SYMPOSIUM PAPERS

ENERGY MODELING AND NET ENERGY ANALYSIS

Presented

August 21–25, 1978

Colorado Springs, Colorado

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Sponsored by

Institute of Gas Technology
3424 South State Street
Chicago, Illinois 60616

Price: $60.00

December 1978
Printed in U.S.A

Produced by
Jack W. White
and

ACKNOWLEDGEMENTS

Many people contributed to the modeling effort, and it is not possible to name them all. The analysis was directed by David Nissen. Other key modelers at FEA included Charles Everett, Robert Eynon and David Knapp. Key contracted analysts included Jerry Eyster, Mike Lerner, Hoff Stauffer and William Stitt.

BIBLIOGRAPHY

1. Data Inputs to the PIES for the President's Base Case, EIA Draft Report, December 1977.
2. Energy Projections for 1980, 1985 and 1990, FEA Technical Report, August 1977.
3. C. Difiglio and D. Kulash, "Methodology and Analysis of Ways of Decreasing the Effectiveness of the Use of Fuel Energy Resources: Increasing Automobile Fuel Economy Via Government Policy," EIA Report, October 1977.
4. R. T. Eynon, "Utilities Modeling in PIES for NEP," Memo, FEA, June 30, 1977.
5. R. T. Eynon, H. J. Greenberg, F. H. Murphy and W. C. Mylander, "Using the Project Independence Evaluation System to Answer Questions About the U.S. Energy Future," Proceedings of the American Institute of Decision Sciences, June 1978.
6. H. J. Greenberg, F. H. Murphy and R. P. O'Neill, "Modeling Natural Gas Regulation in the President's Program," FEA Draft Discussion Paper, June 1977.
7. Project Independence Evaluation System (PIES) Documentation, Vol. I-XV, NTIS, U.S. Department of Commerce, Springfield, VA 22161, September 1976.
8. National Energy Act, Communication from the President of the U.S., U.S. Government Printing Office, April 29, 1977.
9. The National Energy Plan, Executive Office of the President, U.S. Government Printing Office, April 29, 1977.
10. G. R. Schleede, "The Outlook for Coal Demand and Supply in 1985," presented at the Southeast Regional Conferenc of the American Society for Public Administration, October 1977.

ENERGY ANALYSIS AND RESOURCE SUBSTITUTION

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ABSTRACT

Conservation, currently a major issue in the national debate on energy policy, is partly the encouragement of efficient energy use. As a means to define energy efficiency, the net energy standard has been proposed. It is shown, however, that the concept of net energy is not useful for measuring the performance of systems relying on and producing different energy forms and that a broader analytical approach is necessary to obtain credible results. That broader approach, energy analysis, assists in the identification of opportunities within energy systems to reduce consumption through the substitution of resources. Energy analysis leads also to the development of an additional analytical tool: the resource transformation sequence. The sequence is suggested as a means to examine conservation efforts, and the implications either of substituting resources to meet consumer goals or of restricting those goals are discussed.

ENERGY ANALYSIS AND RESOURCE SUBSTITUTION

INTRODUCTION

A major issue in the national debate on energy is conservation, and a principal tool to achieve conservation is efficiency in the production and use of energy. Though it is generally agreed that conservation is a good thing, there are wide differences of opinion as to what criteria define efficiency. Standards of judgment range from the technical knowledge of thermodynamics to the practical wisdom of self-interest, and no ecumenical norm has been found to reconcile one with another. As a consequence, energy conservation currently suffers from too much support and too little agreement on how to achieve it.

During the past several years, much study has gone into describing and improving on energy supply and use (8,20,22,23,26). The information generated by this research will not by itself resolve the difficulties in reaching consensus on what constitutes efficient use of energy. It can, however, contribute to an understanding of why energy is used and of how that use might be modified (9,10,18,21), so that the debate can be conducted intelligently. Specifically, analysis can be applied to comparing the performance of one system against another on the basis of effects on energy (3,4,11,12). Data from such analysis provide means of determining the implications attending the emphasis of one or another technology or of ascertaining the impacts from general policy options.

The discussion which follows explores the utility of a set of analytical methods in responding to the question of what defines conservation and efficiency. It first examines the effort to determine a single, numerical measure of performance from a calculation of the production less the consumption of energy, the net energy analysis. Then the more general concept of energy analysis is introduced, and the information that it provides is described. Finally, an application that results from earlier analyses features substitution as a mechanism to identify and test conservation alternatives. These three techniques present an evolution in attempting to relate analytical capability to the need for information useful to deciding the issue of efficient energy use.

NET ENERGY ANALYSIS

Net energy analysis begins with the problem of whether energy producing systems are likely to reach limits in their return on the energy invested in them (5,6,24). The argument goes like this: If an energy system delivers to society (i.e. other activities) little more energy than society is required to set aside for its construction and operation, the "net energy" and therefore the merit of that technology are suspect (14, 15,16,17). Similarly, comparison of one system with another demonstrates which one is "thriftier" of energy and therefore more efficient. This problem of the net energy return may be particularly important in investigating new technologies (25) that depend on resources that are more difficult to find and exploit or on conversion of one energy form to another, since such technologies have not yet been shown to be feasible using other standards of evaluation.

The term net energy implies that return on energy investment must be positive for an energy system to be viable. Otherwise, the energy system is an energy sink, consuming more than it produces, and is not beneficial to society at large. However, this distinction may be lost, depending on whether the natural resource on which an energy system is based is included or excluded from the calculation (1,2,27). In those cases where natural resources are considered part of the calculation, there is inevitably no net energy production, as the laws of physics state that no system can create energy out of nothing and that there are always losses associated with the supply and use of energy. Consequently, the technical definition of net energy excludes natural resources, treating them as free goods, and deals only with the energy products that can be used in operation of a system and those that are produced by it. The net energy comparison is the energy product of a system minus energy expended by other systems to build and operate it.

The practicality of net energy evaluations rests on one paramount assumption: different energy forms can be equated. If net energy analyses are to work, an appropriate standard of comparison must be found to relate the energy produced to the energy consumed to produce it. Thus the derivation of a net energy number requires that electricity and forms of fuel and of other potential energy be measured on the same scale, and the issue in establishing the credibility of net energy is whether a meaningful scale exists.

Several methods to determine equivalence for different energy forms have been proposed. They fall into four categories. The first is merely the use of the enthalpies, or heat contents. For example, the enthalpy of a kilowatt-hour of electricity is equal to 3,413 Btu, while that for a gallon of gasoline equals approximately 125,000 Btu. Under this standard, then, a gallon of gasoline is equivalent to 36.6 kilowatt-hours of electricity. However, it can quickly be seen that comparing electricity and gasoline strictly on their respective enthalpies ignores qualitative distinctions that preclude practical comparisons. Electricity can perform functions that cannot be directly duplicated by gasoline, and vice versa. As a result, the enthalpies of separate energy forms do not give an adequate equivalence by which to derive a net energy value.

A second method of trying to equate disparate energy forms is to compare their relative scarcities. If there is an estimated ten-year supply of natural gas and an estimated 400-year supply of coal, coal is forty times as plentiful as natural gas, and a Btu of natural gas is therefore forty times as valuable as a Btu of coal. This method suffers from two analytical flaws. It relies on current use rates of each resource, and it is founded on uncertain estimates of the total reserve or resource base. The first objection can be removed by comparing Btu of reserves rather than comparing depletion rates, but this does not reduce the uncertainty of resource estimations. Furthermore, it is not clear that the relative abundance or scarcity of resources is alone a significant criterion of worth, and in fact numerous arguments can be advanced to the effect that availability of supply is important only as it relates to the magnitude and elasticity of demand. In sum, relative scarcities of energy resources do not appear to provide sufficient measures by which to equate different fuel forms.

A third method is to rely on price as the indicator of value. This method leads to no more than a partial economic analysis, since the net energy comparison becomes simply the cost of energy delivered by a system minus the cost of energy consumed by the system. Obviously, there are several other cost components that would be included in even a cursory economic calculation; consequently, a net energy analysis based on price indicators supplies less information of the same kind than could be obtained better by economic methods. Price is not a satisfactory means of establishing energy equivalence for a net energy calculation.

The fourth category of equivalence is obtained by converting different fuels to the same energy form or energy potential. Electricity is a commonly used standard. By this method three Btu of oil are equivalent to one Btu of electricity, since in modern oil-fired power plants the efficiency of converting oil to electricity is approximately 33 percent. Similarly, three Btu of coal translate into one Btu of electricity, because a coal-fired power plant likewise operates at an efficiency of about one-third. Two objections to this method are readily apparent. First, conversion from one energy form to another is technology-dependent; that is, the conversion efficiency can and does change according to specifics of the conversion process. Since the efficiency with which electricity is generated has generally improved over time, the relative "energy worth" of electricity and of fuels such as oil and coal has narrowed according to this method, although there is no physical basis for such a finding. A second objection to this method is that it does not address the unique differences of fuels. A Btu of either oil or coal generates approximately the same amount of electricity, but there are obvious qualitative differences between the two fuels that indicate they are not numerical equals in their uses. Thus this method, too, falls short of introducing a valid rule of equivalence.

All four of these general methods to establish a standard measure by which to conduct net energy analysis fail, and these failures are crucial They signify that there is no universal net energy calculation, because there is no unambiguous energy measure that allows one energy form to be compared to another. Energy cannot be treated as a single entity, because its various forms possess irreconcilable qualitative distinctions. As a consequence, the seemingly straightforward concept of net energy analysis must be replaced with energy analysis, a more comprehensive and practical approach which rests not on the equivalence of energy forms bu rather on the comparability of the uses to which those energy forms can be put.

ENERGY ANALYSIS

Energy analysis is the determination of the energy required to produce goods and services (13,19). It can be used to characterize energy systems, but more generally it traces the energy components of producti processes or services. This tracing is not by itself a standard of valu rather, energy analysis is an accounting of the amount and kind of ener needed to support a specific activity.

The replacement of net energy analysis by energy analysis removes the possibility of evaluating a single system by itself, because the internal comparison by which energy produced is related to energy consume is unobtainable. (For the most part, this is not a serious loss. Posit net energy results would generally be useful in evaluating one system

against another; and so an internal figure of merit would not be essential.) Energy analysis, on the other hand, requires evaluation among alternative energy systems, so that the issue becomes how one system performs relative to another.

Even in comparing system performances, however, one still needs a standard of equivalence. This standard is found by expanding consideration of energy systems to include the functions that energy performs.

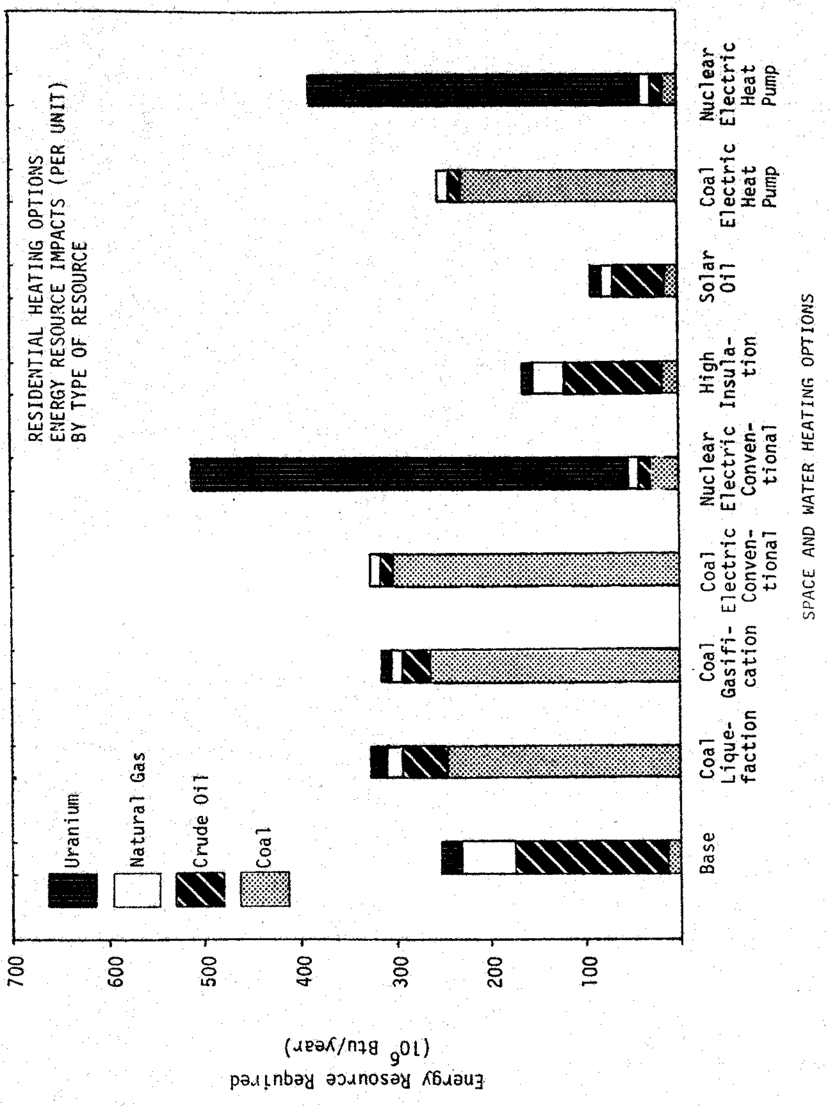
The production of energy is not an end in itself but a means of satisfying demands for the services energy supplies. As a result, the equivalence of two energy systems may be sought in those cases (and only for those cases) in which the same demand can be met by each. Any systems that produce the same energy form, such as two separate systems for producing high-Btu gas, can be directly compared. Additionally, systems that produce different energy forms but that fulfill the same purpose are comparable. So, for example, an oil-producing system and an electricity-producing system can be related to the extent that both products are used to heat interior spaces or to power automobiles. Equivalence can be achieved in end use, and consequently comparison among systems performing the same functions is appropriate and practical.

The establishment of equivalence in end use determines the kinds of comparisons that can be made. Energy systems that supply the same service can be compared with one another, and a holistic comparison of one complete system with another is emphasized. An energy analysis does not evaluate a single technology except as a direct replacement for another use; otherwise a technology is considered in the context of the system it inhabits and of the ends it fulfills. Though a technology may exhibit a distinguishable set of energy characteristics, those features are not fully defined until related to the other technologies required to transform natural resources from primary states through production processes to and including consumption. For instance, inefficiency in electrical generation may be offset by the efficiency with which electricity can be used, so that the performance of the whole system is not reflected by either supply or consumption but only by the combination of both. The complete system from natural resource to end use is the basis of comparison once the equivalence of end use is established.

Another consideration with respect to energy analysis is the actual unit or units of comparison. A summary statistic of energy use does not exist, since the objections to methods of equating different energy forms for a net energy analysis hold as well for energy requirements of complete systems, and the qualitative distinctions among energy forms cannot be removed. To accommodate these distinctions it is necessary to report results in terms of the natural energy resources from which energy is derived rather than to attempt to combine the results analytically. Coal, petroleum, natural gas, uranium, hydropower, wind, and solar energy resources might be listed separately in an analysis of alternatives to power irrigation wells, and one could compare how much of each resource was required by one alternative versus another. With the separate listings, common units of measure can be chosen to demonstrate relative amounts of different resources without implication that a unit of one resource is equivalent to a unit of another.

Figure 1 displays the results of an energy analysis based on equivalence in use (7). In this case the function of each of nine alternative

FIGURE 1



energy systems is to provide space heat and hot water to supply the needs of a typical residence of one year. The alternatives represent three general variations in addition to the Base Case. Four options (Coal Liquefaction, Coal Gasification, Coal Electric, and Nuclear Electric) emphasize changes in energy supply, two (High Insulation and Solar Oil) emphasize changes in end-use technology, and two (Coal Electric Heat Pump and Nuclear Electric Heat Pump) combine supply and end-use changes. Total requirements for four different natural resources have been calculated, and for each option they comprise segments of the bar measuring system performance. The energy of each resource is derived from the amount of resource required and the enthalpy of the resource. This permits illustration on the same graph and highlights the kinds of energy choices that can be made.

Two features of these results deserve attention. First, resource requirements vary widely from one alternative to another, more than do the impression of total energy demands. This finding implies that the question of resource conservation may be better addressed by specific resource rather than by total aggregates. Energy conservation perhaps should be more narrowly defined (e.g. oil conservation), since in aggregate it may take more than one of Btu abundant resource to save one Btu of scarce resources. The substitution, for example, of coal for oil is not always energy conservative in the strict sense, as it can cause higher gross energy requirements.

A second feature of the results is the effect of varying the "point of intervention" in energy systems. Substitution in energy supply may or may not decrease energy consumption, but it is a good method of changing resource dependency (e.g. Base Case oil to Coal Liquefaction coal). On the other hand, changes in end use can be employed to reduce total energy requirements but do not necessarily shift dependency away from scarce resource (e.g. High Insulation is heavily reliant on oil).

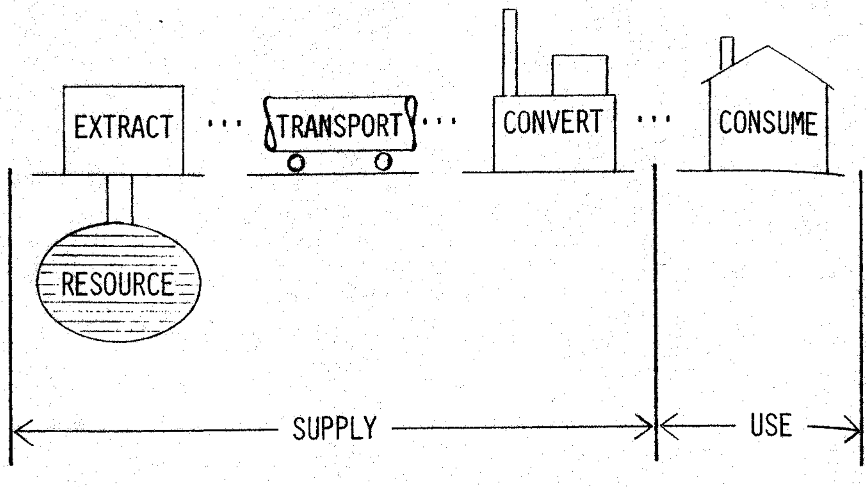
These two findings provide an insight to the utility of energy analysis in dealing with conservation. They imply that natural resources are the proper focus of efforts and that there is a need to establish energy conservation objectives in terms of their effects on natural resources. They also indicate that there may be different effects according to whether supply- or demand-related conservation measures are applied.

To explore these implications further, it is advisable to consider the analytical representation of energy systems. This can be imagined as a series of processes that extract, refine, transport, convert, and consume natural energy resource and resultant energy products (Figure 2). The steps of the series are technologies that modify either the form or the location of energy. During the sequence, energy is lost either physically (e.g. spillage, leakage) or through thermodynamic degradation and is consumed as fuel to power parts of the series. As a consequence, the quantity (enthalpy) of energy consumed in end use is always less than the amount extracted initially.

Energy savings result from improvements in any of the system processes, and therefore there are many separate opportunities to better the total system performance. Conservation is served by efforts designed for different portions of the system, and those efforts may vary considerably depending on how they affect the system as a whole or in its parts. The issues of where and how to intervene are closely related to the analytical

FIGURE 2

SCHEMATIC OF TECHNOLOGIES FORMING AN ENERGY SYSTEM



determination of which conservation targets yield largest effects and what natural resources are involved in the conservation results.

RESOURCE SUBSTITUTION

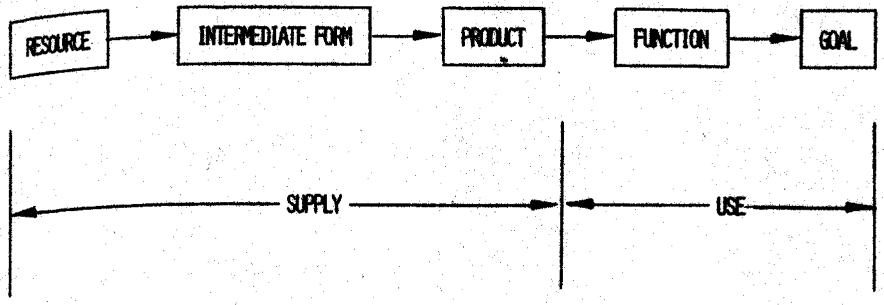
The general means to obtain conservation are substitution and restriction. Traditionally conservation has been identified with the latter means (e.g. restrictions on access to public lands to exploit timber resources, reducing thermostat settings in winter), and it has been left to the marketplace to arrange adequate substitutes or to distribute the consequences. However, findings from energy analysis point out that resource management may rely as well on explicit substitution to accomplish conservation objectives once they have been defined. Policies to encourage the switch from scarce to more abundant resources, along with others that attempt to lower total use, can contribute to conservation, though the methods and places of intervention may differ according to objective.

The debate that is now occurring as to whether supply or demand should be emphasized in order to deal with the energy situation can be described as a discussion of what kinds of substitutions should be made. Are new domestic reserves to be exploited to replace imports and depleted reserves, or is it better to use entirely different means through the substitution of new conservation alternatives. Finally, the debate involves whether to attempt the denial of consumer goals by actions that impinge on current lifestyles.

A simple analog to the process series representing energy systems has been developed to examine these issues and the types of substitutions that might affect energy conservation (Figure 3). Like the process sequence, it begins with natural resource and includes both supply and use. However, instead of tracing the series of technologies to process and consume energy, the sequence of Figure 3 traces the transformations that

FIGURE 3

SCHEMATIC OF RESOURCE TRANSFORMATION AND CONSUMPTION



occur to satisfy demand. Resource is transformed to an intermediate form and from there to a product. The product in turn fulfills a function which is directed toward satisfying a consumer goal. For example, crude oil is transformed to fuel oil and then to electricity. The electricity is used to heat a house in order to maintain the temperature at a satisfactory level.

The sequence indicates major points of substitution in providing energy to meet consumer demands and also implies the consequences of actions to achieve conservation. For example, substitution at the point of resource, such as oil shale for petroleum, does not require any further changes in the sequence. The intermediate forms, products, functions, and consumer goals can remain virtually unchanged. However, as substitutions are made further along the sequence, they cause corresponding changes in earlier steps. The consequences of attempting to substitute at points further to the right in the sequence may be significantly more difficult to mitigate than those to the left due to the numbers of adjustments that must be made. So, for example, consider the impact on the sequence of a shift from the private automobile to electrified mass transit. The goal in the sequence remains the same: transport of people. The substitution begins in the step before (function), and the ripple effects spread backwards. Large-scale introduction of mass transit will require additional electricity generation (product), a greater supply of coal and nuclear fuel (intermediate form), and the expanded exploitation of coal and uranium ore (resource), with all the accompanying demands for new facilities and services. In general, the complexity of energy conservation increases as one moves from left to right along the series of substitution steps.

The last item in the sequence is the goal for which resources are used. It is the item in the sequence which least allows for modification, for a goal such as keeping a house warm or transporting goods does not lend itself to the substitution mode of conservation. To achieve conservation at this step in the sequence normally will entail restriction--a much less pleasant option. Initial energy conservation measures dealt with reducing temperatures and lighting levels without seriously impinging on the basic desires of consumers. These easy reductions in consumption have been achieved and there is now resistance to continuing. Lower thermostats, dimmer lights, less travel--these are not substitution early in the energy sequence. They are restrictions of goals. They are modifications of lifestyles (however misdirected these lifestyles might be).

Such measures to achieve conservation by restricting consumer goals will be the most difficult ones to enforce. They require a disruption of the status quo that will be the least acceptable to the public.

The ability of national policy to address each kind of substitution opportunity and to deal clearly with the ramifications of reducing or frustrating the goals that energy is used to satisfy will likely determine how effective that policy will prove in mitigating energy problems. The sequence describing substitution options, like the analyses from which it is derived, offers a ready means of exploring how substitutions can be used to save scarce resources, switch to more abundant domestic supplies, and reduce or modify energy consumption. The series explicitly addresses where opportunities occur and what kinds of effects they will produce. It provides a conceptual framework within which to identify and test conservation alternatives.

The effects of resource substitution through the several methods indicated in Figure 3 are important contributions that energy analysis and its associated insights can make to defining energy conservation. They provide information to use in determining proper management of resources and to relate one set of management options to another. Thus, the issues of conservation and efficient use of energy are approached through resource substitution and energy analysis by addressing the fundamental questions of how resources are best applied to meeting demands for goods and services and to fulfilling the goals for which goods and services are produced. Such an evaluation of conservation intiatives is valuable in designing and testing criteria of energy efficiency and in recognizing the implications of actions either to replace energy supply or to alter consumption patterns. Though it by no means comprehends all that must be known about the worth of energy systems, the energy analysis structured to deal with substitution, gives data essential to making such decisions.

CONCLUSION

Net energy analysis was the initial response to an analytical problem of how to measure the efficiencies of energy systems. The knowledge that has developed from examining this problem has resulted in the replacement of net energy analysis with the broader energy analysis in order to establish an equivalence on which to make appropriate comparisons. But in seeking a meaningful set of comparisons, the analyst is led to consider what import such comparisons can have for resource conservation.

The characterization of energy systems as process series including both supply and end use indicates graphically the way in which technologies interact to place demands on natural resources. It also points out where conservation efforts might effectuate changes in the type and magnitude of resource requirements. The replacement of a summary statistic by a more precise and practical report of resource requirements points out the potential substitution of one resource for another. Similarly, recognition that energy is a means of satisfying a final goal rather than an end product permits a clear understanding that energy demand and supply are variables that can be related and balanced with one another to achieve conservation objectives. The information resulting from energy analysis and the analytical structure together provide important insights concerning energy use and resource conservation.

A series representing the transformations through which natural resources pass to fulfill consumer goals can be used to simulate the results of actions that are taken to facilitate resource management. The series presents substitution as the mechanism by which to adjust for shortages or to promote new opportunities. Natural resources are exploited and transformed to fulfill identifiable goals in society, and substitutions can provide for those goals and at the same time reduce or shift resource requirements. Thus the substitution series provides a test of the measures taken to achieve conservation objectives.

The fundamental problem for which energy analysis was developed was whether the better ways to use energy could always be distinguished from the worse ones. It is only candid to say that the full answer cannot yet be given. But it is also fair to say that energy analysis, and the understanding resulting from it, contributes to that answer and to the information necessary to achieve resource conservation.

REFERENCES CITED

1. Bullard, C. W. III, "Energy Costs, Benefits, and Net Energy," Center for Advanced Computation Document No. 174, University of Illinois, Urbana, IL (1975) August.

2. Bullard, C. W. III, "Net Energy as a Policy Criterion," Center for Advanced Computation Document No. 154, University of Illinois, Urbana, IL

3. Chapman, P. F., "The Energy Costs of Producing Copper and Aluminum From Primary Sources," Metals and Minerals, 107-111 (1974) February.

4. Chapman, P. F., Leach, G., and Slesser, M., "The Energy Cost of Fuels," Energy Policy, 231-241 (1974) September.

5. Colorado Energy Research Institute, "Net Energy Analysis: An Energy Balance Study of Fossil Fuel Resources," (1976) April.

6. Development Sciences Inc., "A Study to Develop Energy Estimates of Merit for Selected Fuel Technologies," United States Department of the Interior, Washington, D.C. (1975) September.

7. Development Sciences Inc., "Using Net Energy Methodology for Energy Planning: Tradeoffs of Supply vs. End-Use Technologies," United States Energy Research and Development Administration, Washingon, D.C. (1977) April.

8. Dupree, W., et al, "Energy Perspectives 2," United States Department of the Interior, Washington, D.C. (1976) June.

9. Gordian Associates Inc., "Potential for Energy Conservation in Nine Selected Industries," United States Federal Energy Administration, Washington, D.C. (1974) June.

10. Griffin, C. W., Energy Conservation in Buildings, Techniques for Economical Design, The Construction Specifications Institute, Inc., Washington, D.C. (1974)

11. Herendeen, R. A., and Bullard, C. W. III, "Energy Cost of Consumer Goods 1963 and 1967," Center for Advanced Computation Document No. 140, University of Illinois, Urbana, IL (1974) November.

12. Hirst, E., "Energy Use for Food in the United States," Oak Ridge National Laboratory, Oak Ridge, TN (1973) October.

13. International Federation of Institutes for Advanced Study, "Energy Analysis Workshop on Methodology and Conventions," The Nobel House, Stockholm, Sweden (1974) August.

14. Odum, H. T., Environment, Power, and Society. New York, NY: John Wiley & Sons, Inc. (1971)

15. Odum, H. T. and Odum, E. C., Energy Basis for Man and Nature. New York, NY: McGraw-Hill Book Company (1976)

16. Oregon, Governor's Office of Energy Research and Planning, "Transition," Report to the Oregon Energy Council (1975) January.

17. Price, J., "Dynamic Energy Analysis and Nuclear Power," Earth Resources Research Ltd., London (1974) December.

18. Shonka, D. B., Lobel, A. S., and Patterson, P. D., "Transportation Energy Conservation Data Book: Edition 2," Oak Ridge National Laboratory, Oak Ridge, TN (1977) October.

19. Stanford University, "Net Energy Analysis Workshop," Proceedings Report (1975)

20. United States Bureau of the Census, "Annual Survey of Manufactures 1976, Fuels and Electric Energy Consumed", United States Department of Commerce, Washington, D.C. (1976)

21. United States Federal Energy Administration, "Energy Conservation Study," Report to Congress, Government Printing Office, Washington D.C. (1974) December

22. United States Federal Energy Administration, Project Independence Report, Government Printing Office, Washington, D.C. (1974) November.

23. United States House Committee on Science and Astronautics, Subcommittee on Energy, "Energy Facts," Government Printing Office (1973) November.

24. United States House Committee on Science and Technology, Subcommittee on Energy Research, Development and Demonstration, "Energy Accounting as a Policy Analysis Tool," Government Printing Office, Washington, D.C. (1976) June.

25. United States Public Law 93-577, "Federal Non-Nuclear Research and Development Act of 1974," Section 5[a].

26. United States Senate Committee on Finance, "Energy Statistics," Government Printing Office (1975)

27. Varisco, D. C., "Net Energy and Synthetic Fuels," Presented at the 81st National Meeting AICHE, Kansas City, Missouri, April 11-14 Atlantic Richfield Co., Los Angeles, CA (1976)

ENERGY ANALYSIS OF TWO TECHNOLOGIES: GASOHOL AND SOLAR SATELLITE POWER STATION

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ABSTRACT

A large flurry over net energy analysis in 1975 died down quickly when calculations showed that the energy supply technologies under study were far from the net energy limit (i.e., that according to anyone's interpretation they were not in danger of "requiring more energy than they would produce"). Here I report on two technologies which are close to that limit, the production of ethanol from the fermentation of grain for ethanol/gasoline mixture (gasohol) and the production of electricity by the solar satellite power station (SSPS). Many of the classic methodological problems of net energy analysis exhibit themselves in the analysis; these are discussed in context. The SSPS suffers from uncertainty of input data, since much of the technology is only speculative, but appears to provide positive net energy. Gasohol lies either on the good or bad side of the energy limit depending on assumptions of system boundary and end-use efficiency.

I. INTRODUCTION

The notion of the net energy limit - the point at which an energy supply technology requires more energy than it produces - is a plausible one. Surely some day we shall approach that limit. However, as a criterion for policy, net energy analysis has encountered many objections regarding 1) the methodology for determining (or even defining) the net energy balance (4, 13) and 2) the relative merits of energy analysis and economics as a policy tool (10, 20).

To a large extent this debate has turned out to be moot, since a number of computations on a spectrum of energy technologies have shown that the net energy limit is far away. Glossing over the difficulties of definition, one can say that these computations showed current and near-term future supply technologies to "produce" from 5 to 50 times as much energy as they require (14), and the list included several non-breeding nuclear options. (Note, however, that energy costs of decommissioning were neglected). Further, admitted uncertainties in data and method blurred the distinction between different technologies.

In spite of this I believe that energy analysis of energy supply technologies has a useful role as a provider of one kind of information to the general decision-making process. I feel, however, that only when the technology is near the limit can the energy analysis be useful; far from the limit other criteria will dominate (such as