General Discussion

E. Eisner, A. S. Kenkare, P. L. Harrison, J. C. McVeigh, I. Fells, J. M. Cassels, F. J. Weinberg, T. M. Fry and D. C. Ion

Phil. Trans. R. Soc. Lond. A 1974 **276**, 603-609
doi: 10.1098/rsta.1974.0042

Phil. Trans. R. Soc. Lond. A. **276**, 603–609 (1974)
Printed in Great Britain

General discussion

PROFESSOR E. EISNER (*Department of Applied Physics, University of Strathclyde, Glasgow*)

The demand for energy

Throughout this discussion we have heard about the many sophisticated considerations involved in the management of the supply, production, and conversion of energy to meet the estimated future demands. But I have been very disappointed that we have had no paper that discusses the assumptions made in this projection. As far as I can see, such projections are more-or-less sophisticated extrapolations of past trends. Thus, it is assumed that our society will be free to make whatever demand it likes, and that industry must begin to meet this demand. However, I suggest that our society is not a baby that must have demand feeding.

The need for energy depends on per capita production, on energy use per unit of production, and on population. All these have histories, mechanisms, and methods of management, and discussion of these underlies everything we have talked about. Indeed, I suggest that without such a discussion all the rest has been unrealistic.

We seem to be in danger of making the assumption that demand cannot be managed, and that we therefore have to plan to devote huge resources to supplying energy at a rate that is perhaps quite unnecessary. If we devote our resources to this, there will be other things that will go short, many of them things that are vital to a civilized society.

The trouble is that, if our energy producers and converters get all the capital they are asking for, governments are subsequently going to have to show that all this capital really had to be spent, and they will therefore never have an incentive for proper management of the demand. I suggest that we must start by trying to find out how we can reduce the demand for energy made by our society to the lowest rate that is compatible with our goals, and then to ensure that the energy producers and converters do not have any more capital than the least that can possibly meet that demand. Only in that way will there be any pressure to see that our resources are used efficiently.

DR A. S. KENKARE (*Hatfield Polytechnic, Hatfield, Herts*)

Two-tier energy supply system

It is very astonishing that in spite of the looming dangers ahead, on the energy front, there is a strong element of competitiveness in the major suppliers of energy such as coal, oil, gas and electricity. I find this most disconcerting, and only hope that this is a passing phase – the last flicker of the competitive flame, subject no doubt to the formation of an energy board, which seems to be the fashionable idea of the moment. I also hope that the proposed energy board rationalizes the use of energy which will lead to its optimum use.

What is also required in addition is the widest diversification of the energy supply base, so as to include other forms of energy such as solar, wind, tidal, geothermal and energy from waste both physical and biological. Although these 'other' forms of energy add up to a small amount in energy charts at present, their continued use and development could increase this proportion, and what is even more important, make people more receptive to using what in effect is a renewable source of energy supply. The present major energy suppliers almost constitute a cartel and individual consumers have no option but to draw energy from them. By giving encouragement to non-conventional but renewable energy usage, within a framework of safety, people would be able to draw up their own energy schemes with these resources, at least in housing and the non-industrial sector. The distribution of energy supplies by grids is very vulnerable to pressure on fuel resources, and the decentralized arrangement of building 'autonomous houses' that draw minimal amounts of energy from external sources could at least ensure our physical survival in times of scarcity.

In effect, I would like to advocate a two-tier energy-supply system, the industrial and commercial usage of energy being ensured by the four major suppliers, assuming that these are available, and the non-industrial, non-commercial usage having the option, or rather the encouragement, to utilize non-conventional sources of energy supply. It is by these latter options alone that any further development and innovation in energy utilization of non-conventional sources can be made. To me at least, it appears that the near monopoly of the major energy suppliers is seriously inhibiting the innovative potential in so far as the development of non-conventional energy sources is concerned, economic considerations notwithstanding. The so-called energy crisis is really a demand–supply–management problem, and the sooner we adjust the mix the easier will be the problem in the 1980s and beyond.

P. L. Harrison (*Central Electricity Research Laboratories, Kelvin Avenue, Leatherhead, Surrey*)

Solar power

It has been suggested that in the United States of America 3% of the energy required for space heating and cooling could be supplied by solar energy in the late 1980s. If that situation obtained in this country also, what effect would this effective reduction in demand for energy from conventional sources have on the projections that have been discussed at this meeting?

I would draw attention, again, to two factors relating to the use of solar energy as a primary energy source which I think are of particular importance. The first of these is the lack of thermal pollution associated with its use. The second is that, unlike those energy resources that rely on the exploitation of Earth-bound minerals, the cost per unit of energy does not increase with continued use of the solar energy.

Dr J. C. McVeigh (*Brighton Polytechnic and International Solar Energy Society, U.K.*)

One of the questions which should now be receiving serious consideration in the United Kingdom is the extent to which the present knowledge of solar-energy utilization could be implemented in the 1980s. Countries which have been mentioned as having significant nuclear research programmes – U.S.A., France, the U.S.S.R. and Japan – have various solar energy research programmes and many applications. For example, it is estimated that there are well over 2 million domestic solar water heaters in Japan.

Over 20 years ago the late Professor Harold Heywood (*Engineering* **176**, 377, 409 (1953)) first showed that it was feasible to collect an appreciable proportion of the domestic hot-water requirements of an average house in the United Kingdom by using a simple flat-plate solar collector.

It is perhaps surprising to appreciate that even in mid-November it is possible to collect over 4 MJ/m² by using a suitably inclined flat-plate collector. Typically, water temperatures in the order of 40 °C can be obtained from inlet conditions of 10 °C. During the summer period the amount of heat which can be collected is over 10 MJ/m² and water temperatures greater than 60 °C can be achieved.

There are many other applications of basic and applied solar-energy research which could be developed in the United Kingdom and it is very encouraging to note that the United Kingdom Branch of the International Solar Energy Society has been formed with the active cooperation of the Royal Institution.

Dr I. Fells (*Department of Chemical Engineering, University of Newcastle upon Tyne NE1 7RU*)

Manpower

I want to bring to your attention a resource which has not yet been mentioned today but which may have a limiting effect on many of the proposals put forward by Mr Walker and Mr Grainger, that resource being trained manpower. Anyone from the chemical engineering contracting industry must have been delighted by the many suggestions made today to build gasification plant, synthetic oil plant and so on. I am sure contractors if asked if they can cope with such a massive construction programme will say 'yes' because they always do. But they may have difficulty in obtaining the trained chemical engineers to implement the programme. The number of students studying chemical engineering has fallen by almost one third during the last five years. The lead time in education is a long one, schoolboys and girls have to be convinced that chemical engineering offers a rewarding career and it then takes four or five years before they emerge from the universities as qualified chemical engineers.

In some ways it is even more alarming to realize that if a programme of energy conservation is to be implemented, the number of qualified fuel technologists required cannot possibly be met from the 30 or so coming on to the market each year.

This shortage of trained manpower could well limit the programmes necessary to provide oil from indigenous sources in Britain and the U.S.A. to fill the projected shortfall in oil imports.

Professor J. M. Cassels

On the question of manpower, I would like to point out that no immediate action by Whitehall is required. The universities already have the physical resources for a considerable expansion, and they also have in post some of the teachers that would be required. In practice, however, the total university student population is static at present, and within this total the scientific and technological components are declining. The reason is simple: the low level of industrial recruiting among the graduates of one, two and three years ago has sent a wave of dismay through the youth of the country. More vigorous recruiting could be expected to change the situation quite rapidly.

Professor F. J. Weinberg (*Department of Chemical Engineering and Chemical Technology Imperial College, London, S.W.7*)

Combustion of waste

We are doing some research into the combustion of very poor fuels and very lean fuel/air mixtures, some of which are in fact well below the normal flammability limits. This is potentially applicable to burning upcast gas from coal mines and coal seams, exhaust gases from a wide variety of industrial processes, lean methane/air mixtures, wastes fermenting in air, dried sewage, etc. The methods used are based on extensive heat recirculation and on the injection of free radicals into the combustion zone using small plasma jets.

It has been calculated that the entire power requirement of the coal industry in the U.K. could be derived from the methane content of the ventilation air from gassy mines. Even dried excreta contain half the energy value of coal. These are obviously not prime fuels, suitable for every application, but some of them are continuously renewable, some contribute to pollution if they are not burned, and every addition to available energy is obviously to be welcomed. It is likely that in future we shall have to use more and more degraded materials as fuels.

What seems to be lacking from the very interesting compilations presented at this meeting is any estimate of the potential contributions from such sources. Taking the very simplest, what is the total energy value of all the refuse produced by a highly industrialized society?

Mr T. M. Fry (*Tanners, Northbrook, Micheldever, Near Winchester, Hants*)

Energy content of world's reserves of different fuels

At the suggestion of Professor Kurti, I would like to contribute some figures concerning the relative magnitudes of the world's reserves of different types of fuel, expressed in terms of energy content (see table 1). The figures have been compiled in haste from sources that happened to be at hand and are intended to do no more than indicate orders of magnitude, though they are given to one significant figure. In preparing this contribution for inclusion in the published proceedings, I have made some revisions in the data, amplified the commentary upon them and added references, but the table should not be regarded as definitive or even as representative of the best available estimates.

Table 1. Energy contents of the world's initial reserves of fuel

fuel	quantity recoverable	energy content 10^{21} J
coal and lignite	7.6×10^{15} kg	200
oil		
petroleum liquids	2.7×10^{14} kg	10
tar-sand oil	4.1×10^{13} kg	2
shale oil, minimum	2.6×10^{13} kg	1
shale oil, maximum	(4.5×10^{14} kg)	(20)
natural gas	2.8×10^{14} m^3	10
uranium		
thermal reactors, once-through fuel cycle	3.5×10^{9} kg	1
thermal reactors, plutonium recycle	(6×10^{9} kg)	(10)
fast breeder reactors	4×10^{10} kg	2000
thorium	?	(100)
lithium		
cheaply exploitable reserves on land 60 % utilization	1×10^{11} kg	500
1 % utilization of oceanic lithium	2.5×10^{12} kg	200000
fuel consumption to 1990, cumulative		7

Coal and lignite

A figure of 7.6×10^{15} kg for the world's initial reserves of minable coal and lignite is quoted by Hubbert (1971) from estimates by Averitt (1969), both of the United States Geological Survey. It represents 50% of the initial coal in place in beds not less than 0.35 m thick and at depths not greater than 2 km. Although he uses this figure, Hubbert suggests that a lower figure of 4.3×10^{15} kg may be more realistic in view of the thinness and depth of some of the coal seams included in Averitt's estimates.

With regard to distribution, Averitt estimated that 65% of the initial supply occurs in a region comprising Asia and European U.S.S.R., 27% in North America, 5% in Western Europe and only 2.4% in the three entire continents of Africa, South America and Australia.

In converting to energy content, Hubbert assumes a factor of 2.6×10^7 J kg^{-1}.

Oil

Hubbert's estimate of the initial quantity of recoverable petroleum liquids is 2.7×10^{14} kg (32×10^{10} m^3), of which about five-sixths is in the form of crude oil and one-sixth 'natural-gas liquids' (Hubbert 1971).

The figure for tar-sand oil relates to the Alberta deposits only, no world inventory being available to Hubbert (1971).

The figure for shale oil quoted by Hubbert (1971) refers to the quantity regarded as recoverable under conditions prevailing in 1965, i.e. 2.6×10^{13} kg (3×10^{10} m^3). If marginally recoverable material is included, an upper figure of 4.5×10^{14} kg (52×10^{10} m^3) may be considered (B.P. Co. Ltd 1973).

The energy content factors used by Hubbert (1971) were 4.3, 4.4 and 4.6×10^7 J/kg for petroleum liquids, tar-sand oil and shale oil respectively.

Natural gas

Hubbert (1971) based his estimates for natural gas on those for crude oil, on the grounds that, for large productive areas, a roughly constant proportionality exists between them. His figure is 2.8×10^{14} m^3 and his energy content factor 3.75×10^7 J m^{-3}.

Uranium

The magnitude of recoverable uranium reserves is dependent upon the price that they could command, which in turn depends upon the efficiency with which they could be utilized. For currently operating reactor systems, which use natural or enriched uranium on a once-through basis, the efficiency of uranium utilization ranges from 0.2% for Magnox to 0.8% for Candu, according to Moore (1969). With regard to future developments, plutonium recycling in thermal reactors might increase uranium utilization to about 2%, while the alternative of plutonium recycling in fast breeder reactors might result in 60% uranium utilization.

The quantity of uranium likely to be recoverable within a cost limit of the order of \$30/kg (£12.50/kg) is here assumed to be 3.5×10^9 kg. To put the cost in perspective, the contribution that it would make to generating costs, assuming 0.4% uranium utilization and 33% thermal efficiency, would be 11p/GJ (0.04p/kW h). With regard to lower-grade ores, it has been estimated that 6×10^{10} kg are available at costs up to \$200/kg (£83/kg) (Institute of Fuel 1973), but I do not know whether full account has been taken of the possible restrictions that health and environmental factors may impose. Here, it is assumed that 1% of the uranium in the world's oceans could be recovered within a cost limit acceptable for fast breeder systems, yielding a supply of 4×10^{10} kg.

The energy content of natural uranium, on the basis of nuclear fission of both ^{235}U and ^{238}U, is 8.3×10^{13} J kg^{-1}.

Thorium

The total amount of thorium in the lithosphere seems to be three or four times as great as the total amount of uranium, but the amount recoverable at low cost may be less. The efficiency with which it could be utilized is uncertain, but it is possible that a high figure could be achieved by recycling ^{233}U in either thermal or fast reactors.

The energy content of thorium as a fuel for fission reactors is about the same as that of uranium.

The figure shown in the table for the recoverable energy content of the world's thorium reserves cannot even be regarded as indicative of the order of magnitude.

Lithium

Known and inferred reserves of lithium in the United States amounted, in 1970, to about 6×10^9 kg. At that date, known and inferred reserves elsewhere amounted to only 2×10^9 kg, but this figure may merely reflect the lack of incentive for exploration. If, as seems probable, lithium reserves are distributed evenly, world-wide prospecting should reveal reserves of the order of 1×10^{11} kg, exploitable at a cost of \$20/kg, the price level held by lithium metal during the 1950s and 1960s (Holdren 1971). The lithium content of sea-water is 0.17 g m^{-3}. If 1% of this could be recovered at a cost acceptable for fusion reactor systems, the oceans represent a reserve of 2.5×10^{12} kg.

The energy content of lithium as a fuel for the deuterium–tritium fusion reactor would depend on the details of how it was used. Maximizing for lithium utilization by exploiting the endothermic interaction of fast neutrons with ^{7}Li, the energy content factor for natural lithium may be as high as 9×10^{13} J kg^{-1} (Holdren 1971). It is noteworthy that Hubbert (1971) used a factor of about 3×10^{13} J kg^{-1}, which corresponds to the consumption of the ^{6}Li isotope only.

Deuterium

The development of the deuterium–deuterium fusion reactor would open the way to the utilization of a much larger energy reserve.

World energy consumption

Assuming a 5% per annum growth rate in world energy consumption throughout the 1970s and 1980s, the total cumulative consumption of world fuel reserves by the end of the 1980s will have amounted to about 7×10^{21} J.

References

Hubbert, M. K. 1971 *Environmental aspects of nuclear power stations*. Paper IAEA-SM-146/1, International Atomic Energy Agency, Vienna.

Averitt, P. 1969 *Bull. U.S. Geol. Surv.* p. 1275.

British Petroleum Company Limited, Policy Planning Staff. 1973 *World Energy Prospects*.

Moore, R. V. 1969 *Atom* **149**, 59–74.

Institute of Fuel Working Party. 1973 *Energy for the future*. London: Institute of Fuel.

Holdren, J. P. 1971 *Adequacy of lithium supplies as a fusion energy source*. UCID-15953 Livermore, California: Lawrence Livermore Laboratory, University of California.

Mr D. C. Ion (*Britannic House, Moor Lane, London E.C. 2*)

The alternative listing of energy statistics by Mr Fry are welcome but the reader should be aware of serious limitations which arise. In brief terms, the kind of problems involved in use of figures of this kind may be listed as follows:

(*a*) I agree with King Hubbert's caution about Paul Aberitt's coal figures but would much prefer the lower figure of 4.3×10^{15} kg. This itself represents a very much higher recovery ratio than is now adopted (for example) by the National Coal Board, and the reserve-concept behind these figures is very different from that of the petroleum figures.

(*b*) Perhaps the 2.7×10^{14} kg is a reasonable figure for initial recoverable oil reserves, but King Hubbert's reasoning with the gas reserves, using the U.S.A. average, is very dubious.

(*c*) My strongest objection is the adoption of the Alberta figures for tar sands as the total world figure. Venezuela has about the same oil-in-place in its tar sands in Orinoco and there are very big oil reservers elsewhere, in Canada, in Madagascar, and many other places. Some figures were given at the 1973 Institute of Petroleum Summer Meeting and these should be published shortly; see papers by both Leslie and Clegg.

(*d*) I hesitate to comment on the figures for nuclear energy but must express considerable reservation at suggested utilization of 1% of the uranium from the oceans leading to 2000:1 ratio of fast breeder reactor to thermal reactor resource availability.

(*c*) Finally, I would question whether a table including such extremely long-term considerations has detailed relevance to the next thirty years.