ENERGY BUDGETS *A series of articles exploring and reviewing the rapidly-expanding study of the energy costs of production processes, encompassing foods and agriculture, transport, materials, petrochemicals and products, and their importance for policy making.*

1. Energy costs: a review of methods

P.F. Chapman

Forecasts of energy shortages were already stimulating analyses of patterns or energy consumption before the quadrupling of oil prices and the interruption in supplies. These recent events have made such studies urgent. In this article – the first in a series on energy budgets – Dr Chapman examines the problems in constructing energy costs, the aims of such studies and the methods used. These are illustrated by examples of energy costs which indicate the care required in interpreting and using published results.

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Editor's note

This subject is so new and undeveloped that there is no universally agreed label as yet: researchers seem fairly evenly divided in their support of the terms 'energy budgets', 'energy costs', 'energy accountancy'. Each term has its strengths and weaknesses. We have chosen to avoid 'energy accountancy' on the grounds that it could be confused with the economic costs of energy. 'Energy costs' is clear and uncontroversial but rather restricted, and we prefer 'energy budgets' as a title for this series of articles, looking ahead to a time when 'energy costs' are used in the development of energy and resources policies.

Over the past two years there has been a growing realisation that the financial costs of materials and products do not provide an adequate description of the resources needed for their production. When there are no shortages of any inputs to the production system financial analysis provides a convenient decision-making framework. However, if one input does become scarce, then the implicit assumption of substitutability, inherent in financial systems analysis, leads to false conclusions. For a wide variety of reasons a number of investigators have focused their attention on the physical inputs, such as tons of steel and kWh of electricity, needed to make particular products. The forecasts of energy shortages coupled with the realisation that energy is an essential input to *all* production processes have concentrated attention on the energy inputs to, or energy cost of, various products.

At the present time there are almost as many methods of evaluating the energy cost of a product as there are workers in the field. Where, by chance, the same product has been analysed by different methods the results often vary widely. The purpose of this review of methods is to explain the origin of the variations in results so that they can be interpreted and used correctly. To accomplish this it is necessary to examine the aims of various investigations since this explains many of the assumptions made. Finally, it is necesary to show how differing assumptions and methods can account for the divergent results.

The nature of the problem

A modern industrial system, exemplified by countries such as the UK and the USA, is a complex interconnected system with many inputs and outputs. These highly developed systems are linked together, and to the so-called underdeveloped industrial systems, by flows of commodities in international trade. In some respects the total global system is a closed system. All that man's activities accomplish is a temporary change from a stock of raw material or flow of solar energy, into products such as automobiles and food which, in time, become discarded materials and dissipated energy. This view of the world – the 'spaceship Earth' concept[1] – has

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[1] K.E. Boulding, *Economics as a Science* (McGraw Hill, 1970), chapter 2

focused attention on the depletion of non-renewable stocks, particularly fossil fuels. Many analyses of energy costs aim to evaluate the quantity of fossil fuel energy required to produce a consumer product such as an automobile or a loaf of bread.

The production of a consumer product in the UK requires inputs from all the production processes in the country and, through international trade, from all the production processes in the world. For example, a loaf of bread requires wheat which has to be milled, cooked and transported. Transport requires fuel and vehicles, for which steel, rubber, copper and energy for fabrication are necessary. Shops and bakeries need bricks, steel, cement, wood and glass; wheat production must have tractors, fertilisers, insecticides etc. It is clearly impossible to determine the proportion of all the production processes in the world needed to produce a loaf of bread, or any other single product. Any analysis must be based on a sub-system of the world, a sub-system for which all the inputs and outputs are known. The choice of sub-system is the first crucial step in evaluating an energy cost.

Three simple sub-systems of the production of a loaf of bread are shown in Figure 1. The first is confined to the bakery and the

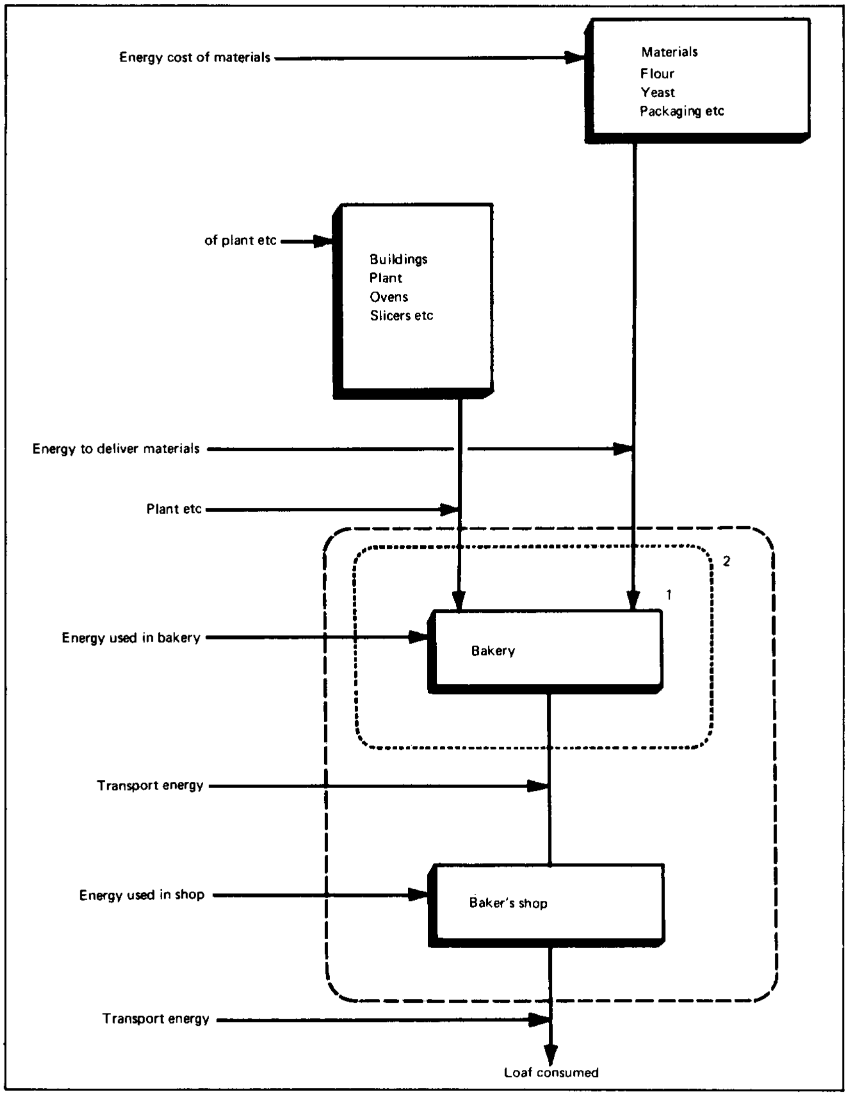


Figure 1. Possible sub-systems associated with the production of a loaf of bread. System 1 is denoted by dotted boundary, system 2 by dashed boundary, system 3 is the entire diagram.

energy cost per loaf is the energy delivered to the bakery divided by the number of loaves produced. The second sub-system includes the baker's shop. The total energy cost is:

$$\frac{\text{energy used at bakery}}{\text{loaves baked}} + \frac{\text{transport energy}}{\text{loaves delivered}} + \frac{\text{energy used by shop}}{\text{loaves sold}}$$

The third sub-system is the entire diagram and includes eight energy inputs. As the sub-system is made larger the total energy cost continues to increase. However, in a finite time it is not possible to take into account all the production processes in the world. A more feasible objective is to follow each network of inputs back from the final product until it is found that the addition of the next input makes an acceptably small difference to the total energy cost.

The choice of sub-system is one type of problem in evaluating energy costs. Another is associated with the types of energy included in the analysis and how these different energies are added together. The largest global source of energy is solar energy, yet this is usually excluded from energy costs. The production and delivery of fossil fuels involves energy consumption which may or may not be incorporated into the energy analysis. Producing secondary energy supplies, such as electricity, town gas and coke, wastes some of the energy available in primary fuels. This inefficiency may or may not be included. Most energy analyses ignore the energy input in the form of manpower or the calorific value of food. These difficulties are compounded by the various calorific values of different primary fuels and by the special role played by electricity in many industrial systems.

A third type of problem which arises is in apportioning energy costs between different products. For example many chemical processes produce two or more products in a single plant from a single set of inputs. On what basis is the energy of the plant and inputs to be divided between the products produced? On a larger scale there is the problem of apportioning the energy costs of general services, such as roads, between many users. As with all the other problems outlined in this section there is no 'correct' solution. These are not questions of fact, but of setting up the most satisfactory conventions. Analyses based on different conventions will imply different procedures for dealing with the problems.

Aims of energy studies

The fact that there is no 'correct' way of apportioning energy costs or choosing a sub-system does not mean that these are arbitrary decisions. The methods adopted within a particular analysis should be consistent with the overall aims of the analysis. Thus the first step in assessing the techniques employed in a particular study is to establish the aims of that study. Although not usually stated explicitly the aims of most studies can be inferred from published reports. There appear to be four types of aim:

1. to analyse particular processes in detail so as to deduce an energy efficiency and hence make recommendations for conserving energy;
2. to analyse the consumption of energy on a large scale either to forecast energy demand or to point to policies which could reduce future demand;
3. to analyse the energy consumption of basic technologies such as food production and mineral extraction so as to show some of the future consequences of technological trends or an energy shortage;
4. to construct energy costs and examine energy flows so as to understand the thermodynamics of an industrial system. This type of long-range aim may be coupled to projects such as 'world modelling' based on physical rather than monetary flows.

This general classification of aims is neither exclusive nor inclusive. The aims are listed hierarchically so that a study under aim (1) could actually be part of an overall project with aims (2), (3) or (4). There are, no doubt, other aims not falling readily under any of these headings.

Studies under aim (1) are often carried out by particular industries in order to make financial savings. The detailed study of particular processes requires data not normally published or generally available. An example of this type of study done outside industry is the examination of packaging.[2,3,20] By far the most popular type of study is associated with aim (2) since this corresponds most closely with 'energy policy' and the most obvious problems of the 'energy crisis'. Such studies[4,5,6] are usually based upon published national statistics. Investigations with aim (3) are often aimed at areas, such as food production[7,8] and mineral resources,[9] where conventional economics is in conflict with the predictions of 'conservationists'. In these examples an energy approach throws a new light on complex problems. The investigations can be based on published data since great accuracy is not important and the conclusions are in terms of national or global averages. Only a few studies,[10,11] are associated with aim (4) on its own; however if aim (4) is the overall project aim then it has considerable influence on the assumptions made (as shown in a later section).

Methods

The implications of adopting and choosing different aims and conventions can best be illustrated by considering detailed examples. Before examining the results obtained by various authors it is necessary to outline the methods they have used. The fundamental principal of energy costing is that for a given industry or sub-system the total energy cost of all the inputs should equal the total energy cost of all the outputs. Thus if it requires 10 tons of steel (at 9940 kWh/ton steel) and 5 gallons of fuel oil (at 55 kWh/gallon) to make 10 girders, the energy cost per girder is [(10 x 9940) + (5 x 55)] ÷ 10 = 9967·5 kWh. The methods used for calculating energy costs of products differ in their sources of data

[2] I. Bousted, *Journal of the Society of Dairy Technology* (in press) 1974

[3] B.M. Hannon, *Environment* Vol 14, No 2, 1972, p. 11

[4] A.B. Makhijani, and A.J. Lichtenberg, *Environment*, Vol 14, No 5, 1972, p. 10

[5] C.A. Berg, *Science* Vol 18, July 1973, p. 128

[6] E. Hirst and J.C. Moyers, *Science* Vol 179 No 4080 1973, p. 1299

[7] D. Pimental *et al*, *Science* Vol 182 November 1973, p. 443

[8] G. Leach and M. Slesser, 'Energy equivalents of network inputs to food producing processes' Strathclyde University, Glasgow, 1973

[9] P.F. Chapman, *Metals and Materials* Feb. 1974

[10] P.F. Chapman, 'Energy and world modelling', Seminar report, Open University 1973.

[11] D.J. Wright, 'Calculating energy requirements of commodities from the input/output table'. Paper presented at Conference, Imperial College, London, July 1973.

and techniques for deducing results. There are three types of method currently in use.

Statistical analysis

The supply of energy to various industries is available, for most industrial nations, in statistical publications such as the UK *Report on the Census of Production, 1968.* This information, coupled with data on industrial output, allows an estimate to be made of the energy cost per unit of output. For example the UK *Digest of Energy Statistics* gives the energy supplied to the iron and steel industry (1968) as 6871×10^6 therms. The output of crude steel (1968) is given as $25{\cdot}86 \times 10^6$ tons (*Iron and Steel Industry Annual Statistics*). This gives a value of 265·7 therms/ton steel.

This result is not a useful value for a number of reasons. The method has made no allowance for:

- the energy cost in generating the electricity and coke consumed. The 6871×10^6 therms is the energy actually delivered to the industry; it requires about 8700×10^6 therms of primary fuel consumption;
- energy sales by the iron and steel industry. Sales of gas and electricity in 1968 were 48×10^6 therms;
- energy expenditures associated with the consumption of raw materials, the depreciation of plant or the delivery of materials and products.

However all these objections can be taken into account by digging a little deeper into the published statistics. In general this method can provide an order of magnitude estimate of the energy cost of products classified by industry. It cannot take into account all the subsidiary energy costs; nor can it distinguish in detail between different products of the same industry. Since this method relies upon national statistics the sub-system assumed is the nation.

Input-output table analysis

The input-output (I/O) table of a national economy is a square matrix, A, summarising the commodities necessary to make other commodities. Thus a single entry in the table, A_{ij}, in the ith row and jth column, indicates the amount (measured in money) of commodity i required as a direct input, to produce £1.00 worth of commodity j. Thus all the inputs necessary to make £1.00 worth of commodity j are the items in the jth column of the square array.

For a given set of outputs, denoted by a vector x, the direct inputs required, denoted by a vector y, can be found by multiplying x by the matrix (the I/O table) A:

$$y = A\,x$$

To find the commodities, z, needed to produce the commodities y, the same procedure is adopted. Hence

$$z = A\,y = A\,(A\,x) = A^2\,x$$

Thus all the inputs, direct and indirect, required to produce the outputs x are $A\,x + A^2x + A^3x + \ldots$ This series can be summed mathematically. The result of this analysis is thus a list of *all* the commodities required, within the nation covered by the I/O table, to produce a specified output. Clearly this method is taking a national sub-system and evaluating *all* the inputs within that system.[11–13]

There are some obvious disadvantages to this approach. Clearly the I/O table cannot be broken down into individual firms; it has to deal with industries in groups. Another disadvantage is that the method deals with transactions in financial terms, not in terms of physical quantities. This can lead to errors if commodities are liable to large price fluctuations or if some purchasers can obtain special prices for the commodity.

Process analysis

Process analysis involves three stages. The first is to identify the network of processes which contribute to a final product, as illustrated in Figure 1. Next each process within the network has to be analysed in order to identify the inputs, in the form of equipment, materials and energy. Finally an energy value has to be assigned to each input.

There are two clear problems with this method. The first is choosing an appropriate sub-system, the other is attaching energy values to particular inputs. This latter problem is crucial and can be illustrated by a simple example. The production of steel requires machines with a finite lifetime. Thus the energy cost of each machine must be averaged over all the steel processed by the machine. The machine will probably contain a great deal of steel and will have been made by other steel-containing machines. So to find the energy cost of the machine (necessary to find the energy of steel production) it is necessary to have an energy cost of steel! In practice this problem is solved by starting with an approximate energy cost of steel,[9,10] (deduced by one of the methods above) and to use this to calculate the energy of the machine and hence a better value of the energy cost of steel. In most cases this feedback interaction only contributes a small percentage to the final energy cost estimate, so provided the final result is not wildly different from the starting value it is only necessary to go round this loop once. For industries which are strongly linked, ie where a significant fraction of each one's output goes into the other, the most direct way to solve the problem is to solve the simultaneous equations involved (shown in Figure 2).

Results

The following examples of results are intended to show the care required in interpreting bald figures. In all cases the aim is not to show that one result is 'wrong' and another 'right' but simply to underline the distinctions drawn in the previous three sections.

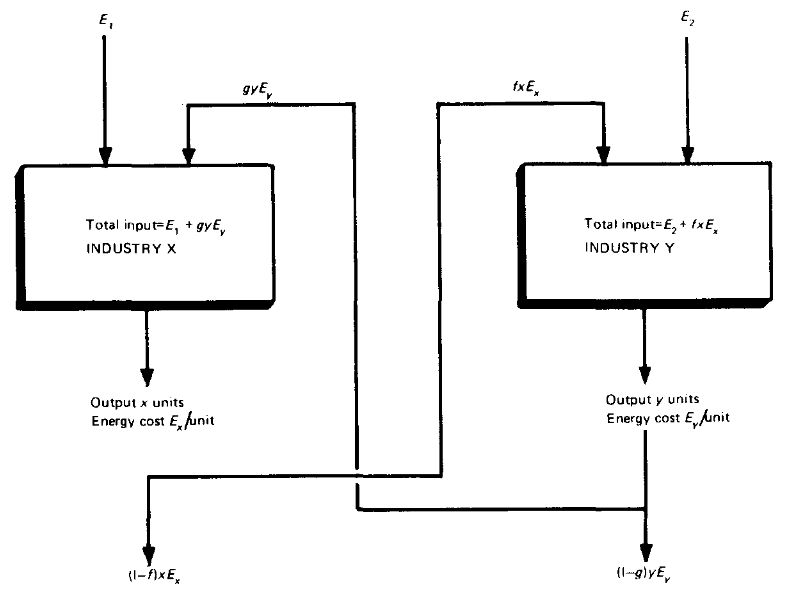
Copper smelting

This provides a convenient example of a detailed process analysis and the variation in results due to different choice of sub-sytem. There are various kinds of smelting furnace available but recently an electric furnace has been recommended to the industry on the

[12] W.A. Reardon, 'An input/output analysis of energy use changes 1974-1975 and 1958-1963' Battelle Northwest Labs, 1971

[13] E. Hirst and R. Herendeen, 'Total Energy demand for automobiles', Society of Automotive Engineers Inc., publ. 730065. 1973.

Figure 2. Two industries, X and Y, supplying each other with raw materials.



For each industry total energy cost in equals total energy cost out

$$xE_x = E_1 + gyE_y \qquad yE_y = E_2 + fxE_x$$

Hence

$$E_x = \frac{E_1 + gE_2}{x(1-fg)} \qquad E_y = \frac{E_2 + fE_1}{y(1-fg)}$$

basis of better thermal efficiency. A detailed examination of the heat processes within an electric furnace[14] shows it has a thermal efficiency of 61% compared to fuel-heated furnaces with an efficiency of 27%. A comparison of the heat inputs required per ton of copper thus shows a factor of two in favour of electricity. Whether this represents a financial saving to a producer depends upon the relative prices (£ per unit of heat) of electricity and other fuels. However, as far as the industry is concerned, this is a significant energy saving.[15]

If the sub-system considered is enlarged to include the electricity supply industry and other inputs to the electric furnace the opposite conclusion results. The present efficiency of electricity generation in the UK is about 25% (see below) indicating that the supply of 1 kWh-electrical (kWhe) requires an input of 4 kWh-thermal (kWhth). Thus the 2 to 1 ratio in favour of electric furnaces becomes almost a 2 to 1 ratio against. A detailed study of both smelting systems[16] shows that for a fuel-fired system the energy cost is about 5400 kWhth/ton copper and for an electric furnace about 8000 kWhth/ton copper. It is a disturbing conclusion that in good faith an industry could improve its own thermal efficiency whilst increasing the national energy consumption.

Supply of electricity

The contradictory results obtained from two analyses of copper smelters hinged on the distinction between energy delivered (as electricity) and total energy input (to a nation). It is worth exploring this topic further if only because different authors use different conversion factors and in any case the efficiency of electricity generation is likely to change with time. This example

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[14] O. Barth, in *Extractive metallurgy of Cu, Ni and Co* ed P. Queneau (NY, Interscience, 1960) page 251.

[15] D.G. Treilhard, 'Copper state of the Art' *Chemical Engineering*, April 1973

[16] P.F. Chapman, 'The energy cost of producing copper and aluminium from primary ore', Report ERG001, Open University 1973

will also show how the aims of a particular study can dramatically alter the answers obtained..

The *Digest of Energy Statistics* for the UK defines the primary input to the UK as coal, oil, gas, nuclear electricity and hydro-electricity. The latter inputs are converted to tons of 'coal equivalent according to the amount of coal needed to produce electricity at the efficiency of contemporary steam stations.'* This dubious procedure therefore introduces a theoretical loss into the energy supply system, as shown in Figure 3. The problem is thrown into focus by considering what energy cost should be attributed to one kilowatt-hour of electricity consumed. On the basis of the convention adopted by the *Digest of Energy Statistics* the total input is 22 784 x 10^6 therms, the output 5826 x 10^6 therms giving an efficiency of 25·57%. This corresponds to an energy cost of 3·91 kWhth per kWhe. However it could be argued that the electricity output of nuclear and hydro-stations is the true input to the system. On this basis the total input is 20 979 x 10^6 therms giving an efficiency of 27·77% so that the energy cost is 3·6 kWhth per kWhe consumed. Alternatively, it could be argued that the inputs to the system are the fossil fuels (19 903 x 10^6 therms), the heat generated at nuclear power stations (2360 x 10^6 therms) and the hydro-electricity output (194 x 10^6 therms).

This set of inputs gives an efficiency of 25·94% and an energy cost of 3·855 kWhth per kWhe. This last set of inputs is consistent

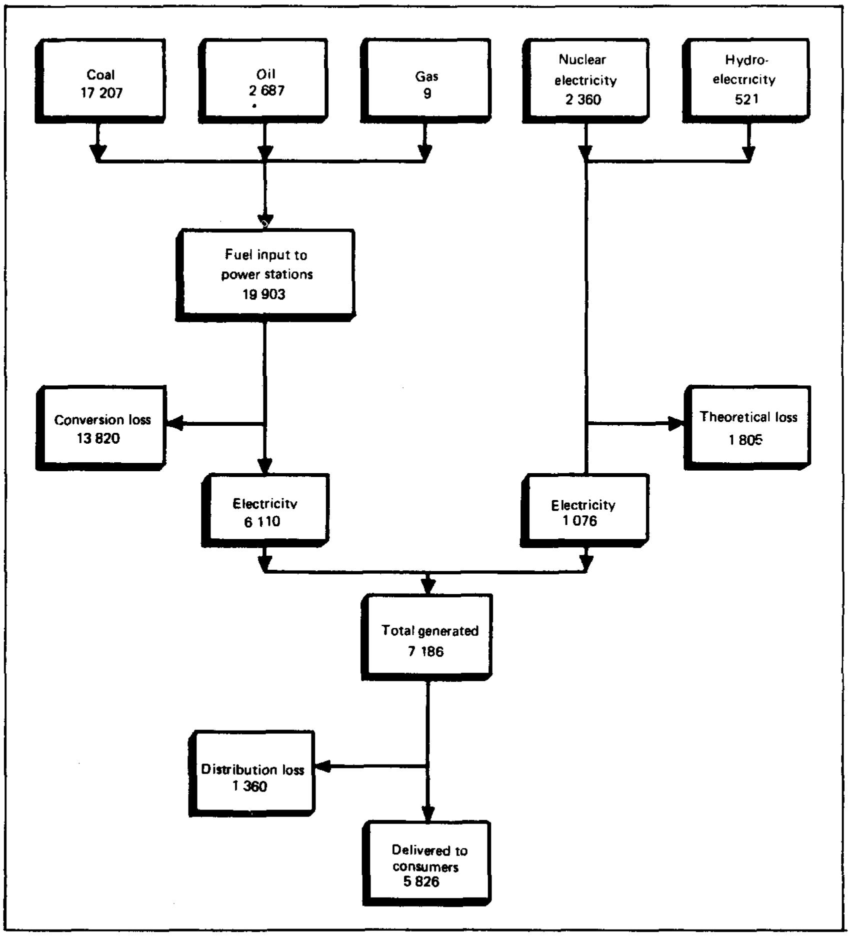

Figure 3. Energy network of electricity generation in the UK, 1968 (source: *UK Digest of Energy Statistics*). (units: 10^6 therms)

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* A similar procedure is adopted for the electricity purchased from industry. The electricity is converted to 'tons of coal equivalent' and added to the 'coal input to the electricity supply industry'.

with a project examining the heat release[17] involved in the supply and consumption of electricity. If the project was investigating maximum possible efficiencies then the primary input to nuclear power stations is the energy theoretically available in the fabricated fuel rods. This may be an order of magnitude larger than the heat extracted from the rods in the reactor.

Apart from these differences there will also be alternatives in the ways in which the indirect energy consumption of power stations is taken into account. Indirect energy consumption is ignored in tables of energy statistics. In the case of nuclear power stations, how does one include the energy and materials consumed in processing and safeguarding nuclear wastes long after the power station has been taken out of commission? Table 1 summarises an analysis of the electricity supply industry based on the *Census of Production 1968.*[18] It includes the purchases of electricity from industry, the consumption of materials and equipment, the energy needed to refine oil, mine and transport coal etc. (It does not include estimates of the energy costs of nuclear wastes or fuel reprocessing.) On this basis the energy cost of 1kWhe is 4·19 kWhth, corresponding to an efficiency of 23·84%.*

In short this example shows that even when the sub-system is well defined there are alternative definitions of inputs which can dramatically alter the final values.

Oil refining

Another input to the energy supply industry is oil. Before any oil is consumed, either as fuel or chemical, it has to be extracted, transported and refined. The oil refinery is an easily identifiable sub-system; however there are differences both in what is counted as an input and how to partition the inputs between various outputs. A simplified flow diagram of the oil refinery system

Table 1. The electricity supply industry

Inputs		**10^6 kWhth**
New buildings (£80·08 million)		1 895
Net plant etc (£462 million)		16 170
Net vehicles (£3·623 million)		178
Vehicle and machine spares		766
Iron and steel (13 500 tons)		134
Wire and cables		1 089
Other materials		985
Nuclear fuels		2 904
Coal (75·54 million tons)		542 015
Coke (314 000 tons)		2 944
Oil products		93 792
Gas		374
Electricity purchased (from industry)		3 479
Heat input (nuclear power stations)		96 113
Electricity (generated in hydro-plant)		3 600
	Total input	*766 438*
Total electricity generated		215 149
Used in works, offices etc		16 195
Loss in distribution		16 182
Sold to final consumers		182 772
Overall efficiency =		23·84%
Hence 1 kWhe =		4·195 kWhth

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[17] P.F. Chapman, *New Scientist* Vol 58, 1973 page 408.

[18] P.F. Chapman, 'The energy cost of delivered energy, UK 1968', ERG 003, Open University 1973

* In fact this value was obtained by solving the five simultaneous equations linking the major energy producing industries.

connected to an 'organic chemicals industry' is shown in Figure 4. The problem is to decide how much energy to associate with an oil fuel and how much with an organic chemical. This is an interconnected system similar to that shown in Figure 2. This example has the added complication that the chemical feedstock is produced by the same plant as the oil fuel products.

Two of the many possible conventions that could be adopted in approaching this problem are that:

- since the crude oil is purchased as a primary fuel, all its calorific value is to be divided between the *fuel* products;
- the calorific value of the crude oil is to be divided between all the refinery products in the ratio of the calorific values of the products.

Following these rules the types of results obtained are:

- All the inputs are set as costs against the *fuel* outputs. The chemical feedstocks therefore have no energy cost attributed to them.* On this scheme the efficiency of the oil refinery as a fuel processor is 82·4%.[8] Thus the energy cost incurred in consuming a gallon of refined petrol is 53 kWhth, compared to an actual calorific output of 44 kWhth/gallon. Thus all industries consuming oil fuels are assigned greater energy costs than under the convention below; industries consuming chemical feedstocks have lower assigned energy costs.
- The sum of all the energy inputs is distributed as energy costs over all the refinery products in proportion to the actual calorific values of the various products. (Thus the energy cost of

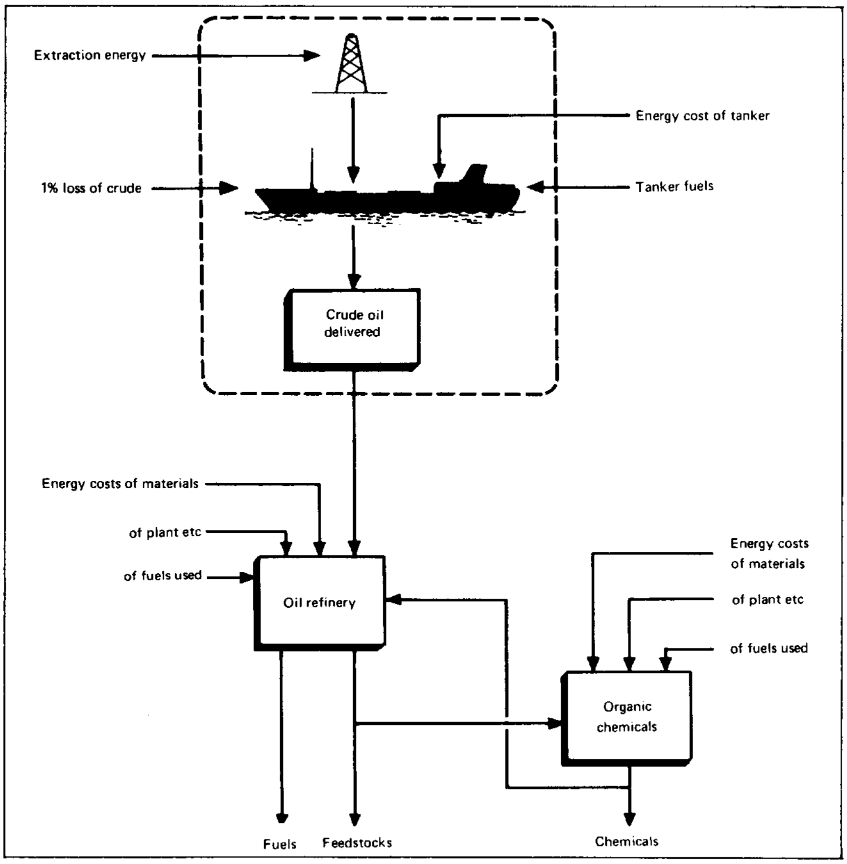

Figure 4. A simplified network of inputs and outputs associated with an oil refinery.

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* This is absurd because it indicates that 'energy costs' could be reduced by using a chemical as a fuel. This is a good reason for insisting that the 'energy cost' of a product should be greater than or equal to its calorific value. See also ref. 18.

each product is its calorific value times a constant.) Note this increases the effective input to the oil refinery as compared to the convention above by virtue of the feedback of organic chemicals to the refinery. The efficiency of the refinery as a fuel processing plant is now 86%,[18] so the energy cost incurred in consuming a gallon of petrol is 51 kWhth. On this scheme 1 tonne of plastics has an average energy cost of about 30 000 kWhth; on the basis of the convention above the figure is between 10 000 and 15 000 kWhth.

The oil refinery is a sub-system which receives as an input the output of another sub-system, namely that shown as the extraction and delivery of crude oil in Figure 4. The energy costs incurred within the extraction and delivery sub-system are equivalent to about 7% of the calorific value of the crude oil.[8] However whether these energy costs are included as part of the input to the refinery depends upon the overall aim of the project. It would be consistent to ignore these energy costs in a project aimed at evaluating the energy costs of products *to the UK* since these costs are incurred outside the UK. If the project is associated with world energy costs then clearly these extraction and transport energy costs must be included as part of the input to the refinery.

Aluminium production

This final example of energy analyses shows how an understanding of different methods and conventions enables sense to be made of apparently contradictory results. Several independent estimates of the energy cost to produce 1 tonne of aluminium have been published. A statistical analysis of US data yielded 67 200 kWhth/ton;[4] an input-output analysis for the UK yielded 16 600 kWhth/ton[11] and process analyses have yielded 91 000 kWhth/ton,[9] 64 200 kWhth/ton[19] and 64 300 kWhth/ton.[20] The estimates made by US authors refer to the energy cost per *short ton*; converting these results to metric tons gives 75 000 kWhth/tonne by statistical analysis[4] and 71 900 kWhth/tonne[19] and 72 000 kWhth/tonne[20] by the process analysis methods. All these US studies assume a conversion efficiency for electricity of 33% whereas my own process analysis[9] assumes 23·8%. Converting my result to 33% electricity generation efficiency yields 72 000 kWhth/tonne, so that all three process analyses are in excellent agreement. The statistical analysis result is slightly higher; however it refers to the energy cost per ton of *rolled*, not crude aluminium.

The only remaining discrepancy is the value obtained by Wright[11] on the basis of an analysis of the UK input-output table. The 'aluminium' sector of this table does not distinguish between aluminium produced from primary ores and that produced from scrap material; nor does it specify whether the product is crude or semi-fabricated aluminium in the form of sheet, tube etc. Thus the energy cost deduced from the I/O table is an average energy given by

$$E_{av} = \frac{PE_p + SE_s}{P + S}$$

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[19] J.C. Bravard, H.B. Flora, and C. Portal, 'Energy expenditures associated with the production and recycling of metals' Oak Ridge. Nat. Lab. Report. ORNL–NSF–EP–24, 1972.

[20] P.R. Atkins, *Engineering and Mining Journal* Vol 174, No 5, 1973, page 69

where P is the quantity produced from primary ores, S is the secondary production and E_p and E_s are the respective energy costs. Assuming that E_p equals 72 kWhth/kg, and E_s equals 3 kWhth/kg. This is close to the I/O table result; the remaining energy cost per ton of aluminium produced in the UK is about 14 kWhtht/kg. This is close to the I/O table result; the remaining difference could be due to some energy used to fabricate sheets etc.

Thus all these estimates of the energy cost of aluminium are self-consistent, they are all 'correct', but they are all based on different conventions. Clearly none of these results should be used in other studies until they have been converted to the conventions appropriate to other studies.

Conclusions

The analysis of energy consumption can show ways of conserving energy and can highlight particular types of problem. However this is a new area of study and there is no uniformity between authors as to what conventions to use or what techniques are most appropriate. This means that results from energy studies should be carefully interpreted and only used when the following points are clear:

- what sub-system of the world has been analysed;
- which energy inputs to the system have been included in the analysis;
- what calorific values are being used for primary fuels;
- what efficiencies are being ascribed to the energy supply industries;
- what conventions are being used to partition the energy costs within plants or industries.

Neglect of any of these factors could produce misleading conclusions even in work based on accurate data. Moreover, any work leaving room for doubt as to its conventions in respect of these points must be interpreted with great caution.

[21] P.F. Chapman, 'The energy costs of producing copper and aluminium from secondary sources', Open University, Report. ERG 002, 1973.

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