of revolution the technicians would have to play a decisive role, made him a clear source of inspiration. However the technocrats did not concern themselves with his "conspicuous consumption".

In conclusion, we are retrospectively giving shape in our work to a school of human ecologic energetics. We are not pleased to have to include the technocrats, a strident group of mentally uncouth people, but they cannot be left out. A note in favour of them is that they -- or perhaps simply M.K. Hubbert -- provided an American link between social energetics before the 1930s and the ecologic study of population and resources of the 1960s and 1970s.

ECOLOGICAL UTOPIANISM: POPPER-LYNKEUS AND BALLOD-ATLANTICUS

Josef Popper (1838-1921), a physicist and engineeer, was born in Kolin, Bohemia, lived in the Jewish ghetto until he was 15 and was then a student in Prague and Vienna. As he was never appointed to a university post, he tried to make a living by selling improvements to the steam engine. In 1862 he wrote a paper on the transmission of electricity. This he deposited with the Viennese Academy of Sciences, where it remained unpublished until 1884. He also wrote a great deal about the physical principles of aerial navigation. A friend of Ernst Mach, he had a considerable influence on the Vienna Circle. He was strongly humanistic and antireligious and wrote often on Voltaire. He adopted the pseudonym Lynkeus for his literary writings, some of which were pornographic and were appreciated by Freud, though Popper-Lynkeus showed no reciprocal appreciation of phychoanalysis.

Popper's ecologism, which proposed both study of the economy of the flow of energy and materials and moderation in the use of exhaustible resources, was left-wing. Popper-Lynkeus would have been totally opposed to the link between energetics and evolutionary theory as applied to different sections of the human species. He would have opposed the fundamental tenet of functionalist ecological anthropology that one can understand human societies by studying how they adapt to the natural environment in which they live, as if they were biological organisms. He argued against the use of organic metaphors for the analysis of human society and inveighed against Haeckel's socialdarwinism (1912, pp. 75-88) on the grounds that human social conflicts could not be analyzed in terms of natural selection. He wrote against antisemitism. When he advocated birth control, he pointed out that this had nothing to do with eugenic proposals. He scorned "race improvement" (1912, p. 774).

In 1912 Popper published a long book, **Die allgemeine Nährpflicht,** developing ideas he had first presented in 1878 in one of the chapters of **Das Recht zu leben.** The title and subtitle translate as "On the general duty of nutrition as a solution to the social question, statistically researched, with a demonstration of the lack of theoretical and practical validity of economic theory". It gave a detailed account of the resources available to the German economy just before 1914. His first objective was to calculate the human work requirement that would guarantee the whole population a subsistence of food, clothing, housing and health services; this would be achieved by means of a **Nährpflicht** (instead of a **Wehrpflicht),** that is, by civil rather than military conscription. The second objective was to discover how the use of exhaustible resources could be gradually reduced, so that the economic system would be permanently viable.

The economy would thus be divided into two. The basic sector would provide subsistence free to everybody, using the labour force of men and women. Popper-Lynkeus pointed out that such an extramercantile method of fulfilling basic needs would increase women's freedom, as this distribution of goods could be to adult individuals rather than to families. The necessary period of conscription was carefully calculated; here Popper took issue with figures supplied by other less scientific writers: Hertzka, Bellamy, Anton Menger and also Bebel. There would be 12 years' service for men and seven for women, with a 35-hour week. This work would be organized by regional or state authorities. (Josef Popper was not an anarchist, though some of his other views come near to anarchism. Thus, in **Das Recht zu leben** [1878], he wrote that each man should himself decide whether or not to take part in a war, and not the government, parliament, or a referendum, because each individual should decide on his own health or life.). As there would be resources and labour left over from those used for the subsistence sector, the economy would have a second sector, which would function according to market principles, though limits could be set to the amount of labour that each employer would be allowed to hire.

Karl Popper chose to classify Popper-Lynkeus's proposals as "piecemeal social engineering", comparable to the introduction of a health service or subsidized housing, rather than "utopian social engineering" (1945, vol. I, p. 143). But it is doubtful that the proposals to abolish the need to sell labour and diminish the use of exhaustible resources, to say nothing of the strongly egalitarian flavour of these proposals, can really be relegated to the category of "piecemeal social engineering". Neurath thought they were scientific utopianism, which is certainly what they seem nowadays. In 1919 Neurath sent a telegram to Josef Popper from Munich, with the joy and devotion of a disciple, announcing that the revolutionary council was going to implement his programme.

People in most developed countries might remark that some of Popper-Lynkeus's more attractive proposals have already been incorporated in the welfare state without interfering with property rights and freedom of markets, including the market for labour. But welfare states comprise a small proportion of humankind, and their prosperity has come in part from the use of exhaustible resources and from the poverty of other peoples. A judgement of the distribution of resources and commodities through the market mechanism favoured by the liberals depends on how one views the intra- and intergenerational distribution of purchasing power.

Popper-Lynkeus himself (in his autobiography) explained the origins, intention and reception of his proposals. He had long been worried by the effects of so-called technical progress, and in 1886 published a long article on "The aesthetic and cultural significance of technical progress", following a train of thought started at the world exhibition of 1873 in Vienna. Perhaps the aesthetic thrill aroused by the transatlantic cable or by flying was analogous to that of the Athenians at the unveiling of a statue of Phidias or at the completion of a new public building. Of course, opinions on artistic works were only expressions of trends in taste; they did not contain any truth-value and could not be forced upon anyone. Nevertheless, he was sceptical about the benefits of technical progress. Some pages in **Das Recht zu leben** dealt with the harmful effects of machinery. He had proposed that technical progress should be made harmless by appropriate sociopolitical institutions or, to put it plainly, by socialist institutions (1924, p. 62). This would be achieved by the separation of a so-called free private economy -- an economy with circulation of money and free competition -- from an economy for existence, based on obligations. This idea, later developed at length in **Die allgemeine Nährpflicht** and statistically shown to be viable, depended on the introduction of "conscription for food production" by which all that was needed for a healthy and comfortable life would be produced and distributed to all citizens without exception, from birth to death, not in the form of money but **in natura.** All the rest, on top of such minimum needs, would belong to the private economy, in which anyone would take part or not, as he or she wished, after having fulfilled service in the "food production army" **(Nährarmee).**

Popper-Lynkeus complained about the predictable reception accorded his proposals. The German marxist journal **Zukunft** dismissed them as only "half-socialist" because they guaranteed only a minimum and not all necessities (1924, p. 81). Others (including the Austrian social democrats) degraded them by using the little words "New Utopia" (1924, p. 92). After 1912 a small group of people in Austria and Germany formed an **allgemeine Nährpflicht** society, dedicated to his scheme. Some Austrian writers in economics, such as Otto Neurath (1882-1945), participated in the minor local cult of Popper-Lynkeus. Others did not even mention him, where they might well have done. Thus Schumpeter, a contemporary of Neurath, did not include Popper-Lynkeus in his history of economic analysis. Schumpeter's exclusion of Popper-Lynkeus suggests the view that the computation of available resources and their use to satisfy human needs over time is not part of economics. Hayek did not include him in his list of "neo-Saintsimonian social engineers" (1952), although he very much included Neurath, who had arrived at his views through Popper-Lynkeus and Ballod-Atlanticus.

Popper-Lynkeus's proposals show some similarities with economic planning in the Soviet Union from the late 1920s onward; innumerable "material balances" were in fact established by Popper-Lynkeus (1912). But his emphasis on basic needs and especially his proposal not to increase so-called capital accumulation and economic growth, but rather to diminish the use of exhaustible resources so that the economy would be permanently viable, are quite different from Soviet concepts. Popper-Lynkeus's ecologism is most in evidence in the last 100 pages of his book (in the 1912 edition) entitled "The Future of the State of the Future". The expression **Der Zukunftsstaat** was taken from Bebel and from Ballod-Atlanticus (1898), and Josef Popper and Ballod discussed each other's figures. In these 100 pages Josef Popper explained the supply of solar energy to Earth. He advanced the hypothesis that solar energy had a radioactive source. He then calculated with care to what extent water power, wind power etc. could replace coal. He carried out similar calculations for different metals and for fertilizers (costing nitrogen in kilowatts). His conclusions tended to be pessimistic; it would be difficult to diminish coal consumption and maintain the standard of living; hence his emphasis on birth control.

When discussing the substitution of renewable energy for coal, Popper-Lynkeus carried out a detailed analysis (1912, pp. 729-730) of the energy costs and value of **Kartoffel Spiritus,** alcohol from potatoes, giving estimates of the (very large) area that would be needed to substitute it for coal for domestic heating. He criticised Kropotkin (whom otherwise he greatly admired) because he had asserted that enormous potato crops could be grown in greenhouses. Josef Popper pointed out that greenhouse farming in northern Europe used so much energy from coal that its energy balance did not compare favourably with that of open-air agriculture. He made his own calculation to show Kropotkin's mistake.

Writing on the "Malthusian problem" (which he thought was misnamed as Malthus had not done a proper study of the rules of human demography), Popper-Lynkeus (1912, pp. 754-755) entered the argument on the carrying capacity of the Earth. He quoted Franz Oppenheimer's estimate of 200 billion persons as the upper limit, on the basis of the productivity achieved in greenhouse farming. Again Popper-Lynkeus emphasized (quoting Ballod-Atlanticus) that one could not generalize the results of greenhouse farming to the world at large, because of the required energy input from coal. This anticipates by some 60 years Gerald Foley's critique of Colin Clark's estimates on land use and population growth (Foley, 1976), based on Clark's failure to consider the flow of energy into agriculture.

Popper-Lynkeus also suggested that the price system did not provide a good criterion for deciding whether to produce alcohol from potatoes in large amounts. He pointed out that if alcohol from potatoes was used for heating, transport etc., this would have the beneficial side effect that no alcohol would remain to drink; on the other hand, it was possible that no potatoes would remain to eat. Controversies over the use of biomass for food energy or fuel energy have a long history.

Nevertheless, even Popper-Lynkeus could, on occasion, adopt a parochial outlook. Thus, he proposed (1912, pp. 735-736) the eurocratic idea of importing peanut oil from the German colonies in Africa and from Spain to burn it in diesel engines, as Rudolf Diesel had just announced (in 1912) that his engines could work on vegetable oils. Popper-Lynkeus, however, stated that this proposal was conditional to obtaining more information on yields and energy costs in peanut farming.[1]

Popper-Lynkeus's work was characterized (in contrast to other utopian writings of this period) not only by the thoroughness of its statistics and by its ecologic-conservationist aspect, but also because his proposals were addressed, if not to the whole world, at least to a considerable section of it. Popper-Lynkeus's utopia was not based on the migration of a small group of people from Europe to America or to Africa, as in Cabet's **Icaria** or in Hertzka's **Freiland.** His achievable utopia, which did not indulge in the literary fiction of abolishing scarcity, was universal in intention, though not in computation.

Ballod-Atlanticus

Karl Ballod (1864-1933), who took the pseudonym Atlanticus from Francis Bacon's **Nova Atlantis** (1627), was an economist and demographer living in Berlin. Early in his professional life he made studies of colonization in Brazil and of the Russian economy. He published several editions of **Der Zukunftsstaat,** the first in 1898 with a preface by Kautsky and the fourth in 1927. This book was also published around 1905 in Russia.

Ballod made a realistic appraisal of the resources at the disposal of future society. Like Josef Popper, he wrote a careful account of how the economy would work in the future. His approach is "scientific utopianism". There is a clear difference between Ballod's approach and planning in socialist countries, where it boils down to adding a few percentage points to the levels achieved in the previous planning period. Planning does not contemplate radical changes in the composition of production.

Ballod, in the 1920s at least, was simultaneously antibolshevik and antisocial-democrat, though he was neither a liberal nor an anarchist. His political position could be described as a somewhat technocratic ecologism. Popper-Lynkeus had written that Marx was, for him, an inspiration more because of his capacity for historical prognosis; a socialist program had to start from an ethical premise, and ethical systems could not be derived from the march of history (Popper-Lynkeus, 1912, p. 322). Ballod saw the origin of his ideas in Marx, but Marx had not supplied a blueprint for the day after the revolution; he had thought out everything, but only until the critical day (1927, p. 7).

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1 Ecologists usually trace to Transeau (1926, in Kormondy, 1965) the first careful estimate of photosynthetic yield not in laboratory conditions but in agriculture, i.e. in maize growing in Illinois. The following comment is of interest: "The worry of Transeau's day was not only food but fuel also. Fossil fuels on which modern civilizations are based obviously would not last forever, and the exhaustion of the world supply then seemed more imminent than it does now because the total reserves were much underestimated. There was then no promise of atomic power to supply the needs of the future, and the only resource seemed to be to grow fuel; to use the energy stored by contemporary plants rather than by those long dead. It became important to know how efficiently crops fixed solar energy in order to calculate the possibilities of producing fuel for power stations and motor cars by agriculture" (Colinvaux, 1973, pp. 152-153). One inescapable conclusion of our reading of Popper-Lynkeus's work is, once again, to raise the question (to which we have no answer): why did modern agricultural energy accounting not develop as a subdiscipline of agricultural science and of agricultural economics much earlier than it did?

One difference between Popper-Lynkeus and Ballod-Atlanticus is that Ballod calculated energy costs only occasionally. Another difference from Popper-Lynkeus is that Ballod was certainly more technocratic, as his choice of pseudonym shows; Francis Bacon had proposed a society ruled by the possessors of knowledge.

Ballod disliked economists -- he was close in some ways to the American technocrats of the 1930s. Writing in German in the 1920s, he was full of enthusiasm for synthetic textiles and synthetic protein and for mechanized agriculture, combined nevertheless with dispersed urbanization and a multitude of domestic gardens. He admired Henry Ford, one capitalist who really profited from the possibilities opened up by increases in productivity and growth of the market, and who was therefore totally opposed to cartelization and restriction of output, but Ballod was also -- and this is crucial -- against the private car.

The nucleus of Ballod's book is a computation of how many people could be nourished by the production from a standard farm of 500 hectares; a **Normalgut.** Such a farm was assumed to have not very fertile soil (a realistic assumption for northern Germany) and to use mechanical traction, the reason being that otherwise a great deal of land would be needed to feed the animals. If rotation was intensive enough, this land could be put instead to the alternative use of human nutrition. If tractors were used, oil from outside the farm would of course be necessary. Ballod reckoned the value of this oil in energy units, but he did not quite establish the global energy balance of this model farm. Assuming the use of tractors, 2000 people could be nourished from 500 hectares, though the number would depend on the amount of meat in their diet.

How would this pattern of mechanized model farms fit in with the rest of the economy? Ballod opposed industrial and urban concentration, on the grounds that it led simultaneously to the construction of large numbers of new apartment buildings in the great cities and to the deterioration of abandoned rural housing. Workers' quarters were built so close together that it became impossible for their inhabitants to contribute to their own food supply. As a rule, cities should not have more than 100 000 inhabitants, thus saving most of the materials used in high-rise buildings and in the infrastructure of the large cities. For Berlin in the 1920s this type of consideration arrived a little late, but for urban planners in Mexico, Brazil and other countries, Ballod's book would still repay close study. There is nothing romantic in it, only a collection of rather arid computations, showing the amounts of materials of different sorts needed to house all Germans in towns and cities of moderate dimensions within a framework of mechanized model farms and domestic gardens. These amounts were then compared with those required for a pattern of concentrated urbanization. Ballod criticized even Ebenezer Howard because in his view the gardens in his garden cities were too small to allow any significant contribution to food intake. He did not quote Patrick Geddes, and neither Geddes nor Lewis Mumford -- whose erudition casts a wide net -- quoted him, perhaps as a result of the triple censorial alliance of liberal economists, social democrats and Stalinists (and also Leninists in this particular context) who relegated to the attic of our intellectual past such authors as Ballod and Josef Popper.

Another drawback of urban concentration was that the waste of the big cities was not used to fertilize agricultural land. In the pattern of settlement he proposed, each **Normalgut** would support a community nearby. In contrast, he calculated the units of nitrogen, phosphorus and potassium in the excrement and other waste produced annually by Greater Berlin which would have fertilized 200 000 hectares (1927, p. 170), but which in fact became a huge and costly disposal problem. This is a calculation that would have pleased Liebig and Marx. He made similar calculations for the entire German economy.

Ballod's attack on the forms of industrial urbanization had little in common, in our view, with the antirational, antitechnologic and antidemocratic tendencies at the time in Germany and elsewhere. Ballod's dung accounts may scarcely be called romantic nature-loving, as were the **Wandervögel** and the **Artamanen**, allegedly a German disease to which even social democracy was prone.

In his well-judged effort to exonerate Haeckel and other monists from any direct responsibility for nazism despite their socialdarwinism, Kelly (1981 p. 134) pointed out that German socialists supported not only Haeckel but even authors as reactionary as Bölsche, and therefore these authors' views had a much wider and diffuse influence than that assumed by the partisans of an exclusive and direct monist-nazi intellectual connection (such as Gasman, 1971). As Kelly puts it, social democratic support for Haeckel and Bölsche meant at least tacit party sanction for locating the origins of workers' problems in urbanization rather than in class exploitation. Several points arise here.

Overcrowding and struggles for green space, better urban transport and rent rebates are aspects of the class struggle. But the critique of urbanization and the critique of capitalist exploitation could be brought together not only in this sense, traditional in marxism since Engels wrote on workers' living conditions in Manchester and on the housing question in general, but also in the ecological discussion on the productive forces of energy flows and materials cycles. Social democratic nature-loving -- such as it was -- did **not** produce this ecological critique, which was compatible with an appeal to reason and alien to the mystic brand of ecologism.

Both Ballod and Popper-Lynkeus remained aloof from the reaction against rational scientific analysis and specialized learning. In this they were much closer to social democracy (and, incidentally, to anarchism in the kropotkinian tradition) than to the conservative back-to-nature movements. There was little distance from the latter to the theosophy and anthroposophy of Rudolf Steiner, which links up with the irrational, apocalyptic ecologism in which back to nature means back to God and religion.

In the German-Austrian context it is important to locate Ballod and Popper-Lynkeus carefully between technocratic social engineering on the one hand, and romantic, conservative, religious nature-loving on the other. It is a characteristic of the struggle for free thought in Europe in the nineteenth century that religion was not simply superseded by agnosticism. Attempts to substitute science or pseudoscience for religion were made by Comte in France and, later, by the monist movement (or parts of it) in Germany. As Haeckel was prominent in this attempt and as it was he also who introduced the word "ecology" into scientific discourse, it is worthwhile to emphasize the distance with authors such as Ballod and Popper-Lynkeus.

When Ballod considered the costs in materials and energy of alternative transport systems, he left his technocratic optimism on one side. He made a case against the expansion of the motor industry and implicitly against an economic and social ideal that, in spite of its rhetoric, proposed industrial urbanization and intensive use of exhaustible resources from German or foreign territories.

Ballod explained (1927, p. 262) that there were 20 million cars, or one for every six persons, in the U.S., 778 000 in Great Britain, 574 000 in France and 308 000 in Germany. Germany then imported 1.2 million tonnes of oil per year (which we might compare with the 100 million tonnes of oil and oil products imported now per year by West Germany alone), and Ballod thought that the figure could be doubled. Since one car consumed about 1200 kg of petrol per year, plus lubricant oil, the number of cars would be able to grow very slightly supposing a continued dependence on imported oil. Oil from coal, however, could in principle allow a considerable increase in the number of cars, perhaps up to 10 million. But Ballod thought such a use of coal reserves was irrational, because lack of water power in Germany made it advisable to keep coal for the production of electricity. Besides, air pollution caused by cars, which one could already smell, was worse than the plague, and this was a further argument in favour of public transport (1927, p. 266).

Ballod's prediction with regard to cars was spectacularly mistaken. There are now about 20 million cars in West Germany alone and, not less remarkably, there are also a few million in East Germany. However, from a world perspective, the present ratio of cars to population (one car per 15 persons, about 300 million cars to 4.5 billion inhabitants) will be difficult to increase; it has probably decreased since 1973. The ratio varies considerably both from one country to another and from one social class to another within these countries, not excluding the so-called socialist countries. It is doubtful that cars will become generally available (one might argue that a car is a "positional" good in Fred Hirsch's sense) not because of negative externalities such as traffic congestion, but because of oil consumption. If you have one, you are depriving somebody else from having one, either now or in the future. Ballod would have agreed, and therefore he can hardly be classified as an all-out technocratic Fordist thinker. Ballod did not envisage a future of poverty. His computations include, for example, the number of workers (100 000) who could construct pianos for Germany's musical needs. Ballod's utopia did **not** presuppose the elimination of the premise of economics, scarcity, yet he vigorously opposed the economist's way of dealing with scarcity, through the market or market-surrogates.

He had bitter words (in the 1927 edition) for the socialists who had failed to take advantage of the revolutionary moment in 1918. He had been a member of the Commission for Socialization and had seen at close quarters how the socialists had not even nationalized coal. They had switched to free-market principles. What was worse, in practice they favoured cartelization. This they tried to hide under the name of "economic democracy".

Ballod proposed a mixture of state, provincial and communal public enterprises (including model farms). No egalitarian, he reserved an important position for technicians, who should be paid more as an incentive for more people to receive the necessary education. He was aware that his attitude of favouring technicians would be criticized. During World War I he had been criticized because of his recommendation that the number of pigs should be restricted so that more energy and protein would be directly available for human consumption; a recommendation that earned him and others the name of **Schweineprofessoren** (pig-professors).[1] His conversations with Moltke on protein requirements (on which he included accurate computations) had led to nothing because Prussian officialdom did not understand such matters (1927, pp. 27-29). It was better to place one's trust in technicians than in bureaucrats or economists. The Austrian school, which had finally triumphed among the German professors of economics, was **Neo-Manchestertum** and **Scholastik.**[2]

Among the authors we have studied, one difference between the German-Austrian and the British (Geddes, Soddy) is that the Germans and Austrians, because of the relevance of social revolution, in some cases (such as those of Ballod and Popper-Lynkeus) went beyond the ecological critique of conventional economics and drew up detailed, global economic plans (though this is not quite the appropriate word). This element of "scientific utopianism" is what appealed to Otto Neurath.

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[1] A play of words, the darwinist professors had been known as **Affenprofessoren** (monkey-professors).

[2] Hayek failed, however, to include him in his list of "neo-Saintsimonians". We learned of him through Neurath's and Popper-Lynkeus's writings. Cf. also the summary of the 1919 edition of Ballod's book in Rolf Schwendter (1982, vol. 1, p. 228f).

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