PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A
MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

General Problems of Collecting and Understanding World Energy Data [and Discussion]

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Phil. Trans. R. Soc. Lond. A 1974 **276**, 431-438
doi: 10.1098/rsta.1974.0029

Phil. Trans. R. Soc. Lond. A. **276**, 431–438 (1974)
Printed in Great Britain

CONVENTIONAL PRIMARY ENERGY RESERVES: REVIEW AND DISCOVERY POTENTIAL (WORLD-WIDE)

General problems of collecting and understanding world energy data

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This paper attempts to improve the understanding of the available world energy supply data, which are being imperfectly interpreted and increasingly used.

There are basic differences in reserves concepts and definitions between the primary energy resources. There is insufficient knowledge to justify the apparent precision of original measurements of most energy resources. The collection of energy data is in many diverse hands, but of paramount importance is collection close to source, because original estimates are progressively amended by opinions which are difficult to ascertain and assess. The factors affecting energy demand are not yet sufficiently understood to take full advantage of the potential of mathematical models. Cooperation between the energy industries must develop.

Experience in preparation for the 1974 Survey of Energy Resources by the World Energy Conference illustrates these points of which an understanding is necessary for wise consideration of world energy problems.

Concepts and definitions

The most recent attempt to define energy resources in such a way that the data are collectable and comparable is that by the Consultative Panel for the 1974 Survey of World Energy Resources for the World Energy Conference organization. This is the latest in their survey series, with that of 1968 being the last previous one. The survey should also satisfy the requirement for such a survey as recommended to the United Nations by the Stockholm Conference on the Environment, 1972.

The definitions agreed are a compromise between differing reserve concepts, and between what some planners, economists and statisticians think is required and what is practical when acknowledging that the precision of the data normally improves with the age of development of a resource and of the country in which it is found.

Solid fuels

Solid fuels include high- and low-ranking coals, peat and non-conventional fuels (wood and agricultural and domestic waste). These latter, though a small and declining proportion of world energy resources, can be important locally. Most available information is on the coals. The broad categories of anthracite, bituminous, sub-bituminous, brown coal, lignite and peat are being used. National standards vary widely and it is not always possible to define ranks by explicit reference to ash, carbon content, etc.

The widespread, general concept behind reserves data as understood by the coal industry was shown in two of the definitions used in the 1968 survey:

'Measured reserves...shall mean the total amounts...occurring within the limits hereinafter prescribed and with respect to which there exist reliable data and thickness of seams...the respective limits...shall be:

'Coals: Seams containing not less than 30 centimetres of coal and not more than 1200 metres below the surface...'

'Percentage Economically Recoverable shall mean the proportion...that is considered of economic value.'

For the 1974 survey the definitions have been changed to be more comparable with those of the petroleum industry, so recognizing four very important concepts:

(*a*) While it is important to know the total amount in place, it is more important to know what can be recovered under current operating and economic conditions.

(*b*) The thickness and depth of seams from which coal may be economically mined by current methods varies from place to place.

(*c*) The only coal which has a comparable 'economic value' is that which can be economically mined. The parameters required to judge the economic value of coals through exploitation by gasification are not yet sufficiently known to warrant inclusion in this survey.

(*d*) Changing conditions can highlight different characteristics, e.g. the request for the sulphur content of coals, (as well as for petroleum), reflects current environmental interest.

Crude oil

The 1968 survey moved its petroleum definitions from the earlier coal-type concept towards oil-industry practice and in the 1974 survey the definition of proved recoverable reserves is: '...the estimated quantities of crude oil (or liquid hydrocarbons) remaining in the ground which geological and engineering information indicate, with reasonable certainty, to be recovered in the future from known oil reservoirs based on the present state of technology and under existing economic conditions.'

This definition is similar to that of the American Petroleum Institute (A.P.I. 1969), which, however, has an important rider: 'Both drilled and undrilled acreage is considered in the estimates of proved reserves. However, the undrilled proved reserves are limited to those drilling units immediately adjacent to the developed area...'

This rider is important for three reasons. (*a*) In conditions where drilling units are small and geology complex, as in U.S.A. and Canada, this results in a very conservative estimate. In areas like the Middle East, 'drilling units' are different because the operating conditions, mineral rights laws and simple geology allow more scientific and less bureaucratic location of wells; hence greater undrilled reserves can be and are included. (*b*) The inhibition is particularly applicable, in areas like the U.S.A., to estimates in the early development of fields. (*c*) Annual revisions and additions, therefore, are much more important in areas of U.S.A. type than of Middle East type. This emphasizes the need for the constant review for both types of reserves, the one because many small additions may give large aggregates and the other because single wells can indicate large additions.

However, all countries show slight variations on the A.P.I. system, even if they subscribe to it in general, while some have very different systems.

The U.S.S.R., for instance, classify their reserves into six categories, with a system of reporting and certification, designed to ensure the application of exploration effort appropriate to the rank of prospect. There is no exact equivalent of the American type 'proved reserves' category. Furthermore, petroleum reserves are subject to the States Secrets Act, 1947 (Campbell 1968).

Natural gas and natural gas liquids

Natural gas occurs as associated or non-associated with crude oil. This raises reserves concept problems.

Associated gas is only recoverable as the crude oil is produced. Non-associated gas is a resource recoverable without reliance on any other resource. Hence a simple summation of estimated reserves would not indicate production potential. It is important to have data on both types. Furthermore, in some circumstances it may be possible to produce wet, associated gas-cap gas, strip it of its condensate and return the dry gas to the reservoir.

Another problem is related to the commitment of natural gas reserves to long-term contracts. Reporting of reserves in U.S.A. and Canada is coordinated by the A.P.I., the American Gas Association and the Canadian Petroleum Association. However, since 1966, Canadian reserves have been reported on a marketable and not recoverable basis. The difference in total in 1965 was some 115×10^9 m^3 (C.P.A. 1969).

Natural gas liquids are recorded in the U.S.A. and Canada and their proved recoverable reserves indicate the estimated quantity which may be extracted by existing or planned plant in the process of producing the natural gas recoverable in proved areas. Elsewhere the natural-gas liquids reserves, and also production, will be included in the crude oil figures as liquid hydrocarbons.

Bituminous sands and oil shales

In the restrictive sense of the definition of 'Crude oil proved recoverable reserves' the only reserves from bituminous sands would be those recoverable by the existing plant at Mildred Lake in the Athabasca oil sands area of Alberta, Canada. The Canadian Petroleum Association estimate (C.P.A. 1969), was some 10^9 m^3 (6.334×10^9 barrels), but they state: 'These estimates in no way detract from published estimates of approximately 300000 million barrels (48×10^9 m^3) which are estimated to be recoverable from the Athabasca type oil sands by mining and thermal processes.'

The 1974 Survey is seeking information similar to the 48×10^9 m^3 estimate and no mention is made of the current conditions restriction. Hence the 10^9 m^3 can be compared with the 1.5×10^9 m^3 (9.7×10^9 barrels) of Canada's proved liquid hydrocarbon reserves (C.P.A. 1972) but the 48×10^9 m^3 must be compared with whatever figure Canada provides under the heading of Additional Reserves of crude oil.

The oil sands, therefore, provide an excellent example of the need to compare like with like. The oil shale situation is similar but the only significant commercial exploitation which could provide reserves in the strict proved sense are in the U.S.S.R. and the People's Republic of China.

Hydraulic energy

For the 1974 Survey, countries have been asked to categorize hydro-electric resources into developed, under construction, proposed for eventual development and those sites which may be economically feasible. This should give useful information more appropriate to discussions such as the present than figures of 'gross theoretical capability' which are also being requested.

Indeed, for the 1974 survey a more simple definition has been adopted than that of the 1968 survey: 'the energy potentially available if all natural flows were turbined down to sea level with 100% efficiency...'. Less comprehensive estimates may be given, using atmospheric precipitation and water run-off.

Such a gross theoretical capability is indeed gross and theoretical. Such a procedure would be impossible on several grounds (amenities, transport, sewage disposal, etc.) and the figure has very limited meaning for comparative purposes. It can only be compared to the gross estimates of other resources, e.g. the average concentration of uranium in the Earth's crust is said to be about $2.9/10^6$ by mass; hence the top kilometre of the continental crust contains about 10^{12} tonnes of uranium, which, in a thermal reactor, would have a thermal value of 1.6×10^{27} J (1.5×10^{24} Btu); current world energy consumption is estimated at 2.6×10^{20} J (2.5×10^{17} Btu) (Leslie 1973).

Nuclear energy

The resources of uranium and thorium for the 1974 survey are sought in terms of their oxides recoverable from known ore deposits within ranges of recovery costs to be given and with currently proved mining and processing technology, quoting also the average grade of ore in terms of percentage by mass of the oxides (U_3O_8 or ThO_2).

This requirement is close to the definition of 'reasonably assured resources' of the Organization for Economic Cooperation and Development/Nuclear Energy Agency (O.E.C.D. 1973), being: 'Uranium which occurs in known ore deposits of such grade, quantity and configuration that it can, within the given process range, be profitably recovered with currently proven mining and processing technology. Estimates of tonnage and grade are based on specific sample data and measurements of the deposits and on knowledge of ore-body habit.'

Recovery costs for this youngest energy resource can be spelled out. O.E.C.D., through N.E.A., and, since 1966, jointly with the International Atomic Energy Agency, have attempted to assess, for the world excluding Eastern Europe, U.S.S.R. and the People's Republic of China, the uranium recoverable within different price categories. The 1973 report, (O.E.C.D. 1973, and see also Boxer, Haussermann, Cameron & Roberts 1972), consider two price categories, up to U.S. \$22/kg U_3O_8 and between U.S. \$22 and U.S. \$33/kg U_3O_8, having already discarded in 1970 the category of between \$33 and \$66/kg of earlier reports as unlikely to be worked in the forseeable future.

Ideally this type of information could be important for all energy resources. Estimation has been attempted for petroleum in the U.S.A. (N.P.C. 1972), but with present knowledge this would be an impossible task, world-wide, at this time.

Renewable energy resources

The contribution of solar and tidal energy is, as yet, insignificant in total but may be important locally. Again, it is only installed or planned capacities which have meaning. The estimate of the total solar flux to the Earth as about 7.5×10^{16} W, with maximum intensity of 8.4 J cm^{-2} min^{-1}, compared to the total of 1970 gross energy use in the U.S.A. of 7×10^{19} J (Ubbelohde 1973), is academically interesting but of very little real value.

However, as highlighted at the U.N.E.S.C.O. World Solar Energy Congress, Paris, July 1973, research into the possibilities of solar energy is being stepped up in the U.S.A., the U.S.S.R., Israel, France and Germany, and perhaps in the 1986 survey some solar energy figures will be significant.

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Measurement

Coal reserves estimates, with seams measured in centimetres, have an accuracy which is more apparent than real. The National Coal Board in Britain, the best geologically mapped country in the world, found it necessary to mount, early in 1973, a borehole drilling programme, costing £3M over two years, to locate precisely the position of potentially recoverable coal and determine its quality and best extraction methods (Broadbent 1973). In July the existence of large new deposits in Northeast England was publicized.

The 1968 survey gave the measured reserves of the U.K. as 12.2×10^9 t, with a note that 'the reserves given are those within the colliery takes and those in the immediate vicinity which are likely to be economically workable'. For the 1974 survey the National Coal Board has provided a figure for 'Known Reserves, Quantity Economically Recoverable', of 3.87×10^9 t, but with the minimum seam thickness of 61 cm (cf. 1968 stated criterion of 30 cm) and maximum depth of 1220 m (close to the 1968 criterion of 1200 m).

These British examples illustrate the problems of measurement, the critical character of the parameters and, possibly, in the latter case, the importance of the realistic application of the economic parameter.

The routine measurements taken in oil and gas fields, after some production experience, normally give sound estimates of the oil-in-place and the proven reserves, though estimates from single discovery wells can be misleading. However, the five common methods for estimating the most speculative category of possible reserves all have major disadvantages (Bakhirov & Ovanessov 1971). The shape of our knowledge of petroleum is that of an inverted pyramid – the farther up from discovery to utilization, the more we know. Yet figures for ultimate oil-in-place or ultimate recoverable reserves are often discussed with surprising arrogance. Current ignorance should engender humility; our successors will know more and find and produce more petroleum than we can estimate at this time. This does not mean that estimates should not continue to be made in the speculative areas. They can be stimulating exercises and of value as long as there is full appreciation that, being based on current knowledge, they have their limitations.

The additional resources of oil sands and oil shales are probably as well 'measured' as those of coal, but when one notes that the 1968 survey world total of coal reserves, which is a figure frequently quoted, included a figure of 1×10^{12} t for the People's Republic of China based on a 1913 estimate, there is obvious need for caution.

In the nuclear field there is the global type of gross average measurement as quoted by Leslie (1973) or calculated by Brinck (1971). The latter gives 80×10^6 t of uranium as 'possible' uranium reserves from which 'reasonably assured' reserves exploitable at prices up to \$13/kg U_3O_8 could be developed. Such estimates have a very different element of measurement than that involved in the estimates of high-grade ore reserves of the world, excluding the U.S.S.R., etc., as compiled by N.E.A./I.A.E.A., of 1.126×10^6 t of 'Reasonably Assured Resources (Reserves)' available at a price of less than U.S. \$22/kg U_3O_8.

The disparity between gross theoretical water-power capability and installed capacity has been mentioned, but at least topography and rainfall are better-known world-wide than mineral geology. In the renewable-resources field one might note that, currently, the measurement of the potential of undrilled geo-thermal hot-spring areas is virtually impossible because of the random distribution of active channels.

Collection

There is no uniformity in the organizations responsible for collecting energy data within and between industries nor within and between countries. Hence to the problems concerned with the data is added that of collection.

The system adopted by the World Energy Conference is of a Consultative Panel, of people versed in the different resources from a spectrum of countries, formulating a questionnaire; a working group of the U.S. National Committee (as hosts for the 1974 Conference), sending the questionnaires to all National Committees, with a request for a nominee with whom to correspond; the working group collating the replies; the Consultative Panel review the collation; the working group finalize and the Conference publish. If in each country a small group of resource specialists assists the nominated correspondent, then this system has the two major virtues that there is the maximum use of local knowledge and, most importantly, there should be the maximum chance of collection as close to the source as possible.

Interpretation and use

The raw material for energy data is produced by operators at colliery, field or plant and their immediate management. Thereafter, up each chain of command, fewer data but more opinion is added at each link; the original basic facts and assumptions are gradually lost and the figures averaged up or down. Despite painstaking effort to ensure that concepts and definitions are compatible, the data collected will, inevitably, have been amended by opinion.

The users of world energy data, economists, planners and managers in industries and governments, analysts and journalists of all types, students and academics, are so many and varied that it is not possible to warn all of the pitfalls on their individual roads, but some general points can be made:

(*a*) The effective size of an energy unit varies according to location, time and ownership (Ion 1970), the method of conversion (there is estimated to be a 30:1 difference in energy value of a unit of uranium whether used in a fast reactor or in a thermal reactor), and end-use (the effective size of a barrel of crude oil in 1900 was that of its kerosine content).

(*b*) Comparison of energy forms by conversion to thermal value can be misleading, for it discounts non-energy uses and process beneficiation – even in the petroleum family combining reserves of crude oil, natural gas and natural-gas liquid can be difficult, whether on heat content or price/value (Lovejoy & Homan 1965).

(*c*) The smooth curve of annual world crude oil productions masks: (1) differences in quality of constituent crudes and changes in quality demand, (2) fluctuations, declines and growths in individual country productions, (3) the influence of regulatory bodies, (4) the effects of price and cost changes in any or all sectors of the industry, (5) the influence of competing energy supplies and the changing pattern of end-use, (6) the sharp increases in prospective areas when knowledge and technological capabilities move together (Ion 1971).

Hence the production figures as well as the reserves figures in the often quoted reserves: production ratio must be treated with caution.

(*d*) Increased financial incentives rarely lead to immediate new discoveries. Explorers find resources, not accountants. Inhibition of risk-taking for lengthy periods breeds cautious managers, not gamblers (Ion 1973).

The mass media can provide many examples of mis-use through over-simplification. Discovery data are very vulnerable (Ion 1970), but so are reserves through confusion of categories (see references to Iran's reserves in *The Times* 1973*a*, *b*). Such points form part of the programming of the 'mental models' of experienced users of energy data, but are difficult to program into mathematical models, which are increasingly used in forecasting and do have two major advantages:

(*a*) Records can be kept of all assumptions and facts used, whereas the detailed programs of 'mental models' are not retrievable, often not even by the 'operator', and his expensive 'machine', is lost when moved from the job.

(*b*) Mathematical models can react so quickly to amended facts and factors that the essential continuous review is possible. Only the 'published' spot checks of forecasts should be out of date, never the working papers.

On the demand side of forecasting there is an impressive list of areas of insufficient knowledge in basic assumptions (Stelzer 1974), including the societal cost of environmental conservation, and much research is required before technological advances and behavioural patterns can be incorporated into models with sufficient precision for reliability (Rothkopf & deVries 1973).

Conclusion

Consideration of the general problems of collecting and understanding the 'facts' of world energy resource supply, with a brief mention of demand forecasting, does not permit a forecast of the changing pattern of supply. However, there is, undoubtedly, a growing realization within the energy industries of their interdependence, their need to understand each other's strengths and weaknesses, and ensure that, by cooperation, all resources are used in the optimum manner.

Optimization of utilization will require more information about the energy resources than at present collected and published, for it will involve dovetailed projects as well as discrete ones, in order to eliminate waste and provide the greatest practical efficiency.

Such cooperation, best accomplished at all levels of industries and governments, should crystallize what data is essential and facilitate its provision and collection, as well as ensuring greater mutual understanding.

The author wishes to acknowledge the help of those from all the energy fields who commented on the first draft.

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Discussion

PROFESSOR D. C. LESLIE (*Queen Mary College*): *The extent of the reserves of nuclear energy*

Mr Ion has stressed the difference between proven and estimated reserves, and has suggested that one should not assume too readily that the estimated reserves will necessarily become available. One can only agree with this wise note of caution, but I would like to stress the great difference in this respect between fossil and nuclear energy reserves. When dealing with fossil reserves one encounters statements such as 'the proven reserves amount to 20 years consumption, the estimated reserves to 50 years'. When dealing with nuclear resources the proven reserves may well be of the same order as the fossil reserves. However, in the nuclear case the estimated reserves are good for millions of years. Therefore, even if only a small fraction of the estimated reserves can be brought into play, none the less the inclusion of this small fraction alters the overall picture beyond all recognition. This is obviously not true in the fossil case.

Furthermore Mr Ion has emphasized that we do not really know where to find the estimated fossil resources. This is not nearly so true of the estimated nuclear resources. Granites contain around 4 parts/10^6 of uranium and we certainly know where to find granite in very large amounts. Comparison with open-cast mining of copper suggests that it might be possible to produce natural uranium from granite at less than £5/g. If burnt in a fast reactor, which was able to fission half of all the uranium atoms, the contribution of the purchase of uranium at this price to the overall cost of electricity would be about 0.1 p/kW h (36 p/GJ). Compared with the current wholesale price of electricity of (say) 0.5 p/kW h (180 p/GJ) it is clear that cost of this uranium is by no means insupportable.

In order to sustain the current world total energy consumption in this way we should have to mine around 2×10^9 t of granite each year. This is comparable with the present rate of extraction of coal and poses a serious but not insuperable environmental problem. Moreover there will be no need to mine granite for a very long while yet. There are very large uranium deposits at concentrations of around 50 parts/10^6: these would be both cheaper and less messy to extract.